This document is downloaded from DR-NTU (https://dr.ntu.edu.sg)
Nanyang Technological University, Singapore.

Investigation into energy efficient wireless sensor networks for smart monitoring and sensing applications

Adnan Nasir

2015

Adnan Nasir. (2015). Investigation into energy efficient wireless sensor networks for smart monitoring and sensing applications. Master’ s thesis, Nanyang Technological University, Singapore.

https://hdl.handle.net/10356/62568

https://doi.org/10.32657/10356/62568

Downloaded on 26 Aug 2022 18:53:03 SGT

NANYANG TECHNOLOGICAL UNIVERSITY

INVESTIGATION INTO ENERGY EFFICIENT WIRELESS SENSOR NETWORKS FOR SMART MONITORING AND SENSING APPLICATIONS

ADNAN NASIR

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

2015

INVESTIGATION INTO ENERGY EFFICIENT WIRELESS SENSOR NETWORKS FOR SMART MONITORING AND SENSING APPLICATIONS

ADNAN NASIR

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

A thesis submission to the Nanyang Technological University
In partial fulfillment of the requirements of the degree of
Master of Engineering

2015

Acknowledgements

First of all, I would like to thank Almighty Allah for His blessings on me. I would also like to express my sincere thanks and great gratitude to my parents. Without their support, I would not have achieved this feat.

I would like to express my deep gratitude to my supervisor, Dr. Soong Boon Hee, for all the encouragement, patience, guidance and support throughout my Ph.D. study and the development of this thesis. For all the help and support he provided me beyond my studies at Nanyang Technological University (NTU), I am also truly grateful.

I would like to thank School of Electrical and Electronic Engineering for supporting my work with research scholarship for four years and the staff of Intelligent Systems Center for providing timely support whenever required.

I am grateful to Dr. Lim Hock Beng, Program Director of Intelligent Systems Center, NTU, for providing his help and support.

I also want to express my gratitude to my friends and colleagues, especially Mr. Shahzad Sattar and Mr. Mohammad Mobeen Movania, for their help and support throughout my research.

Last but not least, I would like to state my gratitude to Prof. Khalid Qaraqe and Dr. Syed Imtiaz Hussain, my supervisors at Texas A&M University at Qatar, for their un-conditional support and help. I would especially like to thank Dr. Syed Imtiaz Hussain for his moral and technical help in making me understand the complex cognitive and cooperative wireless network concepts.

Adnan Nasir

Table of Contents

Acknowledgements ii

Table of Contents iii

Abstract vii

Acronyms ix

Symbols xi

List of Figures xiii

List of Tables xvii

Chapter 1 Introduction 1

1.1 Motivation of the Research Problems 6

1.2 Objectives of the Research Problems 8

1.3 Limitations of the Study 8

1.4 Significance of the Research Study 8

1.5 Organization of the Thesis 9

Chapter 2 Literature Review 11

2.1 Introduction 11

2.2 Meaning and Definition of Wireless Sensor Networks 11

2.3 Meaning and Definition of Radio frequency identification 13

2.4 Applications of WSN and RFID 15

2.5 WSN based in-pipe Monitoring System 15

2.6 RFID based in-pipe Monitoring System 17

2.7 Integration of RFID and WSN based In-pipe Monitoring System 18

2.8 Urban Sensing 22

2.9 Vehicular Sensing 23
2.10 RFID and WSN Simulation Platforms 25
2.11 Summary 32
Chapter 3 RFID based In-pipe Monitoring Systems 33
3.1 Water Distribution Monitoring Systems 34
3.1.1 PipeSense System Description 36
3.1.2 Experimental Set-up and BER analysis 37
3.1.3 Simulation Results 39
3.1.4 PipeSense Framework Architecture 40
3.1.5 System Design and Implementation 42
3.1.6 Human Centric Cyber Physical System (CPS) for water monitoring 46
3.1.7 Water Smart Home 52
3.1.8 Event Detection and Analysis 59
3.1.9 Cognitive RFID Network for Spectrum and Energy Efficiencies 61
3.1.10 Numerical Results 67
3.2 RFID based Moisture Detection for Gas Pipelines 71
3.2.1 Moisture Detection System Model 72
3.2.2 Simulation and Experimental Results 76
3.2.3 Gas Quality Monitoring System Architecture 77
3.2.4 Moisture Sensing System Design 80
3.3 Conclusion 82
Chapter 4 Human Centric Vehicular and Urban Sensing 84
4.1 Vehicular Urban Sensing architecture 86
4.2 System Design and Implementation 87

4.2.1 System Architecture 87
4.2.2 Hardware Platform 88
4.2.3 Software Architecture 89
4.2.4 System Implementation 90
4.3 Integrated Framework for Vehicular and Urban Sensing 91
4.3.1 Vehicle Sensing Architecture 92
4.3.2 Human-Centric Urban Sensing 93
4.3.3 BusSense System Design 94
4.3.4 Experimental Set-up 97
4.3.5 Event Detection and Experimental Analysis 103
4.4 Conclusion 106
Chapter 5 108
5.1 Introducing EnergySim 109
5.1.1 EnergySim Design 111
5.1.2 Properties 111
5.1.3 Energy Evaluation 112
5.1.4 Dynamic Node Layout 113
5.2 Multi Environment Simulator 113
5.2.1 Introduction 113
5.2.2 Design and Implementation 114
5.2.3 Properties 117
5.2.4 Energy Evaluation 118
5.2.5 Dynamic Node Layout 119
5.3 EnergySim Simulation Engines 120

5.3.1 Normal Mode – Communication Range 121
5.4 RFID in-pipe communication 122
5.5 Shortest Path Algorithm 123
5.6 Simulation Results 123
5.7 Statistical Analysis of Simulation Results 126
5.8 Conclusion 134
Chapter 6 136
Conclusions and Future Work 136
6.1 In-pipe Monitoring systems 136
6.1.1 Water Monitoring System 136
6.1.2 Moisture Sensing System for LNG 137
6.2 Vehicular Urban Sensing System 137
6.3 Hybrid WSN Simulator for Energy Efficiency 138
6.4 Recommendation in Future Work 138
6.4.1 In-pipe Monitoring 138
6.4.2 Vehicular Urban Sensing 139
6.4.3 Hybrid WSN Simulation Platform 140
References 141
Author's Publications 154

Abstract

Technological advances in wireless electronics and algorithms have made it possible for us to have a plethora of assorted Wireless Sensor Network (WSN) nodes with diverse applications. Several recent developments have shown promise for the distinct nodes to be integrated and coordinate with each other despite having dissimilar hardware and protocol stacks. Some of the problems associated with the WSNs that have proven to be a major hurdle in their ubiquitous acceptance as the benchmark monitoring solutions are: energy consumption, scalability, reliability and security. All of these aspects demand thorough research; moreover, they also have a trade-off between each other, for instance, having a reliable system may demand an increase in energy consumption. Decreasing the energy consumption will in addition affect the range and scalability of the network.

In this thesis the author has concentrated the research on integrating Radio-Frequency Identification (RFID) nodes with the traditional WSNs, placing more emphasis on reducing overall energy consumption of monitoring applications. Due to the diversity of the available nodes, their requirements and resources are drastically different. This feature introduces a challenge to reduce the energy consumption of an overall application composed of these hybrid platforms. In particular, some challenging in-pipe monitoring applications have been proposed for industries utilizing RFIDs and other sensor nodes, mainly because of the high range of low frequency RFID tags and their magnetic induction property made it suitable for metallic in-pipe monitoring.

In order to reduce energy consumption and increase the network life-time of the proposed inspiring monitoring scenarios, a realistic estimate of the energy consumptions of various nodes deployed in one application with given MAC protocols is absolutely necessary. Experimenting with actual sensor networks to determine energy consumption is both time-consuming and costly, particularly when these diverse nodes are deployed in one application. Normally, simulators are used to estimate the performance of these nodes. Despite the abundance of WSN simulators offered today, none can simulate the energy efficiency given several types of nodes and situations in one application. Hence, a simulation platf

Dedicated to my mother,
Samina Nasir

Acronyms

ACK	Acknowledge
AWGN	Additive White Gaussian Noise
AHEAD	Algebraic Hierarchical Equations for system Design
ASK-NRZ	Amplitude Shift Keying Non Return to Zero
ADC	Analog–to–Digital–Conversion
API	Application Programming Interface
AVL	Automatic Vehicle Location
BPSK	Binary Phase Shift Keying
C#	C-Sharp
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CLT	Central Limit Theorem
CR	Cognitive Radio
CS	Contamination Spread
UTC	Coordinated Universal Time
CDF	Cumulative Distribution Function
CPS	Cyber Physical Systems
DHI	Data Hub Interface
DBMS	Database Management System
EPC	Electronic Product Code
ERP	Electronic Road Pricing
EPA	Environment Protection Agency
EWDS	Expand Water Distribution System
EM	Expectation-Maximization
FCC	Federal Communications Commission
FD	Future Demand
GPRS	General Packet Radio Service
GIS	Geographic Information System
GPS	Global Positioning System
GSM	Global System for Mobile (Communications)
GDI	Graphics Device Interface
HF	High Frequency
HMM	Hidden Markov Models
HHMM	Hierarchical Hidden Markov Models
IDs	Identifications
E_{sleep}	Idle or Sleep State Energy
IWT	Improve Water Treatment
ISM	Industrial Scientific & Medical Radio Frequency Band
IVU	In-Vehicle Unit
IC	Isolate Contaminations
JVM	Java Virtual Machine
LOS	Line of Sight
LNG	Liquefied Natural Gas

LPG	Liquefied Petroleum Gas
LF	Low Frequency
ML	Maximum Likelihood
MRDLG	Maximum Residual Disinfectant Level Goal
MAC	Media Access Control
MCU	Microcontroller Unit
MAS	Multi-Agent System
MIMO	Multiple Input Multiple Output
NTU	Nanyang Technological University
OBD	On-Board Diagnostic
PC	Personal Computer
PDAs	Personal Digital Assistants
PIFA	Planar Inverted-F Antenna
PDF	Probability Density Function
POS	Point of Sale
QPSK	Quadrature Phase Shift Keying
RFIDs	Radio Frequency Identification
RF	Radio Frequency
E_{Rx}	Receiving Energy
RTU	Remote Terminal Unit
SHI	Service Hub Interface
SMS	Short Message Service
SNR	Signal to Noise Ratio
MySQL	Structured Query Language Database
SCADA	Supervisory Control And Data Acquisition
2G	Second Generation Mobile Devices
3G	Third Generation Mobile Devices
2D	Two Dimensional
3D	Three Dimensional
E_T	Threshold Energy
E_{Tx}	Transmission Energy
UHF	Ultra-High Frequency
VLF	Very Low Frequency
WDS	Water Distribution System
WQ	Water Quality
WiFi	Wireless Fidelity
WSNs	Wireless Sensor Networks
WHO	World Health Organization

Symbols

B_Z	Magnetic Field Strength
μ_0	Permeability of free space
I	Current in Amperes
$d(m)$	Energy Detector statistic with m number of samples
N	Number of turns in a coil antenna
$r(t)$	Received signal
r	Radius of antenna wire
a	Radius of the coil antenna
E	Event vector
X_i^d	States of HHMM system
A_{ij}	Matrix of transition probabilities
B_{ik}	Matrix of emission probabilities
λ	Set of entire parameters for transition states in HHMM
δ, ψ, τ	Time steps of HHMM states
N_0	Gaussian Noise
h_{ip}	Channel gain from node to primary user
γ_i	Received Signal SNR
I_{ip}	Interference on primary from i^{th} node
P_λ	Probability of satisfying interference threshold
σ	Average strengths of interfering channels
$p_{\gamma_i}(\gamma)$	Instantaneous PDF of received SNR
$p_{\gamma_T}(\gamma)$	Total PDF of received SNR
$P_{\gamma_T}(\gamma)$	Instantaneous CDF of received SNR
$P_{\gamma_T}(\gamma)$	Total CDF of received SNR
$\binom{L}{l}$	Binomial Coefficients
P_{out}	Outage Probability
η	Outage Threshold
α_i	Randomly selected constant for moisture and no moisture cases
H_0	Hypothesis of no moisture present

H_1	Hypothesis of presence of moisture
$\alpha(t)$	Coefficient of attenuation
$x_i(t)$	Transmitted unknown signal
$h(t)$	Channel Impulse Response
$Y(t)$	Energy Detector's output form
A_n	Attenuation factor
PL_0	Path loss
γ	Path loss exponent
X_σ	Zero-mean Gaussian Random Variable
$\vec{U}$	Peak induced voltage on metal pipe's surface
$\vec{\phi}$	Magnetic Flux of coil antenna

List of Figures

Figure 2.1: RFID Tag illustration…….12
Figure 3.1: Laboratory Experimental Set-up……..……..34
Figure 3.2: PipeSense illustration of Experimental set-up……...….34
Figure 3.3: Comparison of received signal strengths of all modulation schemes with and without water for one and two meter pipes……..…….35
Figure 3.4: (a) S11 parameters simulation on Agilent EMPro software. (b) Electromagnetic Field at low frequencies at the receiving end of the pipe……...……36
Figure 3.5: (a) Conduction currents on the cross-sectional view of the pipe at low frequencies……..……..37
Figure 3.6: (a) CST MWS simulation of the actual EN1057-X One meter pipe and (b) Two meter pipe……..……38
Figure 3.7: S11 and S21 parameter for one meter EN1057 pipe with and without water……..39
Figure 3.8: PipeSense Framework Architecture…….……..40
Figure 3.9: PipeSense system illustration…….……41
Figure 3.10: PipeSense System Design…….……42
Figure 3.11: PipeSense hardware system……..……44
Figure 3.12: Sensor monitoring mechanism……..……45
Figure 3.13: PipeSense software Architecture……..……45
Figure 3.14: Framework for cyber physical PipeSense System……...….46
Figure 3.15: Flow diagram of the cyber physical PipeSense system……...….48
Figure 3.16: HMM to determine patterns and probabilities of future water demand, water quality and contamination spread for the water distribution system.……49
Figure 3.17: Smart Home System Diagram…….……..52
Figure 3.18: Human Centric CPS Cycle Architecture…….….53
Figure 3.19: HHMM for the detection of Tap Event and Seepage Events (T/SE) within the daily Consumption Patterns (CP)……54
Figure 3.20: Pseudo pressure values for (a) Consumption Pattern (CP) (per hour), (b) Tap Event (TE) (per minute), (c) Seepage Event (SE) (per minute)……....56

Figure 3.21: (a) Consumption Patterns (CP) (per hour), (b) Tap Event (TE) (per minute), and (c) Seepage Event (SE) (per minute) quantized state sequences…….58
Figure 3.22: (a) Consumption Patterns (CP), (b) Tap Event (TE), (c) Seepage Event (SE), Predicted 300 points from HHMM……..59
Figure 3.23: System Model: RFID cognitive nodes, the destination node and the primary interferer……..63
Figure 3.24: Outage probability of the system with L = 1, 2, 3, 4, 5 for interference constraint λ = 10 and outage threshold η = 10…….67
Figure 3.25: Outage probability of the system with L = 5 for interference constraint λ = 1, 5, 10, 20 and outage threshold η = 10……..68
Figure 3.26: Outage probability of the system with L= 5 for interference constraint λ = 10 and outage threshold η = 5, 10, 20, 30, 40.....…...69
Figure 3.27: Outage probability comparison between full and limited CSI scenarios for the system with L= 5, λ =10 and outage threshold η=10. ……..70
Figure 3.28: Outage probability for the full CSI scenario for the system with L= 5, λ= 10 and outage threshold η=5, 10, 15, and 20……...70
Figure 3.29: Channel Model for in-pipe RFID communication using ray tracing approach……...72
Figure 3.30: LOS Impulse Response (a) No moisture and (b) with moisture…….74
Figure 3.31: First Bounce Impulse Response (a) No moisture and (b) with moisture…75
Figure 3.32: Energy Received at the receiver simulation (a) No moisture and (b) with moisture……76
Figure 3.33: Experimental result showing probability mass distribution with sample size of 20…….77
Figure 3.34: RFID and WSN based Moisture Monitoring System Architecture…….78
Figure 3.35: Flow diagram of the cyber physical PipeSense system…..……..79
Figure 3.36: Monitoring System Diagram……...80
Figure 3.37: System Implementation Framework……81
Figure 3.38: RFID Measuring Unit Hardware Block Diagram……...82
Figure 4.1: Human-Centric Vehicular Urban Sensing Architecture. ……85
Figure 4.2: BusSense System Architecture……..87
Figure 4.3: The In-Vehicle Unit (IVU)…….88

Figure 4.4: Software Architecture…….89
Figure 4.5: Snapshot of the BusSense web portal…….90
Figure 4.6: Sensor Data Measurements…….91
Figure 4.7: Integrated Framework for Vehicular and Human-Centric Urban Sensing……..92
Figure 4.8: BusSense System Design……93
Figure 4.9: (a) Android Application for Human Feedback, (b): Android setting sampling rate and Map views……96
Figure 4.10: Comparison of received signals through the metal exhaust pipe……...97
Figure 4.11: RFID system illustration……98
Figure 4.12: Proposed system illustration…….99
Figure 4.13: Environmental gas sensors resistance ratio with respect to time……..100
Figure 4.14: Pollution data (CO and CO2) from Experimental run…….101
Figure 4.15: HMMs based on Pollution levels, (a) CO2 (b) CO……..102
Figure 4.16: HMM states for pollution data (CO and CO2)…….103
Figure 4.17: Predicted states for CO and CO2 for 300 seconds based on HMMs……104
Figure 4.18: HMM and Decision algorithm flow……..105
Figure 4.19: Correlation between CO2 emissions with speed……...106
Figure 5.1: Simulator's Flow Diagram for Air Interface Mode…….109
Figure 5.2: Excel graphs output…….110
Figure 5.3: Random topology……110
Figure 5.4: Zoomed view of the simulator with Random node distribution…….111
Figure 5.5: Line topology……..112
Figure 5.6: Grid topology……..113
Figure 5.7: Network Topology distribution flow chart…….……114
Figure 5.8: Simulator's Flow Diagram…….....115
Figure 5.9: RFID Mode……...…….116
Figure 5.10: Random nodes Deployed on the simulation screen…….116
Figure 5.11: Dijkstra algorithm flow chart……..120
Figure 5.12: Average time consumed in seconds for packet transfer for 100 nodes in 50 rounds in Random topology. Red lines show the mean time values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2…….121

Figure 5.13: Average energy consumed in seconds for 100 nodes in 50 rounds in Grid topology. Red lines show the mean energy values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2……..121
Figure 5.14: Average energy consumed in joules for 100 nodes in 50 rounds in Random Topology. Red lines show the mean energy values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2……..……...122
Figure 5.15: Average time consumed in seconds for packet transfer for 100 nodes in 50 rounds in Grid topology. Red lines show the mean time values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2…….……...123
Figure 5.16: (a) Average Energy Consumed per round for 25 Active RFID nodes inside the metal piping structure. (b) Average Time in seconds for packet transfer from the event detection node to the sink node for 50 rounds. Red markers show the mean energy consumed and time taken for the 50 rounds respectively in the current set-up……124
Figure 5.17: Energy PDF and the Gaussian Normalization fitting on it for 100 and 50 nodes simulated in Random topology with SMAC protocol……125
Figure 5.18: The Energy PDF and the Gaussian Normalization fitting on it for 100 nodes and 49 nodes simulated in Grid topology with SMAC protocol……..126
Figure 5.19: The Energy PDF and the Gaussian Normalization fitting on it for 10, 5 and 3 nodes simulated in Line topology with SMAC protocol……..127
Figure 5.20: The Energy Contour after 100 rounds, 100 nodes, 3kJ energy bank, Random topology with SMAC protocol…….128
Figure 5.21: The Energy Contour after 100 rounds, 50 nodes, 3kJ energy bank, Random topology with SMAC protocol……..128
Figure 5.22: The Energy Contour after 100 rounds, 100 nodes, 12kJ energy bank, Grid topology with SMAC protocol…….….129
Figure 5.23: The Energy Contour after 100 rounds, 49 nodes, 6kJ energy bank, Grid topology with SMAC protocol…….….129
Figure 5.24: The Energy Contour after 100 rounds, 10 nodes, 6kJ energy bank, Line topology with SMAC protocol…….…….130
Figure 5.25: The Energy Contour after 100 rounds, 5 nodes, 6kJ energy bank, Line topology with SMAC protocol…….….131
Figure 5.26: The Energy Contour after 100 rounds, 5 nodes, 3kJ energy bank, Line

topology with SMAC protocol……..….131
Figure 5.27: The Energy Contour after 100 rounds, 3 nodes, 3kJ energy bank, Line topology with SMAC protocol……..132
Figure 5.28: The Outage Probability of the nodes with respect to the energy after 100 rounds for Random 100 and 50 nodes deployment……...133
Figure 5.29: The Outage Probability of the nodes with respect to the energy after 100 rounds for Grid 100 and 49 nodes deployment…….134
Figure 5.30: The Outage Probability of the nodes with respect to the energy after 100 rounds for Line 10 and 5 nodes deployment…….134

List of Tables

Table 2-1: The battery and cost comparison of RFID with contemporary technologies……...12
Table 2-2: RFID Frequency Band Table [70]……...13
Table 2-3: Comparison of contemporary in-pipe monitoring system with our proposed system……19
Table 2-4: Comparison of Contemporary Vehicular Urban Sensing Systems……..24
Table 2-5: Comparison of RFID and WSN contemporary simulators with our proposed simulation platform……...27
Table 5-1: Class Diagram of Node…….118
Table 5-2: Experiment Scenarios with Random, Grid and In-pipe RFID deployments……119

Chapter 1

Introduction

Pipelines are the significant way of transporting fluids all over the globe. Almost any kind of chemically stable fluid could be easily transmitted through pipelines. Long length Pipelines has to be monitored for avoiding leakage of fluids such as water, sewage, gases, oil and so on; pipeline breakage due to fluid pressure, corrosion, stress and so on; blockages that affect normal flow of fluid through the pipelines and maintenance cost for repair [1] .

In order to understand the significance of protecting and monitoring the pipeline applications, first it is substantial to understand the problem existing in the water monitoring system, applications and it is also essential to understand the problem existing in the oil and gas monitoring pipelines. After understanding these problems, it is essential to understand and focus on the significant technologies that could be used for monitoring the pipelines namely RFID technologies and WSN technologies.

With the rapid growth of oil production and raise of energy demand and water in those areas and remaining of the world, natural gas, petroleum and water facilitates and resources have become significant assets, [2]. One of the significant and main facilities for such resources is the pipelines that are typically used for transferring petroleum, natural gas and water. Water, gas and oil are considered as the major necessities in major nations [3].

There are numerous technologies available for monitoring and protecting the pipelines. Such technologies are developed particularly to detect and locate the leakages in the pipelines [4]. Such available solutions depend on the network availability for transferring the information and reporting the leakages seen in the pipelines [5]. Such networks are mostly wired using fiber optic or copper cables [4] [6]. These wired networks are connected to specific sensor devices. Such sensors measure particular attributes like pressure, flow rate, temperature and so on. In such setup, there exist numerous problems in monitoring the pipelines [7].

Such problems presents a threat of complete shutdown that is if any damage happens to any part of the wires and then entire pipeline monitoring system would be damaged or affected. Moreover, it would be easy for unauthorized people for disabling the pipeline monitoring system by cutting the wires of the network [8] and it is tough to locate the fault position in a wire [9]. This type of problem would be more complicated with the underground pipelines; when the sensors and wires are not that easy to locate, extract, repair and maintain. Certain information is more significant to be reported to the control station then others. Information

reporting about fire is more critical than reporting about the measurement of pressure. Apart from these, unwanted and duplicate information could be transmitted on network which causes significant delay for other important information for reporting. This would fail because of lack of QoS (quality of service) support in wired networks [5].

The new advances in the fields of computing technology and electronics has particularly boosted the development of tiny wireless sensors [8] [7].Wireless sensor network (WSN) acts as an alternative new tool for wide range of new applications. These tiny sensor nodes are low power, low cost, self-organizing and easily deployable. WSNs have the capability of local processing. Additionally, each sensor node has some restricted processing ability, when combined with the information from huge number of other nodes; WSN is capable of measuring a given physical environment [4]. These qualities have made WSN an alternate technology for sensing the in-pipe systems. It is also used for measuring the quality of water [10].

WSN is an infrastructure which involves measuring or sensing, wireless-based communication and computing elements that provides an administrator the capability to observe, react and instrument to phenomena and events in a specified environment [11]. Such environment that are being monitored could be a biological system, physical world or a framework of information technology while the administrator is typically a governmental, commercial, civil or industrial entity [12]. The main components involved in the sensor network are as follows; interconnecting wireless network; assembly of localized or distributed sensors; a central information clustering point and then finally a set of computing resources beyond or at the central point for handling correlation of data, status querying, event trending and data mining [13]. Sensor network node involve one or more sensors, transceiver radio or other device related to wireless communication, an energy source and small microcontroller [14]. Sensor network involve large numerous sensor nodes that could be implemented on ground, in vehicle, in the air, inside buildings or even on human bodies [15]; and they focus on surveillance, biomedical observation, and security, environment monitoring and other applications [14]

In the oil and gas industry, data type sensed include flow, pipeline pressure, vibration, temperature, fire, gas leaks, equipment condition and so on [1]. Pipelines particularly used in oil and gas sector entailing buried and gas pipelines and sub-sea above ground [15]. At the same time, it was noted that oil and gas sector emphasize processes for extraction, transporting, exploration, marketing and refining petroleum products. As the demand or need for the fossil fuels grows oil and gas firms are focusing on developing new technologies and enhance operations for increasing productivity and expanding their present abilities [16] [17]. WSNs act as an enabling infrastructure for applications related to cyber-physical systems, they interact with the external stimulus. They particularly focus on monitoring and control

applications where relatively large scale deployment and low data through put are the major system features [19] [18].

Pressurized pipeline systems namely distribution network for water could be monitored nondestructively for locating damage by measuring the vibration on surface of pipe at different joints. The change in vibration of pipe could be related to sudden alternation in the pressure of water that would be caused by network rupture [20]. Presence of moisture in LNG (liquefied natural gas) or LPG (liquefied petroleum gas) pipes could create two major issues. Presence of moisture could degrade the fuel's heating ability than corrodes the metal pipes. Moreover, presence of moisture reacts with the liquefied gas refrigerant for creating hydrates which again minimizes gas quality, such hydrates freezes pipes and valves and would affect the plant for shutdown [21] [22].

Likewise it was also noticed that corrosion in the pipeline particularly for aging infrastructure of pipeline results in emissions, leaks and deadly explosions in refineries and facilities of production. Thus, it is critical to perform or function real-time monitoring of temperature changes, flow, pressure build-ups for ensuring efficiency, safety and streamline pipeline operation [23]. It was also noted that WSN give cheaper substitutes for such type of monitoring [15] [23].

An organized system performs predictive and preventive maintenance and enhances the post-fault diagnosis. It was also stated that decisions taken after the measurements of sensor are acquired from real-time monitoring for determining the components condition [23]. WSN are also used for monitoring installations of oil and gas embedded in the ocean. For optimizing production and for ensuring safety, parameters and equipment have to be monitored [13]. It could also be used for monitoring processes in the production, detect or safeguard leakage in oil and gas, improve flow of production as well as yield of well, enhance the working conditions and also safeguard the environment [17] [24]. Technology of WSN is also being used to optimize the well drilling process. It was noticed that new health monitoring systems are also implemented in remote and harsh locations such as offshore rigs [13].

Technology of WSN gives a real-time production monitoring with effective transmission and acquisition of data [17]. WSN would be suitable in harsh environment, supports network expansions and temporary deployment and has cost benefits. If it is fully deployed, derived advantages would be there for long run, such as minimized equipment failures and shutdowns and diagnosis in the remote equipment [24] [17].

State-of-the-art systems for monitoring the pipelines like SCADA (supervisory control and data acquisition) systems utilize expensive equipment that would have high maintenance cost. Such systems are not flexible as the software and protocols used are propriety. This cannot mold the system based on the requirements of monitoring systems. In SCADA systems, only PPC (point-to-point communication) between the RTU (remote terminal unit) and control

room exists that would make the system unscalable and centralized. It poses a main threat to the data integrity that is being transferred. WSNs have created new horizons for monitoring the pipeline [25] [26]. WSNs use numerous inexpensive sensors that could be implemented in various remote locations and environments like deep under the sea, underground and so on where human access is not feasible [23]. Importantly, the communication takes place in WSNs in multi-hop fashion where the node does not normally communicate directly with the control center [26] [2].

Subsequent section of this study focuses on the problems in the vehicular urban sensing. This part focuses on the problems seen in the harmful gases emitted through exhaust metal pipe in vehicles.

Vehicle emissions pollute air and need control [27] [28]. With raising concern for climate change and air toxins caused by exhaust emissions, the necessity for tighter control maximizes its significance [29] [30] [31]. In the present scenario, motor vehicles are main source of air or atmospheric pollution contributes nearly 20 to 25 per cent of globe's carbon dioxide emissions. From fossil fuel transportation and burning, such quantity is continuously increasing. Methane is more harmful gas than carbon dioxide also emitted by vehicles particularly cars [31].

Majority of the efforts in the road traffic concentrated on restricted installation of wired sensors like intelligent video cameras and loop-coils with the capability of image processing. Anyhow, the costs of such advance deployments would be very high because of high devices cost, installation and maintenance [32] [33]. Wired sensors are more vulnerable to high weather in specific areas. Therefore there is necessity for alternative way for collecting traffic data at a minimal cost with a wide range of coverage [34].

It was also stated that it is practically significant for developing, verifying and validating powerful models that would assist in designing and enhancing the efficiency and safety of transportation [33]. Transportation systems and vehicles are included in our daily lives. Such systems involve more types of sensors and seen as a rich information source. As a significant aspect inside the context of urban sensing, the concept of vehicular sensing has been used in different applications like commercial fleet management systems and vehicle tracking systems [32] [33].

RFID (Radio frequency identification) technology is one of the developing fields in the AIDC (automatic identification data collection) industry [35] [36]. Radio frequency identification tags on assets or objects and RFID readers are used for gathering the information for tag. RFID reflects the enhancement on bar codes with relative to non-optical communication [34] [35].

RFID is a generic term for technologies which utilize radio waves for automatically determining the objects or people. Radio frequency identification methods is used for storing a unique serial code in a microchip [39] [36]; and then in the RFID an antenna is associated with

the chip for code identification and could be transferred [38]. The chip and its antenna combined together are referred as RFID tag or RFID transponder [38] [39]. For receiving and identifying the information transmitted by tags, RFID reader is needed, which could forward the data to a server computer. RFID systems are categorized into two broad types as active and passive RFID systems, based on the category of tags used [39].

Active RFID tags include transmitters and a battery as their resource of power. Backscatters or passive tags have neither a transmitter nor own resource of power; they use propagation or inductive coupling for connecting with the reader antenna and reflects the signal produced by the reader [34] [35]. Such tags are cheaper and simpler and have shorter range of reading [35]. Subsequently semi-active tags are present in market only for particular applications. These tags involve batteries which were mainly utilized for supporting the embedded sensors and memories [10] [35].

Tolerating emission on road vehicles includes penalties for offenders or seizure of their vehicles by government agencies. For monitoring and identify such emissions, researchers all around the world are trying to build an efficient vehicle exhaust network. Moreover, the sensing technology for such application type is not developed, but since current problems over our environment and advantages it would bring, it has been influencing great interest among governmental sectors and research circles [33].

Above part focused and discussed about the problem in solving the water monitoring systems through wireless sensor network as well as radio frequency identification, detecting the leakages in oil and gas systems through RFID and WSNs and exhaust pipe vehicular monitoring systems. To understand the integration of RFIDs and WSNs, it is significant to overview the benefits of WSN and RFID separately and then understanding the difference that exist between the RFID and WSN.

The purpose of WSN is to focus on sensing parameters that explain the condition of environment or object. Generally, the purpose of RFID is to detect and identify the tag objects. Components of WSN encompass relay nodes, sensor nodes and sink. Components of RFID include interrogators and transponder [45] [43]. Mobility of the WSN is usually static. Mobility of RFID tags shift with the associated objects. Power supply of the WSN would be battery powered whereas the RFID are the passive or battery powered [43]. Deployment of WSN would either be fixed or random, while the deployment of RFID is fixed [42]. Design goal of the WSN is basically a general purpose, however, the design goal of RFID is single operation like read [41] [45].

WSN and RFID networks include two complementary network technologies and there are numerous benefits when integrating RFID and WSN networks. RFID tags are cheaper making it economical to utilize, and would replace certain sensor nodes in wireless sensor networks [42]. At the same time, it was noted that since an object that is integrated with the tag of RFID

is traceable, RFID technology gives a reasonable inclusion to WSN in detecting and localizing objects other than that it would be much difficult [43] [42].

WSNs provide numerous benefits over conventional RFID systems. It was stated that sensors could offer different sensing capabilities integrated with the tags of RFID, push logic into nodes for enabling the tags and readers of RFID to include intelligence and involve an RFID system with potential of functioning in multi-hop fashion that capability could extend the RFIDs applications [44]. First, sensors could be able to give much more data or information like measurement of humidity, temperature [44], vibration, pressure [14], intensity, [1] [16], sound intensity, chemical concentrations, pollutant levels and more [12] [13] than simple RFIDs. Incorporating with sensors allow RFID to push logic into nodes for intelligence and sensing [45].

RFID system application is wider when compared to wireless sensors. WSNs and RFID would be useful for different scenarios. RFID is utilized for detecting and WSN technologies are used for sensing [42]. RFID and sensors are integrated to the same object. They could be used to monitor PH value, sense temperature, vibrations, heartbeat rate, blood pressure and more [45]. Tag in the RFID is involved in the object and WSN utilized for sensing the object. Generally, WSN used for event detection and on the other hand RFID is utilized for detecting people or objects [44].

1.1 Motivation of the Research Problems

Frequent inspections and proactive monitoring are critical for maintaining pipeline health as oil, water; gas and sewer pipelines have become inseparable part of human life. Therefore, continuous maintenance system and proactive monitoring is significant for these pipelines. However, implementation, maintenance and monitoring these pipelines should remain scalable, cost-effective and also easily customizable [46]. Numerous technologies are present and available for monitoring, controlling and maintaining various types of pipeline, WSN and RFIDs are among these [15]. In the vehicle most harmful gases are emitted that would affect the atmosphere and human health. RFID and WSN are collaborated into a vehicle where WSN present in the vehicle and on the other hand RFID resides into the vehicle's exhaust. Wireless sensor network act as substitute or alternative tool for pipeline monitoring. WSN are suitable for harsh environments, supports sensor network expansions and temporary deployment and has cost benefits [21]. RFID is a technique that utilizes the radio waves for identifying the object uniquely [17] [21].Therefore this study in detail discusses about the energy efficient wireless sensor network for smart monitoring and sensor applications. The proposed study would combine the RFID and WSN under metallic environments and would be useful for the various sensor applications and such integration would be helpful in reducing energy consumption due to the inherent properties of RFIDs.

There are many studies that concentrate on WSNs for various applications. Minetti [12] conducted a study to analyze the wireless sensor networks that enable remote condition monitoring. Authors also focused on the research challenges identified in applying intelligent wireless sensors with specific reference to oil, gas and resources industries [14]. Jawhar, Mohamed and Mohammed and Aziz [1] carried out an investigation to analyze the routing protocol and addressing scheme for oil, gas and water pipeline monitoring specially concentrate on using wireless sensor networks. There are also studies that concentrated on applications of wireless sensor networks in the industries of oil, gas and resources [15]. Dalbro et al [23] examined about the wireless sensor networks for offshore oil and gas installations. Hatler, Gurganious and Chi [25] discussed about the oil and gas sector and wireless sensor networks. This study also focuses on the other applications of WSNs and also challenges faced in the oil and gas sector. Carrillo, Gonzalez, Rosas and Marquez [2] focused on the new distributed optical sensor for the detection and localization of liquid leaks. Lin, Wu and Wassell [20] focused on wireless sensor network with specific focus on water distribution monitoring system. Nasir, Soong and Ramachandran [26] focused on the framework of wireless sensor network based human centric cyber physical in-pipe water monitoring system. Wonkyu et al [47] carried out a research to analyze the RFID tag using a planar inverted-F antenna capable of being stuck to metallic objects. Authors also concentrated on the integrated system for urban sensing using radio frequency identification based WSNs [48].

There are also studies that focused on the specific concept for adaptive proportional routing that is localized quality of service routing approach [7]. Tu and Chen [5] focused on design of oil pipeline leak detection and communication systems that act on the basis of the optical fiber technology. Pires and Oliverira [6] concentrated on the security aspects of SCADA and corporate network interconnection. Authors also focused on the adaptive probabilistic epidemic protocol for wireless sensor networks particularly for urban environment [8]. This study particularly focuses on the WSN and discusses about the significance of implementing WSN in the urban environment. Arampatzis, Lygeros and Manesis [22] conducted a survey to analyze the applications of WSN and wireless sensors. Liang, Huang and Deng [46] concentrated on fault tolerant and energy efficient routing protocol for urban sensor networks. Dohler et al [33] focused on the urban wireless sensor networks routing requirements in low power and lossy networks. This study tried to bridge that gap by investigating the energy efficient wireless sensor networks for smart monitoring and sensing applications. This study concentrated on integrating RFID and WSN for other different sensing applications with special focus under metallic environments. Therefore this research will assist the future researchers to understand the importance of integrating WSN and RFIDs in order to achieve efficient smart monitoring applications.

1.2 Objectives of the Research Problems

Aim of the research is to investigate in detail about the energy efficient wireless sensor networks for smart monitoring and sensing applications. The objectives of the research are as follows.

This study is about how to integrate RFID and WSN for different sensing applications under metallic environments, to explore the importance of water monitoring applications using hybrid RFID and WSN nodes. This study also helps to investigate the importance of vehicular and urban sensing applications by utilizing the two hybrid techniques RFID and WSN due to similar metallic environment presented by the vehicles. The results from the study will help us to implement and develop a novel hybrid WSN simulation platform for determining the energy efficiency of the RFID and WSN hybrid deployment. In conclusion this hybrid deployment can improve sensing ability, range and energy efficiency.

Some of the questions for which this research is intended to find the answers are; how to develop efficient metallic in-pipe monitoring system for water, vehicular exhaust and oil and gas pipes? What is the importance of water monitoring applications using hybrid RFID and WSN nodes? And what is the importance of vehicular and urban sensing applications? And how the use of RFIDs and WSN can help in efficient Vehicular Urban sensing monitoring? The study also tries to find the answer for what is the novel hybrid WSN and RFID simulation platform for determining the energy efficiency? In case it is not present, the question is then, how to develop a hybrid simulator for determining energy efficiency?

1.3 Limitations of the Study

Limitations of the study are as follows:

This research is limited to energy efficient WSN and RFID systems alone. This study takes into consideration exclusively the integration of energy efficient RFIDs and WSNs for smart monitoring and sensing applications. The findings of this study are limited to the smart monitoring and sensing applications. The findings of the study focus on developing a hybrid RFID and WSN simulator.

1.4 Significance of the Research Study

This study will be significant for developing energy efficient wireless sensor networks for smart monitoring and sensing applications. When integrating RFID and other wireless sensor networks for various sensing applications under metallic environments it will be highly efficient for saving energy. RFID systems used in this study will transmit information that will be helpful in quality monitoring of liquefied gas, vehicular exhaust and water pipes. This study

will also focus on integrating RFID active and semi-passive nodes into metal pipes for monitoring the quality of water and leaks in the water distribution system. Collaborating radio frequency identification semi-passive and active nodes also detect moisture in oil and gas pipes. Moreover, it was clear that, combining radio frequency identification with other wireless networks assist in the development of a smart human-centric monitoring system that has the potential to provide maintenance, detect events like presence of strain or moisture on pipe's structure and assists to automatically adjust the pump and value properties based on the decisions taken by the cyber system. Vehicular urban sensing is helpful to monitor the harmful gases emitted by vehicles metallic exhaust pipes.

Moreover it was also noted that wireless monitoring system using low RFIDs could be applied as moisture sensors could prevent gas quality hazards by detecting the received energy of transferred signal. Thus, it is very clear that, the main contribution of the study in the vehicle urban sensing is based on detecting events, recognizing patterns in the in-pipe systems and predicting events. A special-purpose wireless sensor network simulator used in this particular study will include these characteristics namely rapid prototyping, dynamic, interoperable and platform-independent environment simulation platform particularly for RFID and WSN. The simulator developed for the study will provide realistic values of implemented network by considering the actual hardware of deployed nodes, radio transmitting powers and MAC protocols. It will help in determining ways to minimize the consumption of energy and raise the network life-time. Moreover, cooperative networks and cognitive radio techniques used will help in assisting the performance and range of the monitoring applications. At the same time it also enhances the reliability and performance for long range in-pipe communications.

1.5 Organization of the Thesis

The following section provides an overview of the contents of the chapters that are presented in this research:

i. **Chapter One:** The first chapter is the introduction chapter which provides the basic idea about this research concept "investigation into energy efficient wireless sensor networks for smart monitoring and sensing applications" including the background of the research, statement of the problem, research questions, aim of the research and objectives of this research and significance to the study, need for the study and research gap and scope or limitations of the study.

ii. **Chapter Two:** Second chapter is the literature review which provides the existing work related to WSNs and RFID monitoring applications especially for in-pipe monitoring and vehicular and urban sensing scenarios. Apart from these, this chapter also discusses about advantages of wireless sensor network based monitoring system over SCADA and moisture sensing for oil and gas pipelines. This chapter also in detail discusses about the vehicular and

urban sensing and the contemporary systems developed. Further, this chapter also explores the RFID and WSN simulation platform used in various applications and explained the significant benefits of having a simulation platform capable of analyzing the energy efficiencies of such hybrid deployments.

iii. **Chapter Three:** Chapter three explores about the RFID based in-pipe monitoring systems. This chapter discusses about the water distribution monitoring systems. Part of the section discusses about the description of PipeSense system description, experimental set-up and BER analysis, framework architecture, system design and implementation, human centric cyber physical system for water monitoring, water smart home, and cognitive RFID network for spectrum and energy efficiencies. This chapter also explores the RFID based moisture detection for gas pipelines that focuses on moisture detection system model, gas quality monitoring system architecture and moisture sensing system design. This chapter explores the efforts for monitoring and maintaining metallic pipe infrastructure for distribution of water and oil and gas. The simulation and experimental results are provided to test the findings. Techniques for prediction and event detection also presented. Techniques related to cooperative and cognitive network were also explored for enhancing the spectrum efficiency and energy efficiency of the hybrid networks.

iv. **Chapter Four:** Forth chapter discusses about another monitoring situation of urban and vehicular sensing using RFID and WSN networks. This chapter discusses about the vehicular and urban sensing system design and its implementation. The implementation part focuses on the hardware platform, system architecture, and software architecture and system implementation. This chapter also highlights the vehicle sensing architecture, human-centric urban sensing, experimental set-up, BusSense system design and event detection and analysis. This chapter also presents the framework architecture that was developed for experimental results and analysis of obtained data for making decisions.

v. **Chapter Five:** Chapter five presents the event driven hybrid WSN and RFID simulator for determining energy consumption of a deployed hybrid network. The platform methodology, development and simulation results using real life wireless nodes are presented. Moreover the simulator developed for this study was used to accurately predict the lifetime and energy efficiencies of a specific deployed sensor network.

vi. **Chapter Six:** Sixth chapter is the conclusion and suggestion chapter that describes about the contribution of the proposed monitoring techniques summary of findings obtained through the simulation result and also provides conclusion to the research followed by strategies and suggesting direction for the future research. Recommendation is provided in these section namely vehicular urban sensing, in-pipe monitoring and hybrid wireless sensor network simulation platform. This study will be helpful for the future researchers to understand about the concept of energy efficient wireless sensor networks for smart monitoring and sensing applications.

Chapter 2

Literature Review

2.1 Introduction

This chapter in detail discusses about the meaning and definition of WSN, meaning and definition of RFID. Next, this study discusses about the various applications of WSNs and RFIDs as well as their integration. Subsequently, the next sections discus the novel application of WSN integrated with RFIDs and other in-pipe monitoring applications. Apart from these, this chapter also critically reviews the WSN based in-pipe monitoring systems and explain the significance of WSN in monitoring the in-pipe systems. Subsequent sections focus on the urban and vehicular sensing systems and discuss about the networks that used for their sensing utilizing WSN and RFIDs working together especially for exhaust gas monitoring. Further this study also discusses about the simulator platforms available for WSN and RFID deployment

2.2 Meaning and Definition of Wireless Sensor Networks

Wireless sensor networks considered as small devices network represented as nodes capable of sensing the surroundings and directs the data collected from the supervised field through wireless links. The data is forwarded feasibly through numerous hops to a sink that can utilize it locally or is linked to other networks through a gateway. The nodes can be moving or stationary [49]. A wireless sensor networks is a collection of nodes organized into a cooperative network. Every node comprises of processing capability that may consist of numerous kinds of memories, have a RF transceiver, a source of power and accommodates different actuators and sensors. The nodes interact wirelessly and always self-organize after being deployed in an adhoc network. Systems of thousands and tens of thousands of nodes are expected and such systems can revolutionize the way an individual work and live and as well as can have a major effect on several industries [50-52]. Thus, a wireless sensor network in its simplest form can be referred to as a network of feasibly low complexity [53] and small sized devices for sensing the surroundings, collects the data from the deployment area and forwarding it possibly through multiple hops relaying to a sink that can utilize it locally or that

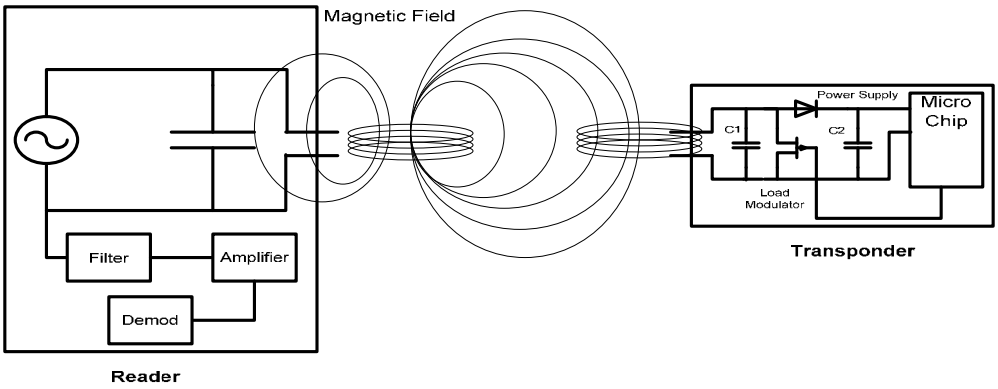


Figure 2.1: RFID Tag illustration

is linked to other networks through a gateway [54].

Wireless sensor networks are comprised of small devices interacting over wireless links without using a fixed infrastructure of network. Because of the restricted range of transmission, communication between any two devices needs collaborating intermediate nodes to forward the data [55]. A wireless sensor network comprises of numerous wireless sensor nodes and these nodes can be described by being little in size with restricted energy generally supplied by battery. They interact through built in antenna over radio frequency signals and these networks are utilized to supervise any field of interest for example; to detect movement, precipitation and changes in the temperature [56]. One another definition states that, 'a wireless sensor network is a deployment of huge number of inexpensive, small and temporarily powered devices that can compute sense and interact with other devices for the intent of collecting local data to make worldwide decisions about physical surroundings' [57]. A larger number of sensors can be deployed to sense over a large geographical area with greater accuracy [58]. Although initially they were considered as a deployment of tiny sensor nodes having a distinct platform and architecture, WSNs can be heterogeneous, mobile, display different network topologies, and may use existing network infrastructures. Hence, WSNs are used ubiquitously for monitoring applications. Generally, WSNs can be defined as networks of nodes with communication, computation, sensing, and even actuation abilities. The power unit is usually a rechargeable battery that is non-replaceable in the field.

Table 2-1: The battery and cost comparison of RFID with contemporary technologies.

	Passive RFID	**Active RFID**	**ZigBee**	**WiFi**	**Bluetooth**
Battery Life (days)	No Battery	365	100 – 1000	5	7
Cost	Very low	Low	Normal	High	Medium

Table 2-2: RFID Frequency Band Table [70].

Frequency	Description	Air interface Range	Applications	Benefits	Drawbacks
125 kHz to 134 kHz	Low Frequency	< 0.5m	• Access Control • Animal Tracking • Vehicle immobilizers • Product Authentication • POS applications	Works well around water and metal products.	Short read range and slower read rates
13.56 MHz	High Frequency	< 1m	• Smart Cards • Smart shelve • tags for item level tracking • Library Books • Airline Baggage • Maintenance data logging	Low cost of tags	Higher read rate than LF
860 MHz to 930MHz	Ultrahigh Frequency (UHF)	3m	• Pallet tracking • Carton Tracking • Electronic toll collection • Parking lot access	EPC standard built around this frequency	Does not work well around items of high water or metal content
2.4GHz	Microwave	1m	• Airline Baggage • Electronic toll collection	Fastest read rates	Most expensive

2.3 Meaning and Definition of Radio frequency identification

Radio frequency identification is a process of recognizing an object or person utilizing a transmission of radio frequency. The technology can be utilized to recognize, sort, track or detect vast number of objects. Communication exists between a transponder and a reader always known as tag. Tag can either be passive or active and occurs in different forms involving tags, smart cards, watches, and labels and even embedded in cell phones. The frequency of communication utilized varies and rely on application to a large extent and it extends from 125 kHz to 5.8 GHz. Several countries have imposed regulations to manage

emission and to hinder interference with other industrial ISM (industrial Scientific and Medical) equipment [59]. A radio frequency identification system comprises of two main tools, a reader (also known as interrogator) and a tag (also known as transponder) illustrated by the fig. 2.1. The tag is configured in such a way to be cheap and small; credit card size or little while in comparison the reader is much larger and costlier. The radio frequency identification tag comprises of a little memory for holding data and whenever that tag comes into proximity with the radio frequency identification reader the reader will find the presence of tag and can read data from tag [60].

Radio frequency identification occurs as a unique subset of bigger family of automated technologies of identification that involves things like visual scanning devices, bar codes and biometric readers. Radio frequency identification system is a way of automated identification that characterizes electronic tags utilized to store information and to perform as transponders for sending stored data as payload using electromagnetic waves sent to detached devices for listening. The tags can be fixed on a static or moving object by different methods and the readers that acquire emissions from tags translate the wave embedded information into meaningful data. As of now the deployed radio frequency identification systems offer real time identity in supervising and tracking and make possible vast number of access control and solutions of inventory management [61]. Radio frequency identification is an automatic method of identification using devices known as radio frequency identification transponders or tags. A radio frequency identification tag is an object that can be attached or incorporated into an animal, product or individual for identification purpose using radio waves. Chip based radio frequency identification a tag comprises of antennas and silicon chips. A passive tag needs no source of internal power whereas active tags needs a source of power, however, a Semi-Passive tag having a battery source depends upon the reader to supply the energy needed for the transmission. The radio frequency identification system permits them to locate and recognize products and parts in their own firm or along their complete supply chain [62].

RFID systems that use frequencies between 100 kHz and 30 MHz operate using inductive coupling, while microwave systems in the frequency range 2.45 - 5.8 GHz are coupled using electromagnetic fields. Lower frequency systems are primarily used due to their better penetration of objects. Electromagnetically coupled systems, or backscatter systems, operate in the UHF and microwave bands. Their reader utilizes a dipole antenna to send out a continuous electromagnetic wave to tags [63]. The communication from a tag to the reader is then achieved by varying the amplitude of the electromagnetic waves reflected by the tag antenna in accordance with the digital data to be transmitted this phenomenon is called backscattering [63, 64]. Table 2-1, shows the battery life and cost comparison for RFID systems. RFID operate in the Scientific and Medical (ISM) frequency band that ranges from 100 kHz to 5.8 GHz [65], table 2-2 summarizes the characteristics of RFID systems based on their operating frequency.

