Cluster Framework for Internet of People, Things and Services

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CLUSTER FRAMEWORK FOR INTERNET OF PEOPLE, THINGS AND SERVICES

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ENGLISH SUMMARY

In the 21st century, more and more devices around us are being connected to the Internet, contributing to what is commonly known as the Internet of Things (IoT). Examples of IoT devices (“things”) are sensors, actuators, items equipped with RFID tags, devices at home and at the hospital, etc. Users can access these devices with the help of different wireless communication technologies such as Wi-Fi, Bluetooth Low Energy (BLE), Zigbee and Near Field Communication (NFC).

IoT devices are capable of sensing, reacting, responding and working autonomously, and they can be deployed in numerous application domains like smart homes, smart cities, intelligent transport systems, enterprises, utilities and e-Health. Current IoT architectures are mostly deployed with a control and automation perspective, but IoT also has the potential to offer a lot of benefits and services for the end users. This future vision will extend the IoT to the "Internet of People, Things and Services” (IoPTS).

In a given context, a large number of IoT devices may need to work together and organizing them as a scalable network of devices is a major challenge for IoPTS. IoT devices differ in size, computational capability, power source and memory, and in general we can say that IoT devices are heterogeneous and resource-constrained in nature. Not every device may be capable of reacting and defining services based on parameters sensed by it, hence there is a need of a mechanism to aggregate information from multiple devices and define services based on the collected information.

Furthermore, a group of devices must somehow announce their services to those who wish to access them. Traditionally, Bluetooth and Wi-Fi technologies are used to advertise services at a given location. For IoPTS, energy-efficient service advertisement is needed because the advertiser device might be battery-powered.

The service advertisement typically uses a broadcast approach and is not directed to a specific user. If a large number of services are available, the users should be able to personalize and filter the list of advertised services. Hence, the service advertiser mechanism must present additional information to notify users about relevant services depending on their requirements, preferences and context.

The thesis focuses on questions like: How to organize a large number of IoT devices? How can a user be made aware about the IoT services provided at a particular location? How to filter services depending on the user's preferences among a large number of available services?

This research work proposes a cluster framework, which addresses the organization of IoT devices, the service advertisement and the service discovery, and can enable seamless interaction between users and clusters of services in a variety of contexts.

In the first part of the thesis, a new Mobility Aware Clustering Scheme (MACS) based on Particle Swarm Optimization (PSO) is proposed. The proposed clustering mechanism provides scalability, energy efficiency and mobility support, making it suitable for context-aware IoPTS applications.

In the second part of the thesis, a new Profile Aware Proactive Service Advertisement (PAPSA) mechanism using modified BLE beacons is proposed, which can enable an optimised service advertisement. A Personalised Service Ranking (PSR) mechanism is proposed, which helps to filter and rank the services according to user requirements, preferences and context. This represents an important step towards realizing a user-centric service framework for IoPTS.

The main research contributions of the thesis are as follows:

- A mechanism to organize devices efficiently based on clustering.
- An energy-efficient and a profile-aware proactive approach for service advertisement using BLE.
- A personalized service discovery mechanism.
- A generic cluster framework for IoPTS.

DANSK RESUME

I det 21. århundrede er vi omgivet af flere og flere enheder, som er forbundet til Internettet og dermed en del af begrebet "Internet of Things" (IoT). Eksempler på IoT-enheder er sensorer, aktuatorer, emner der er udstyret med RFID-tag, enheder i hjemmet og på hospitalet, osv. Brugere kan tilgå disse enheder ved hjælp af forskellige trådløse kommunikationsteknologier som f.eks. Wi-Fi, Bluetooth Low Energy (BLE), Zigbee og Near Field Communication (NFC).

