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Investigation on Design and Development Methods for Internet of Things

Yazeed Al Zahrani

This thesis is presented as part of the requirements for the conferral of the degree:

Doctor of Philosophy

Supervisor:
Professor: Jun Shen,
A/ Professor: Jun Yan

The University of Wollongong
School of Computing and Information Technology
Faculty of Engineering and Information Sciences

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Declaration

I, *Yazeed Al Zahrani*, declare that this thesis is submitted in partial fulfilment of the requirements for the conferral of the degree *Doctor of Philosophy*, from the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Yazeed Al Zahrani

April 23, 2023

Abstract

The thesis work majorly focuses on the development methodologies of the Internet of Things (IoT). A detailed literature survey is presented for the discussion of various challenges in the development of software and design and deployment of hardware. The thesis work deals with the efficient development methodologies for the deployment of IoT system. Efficient hardware and software development reduces the risk of the system bugs and faults. The optimal placement of the IoT devices is the major challenge for the monitoring application. A Qualitative Spatial Reasoning (QSR) and Qualitative Temporal Reasoning (QTR) methodologies are proposed to build software systems. The proposed hybrid methodology includes the features of QSR, QTR, and traditional data-based methodologies. The hybrid methodology is proposed to build the software systems and direct them to the specific goal of obtaining outputs inherent to the process. The hybrid methodology includes the support of tools and is detailed, integrated, and fits the general proposal. This methodology repeats the structure of Spatio-temporal reasoning goals. The object-oriented IoT device placement is the major goal of the proposed work. Segmentation and object detection is used for the division of the region into sub-regions. The coverage and connectivity are maintained by the optimal placement of the IoT devices using RCC8 and TPCC algorithms.

Over the years, IoT has offered different solutions in all kinds of areas and contexts. The diversity of these challenges makes it hard to grasp the underlying principles of the different solutions and to design an appropriate custom implementation on the IoT space. One of the major objective of the proposed thesis work is to study numerous production-

ready IoT offerings, extract recurring proven solution principles, and classify them into spatial patterns. The method of refinement of the goals is employed so that complex challenges are solved by breaking them down into simple and achievable sub-goals. The work deals with the major sub-goals e.g. efficient coverage of the field, connectivity of the IoT devices, Spatio-temporal aggregation of the data, and estimation of spatially connected regions of event detection. We have proposed methods to achieve each sub-goal for all different types of spatial patterns. The spatial patterns developed can be used in ongoing and future research on the IoT to understand the principles of the IoT, which will, in turn, promote the better development of existing and new IoT devices.

The next objective is to utilize the IoT network for enterprise architecture (EA) based IoT application. EA defines the structure and operation of an organization to determine the most effective way for it to achieve its objectives. Digital transformation of EA is achieved through analysis, planning, design, and implementation, which interprets enterprise goals into an IoT-enabled enterprise design. A blueprint is necessary for the readying of IT resources that support business services and processes. A systematic approach is proposed for the planning and development of EA for IoT-Applications. The Enterprise Interface (EI) layer is proposed to efficiently categorize the data. The data is categorized based on local and global factors. The clustered data is then utilized by the end-users. A novel four-tier structure is proposed for Enterprise Applications. We analyzed the challenges, contextualized them, and offered solutions and recommendations.

The last objective of the thesis work is to develop energy-efficient data consistency method. The data consistency is a challenge for designing energy-efficient medium access control protocol used in IoT. The energy-efficient data consistency method makes the protocol suitable for low, medium, and high data rate applications. The idea of energy-efficient data consistency protocol is proposed with data aggregation. The proposed protocol efficiently utilizes the data rate as well as saves energy. The optimal sampling rate selection method is introduced for maintaining the data consistency of continuous and pe-

riodic monitoring node in an energy-efficient manner. In the starting phase, the nodes will be classified into event and continuous monitoring nodes. The machine learning based logistic classification method is used for the classification of nodes. The sampling rate of continuous monitoring nodes is optimized during the setup phase by using optimized sampling rate data aggregation algorithm. Furthermore, an energy-efficient time division multiple access (EETDMA) protocol is used for the continuous monitoring on IoT devices, and an energy-efficient bit map assisted (EEBMA) protocol is proposed for the event driven nodes.

Acknowledgment

All praises are due to Allah, The Most Beneficent, The Most Merciful, Who has enabled me to accomplish my PhD study. All the goals that I have achieved are due to His mercy; while all the mistakes are mine.

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List of Symbols

X_i	Data sample at i^{th} iteration
X_{i-1}	Data sample at $i-1^{th}$ iteration
X_L	Lower Threshold Limit
N	Total number of nodes
n	n^{th} sensor node
i	i^{th} iteration
X_{iM}	Mean value for i^{th} iteration
X_{iSTD}	Standard Deviation for i^{th} iteration
f_{Dev}	Function Deviation
N_c	Number of continuous monitoring nodes
P_t	Transmit Power
P_r	Receive Power
P_i	Idle state power
T_c	Time Duration of control packet
T_{ch}	Time Duration of cluster head control packet
T_d	Time Duration of data packet
T_e	Time Duration for checking buffer
N_e	Number of Event monitoring nodes
q	Probability of generation of data packet by event monitoring node

List of Abbreviations

IoT	Internet of Things
SDDS	System Design and Development Methodologies
GORE	Goal-oriented requirements engineering
RF	Radio Frequency
VR	Virtual Reality
AR	Augmented Reality
AI	Artificial Intelligence
SR	Spatial Reasoning
QSR	Qualitative Spatial Reasoning
QTR	Qualitative Temporal Reasoning
RCC8	Region Connection Calculus
TPCC	Ternary Point Configuration Calculus
SDWIT	Spatial Data Warehouse system in IoT environments
BD	Big Data
MDD	Model-Driven Design
SOA	Service-Oriented Approach
HDS	Hardware-Defined Software
SPWIT	Spatial Data Warehouse system in IoT environments
UBI	Usage-Based Insurance
IIoT	Industrial Internet of Things
EI	Enterprise Interface
SVM	Support Vector Machine
QoE	Quality of Experience

ECCM	Existing clustering cum classification
EETDMA	Energy efficient time division multiple access
EEBMA	Energy-efficient bit map assisted
SN	Sensor node
CH	Cluster Head
ML	Machine learning
DADCZ	Data Aggregation Data Consistency Zonal Protocol
LEACH	Low-Energy Adaptive Clustering Hierarchy
TDMA	Time Division Multiple Access
EATDMA	Energy Adaptive Time Division Multiple Access
BMA	Bit Map Assisted
EEBMA	Energy Efficient Bit Map Assisted
ZEP	Zonal Elective Protocol
SEP	Stable Election Protocol
TLHA	Two Layer Hierarchical Aggregation
RFD	Reduced Function Device
FFD	Fully Function Device
CG-E2S2	Consistency Guaranteed-Energy Efficient Sleep Scheduling
OSRDAA	Optimized Sampling Rate Data Aggregation Algorithm
LCCDA	Low complexity Comparison Data Aggregation

Published Papers

Yazeed AlZahrani, *Methodologies for Internet of things: For all commercial and industries needs*, Recent Trends & Best Practices in Industry 4.0, River Publishers, 2022

Yazeed AlZahrani, Jun Shen, Jun Yan, *Multi-Layer Efficient Data Classification Methods for Enterprise Business Applications*, 2022 The Tenth International Conference on Advanced Cloud and Big Data (CBD), IEEE, 2022 [153]

Yazeed AlZahrani, Jun Shen, Jun Yan, "*Spatial Goal Refinement Patterns for IoT Applications*, 2022 IEEE International Conference on Edge Computing and Communications (EDGE), 2022, pp. 50-59, doi: 10.1109/EDGE55608.2022.00019 [1]

Yazeed AlZahrani, Jun Shen, Jun Yan, *The Spatio-temporal Hybrid Development Methodology for Smart IoT: A Review-based Study*, International Conference on Intelligent Education and Intelligent Research, IEEE, 2022 [152]

Yazeed AlZahrani, Jun Shen, Jun Yan, *Energy-Efficient Data Consistency based Sampling Rate Optimization and Aggregation Method for IoT*, The 2023 26th International Conference on Computer Supported Cooperative Work in Design (CSCWD 2023), IEEE, 2023

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction

It is widely assumed that the application of methodologies has a substantial impact on the creation of quality management systems. A development technique is mostly used to co-ordinate the process of developing large-scale, complex systems that require a significant financial investment. IoT systems, like any other system, must be built in a systematic way to meet both functional and non-functional requirements. IoT system development is more difficult than traditional software development, and it comes with its own set of challenges. Although some IoT system design and development methodologies (SDDMs) have been proposed in the literature, an overview and evaluation of SDDMs for IoT are still needed.

System development is a challenging task in general, but it is extremely complex when dealing with systems that combine software, hardware, and communication components. To reduce and control this complexity, many SDDMs have been proposed. The use of such procedures provides a number of advantages. IoT system development is likewise a challenging process that necessitates working with a diverse set of components. The purpose of an IoT SDDM is to guide a project team through the process of constructing and combining these components to meet user requirements.

An SDDM is a way for creating a system based on instructions and rules in a methodical manner. In this thesis, the development of an IoT system is referred to as SDDM. SDDM is preferred over the ”software development process” concept because an IoT system involves a variety of software, hardware, and communication components. As a result, IoT system development requires a more holistic approach than software development. Because IoT systems involve software components, SDDMs can include and/or benefit from software development methodologies. The usage of SDDMs is widely regarded to be crucial in the establishment of quality systems.

SDDMs have numerous advantages as discussed below

- An SDDM gives engineers a set of recommendations for creating artefacts and ensuring that they meet the requirements outlined in a problem statement.
- SDDMs help to avoid ignored challenges in the development process by encouraging and enabling the engineer to think beyond the initial solution that comes to mind.
- SDDMs aid in the development process by ensuring logical consistency among the various processes and phases. This is especially critical when working on huge, complicated systems that are created by large groups of designers and developers.
- For team members, a development process establishes a set of common norms, criteria, and objectives.
- An SDDM aids in the development process by reducing potential errors and providing heuristic criteria for evaluating design decisions.
- An SDDM aids in the identification of critical progress milestones, primarily from an organizational standpoint. This data is required to control and coordinate the various stages of system development.

For the efficient SDDM for IoT, the goal oriented requirement engineering is important method to fulfill the requirement as per need of system.

1.1.1 Goal Oriented Requirement Engineering

We developed a framework for IoT utilizing goals in this thesis. Initial objectives are based on requirement engineering, which categorizes goals into sub-goals. Goal-oriented requirements engineering (GORE) encourages the use of goals in the elicitation, elaboration, structure, specification, analysis, negotiation, documentation, and modification of requirements. As a result, goal-oriented specifications are critical for capturing the desired outcomes of the system under development [2].
There is a form decomposition in which child nodes refine parent nodes, and the top-level goal, which is the system vision, can be considered as a root node. AND-refinement relations connect a goal to a set of sub-goals via related links, implying that in order to achieve the parent goal, all of the sub-goals refinement must satisfy. OR-refinement relations a goal of a set of refinements to alternatives, which means that one of the refinements must satisfy the parent goals in order to achieve the parent goals [3].

1.1.2 Major Goal and Subgoal

The main objective of the thesis work is to design and develop efficient methods for the deployment of IoT. The major goal is to efficiently transmit the data from field to monitoring station and to improve various performance parameters. The objective of the thesis is divided into three different categories as shown in Fig. 1.1.

- The first part deal with the application specific patterns and placement of the devices. The device placement and efficient transmission of the data using spatio-temporal aggregation methods are the major objective in this category. The analysis extended for the development of IoT network for business application. After optimal deployment of the IoT devices, the main objective is to efficiently transmit the real time data.

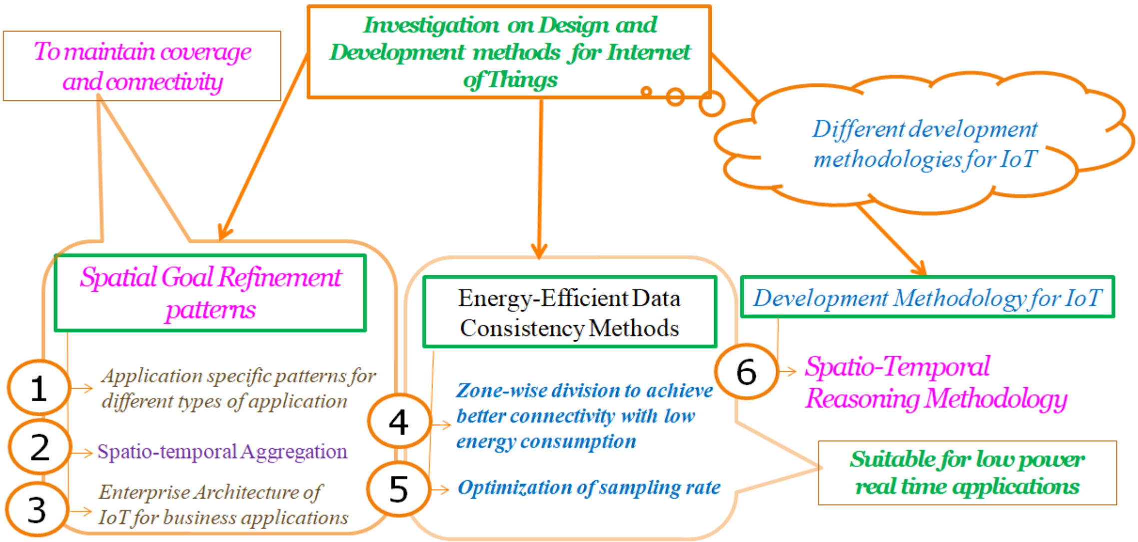

Figure 1.1: Classification of major objective of the research work

- In the second category, the main sub-goal is to develop energy-efficient real time data transmission method. The transmission of data samples with high sampling rate maintains the data consistency and received data considered as high quality real time data. However, high sampling rate increases the total data traffic and as well as energy consumption. Therefore, in this category, the major goal is to develop energy-efficient method with guaranteed data-consistency. To achieve the objective an optimized sampling rate method is proposed without compromising with the data consistency.

- In the third category, different modules of IoT development is discussed. The IoT devices are categorized into event and continuous monitoring devices. Each module output works as input of the second module. The development methodology is useful for the development of the device from the planning stage to final design stage.

The objective of each section is discussed in subsections below:

1.1.2.1 Development Methodology

This section of the project is concerned with efficient development methodologies for the deployment of IoT systems. The risk of system bugs and faults is reduced by efficient hardware and software development. However, one of the major challenges for monitoring applications is determining the best location for IoT devices. To build IoT software systems, a combined Qualitative Spatial Reasoning (QSR) and Qualitative Temporal Reasoning (QTR) methodology is proposed. QSR, QTR, and traditional data-oriented methodologies are all represented in the proposed hybrid methodology. This methodology directs software systems toward a specific goal in obtaining process outputs. The hybrid methodology includes integrated tool support and also fits the general purpose. The structure of spatiotemporal reasoning is repeated in this methodology. The region is divided into sub-regions using segmentation and object detection. Furthermore, the optimal placement of IoT devices using RCC8 and TPCC algorithms ensures coverage and connectivity.

1.1.2.2 Spatial patterns

This section discusses how spatial patterns for the Internet of Things (IoT) can be developed to aid in the resolution of problems associated with extending IoT to new domains. It is made up of interconnected devices such as sensors, embedded systems, and actuators that are primarily used in the development of smart devices and automation routines. The goal of spatial patterns for IoT is to aid current and future research on IoT offerings by providing a seamless breakdown of goals that are spatially grouped according to performance. Spatial patterns are representations of problems and solutions in specific contexts. We considered various Internet of Things contributions, separated repeating demonstrated standards, and organized them into designs. The strategy for objective refinement is used to use the goal so that the unpredictable difficulties can be addressed by breaking them down into simple and attainable sub-objectives. The section provides a library of spatial patterns, simple constructs present in each spatial pattern's definition, how the spatial pattern is used in goal refinement, and how the spatial pattern performs in the real world.

Because the spatial patterns are not defined, we will provide (a) a description of each spatial pattern, (b) an example that provides a more practical explanation, and (c) the performance of how they will be used in the real world. These spatial patterns are discussed in detail, including complete coverage, periphery pattern, center pattern, intersection volume, gradual decay, and managing irregular volume, as well as their corresponding goal refinement.

1.1.2.3 Enterprise Architecture

In this section, a four-tier architecture for the IoT Enterprise Application is proposed. Between the Application Server and the Physical Layer, an enterprise interface layer is proposed. In contrast to previous works, data in this section is clustered based on global and local parameters. The data is precisely divided into clusters using machine learning algorithms. The clustering algorithm can divide data in such a way that end-user-specific requirements can be met efficiently. The concept of categorizing mall retail products based on the specific class of customers is proposed. Customers are divided into clusters based on four key characteristics: salary, spending score, age, and gender. Customers are divided into clusters using the K-Means clustering algorithm. A classification algorithm is also proposed for predicting a specific class for the newly arrived customer. A variety of classification algorithms, including Naive Bayesian, Logistic, Decision Tree, Random Forest, SVM, Kernel-SVM, and K-NN, are compared for performance. The performance is also compared to the existing model [114]. The efficient clustering and classification increase the end-user's trust in the organization and help the organization generate more revenue. The dataset is collected using IoT devices in order to extract the various features of the customers. Revenue generation is a significant challenge for service providers in today's competitive market. An effective IoT-based Enterprise Business can categorize the data/products/e-book optimally [115]. In the proposed work, we have analyzed the performance of the retail online/offline global store/mall. However, the method can be used for different other applications [116].

1.1.2.4 Energy-Efficient Data Consistency

Data consistency is a problem when it comes to designing energy-efficient medium access control protocols for IoT. The protocol is suitable for low, medium, and high data rate applications due to its energy-efficient data consistency method. The concept of an energy-efficient data consistency protocol with data aggregation is proposed in this section. The proposed protocol makes efficient use of the data rate while also saving energy and ensuring consistency. The concept of an optimal sampling rate selection method for maintaining data consistency of continuous and periodic monitoring nodes in an energy-efficient manner is introduced. During the initial phase, nodes will be divided into the event and continuous monitoring nodes. The logistic classification method based on machine learning is used to classify nodes. During the setup phase, the optimized sampling rate data aggregation algorithm is used to optimize the sampling rate of continuous monitoring nodes. Furthermore, for continuous monitoring of IoT devices, an energy-efficient time division multiple access (EETDMA) protocol is used, and an energy-efficient bit map assisted (EEBMA) protocol is proposed for event-driven nodes.

Overall, the proposed thesis work discusses hybrid methodology for spatio-temporal goal refinement. Hybrid methodologies that combine different approaches can be highly useful for spatio-temporal goal refinement. Hybrid methodologies can combine the strengths of different approaches, such as rule-based, data-driven, and model-based methods, to create a more flexible system. This allows for better adaptation to changes in the environment, such as dynamic spatial and temporal conditions, and enables more robust goal refinement. By leveraging multiple methodologies, a hybrid approach can potentially improve the accuracy of spatio-temporal goal refinement. For example, rule-based methods can provide high-level guidance based on predefined rules, while data-driven methods can utilize historical data and machine learning algorithms to make more precise predictions. The combination of these approaches can result in better accuracy in goal refinement. Hybrid methodologies can be designed to adapt to different types of environments, ranging from static to highly dynamic spatio-temporal environments. For instance, a hybrid approach may use rule-based methods for static spatial goals and data-driven methods for dynamic temporal goals. This adaptability enables effective goal refinement in various scenarios, making it more versatile. Hybrid methodologies can also enhance the robustness of spatio-temporal goal refinement. By incorporating multiple approaches, a hybrid system can handle uncertainties and fluctuations in the environment more effectively. Hybrid methodologies can optimize resource utilization by utilizing the strengths of different approaches. For example, rule-based methods can provide fast and efficient guidance, while model-based methods can optimize resource allocation based on computational constraints. This can result in efficient use of computational resources and improved performance.

In addition, the use of machine learning techniques can greatly enhance spatio-temporal goal refinement in dynamic environments. By leveraging data-driven prediction, pattern recognition, adaptive model building, decision support, anomaly detection, and simulation and optimization approaches, machine learning can improve the accuracy, adaptability, and robustness of goal refinement processes. It can enable proactive goal adjustments based on real-time data, assist in decision-making, and optimize resource allocation. Overall, machine learning can be a valuable tool to enhance spatio-temporal goal refinement, leading to more effective goal achievement in complex and dynamic environments.

The refined thesis objectives and scopes are discussed below in the next section.

1.2 Thesis Objective and Scope

The thesis work investigates the system design and development methods for IoT Applications. The following are the major aspects to investigate:

- Efficient development methodologies for software and hardware IoT design.
- Analysis of different possible patterns for the placement of IoT devices.

- The enterprise architecture and data organization for the IoT applications.
- The energy-efficient data consistency methods for IoT Applications.

To achieve the above goal, the thesis objective is divided into four important sections.

- Development methodologies for IoT.
- Spatiotemporal patterns for the placement of IoT devices.
- The enterprise architecture for IoT.
- Energy-efficient data consistency for IoT.

To achieve all the above discussed objectives, the proposed thesis work deals with following research questions.

1.3 Research Questions

Following are the research questions for the proposed thesis work:

- What are the different methods for the hardware and software development for various IoT Applications?
- What are the application-specific patterns for different IoT-based monitoring field?
- What are the new methods and emerging technologies that can improve the development methodology for IoT?
- What are the methods for the integration of IoT infrastructure for Enterprise Architecture?
- The possible strategies for energy-efficient data consistency?

To conduct the research we have considered a few assumptions as discussed in the following section.

1.4 Research Assumptions

The following assumptions have been taken into consideration for the present thesis work.

- For the simulation analysis of the models, we have assumed ideal conditions in simulation tools.
- The sleep mode power consumption is very less with respect to trans-receiving and idle listening power consumption. Therefore, the sleep mode energy consumption is neglected in analytical models.
- For simulation analysis CC2420/CC2520 Radio Frequency (RF) trans-receiver radio is considered for IoT devices.

Various research methods are used to achieve main research objectives. The research methods are explained below.

1.5 Research methods

Particular simulation and analytical methods are used for the validation of research in all the communicated papers. Briefly, the following methods are used:

- Six different types of spatial patterns are proposed for the efficient placement of IoT devices.
- Aggregation method is implemented and analyzed on MATLAB simulator for IoT patterns.
- QSR and QTR methods are used for hybrid methodologies.
- GORE model is used for the efficient achievement of goals and sub-goals
- Optimized sampling rate data aggregation algorithm is used for energy-efficient data consistency-based transmission.

Using above discussed methods at the end of the overall, the following contributions are achieved. The main contributions are explained below:

1.6 Main contribution

The key contributions are summarized as follows:

1.6.1 *Development Methodology*

The novelty and the contribution are as follows [153]:

- A novel method is proposed for the efficient development and deployment of IoT system.
- Combined and hybrid Qualitative Spatial Reasoning (QSR) and Qualitative Temporal Reasoning (QTR) methodologies are proposed to build software systems.
- The object-oriented IoT device placement is the major goal of the proposed work.
- Segmentation and object detection are used for the division of the region into sub-regions.
- The coverage and connectivity are maintained by the optimal placement of the IoT devices using RCC8 and TPCC algorithms.

1.6.2 *Spatial Patterns*

The novelty and the contribution are as follows [1]:

- In the present thesis work, six standard spatial patterns are proposed that can be useful for the efficient placement of IoT devices.
- Most of the major applications are categorized and analyzed for the standard spatial patterns.
- To achieve the goals, it is divided into major sub-goals e.g. efficient coverage of the field, connectivity of the IoT devices, Spatio-temporal aggregation of the data, and estimation of spatially connected regions of event-detection.

- For the effective solution of the sub-goals, Spatio-temporal aggregation is proposed that filters the redundant data as well as helps the monitoring station to determine the spatially connected affected zone.
- The application-specific analysis has been done in the proposed work will be useful for the efficient implantation of IoT devices.

1.6.3 *Enterprise Architecture*

The novelty and the contribution are as follows [152]:

- A four-tier architecture is proposed for the IoT Enterprise Application.
- Between the Application Server and the Physical Layer, an enterprise interface layer is proposed.
- Unlike previously reported works, the data in the current work is clustered based on global and local parameters.
- Machine learning algorithms are capable of precisely dividing data into clusters. The hybrid clustering algorithms can divide the data in such a way that end-user-specific requirements can be met efficiently.
- This increases the end-trust of user's in the organization while also assisting the organization in generating more revenue.

1.6.4 *Energy-efficient Data consistency*

The novelty and the contribution are as follows:

- An energy-efficient data consistency-based optimal sampling rate selection method is proposed for data transmission of IoT devices.
- The machine learning (ML) based logistic regression method is proposed to categorize the devices in the event monitoring and periodic monitoring devices.

- The EETDMA and EEBMA hybrid medium access protocol is proposed for energy-efficient data transmission.

- The data aggregation is performed at the CH node for the efficient transmission of the data.

- Optimized sampling rate data aggregation algorithm is proposed for the periodic monitoring IoT devices.

The main contributions of the work are the development of a novel methodology for efficient IoT system development and deployment, the proposal of six standard spatial patterns for the placement of IoT devices, the design of a four-tier architecture for IoT enterprise applications, and the proposal of an energy-efficient data consistency-based optimal sampling rate selection method for data transmission of IoT devices. These contributions address various challenges in the field of IoT and have the potential to improve the efficiency, reliability, and energy consumption of IoT systems.

1.7 Thesis Outline

The rest of the thesis is outlined in this section. In chapter 2, the detailed literature study of the proposed thesis work is explained. Chapter 3 discusses the development methodologies for IoT applications. In Chapter 4, different types of spatial patterns are discussed for IoT applications. Chapter 5 discusses the enterprise architecture and data organization for IoT applications. Chapter 6 explained the energy-efficient data consistency for IoT. Finally, Chapter 7 summarizes and concludes with major research findings of the present work and also discusses the future scope in this field.

Chapter 2

Literature Study

2.1 Introduction

In this chapter, the literature study related to the design and development methods of Internet of Things (IoT). The IoT and Artificial Intelligence have changed the way we live, work, and earn, and the demand for secure IoT communication with low energy consumption and high data rate continues to increase rapidly. Currently, a variety of wireless networks, e.g., cellular networks and wireless local area networks, coexist and support a broad range of mobile services. Meanwhile, many new types of wireless networks are still being developed to meet the needs of emerging applications with new communication requirements, such as cognitive radio networks and wireless sensor networks. When designing these networks, not only it is important to realize the desired functionalities for new applications, but also it is crucial to investigate how to achieve the required security (deal with various attacks/threats), optimum bandwidth in energy efficient manner.

This investigation requires an interdisciplinary effort that encompasses areas of security, communication, networking, and information theory. Through information-theoretic research, we wish to find the fundamental limits of a protocols, and develop new protocol designs to access the medium that ultimately achieve these limits with high level of security. This can help to solve issues with current Internet of Things for monitoring as well as other applications. The development of the protocol is a big challenge while developing software for the various applications. The features/properties of the development can be divided into two categories, i.e., *global characteristics and local characteristics*. Majorly there are five key requirements of the development methodologies for different applications as given below:

- Physical Infrastructure
- Emerging Technologies
- System Security
- Software Analytic
- Research Methodology

In the present work, we have discussed the development methodologies for the different IoT applications.

2.2 Development Methodologies

2.2.1 Development Methodologies for IoT-based Smart Cities

Smart Cities, often known as Cities 2.0, are digital-age representations of urban living [4]. Suburban and rural residents are likely to migrate to metropolitan regions in the next years, resulting in a massive population concentration in the city center. Emerging paradigms such as Industry 4.0 are expected to support the new needs of cities [5]. Incorporating the Internet of Things (IoT) paradigm as the backbone of civilization is a critical component [6]. IoT-enabled services will generate massive amounts of data that may be used to support and optimize vital infrastructure, as well as give new insights and advancements. However, the vast majority of these data will be sensitive and should be handled invisibly so as not to jeopardize individual liberty and privacy. Today's difficulty is figuring out how to design and deploy massively networked systems that are both effective and reliable. The deployment of monitoring mechanisms in Smart Campuses is one area where we might learn something useful.

A college or university campus is a scaled-down version of a city, containing a somewhat closed community large enough to encounter many of the technological, social, and human concerns that occur at a city scale. However, to the best of our knowledge, no comprehensive and systematic survey of monitoring Smart Campus systems has been conducted. The absence of research that attempts to characterize the state-of-the-art in Smart Campus surveillance prompted the writing of this article. In light of this, the essay examines IoT-based surveillance systems in Smart Campuses, which, while comparable to Smart Cities, have some distinct characteristics that necessitate additional security and privacy protections.

We created taxonomy for these systems, as well as a score methodology for each. Physical infrastructure, supporting technologies, software analytic, system security, and research methodology were all used to evaluate the functionality of the studied systems. The taxonomy's collection of weights allows for a reliable comparative assessment and classification model of state-of-the-art systems. Furthermore, the method makes it easier to draw useful findings and inferences, as well as provide insights and guidance to essential services provided by a Smart Campus monitoring system. Finally, the survey identifies a number of research initiatives aimed towards the creation of future surveillance systems for Smart Campuses.

2.2.1.1 Spatial (Geo-graphical) IoT

The proliferation of sensors and actuators combined to support geographic IoT awareness improves Smart Campus monitoring. Because of stochastic processes based on IoT networks, geographical location prediction and time of arrival estimation are possible [7]. It is feasible to utilize a publish subscribe utility in such systems to associate sensor activity with specific geospatial data sources of observed measures for monitoring purposes [9]. Edge computing models concentrate on data collection, capturing just the most relevant data from IoT devices. Localized data sources like these are utilized to provide geospatial-based services [10]. IoT data streams, which are geospatially annotated to aid big data analytics aimed at providing campus recovery, are used to provide disaster management services [11]. By leveraging geo-located sensors' infrastructure design to deliver a secure IoT-enabled architecture, geospatial modelling is used to facilitate safe student transit within Smart Campus [12].

The research work [13] focuses on a survey on geospatial IoT, which uses context-aware personalised location-based services to provide possible geospatial analytical methodologies and monitoring applications for Smart Campus physical infrastructure. [14] proposes an event-driven architecture for asynchronous transactions across a campus sensor network by utilising spatiotemporal data sources for online analytical streaming processing. Based on data provided by wireless IoT sensors and actuators, geospatial analysis can be used to view and monitor the campus area. A technology like this is utilized to create and maintain a secure Smart Campus public space architecture [15]. A system presented in [16], which uses geospatial IoT-driven apps to provide an integrated solution for campus monitoring, supports location awareness. [17] proposes a software architecture that enables geospatial data sources analytical processing for providing Smart Campus integrated micro-services that students can use. These geospatial IoT services are required for effective campus surveillance utilities.

2.2.1.2 Smart Campus Surveillance

Sensors and actuators may be easily integrated with IoT technology for effective Smart Campus surveillance. Students are unobtrusively watched in such an atmosphere to protect their privacy and human rights. Students must be aware that they are being observed in order to provide well-being in their workplace, according to ethical and legal criteria. Monitoring public spaces is an effective deterrent to delinquent behavior, resulting in a safer environment for everyone [18], [19]. Surveillance systems in IoT-enabled Smart Campuses are also designed to catch such behavior and better understand the individual reasons and core causes. Inferences drawn from the collected data can then be used to guide delinquent behavior prevention, prediction, and early warning before it occurs, acting as a security shield for today's Smart Campus. We examine a large number of systems in the Smart Campus monitoring sector to determine their strengths and limitations in this article. The goal is to create a foundation for categorizing contemporary technologies offered in research efforts and patents based on their surveillance value. However, before we can report on the results of this survey, we need to compare systems based on the suggested taxonomy's study dimensions. To conduct a comparative analysis, we begin by defining a concrete taxonomy that takes advantage of the available systems. This taxonomy will serve as the foundation for mapping any Smart Campus surveillance system, allowing for comparisons to comparable systems in the literature. Readers and researchers will be able to discover any flaws in current research and propose efficient strategies for dealing with new frameworks in the subject using the proposed taxonomy and classification.