2.4 Applications of WSN and RFID

WSN is also used for industrial safety applications, typically they engage sensors to predict the existence of poisonous, noxious or dangerous materials thereby providing early identification and detection of spills or leaks of biological agents or chemicals before severe harm can occur. Wireless networks may involve distributed routing algorithms and can be self-maintaining and self-healing. They can also be resilient in face of an explosion or other harm to industrial plant by providing end users with critical status of plant under dangerous conditions [66]. A modern cable has nearly 8 kilometer of cables to link hundreds of sensors. Wireless sensor networks permit not only the functionality of lowering the weight and volume required by the cabling but also the sensor deployment with much freedom. Nowadays military applications of wireless sensor are common mainly because it is critical to deploy a communication infrastructure in the war zones and similar sensitive operations. The installation of centralized infrastructure is not only time consuming but also becomes a vulnerable solution for the network [67].

Supply chain tracking is the most discussed application of RFID technology that has been given mandate by Walmart, the Defense department and several other notable manufacturers and retailers that suppliers must offer pallet level radio frequency identification tags for tracking products through distribution networks. The objective is to minimize losses due to theft and/or logical failures. Tags are required to be read in large amount at speed that does not intervene with standard work practices. Homeland security is a natural area for tracking technologies application. Assuring the container shipping security is of specific concern. Tamper detecting active radio frequency identification tags along with passive tags as well as containers on items within containers are being suggested as a way to streamline operations of port while developing security [68]. Several RFID applications are mentioned by Matta in [69]. Automatic identification techniques lower labor and time and develop accuracy in data entry and identification. These techniques involve barcode systems, optical character recognition systems, radio frequency identification systems and even facial, fingerprint and retinal scanning systems. Barcodes were the first automatic identification technology form. By automating serial number data input they offer benefits over manual identification and entry of data resulting in reduced errors, developed speed, developed communication and improved management of inventory.

2.5 WSN based in-pipe Monitoring System

There are numerous studies that focused on WSN-based solution for monitoring the pipeline. Jawhar et al [71] proposed an initial framework with the help of WSNs particularly for water, oil and gas pipeline monitoring applications. Next to that, PipeNet is WSN based system used

for automated detection, quantification and localization of bursts, leaks and other anomalies in huge transmission of water pipelines [72]. Accelerometer sensors are typically applied and used for measuring the vibrations emitted from the occurrence of cracks in the pipeline. A non-intrusive, scalable, adaptive and autonomous water monitoring system was included in [73]. It tracks and locates leakages using minimal cost not fixed vibration sensors which are externally associated with the pipes. It could be used for estimating the consumption of water with minimum error. TriopusNet [74] is an autonomous monitoring system used for pipeline. In this system, sensor nodes automatically come from a centralized database situated at the water pipeline source and carried forward by flow of water. Such nodes are automatically placed on the basis of algorithm for sensor deployment. Each node of sensor encompasses a motor that permits the three arms for latching into the inner surface of pipe. Moreover, human effort is not needed for installing and repairing sensor nodes. For a reliable and fault-tolerant architecture it should be based on integrated wireless and wired sensor network for monitoring aboveground infrastructures for pipeline [75]. Underground pipelines are suitable for transmitting water from remote locations. Underground pipelines are the safest way for transferring water but leakages could cause environmental issues [76-78]. Minimal-cost MISE_PIPE (waveguide-based) technique for WSN for underground pipeline monitoring is explained in [76]. Such system use two sensors types, one sensor located inside and other sensor located outside the pipeline. It was also stated and noticed that the external and internal sensors facilitate sufficient data to detect and locate the leakage identified or seen in the pipeline. It was observed that this kind of technique could give accurate real-time detection of leakage and enhanced lifetime particularly for the underground pipelines. It was therefore concluded as reliable and fault-tolerant architecture based on integrated wireless and wired sensor network for monitoring above and underground infrastructures for pipeline. Gerald and Azubogu [79] designed and implemented monitoring system for pipeline using acceleration-based WSN. MEMS (Mirco-electro-mechanical system) based WSN is developed for monitoring the nondestructive pipeline systems. It includes accelerometers for MEMS to gauge flow-induced vibration particularly on pipe surface for determining the change in the pressure of water by rupture and location that is damaged or ruined. This work investigates the relationship between fluctuations of pressure and flow-induced vibration. Vibration measurements were performed in the sections of pipe surface of water-filled loop that are subjected to vast flow rates range. It was observed that water pressure could be transformed into surface vibrations of pipe and become acceleration-monitoring. For enhancing the accuracy of identifying the location of damage in larger-scale distribution of water system much more enhancements are required. From the statistical analysis it was indicated that there is a non-linear link between rate of water flow and flow induced vibration.

Shinozuka et al [80] carried out a research to understand the nondestructive monitoring of a pipe network using MEMS-based non fixed network. The proposed system includes MEMS

accelerometers to gauge vibration on pipe surface for identifying the modifications resulting from the pressure of water caused by rupture and identifies the damage location. The proposed system allows different sensor boards and camera modules to be developed and for transmitting data with a shared board of radio to uplink the data. Issues encompass precise time synchronization, long-range technology, managing power and effective bandwidth usage. The low-cost MEMS technology, simple installation, saved wiring cost without destructive modification and enable large-scale deployment at a minimal cost. It was noted that PipeTect detects and determines the locations of damage parts in the water pipe by maps of contour, data analysis of time-correlated acceleration and frequency domain analysis.

Stoianov et al [72] conducted a research to analyze the WSN for pipeline monitoring. Authors developed PIPENET for monitoring the pipeline that is based on WSN. Pipenet system is designed for analyzing and localizing failures and leaks in transmission of water pipelines. It provides numerous noteworthy properties such as near-real operation with few wrong or false alarms, automated leaks and burst detection and high-frequency data collection. It was also claimed that this system is inexpensive for producing, installing and maintaining with the ability to differentiate system faults false alarms. The sensors can be reusable and flexible and have a data-flow related programming environment. It was also noticed that Pipenet provides much required heights in temporal and spatial resolution of acoustic, hydraulic and water data for quality that would enhance the ability for understanding and monitoring the large scale supply of water and sewer systems. Thus, it was concluded that Pipenet system is designed for analyzing and localizing failures and leaks in transmission of water pipelines using acoustic technology.

2.6 RFID based in-pipe Monitoring System

Nasir et al [81] conducted a research to examine energy efficient cooperation in underlay RFID cognitive networks especially for a water smart home (home equipped with wireless sensor motes and RFIDs to intelligently monitor the consumption of water). Shrinking resources of water all over the globe and maximizing water consumption costs that have prompted users of water and distribution firms to come up with strategies for water conserving by producing accurate patterns of the usage of the water and detecting leaks. This study developed a smart water monitoring application through RFID which is low power. Moreover, in the home environment, it includes various primary interferences inside a room like Bluetooth devices, television signals cordless phones, WiFi and cellular devices. For minimizing the interference this proposed system is utilized by focusing on a cooperating underlay RFID cognitive network with special focus on smart water application. This paper developed a scheme for selecting best node for a cognitive network performing the event detection part. Firstly, this scheme removes those nodes that do not fulfill the constraint of

interference. Furthermore, among such nodes which successfully fulfill the constraint, one node providing the high end-to-end signal-to-noise ratio (SNR) is selected for forwarding the transmitter message to destination. The main observation of this study is to control cost and conserve water as well as by sensing different facts of water network in smart home and for sharing the message to client to preserve, control and enhance their life styles.

2.7 Integration of RFID and WSN based In-pipe Monitoring System

Almazyad et al [82] proposed and designed scalable simulation of WSN-based long-distance monitoring for water pipeline leakages. The proposed system works on the basis of implementing various mobile nodes of sensors and only a single node would be active for specific time period. All the other sleeping nodes are activated through various techniques like time-based, location-based or interrupt-driven technique. Mathematical models for consumption of energy and the usage of memory are developed, analyzed and validated using simulation on Matlab. The findings of analysis indicate that the energy consumption increases with the increase of groups of nodes working together. Consumption of energy could be further enhanced by maximizing the distance between tags of RFID that enhancement is not essential and it is overweighed by degradation in resolution for distance.

In terms of savings for energy time-based and location-based wakeup methods are almost equal, whereas, interrupt-driven method minimizes the consumption. Such benefit overshadows the reliability of such method because nodes are integrated in series. Another benefit of interrupt-driven method is its scalability, on the other hand, time-based and location-based wakeup methods have restricted scalability because of marginal activities of the node required to operate in their sleep mode. Size of memory is also enhanced when deploying the multi-node model. It was concluded that the proposed method would be fault-tolerant and efficient monitoring system for long-distance pipeline for water systems.

Kim et al [83] proposed the sensor-based pipeline autonomous monitoring and maintenance system (SPAMMS). Pipeline based applications have emerged as a main part of life in general. Frequent inspections and active monitoring are crucial for maintaining the health for pipeline. Such tasks are costly using conventional maintenance systems recognizing that the pipeline system could be implemented in a hazardous and inaccessible environment.

Table 2-3: Comparison of contemporary in-pipe monitoring system with our proposed system.

S. No	Model Name	Description	Technology	Pros and Cons	Detection Method
1	PipeSense [111] and [113]	In-pipe monitoring for metal water pipes, measuring flow and pressure values, determines leakages and consumption patterns.	RFID (in-pipe) integrated with WSN at the taping points, flow and pressure sensors. RFIDs can also be used to sense the presence of moisture in case of oil and gas pipes.	• RFID usage means low power systems. • Localization of fault is easy due to RFID identification. • Low cost due to lower cost of RFIDs. • RFIDs are integrated with sensors and also perform moisture detection. • Reliability and Security issues may arise.	• HMM and HHMM
2	TriopusNet [74]	Autonomous sensor deployment in monitoring the pipeline systems.	Kmote WSN, gyroscope, pressure sensors • Pressure can be sensed through flow sensors at the main	• Pipe may have to be removed and taken out. • Not for underground pipes. • Effective for small sections of pipes. • The spatial topology of	• MATLAB statistical tools.

			taps.	pipelines must be known, including the pipe length, the pipe's internal diameter. • Manual intervention required. • Not for all pipes.	
3	NAWMS [73]	Monitoring the water system only at the metering point.	Crossbow MicaZ mote, Accelerometers	• Use vibration sensing to estimate the water flow only. • Use normal water flow meters.	• Linear and mixed linear geometric programming.
4	Pipenet [72]	Acoustic based in-pipe monitoring system typically used for identifying flow, leaks and pressure.	WiFi and GPRS	• Used only at tapping points. • Acoustic and vibration sensing.	• Cross correlation of power spectral density for leaks. • Localization algorithm for location.
5	PipeTect [80]	Noninvasive monitoring of water pipes for rupture detection.	accelerometers, tilt sensors, WiFi and ZigBee	• Uses Zigbee motes for monitoring ruptures and breaks in a pipe only and	• Statistical analysis of acceleration values.

				then sends this data to WiFi enables motes.	
6	WSN-based long-distance water pipeline leakage monitoring system [82]	This system developed for monitoring the leakage in the pipeline system.	WSN and RFID	• Only for aboveground water pipelines. • RFIDs are used for localization only. • Motes are randomly spattered into the pipe.	• Statistical Energy Consumption analysis based on the wake up methods.
7	SWATS [117]	WSN for steam flood and water flood pipeline monitoring system.	WSN leakage monitoring. WiFi, pressure sensors	• Decentralized. • Oil and gas pipes only. • Leakages only through cross correlation of the sensors' data. • No results available.	• Statistical analysis of temporal and spatial patterns.
8	SmartPipes [118]	Smart WSN for leak detection in monitoring water pipelines.	WSN, Force sensitive resistors for measuring pressure	• For plastic pipes only. • Detection of leaks only. • Master Slave approach.	• Statistical analysis on force data.
9	SPRAM [119]	The SPRAM System integrates RFID systems with mobile sensors and autonomous	RFID, WSN SkyeModule M10 UHF and Robot based	• RFIDs used only for localization through a robot in the pipe. • Ultra high	• Multiple channeled redundant array of RFID tags techniques for

		robots.		frequency is applied within the pipe. • Acoustic sensors for corrosion detection.	localization .

This proposed customizable, effective, autonomous, cost-effective sensor-based system namely SPAMMS integrates robotic technologies with sensor technology for tracking the health oriented aspects and permits corrective and active maintenance and monitoring of the pipelines. The proposed method integrates RFID systems with autonomous robots and mobile sensors. The main contributions of SPAMMS encompass the system could apply to wide variety of pipeline systems; robot is autonomous and technique for localization permits controllable errors and the solution given is much more cost effective because it adopts low cost powerless fixed sensors while the system in the pipeline is operating. Apart from these, it allows good tracking or detecting of the mobile sensors. From the result of event analysis, it was identified that a robot agent obtains instruction from the controlling system and then transmits within the pipelines for proper inspection and resolves the reported incidents like leakage, damage or corrosion. It was therefore established that the pipeline based applications have emerged as a main part of life. Frequent inspections and active monitoring are crucial for maintaining the health for pipeline. Such techniques would be customizable, effective, autonomous, cost-effective sensor-based system. Moreover, it was clear from the above analysis that the main contributions of SPAMMS encompass the system could apply to wide variety of pipeline systems. Table 2-3, compares the state of the art with the proposed system. The author has contributed on the above mentioned work by introducing low frequency RFIDs that can work in a metallic environment both above and underground as compared to [82] and [83].

2.8 Urban Sensing

Johnson et al [84] conducted a research to analyze the people-centric urban sensing. This study focusses on the security issues identified in people-centric urban sensing. People-centric urban sensing includes processing, storing, collecting and fusing large data volumes related to daily human activities. Moreover, it was noted that sensing is performed in mobile and highly dynamic environment and supports applications related to pervasive computing that are concentrated on enhancing the experience of user. In such kind of environment, human would be main focus, there would be new issues for security of information, not only due to dynamic and complex communication but also due to the data arriving from sensors which would be

forwarded by a person that is surely not a tiny sensor thrown in forest or mounted on animals' neck. From the findings of the research, it was observed that there are nine challenges faced in the people-centric urban sensing. They are anonymous tasking, reliable data readings, context privacy, anonymous data reporting, authenticity in data, system integrity, participation, preventing data suppression and fairness. Thus it was concluded that sensing is performed in mobile and highly dynamic environment and supports applications related to pervasive computing that are concentrated on enhancing the experience of user.

Lane et al [85] discussed about the urban sensing systems and analyzed about their significance and also analyzed whether it is participatory or opportunistic. This study compared two potential sensor custodians' roles in urban sensing systems. This study considers opportunistic and participatory solutions to be complementary; it was believed that enhancing an approach of opportunistic sensing yields a system that supports application diversity and large scale deployments. It was found that significant issues needed to resolve the opportunistic sensing to make it effective and feasible. When sensor mobility could not be controlled this will ensure continuous sensor calibration, determine context of sensor to allow for focused sampling and safeguarding custodian privacy. From this it was clear that, study develops an evaluation model and claim that opportunistic sensing would support broader diversity and large scale applications. Thus it was concluded that urban sensing systems would be opportunistic.

Pidcock et al [86] developed a NotiSense; an urban sensing notification system for enhancing bystander privacy. Urban sensing network would be developed through clients of mobile devices registered as respondents with a service for urban sensing. Urban sensing service enables tasks for sensing from an application of urban sensing and disseminates these tasks to phones. From the findings of the research it was observed that NotiSense is a good approach for enhancing the bystanders' privacy.

2.9 Vehicular Sensing

Piran and Murthy [87] discussed about a novel routing algorithm for vehicular sensor networks. This paper focuses on different communication aspects in vehicular networks. Novel routing algorithm keeps some of the nodes in the network in the sleep mode for saving power. Subsequently, the decision whether node remains in sleep mode or stays awake would be decided by a probability of factors such as remaining energy in vehicle sensor; previous node state and significance of the message. Moreover, it was noted that novel routing algorithm is free from global positioning system and it does not need any expensive topology for identifying the location information.

Lee et al [88] focused on dissemination and harvesting of urban data using platforms of vehicular sensing. This paper developed opportunistic and decentralized MobEyes solution

typically for monitoring urban environment through vehicular sensor network. The key component of MDHP (MobEyes diffusion/harvesting processor) which works by harvesting or disseminating sensed data is to adopt actual opportunistic protocols which involve intrinsic mobility of regular nodes. The main reason for adopting original protocols for dissemination is to overcome the intermittent urban grids connectivity in off peak hours. This does not include the exploitation of traditional propagation or search techniques on the basis of ad hoc broadcast and multicast. It was indicated that protocols of MDHP are disruption scalable, tolerant and non-intrusive through extensive simulations and analytical models. MobEyes are configured for achieving the most appropriate trade-off between completeness or latency and overhead by perfectly selecting its k-hop scope of relay and quantity of harvesting agents.

Gao and Utecht [89] carried out a research to analyze the high speed data routing with specific reference to vehicular sensor network (VSN). It was observed that proposed protocol could effectively give an accurate and simple answer to communication of VSN. This architecture developed on the basis of sensors that could satisfy most of the key functionalities that are envisioned. Moreover, protocol could support huge deployment. The motes could acquire and sent different aspects of information to the system, for example; patterns in the traffic for sophisticated processing could process and broadcast the obtained data. The table 2-4, shows the comparison of our proposed system with the contemporary systems available today.

Table 2-4: Comparison of Contemporary Vehicular Urban Sensing Systems.

S. No	**Model Name**	**Description**	**Technology**	**Pros and Cons**
1	BusSense [115], [137] Environsense [48]	Monitoring exhaust emissions from campus busses. CO and CO2 were monitored.	WSN, RFID and GPRS	• Monitors exhaust gas emissions. • Real Time. • RFIDs were installed in the metallic exhaust pipes with sensors. • Data sent to WSN installed on vehicle. • In-vehicle monitoring only.
2	OpenSense[114]	Monitoring environmental pollution in atmosphere from	WSN, 2G, 3G	• Monitors pollution levels

		Trams in Zurich Switzerland. O3, NO, NO2, SO2 VOC were monitored.		outside Trams. • Determine contour maps of the polluted areas. • No information of exhaust gases.
3	Online vehicle and atmospheric pollution monitoring [9]	Monitors the exhaust gases from a vehicle using Mica2 mote. CO_2 monitoring.	GPRS	• Monitors exhaust gases from inside the vehicle. • The measurements were not accurate. • Not much is available on its development.
4	Vehicular Wireless Sensor Network for CO2 Monitoring [159]	CO_2 Monitoring within the car using WSN.	ZigBee, 3G	• Only inside the car monitoring. • No real atmosphere or exhaust monitoring.

2.10 RFID and WSN Simulation Platforms

The recent integration of two main technologies for ubiquitous computing RFID systems and WSNs has attracted a great deal of attention. However, these two technologies have diverse research and development areas. Therefore, their integration will exploit the advantages of both technologies. Due to the highly resource-constrained nature of WSNs, the current research aim is to maximize the lifetime of the network.

Many different kinds of sensor network simulators are present, such as NS-2[90], OPNET Modeler[91], OMNeT++[92], J-Sim[93], SNetSim[94], SensorSim[95], SENS[96], TOSSIM[97], ATEMU[98], AVRORA[99], Qualnet[100], SNIPER [101] and SensorMaker[102]. Most of these on-hand simulators are complex and are not easy to extend

to evaluate and compare energy consumption in the network and also of the individual nodes for any given MAC protocol. Furthermore, simulating an application that caters to several distinct node platforms and RFIDs using the available simulation platforms can be hard or sometimes even impossible given their intricacy. Contemporary WSN and RFID simulators mostly depend on queuing models or upon the signal propagation properties, fading and noise models of the simulation application, which makes them difficult to adapt for various routing protocols [97]. Other simulators are too difficult to be extended and trained [90]. Moreover, they cannot accurately predict the energy consumption for different types of nodes and environments, as most of them consider ideal nodes for simulation.

Mainly, researchers are interested in the energy consumption of a WSN to extend its lifespan. Most of the real-world deployments use a few available off-the-shelf node platforms [103 - 105] since, for a given MAC protocol, the energy consumption typically depends on the hardware of the nodes and the environmental conditions of the deployment. Therefore, researchers should be able to approximate the energy consumption of these well-known WSNs either using available MAC protocols such as SMAC [106], TMAC [107] and BMAC [108] or their own customized MAC protocol. The environmental conditions can be incorporated by introducing the outage probabilities for the given application scenario. The re-transmissions of the signals can be performed per these probabilities to get more accurate results.

There have been some efforts to simulate RFID tags but all of them were done using an air interface and on the logistics-related applications. RFIDSIM [109] and RFID-Env [110] are two examples. A new trend has also emerged to use this technology in collaboration with other wireless technologies for better performance and management. One such example is the proposed work on monitoring water attributes and leak determination in metallic piping structures for water distribution system (WDS) [111, 112, 113]. A new simulation platform EnergySim [116] has been developed having the capability to simulate mixed deployment of WSN and RFIDs in diverse environments. This is developed for simulating the consumption of energy and lifetimes of such novel scenarios. The hybrid simulator efficiently measures the energy consumption of other mixed deployment of WSN technology; modular approach makes it more expandable, versatile with ease of programming. The proposed hybrid simulator supports the energy efficiency and calculations of life-time of the network. It supports one routing scheme. It is a unique way that has been built on a modular approach and considers real information from the real mote hardware data sheets. Another distinct feature of this simulator is the ability to simulate RFID in-pipe scenarios which were not present in any simulator available at the time. This simulator does not follow the element by element approach used by other simulators. However, it is built in a way to accommodate any feature necessary in the future. Table 2-5, compares the proposed simulator with the state of art available at the time of writing the thesis.

Table 2-5: Comparison of RFID and WSN contemporary simulators with our proposed simulation platform.

S. No	Model Name	Description	Technology	Pros and Cons
1	EnergySim [116]	Hybrid WSN and RFID simulation platform. Developed for simulations within pipes and buildings.	C#	**Pros:** • Ease of upgrading. • Modular approach. • Capable of simulating RFID and WSN together. • Different Environments and scenarios can be simulated with different customize configurations. • Real motes can be selected with real world power and energy consumption values. **Cons:** • Environmental Fading is not yet implemented. • Only one routing protocol is implemented currently.
2	TOSSIM [97]	To identify the efficiency of the MAC scheme only.	Python and C++, NesC, TinyOS	**Pros:** • Powerful command base simulations. • Opensource. • Good GUI. • Captures the hidden terminal problem. **Cons:** • Not user friendly. • Only for TinyOS.

				• Only to check the MAC schemes. • Cannot measure energy consumption in WSNs.
3	NS-2[90]	Non-specific network simulators. It typically supports a large number of protocols in all layers.	C++	**Pros:** • Very good in simulating wired networks. • Open source. • Non-specific network simulator. **Cons:** • A lot of bugs may occur. • Tool Command Language is somewhat difficult and makes it complex. • Poor graphical support. • Unscalable. • Unable to simulate bandwidth, power consumption or energy saving in WSN.
4	OPNET Modeler (Riverbed Modeler) [91]	Discrete event-simulation engine for analyzing and designing communication networks.	C, C++	**Pros:** • High-fidelity modeling. • Scalable simulation. **Cons:** • Licensed. • Required a learning curve. • Complex. • Energy consumption not readily available.
5	OMNeT+[92],	Starting point for WSN modeling	C++	**Pros:** • Good GUI. • Support MAC protocols.

				• Can simulate power consumption. **Cons:** • High number of reported bugs. • Compatibility issues. • Licensed.
6	J-Sim[93],	It offers real-time process based simulation and it is a discrete event network simulator.	Java	**Pros:** • Open source. • Simulate real-time processes. • Good reusability and interchangeability. • Simulate radio channels and power consumptions. **Cons:** • Not originally designed to simulate WSNs. • Hard to enhance and code.
7	SNetSim[94],	Event-driven simulation software running on Windows.	C, C#	**Pros:** • Event driven simulator. **Cons:** • Not documented well. • Not an open source.
8	SensorSim[95],	Simulation framework for modeling sensor networks.	Tcl, Unix	**Pros:** • Simulates different scenarios in WSNs. • Have Power and Battery Models. **Cons:** • Not available to download. • Cannot be customized.
9	SENS[96],	Wireless sensor network simulator with modular,	C++	**Pros:**

		layered architecture.		• Platform-independent. • Users can assemble application-specific environments. **Cons:** • Not accurately simulate a MAC protocol. • Provides support for sensors, actuators, and physical phenomena only for sound. • Less customizable. •
10	ATEMU[98],	Emulator of an AVR processor.	C	**Pros:** • Good GUI. • Runs TinyOs on Mica2 hardware. • Open source. • Simulates heterogeneous networks. **Cons:** • High simulation times. • Not much routing and cluster simulations support. • Works for AVR controller based systems.
11	AVRORA[99],	It is an instruction-level simulator, can also simulate AVR-based microcontroller MICA2 sensor nodes.	Java	**Pros:** • Supports energy consumption simulation. • Open source. **Cons:** • No GUI. • Does not provide network communication. • Bugs may occur.

12	Qualnet[100]	It is a commercial derivation of GloMoSim simulator.	C++	**Pros:** • GUI based. • Modular layer stack design. • Scalable. **Cons:** • Licensed. • No energy consumption measurements. • Difficult to install. • Slow. • Very expensive.
13	SNIPER (WSNSim) [101]	Less known WSN simulator.	C#	**Pros:** • Good in routing protocols and clustering. **Cons:** • Not downloadable. • Not expandable, code is not available. • No energy measurements.
14	SensorMaker[102]	WSN Simulator that supports fine grained instrumentation.	Unknown	**Pros:** • Simulates routing, clustering and MAC only. • Determines Energy consumptions. **Cons:** • Code is not available.
15	RFIDSIM [109]	RFIDSIM is a simulator for RFID readers and tags.	C++	**Pros:** • Open source. • Multi-channel support. • Realistic physical layer. **Cons:** • Not well tested.

				• Lot of bugs. • No energy consumption stats. • Lack models.
16	RFID-Env [110]	Designed for plant environment in logistic applications. Uses UHF passive RFIDs only	Java	**Pros:** • Evaluate the tag reading and writing speeds. • Simulate anti-collision communication protocols. **Cons:** • Simulator is not available. • It is under an upgrade. • Only for logistic related purpose. • Lack models.

2.11 Summary

From the above evidence it was noted that WSNs and RFIDs are significant tools for active inspection and maintenance systems. In order to monitor huge distance water pipeline for bursts, leakages and other anomalies or to monitor exhaust gases from a metallic vehicle exhaust is a tough task that needs robust, energy-efficient and scalable mechanisms. WSN and RFIDs offer robust answers to these issues. It was stated that a WSN is a collection of nodes organized into a cooperative network. It was also noted that every node involves processing capability may consists of memory, have a radio frequency transceiver, have a source of power and accommodate different actuators and sensors. RFID technology can be utilized to recognize, sort, track or detect vast number of objects. Communication exists between a transponder and a reader always known as tag. Given the vast nature of the deployments, simulations is an integrated part of evaluating a WSN deployment, hence, having a customized simulation platform that can simulate both WSN and RFIDs in different scenarios and environments could become handy in pre-analysis of the systems need and life-time cost. Some of the contemporary simulation platforms were studied and the need for a hybrid simulation platform is highlighted.

Chapter 3

RFID based In-pipe Monitoring Systems

Water is the most desirable resource necessary to maintain life, due to increasing population and higher standards of living, water resources are constantly drying. Water normally distributed in large cities through metal pipes, these pipes frequently develop leakages resulting in the loss of already diminishing resource. The water distribution also requires constant monitoring for the quality of water. Contemporary efforts made are mostly composed of costly, energy consuming and technically complex acoustic based water monitoring or robot based pipe-line monitoring systems. There exists a need to develop cheap, energy efficient and effective system to monitor the huge pipe-line infrastructure. RFIDs being inherently energy efficient and cheap technology offer a scalable, wireless and efficient system for monitoring water parameters in ad-hoc fashion to increase range and efficacy of the proposed system.

Metal pipes are ubiquitously used to transfer fluids (oil, gas and water etc.) in various industries. The fluids being transferred through these pipes need to be monitored regularly. Moreover, the wellbeing of the pipe's infrastructure is absolutely necessary for the productivity of the industry and for the supply of critical necessities of life like water.

These pipes frequently develop leaks due to corrosion and other wear and tear. They are also subjected to intense and harsh environments, bearing extremes of pressure and temperature. It is therefore very critical to monitor and maintain the pipeline's infrastructure health as well as measure and determine the quality of the fluid sent through these pipes. RFIDs integrated with other wireless nodes can help us in detecting and monitoring these pipes while consuming very small amounts of energy.

In this chapter the research contributions in two broad monitoring applications are presented:

1. Monitoring water distribution systems.

Figure 3.2: Laboratory Experimental Set-up.

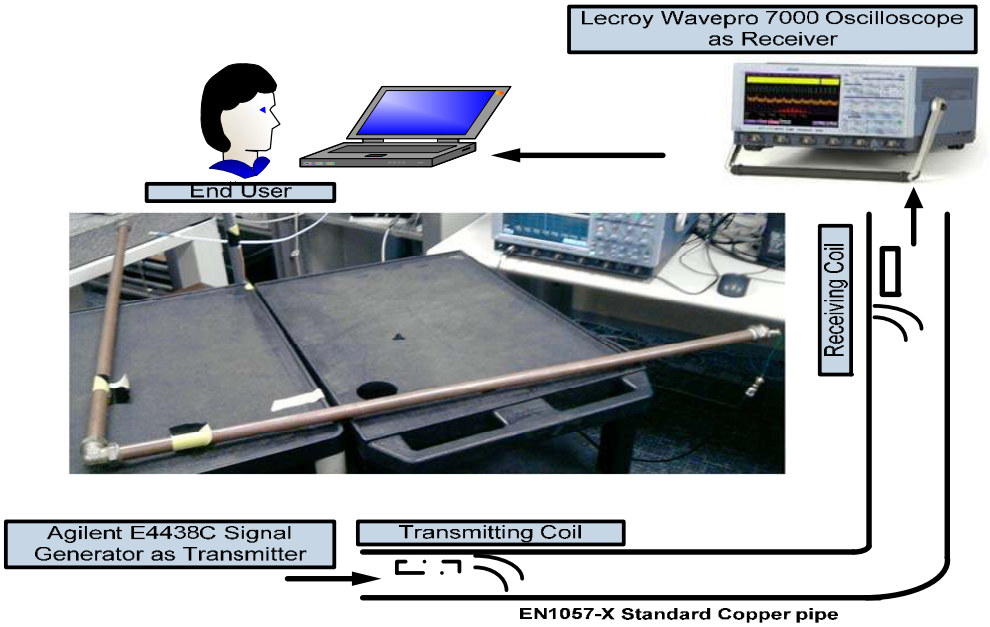


Figure 3.1: PipeSense illustration of Experimental set-up.

2. Detecting moisture in LNG/LGP gas pipes.

3.1 Water Distribution Monitoring Systems

In this section a framework for in-pipe water monitoring and feedback system is presented. The goal is to monitor the leakages within pipes and share this information to conserve water and improve the current water distribution system through feedback. This is achieved through a seamless integration of RFID-based wireless nodes into the water distribution network while going beyond the traditional methods of ultrasonic water monitoring systems. Based on this framework, a prototype PipeSense [111] system is developed. The framework, architecture and

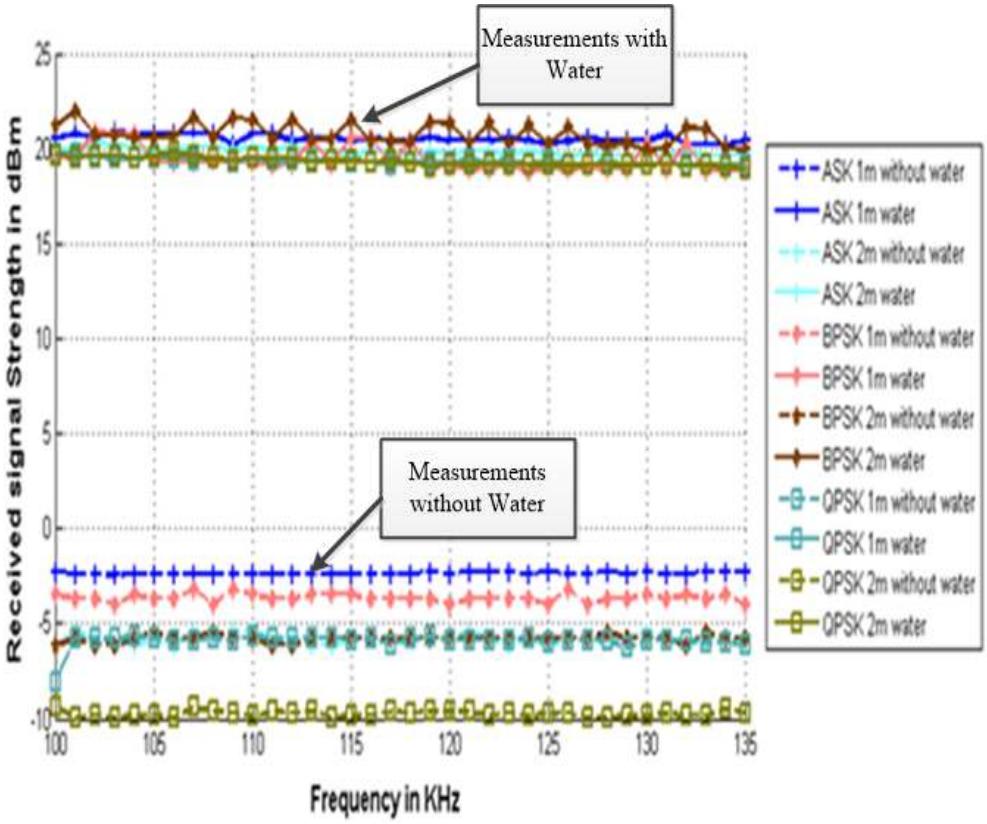
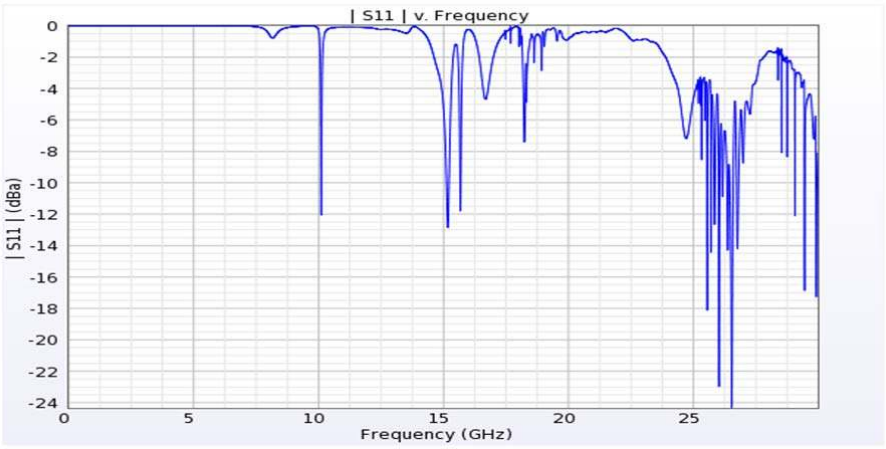


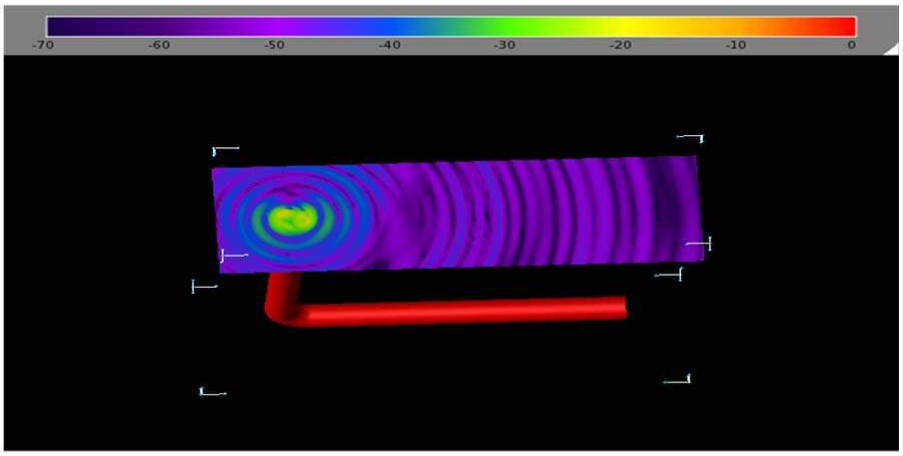
Figure 3.3: Comparison of received signal strengths of all modulation schemes with and without water for one and two meter pipes.

design of this system and details of the current system implementation are described. Experimental and simulation results are also discussed to verify the findings. A Cyber-Physical approach is also proposed to obtain a feedback monitoring system making the domestic water distribution in homes smart. Cognitive and Cooperative networking approaches were implemented to further reduce the energy consumption of the system while simultaneously increasing its spectral efficiency and reducing interference with the other primary wireless devices within a home environment.

To supply water at a specified flow and pressure, PipeSense, a framework for an in-pipe monitoring and feedback system based on RFID Ad-hoc multi-hop wireless sensor networks, was proposed. RFID ad-hoc system provides two main advantages, first they are cheap to deploy and secondly, they are easily scalable. PipeSense utilizes the flow sensor measurement to determine the leakage within the pipes. It can also determine accurate positioning of the leak by comparing the flow readings from two adjacent nodes and the GPS location sent through the GPS/GPRS enabled node which is present at the tapping point or the main hole. The intermediate nodes also send their node IDs along with the measured reading in a multi-hop manner to the GPS/GPRS enabled node. Fig. 3.1 shows the laboratory experimental set-up.



(A)

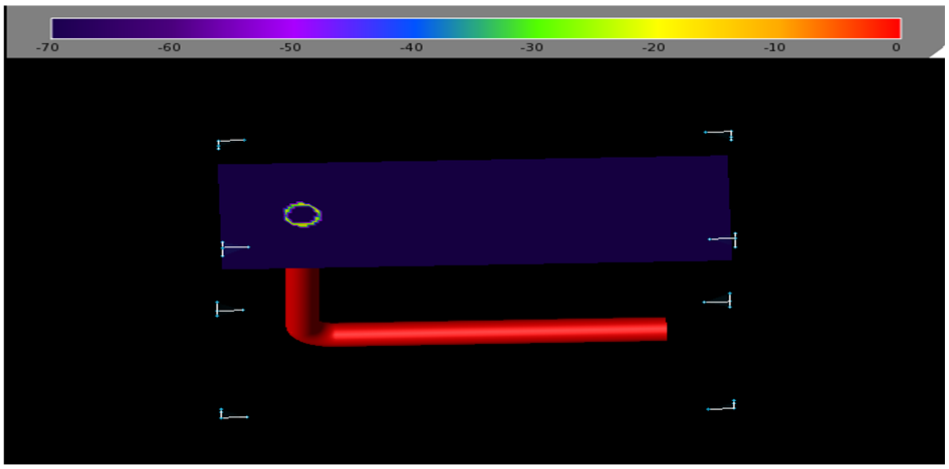


(B)

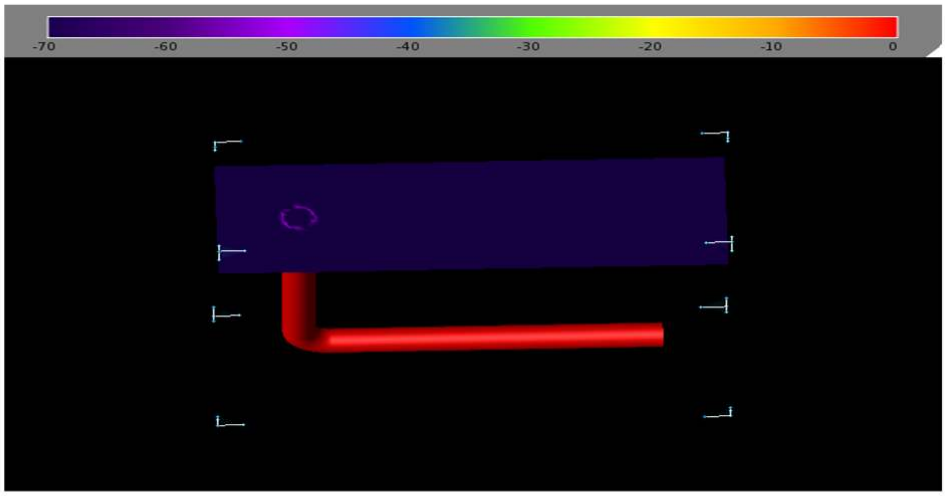
Figure 3.4: (a) S11 parameters simulation on Agilent EMPro software. (b) Electromagnetic Field at low frequencies at the receiving end of the pipe.

3.1.1 PipeSense System Description

PipeSense consists of three major components: sensor module (sensors were bought off the shelf while the integration module was built in the lab), data hub, and service hub. The PipeSense general framework is designed to connect and control the three components through software and hardware. Fig. 3.2 further illustrates the PipeSense experimental set-up. The proposed system makes use of the sensors' capability of detecting the water pressure. We have initially tried to monitor the contaminations using some off the shelf normal sensors but it didn't work as the in-pipe monitoring required industrial grade, rugged and expensive



(A)



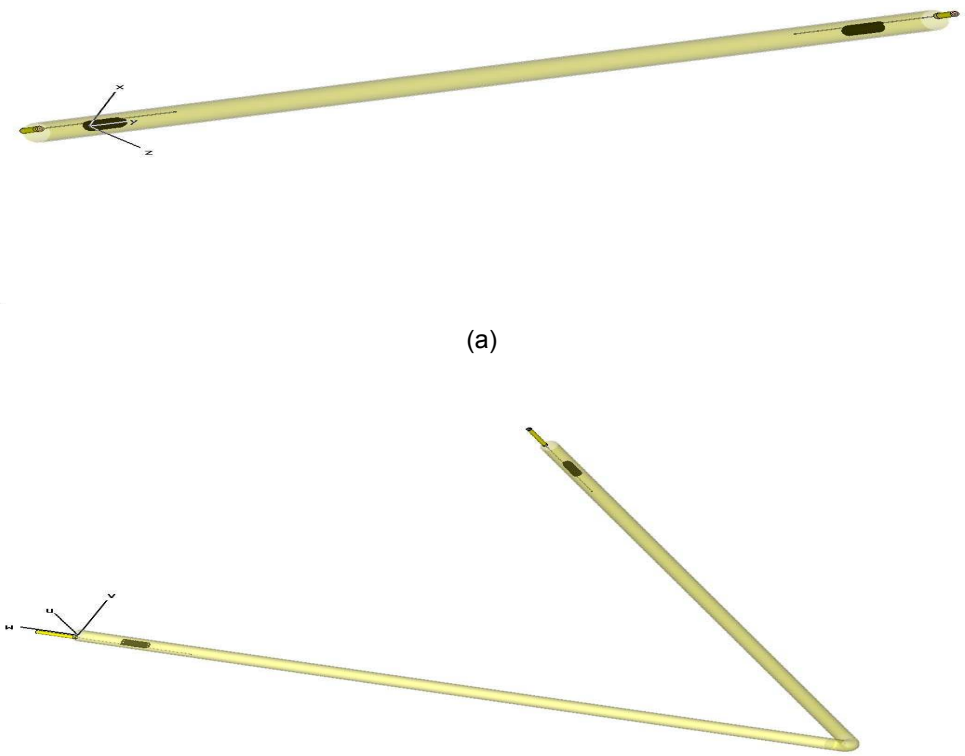
(B)

Figure 3.5: (a) Conduction currents on the cross-sectional view of the pipe at low frequencies. (b) Conduction currents on the cross-sectional view of the pipe at high frequencies.

contamination sensors exceeding the research funds available. The sensed information is stored in the memory where the transmitter sends this information in a multi-hop manner to the access point. The end users and maintainers may use this information to monitor and check the status and quality of a water distribution system.

3.1.2 Experimental Set-up and BER analysis

In order to extend the work for the implementation of the system, RFID induction feasibility tests were performed on standard copper water distribution pipe described in [111]. The test was performed in the lab environment using EN1057-X standard copper pipe with 22 mm diameter and 0.9 mm thickness. Fig. 3.2 shows the experimental set-up, which includes:



(a)

Figure 3.6: (a) CST MWS simulation of the actual EN1057-X One meter pipe and (b) Two meter. pipe.

- Lecroy WavePro 7000 Oscilloscope (as receiver).
- Agilent ESG E4438C Signal Generator (as transmitter).
- EN1057-X European and Singapore water distribution standard copper pipe.
- Two coil antennas (inserted in the pipe) very close to the inner surface of the metal pipe.

A frequency range of 100 kHz to 135 kHz is chosen to incorporate all the available standard low frequency RFID systems, and two lengths of pipes are considered, one meter and a two meter bent at 90º, so as to measure the effect of induction through the joints and elbows of the domestic water piping system. Moreover, the measurements are taken with and without water. The transmitter (frequency generator) is set at a constant 22 dBm output level, which is a 0.158W output power.

Fig. 3.3 shows the comparison of the received signal strengths for all modulation schemes with and without water for one and two meter pipes. It is shown that the water in the pipes aids the induction through the surface of the metal. This test authenticates the feasibility of developing

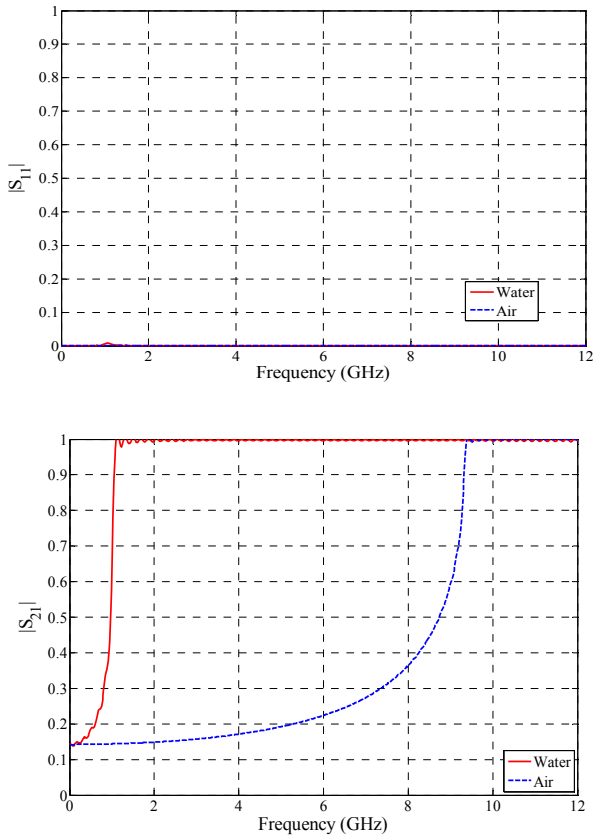


Figure 3.7: S11 and S21 parameter for one meter EN1057 pipe with and without water.

RFID-based water monitoring systems for metallic pipes.

Amplitude Shift Keying non-return to zero (ASK-NRZ), Binary Phase Shift Keying and Quadrature Phase Shift Keying (QPSK) modulation schemes were used in the experiments. The transmitter is fixed at the maximum available power level of 22 dBm, or 2.236 Volts. The modulated output is directed into the pipe through 12-loop coil antenna, and a similar receiving antenna at the other end of the pipe shows the modulated received signal with the help of an oscilloscope. The experiments are performed on one and two meter pipes containing water and with no water inside.

3.1.3 Simulation Results

Simulations were performed using Agilents EMPro [120] software on a two meter 90º bend pipe. The simulation for the S11 parameters shows the expected result, which indicates that before the cut-off frequency of this metal pipe (9.35 GHz), all the signals are reflected back and thus nothing is guided to the other end (fig. 3.4(a)). However, the experiment shows that there are signals available while working on low frequencies on the other end of the pipe, which is also confirmed by simulations done on the same pipe showing a good amount of

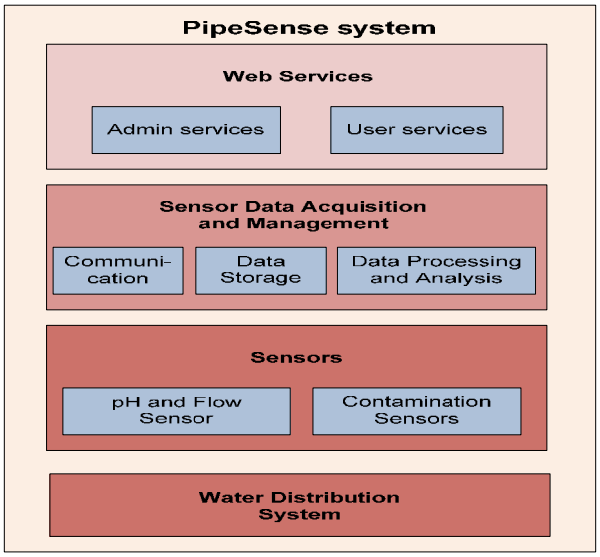


Figure 3.8: PipeSense Framework Architecture

electromagnetic fields present at low frequencies (fig. 3.4(b)). This can only be possible because of the induction phenomenon, which is further proved by the simulation of conduction currents on the cross-sectional pipe's surface, showing high conduction currents on low frequencies and almost none at high frequencies, shown in fig. 3.5(a) and 3.5(b), respectively, thus verifying the experimental findings that the communication is not actually through a wave guide but is done through the surface of the metallic pipe using its induction properties.

Some simulations on the CST MWS [121], fig. 3.6 (a) and (b), on the one/two meter EN1057-X standard pipes were also performed. Two unbalanced coil antennas were inserted at both ends for transmission and reception of the signals. Even though the antennas were not efficient, the output received is quite distinguishable. Hence, an efficient design will increase the transmission and reception of the proposed system.

CST MWS was used to determine the gain and the reflection coefficient parameters of the EN1057-X standard pipe. S11 and S21 parameters of the one-meter pipe with water in fig. 3.7 show a constant 0.142V loss per cm of the pipe below cut-off frequency of 9.65GHz, and S21 gain shown depicts an increase in the value with the increase in frequency. However, low frequencies can be used with shorter distances for communication without much loss. In fig. 3.6(b) two pipes of the EN1057-X standard were connected through an elbow connection at 90º making an overall distance of 2 meter between transmitter and receiver.

3.1.4 PipeSense Framework Architecture

Next, the architecture of the water monitoring system was presented. A traditional four-tiered architecture is proposed, as shown in fig. 3.8. This framework consists of water distribution system, sensors, data management and application layers.

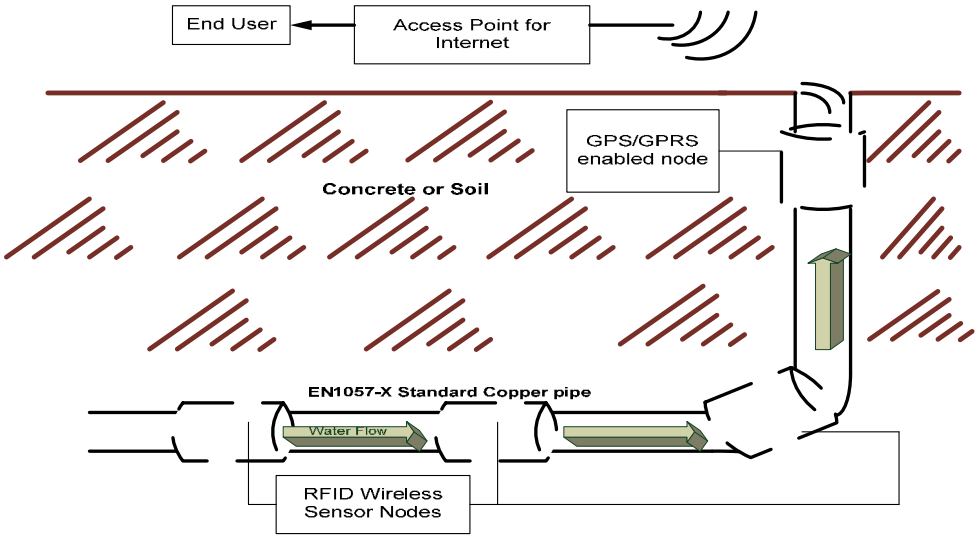


Figure 3.9: PipeSense system illustration.