IoT-enheder er i stand til at registrere, reagere, svare og fungere autonomt, og de finder anvendelse inden for adskillige områder såsom smart homes, smart cities, intelligente transportsystemer, virksomheder, forsynings-selskaber og e-health. De nuværende IoT-arkitekturer er primært udviklet med henblik på kontrol og automatisering, men IoT har også potentiale til at tilbyde en lang række fordele og tjenester for slutbrugerne. Denne fremtidige vision vil udvide begrebet IoT til "Internet of People, Things and Services" (IoPTS).

I en given sammenhæng kan det være nødvendigt, at et stort antal enheder arbejder sammen, og organisering af enhederne i et skalerbart netværk udgør en stor udfordring for IoPTS. IoT-enhederne varierer i størrelse, processorkraft, typen af strømforsyning, og hukommelse, og generelt kan man sige, at IoT-enheder af natur er heterogene og har begrænsede ressourcer. Ikke alle enheder er i stand til at reagere og definere tjenester baseret på de data, de registrerer, og der er derfor behov for en mekanisme, som kan indsamle information fra flere enheder og definere tjenester baseret på den indsamlede information.

Desuden skal gruppen af enheder på en eller anden måde annoncere deres tjenester til dem, der ønsker at få adgang til dem. Traditionelt bruges Bluetooth og Wi-Fi teknologier til at annoncere tilgængelige tjenester på en given lokation. Til IoPTS vil der være behov for energieffektiv serviceannoncering, da annoncørenheden kan være batteridrevet.

Serviceannonceringen vil typisk benytte en broadcast-tilgang, som ikke er rettet mod en specifik bruger. Hvis et stort antal tjenester er tilgængelige, skal brugerne være i stand til at personalisere og filtrere listen af annoncerede tjenester. Mekanismen for serviceannoncering skal derfor omfatte yderligere oplysninger, så brugeren kan få forevist relevante tjenester, som er tilpasset deres behov, præferencer og kontekst.

Afhandlingen fokuserer på spørgsmål som: Hvordan organiserer man et stort antal IoT-enheder? Hvordan kan en bruger gøres opmærksom på de IoT-tjenester, der er tilgængelige på en given lokation? Hvordan filtreres tjenester afhængigt af brugerens præferencer blandt et stort antal tilgængelige tjenester?

Dette forskningsarbejde foreslår et klyngebaseret framework, som addresserer organisering af IoT-enhederne og annoncering og detektion af tjenester, og som muliggør en enkel interaktion mellem brugere og klynger af tjenester i forskellige omgivelser og sammenhænge.

I den første del af afhandlingen præsenteres et nyt Mobility Aware Clustering Scheme (MACS) baseret på Particle Swarm Optimization (PSO). Den foreslåede mekanisme til klyngeformation tilbyder skalerbarhed, energi-effektivitet og mobilitetsunderstøttelse, hvilket gør den egnet til kontekstbevidste IoPTS-applikationer.

I den anden del af afhandlingen præsenteres en ny mekanisme til service-annoncering kaldet Profile Aware Proactive Service Advertisement (PAPSA), som er baseret på modificerede BLE-beacons og muliggør en optimeret serviceannoncering. Desuden foreslås en Personalized Service Ranking (PSR) mekanisme, som er i stand til at filtrere og rangordne tjenester på baggrund af brugerkrav, præferencer og kontekstinformation. Dette er et vigtigt skridt for at realisere en brugercentreret servicestruktur for IoPTS.

De væsntligste forskningsbidrag i denne afhandling er som følger:

- En mekanisme til at organisere enheder effektivt baseret på klynger
- En energieffektiv og profiltilpasset proaktiv tilgang til serviceannoncering baseret på BLE
- En personaliseret mekanisme til service detektion
- Et generisk klyngebaseret framework for IoPTS

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Dedicated to

My Beloved Parents, sister Rohini
and
My life partner Mr. Rahul Shinde

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LIST OF PUBLICATIONS

1. **Gitanjali Shinde** and Henning Olesen, ”**Cluster Framework for Internet of People, Things and Services (IoPTS)**," *IEEE Indicon YASHADA*, Pune, India, December 11, 2014

2. **Gitanjali Shinde** and Henning Olesen, "**Interaction between users and IoT clusters: Moving towards an Internet of People, Things and Services (IoPTS),"** *WWRF 34th meeting*, 21st -23rd April 2015, Santa Clara, CA, USA, Apr. 2015.