The development methodology for smart cities is of paramount importance as it provides a systematic approach for planning, implementing, and managing smart city initiatives. It ensures efficient resource allocation, stakeholder engagement, scalability, interoperability, and risk management. A well-defined methodology promotes effective decision-making, aligns smart city projects with the overall vision, and enhances the chances of successful implementation, ultimately contributing to the sustainable and inclusive development of smart cities.

The development methodology for the smart cities can be classified into five different sections. The first module is physical infrastructure of the smart cities as shown in Fig-2.1. There are three important parts of the physical infrastructure. The first part deals with the smart shopping malls. As shopping is one of the important part of today's life. Due to pandemic (COVID-19), the scenario of shopping is completely changes. The basic requirement of the shopping mall is to develop a smooth rush free shopping environment for the customer satisfaction. The secondary requirement of the business organization is to generate a high revenue from the system. The customer satisfaction will also increase the revenue in a long term. Therefore, the major focus of the smart shopping malls to provide a high quality service with rush free environment. For this door-to-door delivery through online shopping is already popular and are used by the customers. However, there are two major challenges with this technology. The first challenge is that in some cases, the online view of the product is comparably far different than the exact view of the product. This effects the trust of the customer to the organization as well as it also increases the losses of the organization due to return arrangement of the product. The challenge can be addressed by the advancement of the virtual reality (VR) and augmented reality (AR). The second challenge is to provide the online details of the customer density in the mall for the efficient management of the customer density in the mall.

The second important part of the physical architecture of the smart cities is to develop smart buildings for the home and offices. As the demand of the data rate is increasing day by day and therefore the researchers are working to higher frequency range. The 5G already shifted mm-wave range and in 6G, the researchers are working on 150 GHz. Few of the researchers are working in terahertz range for the efficient data transmission. However, the higher frequency shift causes many drawbacks for the infrastructure. The range of the signals reduces for the higher frequency. This will increase the demand of base stations and will increase the density of base station in a particular area. However, the size of the base station will also be reduce. Thus, in the modern smart buildings, we can install the base stations for the buildings. this will improve the communication quality of the system.

The third important part of the smart cities is to develop smart energy system (smart grid). The distribution of the energy is one of the important challenge for the smart cities. IoT based smart grid method can be used for the power distribution and also for smart metering. For this each smart building can be connected to the smart grids. The smart grid we can connect to the IoT Cloud and users can control all the appliances through the IoT cloud.

The next important part of the smart cities is new emerging technologies as shown in Fig-2.2.The new emerging technologies can be categorized into five different parallel sec-

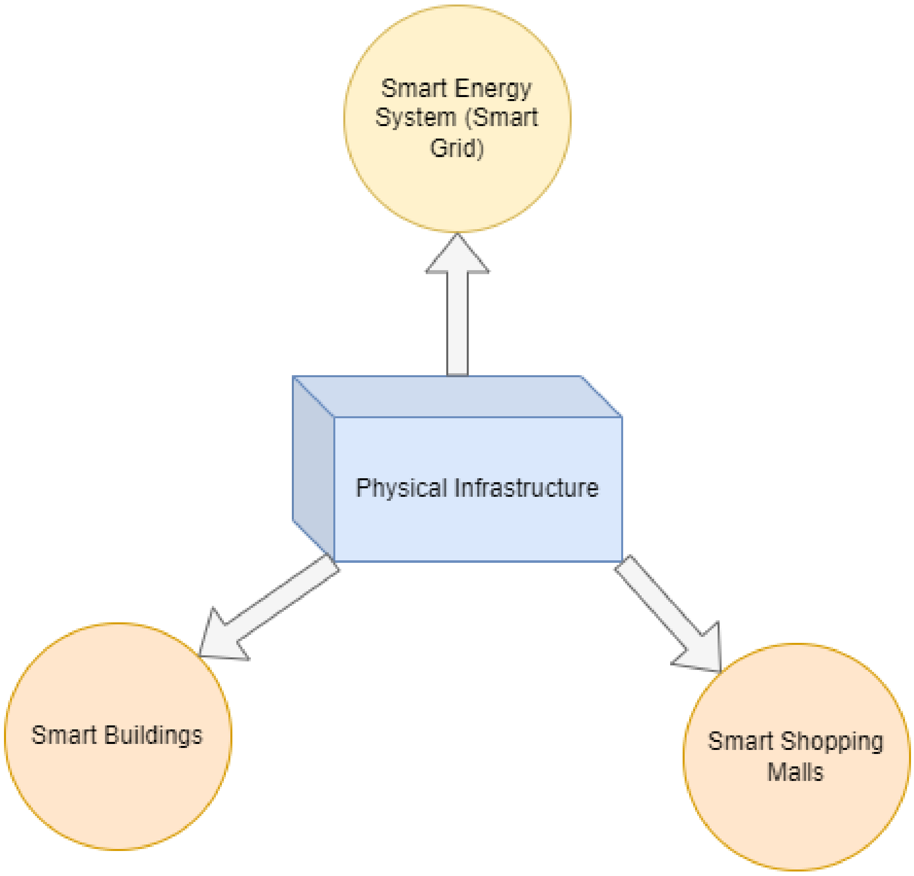

Figure 2.1: Physical Infrastructure of Smart Cities

tions. The first module is adaptability with 5G telecommunication technology. The 5G supports various methods for the integration of other emerging technologies. The high bandwidth availability at mm-Wave range provides short range high data rate communication. The cognitive radio is the second strong field for the data communication. The VHF, UHF and other traditional radio channel frequencies are not utilized now a days due to digital communication methods. Also many other bands are not optimally utilized all the times. Many of the devices doesn't transmit the data all the times. The cognitive radio devices can sense the not utilized bandwidth range and the data can be transmitted through the free channel. The cognitive radio can also be utilize 5G telecommunication range. Apart from that core IoT technologies can also play an important role for smart cities. Active monitoring of temperature, humidity, wind speed , and other air pollution parameter is very important for air quality index and weather for-casting. Similarly, passive monitoring of device performance is also important for the internal monitoring of the local devices.

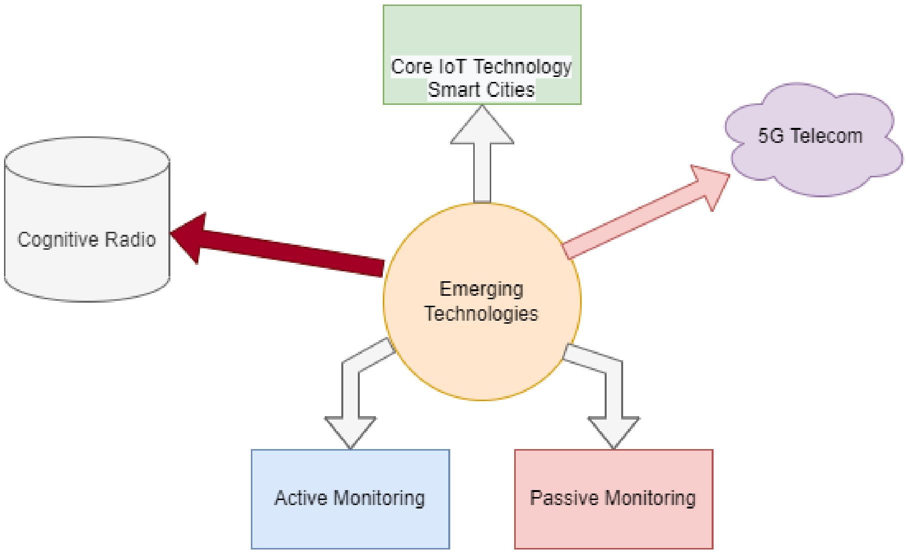

Figure 2.2: Emerging Technologies for Smart Cities

The third important structure of the important smart city is system security as shown in Fig-2.3. The security of the system is one of the most important part of any system. The security requirement depend upon the type of the application. The concept of the smart city is totally based on cloud and internet. Therefore, security standards should be very high. In the smart cities, complete banking system as well as local government data will also utilize cloud services. Thus, the security requirement depends upon some important factors. In today's scenario, blockchain provides distributed security which is more safer as compared to the other security methods. To analyze the security of the network, few trust parameters can be considered based on the security requirement, e.g., latency, efficiency etc. The proposed application specific model can be analyzed for the different attack models. The different standard attack models helps to analyze the security of the protocol.

The software analysis is also one of the important part of all the IoT applications as shown in Fig-2.4. The software plays an important role for the design and development of any machine. Because smart city is completely dependent on cloud and internet, thus; the optimal utilization of the resources are big challenge. Apart from the application requirement, the other important parts of the software design is that it should be able to fulfil the device requirement and field requirement. The device interfacing is also an im-

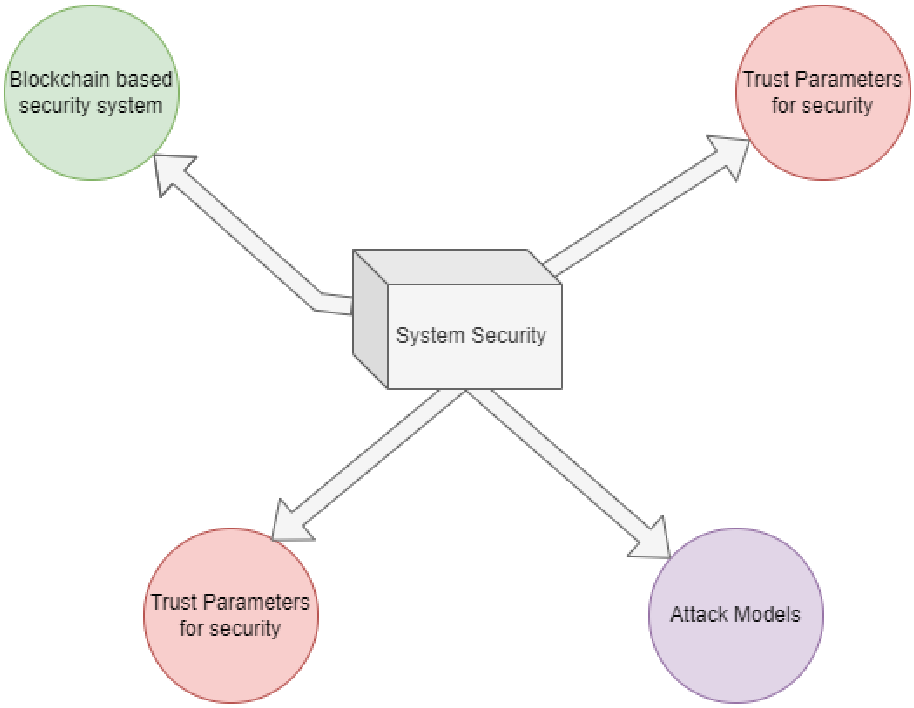

Figure 2.3: System Security for Smart Cities

portant challenge for the advanced IoT based smart cities. The interfacing of the devices should be backward compatible. The smart surveillance system can also be used in smart cities. The defaulters can be traced and it will help the police also to trap the attackers. The efficient software can perform the data analysis for the surveillance system. The last important part is that the software should be compatible with the emerging technologies need.

The last and most important part of all the IoT applications are scope in future development. Various research methods can be used for the performance improvement and development of software as shown in Fig-2.5. However, the IoT integration with 5G is still in development stage. Therefore, the information pre-processing is important for the future development of the tool.

2.2.2 Development Methodologies for IoT based Automatic Driving

The IoT based Automatic driving is now the future of the transportation industry. As we know that the automatic driving is only possible through the sever control from cloud and efficient monitoring of the roads. All the vehicles controlled through the server with the

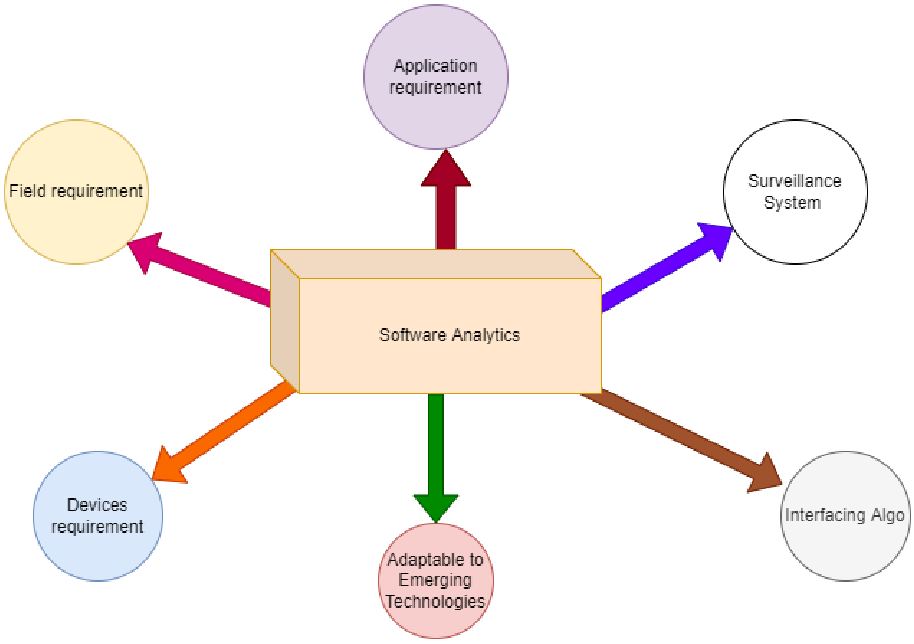

Figure 2.4: Software Analytic for Smart Cities

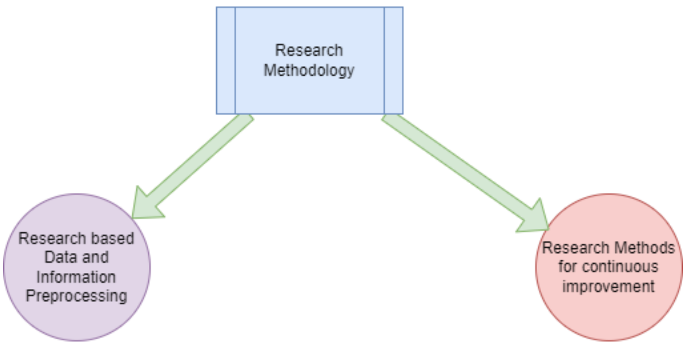

Figure 2.5: Research Methodology for Smart Cities

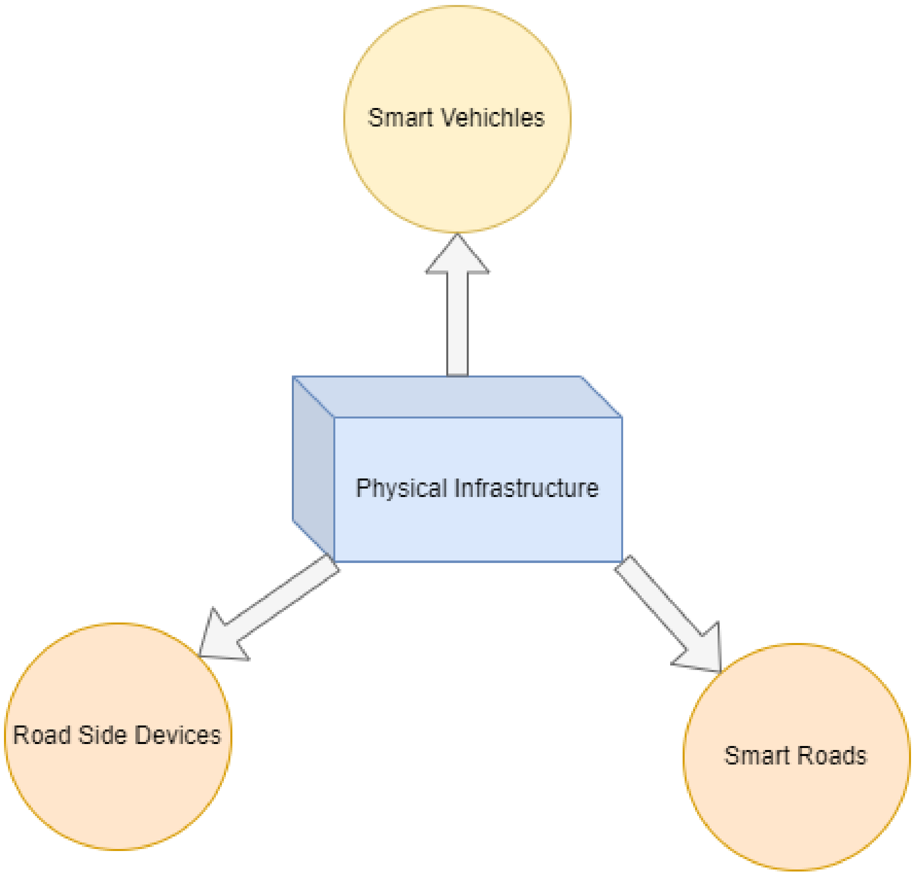

Figure 2.6: Physical Infrastructure of Automatic Driving

help of control signals. The control signal is very important for the control of vehicles, thus, the transmission of control signals should be transmitted through the highly reliable channel. 5G telecommunication technology provides very highly reliable communication through the dedicated channel. The automatic driving development methodology can also be categorized into 5 parts. However, the system security, software analytic, and research methodology are same as already discussed in the smart cities. In this section, the physical infrastructure requirement and emerging technologies for automatic driving is discussed.

The physical architecture of the automatic driving requires modification in the roads as well in the vehicles as shown in Fig-2.6. For the smart roads various sensors are required on the roads, e.g., pressure sensor, FBG sensor, alignment sensor, infrared sensors, ultrasonic sensor etc. Similarly , to make efficient communication between vehicle-2-vehicle and vehicle-2-server require road side devices as well as smart vehicles. The road side devices continuously communicates with the server and transmits the control signals to

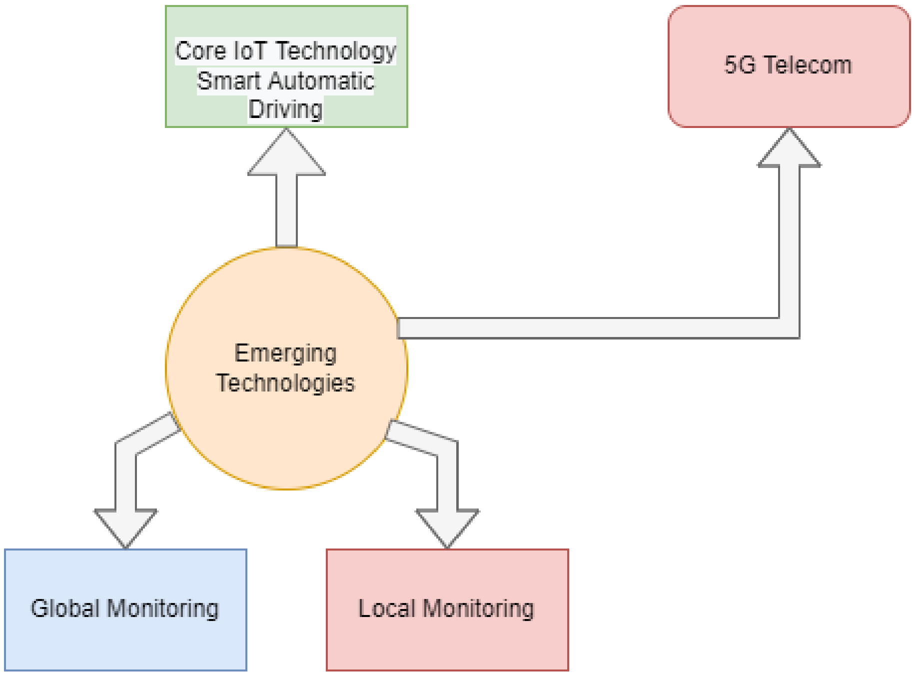

Figure 2.7: Emerging Technologies for Automatic Driving

the vehicles.

The emerging parallel technologies are also very important to discuss as the integration with the other technologies makes the system more powerful as compared to the independent system. The integration is shown in Fig-2.7. The 5G telecommunication integration is one of the primary requirement of the current VANET. The 5G high frequency range, i.e., mm-wave can communicate with directly roadside devices. Also, IoT can be integrated with VANET. IoT with ML and AI can make VANET system very powerful. IoT integration will also make the system more powerful for the real time application. Apart from this the regional monitoring is also very important for the transportation system. Therefore, the integration of VANET with the existing monitoring system is important. The integration of VANET can be done with weather forecasting monitoring, traffic monitoring, road health monitoring, and smart city spatial map.

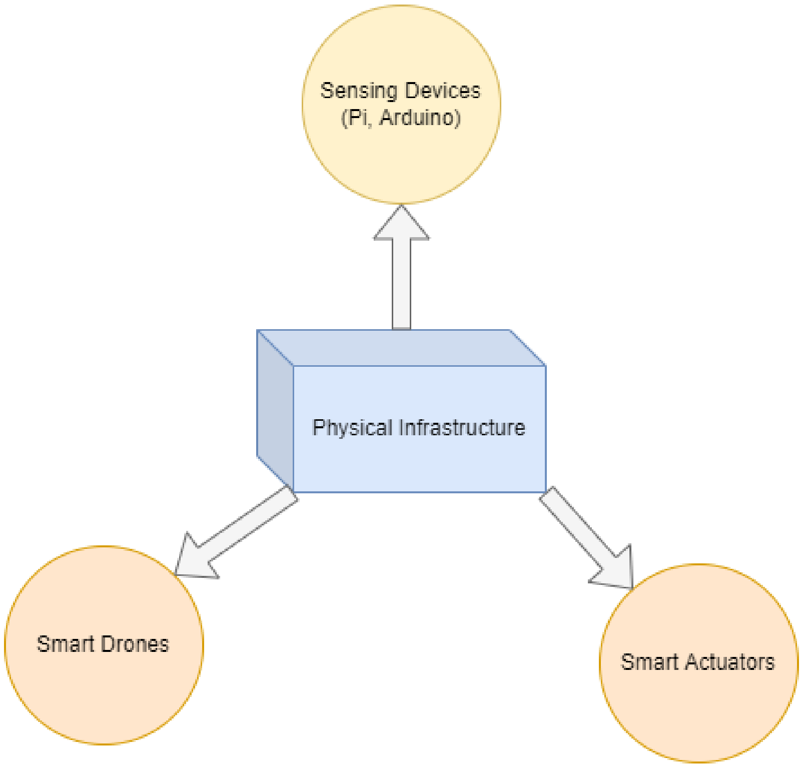

Figure 2.8: Physical Infrastructure of Agriculture Field Monitoring

2.2.3 Development Methodologies for IoT based Agriculture Field Monitoring

The IoT based Agriculture Field Monitoring will be the future of efficient fulfilment of future needs. The agriculture field monitoring improves the efficiency of crop development and also fulfils the optimal need of pesticides and also other agricultural needs. The agriculture sensors can be classified into event driven and continuous monitoring nodes. The agriculture field development methodology can also be categorized into 5 parts. However, the system security, software analytic, and research methodology are same as already discussed in the smart cities. In this section, the physical infrastructure requirement and emerging technologies for agriculture field monitoring is discussed.

The physical devices are the primary requirement for the agriculture field monitoring as shown in Fig-2.8. The smart sensors and actuator plays an important role for smart agricultural field. The drone or smart actuators can be placed on the monitoring field and as per the instruction given by the headquarter these devices performs the operation.

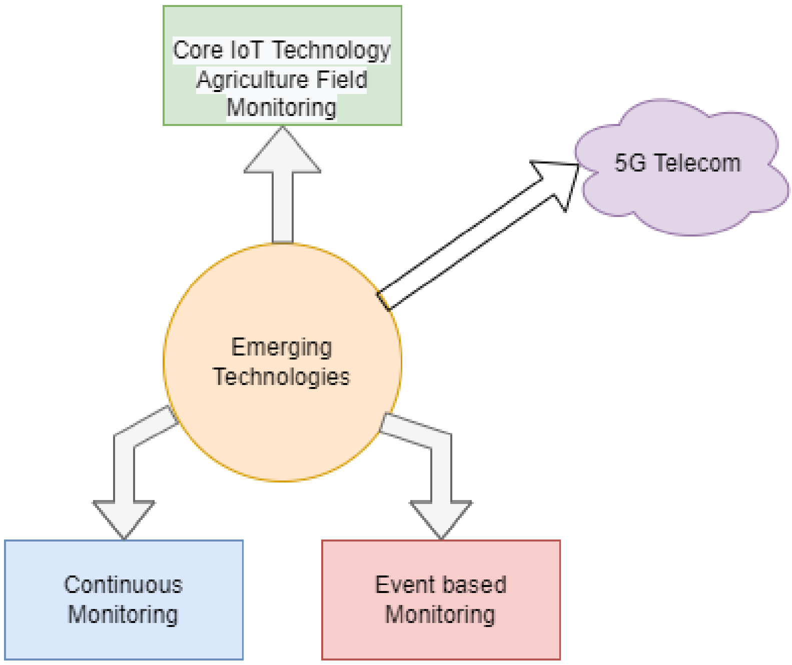

Figure 2.9: Emerging Technologies for Agriculture Field Monitoring

The emerging technologies also plays a big role for the improvement of the devices in future as shown in Fig-2.9. The integration of the devices with the newly available technology and devices is the challenge. The 5G telecommunication integration is one of the primary requirement of the agriculture field monitoring. The 5G high frequency range, i.e., mm-wave can communicate with the intermediate devices. Also, IoT can be developed for field monitoring. IoT with ML and AI can make field monitoring system very powerful. IoT integration will also make the system more powerful for the real time application. Apart from this continuous monitoring and event monitoring nano-fabrication can further improve the performance in terms of sensor accuracy as well as energy consumption of the nodes.

2.2.4 Development Methodologies for IoT based Railway Monitoring

Railway monitoring is one of the most important field where the integration of different emerging fields can play a big role for IoT based monitoring. The development methodology of railway monitoring is basically focuses on heterogeneous data traffic application *e.g.*, railway monitoring and telemedicine applications. A large number of different types of sensors are required for railway condition monitoring application. The traffic generation rate of the sensors is different and it is based on their requirements for railway bridge monitoring, landslide monitoring, track condition monitoring, *etc*. The sensors are placed on different track locations on the basis of their requirements. Analysis of the data traffic generation rate shows that for some places traffic generation rate is low and for other places, it is very high (*20kbps-120kbps*). So, the networks should be analyzed for low, medium and high traffic generation rates from *20-120 kbps*. The development methodology of railway monitoring can also be categorized into 5 parts. However, the system security, software analytic, and research methodology are same as already discussed in the smart cities. In this section, the physical infrastructure requirement and emerging technologies for railway monitoring is discussed.

The physical architecture of railway monitoring is dependent on smart IoT devices as shown in Fig-2.10. The most important development part are smart stations, smart train, and smart track monitoring system. Bogie monitoring and engine monitoring are two different sections of train monitoring. track condition monitoring can also be categorized into different subsections.

The technology is changing day by day. In the today's perspective, the five major field are growing very rapidly as shown in Fig-2.11. IoT and artificial intelligence (AI) is growing very rapidly. The IoT based cloud system with strong machine learning algorithm can be used for the advanced IoT platform. 5G is also advancing day by day. The advancement of 5G is rapidly increasing to meet the user requirement. The bandwidth requirement can also be fulfilled by utilizing the unutilized bands. For this, one can use cognitive radio. The advancement in sensor technology is also changing day by day. Therefore, the energy requirement of both event based monitoring as well as continuous monitoring sensors will decrease and the life time of the overall network will increase.

2.2.5 Development Methodologies for IoT based Forest Monitoring

The development methodology of the forest monitoring is majorly focused on event detection at the monitoring field. The sensors sense the data and transmit the data to the

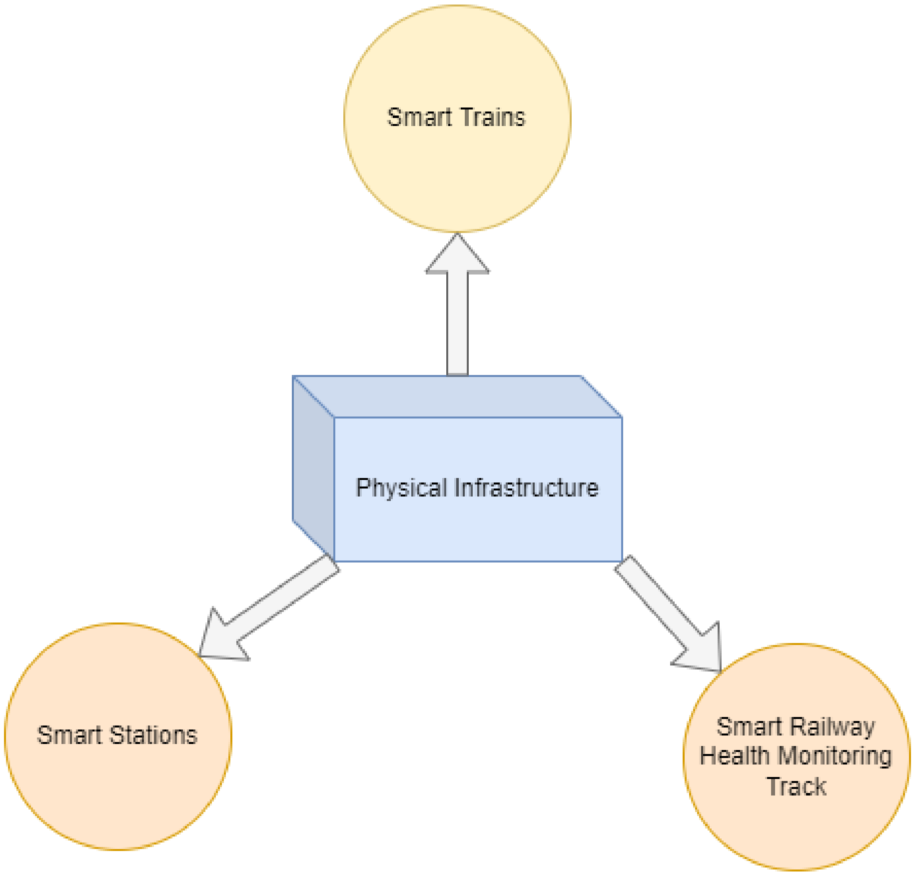

Figure 2.10: Physical Infrastructure of Railway Monitoring

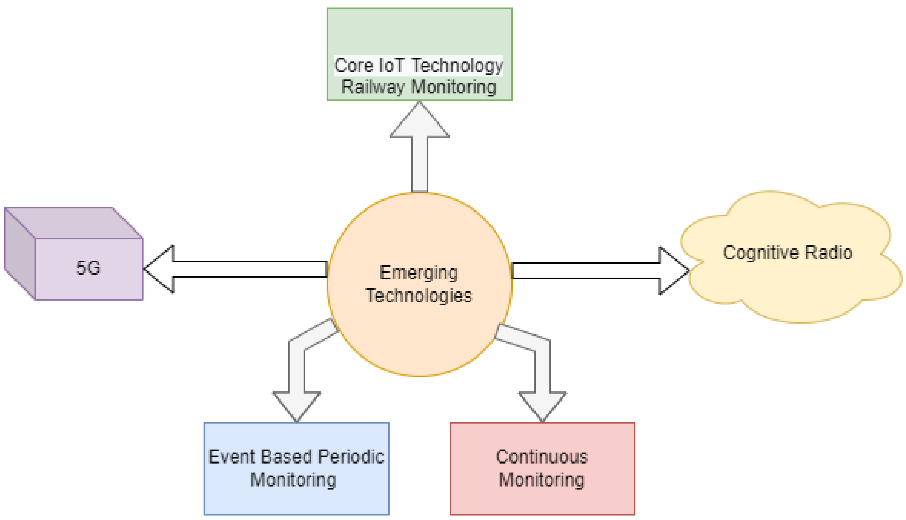

Figure 2.11: Emerging Technologies for Railway Monitoring

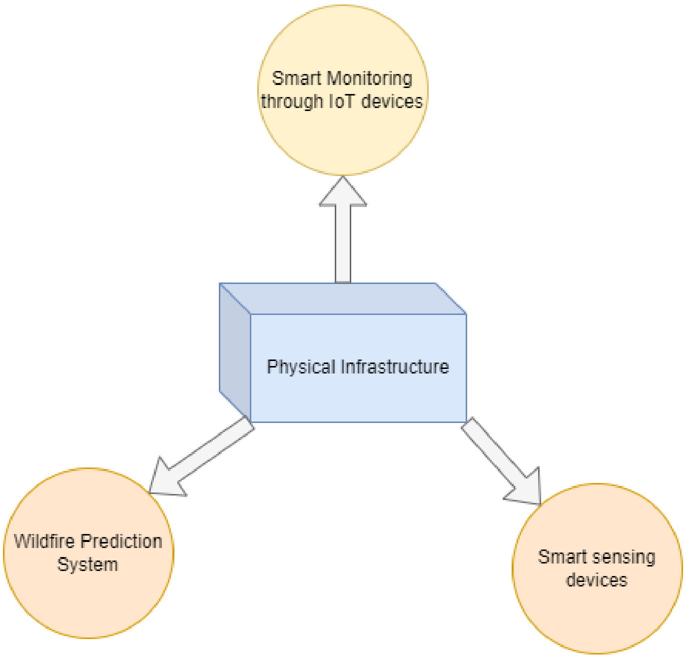

Figure 2.12: Physical Infrastructure of Forest Monitoring

sensor network. The bus system is used to transmit that data to the micro-controller. The sensor analyst is used to analyze that data to further process that data. At the server end monitoring station performs this task. After the analysis of the data monitoring station transmits the command to the actuators to perform the necessary action. The sensors distributed over the forest monitoring field, can detect event monitoring as well as continuous monitoring data. The data traffic generated by event monitoring sensors can be used for detection of an event.