Water Distribution Layer – The underlying purpose of an in-pipe water monitoring system is similar to that of traditional wireless sensor networks, i.e., to sense various objects in the case of the water distribution system. In a water monitoring context, water flow, pressure, pH and contaminations are the sensing objects of the water distribution layer.

Sensor – The second tier of the architecture consists of sensors, or the sensing and data collection/acquisition devices. In water monitoring systems, sensors are categorized into flow and pollution sensors. These sensors augment each other in the decision process and in measuring an event effectively.

Data Management – The major functionality of the third tier is to process the sensed data. This includes data transmission at the network layer, and storage and database management on the server side.

Application – The application tier forms the topmost tier in the water monitoring system architecture. It includes various services for the administration of the system as well as for normal users. Unlike with traditional wireless sensor networks, people closely interact with the applications through various channels such as web query, active feedback, etc. The design of the application tier should account for such feedback.

The Active RFIDs occupy the Sensor's Tier of the framework and their main role is to relay the information sensed through the sensors in a multi-hop fashion.

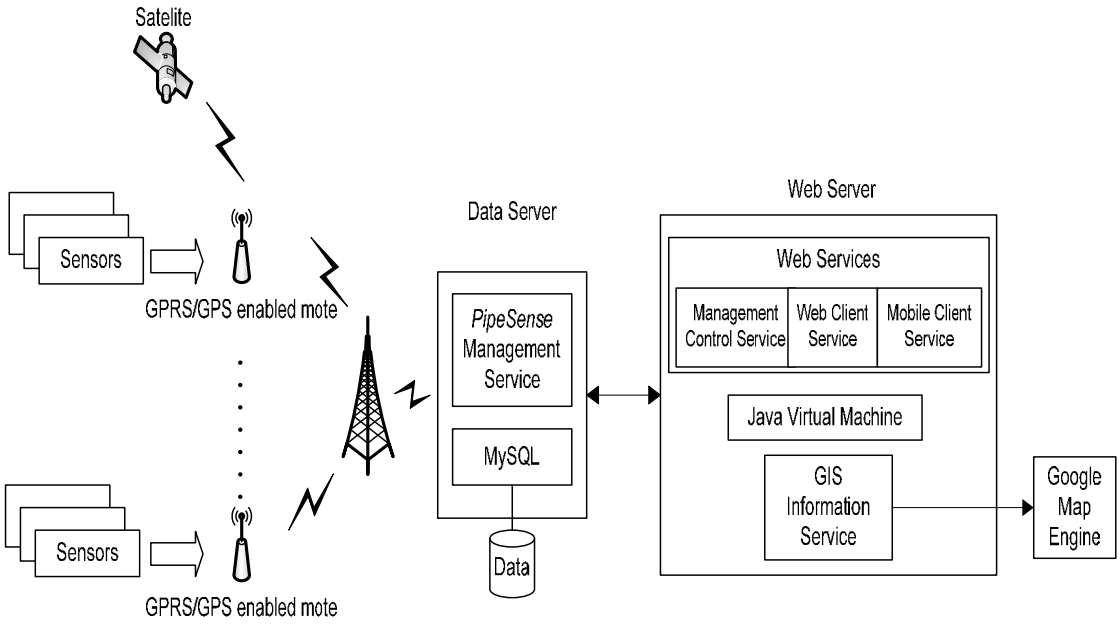


Figure 3.10: PipeSense System Design.

3.1.5 System Design and Implementation

3.1.5.1 System Architecture

PipeSense consists of three major components: sensor module, data hub, and service hub. The PipeSense general framework is designed to connect and control the three components through software and hardware. Figs. 3.9 and 3.10 illustrate the PipeSense system implementation. There are two types of sensors modules. The main sensor module consists of the RFID tag, sensors, microcontroller, GPS/GPRS module and a memory with associated embedded software. The common sensor module is composed of less powerful controllers and does not have a GPS/GPRS module. It gathers information from all the available sensors. In the current implementation, the available information includes water pressure sensor data and data from the GPS receiver, such as the UTC time stamp and location coordinates. The sensor module, being an embedded device, is limited in terms of computational and energy resources. Thus, only minimal pre-processing of the data is done on-board before it is transmitted to the fusion center.

The need for real-time data streams, including location information, prevents us from buffering the data in the sensor module. The sensor module currently uses GPRS to transmit data to the fusion center and for receiving administrative commands and software updates. GPRS provides a reliable communication channel, with data transmission rates of 56-114 kbps over the GSM network, which satisfies the current system requirements.

The data hub acts as the centralized data server to handle the incoming data packets from all the active sensor modules. In the PipeSense general framework, the data hub includes two major components. In the lower layer, MySQL is implemented as the sole database management system. It manages the collected water monitoring data and responds to queries passed from the service hub. On top of the database management system is the PipeSense Management Service. This acts as a data processing service for refining raw data received from the sensing modules. This service accepts raw data and performs decoding, refining, and recomposing before inserting the data at its appropriate position in the MySQL database.

Service hub is a mixed structure that includes the central Apache web server-supported services and other more dynamic client services. There are two types of client services: the Management Control Service and the Web Client Service.

These client services have been built independently of each other and serve different purposes and user groups. Management Control Service is the administrative tool provided for the PipeSense management team. It consists of the web-based administration panel, which provides functions such as database management, sensor module management and historic data query. It also includes back-end scripts that support queries to MySQL database and direct communication to the sensing modules. Web Client Service is the main web interface for the normal users who use PipeSense through a web browser to track real-time measurements of the water distribution system. Details of the described PipeSense general framework are shown in fig. 3.8.

3.1.5.2 Hardware Platform

The hardware of the proposed system is composed of a metallic cylindrical device attached to the water bearing pipes after approximately every 10 meters (the range depends upon the input power supplied to the nodes).

These devices consist of RFID coil antenna wound inside the cylindrical device, microcontroller for processing, a receiver and transmitter, a memory to store the sensed data and an energy source in the form of AA size rechargeable batteries. Sensor block senses the water attributes like pressure, flow, and contaminations and sends this information through RFID multi-hop system to the nearest access point through the last more capable node attached at the main outlet. Data Management block consists of the storage at the server side, where all the data processing will be carried out. This data, after processing, will be forwarded to the applications running on the web portal where this information is presented through statistical graphs and maps on the webpage. The hardware platform in the PipeSense general framework refers mainly to the sensor module. As shown in fig. 3.11, the sensing module consists of four parts connected to form the hardware platform. The Gumstix embedded computer [70] is used to control data acquisition from the sensors. It also provides a connection to the GPS and the communication module. In PipeSense main node implementation, Telit GM-862-GPS [122]

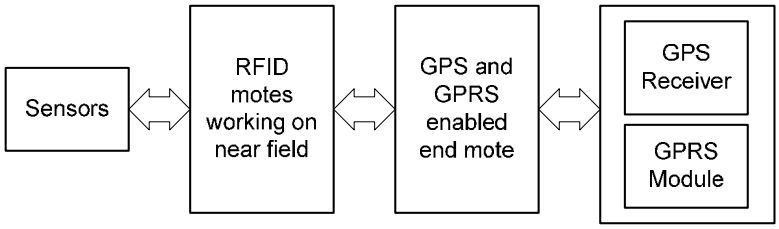


Figure 3.11: PipeSense hardware system.

was chosen as an integrated solution for both the GPS receiver and the GPRS communication module. It is equipped with a 20 channel SIRF GPS receiver, which provides a quick start and highly accurate location coordinates.

The proposed system makes use of the pressure sensors and can be made capable of detecting the presence of Bromide, Chloride, Halo-acetic acids and pH of the water by utilizing correct sensors. Leaks in the metal pipes are mainly caused naturally through corrosion. The pipes corrode due to the presence of Bromide, Chloride, Halo-acetic acids and changes in pH of the water. Initially the sensing frequency is set after every 5 seconds; this sensed information is stored in the memory, where the transmitter sends this information in a multi-hop manner to the access point. The end users and maintainers may use this information to monitor and check the status and quality of the water distribution system.

For efficient resource sharing and energy consumption a MAC protocol for the RFID based wireless nodes was needed. Fig. 3.12 shows the flow chart for the sensor monitoring mechanism for this application. The sensors operate in an unsynchronized manner. The node starts sensing and measures the flow, pH and MRDLG (maximum residual disinfectant level goal) of water through the sensors. If the measurement is within the normal threshold, then each node sends the information and sleeps for 5 seconds. If any of the measured values are above or below a fixed threshold, the node sends a wakeup call to all other adjacent nodes to start measuring the contamination values and send them in a multi-hop manner to the access point. An alarm signal will also be sent with this information.

3.1.5.3 Software Architecture

PipeSense software architecture consists of two sections. First is the embedded software system on the sensor module. The other section is the server side software supporting the data hub and the service hub along with all the supported services. The design of embedded software for the main sensors module is fairly straightforward. The embedded Linux core controls the data acquisition from the sensors. GPS data acquisition and the GPRS data transmission are managed by a Perl script.

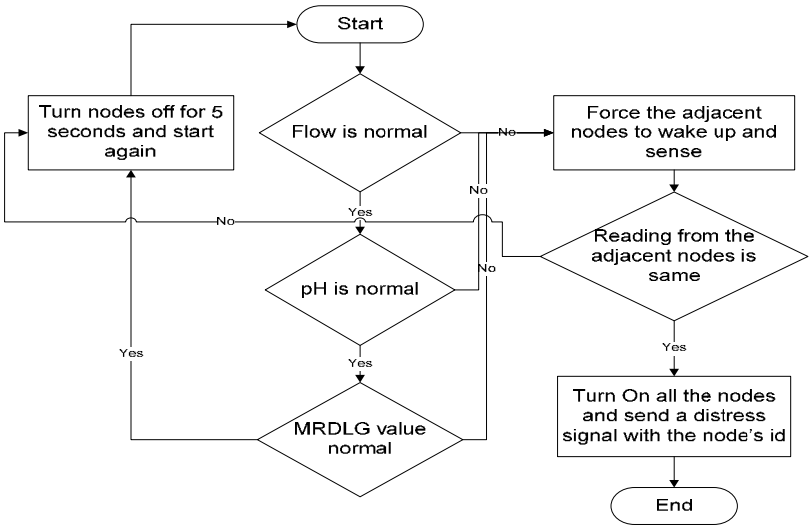


Figure 3.13: Sensor monitoring mechanism.

Server side software is responsible for handling both the incoming sensed data from the sensors modules and the various client requests from the service hub. A middle layer to cover the lower MySQL database management system and the data storage was built. In fig. 3.13, it is shown as Database Operation API. These APIs provide the frequently used database operation functions, such as the creation of data tables and manipulation of each data record. Database Operation API processes requests from two components: the Data Hub Interface (DHI) and the Service Hub Interface (SHI), as shown in fig. 3.13. DHI contains functions for raw data processing, while SHI is responsible for handling requests coming from the end users.

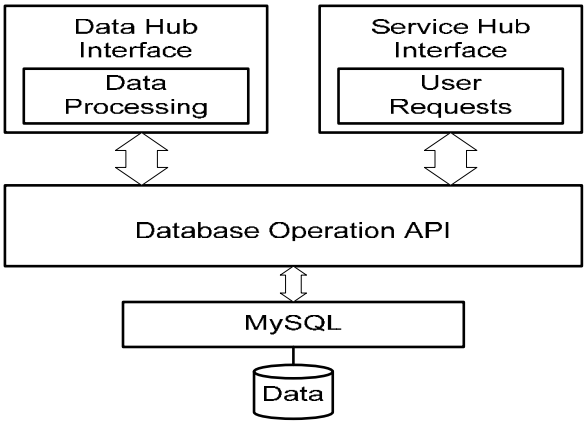


Figure 3.12: PipeSense software Architecture.

3.1.5.4 Implementation

PipeSense is an embedded sensing platform, making it a low-cost and easily deployable solution. It allows us to monitor the water distribution system and determine the position of leaks through geographical location information. It also improves the system efficiency through feedback from users.

The sensor module collects the in-pipe, real-time information, including its geographical location, flow and pollution data. This data is transferred back to the central data service, where it is stored and analyzed. Google Map Engine was used for displaying the real-time geographic locations of the main sensing modules. It provides multiple options for the map viewing mode and convenient map control. It also provides high resolution maps with detailed street views. JVM is used to support the development of various web services, such as the interfaces for various client services and the administrative panel.

3.1.6 Human Centric Cyber Physical System (CPS) for water monitoring

Here human centric cyber physical framework architecture is presented for the in-pipe water monitoring and feedback system. This system comprises of the physical water distribution infrastructure, together with the hardware and software supported intelligent agents for water

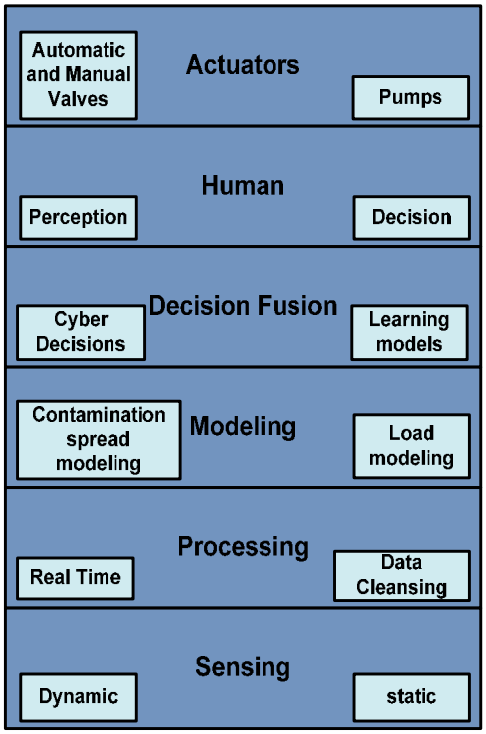


Figure 3.14: Framework for cyber physical PipeSense System.

allotment, leak detection and contamination spread control. An agent-based approach for connecting the cyber and physical layers is selected, where the agents get information from sensors monitoring the physical components and provide this information to the cyber system. The Hidden Markov Models (HMM) are briefly discussed to determine water consumption patterns and make decisions for cyber and physical systems.

In this work, a human-centric framework was designed with the goal of developing an event-driven CPS for an efficient water monitoring system. The system is comprised of a greater number of inexpensive nodes that can communicate with each other, resulting in more efficient sensing and fewer false alarms. The data thus collected will be integrated and assimilated into Markovian models for predicting/updating the state of the system, which will in turn be fed into the physical network to optimize pumping operations for water conservation and allocation and also to cater for spread prevention and removal of contaminants from the system. The same system will also include features to evaluate events such as leaks and pipe bursts that involve multiple geographically distributed sensor node.

The focal point of this research is to build novel techniques for human participation in sensing decisions, analysing sensed data, making inferences, gathering feedback and taking intelligent actions. The advantage offered by the framework for integrating vehicular sensing and human-centric urban sensing [115] is the way it monitors the operation of vehicular systems and associated human activities to understand and mitigate their impact on the environment. A human plays an important role in increasing the efficiency and robustness of sensing systems, and imparting intelligence through inference and feedback mechanisms.

3.1.6.1 Human Centric CPS Framework

Figure 3.14 shows the human-centric CPS framework architecture, which is comprised of six tiers connected to each other. A brief explanation of each tier is given below:

Sensing Tier – This tier is comprised of flow, pressure, pH and pollution or contamination sensors. These sensors can also be divided into static sensors and sensors that monitor ambient temperatures, as well as valves' and pumps' proper functioning, and dynamic sensors that continuously monitor the in-pipe system, as well as give geographical locations of the nodes. The information from the sensor is partially cleansed at the node level and is then transmitted to the server, where the data are fully processed.

Processing Tier – After receiving the partially cleansed data from the sensors, the processing tier performs extensive data cleansing in real-time and can also store the data for historical referencing.

Modeling Tier – The processed data is then fed to the modeling tier. This tier is comprised of Hidden Markov models for demand pattern predictions and for determining contamination spread.

Decision Fusion Tier – The outcomes from the demand and contamination spread models are then fed to the decision fusion tier. Here, the cyber decisions are made according to the standard artificial intelligent models, and these decisions are learned by the cyber systems

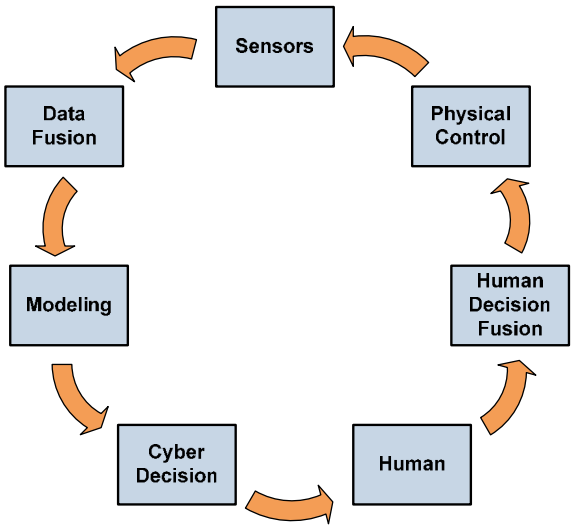


Figure 3.15: Flow diagram of the cyber physical PipeSense system.

through the learning and training models for accurate decisions in the future.

Human Tier – The decisions from cyber models are not imposed on the system instantly but further evaluation of the decision is done in this all important human tier where humans are present in the feedback of the framework. This human feedback along with the human agents responsible for the manual maintenance of the system, makes the framework human centric. The humans may overrule the cyber decisions if it is perceived by the humans as a false alarm. The outcome of the human decision is monitored by the system and used in the learning models to train the system.

Actuator tier – The actuators can be valves and pumps either manual or automatic that can be used to stop, open, increase pressure and isolate a section of pipes in case of leakages, pipe bursts or to stop contamination spread. The final decisions are sent to human operators and automatic systems to perform the specified tasks.

This system is then monitored again by the sensing tier to determine the result of a particular decision. This whole process is shown in a form of a flow diagram in fig. 3.15. Let us consider an example situation, for instance sensors picked up high contamination levels of a certain poisonous element at a certain location. This sensed information is then processed and cleansed (noise removal) in real-time and provided to the modeling tier, which has contamination spread models to isolate that pipe section and prevent water distribution from this section. The models put the data in different scenarios and send the outcomes to the decision fusion, where the HMM models make an appropriate decision. This decision is sent to human decision makers, who then decide/judge the decision per their perception, and they may overrule the cyber decision and send their decision to the physical actuators in the form of warning messages. The cyber system will learn from the outcome of the human decision through a learning model.

Certain events causing leakages and pipe bursts can be very efficiently handled through the human-centric cyber-physical system. The system will determine the best possible routes for the water in case of the said events. The same system can also inform authorities to send maintainers and engineers to the concerned areas to monitor and control. In short, the decisions made are sent to the authorities, warning consumers of a potential threat and the administrators to control any unwanted event.

3.1.6.2 Model for Cyber Physical System

Agent-based modeling was selected due to the distributed nature of the system. Moreover, some of the simulation platforms appropriate for the system were also explored. For physical layer simulation, EPANET 2.0 [123], open-source software by Environment Protection Agency (EPA), was found fitting due to its ability to touch a wide range of water distribution attributes. A realistic model for CPS will consider the randomness of the system's environment where the sensors were deployed and the system components are in fact intelligent agents.

In multi-agent systems, there are numerous techniques that can be used to describe how each agent makes decisions, such as Genetic Programming, Reinforced Learning, Rules-Based Reasoning, Game Theory and Neural Network [124]. However, Bayesian models using Hidden Markov Model (HMM) are selected. HMM is one of the best tools to recognize and predict demand patterns and contamination spread within the data collected.

HMM is a statistical model in which the system being modeled is assumed to be a Markov process with unobserved state [125]. A HMM is a stochastic process generated by interrelated

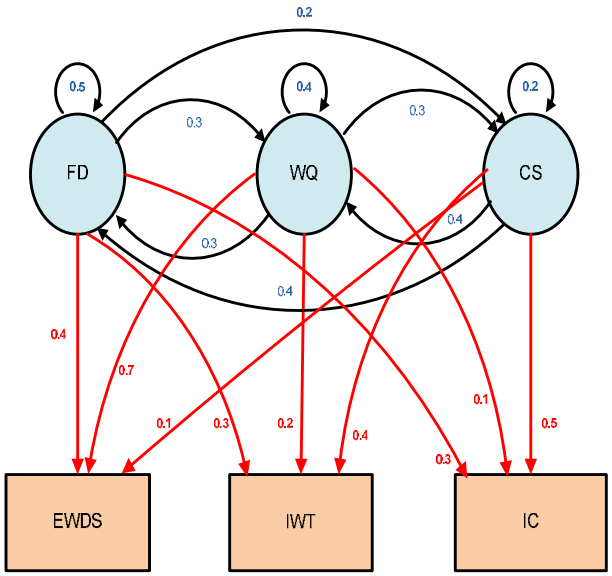


Figure 3.16: HMM to determine patterns and probabilities of future water demand, water quality and contamination spread for the water distribution system.

underlying probabilistic mechanisms called Markov Chain, with a finite number of states and a set of random functions associated with the states in which the states are not directly visible; only output dependent on the state is visible. Every state is associated with a probability distribution over the possible output symbols. HMM generate the sequence of symbols that gives information about the sequence of states [126]. One of the models to solve and predict the demand patterns and contamination spread to some known events using Hidden Markov Model with Bayesian Inference is shown in fig. 3.16.

A system was considered which may be described at any time as being in one of a set of 3 distinct regularly spaced time states:

State 1: Future Demand (FD).

State 2: Water Quality (WQ).

State 3: Contamination Spread (CS).

The proposed HMM will follow three states to determine the desired events. These states shows the output possibilities in case of frequent changes in any of the qualities defined by them such as a change is Future Demand, Water Quality or Spread of contamination. The frequent the changes results in the higher events taking place in the future. These states are the result of one or all of the three output possibilities, like data showing expansions made in the water distribution system, 'Expand Water Distribution System (EWDS)'; improvements made in the treatment system, 'Improve Water Treatment (IWT)' and the number of times a particular section of water distribution system is isolated in a given month, 'Isolate Contaminations (IC)'.

The system undergoes a change of state (possibly back to the same state) according to a set of probabilities associated with the state. The time instances associated with the state changes were denoted as t = 1, 2 and 3. The above stochastic process could be called an observable Markov model since the output of the process is the set of states at each instant of time, where each state corresponds to a physical (observable) event. Some educated guesses were made for the start probabilities in eq. (1) since proper data was lacking; however, this will serve well for evaluating the model. After validating the model with this dummy data, the real data for analysis can easily be provided.

Start Probabilities:

$$\{FD = 0.5, WQ = 0.3, CS = 0.2\} \qquad (1)$$

Transition probabilities represent the change of the water distribution properties in the underlying Markov Chain. Assumptions are made that the events on a particular month are characterized by a single one of the three states above, and matrixes 'A' and 'B' are created for state transition probabilities and emission probabilities, respectively. These probabilities will be determined after several test runs in the real scenario. However, here the dummy readings are provided for model evaluation.

Transition Probabilities:

$$A_{i,j} = \begin{bmatrix} 0.5 & 0.3 & 0.2 \\ 0.3 & 0.4 & 0.3 \\ 0.4 & 0.4 & 0.2 \end{bmatrix} \begin{matrix} FD \\ WQ \\ CS \end{matrix} \quad (2)$$

Emission Probabilities:

$$B_{j,k} = \begin{bmatrix} 0.4 & 0.3 & 0.3 \\ 0.7 & 0.2 & 0.1 \\ 0.1 & 0.4 & 0.5 \end{bmatrix} \begin{matrix} FD \\ WQ \\ CS \end{matrix} \quad (3)$$

The emission matrix was arranged on the following assumptions: if FD increases, then there is a 40% chance of the need to expand the water distribution system. If WQ increases, then there is a 30% chance that the improvements will be needed for the water treatment system. If CS increases, then there is a 50% chance to isolate the contamination. HMM can be utilized to ask the possibility of the need to expand the existing water distribution network in the future, improve the water quality through treatment and the need to isolate the contaminations per effected region in the future.

For an observation sequence in equation (4), the probability of the following properties for a period of 6 months can be determined by:

$$O = \{IWT, EWDS, EWDS, IC, IWT, EWDS\} \quad (4)$$

The Viterbi forward algorithm [127], which is widely used in HMMs, was utilized to obtain the observation sequence probability. The above observation sequence can be optimized to get a meaningful sense; in other words, a state sequence can be found that would have most probably generated this output sequence. This Viterbi forward algorithm reveals the probability of eq. (4) to be 0.0019 and the optimum path of states for this observation sequence is {FD, WQ, WQ, CS, FD, FD, FD}, with probability 1.59exp-5. The Viterbi path contains seven states, as the seventh state was generated by the sixth state and a transition to the seventh state. The model parameters can also be adjusted, such as transition, emission and initial probabilities, to maximize the probability of an observable sequence. This model is just a simple example; more complex situations can also be handled efficiently through the same model after some modifications.

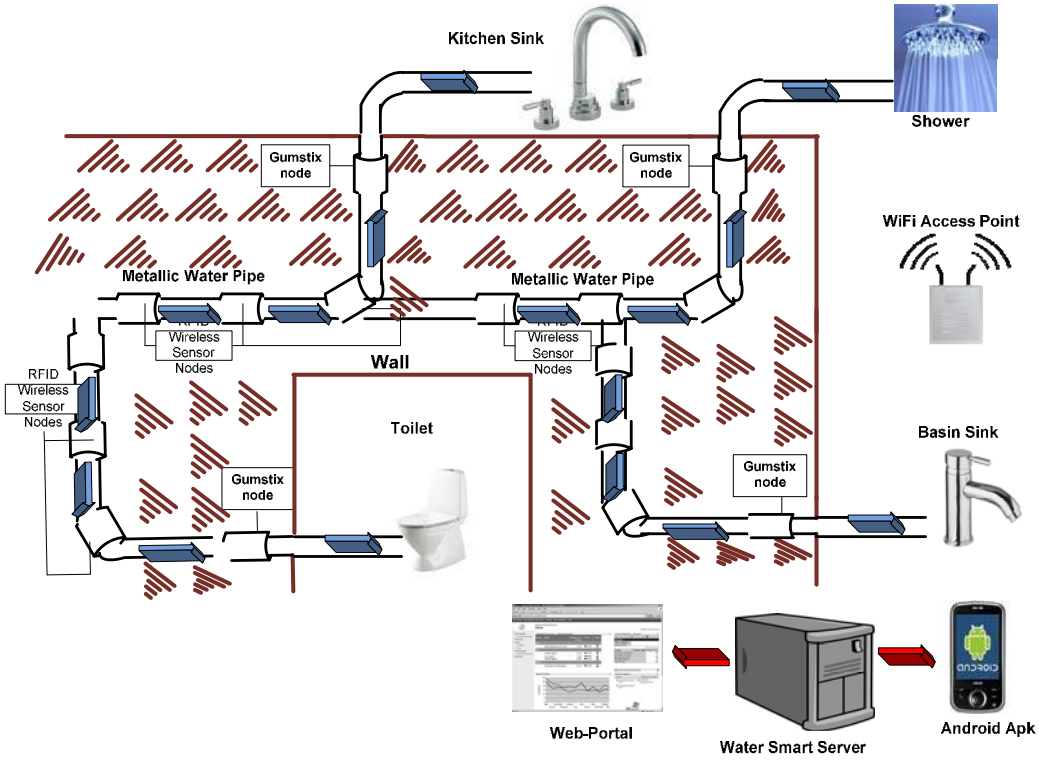


Figure 3.17: Smart Home System Diagram.

3.1.7 Water Smart Home

The scope of home intelligence has now been broadened to context-aware automation services using easily available technologies. Efficient water usage and conservation can be achieved by stopping water seepages and drips occurring almost daily in billions of homes worldwide. These seemingly harmless leaks are responsible for severe water loss, especially when water resources are shrinking. This section is concerned with the proposed water Smart Home. RFIDs and WSNs are integrated to depict the feasibility of having a context-aware system capable of conserving water by informing the users about their water usage patterns and predicting any seepage or leaks occurring in the home piping system, thereby also helping in maintenance and repair work. Hidden Markov Model's (HMM) multi-level variant Hierarchical Hidden Markov Models (HHMM) approach is used for pattern recognition and event detection for this system. Using this model, a human-centric feedback and decision algorithm is also developed. This approach has been applied to simulated water pressure data from Gumstix computer-based high end nodes with WiFi capability deployed at critical taping points in a Smart Home, along with the smaller RFID nodes which were embedded in the metallic pipes. HHMM potential to automatically identify events that represent combination of

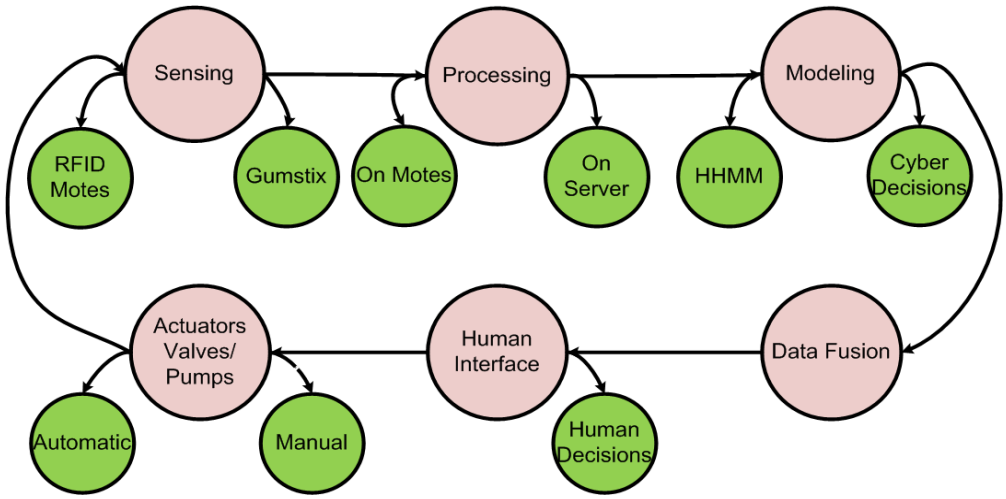


Figure 3.18: Human Centric CPS Cycle Architecture.

different events is demonstrated.

The term “Smart Home” has been used to introduce the notion of networking devices and equipment that distribute information and commands among the networked devices in the home via wired and wireless communications [128]. Smart homes can accommodate a number of information gadgets, home appliances and other Internet-based applications, which can communicate with each other, forming a ubiquitous home network system [129]. It presents an idea of having a server-based home gateway system, which becomes the brain of the Smart Home, making life easier for the average household.

3.1.7.1 System Overview of Smart Home

In the proposed system, cost effectiveness is achieved by opting for low power and low cost active RFID nodes integrated inside the metal piping system shown in fig. 3.9. In a metallic environment RFID nodes can also communicate with each other in bends and elbows of the piping system. These nodes can be programmed to send data after every second with their IDs to the Gumstix mote in a multi-hop manner; a few nodes may be needed to perform this task. A simple sleep and wake-up protocol is initially utilized in the RFID nodes. Once the data is received at the access node, it first separates the data from the ID information and makes a packet to send to the water smart server through WiFi or 3G networks. At the server the event detection and decision algorithms analyze the data and predict the future 50 or 100 states of the system. A feasibility study was conducted for the optimum number of nodes and sensors required for the proposed system. Using available standard commercial nodes it was determined that we can place the nodes at least every 2 meters in a pipe. As the home piping systems usually don't have more than 10s of meters of pipes, it may be assumed that we will not need more than 6 nodes equipped with the sensors and one Gumstix computer with WiFi and 3G capabilities. The RFID nodes are renowned for their low power consumption;

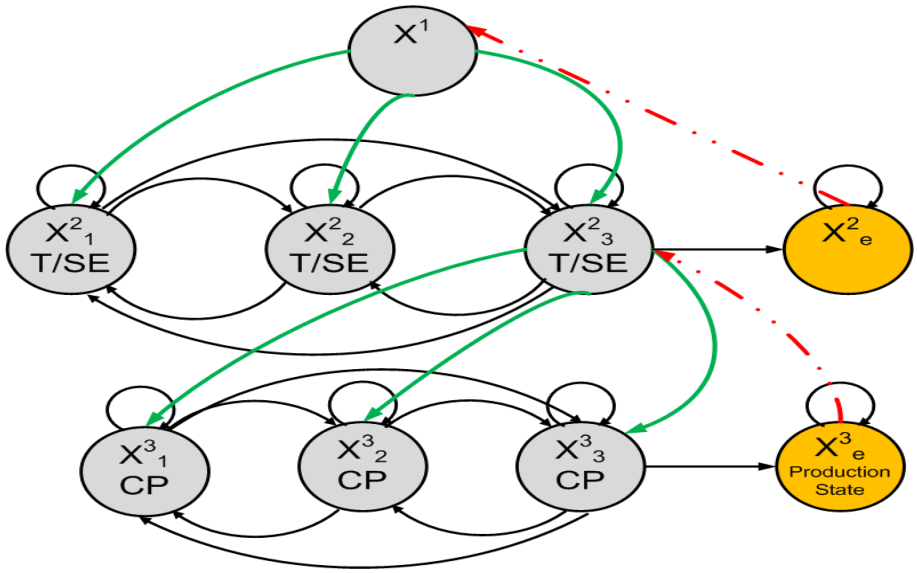


Figure 3.19: HHMM for the detection of Tap Event and Seepage Events (T/SE) within the daily Consumption Patterns (CP).

however, Gumstix computers with WiFi or 3G options will consume some energy. It will be slightly costlier to monitor the piping system than not monitoring it at all, but in the long run it should save much more by reducing maintenance and manpower costs. An Internet-based web portal application and an Android phone application running on handheld devices takes the data from the server and visualizes the data for the consumers. The data in the server also get archived so the consumers can always compare the consumption and find data taken previously. Due to different natures of the events related to the timing of occurrences, for instance, the daily consumption behavior and seepages can be an hourly event while tap opening and closing is an event which can only be detected in a few seconds or minutes' time. This led us to use the hierarchical HMM model, which will first look at the per-second data while checking for any unusual behavior leading to a tapping event. If no such event is detected for an hour, then the model shifts to the per-hour hierarchical level to detect consumption patterns and find seepages. In the context of water consumption, it is expected that consumers' behavior can change when they are regularly made aware of the amount and, in particular, the cost of what they consume.

3.1.7.2 Human Centric CPS Cycle

In this work, a human-centric cycle was designed with the goal of developing an event-driven CPS for efficient water monitoring. Six-step architecture is proposed for an in-pipe monitoring system in fig. 3.18 Its firm assimilation with human-centric sensing is achieved through decision, control and feedback mechanisms involving humans. The data thus collected will be integrated and assimilated into a Markovian model for predicting/updating the state of the system. The same system can also include features to evaluate events such as leaks and

seepages that involve multiple distributed sensor nodes. A brief explanation of each step is given below:

Sensing Step – This step is comprised of the pressure sensors and sensors for monitoring proper functioning of valves and pumps.

Processing Step – After getting the partially cleansed data from the sensors through Gumstix nodes, the processing step performs extensive data cleansing in real-time and can also store the data for historical referencing.

Modeling Step – The processed data is then fed to the modeling step. This step is comprised of the HHMM model for consumption pattern, seepage detection and tap opening/closing events operations predictions.

Decision Fusion Step – The outcomes from the HHMM model are then fed to the decision fusion step. Here, the cyber decisions are made according to the decision model. In addition to the request-reply paradigm, an event-driven model is needed, where applications are notified when events of interest are generated. In addition, human-aided data analysis is an important part of decision fusion processes.

Human Step – The decisions from cyber models were not imposed on the system instantly but further evaluation of the decision occurred in this all-important human step where households are present in the feedback of the CPS cycle. The humans may overrule the cyber-decision if it is perceived by the humans as a false alarm. The outcome of the human decision is monitored by the system and used in the learning models to train the system. Visualization and analysis of the sensed data through human intervention could point to events which hitherto were not identified. For example, it is known that water usage levels are related to parameters such as weather conditions. Correlating weather features (such as hotness or humidity) can reveal new patterns of interest.

Actuator step – The actuators can be valves and pumps either manual or automatic that can be used to stop and open and isolate a section of pipes in case of seepage. The final decisions were sent to households and automatic systems to perform the specified tasks. This system is then monitored again by the sensing step to determine the result of a particular decision.

3.1.7.3 Cyber Physical Model for Smart Home

The Smart Home system diagram is shown in fig. 3.17. The proposed model will allow us to detect as well as predict various events of interest. Every state is associated with a probability distribution over the possible output symbols. In this context an event can be a tap event, high/low usage of water and/or seepage. The HHMM model to solve and predict the valve closure events is shown in fig. 3.19.

3.1.7.3.1 Hierarchical Hidden Markov Models

Hierarchical hidden Markov models [130] are simplifications of HMMs that provide an answer

to two main problems that arise in complex sequence modeling. First, HHMMs are able to correlate events occurring relatively far apart in observation sequences, while maintaining the simplicity and computational tractability of simple Markov processes. Hierarchical hidden Markov models (HHMM) are structured multi-level stochastic processes. HHMMs generalize the standard HMMs by making each of the hidden states a self-governed probabilistic model on its own; that is, each state is a HMM as well. Therefore, the states of a HHMM emit sequences rather than a single symbol. Fig. 3.19 shows this HHMM model to determine consumption patterns and tap events and predict seepage events hierarchically. The third state is also a HMM to detect the usage patterns on top of seepage and tap events. A HHMM generates sequences by a recursive activation of one of the sub-states of a state. Every HHMM can be represented as a standard single level HMM. The states of the HMM are the production states of the corresponding HHMM with a fully connected structure, i.e., there is a non-zero probability of moving from any of the states to any other state. This process of recursive activations ends when a special state called production state is reached. In this context the production state is the final state of the third tier hierarchy of consumption patterns. The production states are the only states that actually emit output symbols through the usual HMM state output mechanism: an output symbol emitted in a production state is chosen according to a probability distribution over the set of output symbols. Hidden states that do not directly emit observable symbols are called internal states. The control is then returned to the state which originated the recursive activation chain. The set of states and vertical transitions induces a

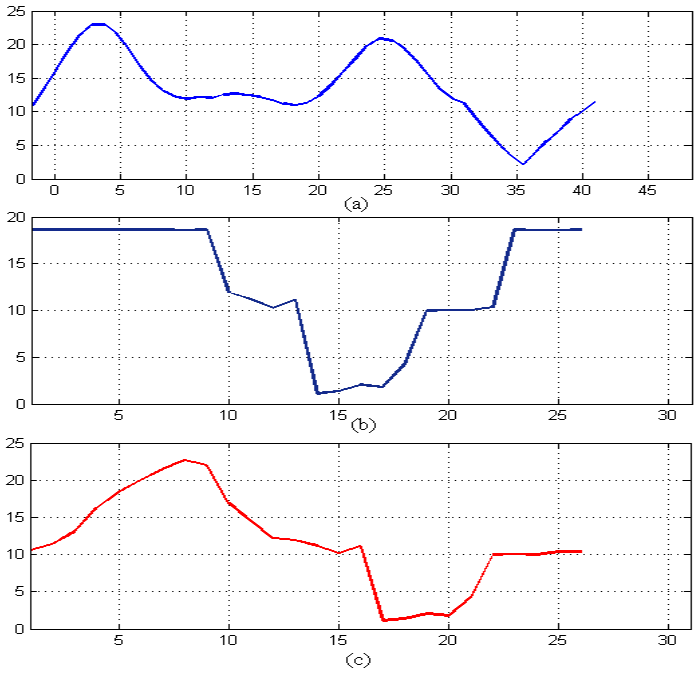


Figure 3.20: Pseudo pressure values for (a) Consumption Pattern (CP) (per hour), (b) Tap Event (TE) (per minute), (c) Seepage Event (SE) (per minute).

tree structure, where the root state is the node at the top of the hierarchy and the leaves are the production states.

To describe the model let E be an event and E* (a set of all possible vectors over E). An observation sequence is a finite string from E* denoted by Ó = O1O2….OT. The states of the system are denoted by X_i^d where i = state index and d is the hierarchy index. The hierarchy index of the root state is 1 and of production state is 3. An HHMM is characterized by the state transition probabilities between the internal states and the output distribution vector of the production states this means, for each internal state a state transition probability matrix was determined by the actual data of demand patterns and reservoir event denoted by eq. (5) is the probability of making a horizontal transition from i^{th} to j^{th} state.

$$A^{X^d} = \left(a_{ij}^{X^d}\right), \text{ where } \left(a_{ij}^{X^d}\right) = P\left(X_j^{d+1} \mid X_i^{d+1}\right) \tag{5}$$

$$\prod X^d = \left\{\Pi^{X^d}\left(X_i^{d+1}\right)\right\} = \left\{P\left(X_i^{d+1} \mid X^d\right)\right\} \tag{6}$$

Equation (6) is the initial distribution vector over the sub-states of X^d, this shows the probability that state X^d will initially activate the state Xid+1 from its parent state. Each production state X^D is parameterized by its output transition probability vector (7) is the probability that the production state X^D output the symbol $\sigma_k \in E$.

$$B^{X^D} = \left\{b^{X^d}(k)\right\}, \text{ where } b^{X^D}(k) = P\left(\sigma_k \mid X^D\right) \tag{7}$$

The Entire set of Parameters is denoted by (8);

$$\lambda = \left\{\lambda^{X^d}\right\} d\varepsilon(1,2,...D) = \left\{\left\{A^{X^d}\right\} d\varepsilon(1,2,...D-1), \left\{\Pi^{X^d}\right\} d\varepsilon(1,2,...D-1), \left\{B^{X^D}\right\}\right\} \tag{8}$$

A string is generated by the starting root state that chooses one of the root's sub-states according to an initial probability π^{X^1}. Each internal state X that is entered, one of X's sub-states is then chosen accordingly to its initial probability vector π^X. This operation proceeds till it reaches the third hierarchy's production state X_e^3, at this point a single output symbol is generated according to the output probability vector B^{X^D}. The control then returns to the state X_3^2 which has activated X_e^3, then the second hierarchy state X_3^2 choose the next

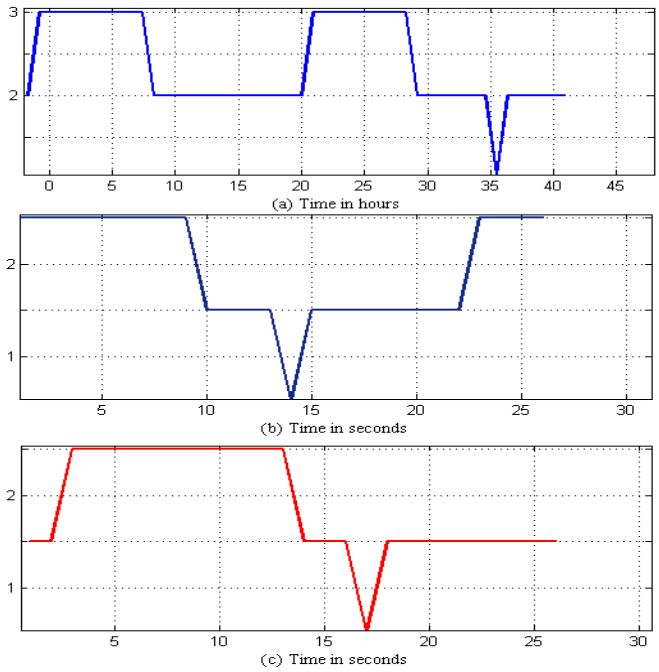


Figure 3.21: (a) Consumption Patterns (CP) (per hour), (b) Tap Event (TE) (per minute), and (c) Seepage Event (SE) (per minute) quantized state sequences.

state which happens to be the final state of second hierarchy that terminates the stochastic state activation process. At this time the control returns to the parent state X^1 thus completing the generation of the predicted states.

The most probable state sequence is a multi-scale list of states i.e. is state X had generated the string $O_i....O_j$, then its parent state generated the string $O_k....O_l$ such that $k \le i \,\&\, j \le l$. The likelihood of the most probable state sequence generated from the given observation states given X^1 at time t was defined, its sub-state X_3^3 is the last state to be activated by X^2 and control returned to X^2 at time $t+k$. For actual hierarchical analysis of sequence into states two additional variables are used namely (5) is the likelihood of the most probable state sequence generating $O_t....O_{t+k}$ assuming it is solely generated by a recursive activation that started at time step t from state X^{d-1} and ended at X_i^d which returned to X^{d-1} at a time step $t+k$.

$$\delta\left(t, t+k, X_i^d, X^{d-1}\right) \tag{9}$$

$$\psi\left(t, t+k, X_i^d, X^{d-1}\right), \quad t' = \tau\left(t, t+k, X_i^d, X^{d-1}\right)\left(t \le t' \le t+k\right) \tag{10}$$

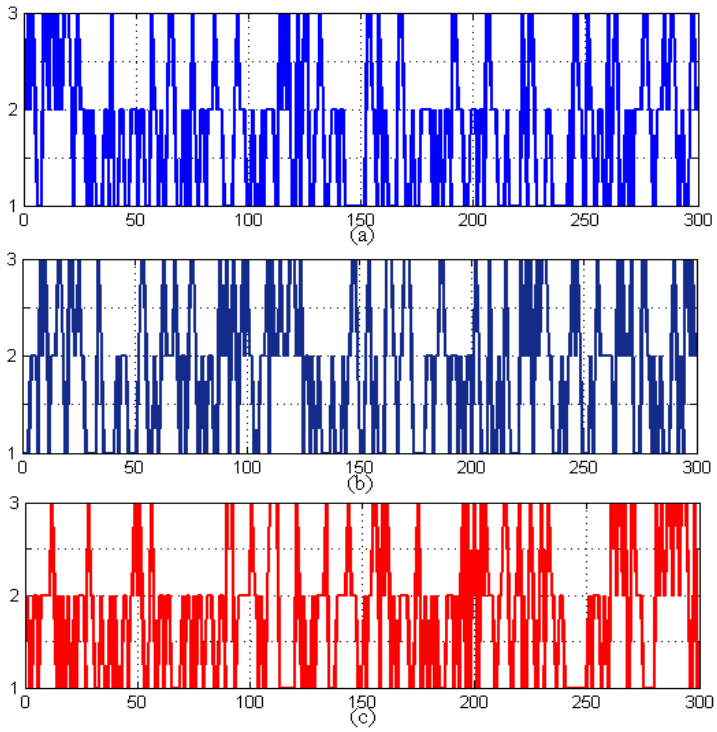


Figure 3.22: (a) Consumption Patterns (CP), (b) Tap Event (TE), (c) Seepage Event (SE), Predicted 300 points from HHMM.

The index of the most probable state to be activated by X^{d-1} before X_i^d is given by (6) is the time step at which X_i^d was most probable to be called by X^{d-1}. The most probable hierarchical state sequence is obtained by scanning the list ψ and τ from the root state to the production state.

3.1.8 Event Detection and Analysis

To determine patterns, a model must be developed that can be used to distinguish between suspicious and real instances of abnormal activities or events. In doing so, the model must be able to detect potential abnormal activities, efficiently analyze large amounts of data, and generate hypotheses with only partial and imperfect information. The model in fig. 3.19 is a transition-based model that identifies an event comparing the predicted outputs with the data sets from different nodes in the network. It is used to detect the water consumption patterns, seepages and tap events hierarchically. The expectation-maximization (EM) algorithm was used for HMM parameter training [131] and performing hypothesis testing using the maximum likelihood (ML) principles to rate the data samples as either normal, a possible event, or a confirmed event during the recognition phase of the algorithm. As the stability is directly proportional to the amount of data collected and the number of events occurred, this proposed

system will periodically train itself and as the data set grows, the stability increases. The initial transition matrix when there were no real data sets available will be stationary. While more and more data is available, the model itself adjusts the probability matrix to determine more stable parameters; however, the emission matrix will be stationary unless the humans perceive it to be outdated and change it to other more current values.

Pseudo-pressure data was used, shown in fig. 3.20, for Consumption Patterns, Tap events and Seepage events, respectively. The initial set of transition probabilities is derived from the pressure data. The initial set of emission probabilities is assigned logical values based on the relationship between the emission parameters. The quantized pressure data (observation sequence) using three threshold levels for the consumption pattern (a), tap event (b) and seepage event (c) are shown in fig. 3.21.

Next the matrix of transition and emission probabilities was obtained based on this pseudo-data. The emission matrix is initialized based on the following assumptions: if usage increases, then there is a 30% chance of the need to repair and expand water supply network. If seepage and leak events increase, then there is 50% chance of the need for repair. If water utility cost increases, then there is a 20% chance to conserve water. The emission matrix was logically assumed with 30% for water system expansion and 50% chance for repair. This matrix can be determined through real analysis of the home piping system during one year. In short, the emission matrix values can be set on the analyzed real data but here, for simplicity, the matrix was assumed. Also, the location of the seepages can be mapped and an alert can be sent to households to take corrective actions. After collecting a sufficiently large data set to train the model to give meaningful predictions and decisions, the model parameters such as transition, emission and initial probabilities can be tuned so as to maximize the system's event detection performance. For instance, a data set of a mere few hours is sufficient for the detection of a taping event, while a consumption event will require at least the data of the whole day. Given this model, HMM algorithm was used to generate predicted states for the three features of interest illustrated in fig. 3.22. The predictions were made after adjusting the transition and emission probabilities over 500 iterations.

Tap events occur within the consumption pattern measurements; this makes it easier and more efficient to model using a single HHMM rather than two HMMs. HHMMs train themselves after getting hourly, daily and monthly data and determining the events from this data set, so it may take as little as a couple of hours to capture the tapping events and a minimum of two days to determine the daily consumption patterns. Figure 3.20 shows the pseudo-daily consumption pattern and tap event pressure data, which is quantized to determine the system’s observation sequence states in fig. 3.21. The HHMM starts with the root state, which can in turn activate and pass the control to any one of the internal states at the second hierarchy according to an initial probability matrix. The third sub-state of the second hierarchy of the consumption measurements can also pass the control to the tap event state at the third

hierarchy according to its own initial non-zero probability matrix. The third tier predicts the tapping event and generates the outcome and passes the control to the hierarchy that activated it through the production state. After that the second hierarchy completes its generation of the predicted events and passes the control back to the root state via X_e^2. As the data set grows and the system comes across a number of events, the proposed HHMM model trains itself using daily and monthly event data sets. This training and parameter determination can be done in few minutes. Figure 3.22 shows the generated state prediction for the two events. HHMM generated prediction states indicate what may be an expected behavior of the system given the current obtained readings. The higher the prediction span, more complex will be the decision. Therefore, an algorithm is needed to detect these predictions to come up with any sort of decision. These HHMM-based predictions for 300 points of data from each node are given to a decision algorithm, which searches for 50 or more continuous state 3 predictions in the predicted sequence for each node and compares them with the other nodes in the region. If three or more nodes show similar predicted behavior, then a SMS alert is sent to the household and an alarm signal to the water smart server. The process then waits for acknowledgement and after receiving it, the system provides visualization of the event with its location.

3.1.9 Cognitive RFID Network for Spectrum and Energy Efficiencies

3.1.9.1 Introduction to Cognitive Radio

Wireless communication systems are continuously evolving and growing, leading to an increasing need for spectrum resources. Although different spectrum bands are allocated to specific services, it was identified that these bands are unoccupied most of the time or partially used by the primary users (PUs). Thus, we need to do something in order to optimize the usage of this scarce spectrum resource. Cognitive radio (CR) was proposed as one of these solutions enhancing the spectrum usage efficiency. It is defined by the Federal Communications Commission (FCC) as a radio that can change its transmitter parameters according to the interactions with the environment in which it operates. Depending on the ability of the secondary user (SU) to coexist and transmit simultaneously with the PR and depending on the spectrum usage, several strategies are considered:

3.1.9.1.1 Interweave CR

In interweave CR, also called opportunistic spectrum access, SUs are only allowed to use the spectrum when the PU is not active. Thus, no interference is tolerated by the PU. In OSA, the SU exploits the spectrum holes left by the PU. In order to locate these spectrum holes and

equivalently detect the PU's existence, spectrum sensing needs to be done by the CR. The main difficulty in the interweave scheme is that of sensing and predicting the activity of the PU in several radio channels especially for highly dynamic PUs (i.e., Pus having a fast spectral activity change). Spectrum sensing performance depends also on the range of the secondary transmission. Indeed, the primary activity sensed by the secondary transmitter and secondary receiver may vary due to different primary signal's strengths. These factors decrease the correlation between the spectrum sensed at the transmitter and at the receiver which reduces the effectiveness of secondary spectrum utilization.