3. **Gitanjali Shinde** and Henning Olesen, “**Survey on Service Discovery Mechanisms**," *International Conference on Intelligent Computing and Communication ICICC – 2017*, August 2-4, 2017, Pune, India

4. **Gitanjali Shinde** and Henning Olesen, “**Service framework for Internet of People, Things and Services (IoPTS),**" *WWRF 36th meeting*, Beijing China, 2nd -3rd June 2016.

5. **Gitanjali Shinde** and Henning Olesen, “**Beacon based cluster framework for Internet of People, Things and Services (IoPTS)”,** Accepted and ready for publication in International Journal of Ambient Computing and Intelligence (IJACI).

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LIST OF ACRONYMS

API	Application Programming Interfaces
BLE	Bluetooth Low Energy
BLE-CH	BLE based CH
BS	Base Station
CBR	Constant Bit Rate
CLC	Consumed Link Capacity
CH	Cluster Head
COH	Control Overhead
CM	Cluster member
DSO	Digital Storage Oscilloscope
EC	Energy consumption
ED	End User Device
ERR	Energy Reduction Rate
FV	Fitness Function Value
GW	Gateway
HART	Highway Addressable Remote Transducer
IE	Initial Energy
IoPTS	Internet of People, Things and Services
IoT	Internet of Things
JSON	JavaScript Object Notation
LAN	Local Area Network
LAT	Link Association Time
LC	Link Capacity
LCR	Listen Channel Randomization
LEACH	Low-energy adaptive clustering hierarchy
LDC	link capacity used presently

MACS	Mobility-Aware Clustering Scheme
NFC	Near Field Communication
NLT	Node Life Time
NS-2	Network Simulator-2
ONS	object name service
PAN	Personal Area Network
PAPSA	Profile-Aware Proactive service advertisement
PDR	Packet Delivery Ratio
PML	Physical Markup Language
PN	Personal networks
PN-F	Personal Network federations
PSO	Particle Swarm Optimization
PSO_HC	Particle Swarm Optimization Protocol for Hierarchical
PSR	Personalized service ranking
QPSO	Quantum-inspired Particle Swarm Optimization
RE	Residual Energy
RL	Ranked List
RDLC	Residual Link Data Capacity
RQ	Research Question
RS	Relative Speed
SoC	System on Chip
TLM	Telemetry
TTL	Time To Live
ucode	ubiquitous code
UDDI	Universal Description Discovery Integration
UDP	User Datagram Protocol
UMA	User Managed Access
URI	Uniform Resource Identifier
URL	Universal Resource Locator
UUID	Universally Unique Identifier
WBAN	Wireless Body Area Network

Wise-IoT	Worldwide Interoperability for Semantics IoT
WPAN	Wireless Personal Area Network
WSDL	Web Service Description Language
WSN	Wireless Sensor Network
Z-CH	ZigBee based CH

CHAPTER 1. INTRODUCTION

The aim of this chapter is to explain motivation and challenges of cluster framework for Internet of People, Things and Services (IoPTS). The IoT and further IoPTS overview along with formulation of the problem statement and research questions are presented in this chapter. In the subsequent sections, research objectives and the methodology adopted are also discussed. IoPTS requirements and challenges to deploy IoPTS applications are discussed in this chapter. The scientific contributions of this thesis are explained along with the details of related publications. Finally, the outline of the thesis is provided to give an overview of individual chapters.