The task of the physical devices for the forest monitoring application can be categorized into two parts, i.e., wildfire monitoring as well as early prediction as shown in Fig-2.12. The second task is to save the forest from un-meaningful, undesired, and criminal activities. For this three different types of IoT network and devices are required as shown in Fig-2.12.

The emerging technologies also plays a big role for the improvement of the devices in future as shown in Fig-2.13. The integration of the devices with the newly available technology and devices is the challenge. The 5G telecommunication integration is one of the primary requirement of the forest monitoring. The 5G high frequency range, i.e.,

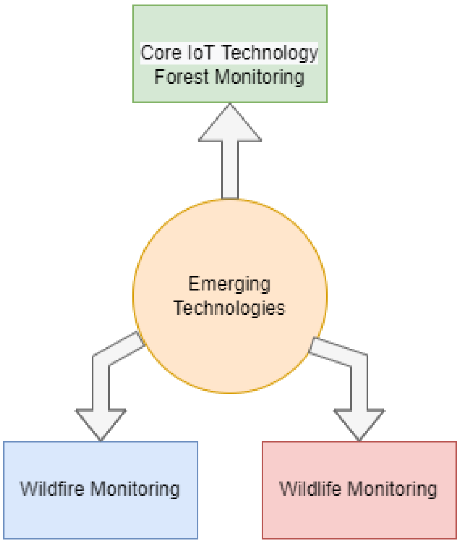

Figure 2.13: Emerging Technologies for Forest Monitoring

mm-wave can communicate with the intermediate devices. Also, IoT can be developed for field monitoring. IoT with ML and AI can make field monitoring system very powerful. IoT integration will also make the system more powerful for the real time application.

2.3 Qualitative Spatial Reasoning

Over the last thirty years, spatial reasoning (SR) is a highly diversified domain of study. The capacity to see spatial articles and reason about their relations appears to be easy for people, yet has demonstrated so hard for computers that they still can't seem to accomplish a five-year-old youngster's abilities. Moreover, qualitative spatial reasoning (QSR) allows for the relation between extended entities (complex and simple regions) or original spatial entities(points, lines, planes), QSR's describe relations between objects in a qualitative concept [24]. Several qualitative spatial reasoning categories are available; we are mostly interested in formalism, which contains: topology [46] and metric [38].

Topology focuses on the relations between regions. Representations of topological relations provide as the basis of reasoning on spatial, one of the phenomenon topology relations in qualitative spatial reasoning is *RCC8*.

RCC8 stands for *Region Connection Calculus*, theory has been thus called because it refers to a group consisting of eight bilateral relations that are comprehensive, double, and complementary, that represent the topological relations between individuals in the form of arranged pairs that are used in calculus. RCC8 based on a reflexive and symmetric primitive basic relationship and relatively explainable. There are several version of the relations, we have chosen RCC8, because it is one of the smallest sets of topological base relations and widely used, the jointly exhaustive and pairwise disjoint (JEPD) has eight relations of the constraint language.Along With the amount of relations defined by C(*x*, *y*), the relations are **DC(*x, y*), P(*x, y*), PP(*x, y*), EQ(*x, y*), O(*x, y*), PO(*x, y*), DR(*x, y*), EC(*x, y*), TPP(*x, y*), NTPP(*x, y*)** and **Pi, PPi, TPPi** and **NTPPi** , the non-symmetric of converse relation **P, PP, TPP** and **NTPP** respectively. Where *x* and *y* defines as a two different regions, C(*x*, *y*) represent as a set of dyadic relations between region *x* and region *y* [33].

Metric is defined as qualitative spatial distance relations as the measurement between two objects by use of Ternary Point Configuration Calculus (TPCC), TPCC is proposed in [38] which deals with point-like objects in a two-dimensional plane. The application-based variable that comes from this calculus allows for a more accurate distinction of positional information than other calculations.

The TPCC has transformations i.e Unary operations and compositions i.e Binary operations. The binary operations deduce information from two relations that have two points in common. The resulted outcome is a relation between one of the common points and the two other points. In the case of unary operations use relations about three points to deduce a relation that holds for a permuted sequence of the same points. The letters of the TPCC relations are f, b, l, r, s, d,c, stand for the front, back, left, right, straight, distant, and close, respectively. Due to the limited pages, the reasoning is present in [38].

2.4 Quantitative Temporal Reasoning

Temporal reasoning is widely used nowadays for powerful intelligent systems or artificial neural networks [22], [51]. The temporal reasoning methods are useful for the intelligent system to make a decision based on the present, past, and future experiences. The temporal reasoning concept can be used for IoT development and deployment. The present work deals with the QTR methods that help to categorize the IoT system into groups and sub-groups. Each group or sub-group consists of specific goals and sub-goals. The intelligent system formation based on the temporal reasoning method can be utilized for IoT deployment. The Spatio-temporal methodologies are widely used for smart IoT deployment with optimal IoT devices with maximum coverage and full connectivity. The present work deals with the Spatio-temporal development methodologies for the smart deployment of IoT devices. [57], [48]

Quantitative Temporal Reasoning (QTR) is crucial for enabling machines to understand and manipulate time-related information in a quantitative manner. It allows machines to reason about temporal relationships, durations, and intervals, which is essential for various applications that require temporal planning and coordination.

In the context of spatio-temporal goal refinement, QTR is used to refine high-level goals into smaller sub-goals based on temporal constraints. This allows machines to adjust their goal refinement based on the temporal context, leading to more effective planning and execution of tasks. By utilizing QTR in spatio-temporal goal refinement, machines can optimize resource utilization, adapt to changing temporal constraints, and improve task completion rates and efficiency in applications such as robotics, logistics, manufacturing, and healthcare.

2.5 Hybrid Methodologies

In the present thesis work, a Qualitative Spatial Reasoning (QSR) and Qualitative Temporal Reasoning (QTR) methodology are proposed to build software systems. The proposed hybrid methodology includes the features of QSR, QTR, and traditional data-based methodologies. In this thesis work, the hybrid methodology is proposed to build the software systems and direct them to the specific goal of obtaining outputs inherent to the process. The hybrid methodology includes the support of tools and is detailed, integrated, and fits the general proposal. This methodology repeats the structure of Spatio-temporal reasoning goals. The object-oriented IoT device placement is the major goal of the proposed work. Segmentation and object detection is used for the division of the region into sub-regions. The coverage and connectivity are maintained by the optimal placement of the IoT devices using RCC8 and TPCC algorithms.

2.6 Spatio-temporal Goal Refinement Patterns

Many of the previously reported works mentioned the role of spatial data in their proposed IoT-based architectures. In [104], the author proposed a framework of Spatial Data Warehouse system in IoT environments (SDWIT). Furthermore, the authors have considered all the system layers in detail which consist of data source, data processing layer, data storage layer, and application analysis layer. Moreover, the IoT spatial technology is discussed in perspective of Big Data (BD) in [98]. In this work, the author focused on BD conceptual modeling and the types of spatial attributes that are produced from a smart object. In addition, the author illustrated the spatial BD handling in different smart city scenarios. In [96], the author introduced an analytical framework of geo-spatial-temporal data with component service architecture. Mainly, the authors focused on the geo-spatial temporal data produced from IoT moving objects such as vehicles. Besides, the authors applied the proposed framework in the domain of the connected vehicle including autonomous driving and Usage-Based Insurance (UBI) areas. After applying the proposed framework, the authors have proven its efficiency. In [76], the comprehensive summary of all potential geo-spatial analysis of IoT data is proposed. The listed analytical methods were ranging from basic geometric measures to more advanced data mining and surface analysis methods. The authors classified the IoT applications' fields concerning the used analytical methods. The author handled 26 pieces of literature by discussing the used hardware, geo-spatial analysis, data types, and reliability issues. Regarding indoor IoT services, [94] presented a framework. They developed a new framework that included a spatial-based IoT service system. Few other spatial pattern based works are also reported for other applications. In [71], author proposed enhanced sub-pixel mapping technique using spatial distribution pattern. In [83], the author have proposed land surface temperature based spatio-temporal variability. Few other works are also proposed on spatio-temporal aggregation pattern

2.7 Enterprise Architecture

Internet of Things introduces new systems and devices that need to be managed by IT and organizations not presently existing [5] [9]. The four key components to IoT are things (products), properties, IoT servers, and applications based on the three-layer architecture as shown in [119] and described as The IoT gateway hierarchy in [120].

The things are products that are the primary key component of IoT that currently appear to be one thing that the corporate has to manage is at the top of the list. They are embedded into the environment and consist of transducers that convert one form of energy to another.

Organizations must now accept responsibility for its connected things which are connected to company servers, which brings a new enterprise design. Thousands of products are connected or are often reached by company IoT servers.

The second key part of IoT shows how every company needs to manage the connectivity aspect. Every company decides which protocol and language will be used, and the ownership is transferred to a highly specialized IoT server.

The third critical component of IoT is a server that gives four basic functions: device management and provisioning; information assortment, processing, and normalization; application enabling and development support; and network information service and subscriber management.

The fourth key part of IoT is the application when integrated, it does not introduce any new parts to the enterprise design, but rather reuses the prevailing web application parts; internet servers, web and internet browsers, and phone applications. However, this does not imply that existing organizations and architectures can continue to function as they are continuing. It need to be custom-made so that they serve the even broader set of external and internal applications developed as a part of the new web of Things business opportunities and operations enterprise.

The Internet of Things can pose significant challenges to existing enterprise architectures, necessitating the emergence and development of new IT systems and organizations, as well as new evolving enterprise architectures. The next section describes the methodology that can be used for the proposed solution.

2.8 Summary

This section discusses the proposed hybrid methodology of Qualitative Spatial Reasoning (QSR) and Qualitative Temporal Reasoning (QTR) to build software systems for the specific goal of obtaining outputs inherent to the process. The methodology involves the support of tools and is integrated and detailed. The section also presents various spatio-temporal goal refinement patterns and their applications in IoT environments. The role of spatial data in IoT-based architectures is discussed, along with the challenges that the Internet of Things poses to existing enterprise architectures. The four key components of IoT are described as things, properties, IoT servers, and applications based on the three-layer architecture. The section concludes by highlighting the need for new IT systems and evolving enterprise architectures to address the challenges posed by the Internet of Things.

Chapter 3

Development Methodologies for IoT

3.1 Overview

The goal of the present work is to develop an IoT system using efficient development methodologies. The traditional development methodologies are not suitable for the development of IoT systems. More specifically, hardware development methodologies require major changes and invite novel contributions for optimal and efficient placement of IoT devices aiming for the development of IoT systems. For efficient sensing, coverage, and connectivity, the optimal placement of IoT devices is a critical challenge. The spatial and temporal reasoning methods are widely used for IoT development methodologies in literature. In this novel research, we propose a goal-oriented and object-oriented development methodology for the optimal placement of IoT devices. Also, unlike to the previously reported work, in the present work hybrid QSR/QTR based development methodology is proposed. The object-based IoT placement ensures the connectivity and coverage of the monitoring field. Also, the goal-oriented methodology guarantees the achievement of predefined objectives. Spatial reasoning, and temporal reasoning are the important components of the proposed methodology that are discussed in the subsequent subsections.

The objective of the methodology used to build a smart city application system is to expose the basic and general issues related to the engineering of complex IoT systems and applications. This happens through the inclusion of all characteristics of the common system scenarios that are used as main concepts in the design and development of IoT systems and applications. Several principles directed towards obtaining a methodology suitable for all IoT systems are organized [28]. The scenario of the smart city includes controlling the environment and devices in multiple places. The smart city is equipped with several different sensors and actuators connected to it. This study aimed to develop all services and provide an infrastructure that includes IoT software based on a reliable methodology.

The chapter is organized as follows. Section 3.2 discusses the background. The research analysis is discussed in section 3.3. The methodology used is presented in Section 3.4, and the implementation is presented in Section 3.5. Section 3.6 discusses the analysis of the results and finally, Section 3.7 concludes the final findings.

3.2 Background

There have been many studies on the development of IoT systems [131], [132], and these studies use a variety of methods following different trends to obtain their results. What characterizes a good IoT system is a scalable approach and a focus on expanded and distributed smart applications.

In [42], the authors proposed a goal-oriented approach whereby data is entered through the sensor directly by the IoT system in real-time; this leads to an understanding of the necessary information taken and the ability to amend it if required. However, the data collected is sometimes massive and needs to be analyzed, which causes pressure on data storage systems and the resources used to analyze it. In many systems, data must be managed and directed toward the goal. It is necessary to ensure that actions reach their target and provide attention to achieving the system's goal; thus, data is managed by sending it to the IoT system with the help of the methodology that was chosen.

Furthermore, A Model-Driven Design (MDD) approach focuses on the importance of a Service-Oriented Approach (SOA) in developing models, and building applications. They concluded SOA can be used to develop different programs and tools, as this methodology includes abstractions, varying degrees of accuracy, and different perspectives that can be used to find Model-driven [53].

In the past, most QSR theories have been derived from Allen's theory of time. A study by [37] presented a QSR approach called Cohn's Region Connection Calculus (RCC) to spatial reasoning. Some of the research suggested a model that considers either temporal or logical constraints whereas they have ignored fundamental spatial aspects as they relate to the objects in smart home applications. In regards to this, constraints of the objects involved in an activity must be defined. For example, the area of object A should not intersect the area of object B during step n of an event. In this context, research by, [20] presented a general mathematical topology and demonstrated the results with the description of spatial relations.

In [47], the authors analyzed the theoretical properties of specific spatial reasoning within the framework of RCC8 over a wide range, but they did not conduct an experimental investigation. The results showed an adaptation of the algorithms used at specific and the authors stated that it can solve complex RCC8 logic states. Even if it is in the transitional zone, one has to use traceable subgroups, where they have identified that the orthogonal structure of the indicative methods has worked in difficult cases to a certain size under a reasonable time. In [21], the authors provided spatial data and indicated the data's main importance in several applications, including spatial information systems, meteorological and liquid flow analysis, and design with ancillary computer programs as well as databases. The study found that these applications need specification of the treatment of the spatial representations, which can be provided by QSR.

3.3 Research Analysis

We have analyzed the contribution of the researchers year-wise. For the selection and rejection of the manuscripts, we have divided some inclusion and exclusion criteria as shown in Fig-3.1. The important keywords are also identified as mentioned in the figure. After screening process, 24 articles are shortlisted for the full literature study. The frequency of keywords of the shortlisted articles are shown in Fig-3.2. The brief contribution of the some important researcher works from shortlisted articles are explained below in Table-3.1.

3.4 Spatio-Temporal Reasoning Methodology

The architecture of Spatio-temporal hybrid methodology is divided into 5 modules. The complete architecture of Spatio-temporal hybrid methodology is shown in Fig-3.3. The first module will start with the system description and requirements. In this module, a smart city application is taken for the analysis of the system. The requirement of the different types of sensors and IoT devices have been explained in this section. Following will be the outcome of this module:

- The outcome of this module shows how many sensors are required for any IoT system?
- Different types of proactive and reactive sensors are required for the network application.
- How the sensors will integrate to achieve the goals and sub-goals?
- The description and specifications of all the sensor IoT devices are specified in this section.

The next module is system architecture and design. The architecture defies, how we can categorize the IoT devices based on their operations. This module also defines the type of operation that we will apply based on the device category. The outcomes of Module-1 are utilized for the various operation of Module-2. The most important task based on coverage and connectivity is performed in this section. The QSR and QTR methods are used for the classification of the operation on IoT devices. This module also fulfills the gap between hardware and software. The hardware-defined software (HDS) is one of the important features of this layer. Following are the outcomes of this module:

- The optimal placement of the IoT Device

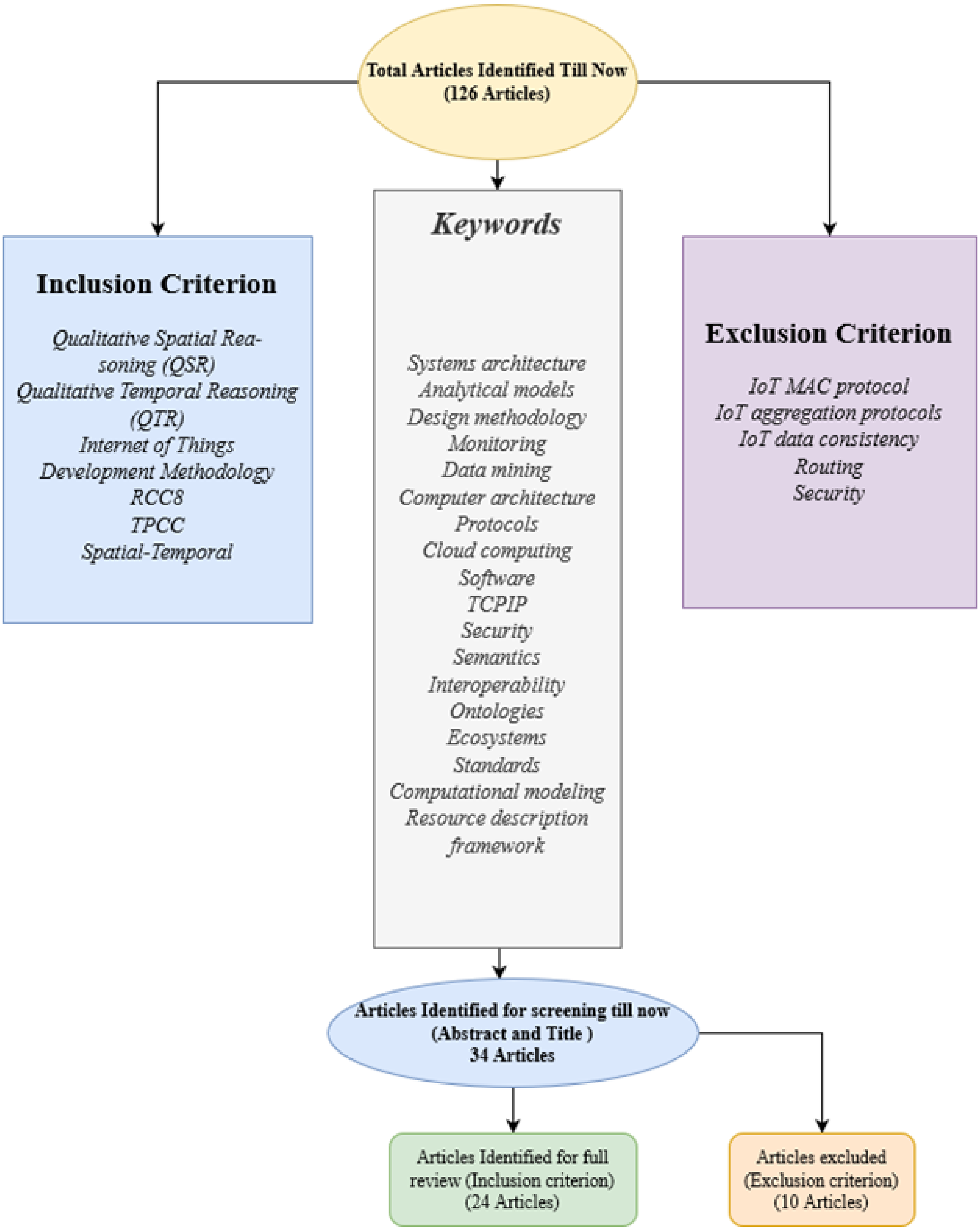

Figure 3.1: Research analysis graph

Table 3.1: Contribution of researchers in the field of development methodology

Objective	Contribution	Method	Conclusion
This article aims at presenting approaches, architectures, and methodologies relevant to the development of mobile IoT solutions [35]	This article aims at presenting approaches, architectures, and methodologies relevant to the development of mobile IoT solutions	Mobile app development	Mobile app development can be used to manage and improve the apps development process, therefore, enabling companies to gain a competitive advantage
Cloud enabled Internet-of-Things [50]	A risk aware development and deployment methodology for IoT systems that can help in focused decision making	Risk management methodology	A case study Smart Baby Car Seat which is essentially a cloud based IoT system to demonstrate the life cycle of our proposed methodology
Methodology for creating Internet of Things (IoT) Applications based on Microservices [23]	This chapter presents the first approach to an agile methodology	DevOps organizational development approach	This array of techniques will allow better version control, helping with the maintenance of the system and integrating the independent components with ease.
Heterogeneous Applications, Tools, and Methodologies in the Car Manufacturing Industry Through an IoT Approach [29]	This chapter describes an IoT platform and the related prototypes developed within the project: Enabling Business-Based Internet of Things and Services (EBBIoTS), with a focus on the industrial domain	Prototypical deployment of the developed prototypes (MDD Tool)	The overall system enables monitoring the manufacturing cells and adapts the information to be displayed on the user interface according to the station and the roles.
ML Based Intrusion Detection Framework and Methodology for IoT Networks [36]	The author implemented and evaluated a software framework using Hadoop cluster to store big dataset and PySpark library to train anomaly detection and attack classification models	Bot IoT dataset was used because of its regular updates	The proposed methodology demonstrates how the big data can be processed and the IoT intrusion detection machine learning model.

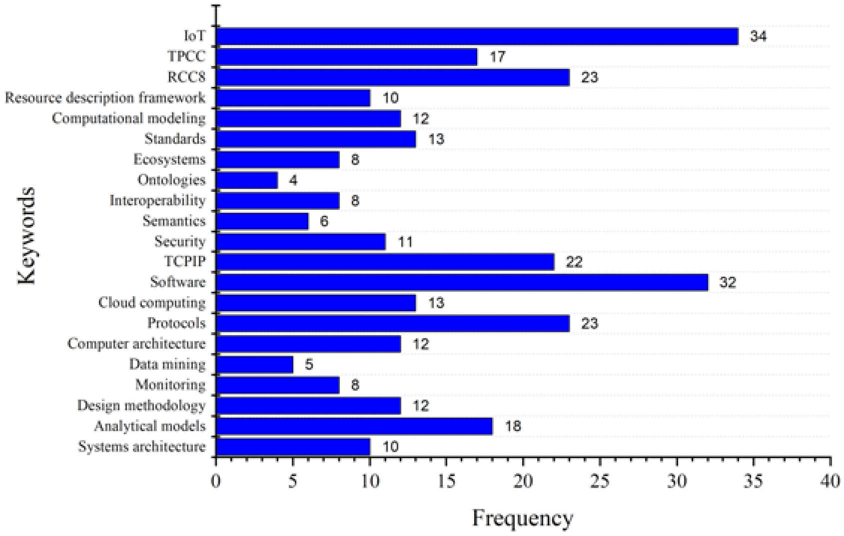

Figure 3.2: Keyword Frequency

- Coverage and connectivity of the network
- Optimal placement of IoT Gateway

The next module is Design-Phase. This module is a cross-layer module where the efforts on the first and second layers are utilized in the third layer. It starts with the planning stage and ends at the final design stage. In between various important reasoning, methods are used for the achievement of defined goals and sub-goals. The module deals with the design strategy. Following will be the outcome of the third module:

- The complete system specification
- The prototype design of the system
- The estimation of the various parameters

The next module is the Operational flow module that defines the operation of the methodology. The activity and action are the two important parameters of this module. In this module, the sensor act as an agent. The agent performs the predefined activity based on the parameters and placement defined in the previous modules. The following will be the outcome of the third module:

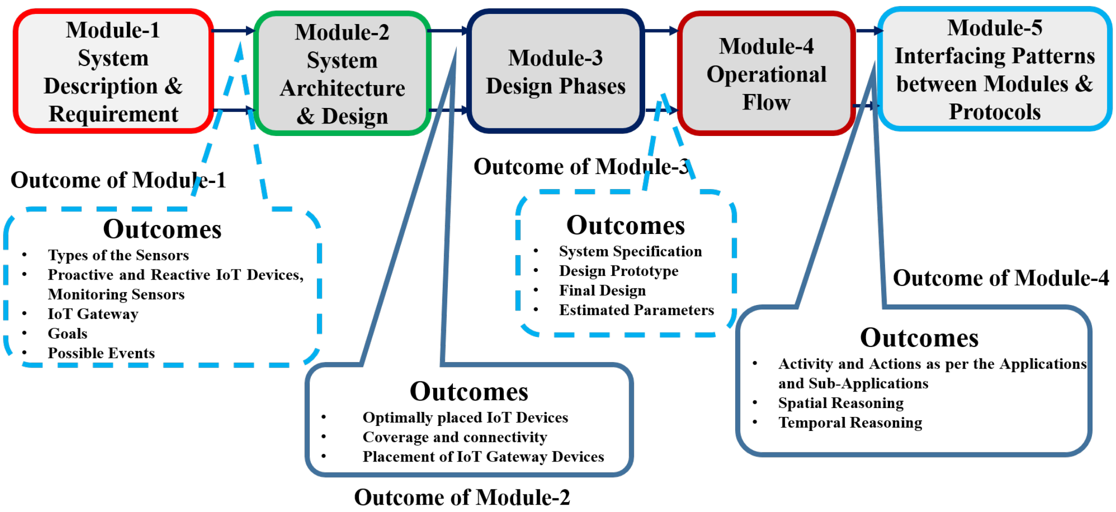

Figure 3.3: Architecture of Spatio-Temporal Hybrid Methodology

- Actions based on the activity
- Spatio-temporal correlation based reasoning for the different types of the activity

The last module is the interfacing module. This is also a cross-layer module that interlinks the various modules. The major objective of this module is to transmit the parameter information to the subsequent next module. This module also performs many of the important tasks to fill the bridge between two layers or cross-layers.
The detailed discussion related to all the different modules is done in the subsequent subsections.

3.4.1 Module-1

In this module, a smart city application is taken for the case study. the complete architecture of Module-1 is shown in Fig-3.4. The application is divided into sub-applications, e.g., environment monitoring, traffic monitoring, etc. Few of the IoT devices will generate low data traffic and few of them will generate high data traffic. Few of them will be continuously monitoring IoT devices (proactive) and a few of them will be event-driven IoT devices (reactive). Each of the devices will start with some initialization of the parameters. Therefore, few initial descriptors are defined in this module, and the performance of the devices is optimized based on the target goals and sub-goals. The major aim of

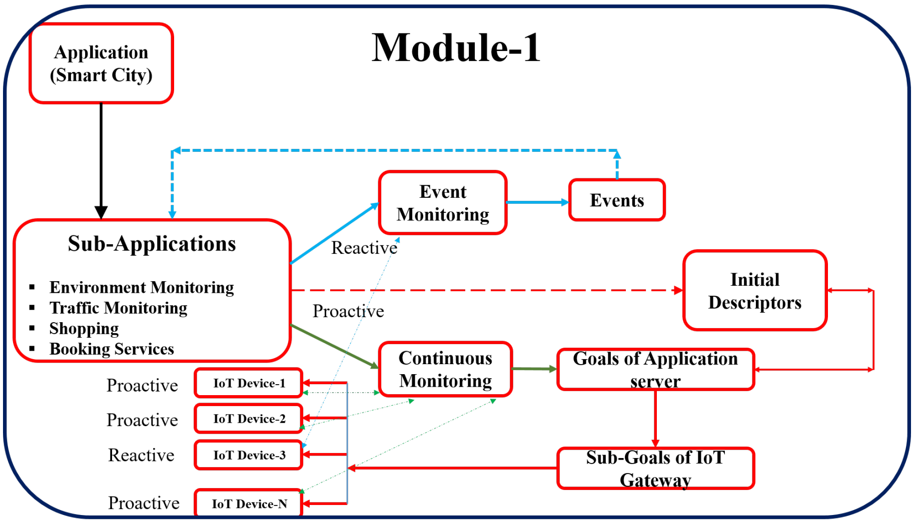

Figure 3.4: Architecture of Module-1

this module is to define the methodology to achieve the application server goal and gateway goals. The gateway can perform the aggregation of the data for optimal performance for continuous monitoring nodes. However, the event-driven nodes detect the event and directly report to the server.

3.4.2 Module-2

The outcome of Module-1 is utilized for Module-2. in this module the objects in the system can be categorized into static and dynamic. The architecture of this module is shown in Fig-3.5. The objects can be classified in the static if the position of the object will not change based on the temporal reasoning method. However, if the object's position will change with respect to time, it will be categorized into a dynamic object. For both static and dynamic objects, coverage and connectivity are important challenges. The Coverage of the IoT device is limited to the particular range. Therefore, maintaining the connectivity of the devices is an important challenge. In the present work, we have proposed the quantitative Spatio-temporal reasoning method to maintain the connectivity of the network such that all the objects can be monitor efficiently by the IoT devices. In this module, the entire region is first divided into grids similar to the cells in cellular architecture. The static objects remain in their corresponding cells permanently. However, the dynamic objects will change their grid with respect to time. The objects in the particular

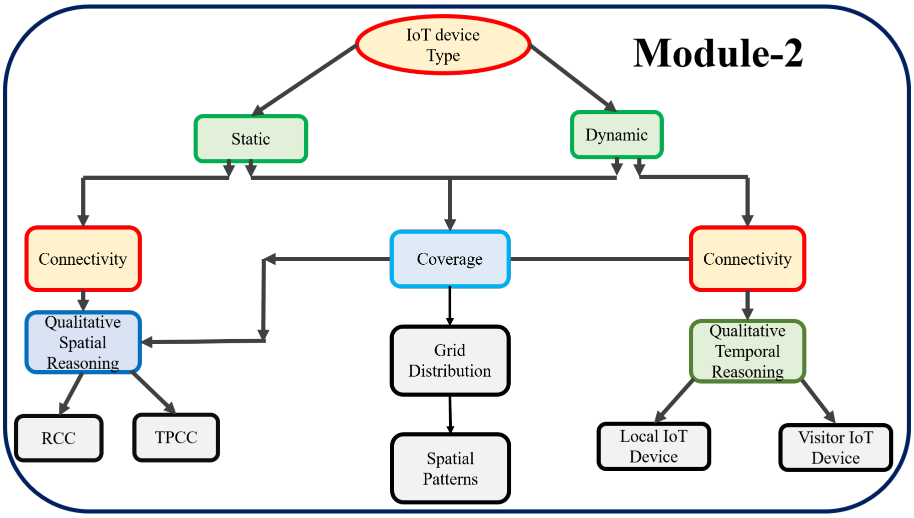

Figure 3.5: Architecture of Module-2

IoT device range can be categorized into local and visitor objects. The objects that do not change temporally their position are called local IoT objects. However, the object that comes from a different cell or grid is called a visitor object. Quantitative Spatio-temporal methods are used for the categorization of the objects. The IoT device should be placed such that all the objects can be monitored by the IoT device efficiently. In the present work, quantitative spatial reasoning is categorized into RCC8 and TPCC algorithms. The region connection calculus is used to identify the connectivity of the regions for the static objects. The intersection of the region can be used for the efficient placement of IoT devices. RCC8 algorithm plays an important role in the connectivity of the different regions. Region connection calculus is used to maximize the coverage with the minimum intersection. The formulation is given in Eq. 1. The two regions are denoted by 'a,b', and coverage is denoted by 'C'. The PO is the property RCC8 algorithm to the overlapping region. The grids are further divided into regions.

$$\max_{C} a,b \quad \min PO(a,b) \tag{3.1}$$

For any specific area, the region is divided based on Ternary Point Configuration Calculus (TPCC). The guaranteed coverage can be achieved by covering all the grids using TPCC algorithm. Please refer Section 1.1.2.1 for the detailed discussion of RCC8 and TPCC and its importance.