3.1.9.1.2 Spectrum Sharing Systems

In spectrum sharing systems, also called underlay cognitive radio systems, the SU and PU can coexist simultaneously on the same spectrum as long as the SU ensures that the interference temperature of the primary user does not exceed a predefined limit. Rather than time and frequency agile radios, the SU needs to transmit at very low power and the secondary transceiver must be able to operate at very low SNR. This typically restricts underlay CR to low data rate applications or very short range applications such as personal area networks. Underlay CR has been adopted by regulatory bodies worldwide, and is allowed when SUs transmit using the Ultra-wideband (UWB) signal format. Due to the restrictive regulations, the applicability of UWB is limited to very short range applications, below 10m, but longer range operation, up to 300m, is possible but at very low data rates.

3.1.9.1.3 Overlay CR

In the overlay approach, the SU have to pay a price in order to access the PU's spectrum. Indeed, the SU devotes part of the transmit power in order to enhance the primary signal and to facilitate its detection at the primary receiver. In exchange, the secondary may be allowed to increase the interference temperature level further and thus to achieves higher performance than the underlay approach. This help handed to the PU by the secondary and its contribution to improve the detection of the PU may also contribute to a higher acceptance of this technique by primary licensees. Thus, the overlay approach can be seen as an evolutionary step from the underlay technique, where a tighter degree of integration between primary and secondary users is necessary.

The proposed RFID system will operate in parallel with other wireless devices utilizing several different spectrums. Cell phones, Bluetooth devices and WiFi are common primary interferers used in our homes. The available wireless spectrum has become a scarce resource due to the rising demand for high data rate wireless services. Due to this scarcity, emergent communication systems are required to exploit the unused licensed spectrum in an opportunistic fashion [132]. It is proposed in [133] that in case the licensed or primary user of the spectrum is inactive, any cognitive or secondary users can use this available spectrum.

When the primary user becomes active, the secondary user must switch off its communication and look for another spectrum hole. This technique is generally referred to as an interweave approach and involves spectrum sensing and detection. In the overlay approach, both the primary and secondary users access the spectrum simultaneously; however, the secondary user implements some advanced signal processing techniques to reduce the interference on the primary user. Another approach, called underlay, allows the sharing of the spectrum by both primary and secondary users simultaneously. In this approach, the secondary user must satisfy strict interference constraints and its transmission power should be below a certain threshold all the time [133]. Underlay cognitive networks use very limited transmission powers, making the system energy efficient. A subset of these RFID nodes was allowed to send the data, which increases the received SNR ratios and will be useful in decision making. In the proposed monitoring application, for better parameter monitoring, maximum number of nodes satisfying the threshold requirements will be needed to be accumulated to increase the overall received SNR.

In the considered techniques in this section, we look at the scenario of spectrum sharing systems. In this context, the RFID sensors are allowed to transmit at the same time as the primary user as long as the interference constraint to the PU is verified. Depending on the knowledge that the sensors have about the interference link to the PU, we consider two different scenarios. In the first one, the sensors have very limited knowledge about the interference channel. In this case, a sensor only knows if the interference constraint is verified or not. Thus, a sensor can be used only if it verifies this constraint. In the second case, on the other hand, the sensors have full channel state information (CSI) about the interference link

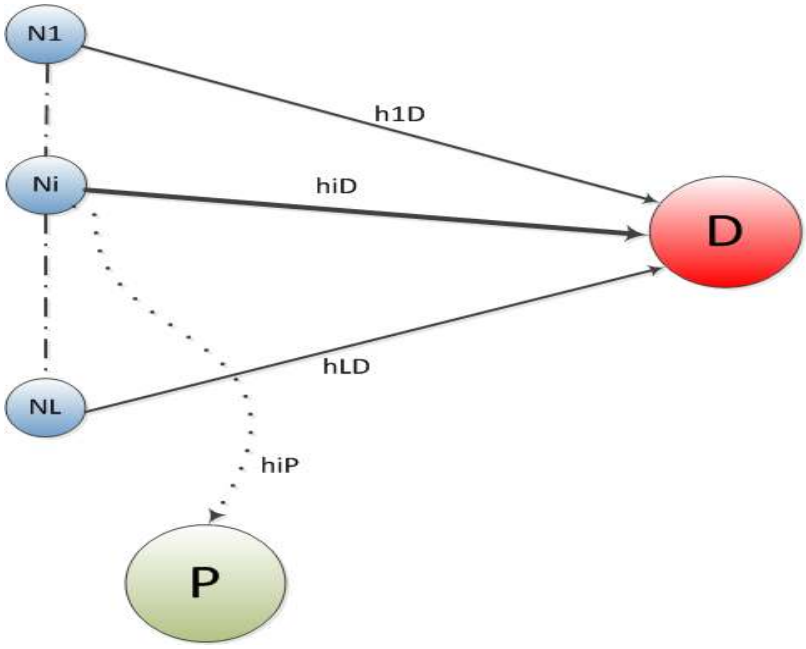


Figure 3.23: System Model: RFID cognitive nodes, the destination node and the primary interferer.

and thus power adaptation can be used at each sensor in order to verify the interference constraint. In this second scenario, all sensors can be used thanks to the power adaptation process. The second scenario helps make this system power adaptive and more energy efficient.

In what follows, we first present the performance analysis and the simulation results for the first scenario. Then we discuss the second scenario using power adaptation as a performance-improving scenario.

This section presents an analysis from the journal extension [81] of our work in PipeSense [111] utilizing an underlay RFID network with fixed transmission power near a primary user. A new commutative nodes selection criterion was proposed, based on satisfying the interference constraint while maintaining the maximum SNR of the node link at the destination. Closed form expressions were derived for the probability density function (PDF) of the total SNR at the destination and outage probability of the system. Here, the approach to signature the taping and other known events in order to recognize unknown events such as a leak or seepage when they occur and track them so as to have an efficient system with less false alarms was discussed. This type of system implementation can be seen as a cyber-physical system (CPS), where the user can also give feedback and actuate certain mechanisms to achieve efficiency.

3.1.9.2 Cognitive Cooperation System Model

An underlay cognitive RFID network was considered operating near a primary user P. The cognitive network consists of L secondary nodes broadcasting their data signals to the destination D, as shown in fig. 3.23. This broadcast is also received at the primary user P and causes some interference. The channel coefficients from the i^{th} node ($N_i \to D$) are $h_i, i = 1,2,3,...L$. The interference channel from the i^{th} node ($N_i \to P$) to the primary user is $h_{ip}, i = 1,2,3,...L$. In addition, an assumption is made that the channels are subjected to additive white Gaussian noise (AWGN) with zero mean and variance N_0. The available power at each node is P. In underlay cognitive networks, the secondary users must maintain strict interference constraints, i.e., the interference at the primary user must be below a certain threshold, say λ. Depending upon the channel gain h_{ip} from the i^{th} node to the primary user, some nodes may not be able to satisfy the interference constraint and hence would refrain from sending the data to the destination. It was also assumed that the nodes estimate their interference channel when the primary user is transmitting or acknowledging any received information. This information may also be available on a dedicated feedback channel from the primary user to the i^{th} node in the form of a yes or no decision. Let us say l nodes satisfy the interference constraint out of the available L nodes. The nodes indexes are grouped into

different sets such as U, which represents the set of all nodes indexes. $A \subseteq U$ is the set of l node indexes satisfying interference constraints. All the channel coefficients are assumed to be Rayleigh distributed and hence their squared amplitudes are exponentially distributed. The received SNR from the i^{th} node transmission can be given as

$$\gamma_i = \frac{P|h_i|^2}{N_0} \qquad (11)$$

Similarly, the interference on the primary due to the i^{th} node is given by:

$$I_{ip} = P|h_{ip}|^2 \leq \lambda \qquad (12)$$

3.1.9.3 Received SNR Statistics

Based on the above discussion, the SNR received at the destination can be defined as the sum of the SNRs of all the nodes satisfying the interference constraint. Mathematically,

$$\gamma_T = \sum_{i \varepsilon A} \gamma_i \qquad such\ that \qquad I_{ip} \leq \lambda \qquad (13)$$

Since, I_{ip} is an exponentially distributed RV, the probability of satisfying the interference threshold is:

$$P_\lambda = 1 - e^{-\frac{\lambda}{\sigma}} \qquad (14)$$

where σ are the average strengths of the interfering channels. The nodes are assumed to be present in the form of a cluster and are roughly at the same distance from the primary user. In this case, the average strengths of the interfering channels can be assumed to be the same; however, their instantaneous values may be different. Therefore, $\sigma_{1P} = \sigma_{2P} = ... = \sigma$.

Similarly, γ_i are also exponentially distributed with PDF, $p_{\gamma_i}(\gamma) = \frac{1}{\gamma_i} e^{-\frac{\gamma}{\bar{\gamma}_i}}$ and cumulative distribution function (CDF), $P_{\gamma_i}(\gamma) = 1 - e^{-\frac{\gamma}{\bar{\gamma}_i}}$, where $\bar{\gamma}_i$ is the average SNR of the i^{th} node branch.

It is important to note that the number of nodes satisfying the interference constraint i.e. l may vary from 0 to L. If l = 0, the destination would not receive any signal from the nodes. For l = 1, only one node will be sending the data, hence no SNR aggregation is possible. In fact, the node SNR aggregation begins with l = 2, but the events with l < 2 should be included when evaluating averages of various performance parameters. Hence, in summary, l

nodes out of total L can satisfy the interference constraint λ with a probability P_λ This dictates Bernoulli's distribution; however, in order to average over all possible values of l, a binomial distribution should be used which is given below:

$$p_l(l;L;P_\lambda)=\binom{L}{l}P_\lambda(1-P_\lambda)^{L-l} \tag{15}$$

where $\binom{L}{l}=\frac{L!}{l!(L-1)!}$

The conditional PDF of the sum of SNR among the l nodes can be obtained by the following expressions.

$$p_{\gamma_T(\gamma|l)}=\frac{1}{\overline{\gamma}_i}e^{-\frac{\gamma}{\overline{\gamma}_i}};\ l=1 \tag{16}$$

$$p_{\gamma_T(\gamma|l)}=\left[\prod_{i\varepsilon A}\frac{1}{\gamma_i}\right]\sum_{j\varepsilon A}\left(\frac{e^{-\frac{\gamma}{\overline{\gamma}_j}}}{\prod_{\substack{k\varepsilon A\\k\neq j}}(\frac{1}{\overline{\gamma}_k}-\frac{1}{\overline{\gamma}_j})}\right);\ l\geq 2 \tag{17}$$

The unconditional PDF of the SNR at the destination through the node aggregation can be obtained by averaging the conditional PDF over PDF of l given as:

$$p_{\gamma_T(\gamma)}=\sum_{l=1}^{L}\binom{L}{l}P_\lambda^l(1-P_\lambda)^{L-l}\,p_{\gamma_T(\gamma/l)} \tag{18}$$

Hence, substituting eq.(6) in eq.(8) we have,

$$p_{\gamma_T(\gamma)}=\underbrace{P_\lambda^1(1-P_\lambda)^{L-1}\sum_{i=1}^{L}\frac{1}{\overline{\gamma}_i}e^{-\frac{\gamma}{\overline{\gamma}_i}}}_{l=1}+\underbrace{\sum_{l=2}^{L}\binom{L}{l}P_\lambda^l(1-P_\lambda)^{L-l}\left[\prod_{i\varepsilon A}\frac{1}{\gamma_i}\right]\sum_{j\varepsilon A}\left(\frac{e^{-\frac{\gamma}{\overline{\gamma}_j}}}{\prod_{\substack{k\varepsilon A\\k\neq j}}(\frac{1}{\overline{\gamma}_k}-\frac{1}{\overline{\gamma}_j})}\right)}_{l\geq 2} \tag{19}$$

The CDF of γ_T can be obtained by integrating eq.(19) from 0 to ∞ given below:

$$P_{\gamma_T(\gamma)}=\underbrace{P_\lambda^1(1-P_\lambda)^{L-1}\sum_{i=1}^{L}(1-e^{-\frac{\gamma}{\overline{\gamma}_i}})}_{l=1}+\underbrace{\sum_{l=2}^{L}\binom{L}{l}P_\lambda^l(1-P_\lambda)^{L-l}\left[\prod_{i\varepsilon A}\frac{1}{\gamma_i}\right]\sum_{j\varepsilon A}\left(\frac{\overline{\gamma}_i(1-e^{-\frac{\gamma}{\overline{\gamma}_j}})}{\prod_{\substack{k\varepsilon A\\k\neq j}}(\frac{1}{\overline{\gamma}_k}-\frac{1}{\overline{\gamma}_j})}\right)}_{l\geq 2} \tag{20}$$

3.1.9.4 Performance Analysis

In this section closed form expressions for outage probability of the system using the results obtained in the previous section were derived.

3.1.9.4.1 Outage Probability

A communication system is said to be in outage when the received SNR is fallen below a certain threshold η . The total SNR expression in (19) is for the situation when at least one node satisfies the interference constraint. However, as mentioned earlier, it is possible that none of the relays satisfy the interference constraint. The probability of this event is $(1-P_\lambda)^L$. Hence the outage probability of the system can be evaluated as,

$$P_{out} = P_{\gamma_T}(\eta) + (1-P_\lambda)^L \qquad (21)$$

3.1.10 Numerical Results

In this section, simulation results were presented to verify the derived analytical expressions. First, the parametric setup was defined for the simulations and later the results are discussed in detail.

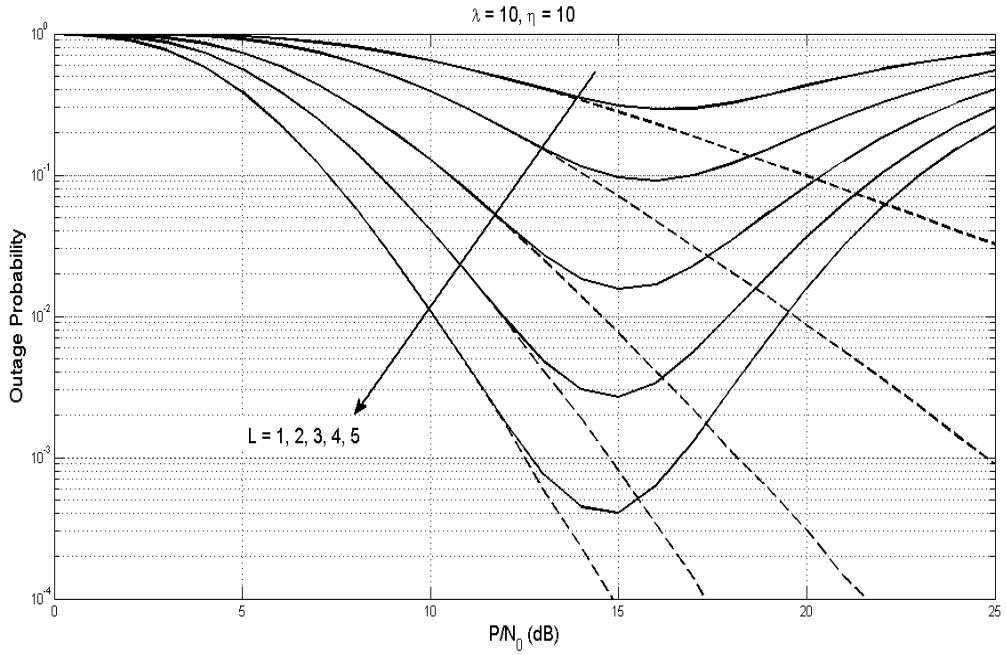


Figure 3.24: Outage probability of the system with L = 1, 2, 3, 4, 5 for interference constraint λ = 10 and outage threshold η = 10.

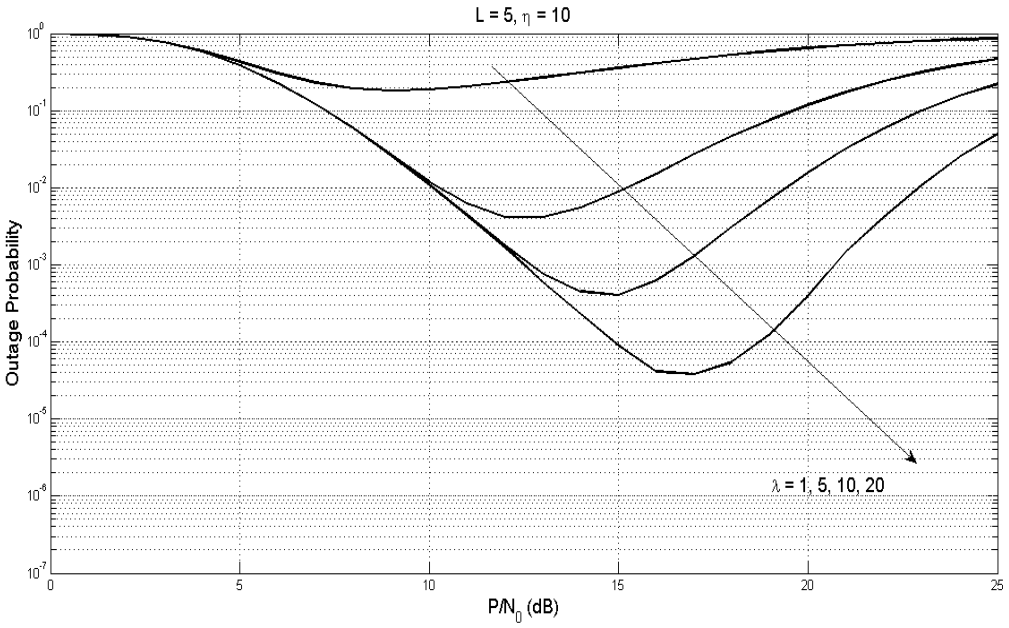


Figure 3.25: Outage probability of the system with L = 5 for interference constraint L = 1, 5, 10, 20 and outage threshold λ = 10.

3.1.10.1 Simulation Setup

All the simulation results are generated by varying the average SNR $\frac{P}{N_0}$, such that $\gamma_i = \alpha_i \frac{P}{N_0}$, where α_i is a randomly selected constant of each node and $\alpha_i \leq 1$. The value of α = 0.1 in case of interference channel. The noise is considered to be AWGN with zero mean and unit variance. The transmission power at the nodes is also assumed to be P = 1. The maximum number of nodes in the system are L = 5 and all the situations are compared with equal power conditions.

3.1.10.2 Discussion

The outage performance of the system is plotted in fig. 3.24 with L = 1, 2, 3, 4, 5, and the values of interference constraint and outage threshold are set to be 10. The outage graph initially follows the regular waterfall curve until it reaches a point where the nodes start to have better SNR and produce more interference to the primary, hence making it more difficult for them to satisfy λ. At this point the outage graph shows an increase in probability. As the number of nodes increases, the outage graph's probability values decreases steeply (shown in solid line). On the same graph the case of interference constraint having a very large value

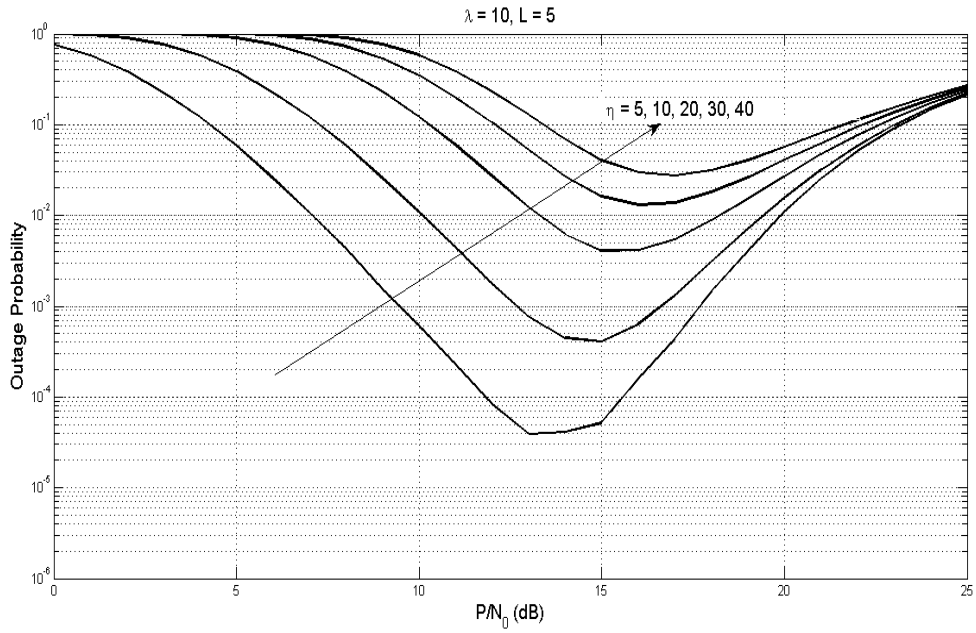


Figure 3.26: Outage probability of the system with L = 5 for interference constraint λ = 10 and outage threshold $_{\lambda}$ = 5, 10, 20, 30, 40.

(shown as a dashed line) is shown. All the nodes satisfy the interference constraint all the time; hence, the system acts like a non-cognitive network.

The graph shown in Fig.3.25 with L = 5, and outage threshold = 10 with varying interference constraint λ = 1, 5, 10, 20. The figure shows that the elbow point indicating the event when the nodes started to violate the interference constraint slopes down with the increase in the interference constraint.

Figure 3.26, shows the outage probability when L = 5 and interference constraint is set to λ = 10 and varying the values of the outage threshold η = 5, 10, 20, 30, 40. It shows that the probability increases with the increase in the outage threshold.

3.1.10.2.1 Power Adaptation Numerical Analysis

In this case, based on the reciprocity principle, we assume that full channel state information of the interference link is available to the ST. As such, the channel coefficients for the forward and the reverse directions between sensors and the PU can be assumed to be similar and the CSI experienced by the reverse link can be used for the forward link especially these sensors and the PU operate in the same frequency band.

In the beginning of each data burst, each sensor transmits a training sequence using its maximum power level P. If the interference constraint is verified, then that sensor can be used for transmission with its maximum power. If on the other hand, this constraint is not respected

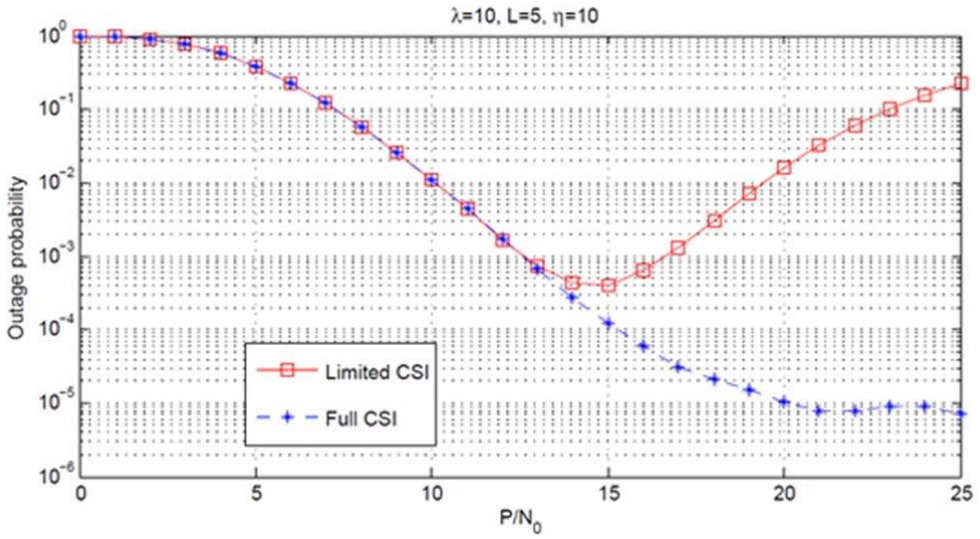


Figure 3.27: Outage probability comparison between full and limited CSI scenarios for the system with L= 5, λ =10 and outage threshold η=10.29

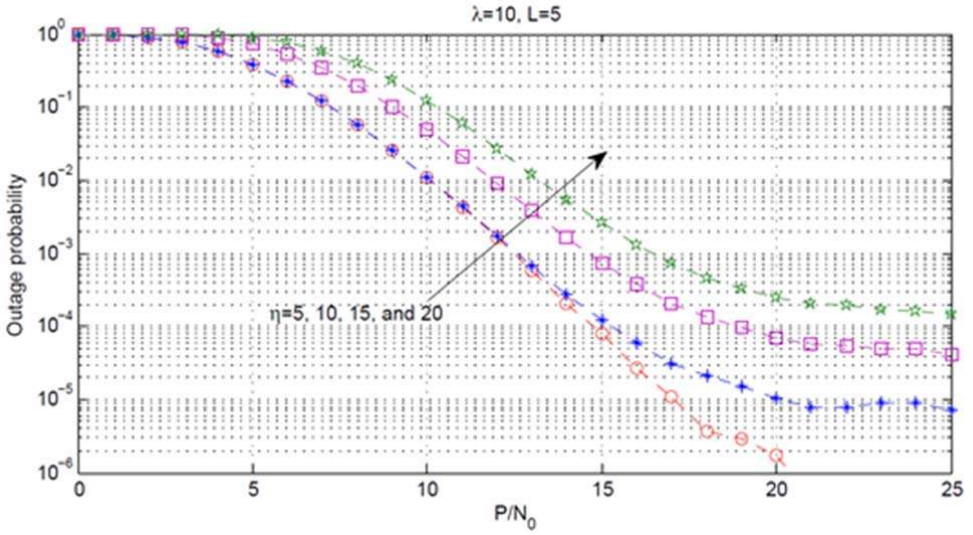


Figure 3.28: Outage probability for the full CSI scenario for the system with L= 5, λ= 10 and outage threshold η=5, 10, 15, and 20.

then the transmit power is adapted to the interference channel and is set to $P_t = \frac{\lambda}{|h_ip\ |^2} N_0$. Thus the tranmit power in this case given by:

$$P_t = min\left(P, \frac{\lambda}{|h_{ip}|^2} N_0\right) \qquad (22)$$

Fig 3.27 shows the improvement offered by the second scenario over the first one. Indeed, assuming that the transmit sensors have full CSI about the interference link offers a considerable improvement in the outage performance of the system. In this context, the advantage of using power adaptation is very clear. Instead of not using a sensor failing the

interference constraint to the PU, that sensor can be used with a lower power which hugely improves the outage performance. Moreover, with this second scenario there is no outage event resulting from the case where all sensors fail the interference. Indeed, even if this scenario happens in the case of full CSI, all sensors can still be used thanks to the process of power adaptation. Still, this comes at the expense of assuming full CSI of the interference link available to the sensors since it is sometimes unpractical or very challenging to have this CSI at the sensors' side. Fig 3.28 also shows the performance improvement offered by the use of power adaptation with the transmit sensors. Indeed, while the limited CSI outage saturate at a probability of 0.1, the perfect CSI case archives much better outage ranging from 10^{-5} to 10^{-4}.

3.2 RFID based Moisture Detection for Gas Pipelines

Presence of moisture in an LPG, LNG pipe can decrease the quality of the gas and is a major problem for the industry. A wireless monitoring system using low frequency RFIDs as moisture sensors can detect the received energy of the transmitted signal using the proposed energy detector algorithm, which is used extensively for spectrum sensing in Cognitive Radios to prevent such hazards. A simple Energy Detector concept was employed to exploit the renowned behavior of the RFID's signal reception and energy absorption in diverse environments. The decision for presence of moisture was made using the threshold values of the energy detector. The experiments were also performed in the Wireless Research Laboratory at Texas A&M University at Qatar to verify the simulation results and the channel impulse response. It is shown in this study that the RFID system is able to send information regarding the presence of moisture for quality monitoring of liquefied gas and enable us to detect and make decisions on the basis of the energy detected from the RFID antenna system.

A human-centric cyber–physical wireless monitoring system was also proposed utilizing hybrid wireless technologies including RFIDs and other sensor nodes to detect and prevent such hazards. The objective of this research is to allow maintainers and administrators to perceive and decide on top of the monitoring system to increase the performance and efficiency of the whole monitoring application.

In this section, an experimental study using low frequency RFID tags on moisture detection is presented and verified through simulation results for the channel impulse response of the detection system. It is shown that a wireless monitoring system using low frequency RFIDs can be used as a moisture sensor with no added circuitry in order to prevent gas quality hazards by detecting the received energy of the transmitted signal. A framework for a human-centric CPS was also proposed to monitor the quality of the gas and the pipeline's health continuously. A system design is also proposed to monitor the issues related to gas pipelines. A brief description is also provided of the hierarchical Hidden Markov model

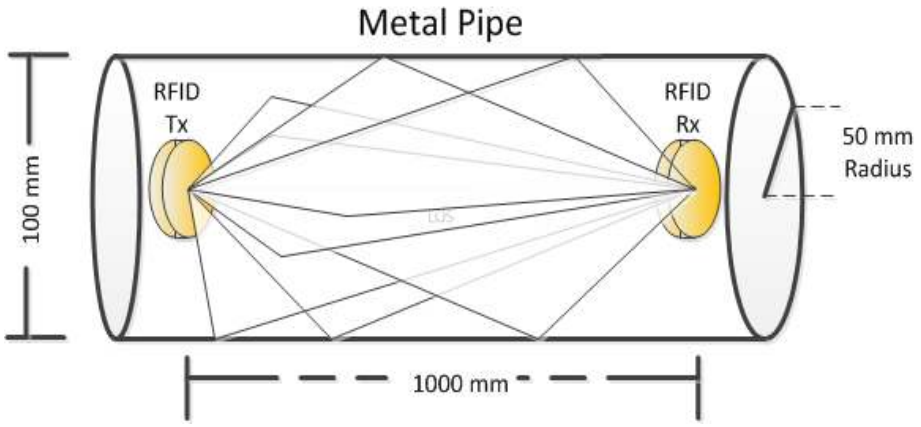


Figure 3.28: Channel Model for in-pipe RFID communication using ray tracing approach.

(HHMM) that can be applied in this approach to predict the events based on the data received.

3.2.1 Moisture Detection System Model

Through spectrum sensing we can infer the absence or presence of a signal transmitted by an unknown source. In the presence of moisture over the transmission medium, the hypothesis to detect its presence can be expressed as:

$$r(t) = \begin{cases} H_0 = x_1(t) \; no \; moisture \\ H_1 = x_2(t) * \alpha(t) \; moisture \end{cases} \qquad (23)$$

where $\alpha(t)$ is the coefficient of attenuation in case of moisture present in the system; $x_i(t)$ are the transmitted unknown signals; H_0 represents the hypothesis analogous to the absence of the moisture in the gas pipe, and H_1 refers to the hypothesis corresponding to its presence. Hence, the problem can be stated as identifying the presence of moisture in the LNG/LPG gas pipe section by determining the energy of the unknown signal $x_i(t)$ by examining the statistical characteristics of the received signal $r(t)$ in the presence of moisture $\alpha(t)$.

An energy detector collects the energy of the received signal for a specific period of time. Next, its output is fed to a decision device. The output of the energy detector is called the decision statistic *d*(m) and it is compared against a threshold to decide on the absence/presence of moisture in the pipe. Assuming that the receiver is able to sample the signal at a sufficiently high rate, the energy detector output can be expressed as:

$$d(m) = \sum_{i=0}^{m-1} |\, r(i) \,|^2 \qquad (24)$$

where m is an arbitrary integer number of samples and $r[i]$ denotes the discrete counterpart of $r(t)$. It is also important to state that in case the number of samples $'m'$ is

large enough, the decision statistics can be considered to be asymptotically normally distributed with certain mean and variance values according to the Central Limit Theorem. Figure 3.29 shows the in-pipe moisture detection system model. Two RFID antennas are placed one meter apart in a metallic LPG/LNG pipe. The radius of the metal pipe section is 5cm; the antennas are placed at the center of the pipe. The channel impulse response is divided into two parts: Line of Sight (LOS) and Reflected (Multipaths) from the inner surface of the pipe. These multipaths are characterized by an impulse response $h(t)$. Hence, the detector's output will be of the form:

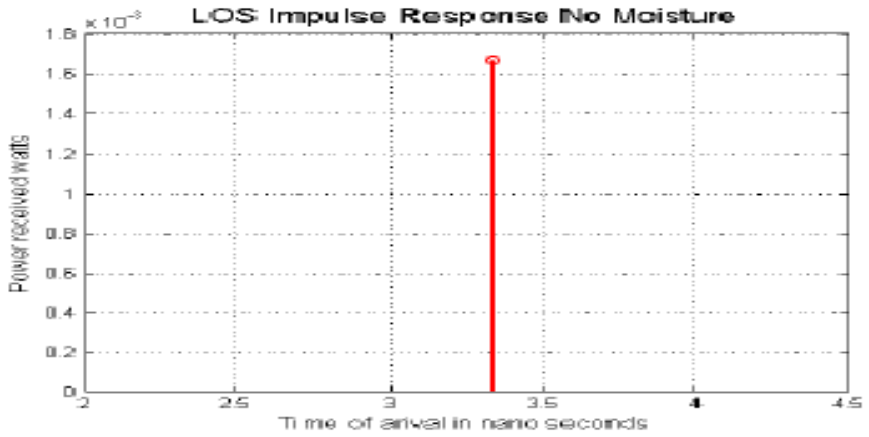
$$Y(t) = h(t) \otimes \{r(t) + \alpha(t)\} \qquad (25)$$

Where $\alpha(t)$ is the attenuation occurring due to the presence of moisture in the transmitted signal $r(t)$. Using the impulse response of the form:

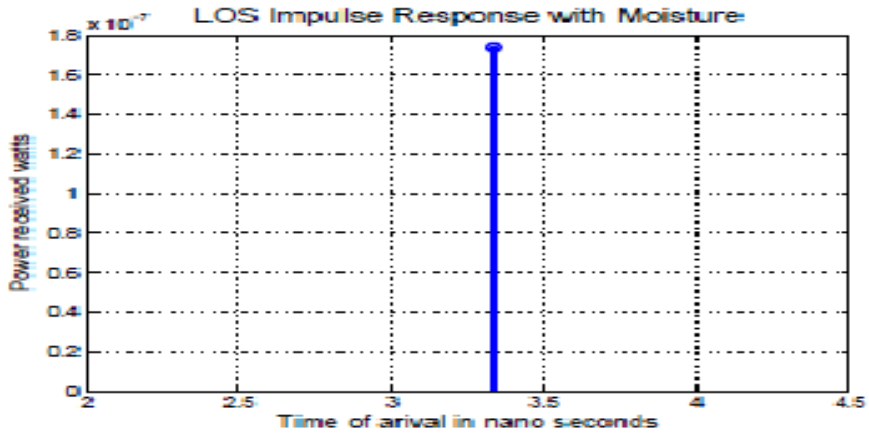
$$h(t) = \left(\frac{n+1}{2\pi}\right)\sum_{j=1}^{M} A_n \delta\left(t - \tau_n\right) \qquad (26)$$

Where n is the mode number of the RF rays, M are the number of multipaths, and τ_n is the delay. The expression $(\frac{n+1}{2\pi})$ helps integrate all the received rays over the circumference of the receiver antenna. A_n is the attenuation, defined separately for no-moisture and moisture cases. In case of no moisture present between the antennas, A_n is defined through a distance path-loss model as follows: For the direct line of sight;

$$P_{L0} = \left(\frac{4\pi d_0}{\lambda}\right)^2 \qquad (27)$$



(a)



(b)

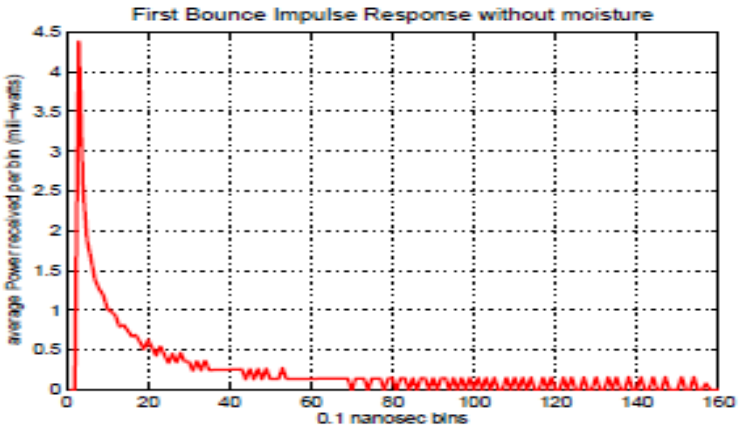
Figure 3.30: LOS Impulse Response (a) No moisture and (b) with moisture.

Where P_{L0} is the path loss and d_0 is the LOS distance between the transmitter and the receiver. The equation(5) can be modified to cater for the multipaths and the heavily metallic environment as below:

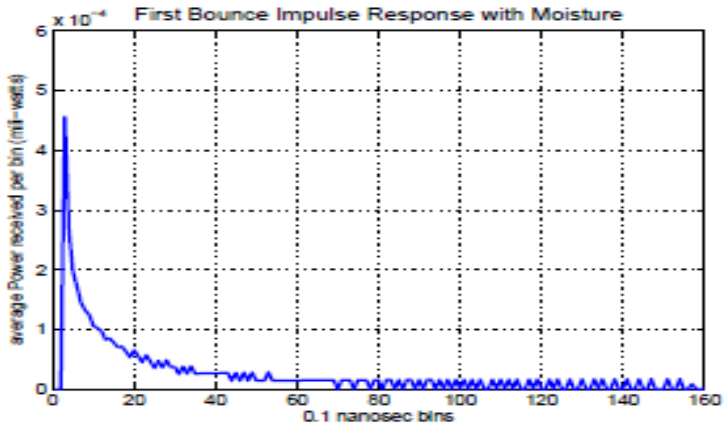
$$P_L\left(no\ moisture\right) = P_{L0}\left(\frac{d}{d_0}\right)^{\gamma} \qquad (28)$$

Where γ is the path loss exponent. Its typical value for free space communication is 2, but it varies between 1.6 and 3.3 for heavily metallic environments [134]. Since the RF radiations both attenuate and scatter in rain [135], $\alpha(t)$ can be used as coefficient of attenuation due to moisture, where $\alpha(t)$ can be stated as:

$$\alpha = \frac{radius\ of\ the\ water\ particle}{wave\ length} \qquad (29)$$



(a)

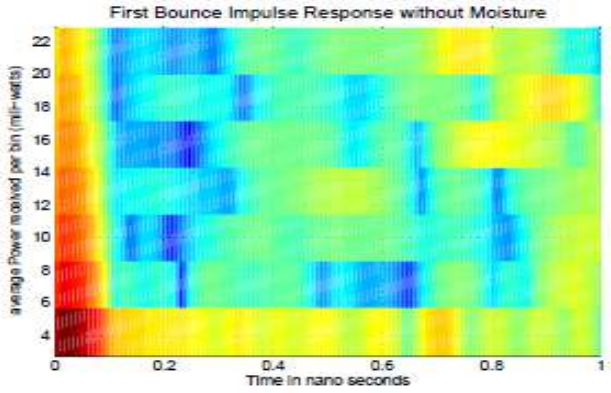


(b)

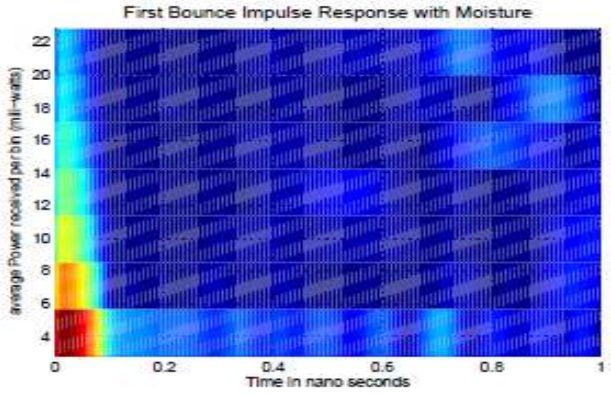
Figure 3.29: First Bounce Impulse Response (a) No moisture and (b) with moisture.

The standard radius of the water particle is used as 2.5 μm [135]. That gives us $\alpha = 1.0410^{-9}$. Hence, the multipath attenuation in the presence of water can be written as:

$$P_L\left(moisture\right) = \alpha P_{L0}\left(\frac{d}{d_0}\right)^{\gamma} \qquad (30)$$



(a)



(b)

Figure 3.30: Energy Received at the receiver simulation (a) No moisture and (b) with moisture.

3.2.2 Simulation and Experimental Results

Channel impulse response simulations were performed using a ray-tracing method on the moisture detection system model shown in fig. 3.29. The metallic pipe was divided into 1mm elements for the circumference of the pipe. The transmitted RF radiations struck the elements and reflected them to the receiver in the multipath case. It was also assumed that the 30% of the total energy from the ray was absorbed by the metal pipe, and the remaining 70% was reflected to the receiver. Figures 3.30(a) and 3.30(b) show the result of simulated LOS impulse response for the no-moisture and moisture cases respectively. On comparison, the received energy in case of moisture is significantly less than in the case of no-moisture. Furthermore, the fig. 3.31(a) and 3.31(b) depicts the channel impulse response for the multipath for the no-moisture and with moisture cases respectively. Here once again a significant difference between the received energies for the two cases can be seen. The energy graph in fig. 3.32(a) and 3.32(b) of the multipath impulse response clearly shows the difference in received energies for the no-moisture and with moisture cases.

In order to authenticate the results, experiments were performed using the Pico RFID module

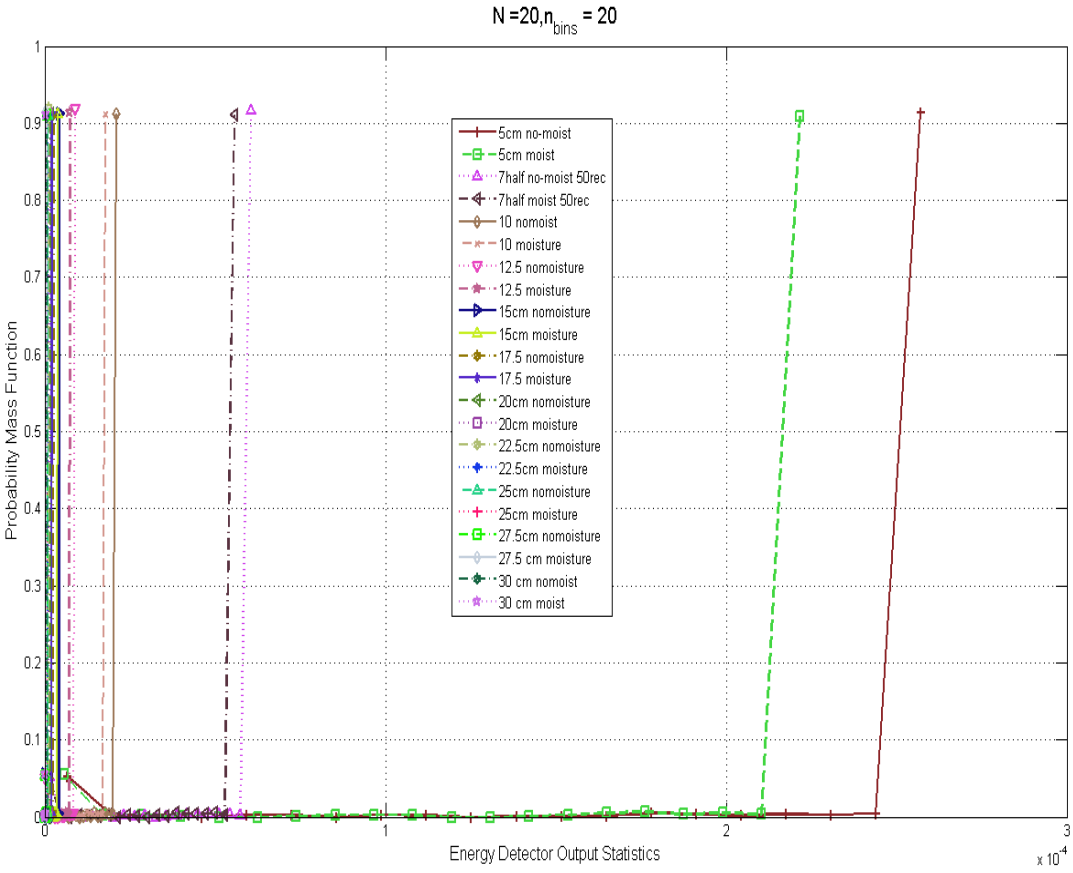


Figure 3.31: Experimental result showing probability mass distribution with sample size of 20.

[136]. These experiments were performed in Texas A&M University's Wireless Research Lab using different distances between the transmitted and received antennas. The experimental set up was composed of a metal pipe, Pico-RFID module as the transmitter, and Agilent's PSA E4440A as receiver.

Agilent's 89600 VSA software installed on a PC was used to acquire the received signal. The received signal was operated by the energy detector algorithm, and the detection statistics were generated. The maximum output from the transmitter was 250mW. The output statistics at different distances between the transmitter and receiver antennas were measured and are shown in fig. 3.33. It was noted that the distance and the transmitted power play major roles in the precision and range of the moisture detection system. It was clear that lower the distance, the better the received statistics; however, an optimal distance can be calculated that can detect the presence of moisture without giving false alarms. These results prove that the use of RFIDs as moisture sensors can be feasible for oil and gas in-pipe monitoring applications.

3.2.3 Gas Quality Monitoring System Architecture

The originality of this proposed system is the way different wireless technologies can co–exist

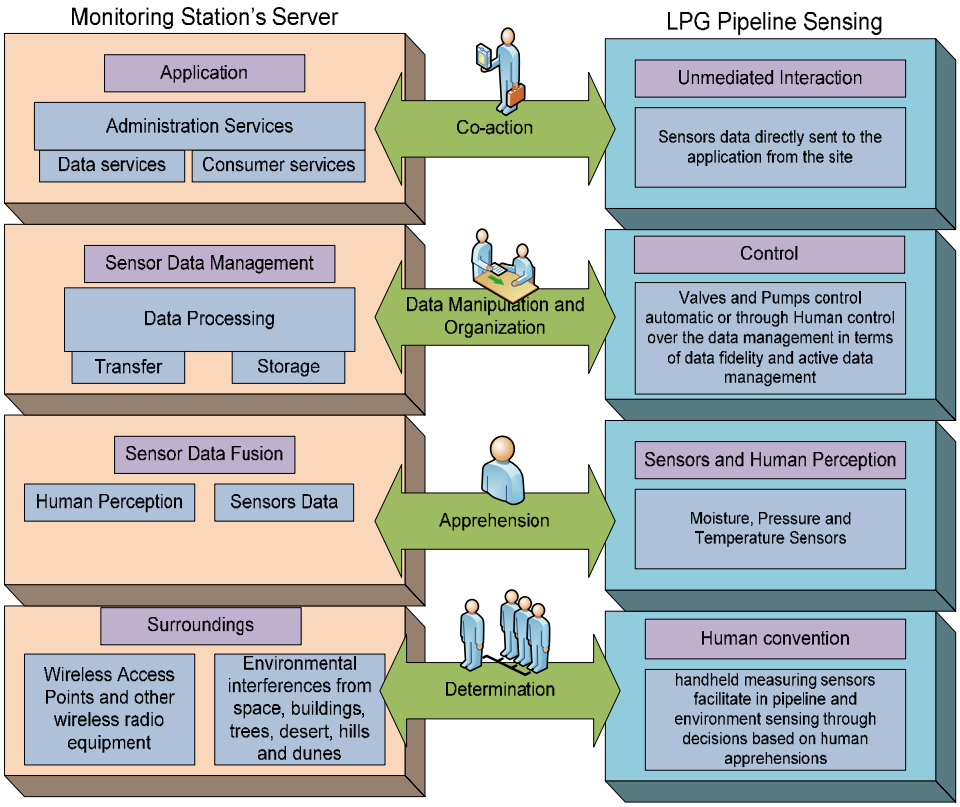


Figure 3.32: RFID and WSN based Moisture Monitoring System Architecture.

and coordinate in a tight integration for closed loop monitoring tasks. Another factor that elevates the importance of this research work is the participation of the users and maintainers in the decision making. Participatory systems involve individuals in all kind of sensing decisions based on the collected information. This involvement boosts the efficiency of the overall system. A maintainer can perceive an event such as a leak during a regular inspection and convey this information to the administration room using a mobile application.

In this section the integration of participatory sensing into the closed loop sensing was presented to detect, monitor/measure and communicate collected information regarding the presence of moisture and parameters like pressure, flow and strain on the infrastructure. Experiments were performed on the moisture detection in Wireless Research Laboratory at Texas A&M University at Qatar. On a similar note, other sensors can also be associated with the radio–frequency identification (RFIDs) and their data can be relayed to the server using other wireless technologies. Framework architecture was proposed for the human-centric approach of detection and monitoring systems. The events were detected on the output of the HHMM, which takes input from the energy detector algorithm in case of moisture monitoring.

In fig. 3.34, the proposed human-centric CPS framework architecture is presented, comprised of eight tiers or blocks connected to each other. These tiers are divided into two big blocks, monitoring station and pipeline. A brief explanation of each tier is given below:

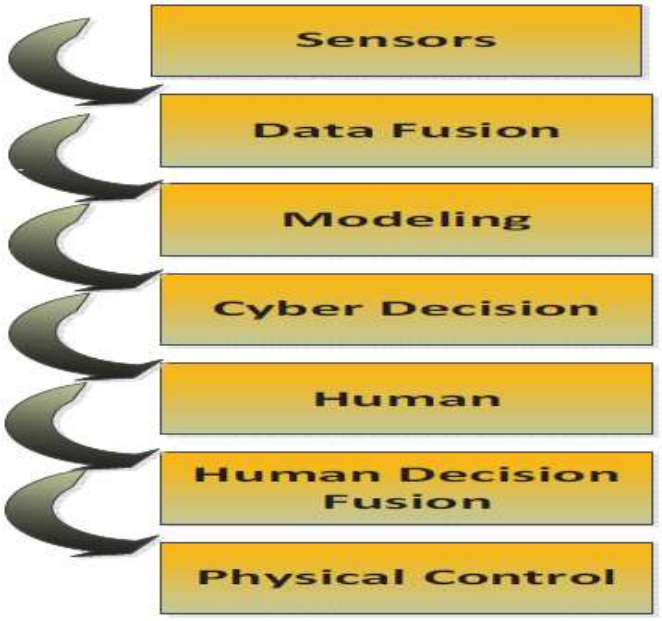


Figure 3.33: Flow diagram of the cyber physical PipeSense system.

1) Sensing Block: The bottom two tiers are composed of a sensing block comprised of the sensors both embedded in the pipeline and handheld by maintainers. These sensors can be flow, pressure and strain sensors. These sensors can also be divided into static sensors, sensors that monitor ambient environment conditions such as temperature and light, and those that monitor the valves' and pumps' proper functioning. There are also dynamic sensors that continuously monitor the in–pipe system and give geographical locations of the nodes. The information from the sensor is partially cleansed at the node level, then transmitted to the server, where the data is fully processed.

2) Processing Tier: Here the data from the sensors is fused in and human perception is used to determine false alarms. After getting the partially cleansed data from the sensors, the processing tier performs extensive data cleansing in real time and can also store the data for historical reference.

3) Sensor Fusion Tier: The output of the processing tier is fed here, and humans can monitor the data runtime in order to determine any ambiguity.

4) Modeling Tier: The processed data is then fed to the modeling tier. This tier comprises of Hidden Markov and energy detection models for pattern prediction and moisture monitoring, respectively.

5) Application and Decision Fusion Tier: The outcomes from the models are then fed to the decision fusion tier. In this tier the cyber decisions were made according to the standard artificial intelligence models. These decisions are used to train the cyber systems through the learning and training models for accurate decisions in the future.