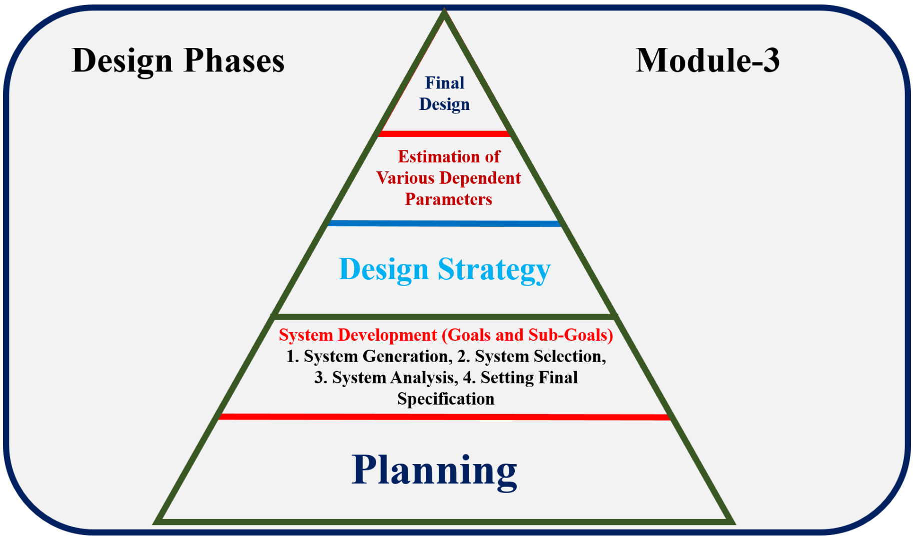

Figure 3.6: Architecture of Module-3

3.4.3 Module-3

The outcome of Module-2 is utilized for the designing of the IoT network. The design phase starts with the planning of various parameters. The initial parameters of Module-1 are utilized in this step for the modeling of new parameters in this step. The design phases of the development methodology are shown in Fig-3.6. The goal-oriented and object-oriented optimal IoT device placement is the major objective of the present work. After the design phase, the system development phase is the objective of this module. For the development of the complete system, first, the generalized system is formed to fulfill the requirements of the goals and sub-goals. After the formation of the generalized system, optimal values are selected for the effective performance of the IoT network. The final system is then analyzed and all the specifications are defined for the optimal performance of the IoT network. After the system development, the design of the final IoT network is the major challenge of the IoT network. Therefore, the design strategy is defined in this module. The estimation of the different dependent parameters is used as a cross-layer analysis for the final design of the network.

3.4.4 Module-4

The operational flow is the next step of the development methodology. The architecture of operational flow is shown in Fig-3.7. The operation of the IoT Device is a function of two important parameters, i.e., activity and action. The sensors in IoT devices act as Agent. The Agent performs some activity. The activity can be categorized into proactive and reactive. Based on the activity the server generates a command for the IoT device actuators. The actuators perform the action. In this proposed work, the network is designed for the smart city application. The parameter is measured by the IoT device and the measured value of the parameter is only transmitted based on the update of the data. If the data is not updated over the sampling interval, it is not transmitted to the IoT Gateway. Similarly, spatial correlation-based reasoning is performed at the IoT Gateway end to perform the action to the activity as a collection of the data. At the server end, based on all the collective data, the monitoring station generates a command for the IoT Device for the necessary action.

Overall, the proposed operational flow involves the IoT device measuring parameters, transmitting data only when necessary, performing reasoning at the IoT Gateway end, generating commands for actions at the server end, and executing actions using the actuators in the IoT device. This operational flow is designed to enable efficient and effective functioning of IoT devices in the context of smart city applications.

3.4.5 Module-5

Module-5 defines the interfacing and dependency of each module to the other modules. The architecture of Module-5 is shown in Fig-3.8. Module-2 depends on Module-1 for the basic classification and types of devices so that it can perform the necessary action. Module-2 further classified them to perform coverage and connectivity. Module-3's design phase is totally based on local and global divisions of objects and IoT devices. This information is useful again to perform the necessary action based on the activity. Modules-5 also ensures the achievement of necessary goals and sub-goals in an optimal manner.

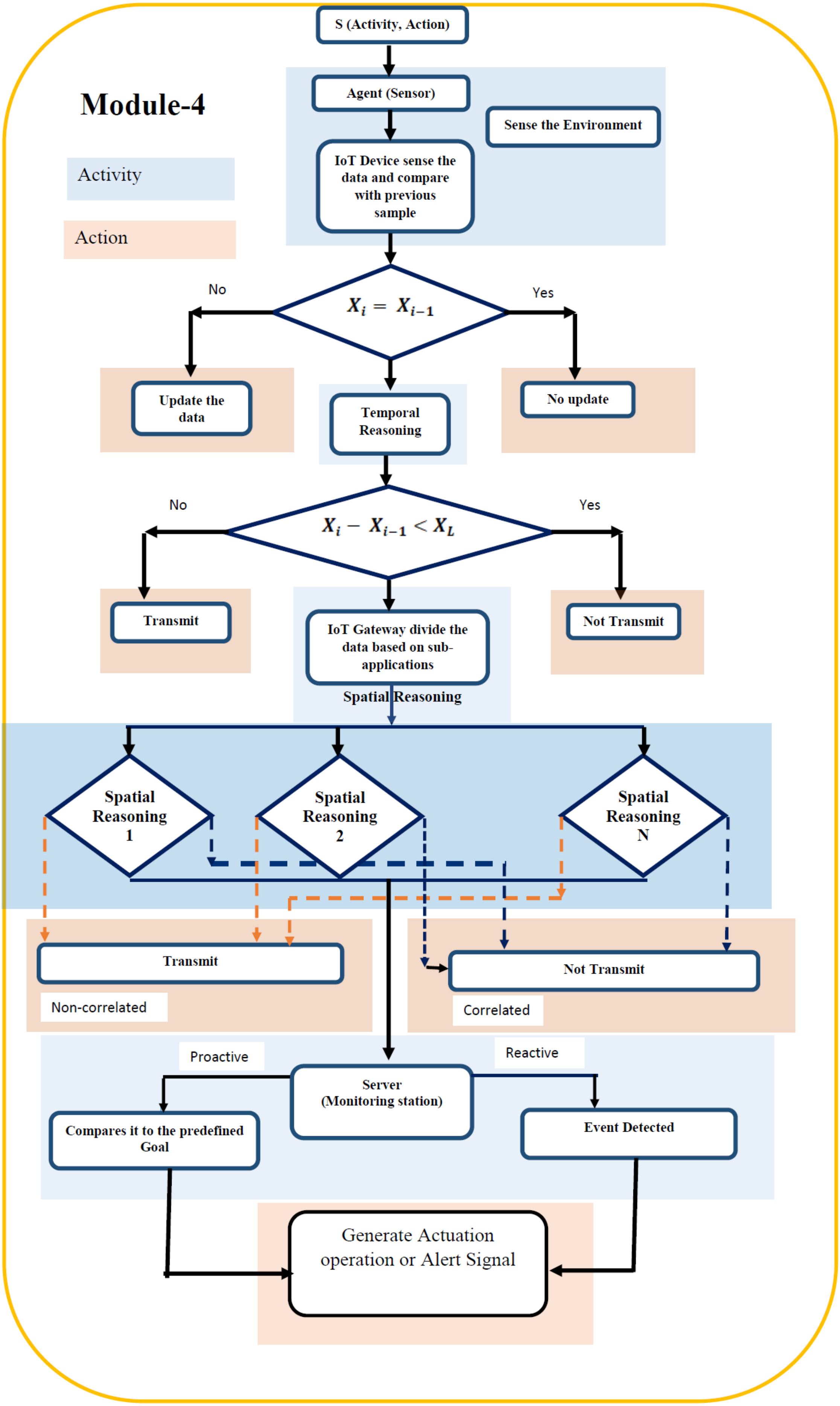

Figure 3.7: Architecture of Module-4

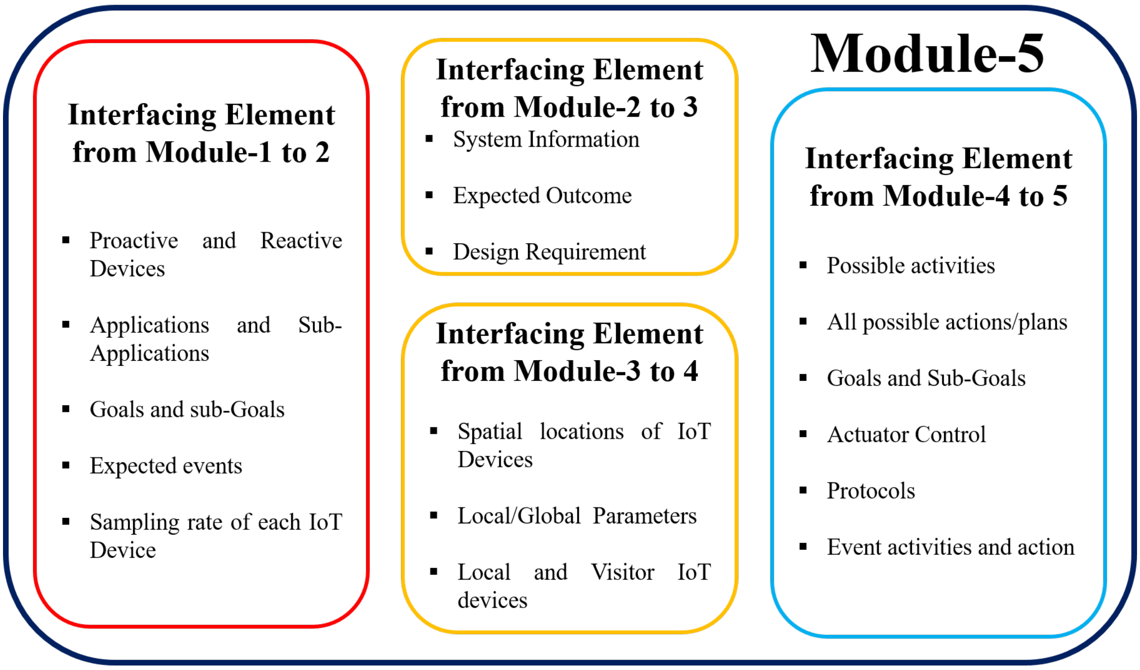

Figure 3.8: Architecture of Module-5

3.5 Implementation

In this section, the implementation of the algorithm is discussed using QSR and QTR methods. The major part of this algorithm is the division of the objects based on the context as shown in Fig-3.9. The object division is important because the IoT device has to monitor the objects and other external parameters. Therefore, different objects have their own symbols. The notation language is used to identify the objects. Also, for each activity and the action, different notations are used. A few of the notations are shown in Fig-3.10.

For this, objects are first classified into the basic shapes and then based on the training pattern, they are classified into patterns. After identification of the object, the suitable IoT device is used in the particular region based on QSR and QTR methods. Different objects are classified into different Class IDs. The connected objects and the corresponding IoT devices are also identified by the Relationship ID. The identification of the object can be ensured with the help of the comparison with the predefined threshold to get the confidence value. The first step of context-based object identification is segmentation. The region is divided into sub-regions based on the object. The object is identified into each sub-regions. Based on the objects QSR and QTR reasoning method is applied into each

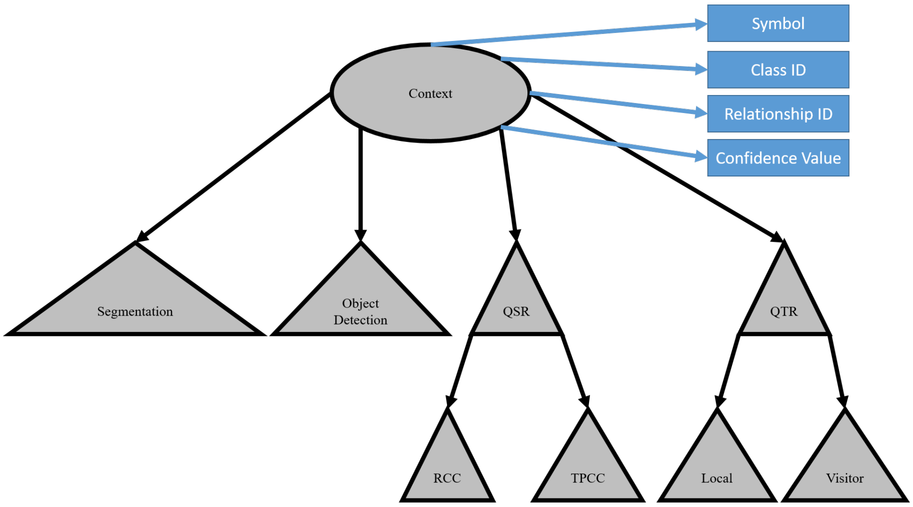

Figure 3.9: Classification of Pattern on the basis of object

Context (Labels)	Notations	Symbol
Training Shapes	Square, Rectangle	S, R
	Circle	C
	Diamond	D
	Horizontal and Vertical Edge	HE, VE
Segmentation		Sn
Object Detection		OD
Temporal Reasoning		StO (Static Object) DyO (Dynamic Object)
Spatial Reasoning		TPCC, RCC8

Figure 3.10: Notation language and Symbols

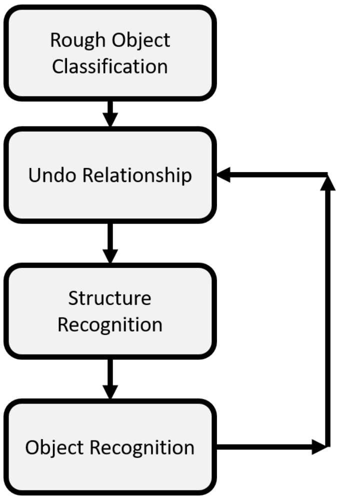

Figure 3.11: Objection Recognition and Relationship

sub-region for the optimal placement of IoT device into each sub-region. As already discussed in Module-2, the RCC8 and TPCC algorithms will be used to maintain the optimal coverage and connectivity of the devices. Object recognition is one of the major tasks of classification. The classification steps are shown in Fig-3.11. The classification of the object starts with a rough classification based on the shape of the object. The object is then passed to the structure recognition phase for the identification of the correct identity. The loop-based operation is performed till the recognition gets the confidence value.
Object labeling is the next of the important task of context-based object identification. The block diagram of the object labeling for object classification is shown in Fig-3.12. Object labeling is used to determine the object relationship. The object relationship is used in the module to manage connectivity and coverage of the IoT Devices. The labeling is started from the lower object to the higher object.

The operation of the proposed Quantitative Spatio-Temporal Algorithm is explained in Algorithm-1. The first step of the algorithm is the grid distribution of the field. To maintain coverage and connectivity, the grid is segmented into regions based on objects. Each region is labeled with identity. To identify the object, each object is classified into shapes based on training patterns. The object is identified and the quantitative Spatio-temporal algorithm is used to classify the static and dynamic objects. RCC8 and TPCC algorithm is used to maintain the coverage and connectivity. Based on the regions, coverage, and connectivity, the Spatio-temporal reasoning method identifies the exact location of the

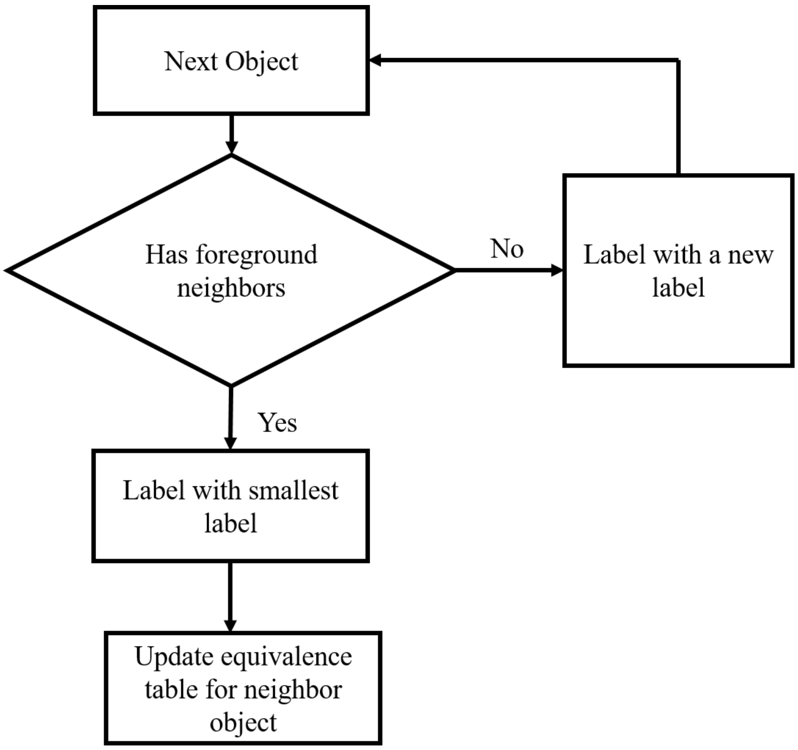

Figure 3.12: Object Labeling

IoT devices.

3.6 Results

To analyze the performance of the proposed Spatio-temporal algorithm, several objects are taken in the specified region. Different types of objects are randomly distributed into the field as shown in Fig-3.13.

The region is segmented based on objects as shown in Fig-3.14. The regional objects are than compared with the predefined objects as per the training pattern as shown in Fig-3.15. Based on the shape the Monitor and printer are labeled as S (Square). In the next step, the object is identified based on the shape as shown in Fig-3.16. Based on the identified object, the QSR and QTR algorithm are used to identify the exact placement of the IoT device to maintain the coverage and connectivity as shown in Fig-3.17.

Algorithm 1: Sensor and Actuator Placement

Result: Sensor and actuator Placement based on QSR and QTR
while $CurrentArea \leq TotalArea$ **do**
  Grid Distribution
  Coverage and Connectivity
  Segmentation of Grid based on Objects
  Shape classification based on Training Pattern
  Object detection based on Shapes
  Quantitative Temporal Reasoning on Objects
  Classification into Static and Dynamic Objects
  Division into Local and Visitor objects
  Connectivity of Objects
  Labeling and allotment of Class ID, Referencing ID and Confidence Value
  Quantitative Spatial Reasoning on Connected Objects
  Region Classification based on RCC8
  Direction based on TPCC
  Based on segmentation, object detection, and pattern distribution, placement of sensors and actuators
end

Figure 3.13: Objects before Segmentation

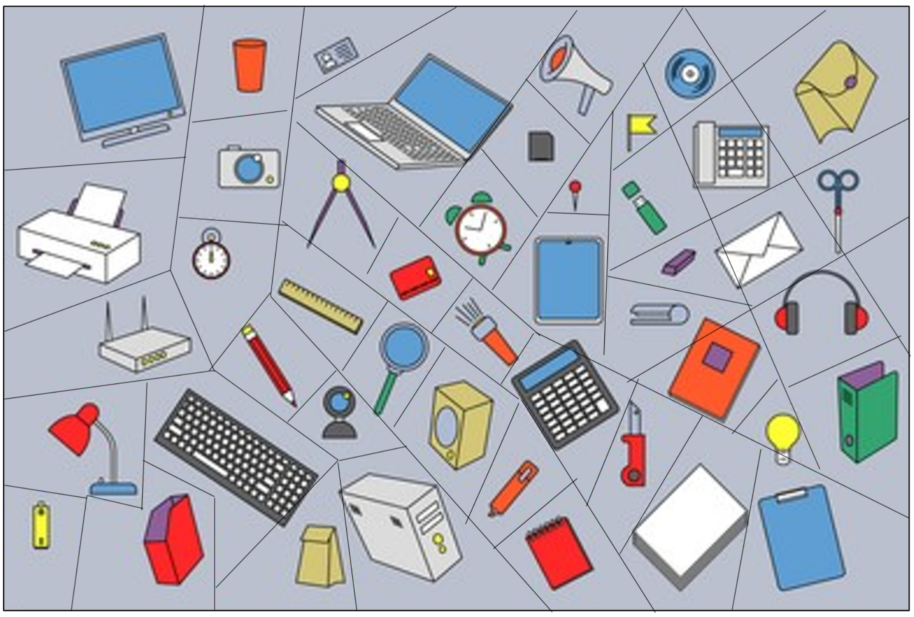

Figure 3.14: Object Classification

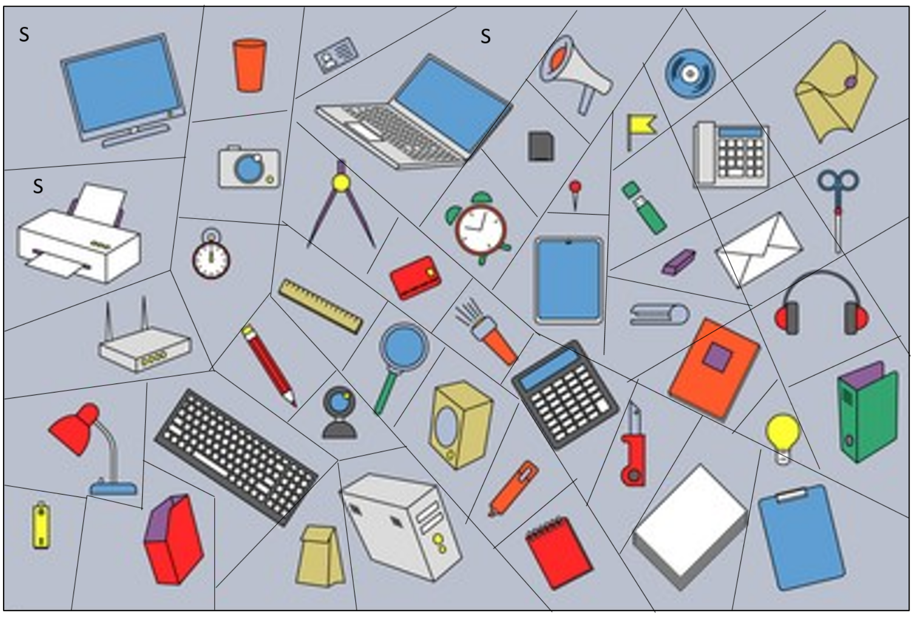

Figure 3.15: Object Shape Detection

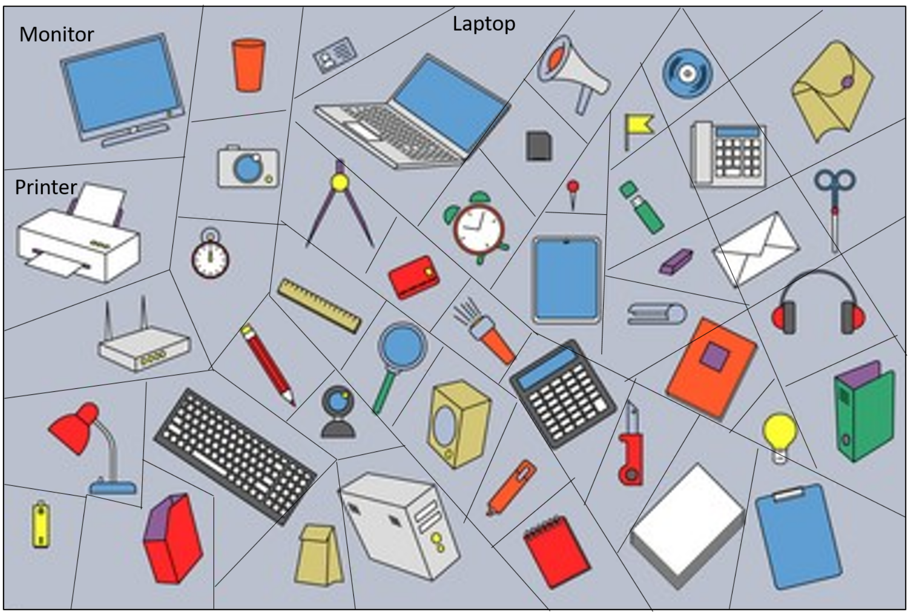

Figure 3.16: Object Identification

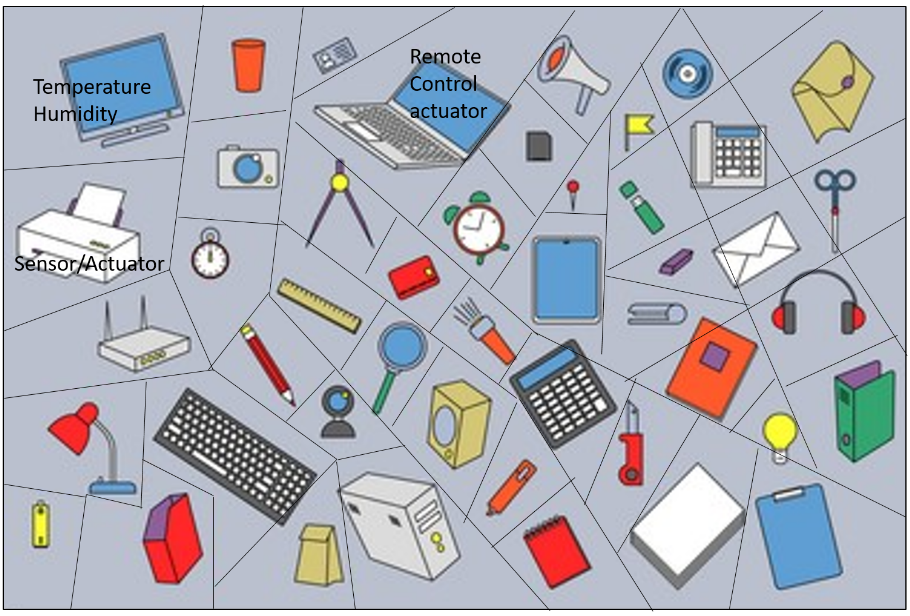

Figure 3.17: Sensor and Actuator Placement

In conclusion, in this work, a spatio-temporal algorithm is proposed to identify the placement of IoT devices to maintain coverage and connectivity. The algorithm involves several steps, including analyzing the performance of the algorithm, segmenting the region based on objects, comparing regional objects with predefined objects, identifying objects based on shape, and using the QSR and QTR algorithm to identify the exact placement of the IoT device. The objects used in the analysis are randomly distributed into the field and include monitors and printers, which are labeled as squares. The proposed algorithm is illustrated through several figures in the passage.

3.7 Summary

In the present work, a quantitative Spatio-temporal algorithm-based development methodology is proposed for the IoT System. The appropriate placement of the IoT devices in the region is the major goal of the present work. To achieve the goals and sub-goals, the five-layer module is proposed. The first phase starts with the types of IoT devices and general classification. The second phase manages the coverage and connectivity of the IoT device over the region. The coverage and connectivity are then used for the placement of the IoT device. The proposed methodology also discusses the design phases and the operational flow of the IoT devices. Object-oriented IoT device placement is the unique feature of the proposed algorithm. The results explain the optimal placement of the IoT devices.

Chapter 4

Spatial goal refinement patterns for IoT

4.1 Overview

This chapter presents a discussion on how spatial goal refinement patterns for IoT are developed to assist in solving problems associated with IoT. It consists of interconnected devices such as sensors, embedded systems, and actuators, which are mainly involved in the development of smart devices and automation routines. The idea behind spatial goal refinement patterns for IoT is to aid current and future research on IoT offerings through the seamless breakdown of goals that are grouped spatially according to performance. Spatial patterns are an embodiment of problems and solutions under specific contexts. We have considered various Internet of Things contributions, separate repeating demonstrated arrangement standards, and group them into designs. The strategy for refinement of the objectives is to be utilized with the goal so that the unpredictable difficulties can be addressed by separating them into straightforward and attainable sub-objectives [95].

4.1.1 *Spatial reasoning*

Spatial reasoning vitally informs our ability to investigate and solve problems, especially non-routine or novel problems. Spatial reasoning in IoT allows us to present the relationship between extended entities or original space. It is fundamental for reasoning to have physical space [25]. There are different numbers of approaches in spatial reasoning, for instance, topology [46], metric [38], and orientation [25].

Pattern definitions A pattern is a repeated form or design, especially one that is used to decorate something: the regular and repeated way in which something happens or is done [88]. The pattern gives us a lead on how to engage with the world; this is highly relevant in the real world and software design. Context can be a productive area of sensors and actuators of the objects. This can measure the range of area of the sensors to sense [62]. For example, a temperature sensor covers the area of the room or an actuating range such as lighting the whole room with the same brightness. Also, the relation between objects to realize between sensors to other sensors, or sensors to other actuators.

4.1.2 *Problem*

In this chapter, we have illustrated problems related to the spatial goal refinement patterns for IoT application and their possible solutions. Indeed, even without formal capability, the particular highlights of various spatial goal refinement patterns imply essentially unique semantics [75]. A few dialects permit different cases of the same action type simultaneously in a spatial pattern setting, while others don't. A few dialects structure circles with one entry point and one exit point, while in others, patterns are permitted to have subjective entry and exit focus. A few dialects require unequivocal end exercises for work processes and their compound exercises, while in others the end is verifiable. Such contrasts highlight various experiences of reasonableness and various degrees of expressive power [89]. In this chapter, a goal refinement pattern based methods are discussed for IoT application. The proposed technique is more functional. We wish to bring a more extensive understanding into the execution ramifications for the enormous and conceivably enormous patterns, with the expanding development of spatial goal refinement patterns. In many cases of the IoT field, several papers talk about spatial patterns [73]. In the previously reported works, authors address only the spatial goal patterns with the fundamental concept to identify beneficial constructs. The goal refinement is identified in this chapter. Sometimes while building the IoT system, some devices may perform errors and provide inaccurate data leading to many problems in the spatial patterns. To find a way to solve them, we need to have some questions about where what, and how. For example, where the sensors and actuators are, what are their spatial patterns, and how the IoT devices are oriented? Our study is meant to discuss the spatial patterns of the devices connected to the Internet. How efficiently the IoT devices can transmit the data to the internet. How we can spatially place the sensor devices so that the spatially correlated data can be filtered from the system. And in last, how we can determine the connected spatial region which is affected by the occurrence of some event e.g. affected region due to fire in a forest monitoring application.

4.1.3 *Approach*

To address the above problem, we have divided the goal into various sub-goals. The major sub-goals are efficient coverage of the field, connectivity of the IoT devices, Spatio-temporal aggregation of the data, and estimation of spatially connected regions of event detection. To analyze the system, we have categorized the applications into six different types of standard spatial patterns. The goal refinements for spatial patterns is indicated in the IoT system. With the help of goal refinement processes for IoT devices, it is easier to capture data for temperature, light, or any IoT devices in any available system. The necessities for spatial patterns through spatial objective is demonstrated for the refinement of the designs as depicted in [72].

4.1.4 *Goal refinement*

Goal-oriented requirements engineering (GORE) has been increasingly used for requirement engineering, which refers to the use of elicitation requirement, elaboration, analysis, evaluation, and modification requirements [3]. For this, goal-oriented specifications are essential for capturing the objectives that the system to be developed should achieve. GORE'S main aim was to elicit requirements from an analysis of a wider context in which the system will operate [103].