This system is then monitored again by the sensing tier to determine the result of a particular decision. This whole process is shown in the form of a flow diagram in fig. 3.35. Let us consider an example situation, for instance, sensors picked up an event in a section of a pipe at certain location. This sensed information is then processed and cleansed in real time and provided to the modeling tier, which has algorithms to isolate that certain pipe section and gas distribution from this section. The models will put the data into different scenarios and send the outcomes to the decision fusion, where the HHMM models make an appropriate decision.

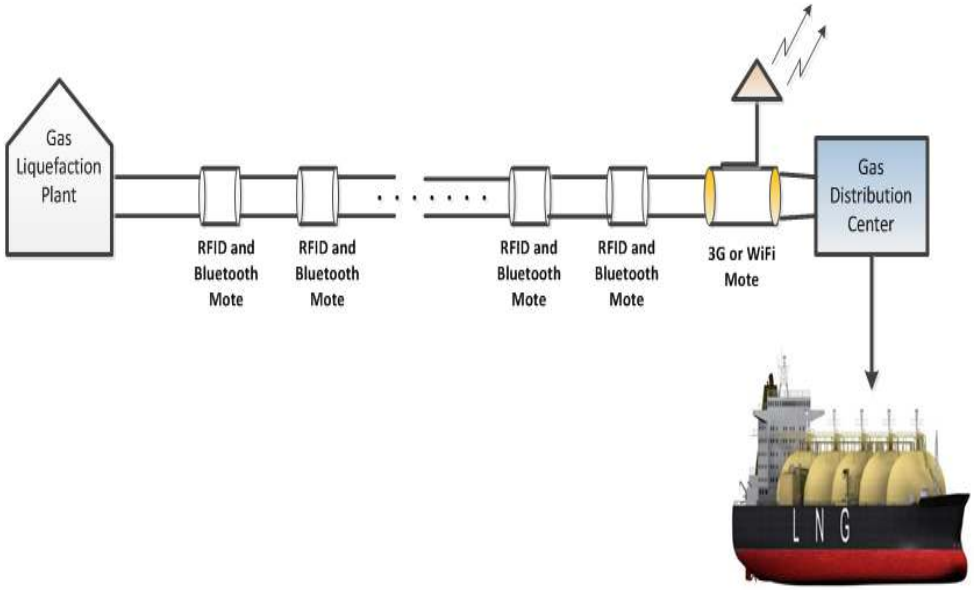


Figure 3.34: Monitoring System Diagram.

These decisions are sent to administrators and decision makers who then decide/judge the conditions per their perception. They may also overrule the cyber decisions and send their decision to the physical actuators in the form of warning messages. The cyber system will learn from the outcome of the human decisions through a learning model.

Certain events causing leakages can be very efficiently handled through the human-centric CPS. The same system can also inform authorities to send maintainers and engineers to the concerned areas. To sum up, the decisions made will be sent to the authorities, warning consumers of a potential threat and administrators to control any unwanted event.

3.2.4 Moisture Sensing System Design

3.2.4.1 General Framework

The monitoring system diagram is shown in figures 3.36 and 3.37 with monitoring, data processing, application and decision making blocks. The monitoring block contains the sensors

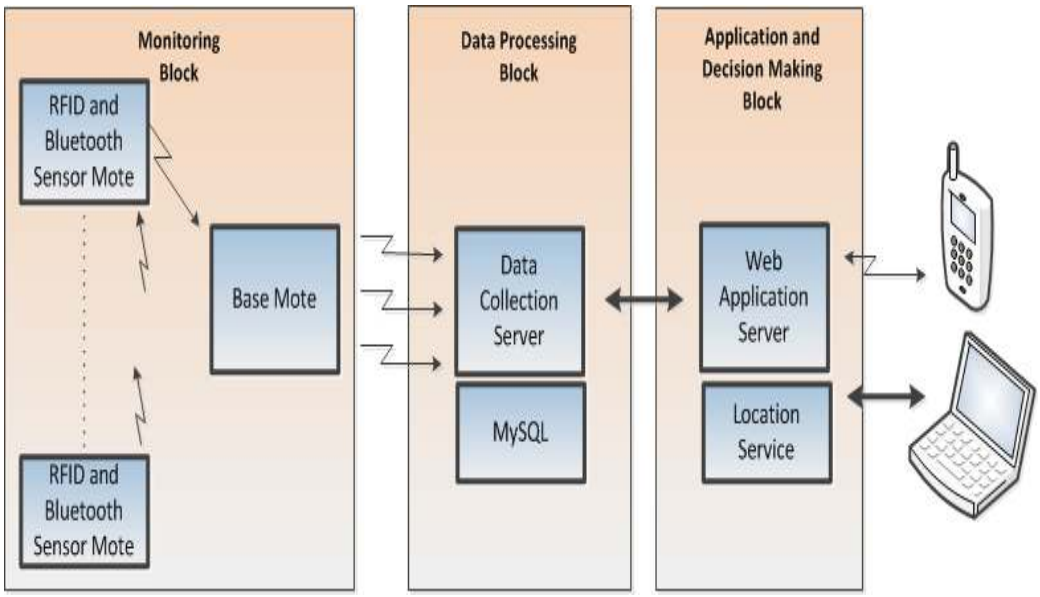


Figure 3.35: System Implementation Framework.

and hardware device mounted on the pipes for monitoring along with its firmware. The data are collected by the monitoring block from all sensors. This information can be global positioning system (GPS) coordinates, pressure, temperature or time stamps with received signal energies. Not much processing speed and computation power is available in the monitoring block, as it must conserve the resources of the system. Hence, basic data processing and signal cleansing are performed at this block before sending the data to the processing block. The monitoring block uses RFID and Bluetooth as the communication methods to transmit data in a multi–hop manner to the processing block. The semi-active RFIDs integrated with pressure, flow and strain sensors can be placed at regular intervals on the pipe infrastructure. The presence of moisture can be detected from the received signal itself by performing energy detection on it. The data is then transmitted to the next hop mote using Bluetooth technology.

In the processing block all the data from the sensors get fused into the data collection server under which MySQL data management runs. At the monitoring block only a small amount of data processing was performed; therefore, at the processing block the collected data is deciphered, recomposed and inserted into the correct position in the MySQL database. Following is the application and decision making block, which is responsible for running event detection, energy detection and decision algorithms. Moreover, it also houses web applications for the users and administrators and a localization service. It also has two software parts, embedded software for monitoring block and the server side software.

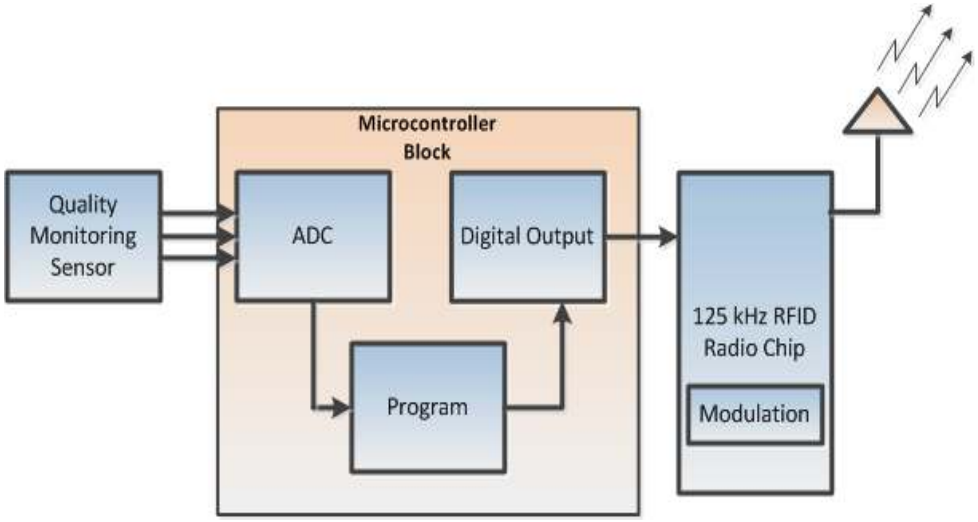


Figure 3.36: RFID Measuring Unit Hardware Block Diagram.

3.2.4.2 Hardware

The hardware block, fig. 3.38, represents a RFID mote comprised of the sensors like pressure, flow and strain. A micro–controller performs the analog–to–digital–conversion (ADC) and temporarily stores it; from here the RFID chipset modulates and sends the readings to the reader.

3.3 Conclusion

Sensing various aspects of water distribution systems and sharing the information to preserve and improve water quality are of major interest. The experimental validation and results for the in-pipe communications using low frequency RFID spectrum range are presented in this chapter. PipeSense, which is an integrated framework for in-pipe water monitoring system based on near field RFID WSNs, was also presented. The current system implementation, design and some feasibility results of PipeSense have been described. A CPS framework for PipeSense architecture and a proposed model for demand pattern and contamination spread for water has also been described.

The concept of water Smart Home has also been proposed to share the information to users in order to control, preserve and improve their lifestyles. The end-user, which can be a household or an authority, is informed each day about the consumption and can decide how to be more efficient. The tight integration of human users is achieved through various decision, control and feedback mechanisms. The CPS cycle and the proposed models for consumption patterns and tap opening/closing events for the water network system have been described. The application of HHMM for modeling the system and their use for detecting events, identifying patterns in the data, predicting events and making decisions was also described. Modeling

results and analysis based on the pseudo-pressure data were presented at the end.

The research work is targeting the quality monitoring for oil and gas applications, mainly in in-pipe monitoring systems, for moisture in LNG/LPG pipes was presented. This study has shown that the RFID system can be used to send information regarding the presence of moisture for quality monitoring of liquefied gas pipes. By using the Cognitive Radio's spectrum sensing technique called Energy Detector, the monitoring decisions can be made upon the basis of the energy detection output from the RFID antenna system. This technique, integrated with other monitoring sensors, can be used in a wireless cyber-physical moisture detection system.

A framework of the feedback human-centric monitoring system for gas quality monitoring in LNG/LPG pipes is also presented. In the proposed system, RFID-active and semi-passive tags are embedded with sensors such as pressure, temperature, flow, strain etc. in collaboration with other wireless technologies. They are able to send information regarding the gas quality and the pipe's infrastructure health. The collaboration of RFIDs with other wireless technologies helps to create a smart human-centric monitoring system capable of providing maintenance, detecting events such as the presence of moisture or strain on pipe's structure, and automatically adjusting the valves' and pumps' properties according to the decisions made by the cyber system.

Chapter 4

Human Centric Vehicular and Urban Sensing

Prolific development in vehicular and sensor technologies has made it possible to integrate numerous sensors in the vehicles. Today's vehicles are already equipped with most of the critical sensors and systems to monitor the functioning and maintenance of the vehicles.

Among various research aspects of wireless sensor networks, urban sensing stands out for its unique characteristic of human-centric sensing and its interaction with human activities. This is especially evident when examining the integration of vehicular and urban sensing to assess the operation, performance and environmental impact of vehicles. Environmental monitoring and urban sensing are seen as the most important areas of research. Urban sensing through integration of technologies is now being seen in the likes of vehicle tracking. This interesting field is still in its early stages.

Due to the environmental pollution caused by the vehicles most of the major cities of the world have developed serious health issues. The need to precisely measure the harmful amounts of pollutants present in vehicle exhausts is becoming a top priority for governments worldwide. EnvironSense [48] is a novel technique based on RFID magnetic induction to measure the air contamination through environmental sensors installed near the vehicle's exhaust and convey the information back to the driver through feedback. The government authorities are also notified through the gantries installed on checkpoints. This will enable detection and prevention of environmental pollution.

Moreover, here the framework design and modeling for an integrated vehicular and human-centric urban sensing system is presented. The goal is to understand the impact of vehicles and human activities on the surrounding environment. This is achieved through a seamless integration of the human aspect into vehicular and urban sensing, going beyond the traditional human-in-the-loop sampling methodologies. The framework design of this system allows humans to take certain decisions or actions and gather feedback to understand the effect of those actions. Based on this framework a prototype BusSense [48, 115, 137] system has been developed for the university campus shuttle buses. The system architecture and implementation is also described. The tools for modeling the system based on Hidden Markov

Models (HMM) are also presented. These models are used for detecting events and identifying patterns in the data. The modeling results and analysis based on the experimental data were also presented.

Vehicles constitute a large part of our transport system. A large number of vehicles consuming fossil fuels also means huge amount of pollution emitted by them directly into the environment. Due to the threat it poses to the already damaged ozone layer and the environment, the researchers all around the world are contributing to develop more environmental friendly systems for vehicles and control the pollutants produced by the existing vehicles by monitoring them. Moreover, this information from the vehicles can also be conveyed to the authorities' in-order to constitute standards and laws governing the emission of such hazardous toxins in the environment. Newly arrived technologies and sensor has made this task comparatively easy. Contemporary systems mostly developed by universities for this

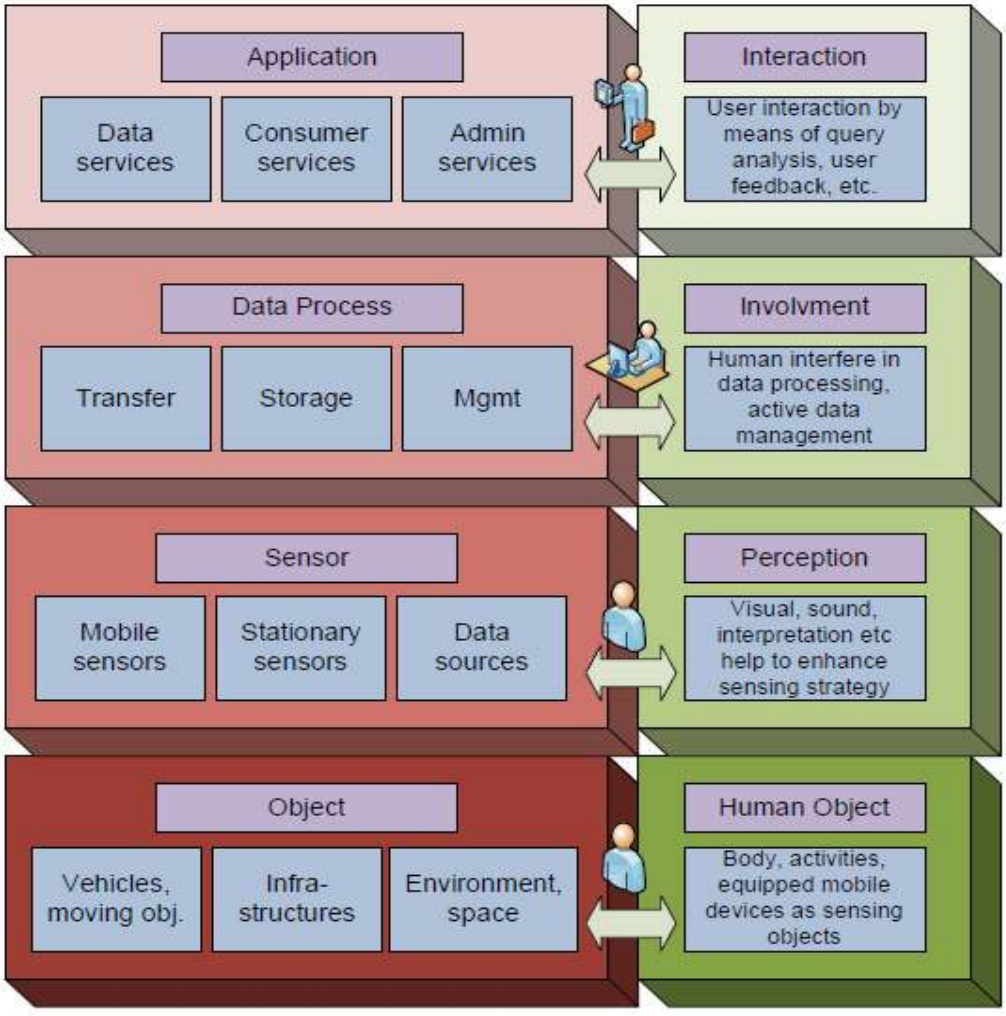


Figure 4.1: Human-Centric Vehicular Urban Sensing Architecture.

purpose are not available in the consumer markets and are still in there prototypes. Moreover, the technology used is either expensive or bulky to be used in such system. We have proposed a cheap and efficient RFID based vehicle and urban sensing system based on our findings in chapter 2.

4.1 Vehicular Urban Sensing architecture

The architecture of the human-centric vehicular urban sensing system is presented in this section. A traditional four-tiered architecture is proposed, as shown in fig. 4.1. Each tier consists of two parts: the vehicular sensing part (shown on the left) and the urban sensing part (shown on the right). The two parts are connected by a set of human activities and factors, which are also identified.

Object – The underlying purpose of urban sensing systems is similar to that of traditional wireless sensor networks, i.e., to sense various objects. In a vehicular sensing context, objects include moving vehicles and the surrounding environment. In human-centric urban sensing, objects often include the human body, human activities, and mobile devices used by the public. The human objects can be used to collect data about nearby vehicles (or the vehicle in which the human object is traveling) and their surrounding environment.

Sensor – The second tier of the architecture consists of sensors, or the sensing and data collection/acquisition devices. In an urban space, sensors are categorized into mobile and stationary sensors. Mobile sensors are normally embedded in vehicles, while stationary sensors are used in infrastructure monitoring applications. Human-centric urban sensing includes human perceptions such as visual, sound and human interpretation as a bridge between human and urban spaces. In an integrated framework, human perceptions can be used to augment the traditional sensing modes and interpret the sensed data, resulting in better sensing decisions.

Data Process – The major function of the third tier is to process the sensed data. This includes data transmission at the network layer, and storage and database management on the server side. Human involvement can be in the form of additional inputs in the data processing, as well as active data management.

Application – The application tier forms the topmost tier in the urban sensing system architecture. It includes various services for the administration of the system as well as for normal users. Unlike traditional wireless sensor networks, in human-centric urban sensing, people closely interact with the applications through various channels such as web query, active feedback, etc. The design of the application tier should account for such feedback. It must be pointed out that due to human interaction/involvement, the architecture needs components that can extract human inputs and interpret them.

4.2 System Design and Implementation

4.2.1 System Architecture

BusSense consists of three major components: in-vehicle unit (IVU), data hub, and service hub. The BusSense general framework is designed to connect and control the three components through software and hardware. The in-vehicle unit consists of the sensing module and the associated embedded software. It gathers information from all the available sensors. In the current implementation, the available information includes environmental pollution data from gas sensors and data from the GPS receiver, such as the UTC time stamp, location coordinates and vehicle speed. The in-vehicle unit, being an embedded device, is limited in terms of computational and energy resources. Thus, only minimal pre-processing of the data is done onboard before it is transmitted to the fusion center. The need for real-time data streams, including location information, prevents us from buffering the data in the in-vehicle unit. The in-vehicle unit currently uses GPRS to transmit data to the fusion center and for receiving administrative commands and software updates. GPRS provides a reliable communication channel with data transmission rates of 56-114 kbps over the GSM network, which satisfies the current system requirements. The data hub acts as the centralized data server to handle the incoming data packets from all the active in-vehicle units. In the BusSense

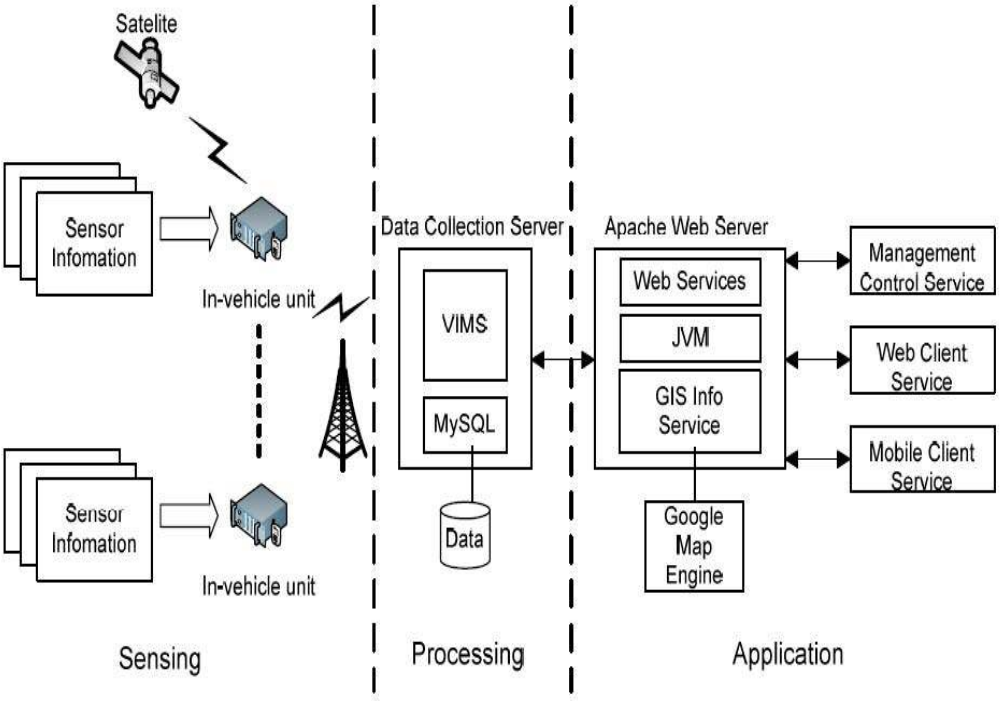


Figure 4.2: BusSense System Architecture.

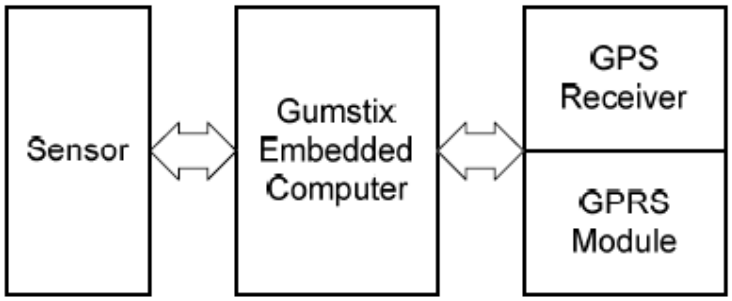


Figure 4.3: The In-Vehicle Unit (IVU).

general framework, the data hub includes two major components. In the lower layer, MySQL is implemented as the sole database management system. It manages the collected vehicular sensing data and responds to queries passed from the service hub. On top of the database management system is the BusSense Management Service. This acts as a data processing service for refining raw data received from the sensing modules. This service accepts raw data and performs decoding, refining, and recomposing before inserting the data at its appropriate position in the MySQL database.

The service hub is a mixed structure that includes the central Apache web server supported services and other more dynamic client services. There are three types of client services: the Management Control Service, the Web Client Service and the Mobile Client Service. These client services have been built independent of each other and serve different purposes and user groups. Management Control Service is the administrative tool provided for the BusSense management team. It consists of the web-based administration panel, which provides functions such as database management, in-vehicle unit management and historic data query. It also includes back-end scripts that support queries to MySQL database and direct communication to the sensing modules. Web Client Service is the main web interface to the normal users who use BusSense through a web browser to track real-time locations of the campus shuttle buses on a map. Meanwhile, the Mobile Client Service provides a more convenient and friendly channel for the end users – the passengers - a lightweight and intuitive method to access the service through their mobile phones. Details of the described BusSense general framework are shown in Figure 4.2.

4.2.2 Hardware Platform

The hardware platform in the BusSense general framework refers mainly to the in-vehicle unit. As shown in Figure 4.3, the sensing module consists of three parts connected together to form the hardware platform. The Gumstix embedded computer [70] is used to control data acquisition from the exhaust gas sensors. It also provides a connection to the GPS and the communication module. In the BusSense implementation, Telit GM-862-GPS [122] was chosen as an integrated solution for both the GPS receiver and the GPRS communication

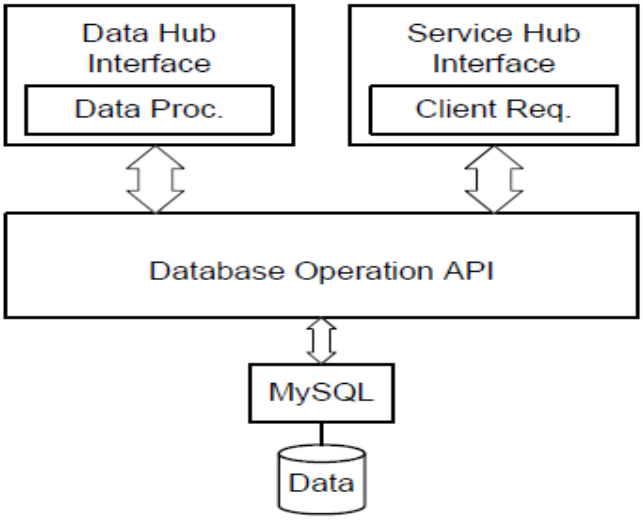


Figure 4.4: Software Architecture.

module. It is equipped with a 20-channel SIRF GPS receiver, which provides quick start and high accuracy location coordinates. In the current BusSense implementation, the following gas sensors, manufactured by Figaro [138], are installed.

4.2.3 Software Architecture

BusSense software architecture consists of two sections. First is the embedded software system on the in-vehicle unit. The other section is the server side software supporting the data hub and the service hub along with all the supported services. The design of on-board embedded software for the in-vehicle unit is fairly straightforward. The embedded Linux core controls the data acquisition from the gas sensors. GPS data acquisition and the GPRS data transmission are managed by a Perl script.

Server side software is responsible for handling both the incoming sensed data from the in-vehicle units and the various client requests from the service hub. A middle layer was built to cover the lower MySQL database management system and the data storage. It is shown in Figure 4.4 as Database Operation API. These APIs provide the frequently used database operation functions, such as the creation of data tables and manipulation of each data record. Database Operation API processes requests from two components: the Data Hub Interface (DHI) and the Service Hub Interface (SHI), as shown in Figure 4.4. DHI contains functions for raw data processing, while SHI is responsible for handling requests coming from the end users.

Figure 4.5: Snapshot of the BusSense web portal.

4.2.4 System Implementation

A prototype system called BusSense was developed, based on a tight integration of human-centric urban sensing and vehicular sensing, to understand the environmental impact of vehicles. The system is being implemented for the university campus shuttle bus service. The prototype BusSense is based on an embedded mobile sensing platform, making it a low-cost and easily deployable solution. It allows us to monitor the campus shuttle transportation system and the surrounding environment through geographical location information, environmental sensing data and OBD-II information. The in-vehicle unit collects the vehicle's real-time information, including its geographical location, speed, altitude, pollution data and other OBD-II information. This data is transferred back to the central data service, where it is stored and analyzed.

The Google Map Engine was used for displaying the real-time geographic locations of the vehicles (or the sensing modules). It provides multiple options for the map viewing mode and convenient map control. It also provides high resolution maps with detailed street views. JVM is used to support the development of various web services, such as the interfaces for various client services, and the administrative panel. A snapshot of the BusSense campus shuttle bus tracking web portal is shown in Figure 4.5.

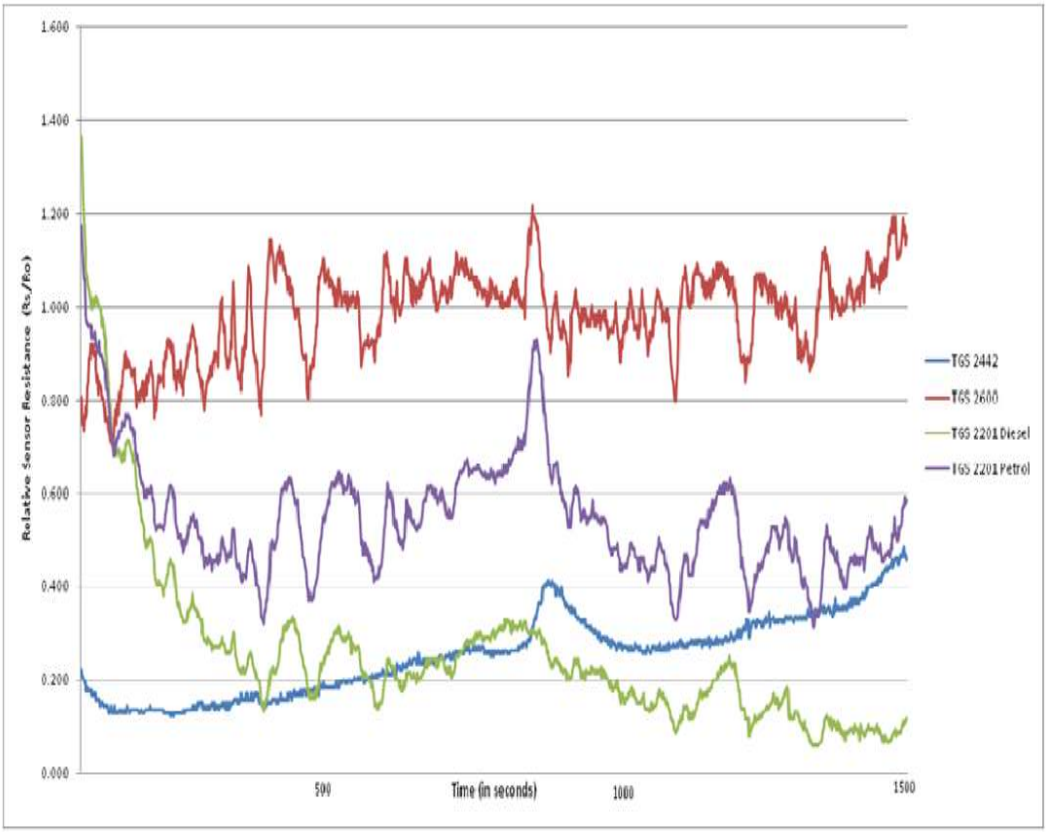


Figure 4.6: Sensor Data Measurements.

Figure 4.6 shows a plot of the acquired gas sensor data during a test run, lasting about 1500 seconds, to detect pollutant gases in the campus environment. The plot shows relative sensor resistance (RS/R0) vs. time in seconds. A drop in the sensor resistance indicates increased pollution levels. TGS 2600 and 2201 sensor readings show similar patterns, while TGS 2442 readings show little variability indicating low levels of carbon monoxide. It was intended to correlate this data with vehicle speed and other parameters to understand the environmental impact of specific driving patterns.

4.3 Integrated Framework for Vehicular and Urban Sensing

An integrated framework for vehicular and human-centric urban sensing was presented in [115]. The proposed framework is a traditional four-tiered architecture proposed for vehicular sensing (fig. 4.7).

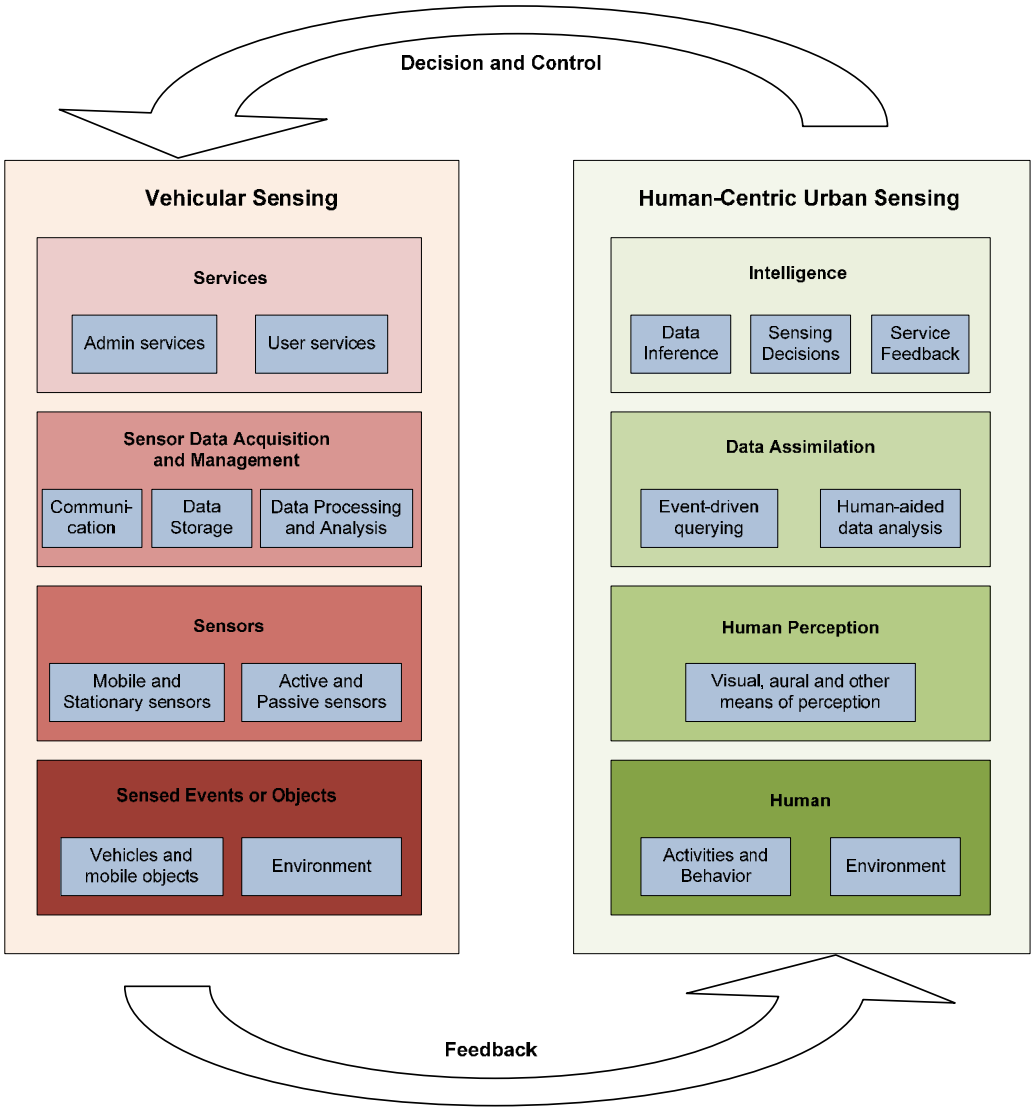


Figure 4.7: Integrated Framework for Vehicular and Human-Centric Urban Sensing.

Its tight integration with human-centric urban sensing is achieved through decision, control and feedback mechanisms involving humans. The framework architecture is composed of two parts: Vehicular Sensing and Human-Centric Urban Sensing.

4.3.1 Vehicle Sensing Architecture

Sensed events or Objects - The underlying purpose of vehicular sensing is similar to that of traditional sensor networks, i.e., to sense various events and objects. In the vehicular sensing context, objects include vehicles and other mobile objects, along with their surrounding environment.

Sensors - The second tier consists of the sensors used to sense the various physical parameters and events.

Sensor Data Acquisition and Management - This tier deals with acquiring, processing and managing the sensed data. This involves communicating the data from the sensing unit(s) to a central location or data server.

Services - After the sensed data has been processed, a number of services enable better visualization of the data. These services can be categorized as administrative services and user services.

4.3.2 Human-Centric Urban Sensing

The term human-centric urban sensing has typically been used in the context of human-in-the-loop sampling but in the proposed framework, human-centric urban sensing refers to human involvement in data assimilation, processing, and inference, as well as decision, control and feedback processes.

Human - The human element refers to human activities and behavior and their effect on the surrounding environment. These are the features of interest in a human-centric urban sensing context. The integration with vehicular sensing would result in monitoring activities or events such as driving patterns, traffic hot-spots and pollution levels.

Human Perception - Human-centric urban sensing introduces human perception as an

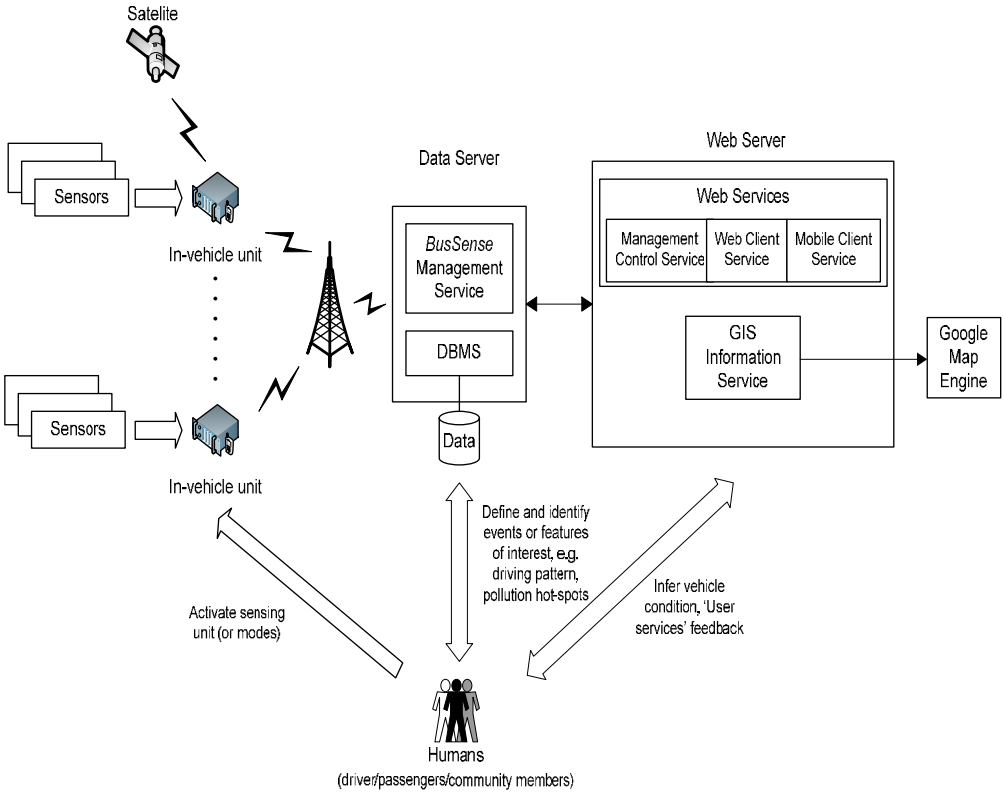


Figure 4.8: BusSense System Design.

additional sensing modality that will augment the measurements obtained from the various sensors. Human perception can be in form of visual (eyes), aural (ears), or smell (nose) senses, etc. In addition, these senses can be involved in the sensing decision to activate certain sensors or sensing modalities when an event of interest is perceived as imminent.

Data Assimilation - Traditionally, data management involves storing the data in a database and then querying the database via the request-reply paradigm. However, data is a dynamic entity, which changes rapidly and is updated by many processes in a distributed environment. Thus, in addition to the request-reply paradigm, an event-driven model is needed where applications are notified when events of interest are generated in the data. Visualization and analysis of the sensed data through human intervention could point to events which hitherto were not identified. For example, it is known that pollutant emission levels are related to vehicle condition and parameters such as speed [139]. Correlating pollution levels and terrain features (such as altitude or gradient) can reveal new patterns of interest.

Intelligence - The data assimilation processes described above enable us to identify and infer various events and recognize new patterns and the impact of such events. For example, driving patterns resulting in lower pollution levels can be inferred and used in formulating new driving guidelines and pollution standards. Based on the data gathered, decisions can be made about when, where and which sensing modes should be activated. These decisions could also be based on various data quality metrics such as relevancy, coverage, timeliness, etc. In addition, users' experiences with the various services will enable them to provide feedback and suggest improvements to existing services, request new services, etc.

4.3.3 BusSense System Design

A prototype system [115], based on the framework proposed in previous section, has been developed to understand and find ways to mitigate the impact of vehicles and human activities on the environment. The BusSense system design, illustrated in fig. 4.8, consists of the in-vehicle unit (IVU), the data hub, the service hub and the human element. This system is designed such that the first three components can connect and interact with each other and with the human element via software and hardware interfaces.

4.3.3.1 In-Vehicle Unit

The in-vehicle unit consists of the sensing module and the associated embedded software. It gathers information from the available sensors. IVU does minimal pre-processing of the data on-board before it is transmitted to the data server or fusion center via a suitable communication link.

4.3.3.2 Data Hub

The data hub acts as the centralized data server to handle incoming data packets from all the active IVUs. It includes two major components. At the lower level, database management

system (DBMS) is implemented using MySQL. It manages the gathered sensing data and responds to queries passed from the service hub. On top of the database management system is the BusSense Management Service, which acts as a data processing service for refining raw data received from the sensing modules (or IVUs). This service accepts raw data and performs decoding, refining, and recomposing before inserting the data at its appropriate position in the database.

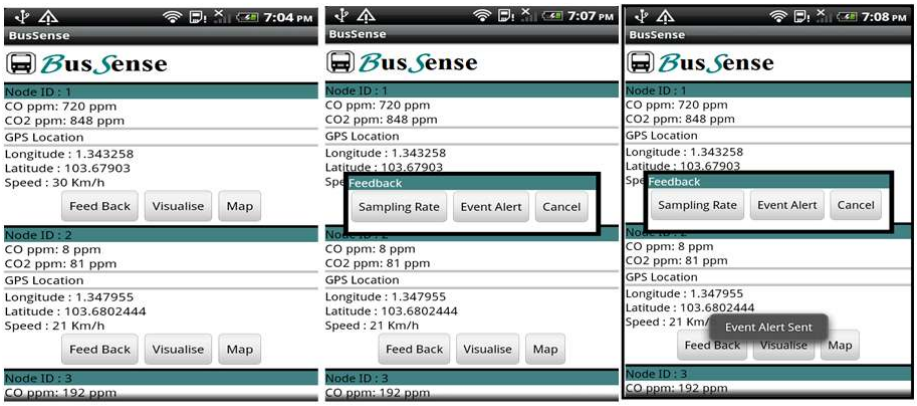
4.3.3.3 Service Hub

The service hub is a mixed structure consisting of the central web server supported services and other more dynamic client services. The services can be categorized as administrative services and user services. The administrative service, labeled as the Management Control Service, is the administrative tool provided for the BusSense management team. It consists of the web-based administration panel, which provides functions such as database management, in-vehicle unit management and historic data query. It also includes back-end scripts which support queries to MySQL database and direct communication to the sensing modules. In addition, some services within the Management Control Service are accessible to the participants of the BusSense system. These allow the participants to define events or features of interest. User services include the Web Client Service and the Mobile Client Service. Web Client Service is the main web interface to the users (or community members) who access BusSense system information through a web browser. This service interacts with the GIS information service and the Google map engine to allow users to track real-time locations of the campus shuttle buses on a map, along with the estimated arrival times at the nearest bus stop. Mobile Client Service provides an efficient and faster interface for mobile users such as pedestrians. Java Virtual Machine (JVM) is used to support the development of various web services such as the interfaces for client services and the administrative panel.

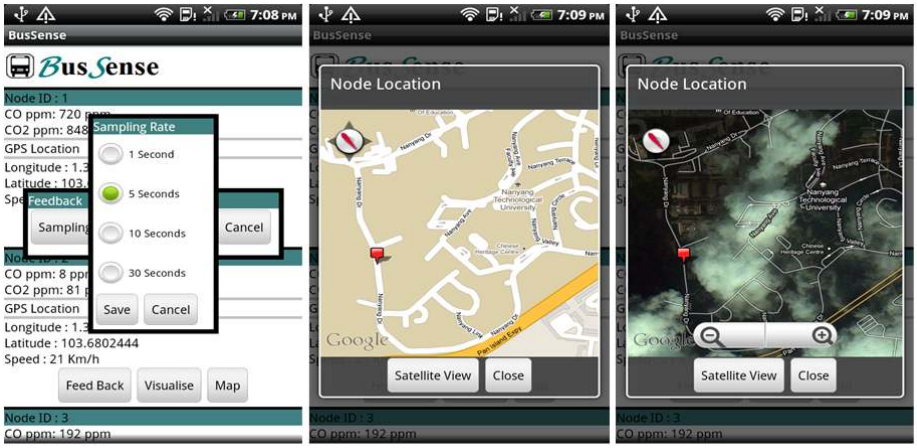
4.3.3.4 Human Element

The human element represents the system users (or community members) and the administrative users. The BusSense system design incorporates decision, control and feedback mechanisms for the human elements to understand and gain more from the system. Users who participate in the system implementation will have the ability to define features or patterns of interest to search for in the sensed data. Participating users who install the IVU in the vehicles they drive will have the ability to activate different sensors based on their perception. The user services and visualization would allow users to better understand the relationship between driving habits, vehicle condition and pollution levels. This would allow users to take action in terms of altering their driving habits, servicing their vehicles, etc., and to observe the effect of these actions. In addition, users will be able to submit their feedback about the web services and suggest new services or improvements to existing services. Two methods were utilized to develop a feedback and control system with humans in the loop

approach:



(a)



(b)

Figure 4.9: (a) Android Application for Human Feedback, (b): Android setting sampling rate and Map views.

4.3.3.4.1 Android Application

Android programming is utilized to make a feedback application used by the driver and the users of the system. Through this application the node IDs and their corresponding CO and CO2 data and their respective locations will be visible in real time to the driver and the users. This application (snapshots were shown in fig. 4.9(a) and 4.9(b)) will enable the driver to report an anomaly or an event to the authorities and the system administrators by just pressing the “Feedback” and then “Event Alert” buttons on the application shown in the figures. The user or driver can also change the sampling frequency of the sensors by selecting one of the default values from the list that appears after pressing the “Sampling Rate” button. This will send a command to the base server, which will trigger another command to the sensing platform to alter the sampling rates. The sensed data can also be visualized by pressing the

"Visualize" button. Additionally, the users can view the current GPS locations of the moving nodes. This will help locate the place in case of an event.

4.3.3.4.2 Web-portal

Another method utilized to communicate with users and the administrators, and to get feedback from the customers and normal users of the system is the web portal. This web portal will enable the common people to leave feedback through a user-friendly interactive system [115]. The web portal, in addition to giving us feedback, will also be used to provide information about the approaching buses and times for the next bus arrival.

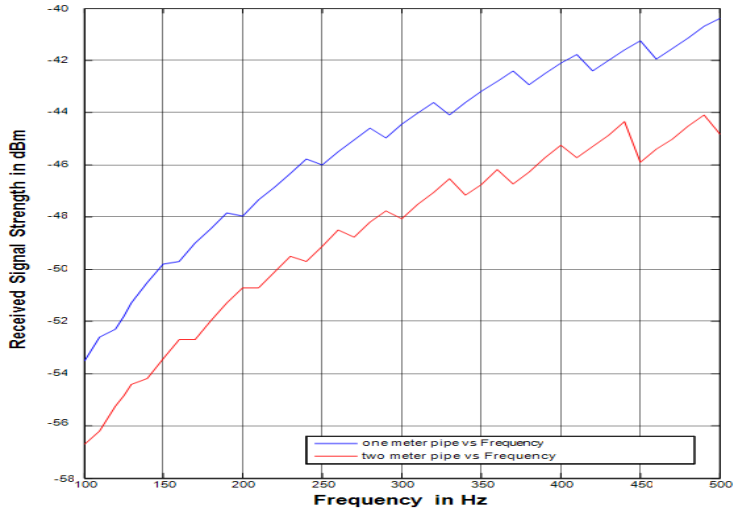


Figure 4.10: Comparison of received signals through the metal exhaust pipe.

4.3.4 Experimental Set-up

The experiment was performed in the lab environment using JIS G3314 (SA1D) standard Aluminized steel pipe with 22.2 mm diameter and 1.2 mm thickness. The experimental set-up includes:

- HP 8593E Spectrum Analyzer (as Receiver).
- Agilent 8648B Signal Generator (as Transmitter).
- EN1057-X European and Singapore water distribution Standard Copper pipe.
- Two SMA connectors.

- Two coil antennas (inserted in the pipe).

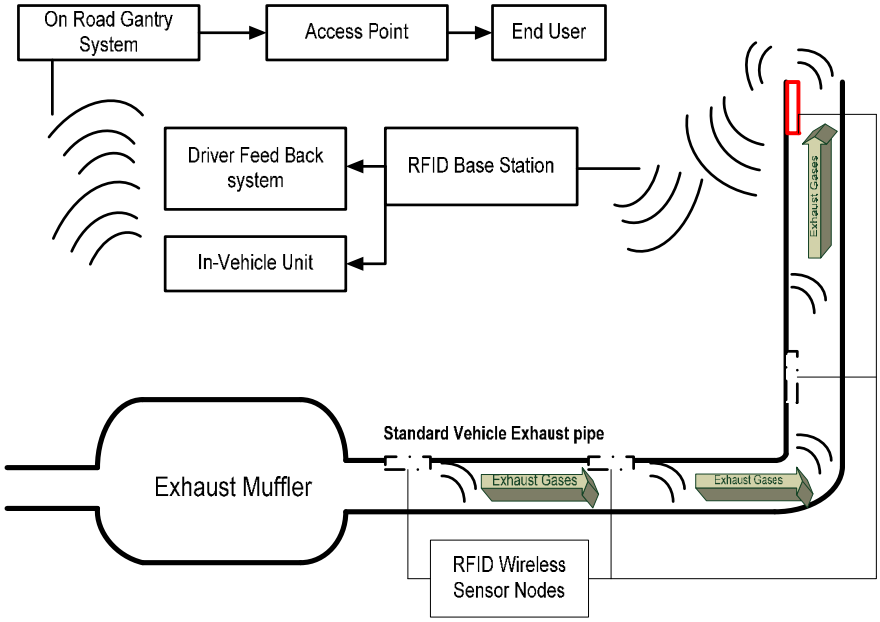


Figure 4.11: RFID system illustration.

For the experiment two lengths of pipes were considered, one meter and a two meter bent at 90º so as to measure the effect of induction through the joints and elbows of the piping systems. The transmitter (frequency generator) was set at a constant 22 dBm output level, which is merely a 0.158W output power level or 2.815 V. The system performance will be much better using a conventional power level of 4 watts. Fig. 4.10 shows the comparison of dBm signal strength for one and two meter exhaust pipes. The results reveal the possibility of RFID-based communication and monitoring systems specific to this kind of application.

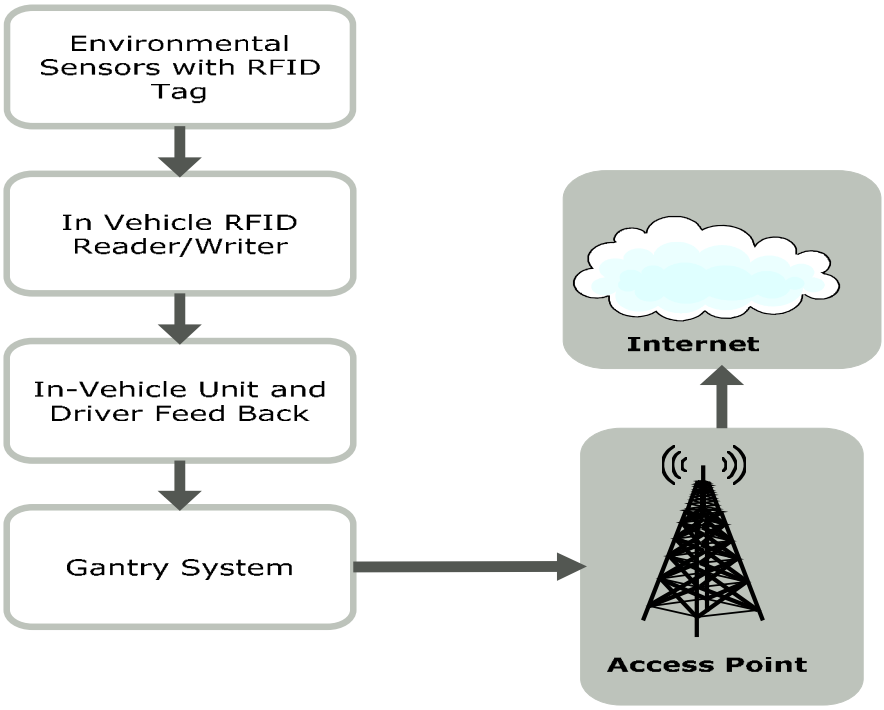


Figure 4.12: Proposed system illustration.

In RFID systems, tags are embedded in objects varying in shape and material. A data transfer between a tag and reader is carried out by backscattering electromagnetic waves. It is the antenna that determines the performance of a tag stuck to a specific object [47]. Therefore, it must be designed and optimized for the materials and locations of objects it will be attached to. One of the biggest challenges is to design a tag antenna capable of being stuck to metals. Examples are planar inverted-F antenna (PIFA) [47] and a novel antenna design for passive RFID [140]. Semi-passive RFID tags are becoming popular for applications requiring more computation power and storage.

A semi passive-RFID tag wireless sensor network was proposed with support batteries to power up the sensors, which can be deployed inside standard exhaust metal pipes. This network can (without affecting the other radio transmissions and cellular networks) monitor the contaminations in air and around the vehicle and send this information in a multi-hop manner. A diagram illustrating the proposed system is given in the fig. 4.11. Fig. 4.12 illustrates the proposed system. It will consist of the following main blocks:

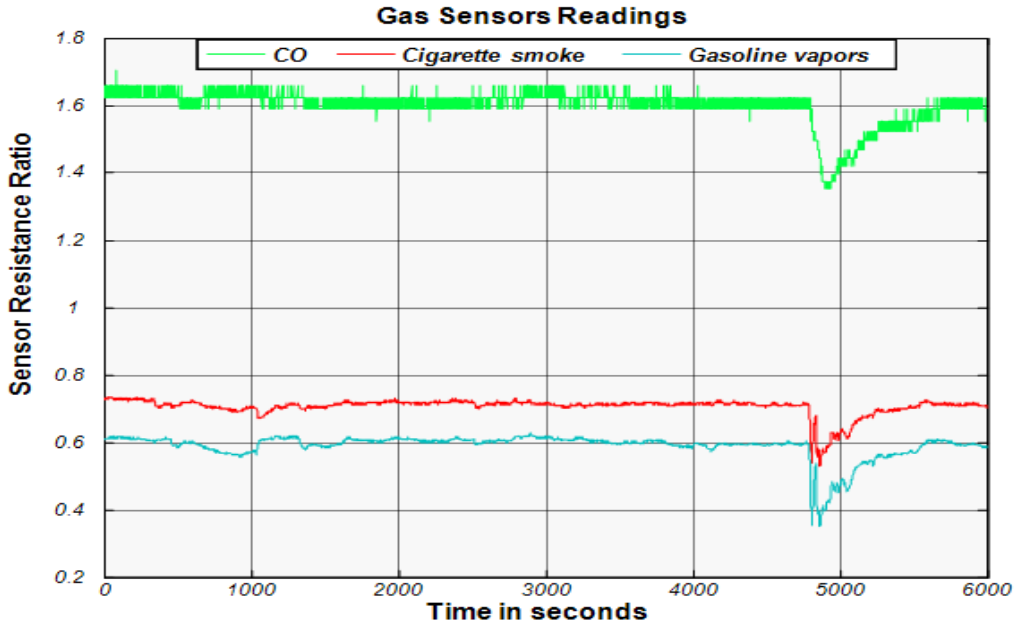


Figure 4.13: Environmental gas sensors resistance ratio with respect to time.

- Sensors.
- RFID Reader/Writer.
- In-Vehicle Unit.
- Gantry System.
- Access Point.

The sensor block senses the gases at the exhaust of the vehicle and sends this information through the RFID multi-hop system to the base station, which works on the same principle. This last node forwards the sensed information to the in-vehicle RFID read/write block that performs statistics and storage operations on the available data. This processed information is then relayed toward the in-vehicle unit block that shows the information to the driver in real time and also assists the driver in taking any pre-emptive action. The in-vehicle unit will also broadcast the data to the transportation officials through the gantry for emissions monitoring. This same data may also be made available through the Internet web portal by connecting to any available access point.

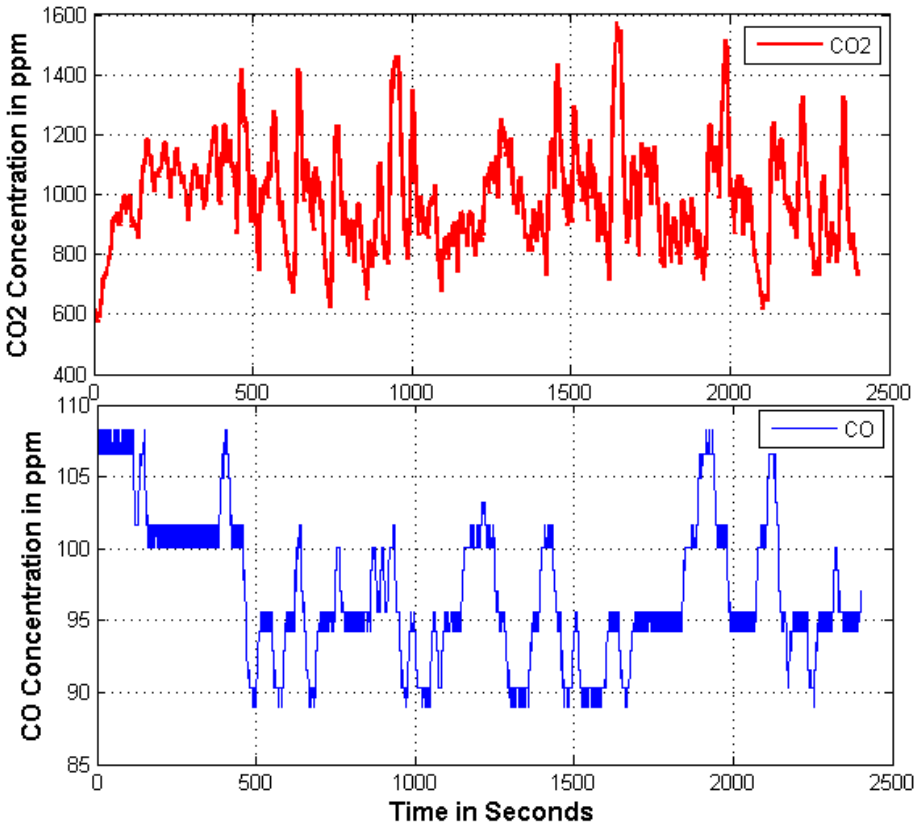


Figure 4.14: Pollution data (CO and CO_2) from Experimental run.

4.3.4.1 Pollution/gas Sensors

The gas sensors manufactured by Figaro [138] were used in the current proposed system. TGS 2201 sensor is used for detection of gasoline and diesel exhaust gases. The major components of diesel and gasoline exhaust are nitrogen oxide, carbon monoxide, hydrogen and incombustible hydrocarbons. TGS 2442 sensor is used to detect carbon monoxide, as it is necessary to detect this poisonous gas separately. TGS 2600 sensor is used to detect air contaminants such as hydrogen and carbon monoxide, present in cigarette smoke. TGS 2600 was chosen due to its sensitivity to hydrogen, which is a good indicator of air pollution. These sensors are miniature in size, consume low power and have a long life.

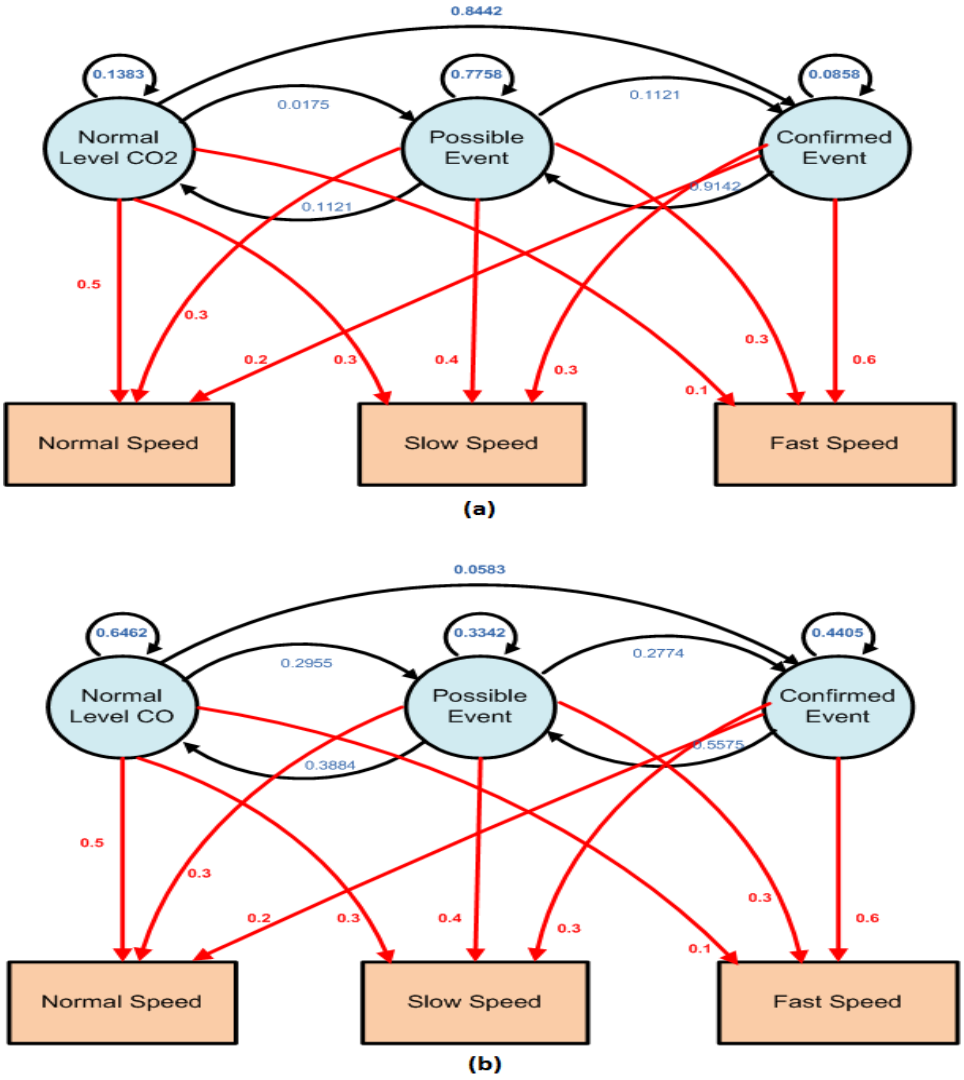


Figure 4.15: HMMs based on Pollution levels, (a) CO_2 (b) CO.

Fig. 4.14 shows a plot of the acquired gas sensor data during a test run lasting 6000 seconds, to detect pollutant gases in the campus environment. The plot shows the logarithmic values of the relative sensor resistance (R_S/R_0) against time in seconds. The sensor readings remain approximately steady for about 4800 seconds. A sharp drop in the relative sensor resistance around this time indicates relatively higher pollution levels. This is during the lunch hour, when considerably more vehicles were moving around the campus.

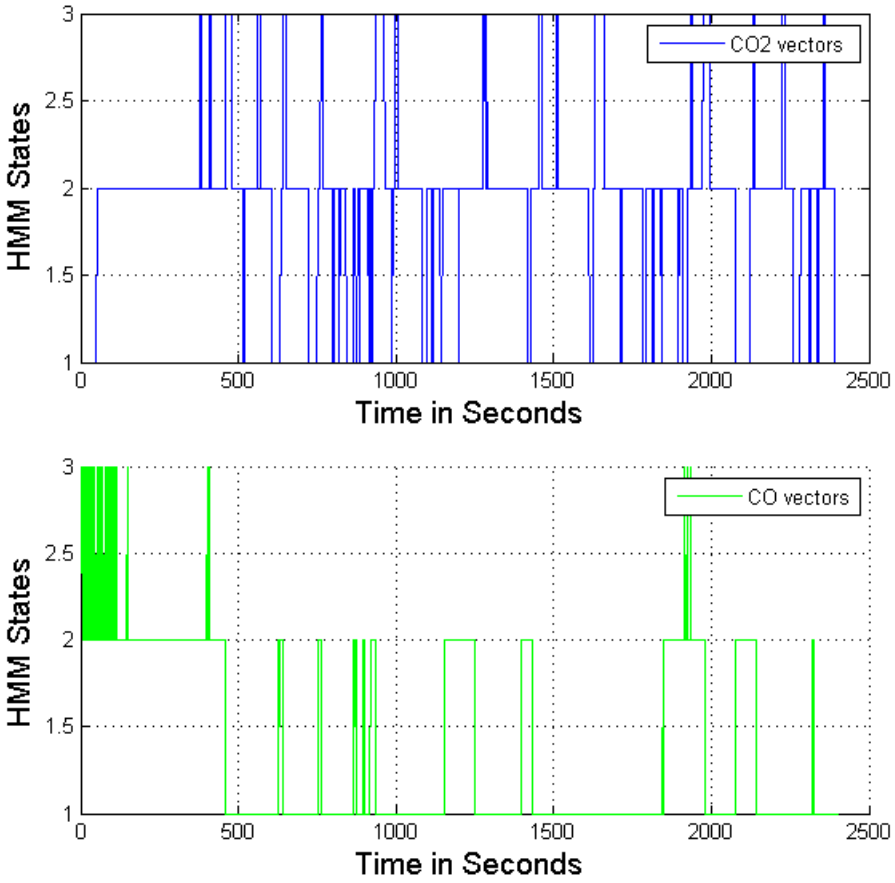


Figure 4.16: HMM states for pollution data (CO and CO_2).

4.3.5 Event Detection and Experimental Analysis

HMMs can typically address three types of problems: (i) evaluate the probability of a sequence of states given a specific model, (ii) determine the most likely evolution of an abnormal activity (state sequence) represented by the HMM, and (iii) estimate the HMM parameters that produce the best representation of the most likely state sequence. In this context an event can be a high level of CO and/or CO_2 shown in fig. 4.15. To solve the determination problem (ii), a model is needed that can be used to distinguish between suspicious and real instances of abnormal activities or events. In doing so, the model must be able to detect potential abnormal activities, efficiently analyze large amounts of data, and generate hypotheses with only partial and imperfect information. The model is a transition-based model that identifies an event, comparing the predicted outputs with the real data sets from different nodes in the network. The expectation-maximization (EM) algorithm is used for HMM parameter training [131] and performs hypothesis testing using the maximum likelihood (ML) principles to rate the data samples as either normal, a possible event, or a confirmed event during the recognition phase

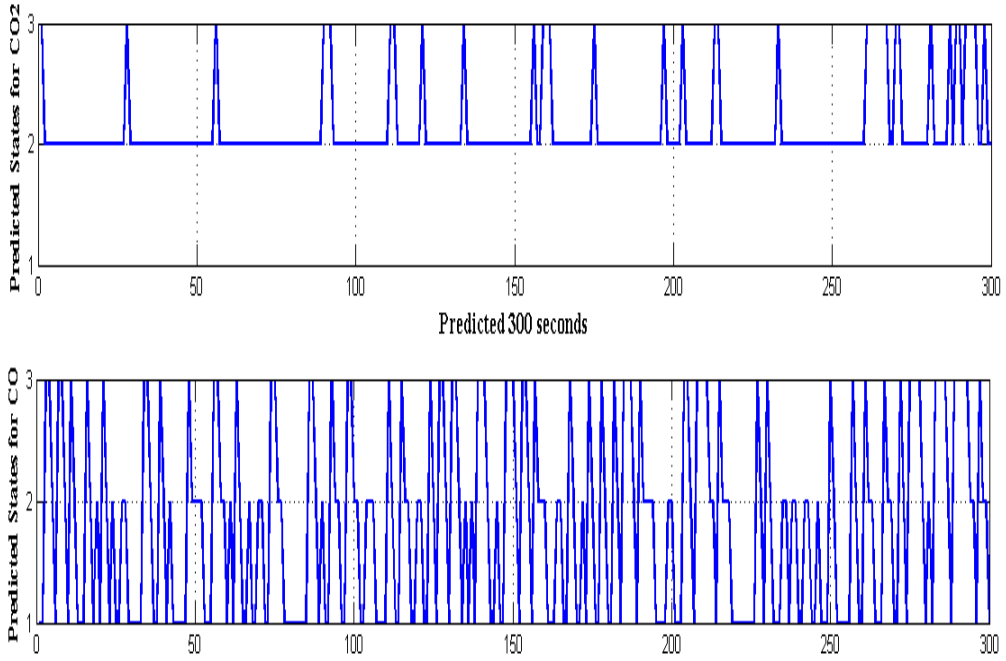


Figure 4.17: Predicted states for CO and CO_2 for 300 seconds based on HMMs.

of the algorithm. The pollution data from the gas sensors (CO and CO_2) is used for training the models. The pollution data collected during one of the experimental runs around the campus lasting close to 2500 seconds are shown in fig. 4.16. The resulting HMMs, after parameter training, are shown in fig. 4.15.

The system is considered to be in one of three distinct states at any point of time: State 1, normal level; State 2, possible event; and State 3, confirmed event. These states can be the result of one or all of the three output possibilities based on the speeding behavior of the vehicle, namely, normal speed (30-40 km/hr), low speed (0-30 km/hr) and high speed (>40 km/hr). The system undergoes a change of state (or possibly stays in the same state) according to the set of transition probabilities associated with the state. The initial set of transition probabilities is derived from the experimental pollution data. The initial set of emission probabilities is assigned logical values, based on the results of correlating the vehicle's speed with the emitted CO and CO_2 levels. The quantized pollution data, using three threshold levels for CO and CO_2 indicating the distinct states, are shown in fig. 4.16. It was assumed that the events are characterized by one of the above three states. Next, the matrix of transition and emission probabilities was obtained. These probabilities were estimated based on the data from one of the test runs for the purpose of model evaluation. The emission matrix is initialized based on the following assumptions: for a vehicle running at normal speed there is a 50% chance that the CO and CO_2 emission levels will be normal. Similarly, for a vehicle at low speed there is a 40% chance that its emission levels will be above normal, and for a vehicle at

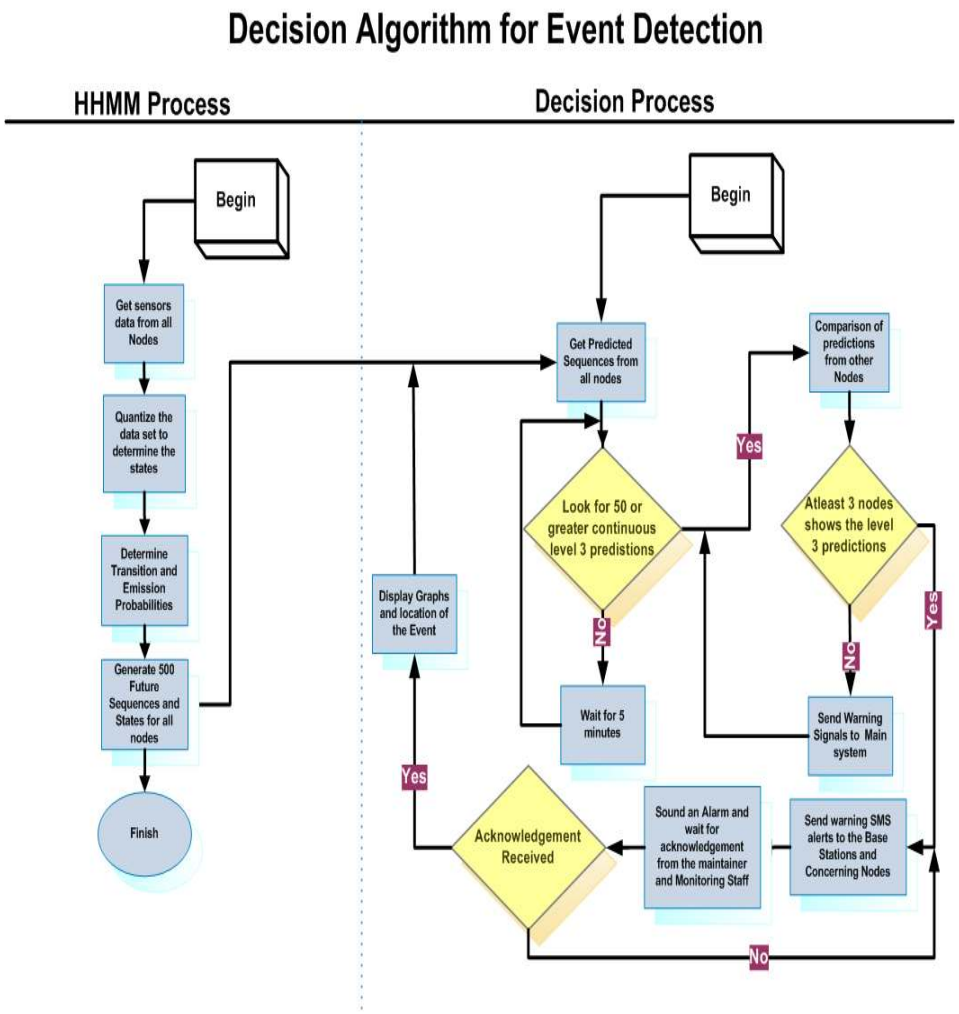


Figure 4.18: HMM and Decision algorithm flow.

high speed there is a 60% chance that its emission levels will be high. This HMM can be utilized to understand the need for enforcing strict speed limits in the campus area and determining ways to improve the campus environment and the need to map the pollution levels around the campus area in the future. After collecting a sufficiently large data set, the model parameters such as transition, emission and initial probabilities can be tuned so as to maximize the system's event detection performance. Given these models, forward HMM algorithm was used to generate the predicted states and concentration signal sequences, which are illustrated in fig. 4.15. The predictions were made after adjusting the transition and emission probabilities over 500 iterations. These HMM-based predictions for 300 seconds of data from each node are given to a decision algorithm, illustrated in fig. 4.17. The decision algorithm fig. 4.18, searches for 50 or more continuous state 3 predictions in the predicted sequence for each node and compares them with the other nodes in the region. If three or more nodes show similar

predicted behavior, then an SMS alert is sent to the central server and an alarm signal is sent to the concerned nodes, which in turn sound an alarm to the driver. The process then waits for acknowledgement from the driver and the monitoring staff at the central server. After receiving the acknowledgements, the system provides visualization of the event in the form of graphs, along with the geographic location of the event.

Next some results were presented from the correlation analysis of the experimental pollution data with vehicle speed. In fig. 4.19 a scatter plot shows the mean value of the CO_2 emission level as a function of the vehicle speed. An approximate degree 3 curve-fit indicates the non-linear relationship between the two parameters. We aim to use the gas sensor and vehicular data collected by the IVU to understand the environmental impact of specific driving patterns. The CO sensor readings show little variability, indicating low levels of CO and therefore are not shown here.

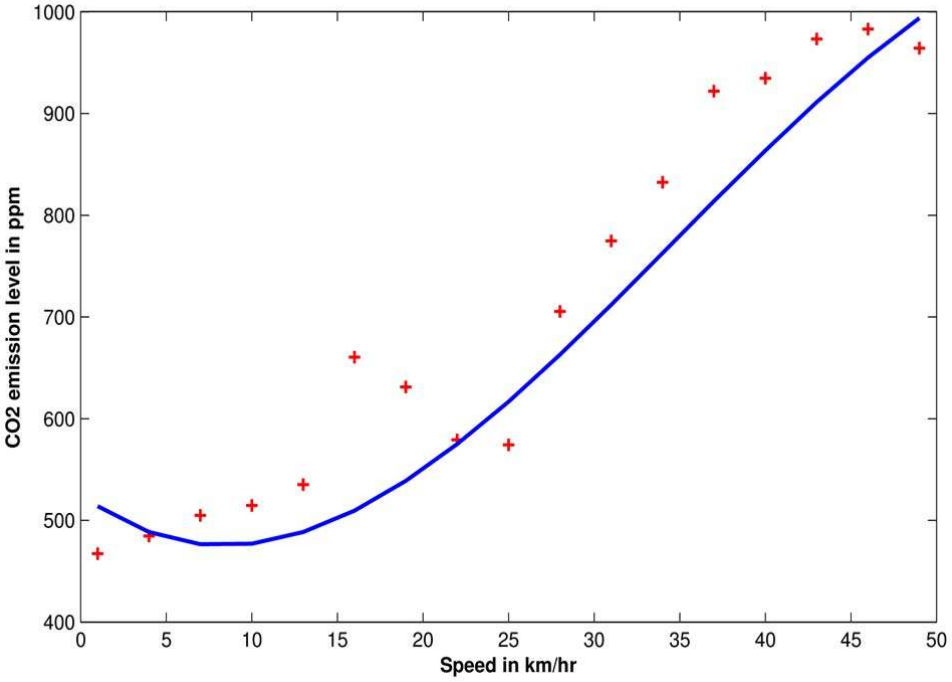


Figure 4.19: Correlation between CO_2 emissions with speed.

4.4 Conclusion

An integrated framework for vehicular and urban sensing was presented within the context of human-centric urban sensing. Sensing aspects of human activities and their interaction with and impact on the surrounding environment is of major interest. The design of BusSense, a prototype campus vehicle information system, was described. Details of the software architecture and the hardware platform were presented.

The application of HMMs was described for modeling the system and their use for detecting events, identifying patterns in the data and predicting events. The modeling results and analysis based on the experimental data were also presented.

The monitoring of hazardous pollutants emitting from the vehicles is also critical for the environmental safety. Vehicles emit tremendous amounts of toxins harmful to humanity in general and the driver specifically. EnvironSense, a novel technique to measure these contaminations through a wireless network feedback system inside the vehicles, was also introduced. The experimental results show the feasibility of such a system, using magnetic induction and RFIDs.

Chapter 5

RFID and WSN Simulation Platform for Energy Efficiencies

Advances in wireless, RFID and sensor technologies have made it possible to have a plethora of assorted WSN nodes that can be used in coordination in numerous applications. Experimenting with new MAC algorithms using countless functions on a real sensor network to obtain energy efficiency is both time-consuming and expensive, especially when these diverse node platforms are deployed in one application. Generally, simulators are used to approximate the performance of MAC protocols. Out of the numerous simulators available, none can simulate the energy efficiency given various types of nodes and environments in one application. Hence, there is a need for a simulation platform for a mixed deployment of distinct types of WSNs and RFIDs to access application performance requirements while curtailing energy consumption to enhance the application's lifespan. In this chapter, an extension of the effort EnergySim [116] is presented, which is a dedicated simulation platform developed for evaluating energy efficiency. The simulation modes, methodology and architecture of the proposed simulator are discussed in this chapter.

The systems presented in chapters 3 and 4 utilize different WSN platforms to perform. The problem arrives when one want to integrate distinct WSN technologies to develop a single sensing application. Energy consumption is the most desired feature of any such deployment; this parameter gives a broad idea of the life-time of network. Generally, simulators are used to get an approximate idea about the possible behavior, number of motes required, energy consumption and routing needs of a typical application deployment. However, no single simulation platform is currently available which can approximate heterogeneous mote platform deployments. Moreover, it is more difficult to find RFID simulators that could simulate the metal in-pipe environment. Our proposed simulation platform to determine energy efficiencies is based on the real hardware defined energy consumptions of the available consumer motes in the market. Its modular approach enabled us to add any new mote platform or define our own system.

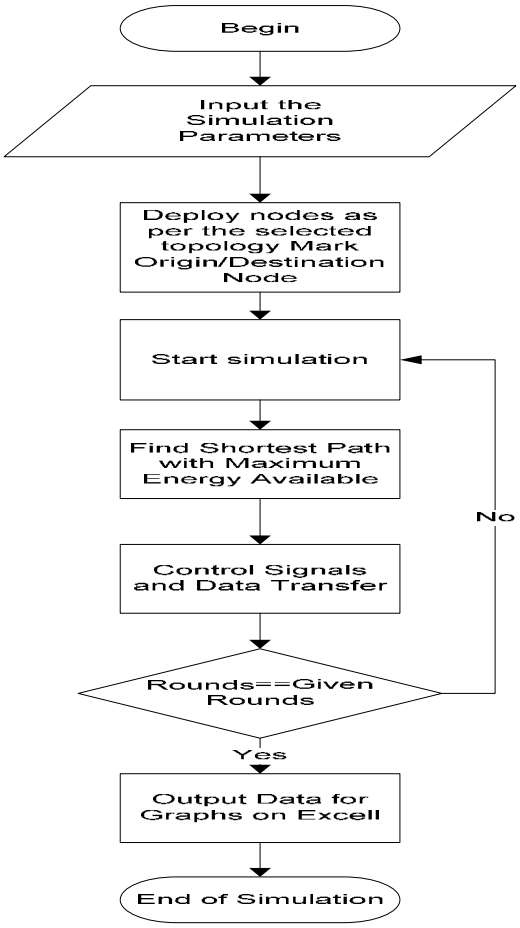


Figure 5.1: Simulator's Flow Diagram for Air Interface Mode.

5.1 Introducing EnergySim

EnergySim is a versatile event-driven simulator based on C# visual programming language, which has an ease of Visual Basic and the object orientation of Java. C# was chosen because of the portability of applications provided by the .Net runtime operating system, making EnergySim platform independent. Some important benefits that C# provides include dynamic implementation of sensor nodes, graphical support using GDI plus API, and interoperability with different packages like Microsoft Excel. This simulator generates Excel worksheets and plots of the energy states after the simulation. Similarly, MATLAB or any other software package can also be linked. Other benefits provided by C# include rapid prototyping, scalability of code (new protocols can be easily accommodated), etc. Furthermore, the component-based architecture enables the easy appending of new features. A number of simulators are available; however, none of them specifically targets energy consumption of specific MAC protocols. EnergySim addresses these concerns by facilitating runtime modification of topologies and producing energy plots of the network and nodes. It also

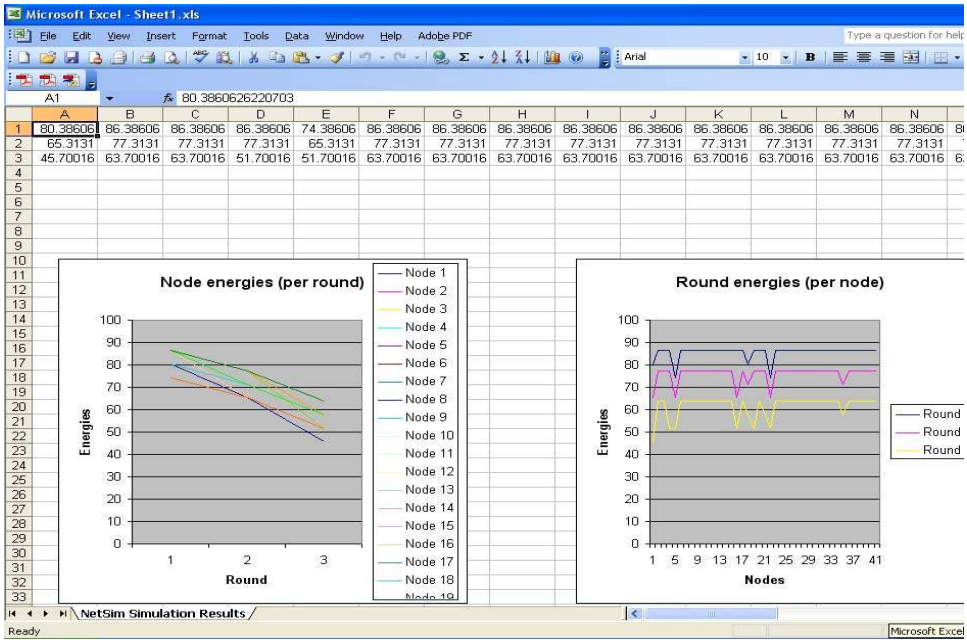


Figure 5.3: Excel graphs output.

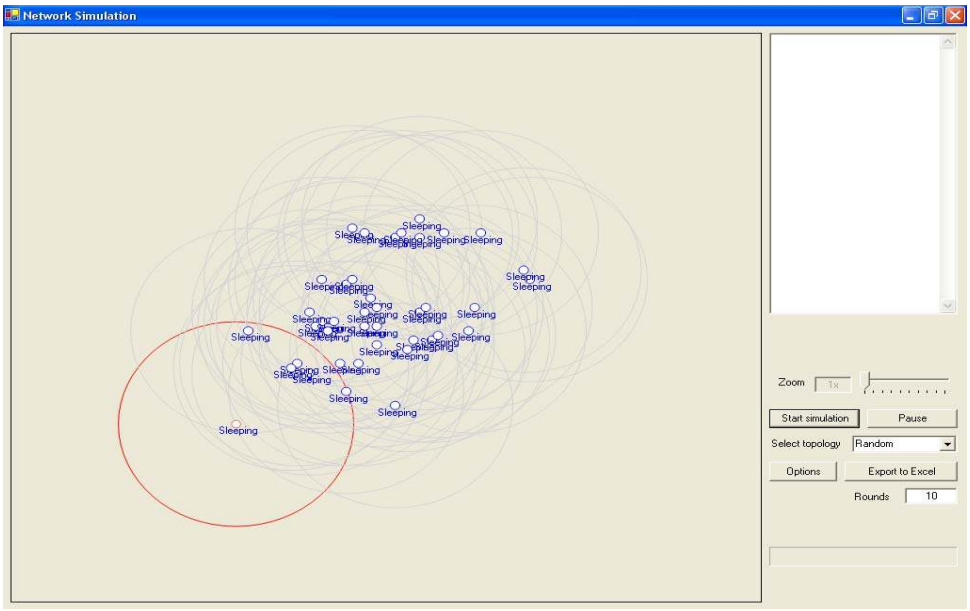


Figure 5.2: Random topology.

incorporates infinite zoom, which enables visibility of occluded nodes. The current state changes are also shown as animations underneath the nodes for user convenience. Currently EnergySim does not follow a physical model but in the future we hope to incorporate deployment of mobile nodes using GPS-based localization. Such a technique would enable efficient environmental monitoring and urban sensing.

5.1.1 EnergySim Design

Figure 5.1 shows the flow of the EnergySim simulator for air interface mode. The simulation begins after the user submits the input parameters according to the MAC protocol. The parameters include number of nodes, number of rounds, initial node energies, threshold energy, energy consumption in sleep and idle modes, node's communication range, topology, etc. After taking the inputs and before the "simulate" button is pressed, the simulator deploys the nodes on the simulation space, per the selected topology. A random node is selected and the simulator determines the shortest path using Dijkstra algorithm from this node to the sink node. Once the path is established the nodes start communicating by sending control signals and showing all the intermediate states of the communication. The simulator tallies the number of rounds entered by the user to the actual simulated rounds and if found unequal, it resumes the simulation till the number of rounds elapsed is equal to the given number of rounds. After completion of the rounds the simulator generates an Excel worksheet and graph plot when the "Export to Excel" button is pressed, as shown in fig. 5.2.

5.1.2 Properties

Here some of the unique properties of EnergySim are listed. The sensing radius of the nodes can be altered by the user. This helps to evaluate different wireless nodes with custom specifications. The number of deployed nodes is also taken as input for a scalable network evaluation. EnergySim readily evaluates the residual energies of the nodes and the number of

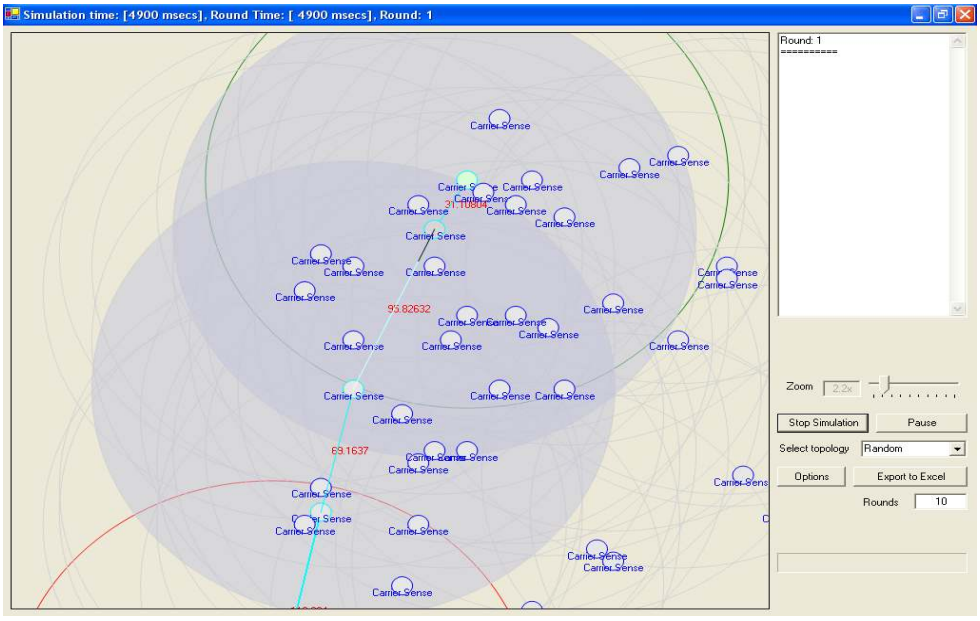


Figure 5.4: Zoomed view of the simulator with Random node distribution.

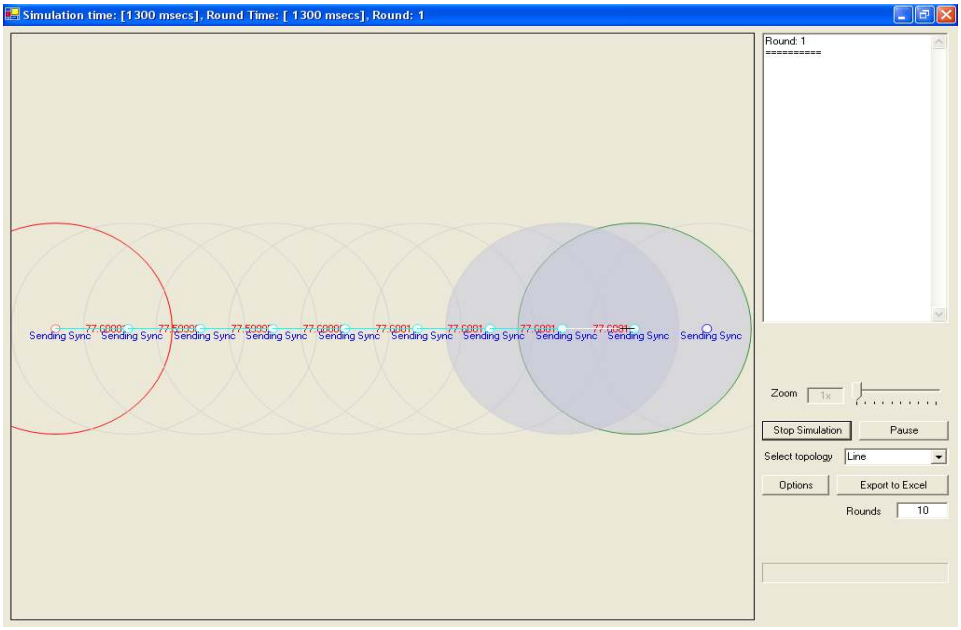


Figure 5.5: Line topology.

alive and dead nodes after the simulation to estimate network lifetime.

5.1.3 Energy Evaluation

After every round, the information pane on the right side of the simulator (shown in fig. 5.3) indicates the state of every node till the final round. These results are then exported to an Excel file and statistical graphs like mean energy, median, standard deviation and contours are generated automatically. Another unique feature of EnergySim is customization. The node properties specific to energy, like Threshold energy ET (defaults value 1x10-5Joules), Transmission energy ETx (default value 2 Joules), Receiving energy ERx (default value 1 Joule) and Idle or Sleep state energy Esleep (default value 1x10-3 Joules), can be completely customized for energy evaluation. These parameters can be input per the selected MAC protocol in the “Options” dialog box. Some of the properties specific to simulation include number of nodes, initial energy states of the nodes, number of rounds, communication range of the nodes in meters, energy consumed during sending/receiving data, ACK and other control signals. Any other parameter can also be incorporated easily in the simulator. The simulator also shows the intermediate states of the nodes, shortest distance between the nodes and the currently communicating nodes with their range highlighted. This prevents the user from diverting elsewhere and allows him to focus on the current communication link. Dead nodes are shown in black (signifying no energy) while alive nodes are shown in white (signifying maximum energy). The intermediate energy states are shown in a shade of grey.

Figure 5.6: Grid topology.

5.1.4 Dynamic Node Layout

The nodes on the screen can be displayed in a number of ways. Some are more general, like grid and line topologies, and others are more complicated, like random topology (as shown in fig. 5.4). Line topology is based on a one-dimensional function of position in screen space P(x), while grid topology uses a 2D function in screen space P(x, y) of rows and columns, as shown in fig. 5.5 and fig. 5.6, respectively. Any other topology can also be easily implemented into the simulator's dynamic layout. The flow of the distribution of the network topologies is shown in fig. 5.7. The properties and features of the nodes can easily be modified in real time. The "Pause" button on the simulator's main window will halt the simulation and allow the user to modify the contents of the simulation in progress. After modification, the simulation will start again from the beginning. This feature prevents the loss of precious time for the user if he mistakenly submitted a wrong input.

5.2 Multi Environment Simulator

5.2.1 Introduction

The proposed simulator is a versatile event-driven platform capable of simulating multiple environments. It is based on C# visual programming language, which offers an ease of Visual Basic and object orientation of Java. C# was chosen because of portability of applications provided by the .Net runtime, which enables this software to run on any .NET compliant

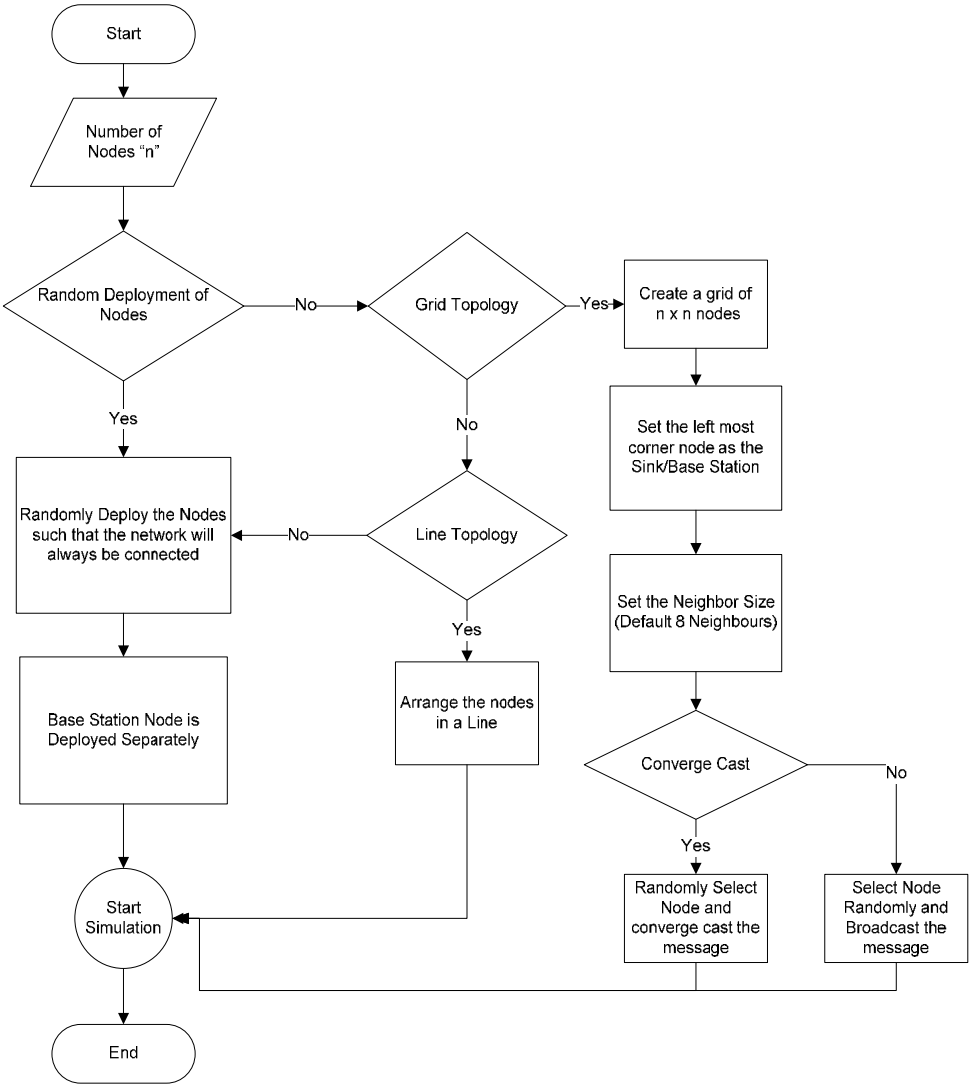


Figure 5.7: Network Topology distribution flow chart.

operating system, making it platform independent. Some important benefits that C# provides include dynamic implementation of sensor nodes, graphical support using GDI plus API, and interoperability with different packages like Microsoft Excel and MATLAB. This simulator generates Excel sheets and plots of the energy states after the simulation. Similarly, any other software package can also be linked.

5.2.2 Design and Implementation

Figure 5.8 shows the flow of the EnergySim simulator in case of both RFID and normal air modes. The simulation begins after a user chooses the environment (RFID in-pipe or normal air interface) and then submits the input parameters according to the MAC protocol. The parameters include number of nodes, number of rounds, initial node energies, threshold

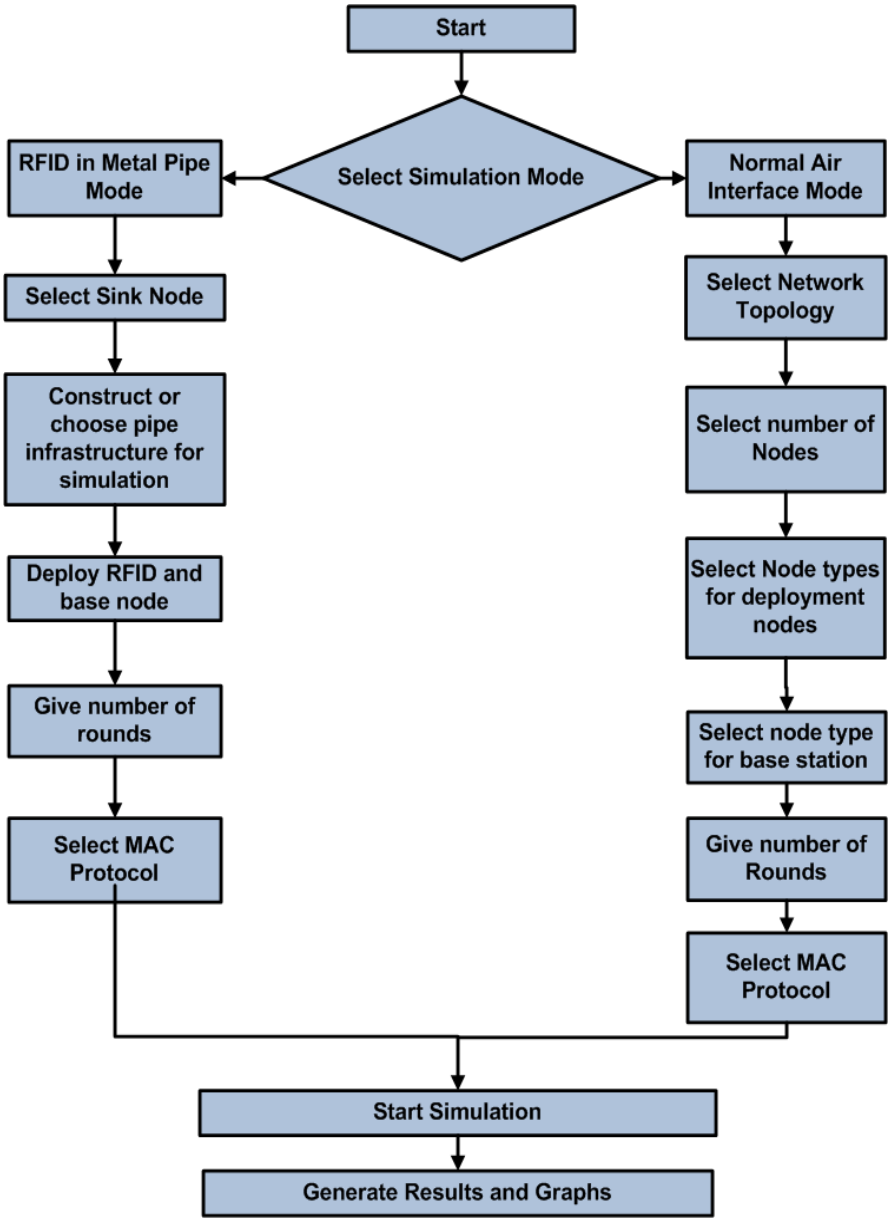


Figure 5.8: Simulator's Flow Diagram.

energy, energy consumption in sleep and idle modes, node's communication range, topology, etc. After taking inputs and before the "simulate" button is pressed, the simulator deploys the nodes in the simulation space per selected topology, in case the air interface option is chosen. Otherwise, it will allow the user to either make a pipe network using tools provided or download a piping map structure and deploy the RFID nodes inside the pipe. Afterwards, a random node is selected, and the simulator determines the shortest path using Dijkstra algorithm from this node to the sink node (an air interfaced node in case of RFID in-pipe mode). Once the path is established the nodes start communicating by sending control signals

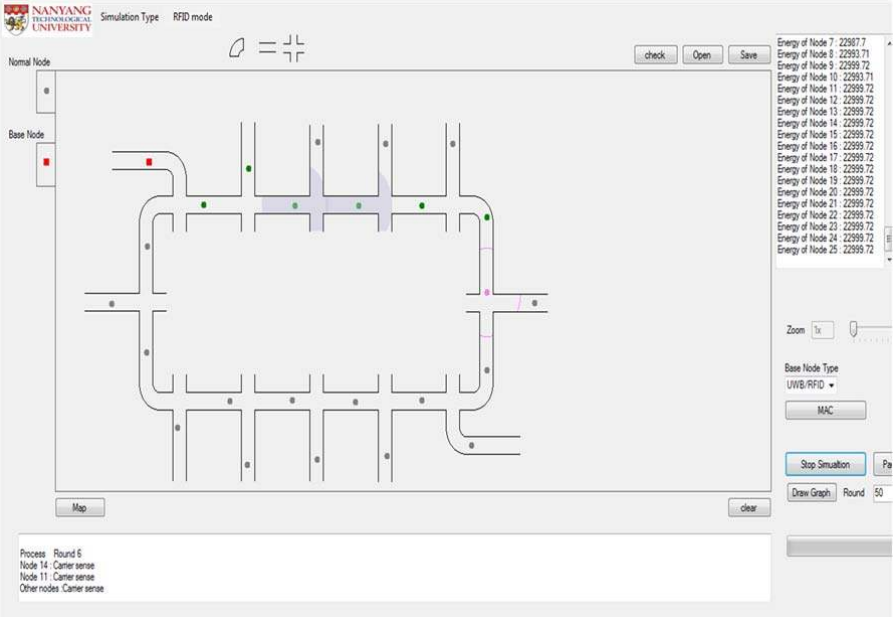


Figure 5.10: RFID Mode.

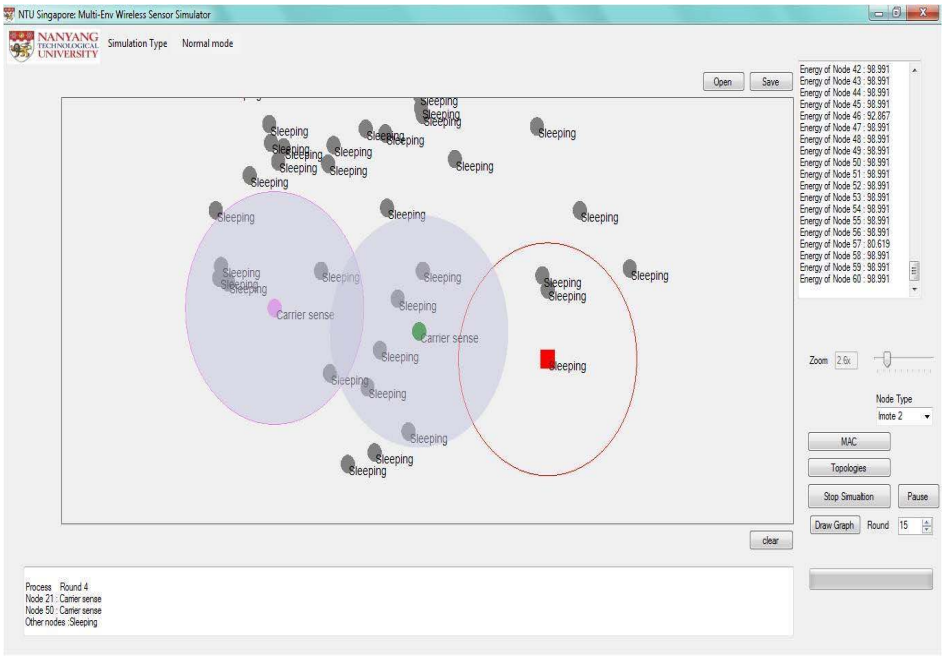


Figure 5.9: Random nodes Deployed on the simulation screen.

and showing all the intermediate states of the communication, per the chosen MAC protocol. The simulator tallies the number of rounds entered by the user to the actual simulated rounds and if found unequal it resumes the simulation until the number of rounds elapsed are equal to the given number of rounds. After completion of the rounds, the simulator generates an Excel worksheet and a graph when the “Draw Graph” button is pressed, as shown in fig. 5.9 for

Normal mode and fig. 5.10 for RFID mode.