GORE approaches increased dramatically due to the inadequacy of the traditional systems. These processes can't full-fill completely the high-level concerns. Most techniques focus on the modeling and specification of the software alone. There is a form of refinement in which child nodes refine the parent node and the top-level goal can be considered as a root node which is the system vision [91]. AND-refinement, and OR-refinement relations are used for the set of goals and sub-goals [103].

4.1.5 *Related work*

Many of the previously reported works mentioned the role of spatial data in their proposed IoT-based architectures. In [104], the author proposed a framework of Spatial Data Warehouse system in IoT environments (SDWIT). Furthermore, the authors have considered all the system layers in detail which consist of data source, data processing layer, data storage layer, and application analysis layer. Moreover, the IoT spatial technology is discussed in perspective of Big Data (BD) in [98]. In this work, the author focused on BD conceptual modeling and the types of spatial attributes that are produced from a smart object. In addition, the author illustrated the spatial BD handling in different smart city scenarios. In [96], the author introduced an analytical framework of geo-spatial-temporal data with component service architecture. Mainly, the authors focused on the geo-spatial temporal data produced from IoT moving objects such as vehicles. Besides, the authors applied the proposed framework in the domain of the connected vehicle including autonomous driving and Usage-Based Insurance (UBI) areas. After applying the proposed framework, the authors have proven its efficiency. In [76], the comprehensive summary of all potential geo-spatial analysis of IoT data is proposed. The listed analytical methods were ranging from basic geometric measures to more advanced data mining and surface analysis methods. The authors classified the IoT applications' fields concerning the used analytical methods. The author handled 26 pieces of literature by discussing the used hardware, geo-spatial analysis, data types, and reliability issues. Regarding indoor IoT services, [94] presented a framework. They developed a new framework that included a spatial-based IoT service system. Few other spatial pattern based works are also reported for other applications. In [71], author proposed enhanced sub-pixel mapping technique using spatial distribution pattern. In [83], the author have proposed land surface temperature based spatio-temporal variability. Few other works are also proposed on spatio-temporal aggregation pattern [97] [102] [66] [101]. As per the best of our knowledge, no work is reported for the analysis of different spatial patterns for spatio-temporal aggregation, event detection based on spatially connected regions and the suitable pattern analysis of different IoT applications.

The organization of the present work is described as follows. Section 4.2 describes the spatial goal-refinement patterns. Section 4.3 deals with the comparison of IoT applications against spatial patterns. Section 4.4 deals with aggregation applications. Section 4.5 discusses the result & discussion and Section 4.6 summarizes the final findings.

4.2 Spatial goal refinement patterns for IoT

The present work deals with the spatial goal refinement pattern for the IoT applications. Therefore, this section deals with different spatial patterns. The section offers a library of the spatial patterns, simple constructs present in the definition of each spatial pattern, how the spatial pattern used in goals refinement, and performance of the spatial pattern in the real world. Since the spatial patterns are not defined, we will give a (a) *description* which describe each spatial pattern, (b) *example* it gives a better idea, (c) *performance* to how would be used in real world. These Spatial Patterns i.e complete coverage, periphery pattern, Center pattern, intersection volume, gradual decay, and Managing irregular volume are discussed in detail and their corresponding goal refinement is also illustrated.

4.2.1 Spatial pattern 1 (Complete Coverage)

Description:

In complete coverage, IoT devices must visit all the reachable surfaces in their environment sweeping all long-range sensors in the process. The devices must use a strategy to gather information about obstacles as it moves, and it must formulate and remember some form of a map of the area covered [99]. For instance, in our test case, we placed sensors 2 meters squared apart to detect the temperature of the designated smart area. This spatial pattern is characterized by the application of individual substances in space (IoT devices) and the geographic connections among them. To be able to test spatial examples, it is essential to understand the co-founded spatial cycles portrayed complete coverage spatial pattern. This pattern maps the area and saves the exact location of the sensors to ensure effective recurring temperature recording all through [100]. ***Example***: *G 1*: To accurately measure the room temperature of a smart area.

G 2: To install sensor and actuator in each area of the room.

G 3: To restrict the temperature level inside the smart area.

Performance: This pattern uses the concept of systematic steps in spatial patterns. The concept here is to have the required area covered completely to ensure accuracy in temperature recording [92]. To achieve this, the IoT devices must be connected to the internet, and deploy the actuators to the covered area which generally uses battery power. Due to the purposes of this spatial pattern, it has to be designed to last longer under a tough condition. For instance, In coverage of an area, there could be a user controlling different sensors in the same area. Sensor 1 and sensor 2 might be located and covering one specific area. In this instance, we will use temperature sensors to enable complete sensing of temperature in the smart area. The goal of the tool is to complete temperature sensor coverage of the building to detect the accurate temperature of the area. The idea of IoT is meant to generate a solution in the business-industry through the use of sensors, and the possibility of transferring data and information through sophisticated specifications and protocols. The system can record all the temperatures of the smart building [100].

The architecture of the complete coverage spatial pattern is shown in Fig. 4.1. In this pattern, the circular area is representing coverage of the IoT sensor device. The sensors are labeled from 1 to 16 for two different clusters. The left side of the labeled devices (1-16) exists in the connectivity range of IoT Gateway device, i.e., Node-A and the right side of labeled devices exists in the connectivity range of IoT Gateway device Node-B. In the complete coverage connectivity, the sensor devices should be placed such that the coverage of the area should not contain any gap (uncovered area/hole). In Fig. 4.1, the

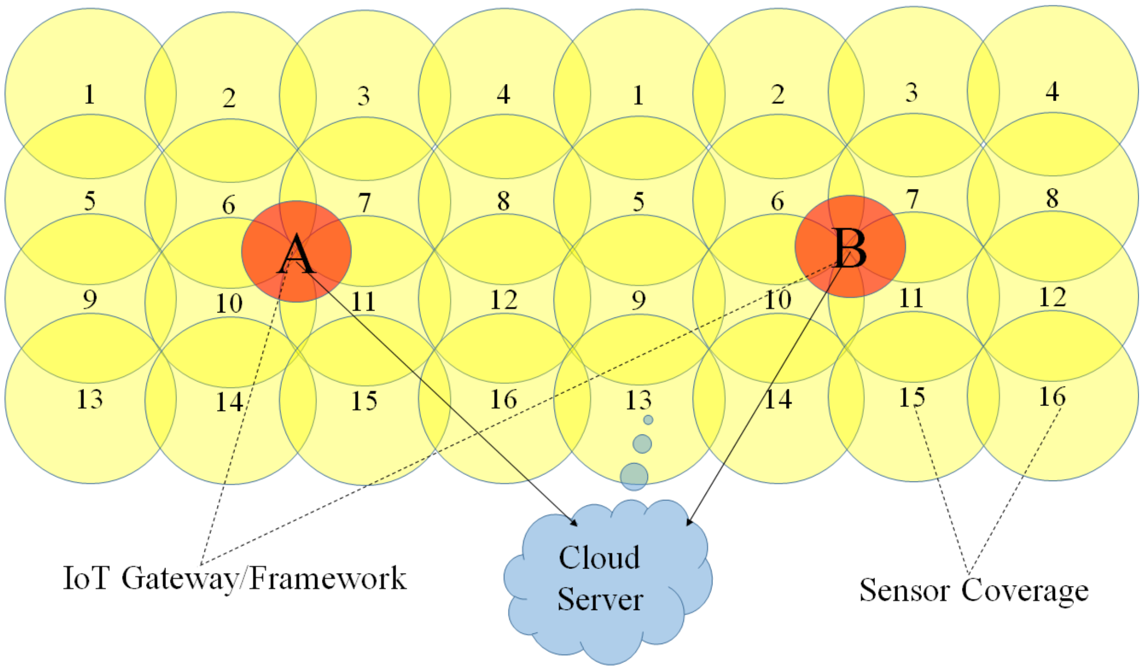

Figure 4.1: Architecture of Complete Coverage

sensor devices and Gateway devices are placed such that both the coverage and connectivity are maintained for satisfactory communication. IoT Gateway devices, i.e., Node-A and Node-B, communicate with the cloud server. The complete coverage pattern is useful for many types of monitoring applications e.g., Agriculture field monitoring, 5G-IoT, etc.

4.2.2 Spatial pattern 2 (Periphery Pattern)

Description: The periphery pattern solves the problem associated with the whole circumference of an area when installing various sensors. This type of spatial pattern is present in several realistic applications e.g. military camp surveillance, very sensitive buildings (i.e., nuclear center) surveillance, and contaminated region monitoring, etc. Therefore, the objective is to detect any intrusion coming from the outside (viewed by at least one multimedia sensor node) [79]. Devices using this pattern will typically be focused on the peripheries/outskirts of the jurisdiction of device operation [74]. ***Example***: *G 1*: To count all IoT devices outside of a smart building. *G 2*: To locate each directional flow of IoT devices outside the building. *G 3*: To avoid counting any devices inside the building.

Performance: When installing the IoT devices, take note that the area is divided into

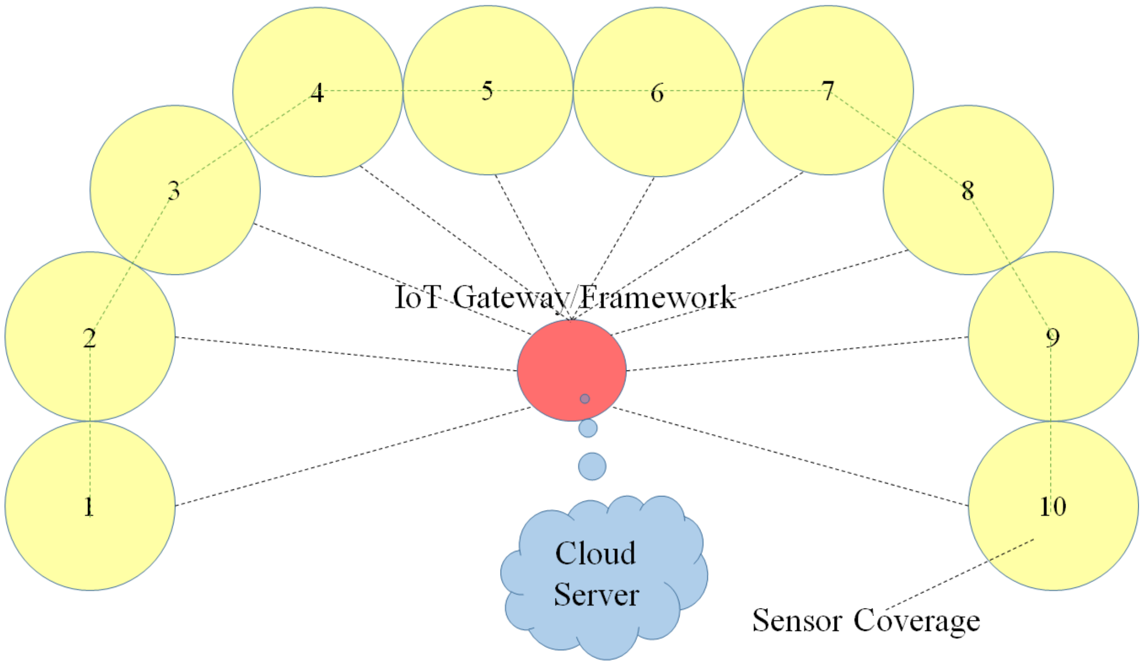

Figure 4.2: Architecture of Periphery Pattern

two sides. One region is the central area where the IoT devices are installed inside the building, while the other region is the devices that are installed outside the building to collect the data outside the building [74].

The architecture of the periphery pattern is shown in Fig. 4.2. In this pattern, the circular area is representing coverage of the IoT sensor device. The sensors are labeled from 1 to 10. In this type of pattern, the IoT sensor devices are either distributed linear or circular to the boundary of the surface. The architecture is shown in Fig. 4.2 for a circular boundary. The sensors should be placed over the circular range such that the coverage and connectivity should be maintained over the boundary. All the IoT sensor devices transmit the sensed data to the central IoT Gateway device. The periphery pattern is useful for many types of monitoring applications e.g., Border security application, Railway monitoring application, etc.

4.2.3 Spatial pattern 3 (Center Pattern)

Description: The center spatial pattern focuses on the middle area/area inside a smart area, and is used to locate all IoT devices in that area. In center spatial pattern, all sensors and actuators are installed inside the building. In addition, it is important to have

IoT device connected to the internet inside the required coverage area. For instance, the IoT devices are installed inside the building to sense and actuate the parameter inside the monitoring area [76]. These IoT devices are programmed to perform only inside the building. In a smart building, there might be different devices programmed to sense different environmental factors, thus the need to have a specific IoT tool to detect the required temperature. For instance, we need to determine motion on a specific area inside the house, the center pattern enables us to locate the sensor. An IoT development device, M2M lab Mainspring, equipped with sensors like the temperature sensors and actuators is used to communicate with a server application that is running the device communication protocol. This GPS like structure captures the exact location of sensors located inside the building and can be tracked easily. ***Example***: *G 1*: To count all the devices that are installed inside the smart building. *G 2*: To locate each area outside the smart building. *G 3*: To avoid counting any IoT devices outside the smart building.

Performance: Center patterns are architectural concepts describing how messages are transported in the pattern to accomplish certain tasks. Knowledge of these patterns is important to be able to correctly design and implement applications and scale networks of things accordingly so that functional and performance requirements are met. This is the opposite of the previous pattern, all sensors and actuators are installed inside the building. In addition, it is important to have an IoT device connected to the internet inside the required coverage area. For instance, in the required smart environment, there are IoT devices installed inside the building designed to sense and actuate inside. The IoT devices are programmed to perform only inside of the building. This means that there will be many IoT devices. So, we would be looking for a specific one of the sensors. For instance, we need to know the motion sensor sensing a specific area inside the house. The architecture of the center pattern is shown in Fig. 4.3. In this pattern, the circular area is representing coverage of the IoT sensor device. The sensors are labeled from 1 to 8. In this type of pattern, the IoT sensor devices are distributed over the circular region. The sensors should be placed over the circular region such that the coverage and connectivity should be maintained over the entire circular area. This pattern is similar to

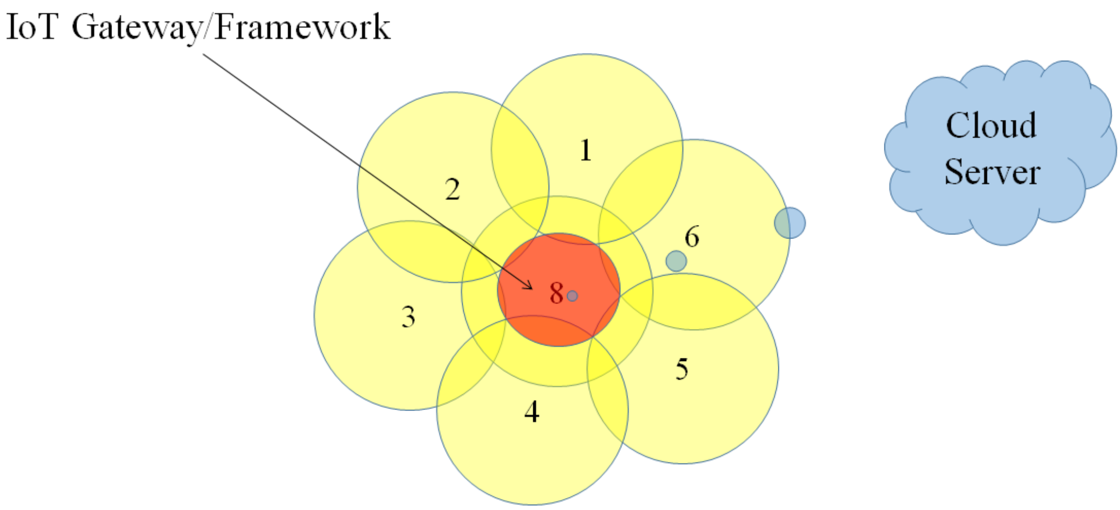

Figure 4.3: Architecture of Center Pattern

the complete coverage pattern. However, in this case, IoT sensor devices are distributed such that the overall coverage should be circular to monitor a circular region. All the IoT sensor devices transmit the sensed data to the central IoT Gateway device as shown in Fig. 4.3. The center pattern are useful for many types of monitoring applications e.g., IIoT (Industrial Internet of Things).

4.2.4 Spatial pattern 4 (Intersection Volume)

Description: In intersection volume, it solves the problem associated with the objects or things interacting with each other, that affect the IoT devices' performance. With the volume of space indefinite, devices have indefinite points of interaction. However, we will focus on those ones in a smart area and look at how their smart components i.e sensors and actuators work together to complete a task in that area. ***Example***: *G 1*: To make sure all IoT devices are installed separated. *G 2*: To check each area of IoT device, the devices will be installed separately. *G 3*: To check each area of the smart building for IoT devices.

Performance: In this pattern, the IoT devices must be installed carefully in the smart environment, where each IoT device should not be in touch with the other IoT devices. One example, when the technical person installs two temperature sensors beside each other by mistake or was not aware that they are the same sensors at the same area to detect the same environment, thus, that create several problems much as the conflict of sensing

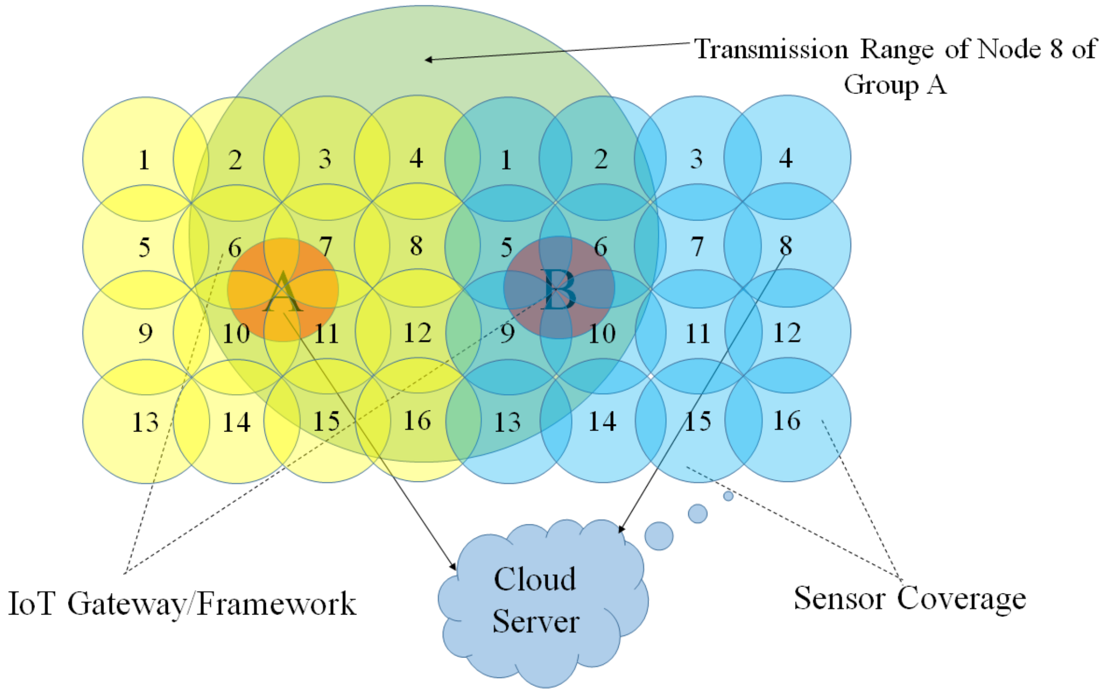

Figure 4.4: Architecture of Intersection Volume

wrong readings. When two different IoT clusters are very close to each other, the devices which are placed at the boundary of the cluster come into the direct connectivity range of both the IoT Gateway. Therefore, boundary nodes should be placed very carefully so that the connectivity and coverage should be maintained without exposing the boundary nodes to the secondary IoT Gateway device. As shown in Fig. 4.4, the IoT device in the yellow region is under the coverage range of both the IoT Gateway devices A and B. Therefore, the connectivity range of the boundary devices should be maintained such that it only allows communication with the corresponding IoT Gateway device only.

4.2.5 Spatial pattern 5 (Gradual Decay)

Description: Gradual decay would ensure maximum coverage of an area within the same time. It's the decline in area or environment of the perfection that leads to gradual decay. ***Example***: *G 1*: To guarantee that light reaches all areas of the room. *G 2*: To limit the strength of the light sensor area. *G 3*: To reach the last weakness of the light sensor area. ***Performance***: The designer engineers installed light sensors in the smart building in each room. The actuators of the light sensor are supposed to light the room, sometimes the

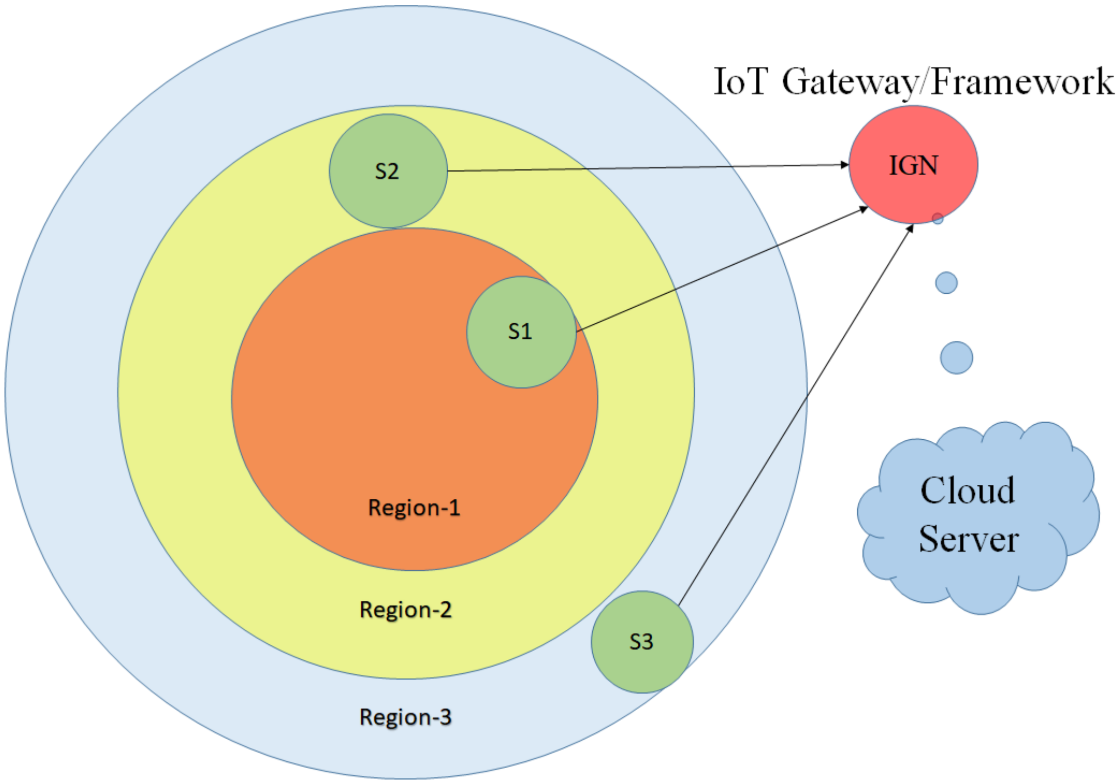

Figure 4.5: Architecture of Gradual Decay

person sitting in the corner of the room cannot see clearly as the person sitting nearby the light. We consider this as a gradual decay pattern, so that the person sitting in the corner has the least possible light to see. Suppose one has designed a system to turn on and off lights in a room, they need to update frequently or change the duration of the lights [76]. Maintainability and adaptability are the most important challenges in such designs. You must be able to update the code and deploy it to all your devices at once. The architecture of the gradual decay pattern is shown in Fig. 4.5. In this pattern, the source is present at the center and the magnitude of the source decreases gradually. In Fig. 4.5, the overall area is divided into 3 regions. The region-1 experience highest intensity, sensor-1 senses the data and transmit it to the IoT Gateway node. Region-2 has a lower intensity than region-1. The region-3 has the lowest intensity. For each region, sensors sense the data and transmit it to the IoT Gateway device. IoT Gateway device compares all the sensed data. If the difference becomes greater than the threshold, it actuates to the central device to increase the intensity so that region-3 also receives a sufficient amount of intensity. This type of pattern is useful for smart libraries. In smart libraries, a sufficient amount of

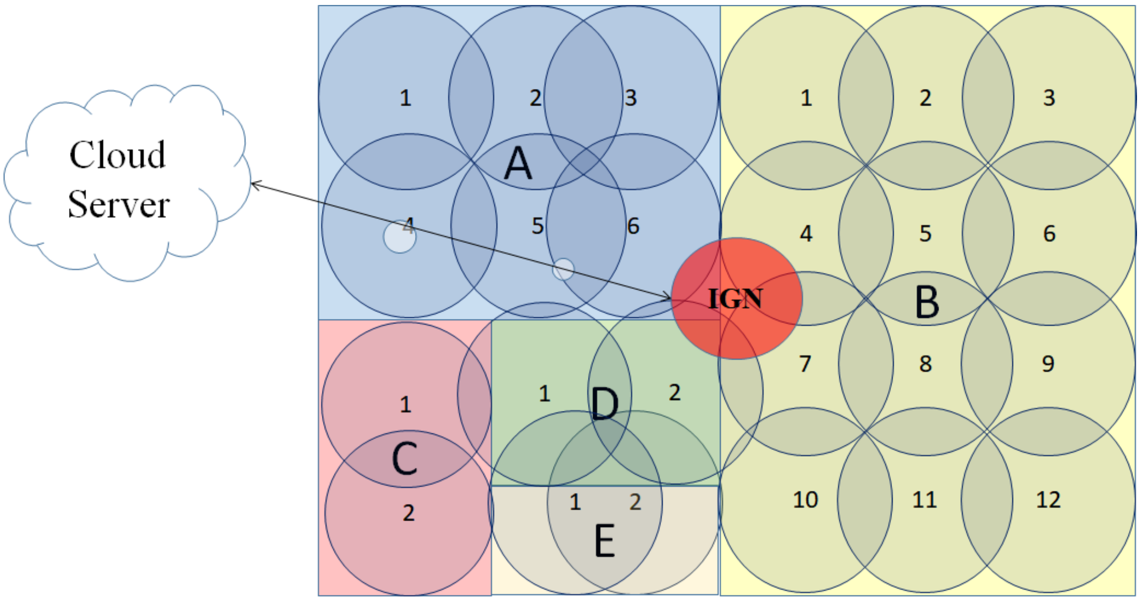

Figure 4.6: Architecture of Irregular Volume

light reaches all the end-users with optimal energy consumption.

4.2.6 Spatial pattern 6 (Managing Irregular Volume)

Description: Managing irregular volume focuses on location of all IoT devices that occupy an irregular shape. ***Example***: *G 1*: Keep track of environment conditions. *G 2*: Installing sensors all over the place. *G 3*: Providing connectivity to these sensors to send their data. ***Performance***: The IoT devices must be installed carefully in the smart environment, where each IoT device should cover the desired space to achieve correct motion sensory. In our test, we installed motion sensors in front of a smart building, this was a check on achievability of our goal. Therefore, human activities such as walking, running, and standing are definitely captured. It encountered challenges of data transmissions from various sensing devices to a remote OM (Operation and Management) server through the Internet. This leads to arising problems, such as an explosion of network traffic, and delayed responses to data.

The architecture of irregular patterns is shown in Fig. 4.6. In this type of pattern, the region is sub-divided into small sub-regions. Due to the irregularity of the pattern, the sensors should be placed smartly so that complete coverage can be achieved with a minimum number of sensor nodes. As shown in Fig. 4.6, the complete region is divided into 5 different regions, i.e., A,B,C,D,E. The shapes of all the regions are different. An example of this type of pattern is the smart home where different sensors are distributed into different regions.

4.3 Comparison of IoT Applications Against Spatial Patterns

This section shows how the proposed spatial patterns can be used in the various IoT applications outlined. Table 4.1 summarizes the applications, their most suitable spatial patterns, sensor distribution, coverage, connectivity, cost, and mobility. Table 4.2 summarizes the result comparison of the applications that can be used with the spatial patterns. For each spatial-application combination, if the spatial can be used in the application, we mark a ’+’. If the spatial patterns cannot be used for a specific smart application, we marked ’-’. The comparison shows that the complete coverage and center are used in all applications because there was a complete area utilization and center area utilization. For instance complete coverage is needed in healthcare, industrial and smart retail to manage and monitor room temperatures especially for storage rooms. For the industrial application where many machines operates, the temperature has to be monitored and regulated within the suitable range. The center pattern is specifically essential for the retail stores to detect and monitor motion of customers in the store to later use this data to determine customer behaviors towards various products. It’s also essential for the healthcare sector to keep track and take records of employees, patients and equipment activities within the hospital premises. The intersection volume is essential in all applications so the devices like temperature sensors are strategically positioned to cover the whole area and not waste resources.

Similarly, intersection volume patterns is applied in all applications simply because devices across all these applications must interact at one or another level hence satisfying requirements of the patterns. On the other hand, the other patterns are used selectively according to relevance. This information come in handy for ongoing and future research

Table 4.1: IoT Applications and suitable IoT Pattern

IoT Applications	Suitable Spatial Pattern	Distribution	Coverage and Connectivity	Cost	Mobility
Railway Condition Monitoring [1]	Peripheral Pattern	Linear	Moderate	Moderate	Static
Agriculture Field Monitoring [1]	Complete Coverage	Rectangular	High	High	Static
Industrial field Monitoring	Center Pattern	Circular	High	low	Static
Smart Grid	Peripheral Pattern	Linear	Moderate	Low	Static
Smart Health Monitoring	Intersection pattern	Circular	High	low	Dynamic
Smart Building	Irregular Volume	Linear/ Circular	Moderate	Moderate	Static
Self-driven Car	Peripheral Pattern	Linear	Moderate	Moderate	Dynamic
Smart Library	Gradual Decay	Circular	High	Low	Static
Smart Transportation	Peripheral and Complete Coverage	Linear and Rectangular	High	High	Dynamic
Smart Shopping Malls [152]	Centered	Circular	High	Moderate	Static and Dynamic
AR and VR Iot	All types	Depend upon Application	High	Moderate	Static and Dynamic
5G IoT	Complete Coverage	Cellular	High	High	Static and Dynamic

in the field of IoT to help resolve spatial managerial demands of IoT applications by using it as a guide in developments.

Complete coverage, center, and intersection volume patterns are realized across all applications because of the wholeness of spatial area that they cover. Peripheral coverage pattern is applied in self-driven cars, smart-grid, smart transportation, smart buildings, IoT in healthcare, Industrial IoT, and smart retail because they have peripheral areas that lead to protection of the center areas. It is essential for tagged hospital, retail and industrial equipment and products to prevent them from going outside a certain restricted area and sending an alert when they do thus improving security. It also keeps the intruders outside of restricted areas and sends an alert when unauthorized personnel tries to get-in.

The Peripheral areas therefore serve as lookout for the important central areas. Smart Farming and Smart Supply-chain management are only concerned about the areas of application of IoT devices at a time and do not need external areas. They therefore will not the peripheral coverage pattern.

For gradual decay pattern, all but smart supply-chain management and smart grid are applied. Since the area of coverage is solely responsible for the gradual decay, all applications have a decreasing area of coverage except the smart grid and smart supply-chain management which has a constant area of coverage even with movement. Exactly opposite to the gradual decay pattern, managing irregular volume pattern is only used in the smart supply-chain management and smart grid. This is because of the spatially alternating volumes but constant areas, i.e., devices in this application cover only a defined place. The table below summarizes the comparison of all IoT applications against the proposed spatial patterns.

4.4 Spatio-temporal Aggregation

To achieve the sub-goals, the Spatio-temporal aggregation protocol is proposed. With the help of the Spatio-temporal algorithm, we can achieve two major sub-goals: 1) The redundant data can be filtered that reduces the energy consumption of IoT devices. 2) For any alert signal or event detection, it determines the spatially correlated values that help to de-

Table 4.2: Comparison of IoT Applications against Spatial Patterns

Patterns /Applications	Complete Coverage	Peripheral pattern	Center pattern	Intersection Volume	Gradual Decay
Self-Driven Cars	+	+	+	+	+
Smart Farming	+	-	+	+	+
Smart Supply-Chain	+	-	+	+	-
Smart Grid	+	+	+	+	-
Smart Transportation	+	+	+	+	+
Smart Buildings	+	+	+	+	+
IoT in healthcare	+	+	+	+	+
Industrial internet of things	+	+	+	+	+
Smart retail	+	+	+	+	+

termine the region of the affected area. In the present work, six different types of patterns are proposed for different types of IoT applications. The efficient transmission of sensed data from the sensor to the monitoring station or cloud is also very important. Sometimes sensors placed in a certain spatial point measures the same data again and again. The IoT sensor device each time transmits all the data to the IoT gateway device. If the sensor generates the same data in $i-1^{th}$ and i^{th} iteration, the data samples are called temporally correlated data. Similarly, when all the IoT sensor devices from different spatial locations transmit the same parameter to the IoT gateway device. Sometimes, the data collected from different spatial locations from different IoT devices measure the same data. The IoT Gateway device compares both the data and if the data samples from different IoT sensor devices have the same value, they are called spatially correlated data. Therefore, for efficient transmission of data, filtration of temporally and spatially correlated data is important. In the present work, we have proposed a Spatio-temporal algorithm for filtration of data for six different types of spatial patterns which can be utilized for all the possible IoT applications as per the pattern requirement. The architecture of the Spatio-temporal algorithm is shown in Fig. 4.7 The architecture of filtration of correlated data for all six patterns will remain the same. However, each different type of pattern transmits a different status flag to the cloud. The flags are utilized by the monitoring station. The task

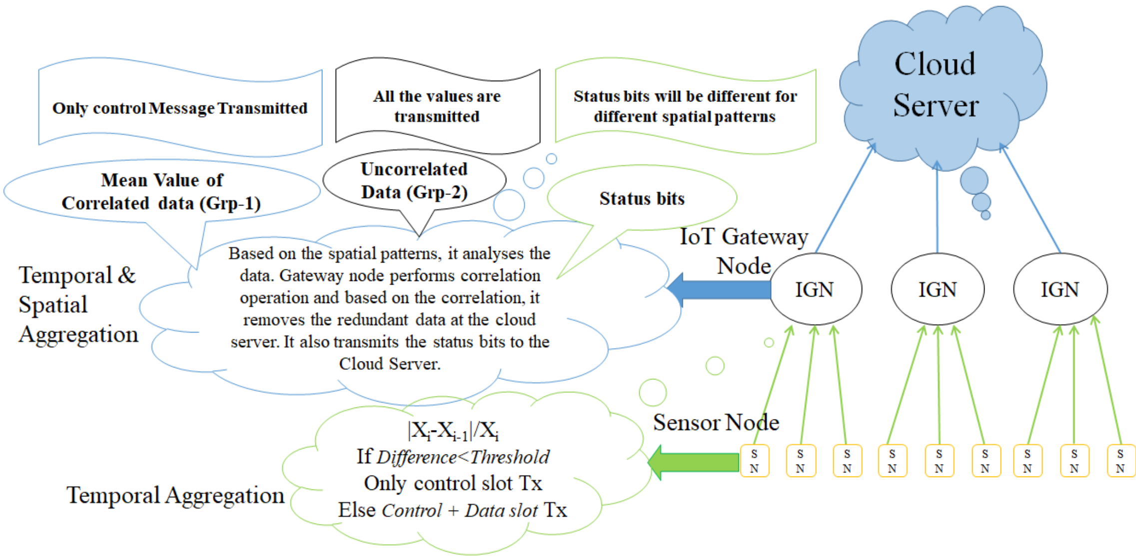

Figure 4.7: Architecture and operation of Spatio-temporal IoT

of the status flag is to generate an alert signal for any event detection and also inform the monitoring station to identify the affected area. The affected area can be determined with spatially correlated data. The temporal aggregation operation is given in $Algorithm-1$.

Algorithm 2: Temporal Aggregation at Sensor Node

Result: Data is temporally correlated or not
each n^{th} sensor node performs temporal aggregation for every i^{th} iteration;
while $i \leq I$ **do**
  while $n \leq N$ **do**
    n^{th} sensor node checks buffer data at i^{th} iteration;
    if $X_{in} == X_{(i-1)n}$ **then**
      n^{th} sensor node not transmit data Packet in i^{th} iteration;
    else
      n^{th} sensor node transmit data Packet in i^{th} iteration;
    end
  end
end

The temporal aggregation operation is performed by IoT sensor device at lower layer. In this case each sensor compares the readings of current and previous iteration. If the difference is less than lower deviation threshold, it do not transmit any data to the IoT gateway device. The spatio-temporal aggregation operation is given in $Algorithm-2$. The spatial algorithm is performed at the IoT gateway node. The IoT gateway node determines the mean value of all the sensed data of different coordinates for same parameter as given in

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Algorithm 3: Spatial Aggregation at IoT Gateway Node

Result: Data is Spatially correlated or not, identifies the effected spatial region
Perform spatial correlation operation for N distinct sensor node (placed at different spatial coordinates);
while $i \leq I$ **do**
  while $n \leq N$ **do**
    $X_{iM} = \frac{\sum_{n=1}^{n=N} X_{in}}{N}$;
    $X_{iSTD} = \sqrt{\frac{\sum_{n=1}^{n=N}(X_{in}-X_{iM})^2}{N}}$;
    if $X_{iSTD} < X_L$ **then**
      Tranmit only X_{iM} in i^{th} iteration to cloud;
    else
      $G = X_{i1}, X_{i2}, X_{i3}.......X_{iN}$;
      $[G_1, G_2] = k - means(G)$;
      Here, $N_{Count}(G_1) > N_{Count}(G_2)$;
      $X_{iMG1} = Mean(G1)$;
      Tranmit X_{iMG1} and all values of group G_2 in i^{th} iteration to cloud;
      Analyze the G_2 data;
      Identifies the connected sensors from G_2 readings;
      Transmits the status flag for effected area based on spatial patterns;
    end
  end
end

Eq. 4.1. It also determines the standard deviation of all the spatial IoT sensor devices data. If the deviation is smaller than the lower threshold, it only transmits the mean value to the cloud as given in Eq. 4.2. Otherwise, it again divides the data into spatially correlated groups. It transmits the mean value of spatially corrected group data and also transmits all the spatially correlated data belongs to G_2.

$$X_{iM} = \frac{\sum_{n=1}^{n=N} X_{in}}{N} \tag{4.1}$$

$$X_{iSTD} = \sqrt{\frac{\sum_{n=1}^{n=N}(X_{in} - X_{iM})^2}{N}} \tag{4.2}$$

Interconnected **Rectangular** Region Sensor Nodes (4 bits)	Alarming (1-bit)	R (1-bit)	Event Detected (1-bit)	R (1-bit)

Figure 4.8: Complete Coverage Pattern Status Flag

Interconnected **Linear** Region Sensor Nodes (4 bits)	Alarming (1-bit)	R (1-bit)	Event Detected (1-bit)	R (1-bit)

Figure 4.9: Peripheral Pattern Status Flag

4.4.1 Status Flag

4.4.1.1 Complete Coverage Pattern

The status flag of complete coverage pattern is shown in Fig.4.8. In this status flag bit-1 and bit-3 are reserved for the future uses. If any event detected by any of the sensor or cumulative sensors, IoT gateway device set bit-2. If the value is larger than the upper deviation threshold, it also set the bit-4.The next 4-bit is reserved for the spatially correlated points. It checks the spatially correlated points which have value greater than the threshold to identify the affected region.

4.4.1.2 Peripheral Pattern

The status flag of peripheral pattern is shown in Fig.4.9. In this status flag also bit-1 and bit-3 are reserved for the future uses. If any event detected by any of the sensor or cumulative sensors, IoT gateway device set bit-2. If the value is larger than the upper deviation threshold, it also set the bit-4.The next 4-bit is reserved for the spatially correlated linear or circular points. It checks the spatially correlated points which have value greater than the threshold to identify the affected region.

Interconnected **Circular** Region Sensor Nodes (4 bits)	Alarming (1-bit)	R (1-bit)	Event Detected (1-bit)	R (1-bit)

Figure 4.10: Centered Pattern Status Flag

4.4.1.3 Centered Pattern

The status flag of centered pattern is shown in Fig.4.9. In this flag also status flag bit-1 and bit-3 are reserved for the future uses. If any event detected by any of the sensor or cumulative sensors, IoT gateway device set bit-2. If the value is larger than the upper deviation threshold, it also set the bit-4. The next 4-bit is reserved for the spatially correlated circular points. It checks the spatially correlated circular points which have value greater than the threshold to identify the affected region. ‘

4.4.1.4 Intersection Pattern

The status flag of intersection pattern is shown in Fig.4.11. In this flag, if any event is detected by any of the sensor or cumulative sensors, IoT gateway device sets bit-1. If the value is larger than the upper deviation threshold, it also sets bit-4. Bit 2 and 3 used to transmit the status of the merged IoT devices of two different boundaries which are intersected with each other. The next 4-bit is reserved for the spatially correlated rectangular points. It checks the spatially correlated points which have value greater than the threshold to identify the affected region.

4.4.1.5 Gradual Decay Pattern

The status flag of gradual decay pattern is shown in Fig.4.12. In this flag, if any event is detected by any of the sensor or cumulative sensors, IoT gateway device set bit-1. If the value is larger than the upper deviation threshold, it also set the bit-4. Bits 2 and 3 are reserved for the future use. The next 4-bit is reserved for the spatially correlated circular regions where the intensity less than the threshold parameter value.

Interconnected **Rectangular/Circular** Region Sensor Nodes (4 bits)	Alarming (1-bit)	**Boundary Intersecting Nodes (2-bits)**	Event Detected (1-bit)

Figure 4.11: Intersection Pattern Status Flag

4.4.1.6 Irregular Region Pattern

The status flag of irregular region pattern is shown in Fig. 4.13. In this flag, if any event is detected by any of the sensor or cumulative sensors, IoT gateway device set bit-1. If the value is larger than the upper deviation threshold, it also set the bit-4.Bits 2 and 3 are used to transmit the number of IoT sensor devices which are present at the boundary of the two different regions. The next 4-bit is reserved for the spatially correlated rectangular points. It checks the spatially correlated points which have value greater than the threshold to identify the affected region.

4.5 Result and Discussion

In this section, the results are analyzed that are obtained from the IoT sensor devices. The IoT sensor devices are placed on four different spatial locations. A center spatial model is developed. The IoT sensor devices have been distributed over the land. The temperature sensor is connected with each of the IoT sensor device. IoT sensor devices sense the data and as per the Algorithm-1, it performs temporal correlation operation. Similarly, as per the Algorithm-2, IoT Gateway nodes perform spatial correlation and classification of data into groups. It also identifies the spatially correlated regions affected due to occurrence of an event. The center spatial pattern of the proposed architecture is shown in the figure.

For the experimental analysis, we have taken sampled data of 26 hours. The sample duration is 1 minute. Total 1649 samples are collected from spatially distributed sensors. For the testing and analysis purpose, we have generated the events in the connected re-

Interconnected **Circular** Region Sensor Nodes parameter less than Threshold (4 bits)	Alarming (1-bit)	**R (2-bits)**	Event Detected (1-bit)

Figure 4.12: Gradual Decay Pattern Status Flag

Interconnected **Irregular Region** Sensor Nodes parameter less than Threshold (4 bits)	Alarming (1-bit)	**Irregular regions Interconnection (2-bits)**	Event Detected (1-bit)

Figure 4.13: Irregular Region Pattern Status Flag

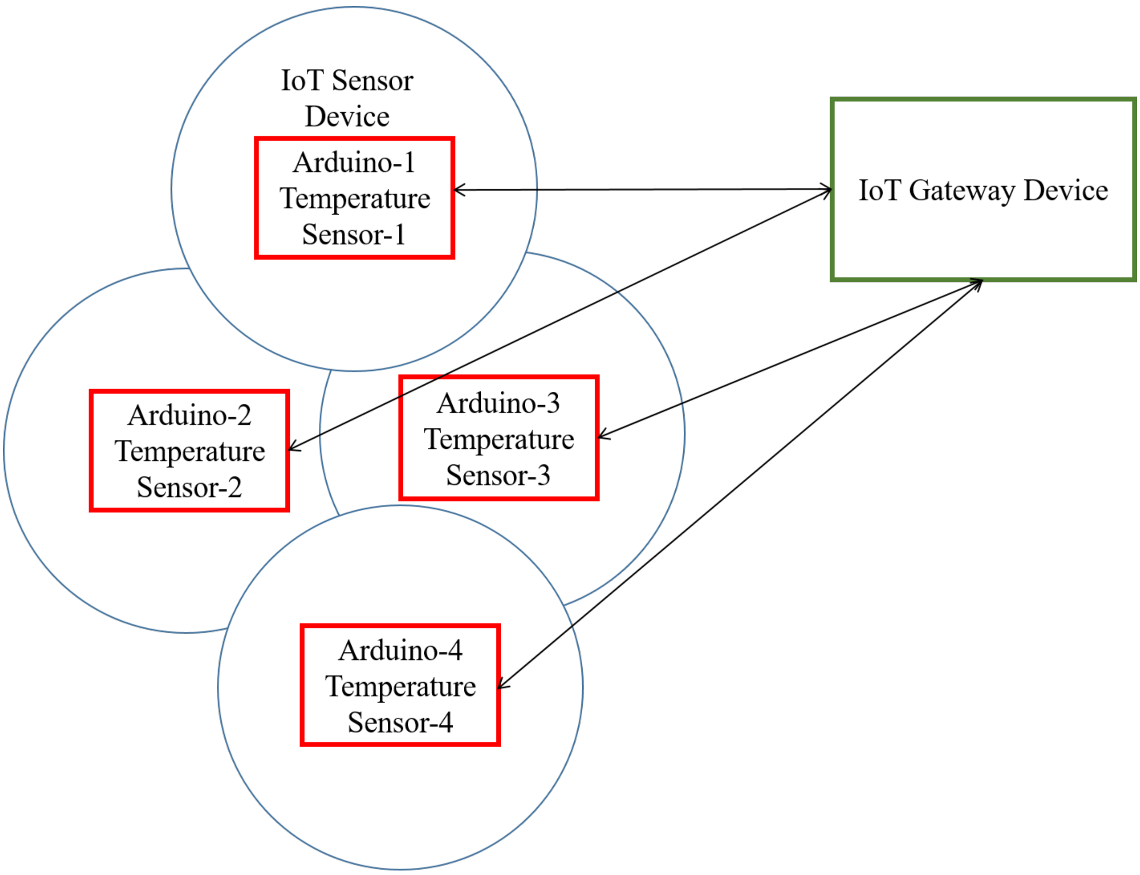

Figure 4.14: Experimental setup

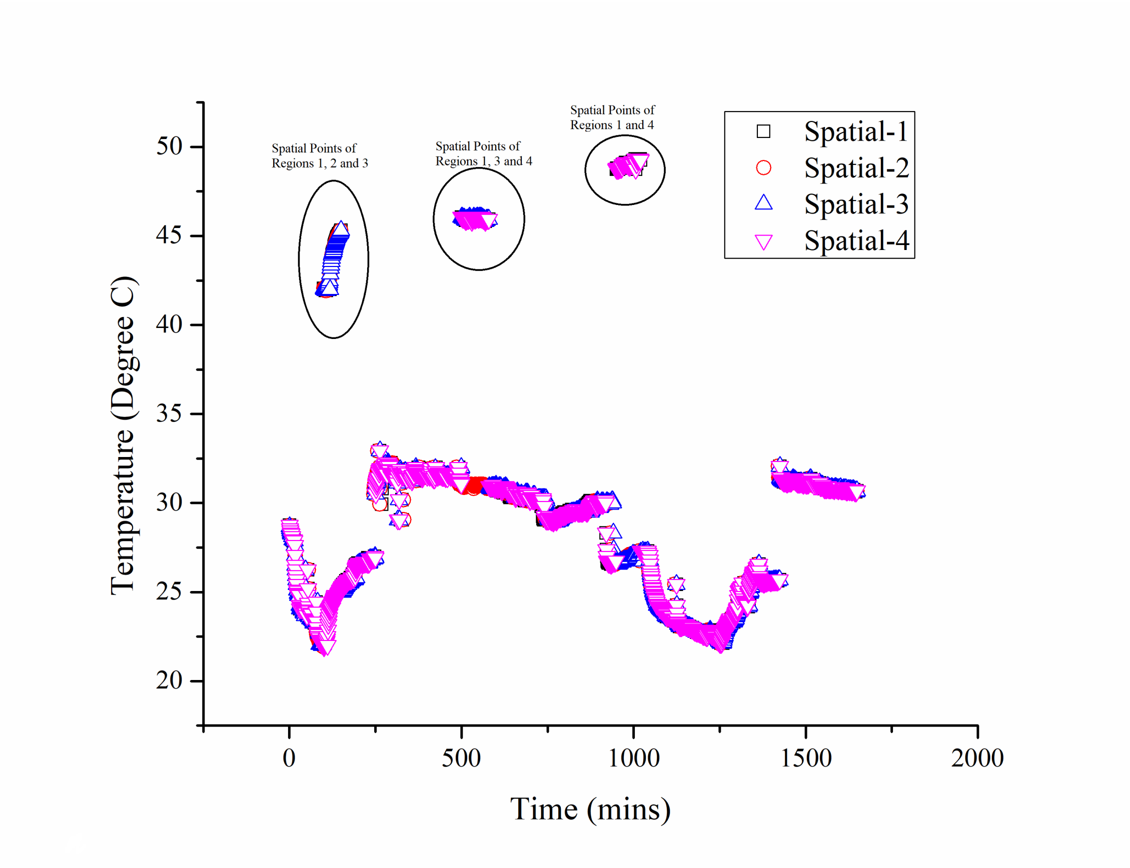

Figure 4.15: Experimental Result (Recorded readings of Temperature Sensor and the interconnected regions)

Table 4.3: Experimental Results

Parameters	Values	Concluded Results
No. of samples sensed	1649	–
Samples filtered by first IoT sensor device	817	49.5% redundant data removed
Samples filtered by second IoT sensor device	815	49.4% redundant data removed
Samples filtered by third IoT sensor device	802	48.6% redundant data removed
Samples filtered by fourth IoT sensor device	827	50.1% redundant data removed
Mean values transmitted by IoT Gateway device	1352	82% redundant data removed at IoT Gateway Device
Event Detection (First time)	T≥ 35°C	Spatially interconnected Regions 1, 2 and 3
Event Detection (Second time)	T≥ 35°C	Spatially interconnected Regions 1, 3 and 4
Event Detection (Third time)	T≥ 35°C	Spatially interconnected Regions 1 and 4
Mean Square Error after complete filter operation	0.0855	Transmits the unique data with very high accuracy

gions and using the algorithm 2, the grouped data are verified and analyzed. As shown in the Fig-4.15 of the sampled data, the first few samples where the event is detected (the readings are greater than 35°C), the regions 1,2 and 3 readings are interconnected regions. In this range, all the three regions are showing same readings. Therefore regions will be called spatially interconnected regions. Similarly, the next sampled data where the readings are high and more than 35°C is shown in the Fig. 4.14. The interconnected regions are 1, 3 and 4. In last one, the interconnected regions are 1 and 4.

The IoT sensor devices and IoT Gateway devices performs the task as per the algorithm given in the previous section. The results show that IoT Sensor devices removes the 50% of redundant data. Similarly, IoT Gateway node transmit the data to the internet. Similarly, IoT Gateway Device removes the approx. 80% of the redundant data. The results are shown in Table 4.3.

4.6 Summary

IoT is evolving and is being experimented and used in tons of different ways and the applications discussed in the previous section. With the guide of the spatial patterns, IoT applications can be explored with ease so that even the most complex ideas can be refined spatially hence achieved easily. In the future, almost all applications of IoT will necessitate breakdown of the goals along different lines so as to cover for the ever-growing use of IoT.

In conclusion, this chapter presents the aspects to guide individual steps in development and procedures to build and sustain the device and displays several spatial refined patterns that when considered can evolve the IoT space and define what holds for the future. To achieve the goal for each of the refined spatial pattern, the goals are divided into sub-goals. To achieve the sub-goals, we have presented spatio-temporal algorithm. The algorithm not only filters the redundant data but also it reports the monitoring station about spatially connected and affected zones. For the accurate analysis of the field, the spatio-temporal algorithm is analyzed for all six types of standard spatial patterns.

Sometimes while building the IoT system, some devices may perform errors and provide inaccurate data. However, with the procedure in this chapter and description, one can come up with accurate programs to enable and smooth the buildup of sensors for smart applications.The experimental results show high accuracy with very high ratio of redundant data filtration.

We hope that the patterns presented in the present work can provide a direction for future developments in the IoT world. Further research is needed to educate and train more design engineers to join the IoT space.

Chapter 5

Enterprise Architecture for IoT

5.1 Overview

The efficient maintenance and classification of huge amounts of data is a big challenge for the websites which provide services for online businesses. Many of the websites provide multiple services for the customer. In the present work, we have compared various machine learning-based classification methods for the efficient distribution of data. To effectively categorize the data, the Enterprise Interface (EI) layer is suggested between the application layer and the physical layer. Methods based on global and local clustering are proposed for the effective distribution of the data in the EI layer. For the effective classification of the merchandise as per the various client classes, we have collected four parameters/features from the mall's customers. We have utilized the K-Means clustering approach to efficiently divide classes (Global Clustering). Additionally, we have examined seven categories for the proper group selection and prediction of recently arrived customers. The performance comparison makes use of Naive Bayesian, Logistic, Decision Tree, Random Forest, Support Vector Machine (SVM), Kernel-SVM, and K-Nearest Neighbor algorithms. The results show that Naive Bayesian and Random Forest Classification approaches outperform other classification techniques. The results also show that the proposed method is better than the existing cluster cum classification method.

5.2 Introduction

Enterprise architecture (EA) outlines an organization's structure and operations to determine the most efficient way for it to accomplish its goals, according to [107]. End customers now rely on the internet for services, information sources, and applications. As a result, a variety of websites offer their users services for all types of information, such as an online store for making purchases, e-books, etc [108] [109] [110] [111]. However, a single website or server cannot maintain such a large amount of data. To gather the data users require, websites can leverage open-source cloud data as well as data collected from various sources. However, the information gathered from numerous sources and stored in databases is categorized as unstructured information. By processing the data in an organized fashion, the EA is one method for achieving the goals of the specific organization. End-user (client), Application Server, and Database are the three tiers of the enterprise business model. At the back end, the application server processes data from databases, and at the front end, it gives the information to the end user. Through research, planning, design, and execution, it converts business objectives into IT capabilities for retail businesses, such as malls. It also gets rid of unnecessary and ineffective processes [112]. In addition to these, EA has demonstrated value in improving people, processes, and technology. A roadmap for preparing IT resources to support business services and processes may be found in the IoT-enabled enterprise design [113].

In the present work, a four-tier architecture is proposed for the IoT Enterprise Application. An enterprise interface layer is proposed in between the Application Server and Physical Layer. Unlike the previously reported works, in the present work, the data is categorized into clusters based on global and local parameters. The machine learning algorithms can precisely divide the data into clusters. The clustering algorithm can divide the data in such a manner that the end-user-specific requirement can be efficiently fulfilled. In the present work, we have proposed the idea for the categorization of the retail products of malls based on the specific class of customers. The customers are categorized into clusters based on the 4 important features, i.e., salary, spending score, age, and gender. The K-Means clustering algorithm is used for the division of the customers into clusters. In addition, for the prediction of a specific class for the newly arrived customer, a classification algorithm is proposed. For the performance analysis, a different classification algorithm is compared, i.e., Naive Bayesian, Logistic, Decision Tree, Random Forest, SVM, Kernel-SVM, and K-NN. Also, the performance is compared with the existing model [114]. The efficient clustering and classification increase the trust of the end-user in the organization as well as it will help the organization to generate more revenue. For the extraction of the different features of the customers, the dataset is collected with the help of IoT devices. In today's competitive market, revenue generation is an important challenge for service providers. An efficient IoT-based Enterprise Business can optimally categorize the data/products/e-book [115]. In the proposed work, we have analyzed the performance of the retail online/offline global store/mall. However, the method can be used for different other applications [116].

The chapter is organized as follows. Section 5.3 briefly describes the background foundation of applying IoT in enterprise business. Section 5.4 discusses the research gap. Section 5.5 presents the proposed methodology. Section 5.6 highlights the results obtained from the clustering and classification. Finally, summary is presented in Section 5.7.

5.3 Background

Internet of Things introduces new systems and devices that need to be managed by efficient artificial intelligence and machine learning methods [117] [118]. The four key components of IoT are things (products/devices/customers/ mobile), properties, IoT servers, and applications based on the three-layer architecture as shown in [119] and described as the IoT gateway hierarchy in [120]. In the present work, we have proposed four-tier architecture with seven key components. We have proposed one extra interface layer for two key operations, clustering, and classification.

The things are products that are the primary key component of IoT that currently appear to be one thing that the corporate has to manage is at the top of the list. The customer's mobile application and data logs can be used for the mall for data extraction. Similarly, for

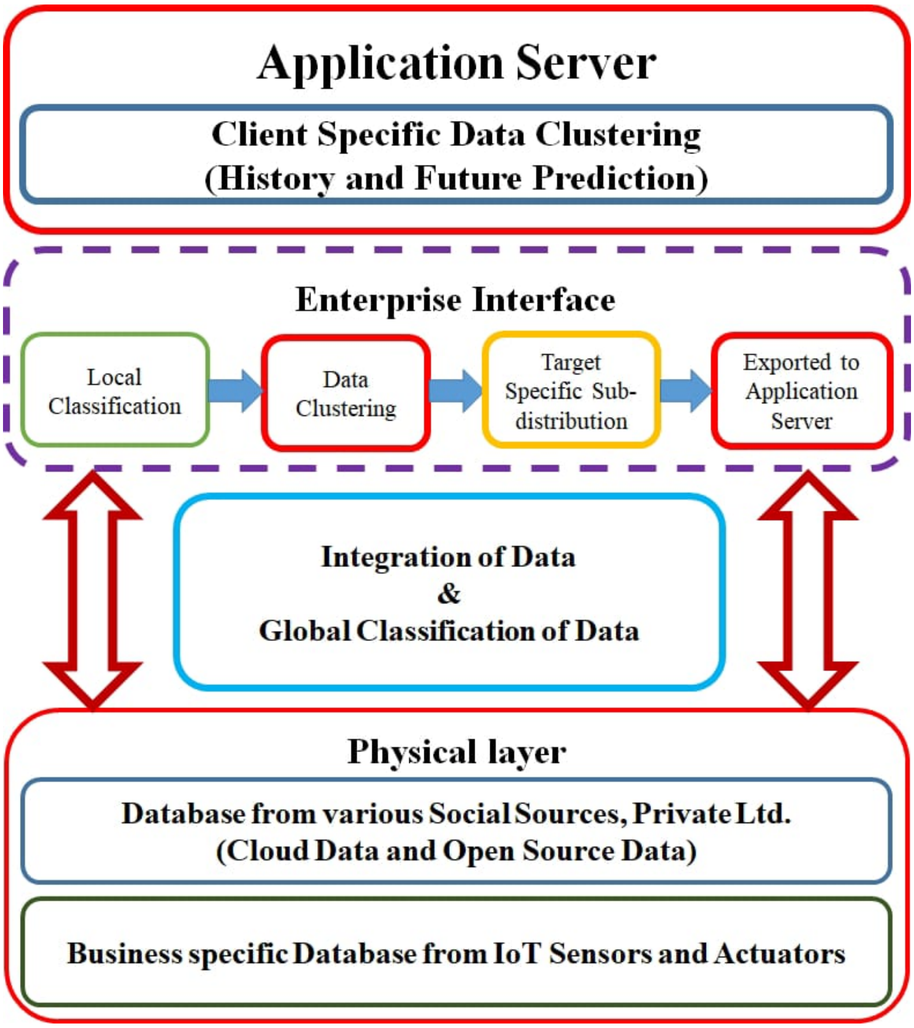

Figure 5.1: IoT enterprise Business Model

agriculture applications, temperature, humidity, and pH sensors-based boards can be used as IoT end devices. Business organizations must now accept responsibility for their connected things which are connected to mall/retail industry/company servers, which brings a new enterprise design. Thousands of products are connected or are often reached by company IoT servers as shown in Fig 5.1 architecture. The second key part of IoT shows how every company/retail industry needs to manage the connectivity aspect. Every company/retail industry decides which protocol and language will be used, and the ownership is transferred to a highly specialized IoT server.

The third critical component of IoT is a server that gives four basic functions: device management and provisioning; information assortment, processing, and normalization; application enabling and development support; and network information service and subscriber management.

The fourth key part of IoT is the application when integrated, it does not introduce any new parts to the enterprise design, but rather reuses the prevailing web application parts; internet servers, web and internet browsers, and phone applications. However, this does not imply that existing organizations and architectures can continue to function as they are continuing. It needs to be custom-made so that they serve the even broader set of external and internal applications developed as a part of the new web of things, business opportunities, and operations enterprise.

The fifth and sixth key components are clustering and classification for the efficient distribution of the existing customer and the classification of the newly arrived customer. The Internet of Things can pose significant challenges to existing enterprise businesses, necessitating the emergence and development of new IT systems and organizations/retail industries, as well as new evolving enterprise businesses [130].

To analyze the proposed enterprise business, the example of the retail business (Mall) is considered. In the previously reported works, the researchers have proposed many cluster cum classification methods. However, the performance of different methods are not analyzed for the best possible performance. In the proposed work, we have analyzed

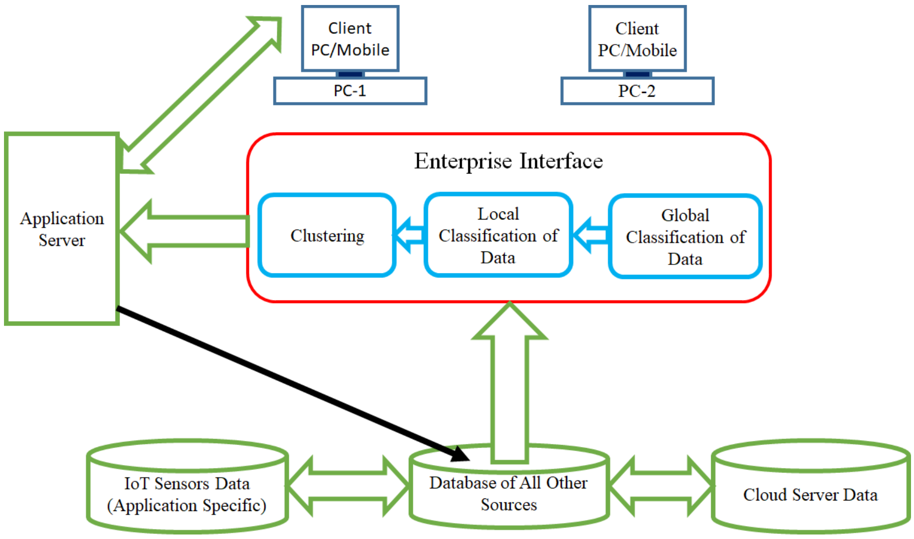

Figure 5.2: Four Tier Operation of Enterprise Business

the performance of the different classification methods. The next section describes the problem statement and research gap.