5.2.3 Properties

Here some of the unique properties of EnergySim are listed. The sensing radius and the range within the metallic pipes of the nodes can be altered by the user. This helps to evaluate different wireless nodes with custom specifications. The number of deployed nodes is also taken as input for a scalable network evaluation. For air interface mode, stochastic process is chosen, which randomly distributes sensor nodes in the simulation space of the simulator. Through this process, an entirely random distribution is possible. The grid and line distribution topologies are also included for versatility.

EnergySim readily evaluates the residual energies of the nodes and the number of alive and dead nodes after the simulation to estimate the network lifetime. The simulator can also calculate the latency by sending data packets from the source to a sink node during the rounds simulated. Its interoperability and portability give EnergySim a competitive edge over all prior simulators.

Table 5-1: Class Diagram of Node.

NODE
VARIABLES Dtycycle; Energy; ID; NodesDistances; NodesInRange; NodeState; Position; Range; Static Counter; *Parent;
EVENTS ONREC ACK(); ONREC CTS(); ONREC DATA(); ONREC RTS(); SEND ACK(); SEND CTS(); SEND DATA(); SEND RTS();
METHODS ADDEDGE(); CLEAREDGES(); DRAW(); FINDSHORTESTPATH(); MOVE(); RELAX(); UPDATE();

5.2.4 Energy Evaluation

After every round, the information pane on the right side of the simulator (shown in the figs. 5.9 and 5.10) indicates the energy state of every node until the final round. The bottom pane shows the spontaneous hand shaking between the simulated nodes, showing their immediate states and node IDs. These results are then exported to an Excel file and statistical graphs like mean energy, median, standard-deviation, latency and contours are generated automatically.

Another unique feature of EnergySim is the ability it gives to the users to customize. An option is presented to the user to select the node type and make, e.g., imote2, TelosB, MicaZ and Gumstix computers, to do away with the hassle of submitting all the parameters related to these nodes at the time of simulation. The node properties specific to energy, like Threshold energy ET, Transmission energy ETx, Receiving energy ERx and Idle or Sleep state energy Esleep, can be completely customized for energy evaluation. These parameters can be input per selected MAC protocol in the “Options” dialog box. Some of the properties specific to simulation include number of nodes, initial energy states of the nodes, number of rounds,

communication range of the nodes in meters, energy consumed during sending/receiving data, ACK and other control signals. Any other parameter can be incorporated easily in the simulator. The simulator also shows the intermediate states of the nodes, shortest distance between the nodes and the nodes currently communicating, with their range highlighted. This prevents the user from diverting elsewhere and allows the user to focus on the current communication link. Dead nodes are shown in black (signifying no energy) while alive nodes are shown in white (signifying maximum energy). The intermediate energy states are shown in various grey shades.

5.2.5 Dynamic Node Layout

Node distribution on the simulation screen is an important part of a simulation area optimization to ensure that a large number of nodes can occupy the space as well as guaranteeing the network connectivity. Area-based distribution technique is used to distribute the nodes evenly on the simulation screen. The drawback of this technique is its uncertainty in assuring that the network remains maintained and nodes connected. Also, in the case of mobile a node, which is the future extension on this simulator, it may be that nodes

Table 5-2: Experiment Scenarios with Random, Grid and In-pipe RFID deployments.

Random Deployment								
	Simulated Nodes	**Simulated Rounds**	**Radio Range (meter)**	**MAC Scheme (50% duty cycle)**	**Max. Energy (Joules)**	**Sink Node**	**Assumptions**	**Interface**
MicaZ	100	50	100	SMAC	18720	1	No re-transmission	Air
TelosB	100	50	100	SMAC	18720	1	No re-transmission	Air
Imote2	100	50	30	SMAC	15213	1	No re-transmission	Air
Grid Deployment								
	Simulated Nodes	**Simulated Rounds**	**Radio Range (meter)**	**MAC Scheme (50% duty cycle)**	**Max. Energy (Joules)**	**Sink Node**	**Assumptions**	**Interface**
MicaZ	100	50	100	SMAC	18720	93	No re-transmission	Air
TelosB	100	50	100	SMAC	18720	93	No re-transmission	Air
Imote2	100	50	30	SMAC	15213	93	No re-transmission	Air
RFID In-pipe Deployment								
	Simulated Nodes	**Simulated Rounds**	**Radio Range (meter)**	**MAC Scheme (50% duty cycle)**	**Max. Energy (Joules)**	**Sink Node**	**Assumptions**	**Interface**
Active RFID	25	50	10	SMAC	18720	1	No re-transmission	Metal pipe

move to the same area on the screen. The node layout is composed of two parts, Normal mode

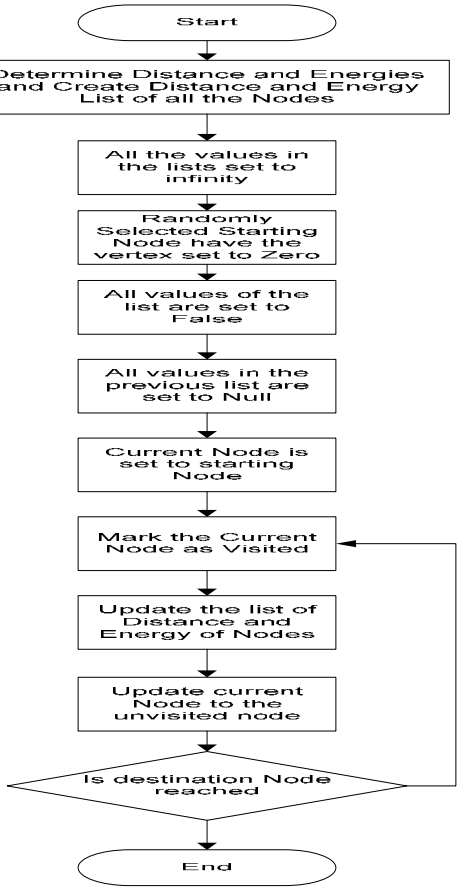


Figure 5.11: Dijkstra algorithm flow chart.

and RFID mode.

5.3 EnergySim Simulation Engines

The simulation architecture can simultaneously support two engines or modes and, depending upon the mode chosen at run-time, MAC and other parameters used in the nodes will change. In the initial development, it was assumed that all the nodes are stationary and may be equipped with one or more sensors and that the simulation environment can support more than one type of device for both sensor node and sink. The sink node is considered to be a more powerful WSN device in comparison to the other sensor nodes in terms of energy and computation power. The communication between the nodes is ideal, with no collisions and no interference. Path loss model is chosen to determine the communication ranges. These properties will be incorporated in the future for more accurate results. The Normal mode engine does not require the nodes to be location–aware, with no sink node in sight. It also assumes that the nodes within the network are simple, with low power requirements.

5.3.1 Normal Mode – Communication Range

Hata [141] is the commonly used path loss model for planning in the industry. Path loss is one

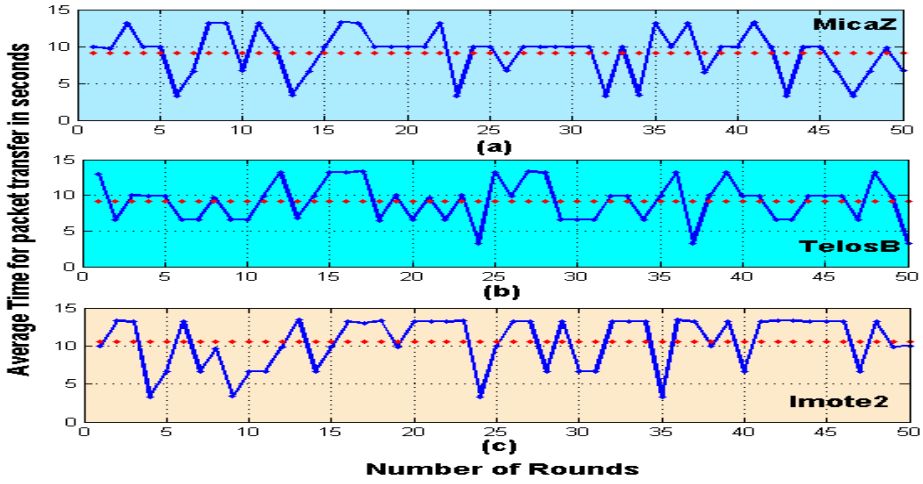


Figure 5.13: Average time consumed in seconds for packet transfer for 100 nodes in 50 rounds in Random topology. Red lines show the mean time values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2.

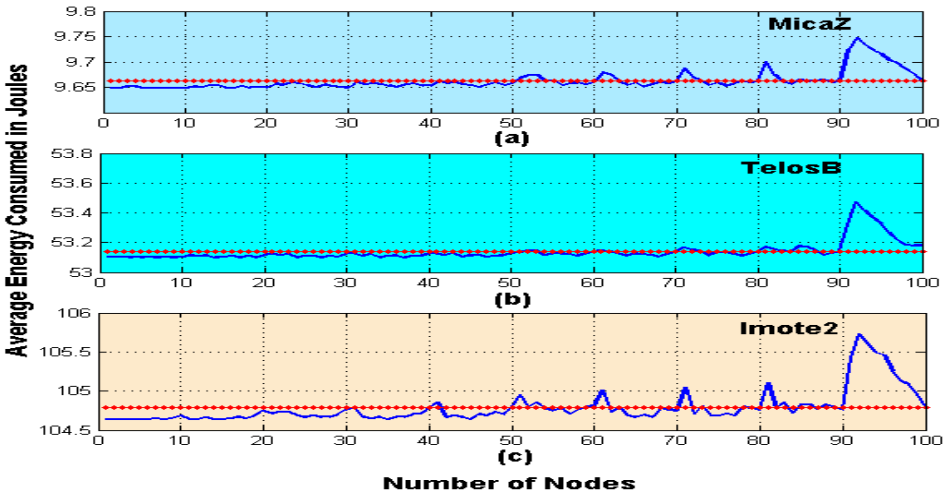


Figure 5.12: Average energy consumed in seconds for 100 nodes in 50 rounds in Grid topology. Red lines show the mean energy values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2.

of the most important parameters for channel prediction models. To calculate the transmission distance, path loss equations are taken into consideration. It is a relationship between attenuation, often in decibels (*dB*), and the distance between transmitter and receiver.

The simplest path loss model occurs when there is no obstacle between transmitter and receiver. Equation (1) shows the relationship between the attenuation and the distance between

transmitter and receiver in mathematical form, where L is the attenuation in *dB*, L_0 is the path loss at 1 meter, *n* is the path loss exponent and *d* is the distance in meters.

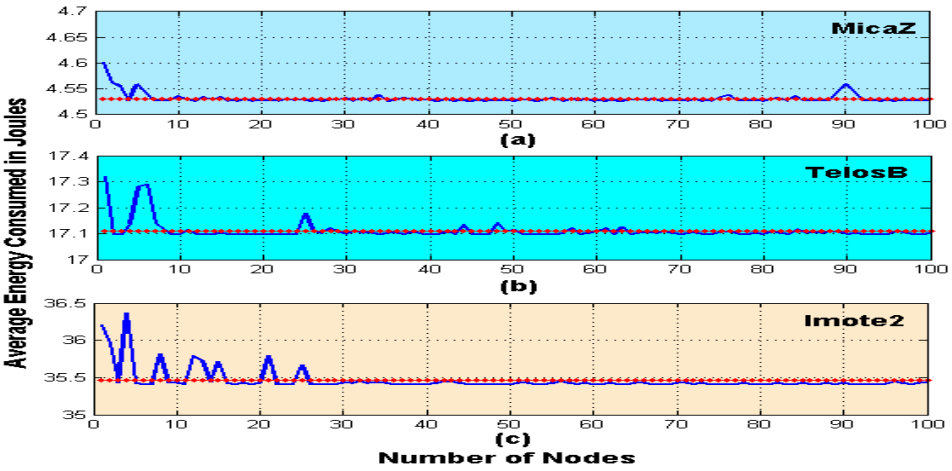


Figure 5.14: Average energy consumed in joules for 100 nodes in 50 rounds in Random Topology. Red lines show the mean energy values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2.

$$L = L_0 + n.10\log(d) \qquad (1)$$

The path loss equation given in

$$PL(d) = PL(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (2)$$

Where γ is the power-law relationship between the separation distance and the received power, γ is 2 for free space and normally higher for wireless channels [142], [143], d is the distance between the receiver, and the transmitter and d_0 is the received-power reference point. X_σ is the zero-mean Gaussian random variable of standard deviation, which reflects deviation, on average, of the received power that naturally occurs.

5.4 RFID in-pipe communication

Efforts to characterize the RF propagation for passive RFID in metal pipes are presented in [144, 145, 146]. The low-frequency RFID signals can be modeled using the equation (3) from [147].

$$\vec{U} = 2\pi f N \vec{\phi} \qquad (3)$$

Where $\vec{U}$ is the peak induced voltage on the metallic pipe's surface, f is the frequency, *N* is the number of turns of the loop antenna and $\vec{\phi}$ is the magnetic flux of the coil antenna. This equation can be used to determine the range of the induced voltage on the metallic surface of the pipe in order to determine optimal positioning of the RFID nodes within the network.

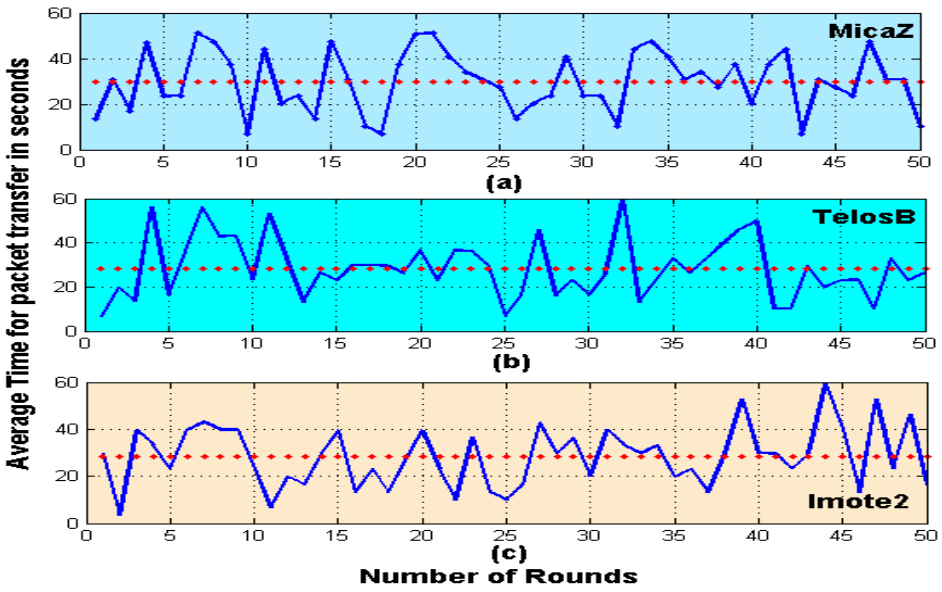


Figure 5.15: Average time consumed in seconds for packet transfer for 100 nodes in 50 rounds in Grid topology. Red lines show the mean time values for 50 rounds. (a) MicaZ, (b) TelosB, and (c) Imote2.

5.5 Shortest Path Algorithm

Figure 5.11 shows the flow diagram of the Dijkstra algorithm implemented into the simulator to find the shortest path with two cost functions, Energy and Distance, between the nodes. In determining the shortest path between the source node and the sink, the node with relatively high energy content and less distance is selected. Random nodes were generated onto the quadrilateral screen space for equidistribution of the wireless sensor nodes. The methods normally employed for random distribution establish a set of N number of nodes equidistributed on the space (u_1, v_1) through (u_N, v_N). In this case random uniform distribution of nodes on the screen space is implemented using a stochastic process. The screen space of the simulator is divided into equal regions, and the nodes are randomly deployed in these regions. This ensures that the nodes deployed are evenly distributed over the screen space and there is no node disconnected within the network at any time. In addition, at least five nodes are deployed in close vicinity of the base station so that if it dies, any of these nodes can assume the status of the base station provided it has sufficient energy.

5.6 Simulation Results

SMAC [148] and TMAC [107], the most widely used MAC protocols, were implemented. The simulation scenarios were summarized using Random, Grid and RFID deployments in Table 5-1. 50 rounds were simulated using 100 nodes in Random and Grid topologies for MicaZ, Imote2 and TelosB [103, 149, 105] nodes. The radio ranges were selected to be 100 meters for

MicaZ and TelosB and 30 meters for Imote2, and SMAC was chosen as the resource sharing mechanism. For MicaZ and TelosB, the maximum energy was assigned taking into consideration two alkaline AA sized batteries (18720J [150]) and for Imote2, three alkaline AAA sized batteries (15213J [150]). All the values for the internal node's energy consumption such as radio, syncing, carrier sensing, sleep, idle etc. are assigned according to their datasheet.

Simulation results showing the energy consumption of the 100 nodes in Random deployment for MicaZ, TeloB and Imote2 are presented in Fig. 5.12(a-c) respectively. Node '1' is the sink node that explains the higher amount of energy consumed by sink and its adjacent nodes due to their continuous packet transfer. The simulation results were obtained after the 'Draw Graphs' button was pressed at the end of the simulation. An average of 4.53, 17.11 and 35.4 Joules of energy were consumed per round for a random event generated for a deployed MicaZ, TelosB and Imote2 based WSNs, shown in red lines in fig. 5.12. That gives an approximate life of 4131, 429 and 1094 rounds of actual event detection for the simulated random topology networks, given full capacity batteries. However, the energy consumption must be considered during non-detection phases that may make detection rounds decrease, but these statistics can give us an approximation that is very near to the actual deployment scenarios. Fig. 5.13 (a-c) indicates the time nodes spent sending the packet from the node that detects the event to the sink node, deployed in random topology. This time is calculated assuming ideal conditions (no re-transmissions), and the average simulated time to complete the transfer per round is

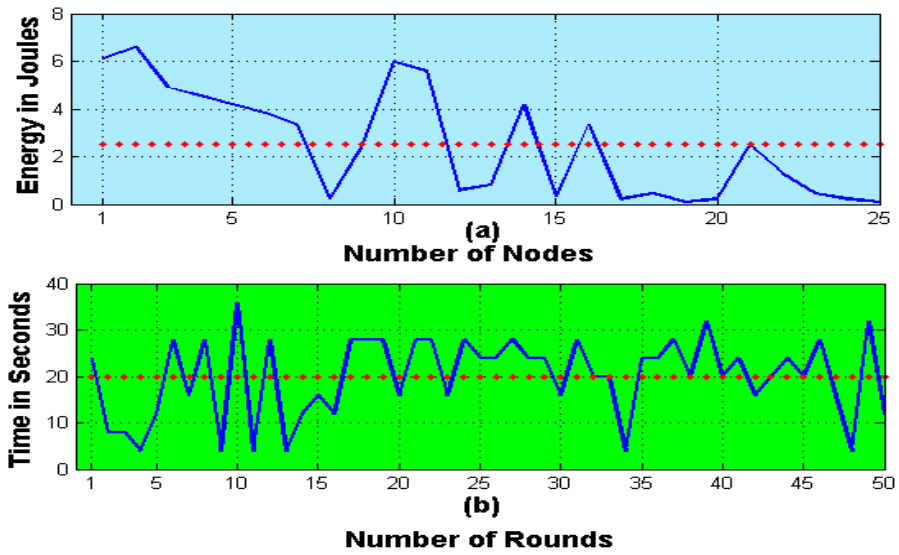


Figure 5.16: (a) Average Energy Consumed per round for 25 Active RFID nodes inside the metal piping structure. (b) Average Time in seconds for packet transfer from the event detection node to the sink node for 50 rounds. Red markers show the mean energy consumed and time taken for the 50 rounds respectively in the current set-up.

found to be approximately 9, 8 and 11 seconds per round for the MicaZ, TelosB and Imote2,

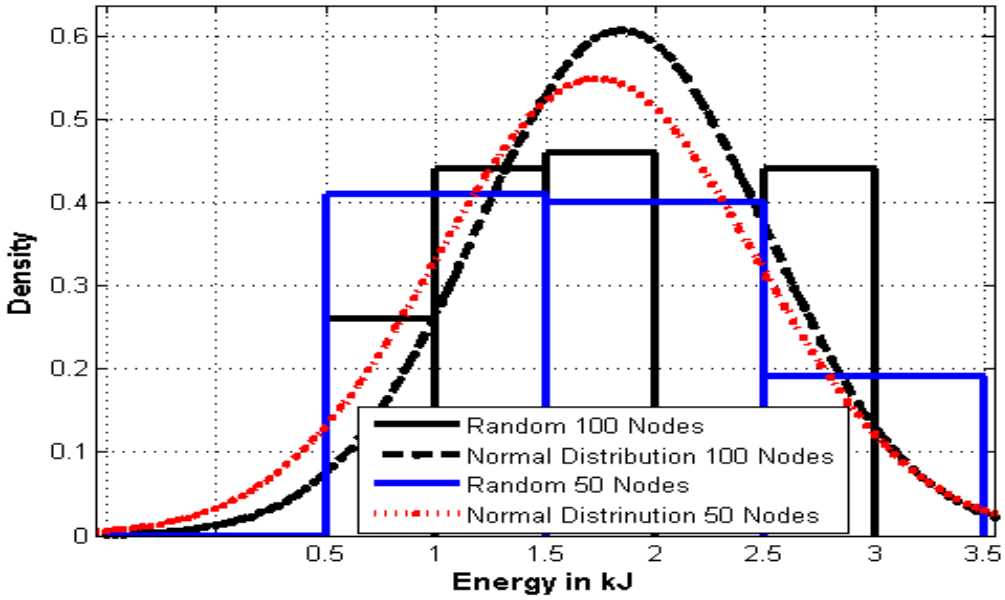


Figure 5.17: Energy PDF and the Gaussian Normalization fitting on it for 100 and 50 nodes simulated in Random topology with SMAC protocol.

respectively. That gives an approximate lifespan for the simulated networks of 10, 2.4 and 1.3 hours if events were detected continuously.

Another simulation was performed with Grid topology deploying 100 nodes of MicaZ, TelosB and Imote2 for 50 rounds, shown in fig. 5.14 (a-c). Here node number 93 represents the sink node. As expected, the sink and its adjacent nodes were consuming more power. An average of 9.66, 53.1, 104.55 Joules of energy consumed per round for the grid topology was obtained. This gives an approximate life in rounds of 1937, 352 and 145 for MicaZ, TelosB and Imote2, respectively. The time the nodes spent sending packets from the event detection node to the sink node for the grid topology simulation is shown in fig. 5.15 (a-c). Time is calculated assuming the same ideal conditions of no re-transmissions, and the average simulated time to complete the transfer per round is found to be 30, 28.5 and 28.3 seconds per round, shown in fig. 7 with red lines for the MicaZ, TelosB and Imote2, respectively. That gives an approximate lifespan for the simulated networks of 16, 2.78 and 1.13 hours if events were detected continuously. Hence, this shows the impact of topology on the deployed networks' energy consumption. Similar results can be acquired using TMAC protocol or any other customized protocol to determine network power consumption and approximate the lifetime.

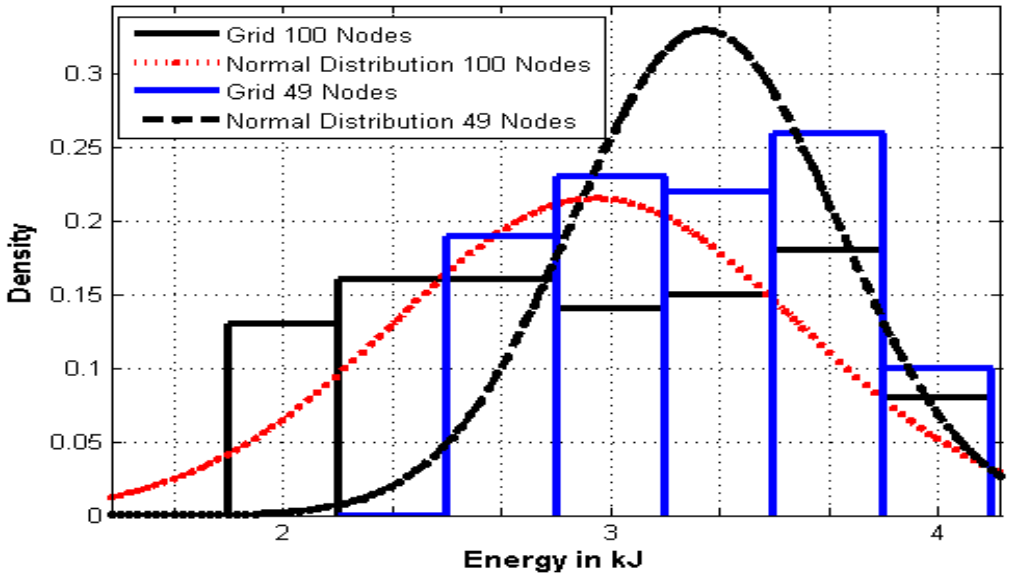


Figure 5.18: The Energy PDF and the Gaussian Normalization fitting on it for 100 nodes and 49 nodes simulated in Grid topology with SMAC protocol.

The simulation results of RFID deployment inside a piping structure (fig. 5.10) are shown in fig. 5.16. The simulation was performed deploying 25 Active RFID nodes, including the sink node. Simulation was performed for 50 rounds with node 1 being the sink node. An average of 2.5 Joules of energy consumed per round fig. 5.16 (a) and an approximated life of 920 in "number of rounds" was obtained. The packet delivery time with no re-transmission assumed is shown in fig. 5.16 (b). The average simulated time to complete the transfer per round is found to be 20 seconds per round, giving an approximate lifetime of 5.1 hours of continuous event detection, which is quite low because the nodes were embedded with energy-consuming sensors for detecting events.

5.7 Statistical Analysis of Simulation Results

Some more simulations were performed in order to determine the behavior of the deployed nodes in Random, Grid and Line topologies and to analyze the concentration of energies for each individual topology, energy consumption analysis per round and outage behavior. The simulations results are interesting and convey the nodes behavior which is normally hidden from analysis using Matlab statistical tools.

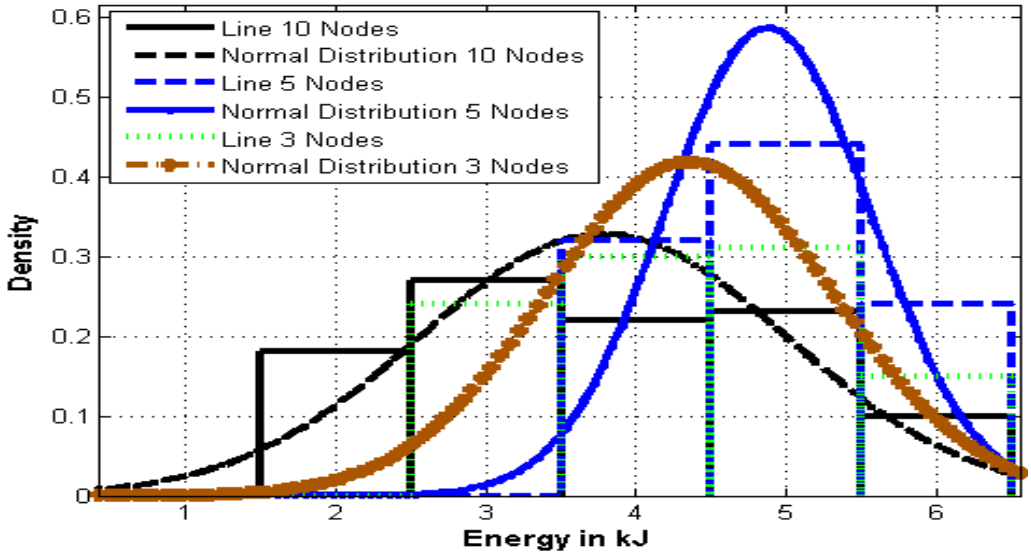


Figure 5.19: The Energy PDF and the Gaussian Normalization fitting on it for 10, 5 and 3 nodes simulated in Line topology with SMAC protocol.

Figure 5.17, shows the energy density of nodes follow a normal distribution when randomly deployed. The energy data was obtained by running the simulations in the EnergySim simulator taking 100 and 50 nodes and running for 100 rounds. The PDF shows that the energy distribution is normal in nature with 40% of the nodes have energy values between 1kJ to 3 kJ after 100 rounds. Figure 5.18, shows energy densities of the nodes follows a normal distribution when deployed in a grid topology. The simulations were run taking 100 and 49 nodes and running for 100 rounds. The PDF shows that the energy distribution is normal in nature with around 20% of the nodes have energy values between 2.5kJ and 3.5 kJ after 100 rounds in case of 49 nodes and 15% of the nodes have energy values between 2.5kJ and 3.5 kJ after 100 rounds. Figure 5.19, shows energy densities of the nodes follow a normal distribution when deployed in a line topology. The simulations were run taking 10, 5 and 3 nodes and running for 100 rounds. The PDF shows that the energy distribution is normal in nature with around 20% of the nodes have energy values between 2.5kJ and 5.5 kJ after 100 rounds in case of 10 nodes, 30% of the nodes between 3.5kJ and 5.5kJ in case of 5 nodes and 30% of the nodes have energy values between 3.5kJ and 5.5 kJ after 100 rounds.

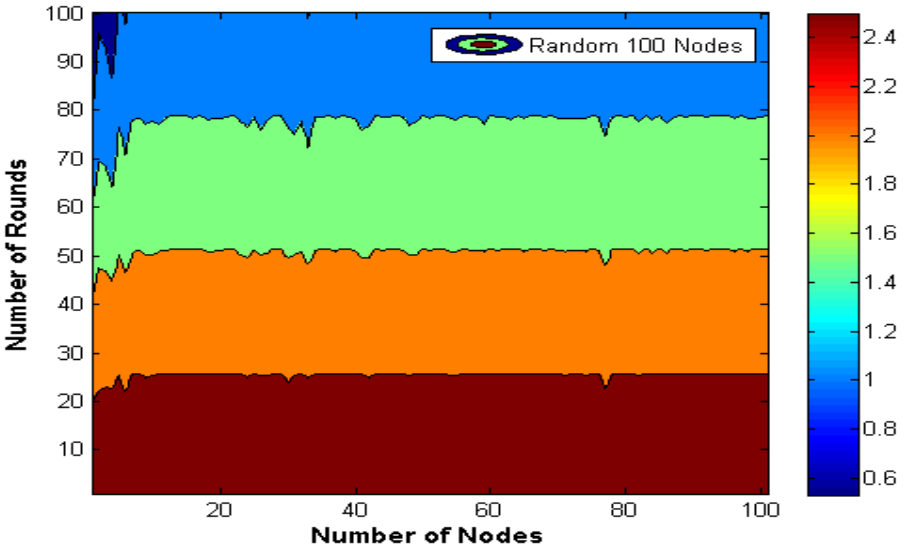


Figure 5.20: The Energy Contour after 100 rounds, 100 nodes, 3kJ energy bank, Random topology with SMAC protocol.

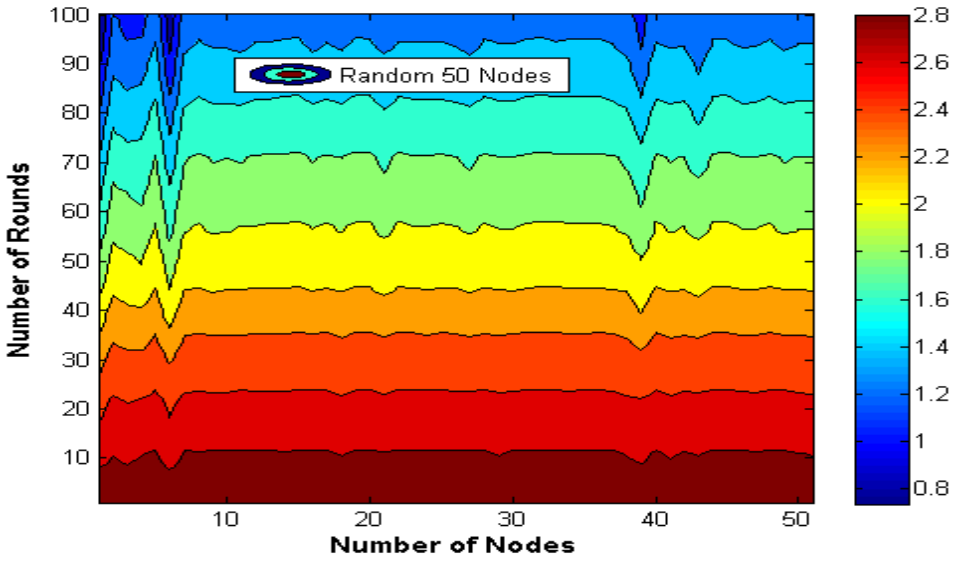


Figure 5.21: The Energy Contour after 100 rounds, 50 nodes, 3kJ energy bank, Random topology with SMAC protocol.

Figure 5.20, shows energy contour map, indicating the energy consumption in 100 randomly deployed nodes. Node 1 is the gateway node, hence, showing bulk of the consumption after every round. The nodes showing a lot of consumption are the nodes deployed in the surrounding of the gateway node. These nodes are more often selected by the shortest path algorithm to convey the event through multi-hop to the gateway node. The energy data was obtained by running the simulations taking 100 nodes, 3kJ of battery capacity and running it for 100 rounds. Figure 5.21, shows energy contour map, indicating the energy consumption in

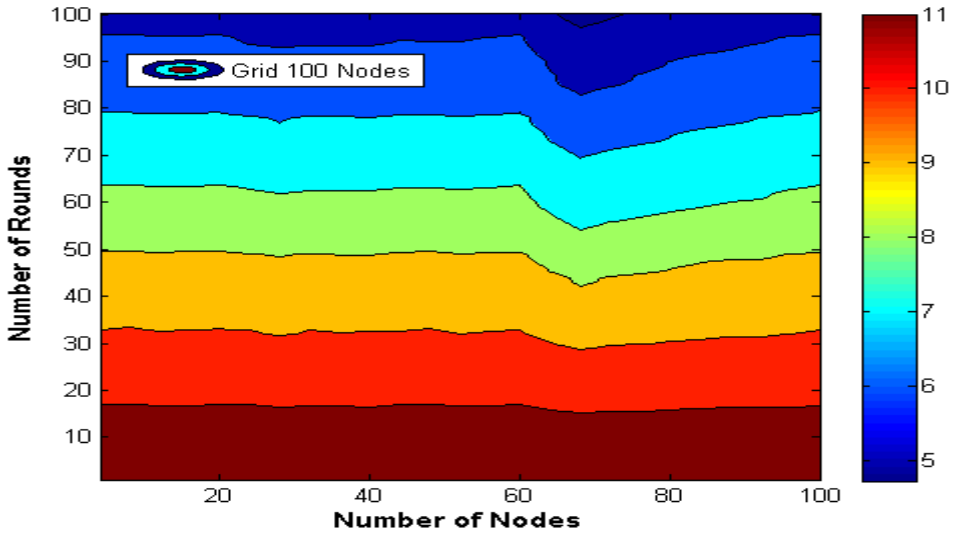


Figure 5.22: The Energy Contour after 100 rounds, 100 nodes, 12kJ energy bank, Grid topology with SMAC protocol.

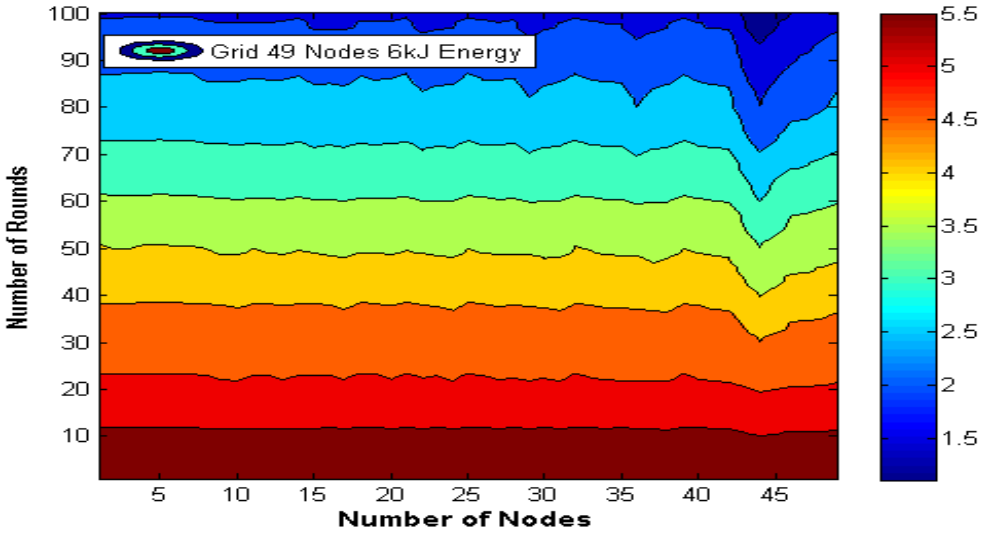


Figure 5.23: The Energy Contour after 100 rounds, 49 nodes, 6kJ energy bank, Grid topology with SMAC protocol.

50 randomly deployed nodes. Node 1 is the gateway node, hence, showing bulk of the consumption after every round. The nodes showing a lot of consumption are the nodes deployed in the surrounding of the gateway node. These nodes are more often selected by the shortest path algorithm to convey the event through multi-hop to the gateway node. The energy data was obtained by running the simulations taking 50 nodes, 3kJ of battery capacity and running it for 100 rounds. Figure 5.22, shows energy contour map, indicating the energy

consumption for 100 nodes deployed in grid topology. Node 70 is the gateway node, hence, showing bulk of the consumption after every round. The nodes showing a lot of consumption are the nodes deployed in the surrounding of the gateway node. These nodes are more often selected by the shortest path algorithm to convey the event through multi-hop to the gateway node. The energy data was obtained by running the simulations taking 100 nodes, 12kJ of battery capacity and running it for 100 rounds. It was found that compared to random deployment the energy of the grid nodes deplete faster than the random deployment due to the regular distances between the nodes as compared to diverse distances between the randomly deployed notes.

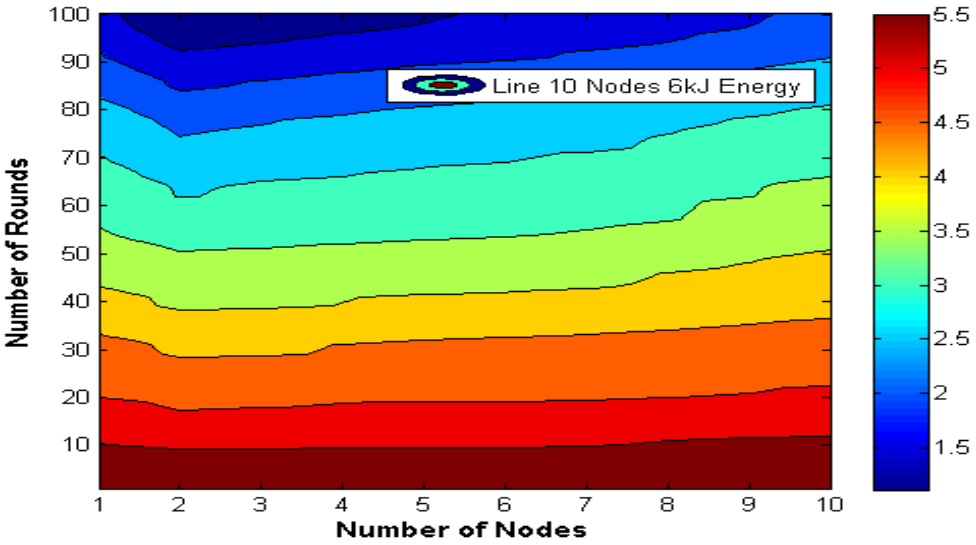


Figure 5.24: The Energy Contour after 100 rounds, 10 nodes, 6kJ energy bank, Line topology with SMAC protocol.

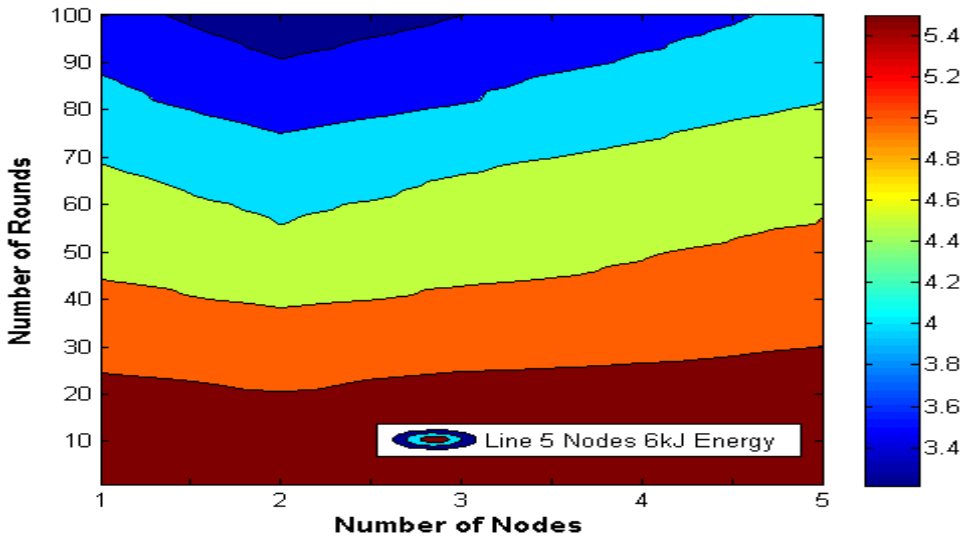


Figure 5.25: The Energy Contour after 100 rounds, 5 nodes, 6kJ energy bank, Line topology with SMAC protocol.

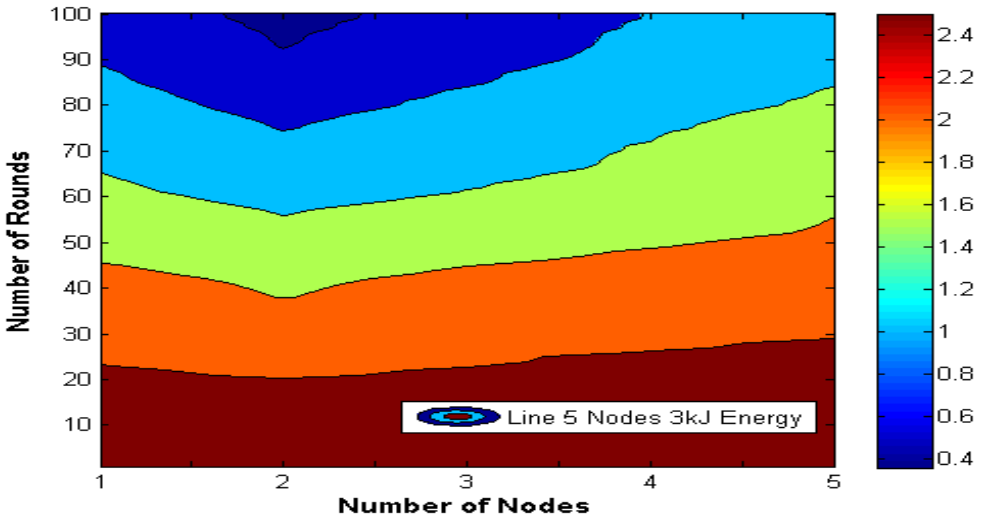


Figure 5.26: The Energy Contour after 100 rounds, 5 nodes, 3kJ energy bank, Line topology with SMAC protocol.

Figure 5.23, shows energy contour map, indicating the energy consumption for 49 nodes deployed in grid topology. Node 44 is the gateway node, hence, showing bulk of the consumption after every round. The nodes showing a lot of consumption are the nodes deployed in the surrounding of the gateway node. These nodes are more often selected by the shortest path algorithm to convey the event through multi-hop to the gateway node. The energy data was obtained by taking 49 nodes, 6kJ of battery capacity and running it for 100 rounds. It was found that compared to random deployment the energy of the grid nodes deplete faster than the random deployment due to the regular distances between the nodes as compared

to diverse distances between the randomly deployed notes. Moreover, 49 nodes deplete faster than the 100 nodes deployed in a grid. Figure 5.24, shows energy contour map, indicating the energy consumption for 10 nodes deployed in line topology. Node 2 is the gateway node, hence, showing bulk of the consumption after every round. The nodes showing a lot of consumption are the nodes adjacent to the gateway node. The energy data was obtained by

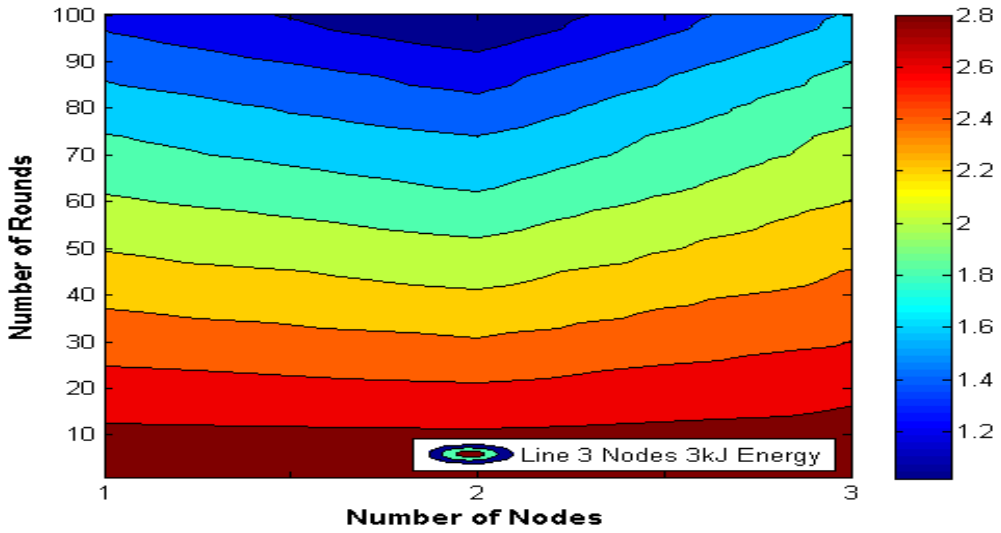


Figure 5.27: The Energy Contour after 100 rounds, 3 nodes, 3kJ energy bank, Line topology with SMAC protocol.

taking 10 nodes, 6kJ of battery capacity and running it for 100 rounds. It was found that compared to random and grid deployment the energy of the line nodes depletes faster due to the less number of nodes sharing the same path towards the gateway. Figure 5.25, shows energy contour map, indicating the energy consumption for 5 nodes deployed in line topology. Node 2 is the gateway node, hence, showing bulk of the consumption after every round. The energy data was obtained by taking 5 nodes, 6kJ of battery capacity and running it for 100 rounds. It was found that compared to random and grid deployment the energy of the line nodes depletes faster due to the less number of nodes sharing the same path towards the gateway. Figure 5.26, shows energy contour map, indicating the energy consumption for 5 nodes deployed in line topology. Node 2 is the gateway node, hence, showing bulk of the consumption after every round. The energy data was obtained by taking 5 nodes, 3kJ of battery capacity and running it for 100 rounds. It was found that compared to random and grid deployment the energy of the line nodes depletes faster due to the less number of nodes sharing the same path towards the gateway. Moreover, as compared to lower energy bank as compared to 6kJ case the energies depletion is faster, hence lowering the network lifetime. Figure 5.27, shows energy contour map, indicating the energy consumption for 3 nodes deployed in line topology. Node 2 is the gateway node, hence, showing bulk of the consumption after every round. The energy data was obtained by taking 3 nodes, 3kJ of battery

capacity and running it for 100 rounds. It was found that compared to random and grid deployment the energy of the line nodes depletes faster due to the less number of nodes sharing the same path towards the gateway. Moreover, as compared to lower energy bank as compared to 6kJ case the energies depletion is faster, hence lowering the network lifetime.

Figure 5.28, shows the outage probability with respect to the energy consumption after 100 rounds of random deployment of 100 and 50 nodes. The graph is the reverse water fall showing the outage probability of a 50 nodes network is slightly more than the 100 nodes deployed in a random topology. The two probabilities follow each other till 2kJ mark and then the 50 node network takes a sharper decline to show more outages. The simulation was performed using 100 and 50 nodes in random topology, running for 100 rounds with 3kJ of energy bank in the starting of each round. Figure 5.29, shows the outage probability with respect to the energy consumption after 100 rounds of grid deployment of 100 and 49 nodes. The graph is the reverse water fall showing the probability of a 49 nodes network outage is significantly more than the 100 nodes deployed in a grid topology. The two probabilities follow each other till 3.75kJ mark and then the 49 node network takes a sharper decline to show more outages. The simulation was performed using 100 and 49 nodes in grid topology, running for 100 rounds with 4kJ of energy bank in the starting of each round. Moreover, as compared to fig. 5.28, the grid network shows steeper outage. Figure 5.30, shows the outage probability with respect to the energy consumption after 100 rounds of line deployment of 10 and 5 nodes respectively. The graph is the reverse water fall showing the probability of a 5 nodes network outage is significantly higher than the 10 nodes, deployed in a line topology. The two probabilities follow each other for a very short period till 3.9kJ mark and takes

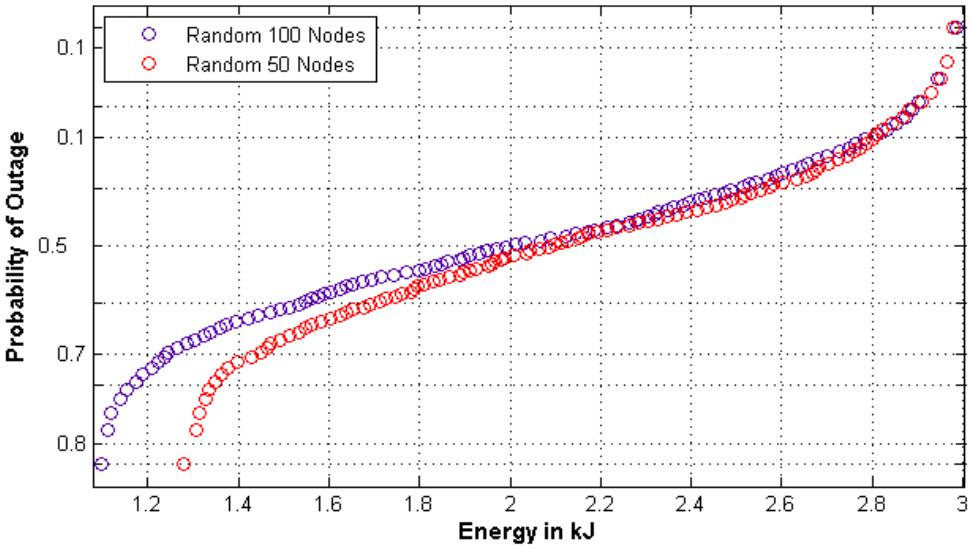


Figure 5.28: The Outage Probability of the nodes with respect to the energy after 100 rounds for Random 100 and 50 nodes deployment.

separate ways after this point. The 10 node deployment takes considerably longer time to show pure outage as compared to the 5 node network that dies halfway. The simulation was performed using 10 and 5 nodes in line topology, running for 100 rounds with 3kJ of energy

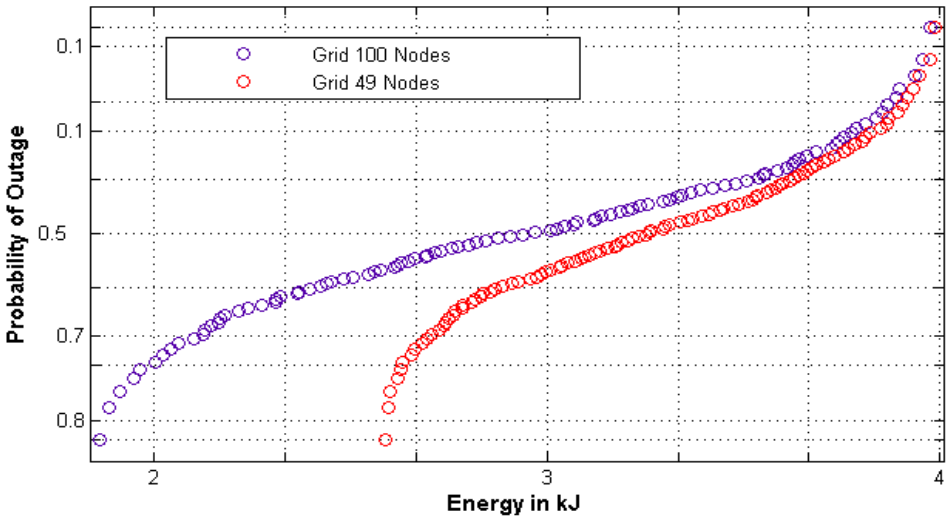


Figure 5.29: The Outage Probability of the nodes with respect to the energy after 100 rounds for Grid 100 and 49 nodes deployment.