5.4 Research Gap

In the previously reported work, the authors have proposed many different models of enterprise architecture for IoT [114, 116, 121–125]. However, the authors have not proposed a method to deal with datasets when the system interfaced with multiple data servers and as well as from IoT data servers. For IoT, the sources are IoT devices that will mix the other existing data, and thus data clustering and classification are required. So, the integration of IoT devices in the organization has many problems. Due to huge data, when the customer tries to access the data/service/virtual product, the server takes more time than usual. To deal with the issue, a global and local clustering-based method is proposed for efficient distribution of the data (in form of virtual products). As per the best of our knowledge, the researchers have not proposed the idea of an interface layer (in between the application layer and physical layer) to deal with the issue of efficient distribution of data in clusters. In the proposed work, we have taken the example of a mall and a dataset of the mall. We have extracted 4 parameters/features of customers of the mall for the efficient classification of the products as per the different classes of customers. For the efficient division of classes, we have used the K-Means clustering method (Global Clustering). And for the classification and prediction of the newly arrived customer, we have analyzed 7 different classification methods. We have also compared the performance of 7 classification methods. In addition, the performance of the proposed method is also compared with the existing clustering and classification work. Our proposed clustering and classification method is used in the interface layer of enterprise business.

5.5 Methodology

The methodology of the enterprise business is shown in Fig 5.2. The first level is the end-user, the second level is the application server, the third layer is the enterprise interface, and the fourth layer is the database server. The application server provides the service to the end-user. However, the application server doesn't contain all the data. Therefore, it requests the data to the database. The database contains unorganized data. Fetching the data for the user application takes time. For the good QoE (Quality of Experience) of the end-user, the delay must be low. Therefore, between the application server and database, an enterprise interface is used that efficiently organizes the data/products. The fetched data from the database goes to the global classifier. The global classifier then classifies the data into local groups. The local groups again divide the data into small subgroups, i.e., clusters.

The clustering of the data can be done using a k-Means-based machine learning algorithm [126] [127]. The database also contains limited data. Various databases can be integrated for business requirements and enterprise applications [128]. Application-specific IoT sensor devices can be used for data integration. The collected data from the sensors can be stored in the integrated database. The main task is performed by the interface layer. The interface layer performs global and local clustering. At present, we have collected data from one of the sources, i.e., kaggle.com [129]. The four important features are taken into consideration, i.e., age of the customer, the age group of the customer, the purchased score of the customer, and the annual income of the customer. All the parameter plays

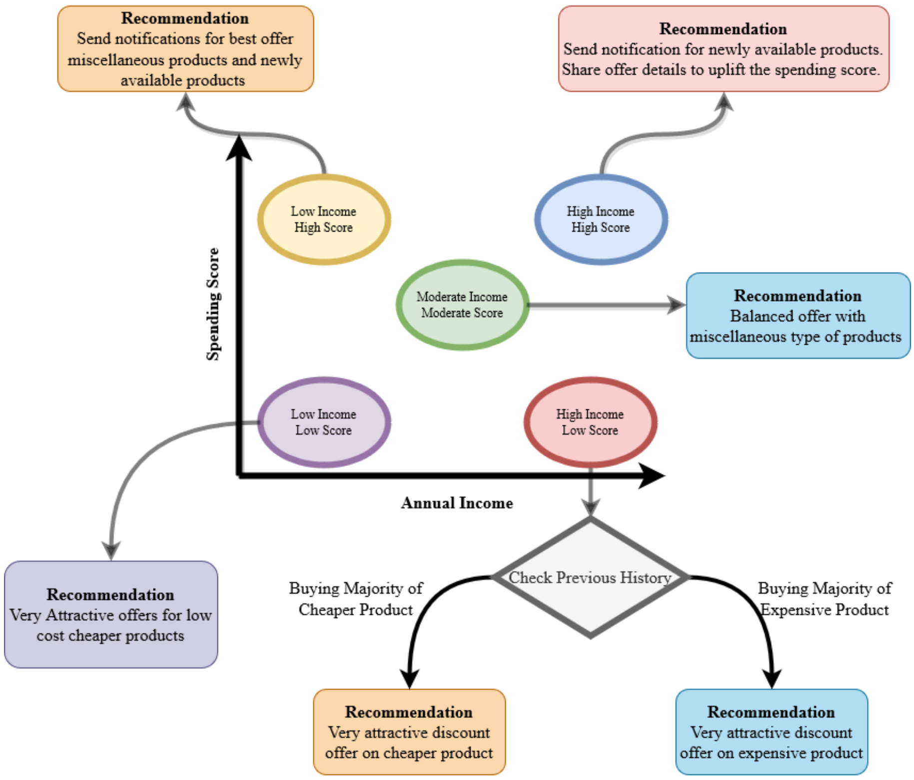

Figure 5.3: Classification of customers

an important role in the purchasing of the product. A mall can be divided into a group of clusters. Each cluster consists of a group of products for a special class of customers. As shown in Fig 5.3, the customers are classified into 5 different groups as given below:

- Low-Income Low Spending Score Customers
- High-Income Low Spending Score Customers
- Low Income High Spending Score Customers
- High Income High Spending Score Customers
- Moderate Income Moderate Spending Score Customers

In the proposed work, we have recommended different offers for the different clusters of customers. As shown in Fig 5.3 that very attractive offers can be suggested to the customers who earn low amounts and have low spending scores. Similarly, the High annual income and low spending scores can further be categorized into two sub-clusters. In the first sub-cluster, a very attractive discount can be offered on the cheaper products. Also, based on the previous history of the customers if the majority of the products are branded and expensive, a branded product with a higher discount can be offered to the customers. For the moderate-income moderate score customers, a balanced amount of miscellaneous types of the product can be offered. Similarly, customers who are earning more but have low purchasing scores can be targeted to increase their spending from them. To increase the spending of such customers they can be targeted locally or globally. The individual notification can be sent to each customer to gain more money. In addition, the individual history of the customer for the previous spending can be used for the new product. Different other features can also be used for the classification of the cluster. In the previously reported work, the researcher has targeted only two parameters, i.e., annual income and spending score. However, customers can also be categorized based on their age group as well as their gender. Gender is important for the classification of customers. In the present work, we have proposed intelligent clustering methods which divide the customer based on their gender, age group, annual income, spending score, etc.

The methodology section of the proposed work is divided into three different sections as explained in Algorithm-1. The first part deals with data preprocessing. In the data preprocessing, the data is first imported into the library then the data is divided into training and testing data sets. The missed values and the normalization operations of the dataset are performed for both the training and testing datasets. After data preprocessing, the optimal number of customers is estimated based on the elbow method. In the elbow method, the optimal numbers of clusters are obtained by squared distance estimation of the data. In the proposed work, the analysis is divided into 2 different parts. The first part divides the customers into different clusters based on their annual income and spending score. The second part classifies the customer based on gender and age. In the proposed work, the optimal number of clusters is estimated based on the elbow method.

The data preprocessing is the first step of the clustering operation. The data is first imported and normalized. The data is divided into training and testing data sets. Again the featured column is imported to the library for the processing and estimation of the optimal number of the cluster. As shown in the flowchart, the within-cluster sum of square (WCSS) method is used for the estimation of the optimal number of the cluster. The K-Means-based clustering method is used for the clustering of customers into different groups/sections. For the newly arrived customers, 7 different classification methods are analyzed for the appropriate section and subsection. The complete operation is represented in Algorithm-1. The detailed discussion of the results of the EA is described in the next section.

Algorithm 4: Clustering and Classification in Enterprise Interface

```
Result:
1. Global and Local grouping of the products into different sections based on
clustering of the existing customers
2. Prediction of the appropriate section (cluster) for the newly arrived customer
1. Data preprocessing
2. Division of the existing customers feature into training and testing dataset
3. Estimation of the appropriate number of clusters using the Elbow Method
while g ≤ G do
    Division of the Mall in G sections based on the salary and spending score
      using the K-Means clustering method
    Each G group data is divided into L and M groups based on age and gender;
    while l ≤ L do
        while m ≤ M do
            Classify and notify the newly arrived customer for the appropriate
              global cluster (section) and local cluster (subsection) based on
              features, i.e., age, gender, spending score, and salary;
        end
    end
end
```

5.6 Results and Discussion

For the analysis of the proposed protocol, the sklearn-based machine learning library is used. The program is developed in python language. The pandas and the NumPy library are used for the analysis of the proposed protocol. The performance of the proposed method is divided into two parts. The two important parameters are considered for the clustering of retail customers into groups. The annual salary and spending score are

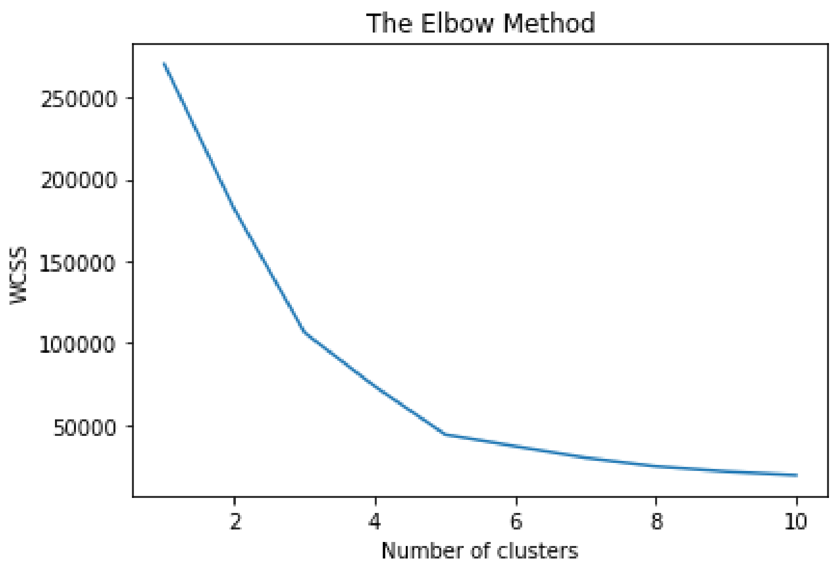

Figure 5.4: Elbow method for measurement of the optimal number of cluster

Table 5.1: Accuracy of different classification methods for Enterprise Interface

Classification Method	Confusion Matrix					Accuracy
ECCM [114]	16	9	8	4	11	96%
Decision Tree	16	10	7	4	11	96%
Support Vector Machine (SVM)	16	9	8	4	11	96%
Kernel-SVM	16	10	8	4	11	98%
K-NN	16	9	8	4	11	96%
Logistic	16	9	8	4	11	96%
Random Forest	16	10	8	5	11	100%
Naive Bayesian	16	10	8	5	11	100%

considered for the clustering of the customers. The elbow method is used for the optimal number of clusters. As shown in Fig 5.4 that the optimal number of clusters is 8. Therefore, the K-means algorithm is used for the division of the customers into the 8 groups of clusters as shown in Fig 5.5. In the second part of the work, we have analyzed the classification of the customers using different ML-based classification methods. The performance is also compared with the existing clustering cum classification method (ECCM). For the prediction accuracy analysis of the different classification methods, the confusion matrix is analyzed. The 200 data samples are considered for the training and testing of the models. The 75% of the dataset is used for the training and the rest of the dataset is used for the testing. Thus, 50 samples are used for the analysis of the trained model. The diagonal elements of the confusion matrix show the correct classification of

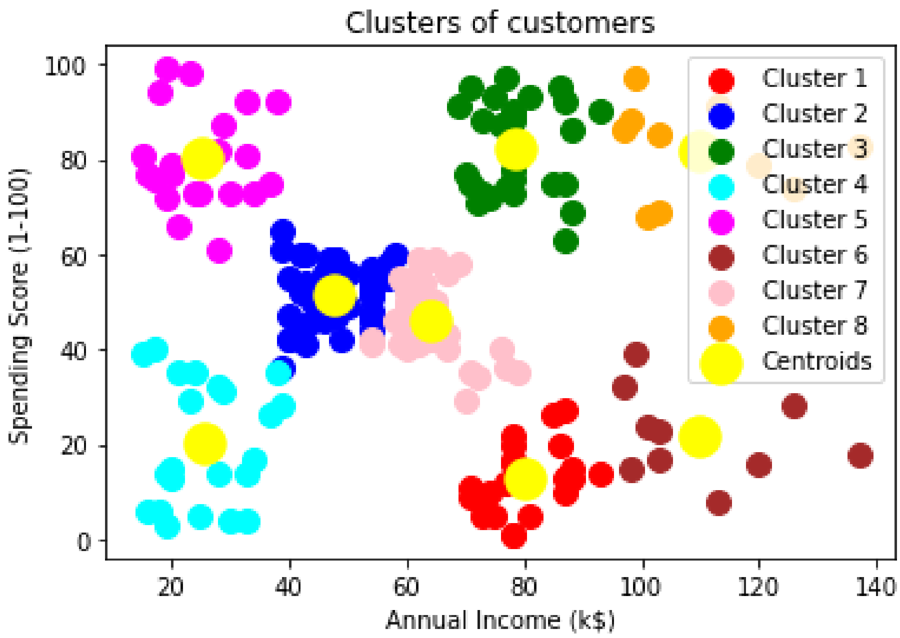

Figure 5.5: Clustering of the customer into different groups

the newly arrived customer. The diagonal elements of the seven different ML classification methods are analyzed as shown in Table 5.1. The results show that the accuracy of the decision tree, K-NN, SVM, Logistic, and ECCM classification methods are 96%. However, kernel-SVM performs better than the SVM with 98% accuracy. The accuracy of Naive Bayesian and Random Forest is 100%. Therefore, it can be concluded that the accuracy of the Naive Bayesian and Random Forest are superior to the all the existing methods.

Naive Bayesian is known for its simplicity and efficiency, as it assumes that all the features are independent of each other, and it works well with small and medium-sized datasets. It is generally faster than other algorithms and requires less training data to build a model.

On the other hand, Random Forest is a more complex algorithm that works by creating multiple decision trees and combining them to form a single model. It is effective in handling large datasets and can work with both categorical and continuous data. However, it can be slower than Naive Bayesian and may require more training data to build an accurate model. So, in terms of complexity, Naive Bayesian is generally considered to be simpler and more efficient than Random Forest.

As per the results shown in Fig 5.5, very attractive offers can be suggested to the customers who earns low amount and have low spending score. Similarly the High annual income low spending score can further be categorized into two sub-clusters. In the first sub-cluster, very attractive discount can be offered on the cheaper products. Also, based on the previous history of the customers if the majority of the products are branded and expensive, a branded product with a higher discount can be offered to the customers. For the moderate-income moderate score customers, a balanced amount of miscellaneous types of the product can be offered. Similarly, customers who are earning more but have low purchasing scores can be targeted to increase their spending from them.

5.7 Summary

The Enterprise Interface (EI) layer is proposed between the application layer and the physical layer to efficiently categorize data. For efficient data distribution, a global and local clustering-based technique is proposed. For the performance study in the proposed work, we have used a mall as an example and a mall dataset. For the efficient classification of merchandise according to distinct client classes, we retrieved four parameters/features from mall customers. The results reveal that the younger age customers have a moderate income. Therefore, the notification of low-cost and high discount offers can be sent to younger age customers to attract the buying of products. The results also reveal that the spending score of more than 70% of customers is less than the moderate range for all ages of people. However, in middle to old age, people only spent very high. Therefore, an attractive offer can be sent to the high spending score customers to gain more profit. Similarly, customers who are earning more but have low purchasing scores can be targeted to increase their spending from them. The overall results show that the proposed global and local clustering method and efficient section division method based on the customer can increase the overall earnings of the mall. Thus the efficient clustering and efficient classification of the newly arrived customer can increase the overall revenue of the retail business. For the classification methods, it is proven that Naive Bayesian and Random Forest are superior to the other existing methods. The proposed model is analyzed for the retail business. However, the proposed method can be used for any IoT-based enterprise business application.

Chapter 6

Energy-Efficient Data Consistency

6.1 Overview

Data consistency is a challenge for designing energy-efficient medium access control protocols used in IoT. The energy-efficient data consistency method makes the protocol suitable for low, medium, and high data rate applications. In this work, we have proposed the idea of energy-efficient data consistency protocol with data aggregation. The proposed protocol efficiently utilizes the data rate as well as saves energy. In this chapter, we have introduced optimal sampling rate selection method for maintaining the data consistency of continuous and periodic monitoring node in an energy-efficient manner. In the starting phase, the nodes will be classified into event and continuous monitoring nodes. The machine learning based logistic classification method is used for the classification of nodes. The sampling rate of continuous monitoring nodes is optimized during the setup phase by using Optimized sampling rate data aggregation algorithm. Furthermore, an energy-efficient time division multiple access (EETDMA) protocol is used for the continuous monitoring on IoT devices, and an energy-efficient bit map assisted (EEBMA) protocol is proposed for the event driven nodes. The experimental results proves the superiority of the proposed protocol with respect to existing work.

6.2 Introduction

The demand of internet of things (IoT) network is increasing day by day due to its vast range of applications. The researchers are working in different fields of IoT networks, e.g., security, medium access control, routing protocol, clustering, etc. In most of the cases, the IoT sensor devices directly communicate with the IoT gateway nodes. However, for commercial applications, a large IoT network is used, and therefore the two-hop or three-hop communication is quite common [131]. Also, the large network deals with heterogeneous IoT devices which consist of different types of sensors [131], [132], [133], [134], [135], [136], [137], [138]. In such cases, each IoT device consists of a different optimal sampling rate. However, each device transmits the data with a common sampling rate, which makes it difficult to transmit the data with an optimal sampling rate due to the restriction of the medium access control protocol. In this chapter, we have proposed the idea of non-uniform sampling rates. The energy consumption can be minimized in such applications for reducing the sampling rate. However, a reduction in the sampling rate may cause data inconsistency. Therefore, we have proposed the idea of optimization of the sampling rate to deal with the trade-off between energy consumption and data consistency [138].

The operation of the proposed protocol is divided into the setup phase and the steady state phase. In the setup phase, the IoT devices (mostly sensor nodes (SNs)) are classified into continuous monitoring and event monitoring nodes. After classification, the optimal sampling rate is allotted to each continuous monitoring node for the transmission of the data. After that, the sessions are divided into sub-sessions. In the proposed work we have assumed a large network. Therefore, during the setup phase, the network is divided into clusters. In each cluster, a random node is selected as a cluster head (CH) node. After the setup phase, the steady-state phase starts. In the steady state phase, the session is divided into two sub-sessions. The continuous monitoring nodes transmit the data using the EETDMA method and event monitoring nodes transmit the data using the EBMA protocol. The architecture of the proposed protocol is shown in Fig 6.1.

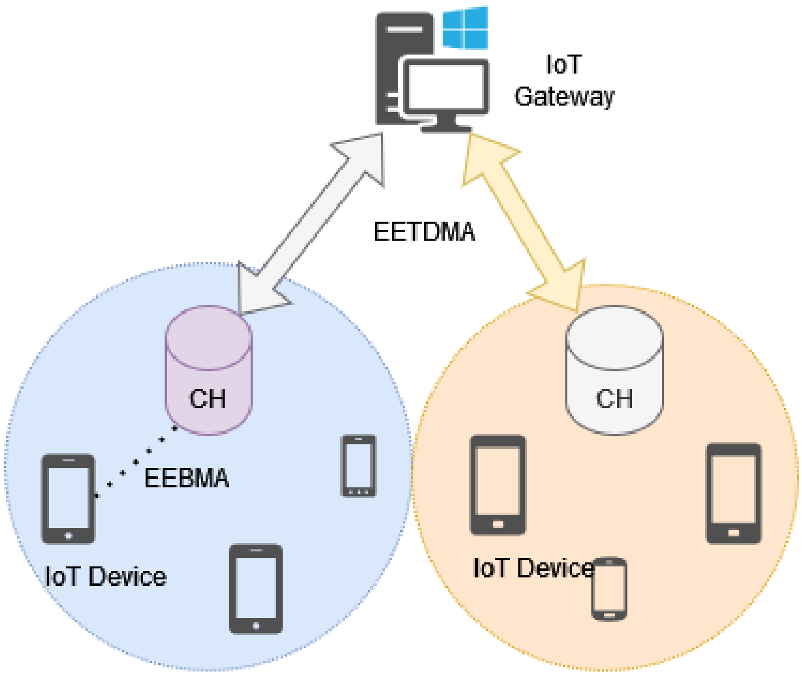

Figure 6.1: IoT Network Architecture

The IoT Devices in a cluster transmit the data to the CH node, and the CH node is aggregating the data and transmitting it to the IoT Gateway. The novelty and the contribution of the proposed work are explained below:

- An energy-efficient data consistency-based optimal sampling rate selection method is proposed for data transmission of IoT devices.
- The machine learning (ML) based logistic regression method is proposed to categorize the devices in the event monitoring and periodic monitoring devices.
- The EETDMA and EEBMA hybrid medium access protocol is proposed for the energy efficient data transmission.
- The data aggregation is performed at the CH node for the efficient transmission of the data.
- Optimized sampling rate data aggregation algorithm is proposed for the periodic monitoring IoT devices.
- Unlike the previously reported works, the present work deals with both phases, i.e., setup phase and steady state phase.

The structure of the chapter proceeds as follows: Section 6.3 presents the literature study. Section 6.4 provides the explanation of DADCZP, namely Data Aggregation Data Consistency Zonal Protocol, in detail. Section 6.5 presents the analysis of the experimental results. Section 6.6 summarizes the findings.

6.3 Related works

The proposed protocol deals with the setup phase as well as the steady state phase. Thus, our literature study is also focusing on two parts. The first part deals with the setup phase studies and the second part deals with the steady state phase. In addition, data consistency based existing works are also discussed.

In the previously reported works, the researchers have proposed many different types of clustering algorithms. The base clustering protocol is low-energy adaptive clustering hierarchy (LEACH) which is used in most of the energy-efficient clustering applications [131]. Many modifications are proposed for the LEACH protocol. The zonal-based clustering is quite common for clustering for longer lifetimes of the wireless sensor network. However, in most of the networks, the zones are divided into a single dimension which is inappropriate for most practical applications [132]. To further improve the performance, the stable election of CH is proposed in [133]. However, the stable election also causes a drain of energy in some cases and it causes failure of time constraint nodes. The improved version of the one-dimensional zonal protocol is proposed to improve the performance. However, the protocol is only suitable for limited applications. To further improve the performance, other researchers have also proposed various steady-state protocols. In all the previously reported works which deal with the clustering protocol, some studies have used TDMA protocol which is similar to LEACH. Although they have proposed various steady state protocols, in all such protocols, they have still used a setup phase similar to LEACH.

In [136], the modified TDMA protocol is proposed to reduce energy consumption. In [136], the energy-efficient TDMA (EETDMA) protocol is proposed to reduce the en-

Table 6.1: Comparative analysis of setup phase and steady state protocols

Scheme /Ref.	Route Structure	Objective	Clustering Method	MAC Protocol	Overhead	Drawback
LEACH-D [131]	Tree	Clustering, Routing	K-Means	TDMA	Low	High Energy Consumption
ZEP [132]	Multihop	Clustering	Zone division	TDMA	Low	Not suitable for event data traffic
E-SEP [133]	Multihop	Clustering	–	TDMA	Low	Not suitable for event data traffic
I-ZEP [134]	Multihop	Clustering	Zone division	TDMA	Low	Not suitable for event data traffic
EBMA [135]	Tree	Energy-Efficient Data Transmission	K-Means	EBMA	Moderate	Clustering is not efficient
EA-TDMA [136]	Tree-based cluster	Energy-Efficient Data Transmission	K-Means	EA-TDMA	Low	Not suitable for event data traffic
TLHA [137]	Tree	Eliminate data redundancy, Aggregation	K-Means	EA-TDMA	High	High Complexity
CG-E2S2 [138]	Tree	Data Consistency	Sleep Mode Management	TDMA	Low	No Clustering and classification
ICN [139]	Tree	Data Consistency	Push Mechanism	–	Low	No Clustering
ST-MAC [140]	Tree	Data Consistency	Spatio-Temporal	ST-MAC	Moderate	No Clustering
FSDA [141]	Tree	Data Aggregation	Tree Aggregation	TDMA	Moderate	High Complexity
LPPDA [142]	Tree	Data Aggregation	Lightweight MAC	TDMA	Low	Less Energy Efficient
EODA [143]	Tree	Data Aggregation	Energy-Optimal MAC	–	Moderate	No Clustering
LCCDA [144]	Tree	Data Aggregation	Low Complexity	–	Moderate	High Complexity
Survey [145]	–	Data Aggregation	Comparison	–	Moderate	Only Comparison

ergy consumption of IoT devices by an efficient buffer monitoring scheme. EETDMA protocol performs optimally for continuous or periodic IoT devices. However, the above discussed protocols fail to perform optimally for event-driven application. Therefore, in [135], the authors have proposed a bit-map-assisted (BMA) protocol for low-data traffic applications. The researchers analyzed the performance of the BMA protocol for moderate to high data traffic applications. It is evidently found that the BMA MAC protocol is completely incompatible with EETDMA. To further improve the performance, in [135], the researchers proposed an EEBMA MAC protocol, which utilizes the bit-mapping of data packets instead of control packets to reduce the number of control packets and energy consumption [135].

From the last few years, data consistency also becomes an important concern for efficient protocol design. Now the researchers are focusing on data consistency protocol along with lifetime improvement. Sunny et al. proposed a lifetime improvement protocol using an energy-efficient data aggregation protocol. In [138], the authors have proposed a data consistency algorithm for efficient data transmission and a sleep mode selection to improve the lifetime. The comparative analysis of the previously reported works is explained below in Table-6.1.

The researchers also proposed various spatio-temporal data aggregation methods to reduce redundancy and energy consumption [146], [147], [148], [149], [150], [151]. In all the previously mentioned literature the researchers have improved either the clustering protocol in the setup phase by assuming the steady state as it is, or they improved the steady state protocol by assuming the setup phase as it is. Our work proposes to deal with both the steady state as well as setup phase. In addition, unlike the previous works, the present work divides the zone into two-dimensional zone and sub-zones for better coverage and connectivity. The proposed work also selects the optimal sampling rate by using the window function for energy-efficient data transmission without compromising with data consistency. The operation of the proposed protocol is explained in the next section.

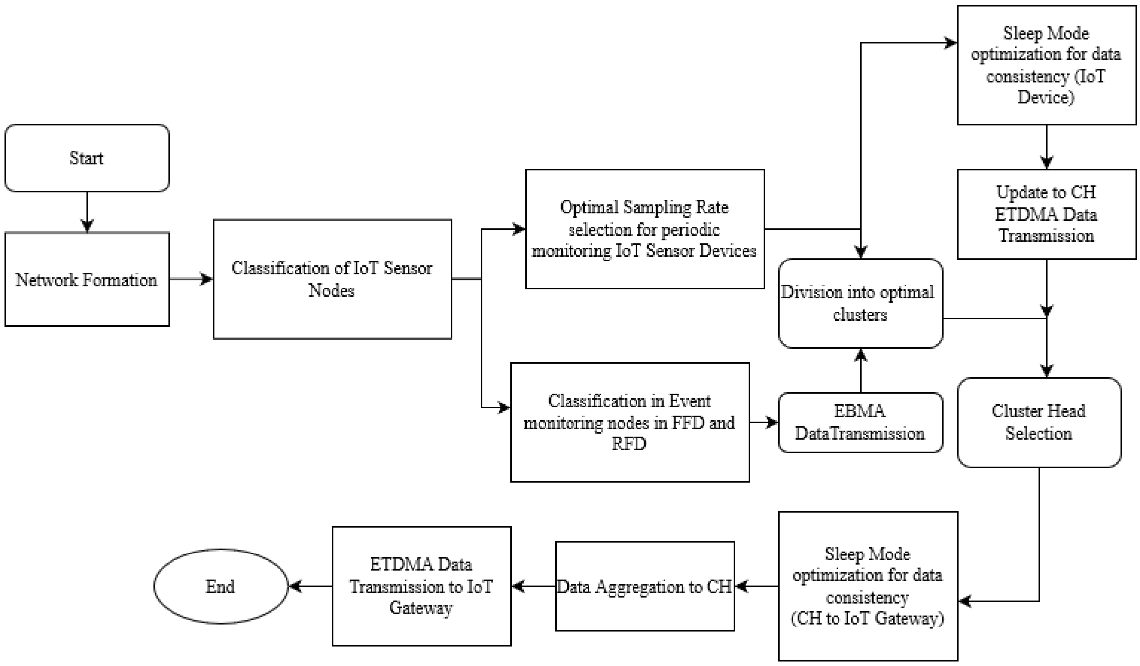

Figure 6.2: Process flow of proposed DADCZP

6.4 Data aggregation data consistency zonal protocol (DADCZP)

The overall operation of the proposed protocol, namely DADCZP is shown in Fig 6.2.

The operation of the proposed protocol starts with the network configuration. The IoT Gateway node identifies all the IoT devices in the network range. After the identification of IoT devices, the IoT sensor devices are classified into continuous monitoring and event monitoring devices. In addition, the devices are also classified into reduced function devices (RFD) and fully functional devices (FFD). Based on the division, the FFD devices are identified for the eligibility of the CH node. The network is classified into an optimal number of clusters. The EEBMA slots are allotted to the event monitoring devices and EETDMA slots are allotted to the continuous monitoring nodes. Based on the observation on the previous data transmissions, the sampling rate optimization is performed for each IoT device. The updated sampling rate is continued in a full session of steady state phase.

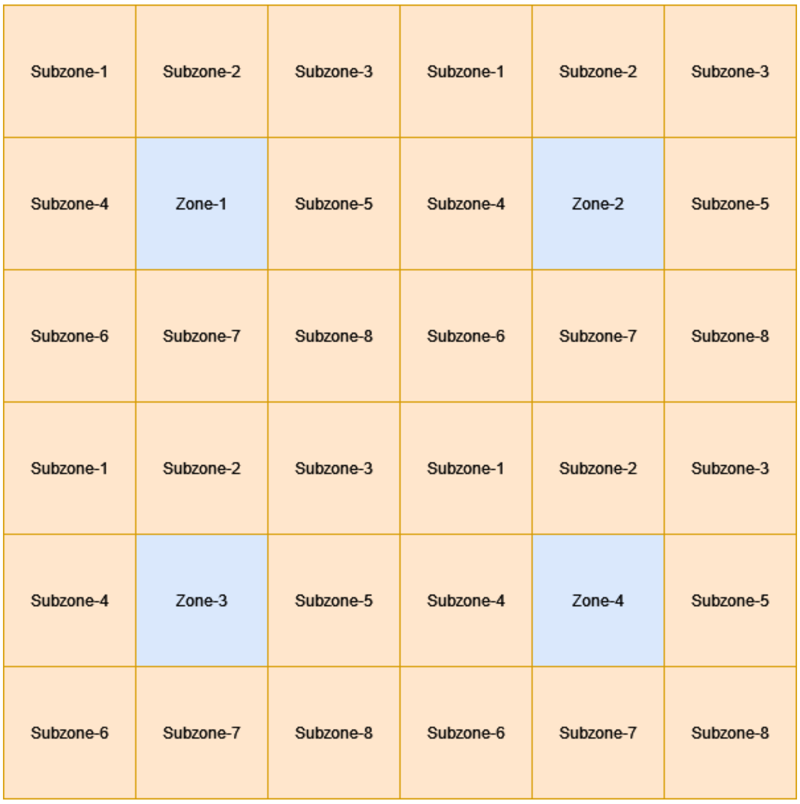

Figure 6.3: 2D Zonal division

6.4.1 Zone Division

In the present work, we have divided the zones into two dimensions. The zone architecture is shown in Fig 6.3.

In this zonal division, the complete area is divided into 4 zones (2 rows and 2 columns). The rectangular region can also be divided into zones. In the proposed work each zone is subdivided into 9 sub-zones. The 8 sub-zones are surrounded by the central zone. It is assumed that the IoT Gateway is placed at the center of each zone. The IoT Devices of the central zone transmit the data to the IoT Gateway directly without any hopping Gateway node. However, the devices of the sub-zones transmit the data via the cluster head node. In the present work, the overall size of each zone is 300x300 meter-square. We also have assumed mini zones of size 100x100 meter square. Therefore, the single layer of subzones is considered. The total number of subzones for each zone can be formalized as $4L(L+1)$, where L is the number of the outer layer. For better coverage and connectivity, we have assumed a single layer for mini cells. However, for micro-cells, the number of

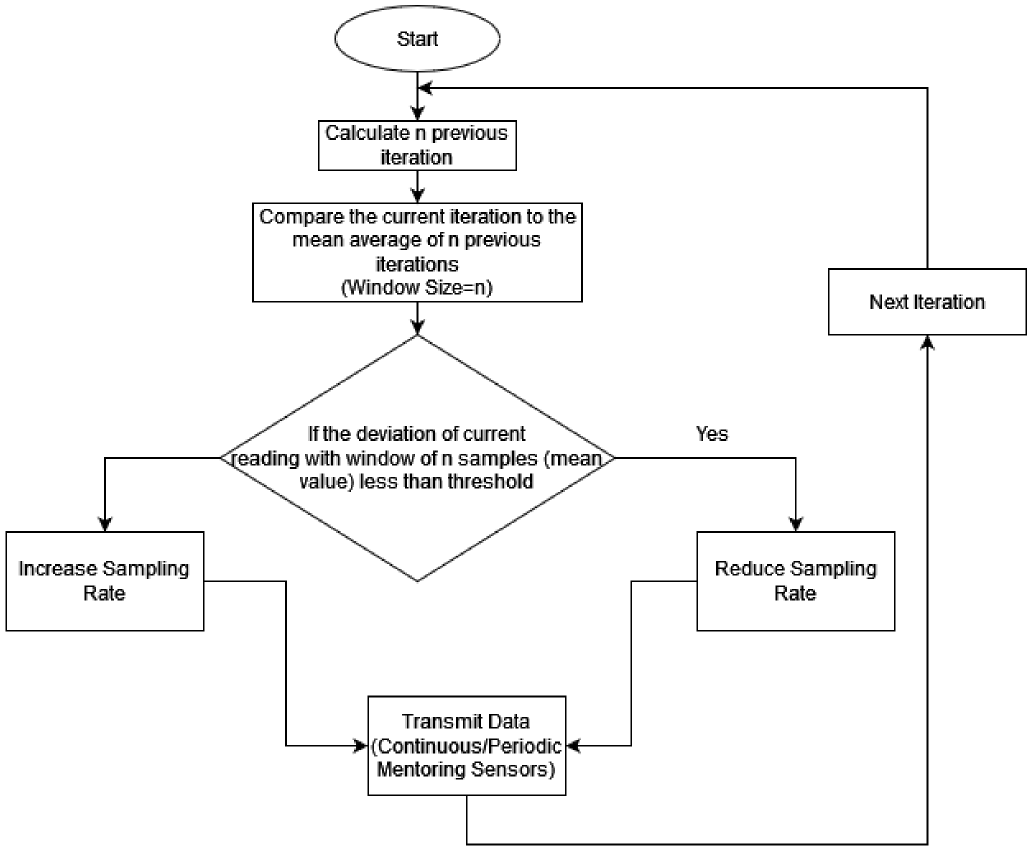

Figure 6.4: Optimized sampling rate data aggregation algorithm (OSRDAA)

cells can be increased.

6.4.2 Optimized sampling rate data aggregation algorithm (OSRDAA)

As we already discussed that each IoT device performs sampling rate optimization, for the sampling rate optimization, the window function is used. At each node, window of *n* previous samples are used for the calculation of deviation with regard to the current reading, as shown in Fig 6.4.

Assume that at i^{th} iteration the sample value is X_i. The *n* previous samples are *i-1* to *i-n*. The average value of *n* previous samples is compared with current reading. The deviation function is given below:

$$f_{Dev} = \left\{ \begin{array}{ll} \frac{\sum_{k=n-i}^{n-1} X_k}{n} - X_i \leq X_{th}, & SR/2 \\ \frac{\sum_{k=n-i}^{n-1} X_k}{n} - X_i \geq X_{th}, & 2*SR \end{array} \right\} \tag{6.1}$$

In the above equation, *SR* is sampling rate. If the deviation is less than the threshold, the sampling rate will be reduced by 50%. Otherwise, for high deviation the sampling rate becomes double. The above method might maintain the data consistency with optimal energy consumption.

6.4.3 Analytical model for the medium access control

Typically, the periodic monitoring based IoT devices transmit the data to the CH node via EETDMA MAC protocol. The operation is divided into two parts, for example, contention phase and data transmission phase. It is assumed that P_t, P_r, and P_i are transmitting, receiving, and idle state power consumption. The total number of continuous monitoring nodes are N_c, and P_e is the power consumption in checking buffer. It is assumed that the total s_0 nodes are time constraint nodes. T_c, T_d, and T_e are packet duration for control packet, data packet, and duration for checking buffer. In addition, q is the probability that node consist data for transmission. In the contention phase the CH node transmits the control packet to the IoT devices. The energy consumption of the CH node, IoT Device, and the total energy consumption are given in below equations.

$$E_{EETDMA-C-CH} = P_t T_c \tag{6.2}$$

$$E_{EETDMA-C-IoTD} = N_c P_r T_c \tag{6.3}$$

$$E_{EETDMA-C-T} = P_t T_c + N_c P_r T_c \tag{6.4}$$

The next phase is data transmission phase. In this phase all the IoT devices transmit the data. The energy consumption of the CH node is given by:

$$E_{EETDMA-T-CH} = s_0 P_r T_d + (N_c - s_0) q P_r T_d + (N_c - s_0)(1-q) P_i T_d \tag{6.5}$$

The energy consumption of IoT device is given by:,

$$E_{EETDMA-T-IoTD} = s_0 P_t T_d + (N_c - s_0) q P_t T_d + (N_c - s_0)(1-q) P_e T_e \tag{6.6}$$

The overall energy consumption of the transmission phase is given by:

$$E_{EETDMA-T-T} = s_0P_tT_d + (N_c - s_0)qP_tT_d + (N_c - s_0)(1-q)P_eT_e + s_0P_rT_d + (N_c - s_0)qP_rT_d + (N_c - s_0)(1-q)P_iT_d \tag{6.7}$$

The overall energy consumption of the EETDMA protocol for the continuous monitoring node is given by:

$$E_{EETDMA} = P_tT_c + NP_rT_c + S(s_0P_tT_d + (N_c - s_0)qP_tT_d + (N_c - s_0)(1-q)P_eT_e + s_0P_rT_d + (N_c - s_0)qP_rT_d + (N_c - s_0)(1-q)P_iT_d) \tag{6.8}$$

The event monitoring devices transmit the data using EEBMA MAC protocol. Similar to the EETDMA, the operation of EEBMA MAC protocol is also divided into contention and data transmission phases. Let N_e to be the number of event monitoring IoT devices. The energy consumption of CH node IoT device and overall energy consumption are given by the below given equations:

$$E_{EEBMA-C-CH} = P_iT_c + N_eq(1-q)P_rT_c + N_e(1-q(1-q))P_iT_c + P_tT_{ch} \tag{6.9}$$

$$E_{EEBMA-C-IoTD} = N_eP_rT_{ch} + N_eq(1-q)(P_tT_c + (N_e-1)P_iT_c) \tag{6.10}$$

$$E_{EEBMA-C-T} = N_eq(1-q)P_rT_c + N_e(1-q(1-q))P_iT_c + N_eP_rT_{ch} + N_eq(1-q)(P_tT_c + (N_e-1)P_iT_c) + P_tT_{ch} \tag{6.11}$$

The energy consumption of theCH node in data transmission phase is given by:

$$E_{EEBMA-T-CH} = N_eqP_rT_d \tag{6.12}$$

The energy consumption of IoT Device in data transmission phase is given by:

$$E_{EEBMA-IoTD} = N_e q P_t T_d \tag{6.13}$$

The total energy consumption in data transmission phase is given by:

$$E_{EEBMA-T-T} = N_e q P_r T_d + N_e q P_t T_d \tag{6.14}$$

The overall energy consumption of EEBMA MAC protocol is given by:

$$\begin{aligned} E_{EEBMA} =& (N_e q(1-q)P_r T_c + N_e(1-q(1-q))P_i T_c + N_e P_r T_{ch} + N_e q(1-q)(P_t T_c + \\ & (N_e - 1)P_i T_c) + P_t T_{ch} + N_e q P_r T_d + N_e q P_t T_d)S \end{aligned} \tag{6.15}$$

6.5 Result Analysis

For the analysis of the proposed network, the network is categorized into zones and each zone is divided into sub-zones. As mentioned, the size of the each zone is 300X300 meter square. The IoT Gateway is placed at the centre position, i.e., (150, 150). In this network, the 50nJ/bit energy consumption is assumed for data transmission. Similarly, the other parameters are assumed as per the standard protocol reported in [134].

The result section of the proposed work is divided into two sub-sections. The first sub-section deals with the analysis of the energy consumption, network lifetime, and other parameters of the setup phase. The second sub-section deals with the steady state energy consumption.

The analysis of the proposed work is started with the classification of nodes in continuous and event monitoring nodes. We have collected the data set of 10 sensors. The K-Means clustering of 5 sensors is shown in Fig 6.5 to 6.9, i.e., temperature, humidity, etc. The elbow method is used for the optimal number of clustering, and the data variation is analyzed for the classification of the nodes. To analyze the network lifetime, the total number of alive nodes and dead nodes are compared in Fig 6.10 and Fig 6.11. The

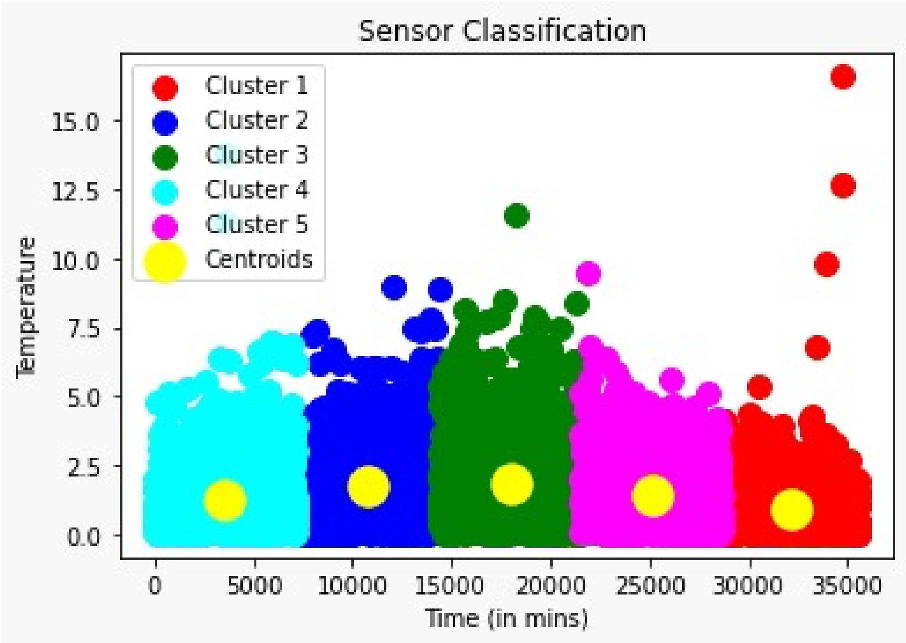

Figure 6.5: Temperature Sensor vs Time

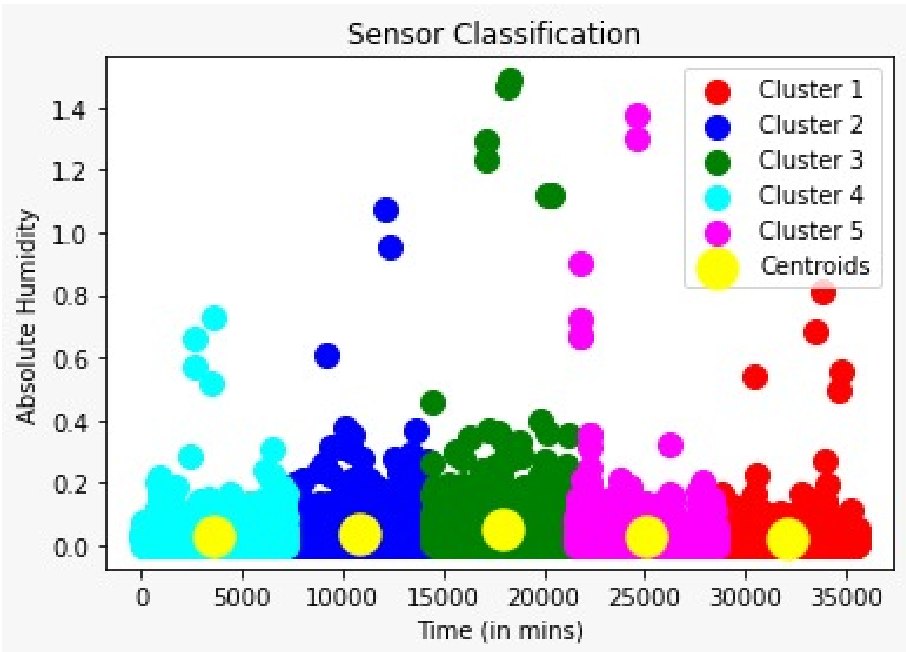

Figure 6.6: Absolute Humidity vs Time

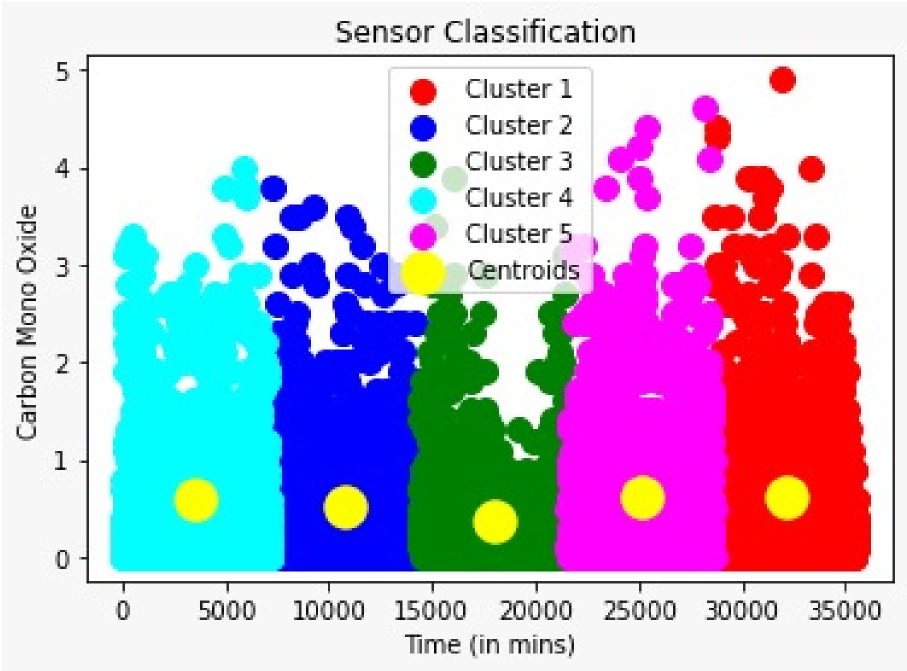

Figure 6.7: Carbon Mono Oxide vs Time

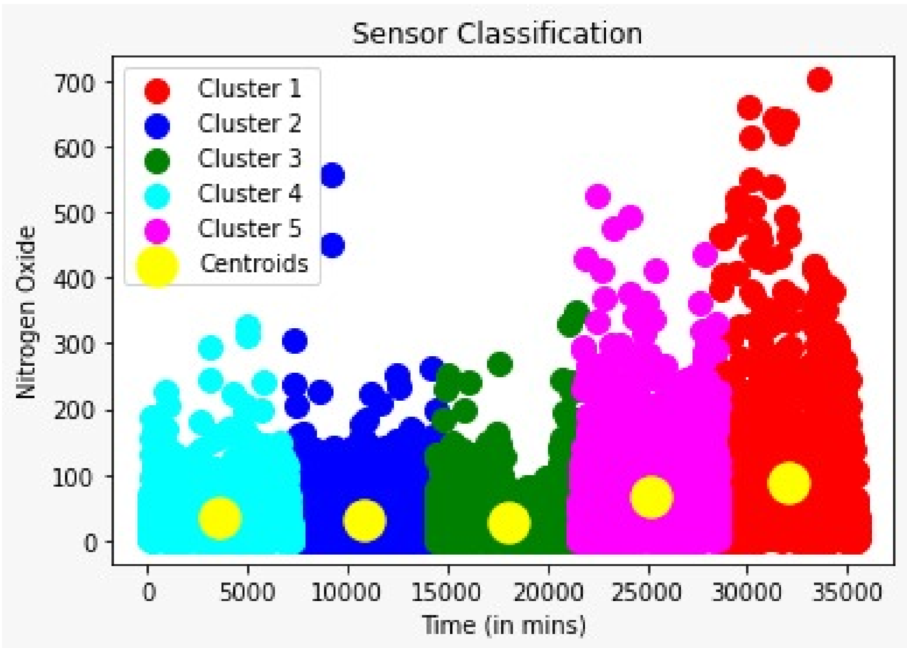

Figure 6.8: Nitrogen Oxide vs Time

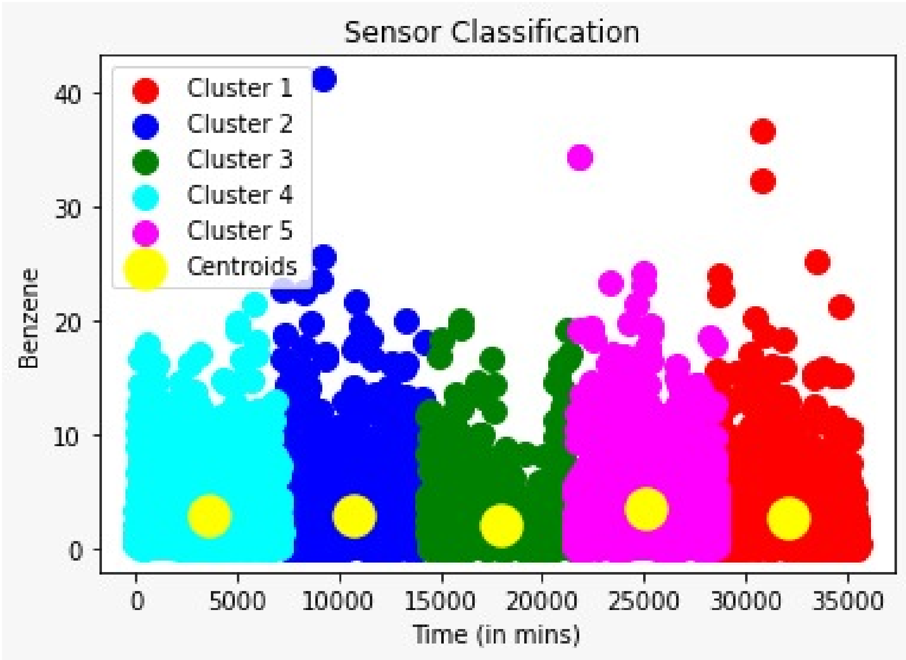

Figure 6.9: Benzene vs Time

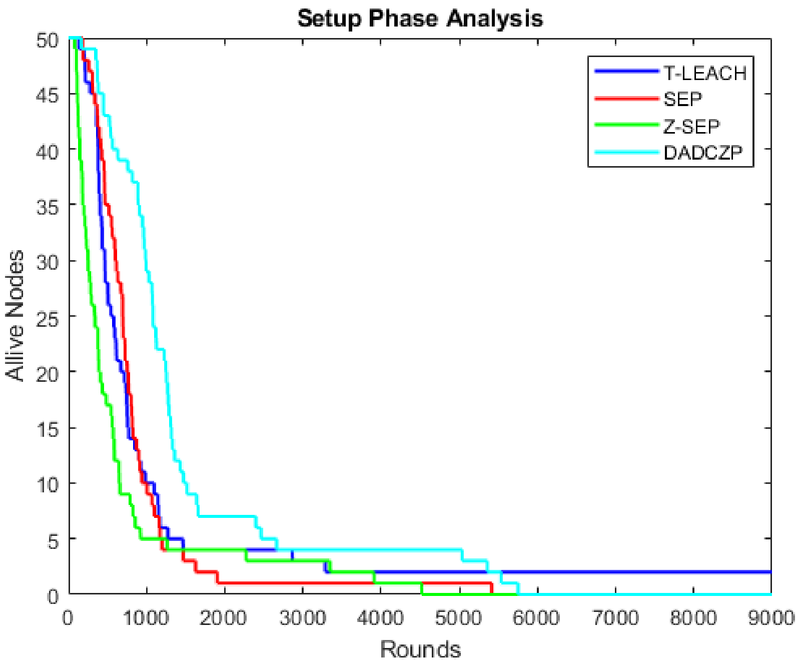

Figure 6.10: Alive Nodes vs Rounds

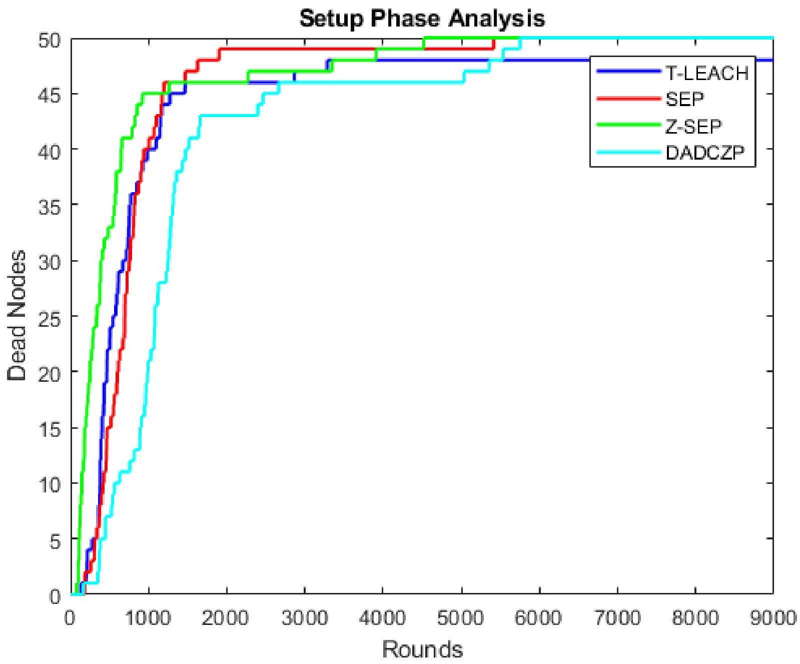

Figure 6.11: Dead Nodes vs Rounds

performance of the proposed protocol is compared with the traditional LEACH protocol (T-LEACH), stable election protocol (SEP), and zonal election protocol (ZEP) for the setup phase. The simulation is performed for the 9000 rounds. As shown in Fig 6.10 and 6.11 that the lifetime of the proposed protocol is much better than the mentioned protocol.

Due to the failure of the nodes, the overall throughput can also be reduced. To analyze the overall throughput, the total number of received packets is analyzed at the Gateway node. As per the result, the overall throughput is two times of the Zonal Election protocol. The result is shown in Fig 6.12.

In the last case, the steady state phase is analyzed as shown in Fig 6.13. The performance of the proposed protocol is compared with the EETDMA-EEBMA protocol. The proposed protocol is analyzed for the sampling window of 5, 10, 15, and 20 samples. A higher window size reduces the energy consumption but increases the data inconsistency. Therefore, it can be concluded that their is trade-off between energy consumption and window size.

Therefore, from the result analysis, we can conclude that the proposed protocol saves energy in both the setup phase and steady-state phase and increases the overall lifetime of the network.

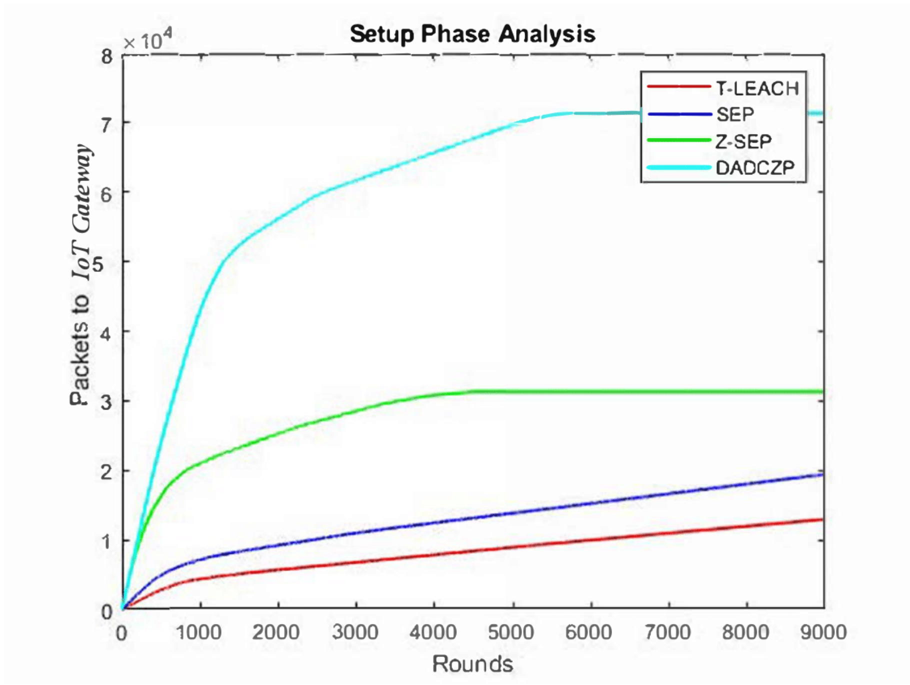

Figure 6.12: Packets of IoT Gateway vs Rounds

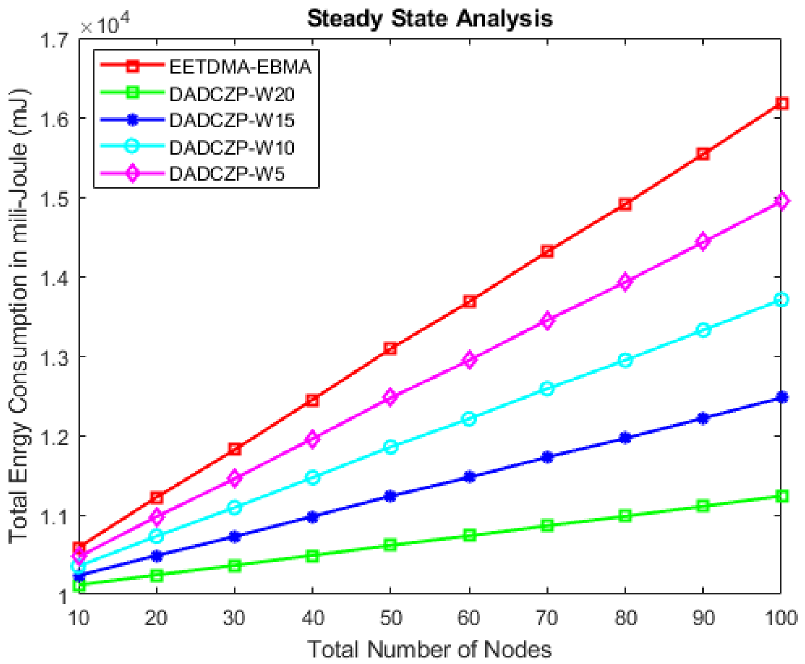

Figure 6.13: Energy Consumption vs Total Nodes

6.6 Summary

In the present work, an energy-efficient data aggregation data consistency protocol is used. In the proposed method sampling rate optimization is also performed for the continuous monitoring nodes. The nodes will initially be divided into the event and continuous monitoring nodes.

The logistic classification method based on machine learning is used to classify nodes. A data aggregation approach called Optimized sampling rate is used to optimize the sample rate of continuous monitoring nodes during setup. The energy-efficient bit map assisted (EEBMA) protocol is suggested for the event driven nodes in the proposed study, while the continuous monitoring IoT devices employ the energy-efficient time division multiple access (EETDMA) protocol. The performance of the proposed protocol is compared with the existing protocol for both the setup phase as well as steady state phase. The results proves the superiority of the proposed DADCZP protocol.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

The present thesis work deals with the investigation on design and development methods for IoT. To achieve the goals and sub-goals of development, the five-layer module is proposed in the thesis work. The first module covers the various types of IoT devices and their general classification. The second module manages the IoT device's coverage and connectivity across the region. The coverage and connectivity are then used for the placement of the IoT device. The proposed methodology goes over the design phases as well as the operational flow of IoT devices. The proposed algorithm's distinguishing feature is object-oriented IoT device placement. The results shows the optimal placement of the IoT devices.

To achieve the goal for each of the refined spatial pattern, the goals are divided into sub-goals. To achieve the sub-goals, we have presented spatio-temporal algorithm. The algorithm not only filters the redundant data but also it reports the monitoring station about spatially connected and affected zones. For the accurate analysis of the field, the spatio-temporal algorithm is analyzed for all six types of standard spatial patterns. Sometimes while building the IoT system, some devices may perform errors and provide inaccurate data. However, with the procedure in this paper and description, one can come up with accurate programs to enable and smooth the buildup of sensors for smart applications.The experimental results show high accuracy with very high ratio of redundant data filtration.

The enterprise architecture is also introduced for enterprise application of IoT network. The Enterprise Interface (EI) layer is proposed between the application layer and the physical layer to efficiently categorize data. For efficient data distribution, a global and local clustering-based technique is proposed. For the performance study in the proposed work, we have used a mall as an example and a mall dataset. For the efficient classification of merchandise according to distinct client classes, we retrieved four parameters/features from mall customers. The results reveal that the younger age customers have a moderate income. Therefore, the notification of low-cost and high discount offers can be sent to younger age customers to attract the buying of products. The results also reveal that the spending score of more than 70% of customers is less than the moderate range for all ages of people. However, in middle to old age, people only spent very high. Therefore, an attractive offer can be sent to the high spending score customers to gain more profit. Similarly, customers who are earning more but have low purchasing scores can be targeted to increase their spending from them. The overall results show that the proposed global and local clustering method and efficient section division method based on the customer can increase the overall earnings of the mall. Thus the efficient clustering and efficient classification of the newly arrived customer can increase the overall revenue of the retail business. For the classification methods, it is proven that Naive Bayesian and Random Forest are superior to the other existing methods. The proposed model is analyzed for the retail business. However, the proposed method can be used for any IoT-based enterprise business application.

At the end, the thesis focuses on efficient transmission of data from IoT devices to IoT server. To achieve this we have proposed an efficient data consistency method for IoT devices to server. The logistic classification method based on machine learning is used to classify nodes. A data aggregation approach called Optimized sampling rate is used to optimize the sample rate of continuous monitoring nodes during setup. The energy-efficient bit map assisted (EEBMA) protocol is suggested for the event driven nodes in the proposed study, while the continuous monitoring IoT devices employ the energy-efficient time division multiple access (EETDMA) protocol. The performance of the proposed protocol is compared with the existing protocol for both the setup phase as well as steady state phase. The results proves the superiority of the proposed DADCZP protocol.

In the proposed thesis work, we have discussed all the aspects of the design and development methodologies for the IoT application. Therefore, it can be concluded that the thesis work discusses all the aspects of the IoT platform.

7.2 Future Work

The present thesis work concentrates on design and development part of IoT. The IoT can be used for various applications. In the present work we have briefly discussed the uses of IoT network for various applications. In the future work, the depth study and design-development methods can be proposed for the application-specific services. The efficient methods can also be developed for efficient bandwidth utilization in IoT network for the enterprise architecture. For future works, cross-layer approach can also be used for the efficient data consistency.

The present work has briefly discussed the uses of IoT in various applications, but there is potential for in-depth study and development of application-specific services. This could involve exploring specific use cases in domains such as smart agriculture, smart healthcare, smart transportation, industrial automation, and more, and designing IoT solutions tailored to the unique requirements and challenges of these domains. Similarly, bandwidth utilization is a critical factor in IoT networks, as it impacts the efficiency and cost-effectiveness of data transmission. Future work could involve developing methods and algorithms to optimize bandwidth utilization in IoT networks, considering factors such as data prioritization, compression techniques, adaptive data sampling, and efficient data aggregation techniques.

Apart from this, enterprises often have complex and diverse IoT deployments with multiple devices, sensors, and data streams. Future work could focus on designing and developing efficient and scalable enterprise architecture for IoT, including strategies for data management, security, interoperability, and integration with existing enterprise systems.

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