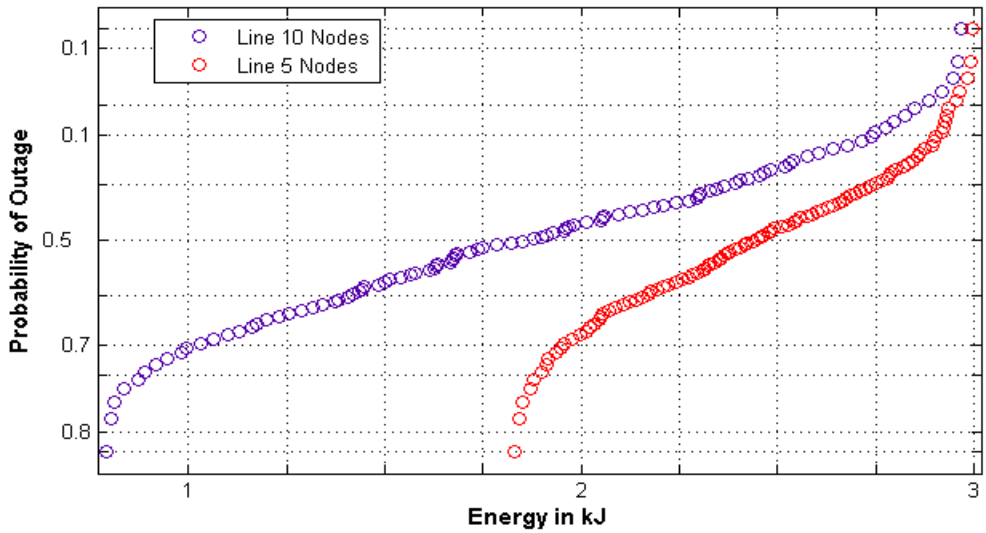


Figure 5.30: The Outage Probability of the nodes with respect to the energy after 100 rounds for Line 10 and 5 nodes deployment.

bank in the starting of each round. Moreover, as compared to fig. 5.28 and 5.29, the line network shows steeper outage.

5.8 Conclusion

The energy efficiency of a system consisting of diverse WSN nodes is the new research

concern. In this chapter, a special-purpose WSN simulator, EnergySim, was described. EnergySim is a dynamic, platform-independent, rapid prototyping and interoperable multi-environment simulation platform for RFID and WSNs. This work is being extended by improving the proposed simulator in terms of both its performance and functions.

There are still several features of the simulations that can be further examined. As an example, the inter-node communication currently is understood to occur in an ideal environment; therefore, issues like collision, interference, communication outages, multi-path reflections due to obstacles, have not been fully evaluated. Moreover, there is still more work to be done toward communication, physical, WSN radio and RFID tag models.

Chapter 6

Conclusions and Future Work

This thesis focuses on RFID and WSN hybrid monitoring applications. This research falls under the following three categories:

1. Water monitoring systems (discussed in chapter 3).
2. Vehicular and Urban sensing systems (discussed in chapter 4).
3. Design of the hybrid RFID and WSN simulator for energy efficiency (discussed in chapter 5).

The main focus of this research is on integrating RFID and other WSNs for different sensing applications under metallic environments. This chapter concludes the thesis by describing briefly each category's performance while also discussing several unresolved issues in research by suggesting prospective future directions.

The rest of the chapter is organized as follows: section 6.1 concludes water monitoring applications using hybrid RFID and WSN nodes. Section 6.2 discusses vehicular and urban sensing applications. Section 6.3 concludes the novel hybrid WSN simulation platform to determine energy efficiency. Section 6.4 briefly suggests prospective directions for further research.

6.1 In-pipe Monitoring systems

In this section, the focus is in-pipe monitoring systems mainly comprised of water and gas quality monitoring. This study has shown that the RFID system can be used to send information regarding quality monitoring of water and liquefied gas pipes.

6.1.1 Water Monitoring System

Sensing various aspects of water distribution systems and sharing the information to preserve and improve water quality are of major interest. The experimental validation and results for the in-pipe communications using low frequency RFID spectrum range are presented. PipeSense, an integrated framework for in-pipe water monitoring system based on near-field RFID WSNs, is also presented. The current system implementation, design and some feasibility results of PipeSense have been described in chapter 3. Then a CPS framework for PipeSense was presented. The CPS framework architecture and a proposed model for demand pattern and

contamination spread for water has been described.

The concept of water Smart Home was proposed to share the information with users in order to control, preserve and improve their lifestyles. The end-user, which can be a household or an authority, is informed each day about the consumption and can decide how to be more efficient. The tight integration of human users is achieved through various decision, control and feedback mechanisms. The CPS cycle and the proposed models for consumption patterns and tap opening/closing events for the water network system have been described. The application of HHMM is also described for modeling the system and their use for detecting events, identifying patterns in the data, predicting events and in making decisions. Modeling results and analysis based on the pseudo-pressure data are also presented.

Some of the recent efforts made in the water monitoring field are based on the quality monitoring of water in fresh ponds and lakes. However, no new effort is made to monitor water quality in metal pipes recently.

6.1.2 Moisture Sensing System for LNG

The research work targeting the quality monitoring for oil and gas applications is presented in chapter 3. The interest is primarily in in-pipe moisture monitoring systems for LNG/LPG pipes. This study has shown that the RFID system can be used to send information regarding the presence of moisture for quality monitoring of liquefied gas pipes. By using the Cognitive Radio's spectrum-sensing technique called Energy Detector, detection is possible and decisions can be made upon the basis of the energy detection output from the RFID antenna system. This technique, integrated with other monitoring sensors, can be used in a wireless cyber-physical moisture detection system.

Interest in a feedback human-centric monitoring system for gas quality monitoring in LNG/LPG pipes is also shown. A system is proposed where these RFID active and semi-passive tags, when embedded with sensors such as pressure, temperature, flow, strain, etc. in collaboration with other wireless technologies, can send information regarding the gas quality and pipe's infrastructure health. The collaboration of RFIDs with other wireless technologies helps us to create a smart human-centric monitoring system capable of providing maintenance, detecting events such as the presence of moisture or strain on pipe's structure and helping to automatically adjust the valve and pump properties according to the decisions made by the cyber system.

6.2 Vehicular Urban Sensing System

An integrated framework for vehicular and urban sensing within the context of human-centric urban sensing is presented in chapter 4. Sensing aspects of human activities and their interaction and impact on the surrounding environment is the major interest of this study. The

design of BusSense, a prototype campus vehicle information system, was described. Details of the software architecture and the hardware platform were presented. The application of HMMs is also described for modeling the system and their use for detecting events, identifying patterns in the data and predicting events. Modeling results and analysis were also presented on the experimental data.

The monitoring of hazardous pollutants emitted from vehicles is also critical for environmental safety. Vehicles emit tremendous amounts of toxins harmful to humanity and to the driver. EnvironSense is also introduced, a novel technique to measure these contaminations through a wireless network feedback system inside the vehicles. The experimental results in chapter 4 show the feasibility of such a system, making use of the magnetic induction and cheap RFID technologies.

Some of the recent effort made in the field of vehicular and urban sensing is mentioned in the references [151 – 155]. In [151], authors investigated the level of accuracy of monitoring pollution through a mobile crowdsourcing application. While, [152] deals with the Traffic monitoring in urban transportation systems using vehicular sensor networks (VSNs). [153] details a cognitive radio based scenario to examine feasible results to integrate cooperative sensing and spectrum database querying. The paper at [154] makes use of the smartphone sensors to determine the vehicle speed without having the GPS system. All these systems though related but not directly follow the theme of the research work presented in this thesis. A similar kind of work has been proposed recently in [155], this work focuses on creating high resolution pollution maps.

6.3 Hybrid WSN Simulator for Energy Efficiency

The energy efficiency of a system consisting of diverse WSN nodes is the new research concern. No recent work has been proposed on simulating hybrid and distinct hardware platforms on a single simulation environment. Chapter 5 describes a special-purpose WSN simulator, EnergySim, which is a dynamic, platform-independent, rapid prototyping and interoperable multi environment simulation platform for RFID and WSNs. This work is being extended by improving the proposed simulator in terms of both its performance and its functions.

6.4 Recommendation in Future Work

6.4.1 In-pipe Monitoring

6.4.1.1 Water Monitoring

The original intent was to augment PipeSense with a multi-interface data service for

administrative functions and a map service for normal users. PipeSense can also utilize existing sensor modules and feed their data to the users' handheld computing devices for processing and analysis. The uses of communication methods such as Wi-Fi, Bluetooth, etc. are also being explored. These provide a wide choice of data transfer speeds and flexibility in building a network. For a faster and more reliable communication channel, the use of the 3G networks can also be explored.

Energy efficiency is highly desirable to prolong the life of the WSN network. To enhance energy efficiency of RFID systems some protocols have been proposed; two of them are RFIDImpulse [156] and ALOHA-based anti-collision protocol [157]. A simple 802.11-based protocol is initially utilized. At a later stage of the research an improved, energy efficient, event-driven MAC protocol for in-pipe RFID WSN will be introduced.

6.4.1.2 LNG/LPG Moisture Sensing

The performance of the energy detector depends on a number of contributing factors. These factors include but are not limited to an efficient antenna design, pipe material and ambient environmental conditions. Moreover, a good theoretical channel model to describe and predict the efficiency of this monitoring system is absolutely necessary. The concepts of Cognitive Radios can be efficiently utilized to improve the RFID system's performance. Cognitive and Cooperative techniques can also increase the system's reliability and range by introducing relays and MIMO antennas. Along with designing an efficient antenna system and determining the channel characteristics, this same system can be enhanced to utilize and accommodate other sensors for pipeline and gas health monitoring. This can be seen in terms of a cyber-physical system using cognitive radios as agents to efficiently manage and control the process.

6.4.2 Vehicular Urban Sensing

6.4.2.1 In-Vehicle Network and Inter-Vehicular Communication

Modern vehicles are equipped with industry standardized in-vehicle networks for connection and communication with the large number of in-vehicle electronic systems. These electronic systems and sensors cooperatively provide entertainment, comfort and safety to the passengers, as well as offer greater control and improve vehicle performance [31], [158].

Inter-vehicular communication is another challenge for further development of EnvironSense. The interest is in information exchange between neighboring vehicles. In future development we will also explore the usage of the 3G network for a faster and more reliable data transmission channel.

6.4.2.2 Environmental Impact

One of the major functional areas for the system is to comprehend the environmental impact of vehicular emissions. To build a more complex, real-time model of the air quality, we need further information, such as temperature, wind direction and speed, atmospheric pressure, humidity, etc.

6.4.2.3 Human Involvement and Interaction

With the rapid growth in microelectronic devices, a myriad number and types of embedded sensors are available now in consumer electronic devices. Notably, the mobile phone has developed into an extremely sophisticated and intelligent device in the last few years. Today, a mobile phone has sensors for detection of light, sound, speed, vibration, and temperature, In addition to having a GPS receiver, it also has Wi-Fi and 3G, as well as Bluetooth communication ability.

Human-centric sensing would allow us to obtain the most benefit from urban sensing research and applications. Thus, an immediate challenge is to develop an efficient and powerful method to establish and maintain human involvement and interaction in vehicular and urban sensing contexts. We anticipate that the mobile phone and other such devices may play a major role as intelligent gateways between the human and urban spaces. These devices may help us in sensing human activities and act as intelligent agents to communicate with the urban surroundings.

6.4.3 Hybrid WSN Simulation Platform

There are still several features of the simulations that can be further examined. As an example, the inter-node communication currently is understood to occur in an ideal environment; therefore, issues like collision, interference, communication outages, and multi-path reflections due to obstacles have not been fully evaluated. Moreover, there is still more work to be done in perfecting communication, physical, WSN radio and RFID tag models.

References

[1] Jawhar, I., Mohamed, N., Mohammed, M. N., & Aziz, J. , "A Routing Protocol and Addressing Scheme for Oil, Gas, and Water Pipeline Monitoring Using Wireless Sensor Networks", in the Proceedings of 5th IFIP International Conference on, Wireless and Optical Communications Networks, pp.1,5, Indonesia, 2008 .

[2] A. Carrillo, E. Gonzalez, A. Rosas, and A. Marquez, "New distributed optical sensor for detection and localization of liquid leaks", Pat I. Experimental Studies, Sens, Actuators, A(99):229–235, 2002.

[3] I. Jawhar and J. Wu . "Qos support in tdma-based mobile ad hoc networks", In the proceedings of the Journal of Computer Science and Technology (JCST), vol 20, issue 6, pp.797–910, 2005.

[4] I. Gerasimov and R. Simon, "Performance analysis for ad hoc QoS routing protocols", Mobility and Wireless Access Workshop, International, pages 87–94, USA, 2002.

[5] Y. Tu and H. Chen, "Design of oil pipeline leak detection and communication systems based on optical fiber technology", in the proceedings of SPIE, 3737:584–592, August 1999.

[6] W. Lin, "Novel distributed fiber optic leak detection system", in the proceedings of Optical Eng., vol. 43(2), pp. 278-279, 2004.

[7] C. E. Perkins and E. M. Royer, "Ad hoc on demand distance vector (AODV) routing", pp.90,100, USA, 1999.

[8] S. Nelakuditi, Z.-L. Zhang, R. P. Tsang, and D.H.C. Du. "Adaptive proportional routing: a localized QoS routing approach", IEEE/ACM Transactions on Networking, vol.10 (6), pp.790–804, 2002.

[9] Cordova-Lopez L.E. et al., "Online vehicle and atmospheric pollution monitoring using GIS and wireless sensor networks", in the proceedings of Journal of Physics: Conference Series, vol.76, pp.12019-12026, 2007.

[10] O. K. Tonguz, "Biologically inspired solutions to fundamental transportation problems," IEEE Communications Magazine, vol. 49, pp. 106–115, November 2011.

[11] Sohraby, K., Minoli, D., &Znati, T, "Wireless sensor networks: Technology, Protocols, and Applications", in the proceedings of John Wiley & Sons, USA, 2007.

[12] Minetti, G., "Wireless Sensor Networks Enable Remote Condition Monitoring", in the proceedings of Pipeline & Gas Journal, vol.239(7), 2012.

[13] Romer, K., and Mattern, F., "The Design Space of Wireless Sensor Networks", in

the proceedings of IEEE Wireless Communications, 11(6), 54-61, 2004.

[14] Talevski, A., Carlsen, S., & Petersen, S, "Research Challenges in Applying Intelligent Wireless Sensors in the Oil, Gas and Resources Industries", in the proceedings of 7th IEEE International Conference on Industrial Informatics, Perth, Australia, 2009.

[15] Akhondi, M. R., Talevski, A., Carlsen, S., & Petersen, S., "Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries", in the proceedings of 24th IEEE International Conference on Advanced Information Networking and Applications, Perth, 2010.

[16] Sundararajan, V.; A. Redfern; W. Watts; and P. Wright, "Distributed Monitoring of Steady-State System Performance Using Wireless Sensor Networks," in the proceedings of ASME International Mechanical Engineering Congress, 2004.

[17] Cramer, R. "Oil and Gas Asset Integrity Monitoring", Paper Presented at Energy Harvesting and Storage USA, Washington, USA, 2012.

[18] I. Jawhar and J. Wu., "Qos support in tdma-based mobile ad hoc networks", in the proceedings of the Journal of Computer Science and Technology (JCST), vol.20(6), pp.797–910, 2005.

[19] Jagannath, V.M.D. and B. Raman, "WiBeaM: Wireless Bearing Monitoring System." In the proceedings of 2nd International Conference on Communication Systems Software and Middleware, COMSWARE, pp. 1-8, 2007.

[20] Lin, M., Wu, Y., and Wassell, I, "Wireless sensor network: Water distribution monitoring system," in the proceedings of IEEE Radio and Wireless Symposium, Florida, 2008.

[21] Motta Pires and L. Oliveira, "Security aspects of scada and corporate network interconnection: An overview," in the proceedings of IEEE International Conference on Dependability of Computer Systems, DepCos–RELCOMEX'06, pp. 127–134, 2006.

[22] T. Arampatzis, J. Lygeros, and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," in the proceedings of the IEEE International Symposium on Intelligent Control, Mediterrean Conference on Control and Automation, pp.719–724, Cyprus, 2005.

[23] Dalbro, M., Eikeland, E., Veld, A. J., Gjessing, S., Lande, T. S., Riis, H. K., et al, "Wireless sensor networks for off-shore oil and gas installations", in the proceedings of the 2nd International Conference on Sensor Technologies and Applications, Cap Estere, 2008.

[24] T. B. Fischer, "Towards a better consideration of climate change and greenhouse gas emission targets in transport and spatial/ land use policies, plans and programmes," http://www.oneearth.org , 2001.

[25] Hatler, M., Gurganious, D., & Chi, C. “Oil & Gas Wireless Sensor Networks, A Market Dynamics Report”, 2012.

[26] A. Nasir, B. Soong, and S. Ramachandran, “Framework of WSN based human centric cyber physical in–pipe water monitoring system,” in the proceedings of IEEE 11th International Conference on Control Automation Robotics & Vision (ICARCV), pp. 1257–1261, Singapore 2010.

[27] F. Wu, Y. Kao, and Y. Tseng, “From wireless sensor networks towards cyber physical systems,” in the proceedings of Pervasive and Mobile Computing Elsevier, vol. 7, no. 4, pp.397 -413, 2011.

[28] Karlsson HL., “Ammonia, nitrous oxide and hydrogen cyanide emissions from five passenger vehicles”, in the proceedings of Elsevier Science of the Total Environment. Vol. 334/335, pp.125-132, 2004.

[29] Cadle SH, Gorse Jr. RA, Bailey BK, Lawson DR, “Real-world vehicle emissions: A summary of the twelfth Coordinating Research, Council on-road vehicle emissions workshop”, in the proceedings of the Journal of the Air and Waste Management Association. Vol.53(2), pp.152-167, 2003.

[30] Kean AJ, Harley RA, “On-road measurement of ammonia and other motor vehicle exhaust emissions”, in the proceedings of Environmental Science and Technology. Vol.34, pp.3535, 2000.

[31] U. Lee, E. Magistretti, B. Zhou, M. Gerla, P. Bellavista, A. Corradi, "MobEyes: smart mobs for urban monitoring with vehicular sensor networks," in the proceedings of IEEE Wireless Communications, vol. 13(5), pp. 52-57, 2006.

[32] P. Bellavista, E. Magistretti, U. Lee, and M. Gerla, "Standard integration of sensing and opportunistic diffusion for urban monitoring in vehicular sensor networks: the MobEyes Architecture," in the proceedings of IEEE International symposium on Industrial Electronics (ISIE'07). pp. 2582-2588, Spain, 2007.

[33] Dohler M. et al., “Urban WSNs Routing Requirements in Low Power and Lossy Networks”, in the proceedings of IETF draft, IETF ROLL workgroup, January, 2009.

[34] J.W. Wedel,B, Schunemann and I. Radusch, “V2X‐Based Traffic Congestion Recognition and Avoidance, ″ in the proceedings of IEEE 10th International Symposium on Pervasive Systems, Algorithms, and Networks, pp.637‐641, Kaohsiung, Taiwan, 2009.

[35] T.Thianniwet, S, Phosaard and WasanPattara‐Atikom, ″Classification of Road Traffic Congestion Levels from GPS Data using a Decision Tree Algorithm and Sliding Windows,″ in the proceedings of the World Congress on Engineering WCE VolI, ISBN:978‐988‐17012‐2009.

[36] C.M.Roberts, “Radio Frequency Identification (RFID)”, in the proceedings of

Computers & Security, Elsevier Ltd .,Vol. 25, Issue 1, 2006.

[37] H.Lehpamer, “RFID Design Principles”, Artech House Microwave Library, INC.,ISBN 13:978‐1‐59693‐194‐7, USA, 2008.

[38] Chong hua Li “Automatic Vehicle Identification System based on RFID”, in the proceedings of Anti-Counterfeiting Security and Identification in Communication (ASID), pp 281-284, 2010.

[39] M. Ferreira, R. Fernandes, H. Conceic˜ao, W. Viriyasitavat, and O. K.Tonguz, “Self-organized traffic control,” in the proceedings of ACM international workshop on VehiculAr InterNET working (VANET), pp. 85–90, 2010.

[40] O. K. Tonguz, H. Conceic˜ao,and M. Ferreira, “Performance Limits of In-Vehicle Traffic Lights During Rush Hour Traffic,” Proprietary Report, September 2011.

[41] H. Yang and S.-H.Yang, “RFID Sensor Networks, Network Architectures to Integrate RFID, Sensor and WSN,” in the proceedings of Measurement and Control, vol. 40, pp. 56–59, 2007.

[42] L. E. Miller, “Indoor Navigation for First Responders: A Feasibility Study,” Tech. Report of National Institute of Standards and Technology, 2006.

[43] P.Y. Chen et al., “A Group Tour Guide System with RFIDs and Wireless Sensor Networks,” in the proceedings of 6th International Symposium on Information Processing in Sensor Networks IPSN‘07, pp. 561–62, USA, 2007.

[44] C. Englund and H. Wallin, “RFID in Wireless Sensor Network,” Tech. Report of Dept. Signals and Systems, Chalmers Univ. Technol., Sweden, Apr. 2004.

[45] H. Deng et al., “Design of Sensor-Embedded Radio Frequency Identification (SE-RFID) Systems,” in the proceedings of IEEE Int’l. Conf. on Mechatronics and Automation, pp. 792–96, 2006.

[46] Liang C., Huang X., and Deng J., “A fault tolerant and energy efficient routing protocol for urban sensor networks”, in the Proceedings of the 2nd international Conference on Scalable information Systems, vol. 304, Suzhou, China, 2007.

[47] S. H. W. C. Wonkyu, B. Ji-Hoon, C. Gil Young, P. Cheol Sig, and C. Jong-Suk, "An RFID tag using a planar inverted-F antenna capable of being stuck to metallic objects," ETRI Journal, vol. 28, pp. 216-18, 2006.

[48] A. Nasir and S. Hee, "EnvironSense: An Integrated System for Urban Sensing Using RFID based WSNs," in the proceedings of IEEE TENCON, pp– 1-5, Singapore, Jan 2009.

[49] C, Raghavendra, K, Sivalingam and T, Znati, “Wireless Sensor Networks”, in Proceedings of the Springer, NY, USA, 2004.

[50] J. Hill, R. Szewczyk, A, Woo, S. Hollar, D. Culler, and K. Pister, “System Architecture Directions for Networked Sensors”, in Proceedings of the ASPLOS, 2000.

[51] M. A. M. Vieira, C. N. Jr. Coelho, D. C. Jr. da Silva, and J. M. da Mata, “Survey on Wireless Sensor Network Devices,” in Proceedings of the Emerging Technologies and Factory Automation, pp. 537-544, 2003.

[52] J. Feng, F. Koushanfar, and M. Potkonjak, “System-Architectures for Sensor Networks Issues, Alternatives, and Directions,” in Proceedings of the IEEE International Conference on VLSI in Computers and Processors, pp. 226-231, 2002.

[53] Crossbow Technology, Inc., “Product Catalog,” Crossbow Technology”. [Online]. Available: http://www.moog-crossbow.com/. [Accessed: 21 November 2014].

[54] S, La Malfa, “Wireless Sensor Networks”, Available at http://www.dees.unict.it/users/bando/files/wsn.pdf, accessed on 16th November 2014.

[55] H, Frey, S Rührup, and I Stojmenović, "Routing in wireless sensor networks: Guide to Wireless Sensor Networks”, in Proceedings of the Springer London, pp 81-111, 2009.

[56] R, Mulligan, and H. A. Ammari, "Coverage in wireless sensor networks: a survey." in Proceedings of the Network Protocols and Algorithms 2.2, pp 27-53, 2010.

[57] S. Olariu and Q. Xu. "Information assurance in wireless sensor networks", in the Proceedings of the 19th IEEE International Parallel and Distributed Processing Symposium, 2005.

[58] J N Al-Karaki, and A E Kamal, "Routing techniques in wireless sensor networks: a survey." in the Proceedings of the IEEE 11.6, Wireless communications, pp 6-28, 2004.

[59] S. Lewis, “A Basic Introduction to RFID Technology and Its use in the supply chain”, in the Proceedings of the White Paper LARAN RFID, 2004.

[60] Hodges, S, and D McFarlane, “Radio Frequency Identification: Technology, applications and impact”, in the Proceedings of the "WHITE PAPER SERIES/EDITION.", 2005.

[61] S, Shekhar and H, Xiong, “Encyclopedia of GIS”, in the Proceedings of the Springer Science & Business Media, USA, pp 943, 2008.

[62] A Clifton and I I Ericson, “Concise Encyclopedia of System Safety, Definition of Terms and Concepts”, in the Proceedings of the John Wiley & Sons, New Jersey, pp 309, 2011.

[63] K. Finkenzeller, “RFID Handbook, Fundamentals and Applications in Contactless Smart Cards and Identification,” in the Proceedings of the John Wiley and Sons Ltd, 2003.

[64] S. Lahiri, “RFID Sourcebook,” in the Proceedings of the IBM Press, USA, 2006.

[65] ScanSource Europe, POS and barcoding, “Pdf Report,” ScanSource: Home Page, 2013. [Online]. Available: http://www.scansourceposbarcode.eu/. [Accessed: 21

November 2014].

[66] E H Callaway, “Wireless Sensor Networks: Architectures and Protocols”, in the Proceedings of the CRC Press, USA, pp 2, 2004.

[67] J, Tavares, F, Velez and J Ferro, "Application of wireless sensor networks to automobiles." in the Proceedings of the Measurement Science Review 8.3, 2008, 65-70.

[68] National Academic Press, “Radio Frequency Identification Technologies: A Workshop Summary”, in the Proceedings of the National Research Council, 2004.

[69] V A Matta, “Predicting the Adoption of Radio Frequency Identification Systems in the Supply Chain,” thesis from ProQuest LLC, USA, 2008.

[70] K. H. Ko, K. Pochiraju, and S. Manoochehri, “An embedded system for knowledge-based cost evaluation of molded parts,” in the Proceedings of the Knowledge-Based Systems, vol. 20, no. 3, pp. 291–299, Apr. 2007.

[71] Jawhar, I.; Mohamed, N.; Shuaib, K. “A Framework for Pipeline Infrastructure Monitoring Using Wireless Sensor Networks”. In Proceedings of the Wireless Telecommunications Symposium (WTS’07), pp. 1–7, Pomona, CA, USA, 2007.

[72] Stoianov, I.; Nachman, L.; Madden, S.; Tokmouline, T. “PIPENET: A Wireless Sensor Network for Pipeline Monitoring”. In Proceedings of the Sixth International Conference on Information Processing in Sensor Networks (IPSN’07), pp. 264–273, Cambridge, MA, USA, 25–27 April 2007.

[73] Kim, Y.; Schmid, T.; Charbiwala, Z.M.; Friedman, J.; Srivastava, M.B. “NAWMS: Nonintrusive Autonomous Water Monitoring System”, In the Proceedings of the Sixth ACM Conference on Embedded Network Sensor Systems (SenSys’08), pp. 309–322. Raleigh, NC, USA, 2008.

[74] Lai, T.T.-T.; Chen, W.-J.; Li, K.-H.; Huang, P.; Chu, H.-H. “TriopusNet: Automating Wireless Sensor Network Deployment and Replacement In Pipeline Monitoring”. In the Proceedings of the Eleventh International Conference on Information Processing in Sensor Networks (IPSN’12), pp: 61-71, Beijing, China, 16–20, 2012.

[75] Mohamed, N.; Jawhar, I. “A Fault Tolerant Wired/Wireless Sensor Network Architecture for Monitoring Pipeline Infrastructures”, In the Proceedings of the 2nd International Conference on Sensor Technologies and Applications, (SENSORCOMM’08), pp. 179–184, Cap Esterel, France, 2008.

[76] Z. Sun , P. Wang , M. C. Vuran , M. A. Al-Rodhaan , A. M. Al-Dhelaan and I. F. Akyildiz "MISE-PIPE: Magnetic induction-based wireless sensor networks for underground pipeline monitoring", In the Proceedings of Ad Hoc Networks, vol. 9, no. 3, pp.218 -227, 2011.

[77] Akyildiz, I.F.; Stuntebeck, E.P. “Wireless underground sensor networks: Research

challenges", In the Proceedings of Ad Hoc Networks, vol. 4, pp.669–686, 2006.

[78] Kadri, A.; Abu-Dayya, A.; Trinchero, D.; Stefanelli, R. "Autonomous Sensing for Leakage Detection in Underground Water Pipelines", In Proceedings of the Fifth IEEE International Conference on Sensing Technology, (ICST'11), pp. 639–643, Palmerston North, New Zealand, 2011.

[79] Gerald. C and Azubogu. O, "Design and Implementation of Pipeline Monitoring System Using Accerlation-based WSN", In Proceedings of the IJES, pp:49-58, 2014.

[80] Shinozuka. M et al, "Nondestructive Monitoring of Pipe Network using a MEMS-based Wireless Network", Available at: http://www.ece.uci.edu/~chou/pdf/chou-spie10.pdf, Accessed On: 16th Nov 2014.

[81] A. Nasir, S. Hussain, B. Soong, K. Qaraqe, "Energy Efficient Cooperation in Underlay RFID Cognitive Networks for a Water Smart Home", In Proceedings of the MDPI Sensors, pp:18353-18369, 2014.

[82] Almazyad, A.S., Seddiq, Y.M., Alotaibi, A.M., Al-Nasheri, A.Y., BenSaleh, M.S., Obeid, A.M., Qasim, S.M., "A Proposed Scalable Design and Simulation of Wireless Sensor Network-Based Long-Distance Water Pipeline Leakage Monitoring System." In the proceedings of Sensors, vol.14, pp: 3557–3577, 2014.

[83] J. Kim , G. Sharma , N. Boudriga and S. Iyengar, "SPAMMS: A Sensor-Based Pipeline Autonomous Monitoring and Maintenance System", In the Proceedings of International Conference on Communication System Networks, pp.1 -10 2010.

[84] Johnson, P., Kapadia, A., Kotz, D., and Triandopoulos, N., "People-Centric Urban Sensing: Security Challenges for the New Paradigm", Available at: http://www.cs.bu.edu/~nikos/papers/challenges.pdf, Accessed on: 16th Nov 2014.

[85] Nicholas D. Lane , Shane B. Eisenman , Mirco Musolesi , Emiliano Miluzzo , Andrew T. Campbell, "Urban Sensing Systems: Opportunistic or Participatory?" In Proceedings of the 9th Workshop Mobile Computing Systems and Applications (WMCSA 08), ACM Press, 2008.

[86] Pidcock. S et al, "NotiSense: An Urban Sensing Notification System to Improve Bystander Privacy", Available at: http://www.cypherpunks.ca/~iang/pubs/notisense.pdf, Accessed On: 16th Nov 2014.

[87] Mohammd Jalil Piran, G. Ramma Murthy, "A Novel Routing Algorithm for Vehicular Sensor Networks", In the Proceedings of Scientific Research Publishing, WSN, USA, pp. 919-923, December 2010.

[88] U. Lee, E. Magistretti, M. Gerla, Bellavista, and A. Corradi, "Dissemination and harvesting of urban data using vehicular sensor platforms", In IEEE Transaction on Vehicular Technology, 2008 Available at: http://mslab.kaist.ac.kr/wikipages/files/mobeyes_tr.pdf, Accessed On:16th Nov 2014,

[89] Gao. H and Utecht. S, “High Speed Data Routing In VSN,” Journal of Communications, vol 5, pp:181-189, 2010.

[90] P. Levis, N. Lee, M. Welsh, and D. Culler, "TOSSIM: Accurate and scalable simulation of entire TinyOS applications," in the proceedings of the 1st International Conference on Embedded Networked Sensor Systems, pp. 126-137, Los Angeles, CA, United States, 2003.

[91] F. H. Desbrandes, S. Bertolotti, and L. Dunand, “OPNET 2.4: an environment for communication network modeling and simulation,” in the Proceedings of European Simulation Symposium, p. 609–14, Ghent, Belgium, Oct.1993.

[92] G. Pongor, "OMNeT: Objective modular network testbed," in International workshop on Modeling, Analysis, and Simulation on Computer and Telecommunication Systems (IEEE Cat. No.93th0514-0), pp. 323-6, San Diego, CA, USA, 1993.

[93] A. Sobeih, J. C. Hou, K. Lu-Chuan, L. Ning, Z. Honghai, C. Wei-Peng, T. Hung-Ying, and L. Hyuk, "J-Sim: a simulation and emulation environment for wireless sensor networks," in the Proceedings of IEEE Wireless Communications, vol. 13, pp. 104-19, 2006.

[94] "SNetSim”, Internet: http://www.softpedia.com/get/Science-CAD/SNetSim.shtml, 21 November 2014.

[95] S. Park, A. Savvides, and M. B. Srivastava, “SensorSim: A simulation framework for sensor networks,” in the Proceedings of ACM MSWiM the 3rd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 104–111, Boston, MA, United States, August 2000.

[96] S. Sundresh, K. Wooyoung, and G. Agha, "SENS: a sensor, environment and network simulator," in proceedings of the 37th annual symposium on simulation: IEEE Computer Society, pp. 221-8, Los Alamitos, CA, USA, 2004.

[97] B. Yun, M. Ke-qi-lao, H. Jian-feng, R. Zhi-gang, and X. Li, “Mobile network simulation based on NS-2,” In the proceedings of Railway Computer Application, vol. 18, no. 2, pp. 22–5, Feb. 2009.

[98] J. Polley, D. Blazakis, J. McGee, D. Rusk, J. S. Baras, and M. Karir, "ATEMU: A fine-grained sensor network simulator," in the Proceedings of Sensor and Ad Hoc Communications and Networks, 2004. IEEE SECON. First Annual IEEE Communications Society Conference, pp. 145-152, United States, 2004.

[99] B. L. Titzer, D. K. Lee, and J. Palsberg, "Avrora: Scalable sensor network simulation with precise timing," in the Proceedings of Fourth International Symposium on Information Processing in Sensor Networks, IPSN, pp. 477-82, USA, 2005.

[100] M. Tao and S. Hong, “Modeling and simulation of a mobile ad-hoc network based

on QualNet," Electronics Optics & Control, vol. 16, no. 4, p. 60–4, Apr. 2009.

[101] S. Sinha, Z. Chaczko, and R. Klempous, R. Moreno-Díaz, F. Pichler, and A. Quesada-Arencibia, Eds. "SNIPER: A Wireless Sensor Network Simulator," in Computer Aided Systems Theory - EUROCAST 2009, vol. 5717, pp. 913-920, Berlin, Heidelberg, 2009.

[102] Y. Sangho, M. Hong, C. Yookun, and H. Jiman, "SensorMaker: A wireless sensor network simulator for scalable and fine-grained instrumentation," in Proceedings of the International Conference on Computational Science and its Applications, pp. 800-10, Part I Perugia, Italy: Springer-Verlag Berlin, Germany, 2008.

[103] L. Nachman, J. Huang, J. Shahabdeen, R. Adler, and R. Kling, "IMOTE2: Serious Computation at the Edge," in the Proceedings of International Wireless Communications and Mobile Computing Conference, IWCMC '08, pp. 1118-1123, Crete, Greece, August 2008.

[104] A. Prayati, C. Antonopoulos, T. Stoyanova, C. Koulamas, and G. Papadopoulos, "A modeling approach on the TelosB WSN platform power consumption," Journal of Systems and Software, vol. 83, no. 8, p. 1355–63, 2010.

[105] M. Kramer, A. Geraldy, "Energy measurements for micaz node," in technical report, Technical University Kaisers Lautern, GI/ITG KuVS, 1–7, Rep. 2006.

[106] J. Heidemann and D. Wei Ye, "Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks", in the Proceedings of IEEE Communications Letters, vol. 12, no 3, pp. 493 – 506, June 2004.

[107] T. Van Dam, K. Langendoen, "An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks," in the Proceedings of SenSys'03 the First International Conference on Embedded Networked Sensor Systems, pp. 171-180, Nov. 2003.

[108] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in the Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems, SenSys'04, pp. 95–107, Baltimore, MA, United states, November, 2004.

[109] C. Floerkemeier and S. Sarma, "RFIDSim—A Physical and Logical Layer Simulation Engine for Passive RFID," in the proceedings of IEEE Transactions on Automation Science and Engineering, vol. 6, no. 1, pp. 33-43, Jan. 2009.

[110] M. C. de Azambuja, C. F. Jung, C. S. ten Caten, and F. P. Hessel, "RFID-Env: Methods and software simulation for RFID environments," in the proceedings of Business Process Management Journal, vol. 16, no. 6, pp. 1014-1038, Sep. 2010.

[111] A. Nasir, Boon-Hee Soong, "PipeSense: A framework architecture for in-pipe water monitoring system," In the proceedings of the 9th IEEE Malaysia International Conference on Communications, pp. 703-708, Kuala Lumpur, Malaysia 2009.

[112] A. Nasir, B. Soong and S. Ramachandran, "Framework of WSN based human

centric cyber physical in-pipe water monitoring system," 11th International Conference on Control, Automation, Robotics and Vision, ICARCV 2010, 10 December, Singapore, 2010.

[113] A. Nasir and B. Soong, "WSN-based Human-Centric Water Smart Home," in the proceedings of 8th IEEE Asia Pacific Wireless Communication Symposium (IEEE APWCS 2011) Singapore, Aug 2011.

[114] ETH Zurich, "OpenSense Project Overview", Available at: http://www.opensense.ethz.ch/trac/. [accessed on 21 November 2014].

[115] C. Fu, H. Lim, A. Nasir, S. Srirangarajan, B. Wang, S. Wong, B. Soong, "An Integrated Framework for Vehicular and Urban Sensing," accepted in IEEE Workshop on Networking Intelligent Vehicles and Infrastructures (IEEE NiVi09) Co-located with IEEE GLOBECOM, Nov at Honolulu, Hawaii, USA, 2009.

[116] A. Nasir, B. Soong, "A Simulation Platform for Evaluating RFID and WSN's Energy Efficiencies", Published in JCOMSS - Journal of Communications Software and Systems for September issue 2013.

[117] Yoon.S et al, "SWATS: WSN for Steam flood and water flood pipeline monitoring systems", Available at: http://www.isi.edu/~johnh/PAPERS/Yoon09a.pdf, Accessed On: 21st Nov 2014

[118] Sadeghioon.M et al, "SmartPipes: Smart WSN for leak detection in water pipelines", Journal of Sensor and Actuator Networks, pp: 64-78, 2014.

[119] Kim.J, "Sensor-based Autonomous Pipeline Monitoring Robotic system", 2011, Available at: http://etd.lsu.edu/docs/available/etd-11072011-223443/unrestricted/PhD-Jong-Hoon_Kim.pdf, Accessed On: 21st Nov 2014.

[120] EMPro 3D EM Simulation Software, available at : [http://www.home.agilent.com/agilent/product.jspx?nid=-34278.0.00&lc=eng&cc=SG].

[121] Studio, Microwave. "CST-Computer Simulation Technology." Bad Nuheimer Str 19: 64289, 2008.

[122] Telit Wireless Solutions, available at: [http://www.telit.com/].

[123] United States Environmental Protection Agency, "EPANET," retrieved April 2009. [Online]. Available: http://www.epa.gov/nrmrl/wswrd/dw/epanet.html.

[124] R. Oleson, D. J. Kaup, T. L. Clarke, L. C. Malone, L. Boloni, "'Social Potential' Models for Modeling Traffic and Transportation, in Multi-Agent Systems for Traffic and Transportation," IGI Global 2009, pp 155-175.

[125] M. Brameier and W. Banzhaf, "A comparison of linear genetic programming and neural networks in medical data mining," IEEE Trans, Evol. Comput., vol. 5, pp. 17–26, Feb. 2001.

[126] T. Koski, “Hidden Markov Models for Bioinformatics,” Computational Biology Series, vol. 2, Kluwer Academic Publishers, Dordrecht (2001) Springer, 2001.

[127] Press, William H. “Numerical recipes 3rd edition: The art of scientific computing,” Cambridge university press, 2007.

[128] I. Bierhoff, A. van Berlo, et al., “Towards an inclusive future,” In: COST, pp. 110–156, 2007.

[129] X. Li, G. Xu and L. Li, "RFID based smart home architecture for improving lives," 2nd International Conference on Anti-counterfeiting, Security and Identification (2008 ASID), p 440-3, Guiyang, China, 2008.

[130] S. Fine, Y. Singer, N. Tishby, “The Hierarchical Hidden Markov Model: Analysis and Applications, “ In the proceedings of Machine Learning, vol. 32, no. 1, pp. 41-62, 1998.

[131] K. Moon, “The expectation maximization algorithm,” IEEE Signal Processing Magazine, vol. 13, pp. 47-60, 1996.

[132] S. Haykin, Cognitive radio: Brain-empowered wireless communications, in the proceedings of IEEE, J. Sel. Areas Commun., vol. 23, no. 2, pp. 201-220, 2005.

[133] A. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, “Breaking spectrum gridlock with cognitive radios: An information theoretic perspective”, Proceedings of the IEEE, vol. 97, no. 5, pp. 894 - 914, May 2009.

[134] T. S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed., city/state?: Prentice Hall, 2002.

[135] C. C. Chen, “Attenuation of Electromagnetic Radiation by Haze, Fog, Cloud and Rain,” Report R-1694-PR, The Rand Corp, pp. 5, April 1975.

[136] Heddier Electronic GmbH, RFID PICO-Module development kit. Available at http://http://www.heddier.com/electronic/, 2013.

[137] A. Nasir, B. Hock, and S. Hee. “An Integrated Vehicular and Urban Sensing System: Framework and Modeling.” In the proceedings of International Conference on Information Networking (ICOIN), pp. 159 –164, Bali, Indonesia 2012.

[138] Figaro Engineering Inc., Figaro semiconductor gas sensors, [http://www.figaro.co.jp/].

[139] W. V. Beek, H. Derriks, P. Wilbers, P. Morsink, L. Wismans, P. V. Beek, “The effects of speed measures on air pollution and traffic safety,” in: European Transport Conference, pp. 1-17, 2007.

[140] F. N. S. Bovelli, and C. Heller, "A novel antenna design for passive RFID transponders on metal surfaces", in the proceedings of 36th European Microwave Conference, pp. 580–582, Manchester , UK, 2006.

[141] M. Hata, “Empirical formula for propagation loss in land mobile radio service,” in the Proceedings of IEEE Transactions on Vehicular Technology, vol. VT-29, pp.

317-325, Sep 1981.

[142] V. Erceg, L. J. Greenstein, et al., “An empirically based path loss model for wireless channels in suburban environments,” in the Proceedings of IEEE Journal on Selected Areas of Communications, vol. 17, pp. 1205-1211, July 1999.

[143] J. Kunthong and C. F. Bunting, “A novel hybrid propagation model,” in the Proceedings of IEEE Antennas and Propagation Society International Symposium, AP-S, pp. 1-4, 2008.

[144] D. D. Arumugam and D. W. Engels, “Characterization of passive UHF RFID tags in toroidal metal pipes,” in the Proceedings of IEEE Antennas and Propagation Society International Symposium, APSURSI ’09, pp. 1-4, 2009.

[145] D. D. Arumugam and D. W. Engels, "Characterization of RF propagation in helical and toroidal metal pipes for passive RFID systems," published in conference on RFID, IEEE International Las Vegas, NV, pp. 269-276, United States, 2008.

[146] D. D. Arumugam and D. W. Engels, “Characterisation of RF propagation in metal pipes for passive RFID systems,” in the Proceedings of International Journal of Radio Frequency Identification Technology and Applications, vol. 1, no. 3, pp. 303 – 343, 2007.

[147] H. Zangl, A. Fuchs, T. Bretterklieber, M. J. Moser, and G. Holler, “Wireless Communication and Power Supply Strategy for Sensor Applications Within Closed Metal Walls,” in the Proceedings of IEEE Transactions on Instrumentation and Measurement, vol. 59, no. 6, pp. 1686-1692, Jun. 2010.

[148] J. Heidemann and D. Wei Ye, "Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks " in the Proceedings of IEEE Communications Letters, vol. 12, no 3, pp. 493 – 506, June 2004.

[149] A. Prayati, C. Antonopoulos, T. Stoyanova, C. Koulamas, and G. Papadopoulos, “A modeling approach on the TelosB WSN platform power consumption,” Journal of Systems and Software, vol. 83, no. 8, p. 1355–63, 2010.

[150] “All about batteries.” Available at internet: http://www.allaboutbatteries.com/Energy-tables.html, 20 July 2013.

[151] M. Fiore, A. Nordio, C.-F. Chiasserini, "Investigating the accuracy of mobile urban sensing," in the proceedings of 10th Annual Conference on Wireless On-demand Network Systems and Services (WONS), 2013 , pp-25-28, Alberta, Canada, 2013.

[152] R. Du, C. Chen, B. Yang, N. Lu, X. Guan, X. Shen, " Effective Urban Traffic Monitoring by Vehicular Sensor Networks", in the proceedings of IEEE Transactions on Vehicular Technology, issue: 99, pp-1, 2014.

[153] M. Di Felice, A. J. Ghandhour, H. Artail, L. Bononi," Integrating Spectrum Database and Cooperative Sensing for Cognitive Vehicular Networks", in the proceedings of IEEE 78th Vehicular Technology Conference (VTC Fall), pp-1-7,

Las Vegas, USA, 2013.

[154] Haofu Han, Jiadi Yu, Hongzi Zhu et al, "SenSpeed: Sensing driving conditions to estimate vehicle speed in urban environments", in the proceedings of IEEE INFOCOM, pp-727-735, Toronto, Canada, 2014.

[155] David Hasenfratz, Olga Saukh, Silvan Sturzenegger, and Lothar Thiele, "Participatory Air Pollution Monitoring Using Smartphones," in the proceeding of the 2nd International Workshop on Mobile Sensing, Beijing, China, 2012.

[156] R. Jurdak, A. G. Ruzzelli, and G. O'Hare, "Multi-Hop RFID wake-up radio: design, evaluation and energy tradeoffs," published in 17th International Conference on Computer Communications and Networks, St. Thomas, US Virgin Islands, 2008.

[157] D. K. Klair and K.-W. Chin, "A novel anti-collision protocol for energy efficient identification and monitoring in RFID-enhanced WSNs," published in Proceedings of 17th International Conference on Computer Communications and Networks, pp. 22-29, St. Thomas, US Virgin Islands, USA, 2008.

[158] P. Bellavista, E. Magistretti, U. Lee, and M. Gerla, "Standard Integration of Sensing and Opportunistic Diffusion for Urban Monitoring in Vehicular Sensor Networks: the MobEyes Architecture," Proc. Industrial Electronics (ISIE'07). IEEE Intl. Sym., pp. 2582-2588, 2007.

[159] Hu, S.-C., Wang, Y.-C., Huang, C.-Y., & Tseng, Y.-C, “A Vehicular Wireless Sensor Network for CO2 Monitoring”, in the Proceeding of IEEE Sensors, ISBN 978-1-4244-4558-6, pp. 1498-1501, 2009.

Author's Publications

Journals

1. A. Nasir, B. Soong, "A Simulation Platform for Evaluating RFID and WSN's Energy Efficiencies", Published in JCOMSS - Journal of Communications Software and Systems for September issue 2013.

2. A. Nasir, S. Hussain, B. Soong, K. Qaraqe, "Energy Efficient Cooperation in Underlay RFID Cognitive Networks for Water Smart Home", Published in MDPI journal, special issue: Sensors for Fluid Leak Detection, 2014.

Conferences

3. Adnan Nasir, Boon Hee Soong and Khalid A. Qaraqe, "RFID In-pipe Moisture Sensing System for Oil and Gas Quality Monitoring in Qatar," In the proceedings of 19th IEEE International Conference on Networks (ICON), pp.1-5, Singapore, Dec 2013.
4. A. Nasir, A.R. Ekti, K.A. Qaraqe, E. Serpedin, "A human centric approach for RFID based quality monitoring system for gas pipelines", In the proceedings of Mosharaka International Conference on Communications, Computers and Applications (MIC-CCA), pp. 169 - 173, ISBN: 978467352307, Istanbul, Turkey, 2012.
5. A. Nasir, B. Hock, and B. Soong. "An Integrated Vehicular and Urban Sensing System: Framework and Modeling." In 2012 International Conference on Information Networking (ICOIN), pp. 159 –164, Bali, Indonesia, 2012.
6. A. Nasir and B. Soong, "WSN-based Human Centric Water Smart Home," AWPCS Singapore 2011.
7. A. Nasir and B. Soong, "EnergySim - A Novel, Fast, Extensible Wireless Sensor Network MAC Protocol Simulator for Evaluating Energy Efficiency," International High Speed Intelligent Communication (HSIC) Forum Singapore 2010.
8. A. Nasir, B. Soong and R. Selvakumaran, "Framework of WSN based human centric cyber physical in-pipe water monitoring system," 11th International Conference on Control, Automation, Robotics and Vision ICARCV, Singapore, 2010.
9. A. Nasir and B. Soong, "PipeSense A framework architecture for in-pipe water monitoring system," accepted in the Ninth IEEE Malaysia International Conference on Communications (MICC 2009) Kuala Lumpur Malaysia, 2009.

10. A. Nasir and B. Soong , "EnvironSense: An Integrated System for Urban Sensing Using RFID based WSNs," in the Proceedings of IEEE TENCON, pp.1-5, Singapore , Jan. 2009.
11. C. Fu, H. Lim, A. Nasir, S. Srirangarajan, B. Wang, S. Wong, B. Soong, "An Integrated Framework for Vehicular and Urban Sensing," accepted in IEEE Workshop on Networking Intelligent Vehicles and Infrastructures (IEEE NiVi09) Co-located with IEEE GLOBECOM, Nov at Honolulu, Hawaii, USA, 2009.
12. A. Nasir, M. A. Abbasi, S. Q. Hassan and M. Tariq, "Integrated underwater Secure Communication System (IUSC) for Autonomous Underwater Vehicle," published in Proceedings of 5th International Bhurban Conference on Applied Sciences and Technology (IBCAST), Islamabad, Pakistan, January 2007.