1.1. OVERVIEW OF IOT

The Internet of Things (IoT) envisages a deep sense of connectivity and communication between the living and non-living things. Today, the vision of IoT has expanded to connect everything from industrial equipment, to everyday objects, to living organisms such as plants, farm animals, and people. This creates a niche for non-living things to react, respond and work autonomously as and when required and as per their role, position and location to provide services to the user. IoT is developing rapidly in the industrial settings. Machine to machine communication enhances the efficiency and helps to minimize control cost of the industrial plants. IoT integrates the physical world with the information world so that every entity/device works for the betterment and in co-ordination with the other to help to save the most valued resources, and time. According to Cisco, Telular has saved 15 % control cost using the IoT [1]. Telular is development organisation that provides IoT solutions for residential and commercial security as well for home automation.

In the near future, an individual will be surrounded by thousands of devices providing services to the user. In the last decade, deployment of IoT devices has grown tremendously and is expected to initiate deployment of more than 24 billion devices up to 2020 [2]. IoT is growing faster than predicted, as quoted by Wireless World Research Forum",*7 trillion wireless devices serving 7 billion people by 2020*" [3]. The IoT applications can be deployed in a significant number of domains like smart city [4], smart home [5][6], intelligent transport [7], e-health [8], smart agriculture [9], industrial IoT and many more. IoT applications are rapidly capturing the market with the help of recent advancements of the IoT and cloud computing [10], e.g. Apple Smart Watch [11] is used to track health and fitness of the user. With new advancements in the smartwatch, it can be used to control home devices remotely, to provide notification of events, weather reports, and it is also used for contactless payments at shopping malls. Similar to the Apple smartwatch, Microsoft invented IoT smart band [12], it keeps track of user's exercise, calories burnt, sleep quality and also works as an activity reminder. The user can be connected to twitter, facebook and also send text messages through the smart band.

The IoT domains and applications have been listed in this section, we can say that these applications are different from each other concerning the user involvement, the way of accessing IoT services and the purpose of the application. Presently, IoT service architectures have control and automation perspective e.g. smart home, industrial IoT etc. However, in the near future it will be more flexible and oriented towards the user perspective to make user aware about preferred services present at the premises that is unknown to the user e.g. IoT based Airport, shopping malls etc, where user is not necessarily aware of services offered at the location.

Generally, present IoT applications are app/web-based. In the app based IoT applications services are accessed by a smartphone app, e.g., smart home [13]. However, installing a separate app for each application is not efficient and scalable approach due to increasing IoT application deployments. The user should be made aware of IoT services without installing the specific app. This identifies the need for a mechanism to provide services to the user without installing an app. This approach connects the people to the services provided by smart objects, to put it succinctly, the near future will be IoPTS.

1.2. INTERNET OF PEOPLE THINGS AND SERVICES

IoPTS may provide location-based services as the mobile user may enter at some unknown premises, and he may not be aware of services provided by things around him. The market has seized and welcomed such IoPTS approach, e.g., the retail markets for transforming beacons in retail [14]. In this, beacons are used to advertise information about the shop, product information, and different offers. Another example, Amsterdam IoT Living Lab [15], here the lab infrastructure provides services to the people in the lab like crowd control, public way finding and route information.

To achieve this, the service advertisement framework should be used to make user aware about availability of the services in the given premises. In such applications grouping of devices is required since it is not ideally possible that each device has IP connectivity to provide services to the user, some devices may have IP connectivity but exposing the IoT device may lead to few hurdles. It will also require strong security measures to be applied on that device. Also applying strong security measures on IoT devices is not a feasible solution due to less computational capabilities and more energy consumption.

The cluster-based approach can be used for such IoPTS applications deployment. In this approach, IoT devices in the particular devices are grouped in the cluster. In the cluster services are defined based on the information sensed by IoT devices. The GW or single device can advertise these services on behalf of the cluster to make user aware about presence of the cluster.

The cluster-based approach is based on a concept proposed by the former European Union projects MAGNET and MAGNET Beyond [16]. These projects introduced the concepts like "Personal Networks" (PN) and "Personal Network Federations" (PN-F). The PN connects the user's personal devices at any time from anywhere. In the PNF, users share their personal resources in a controlled manner with another user to carry out a joint task. Based on these ideas, we believe that users in the future IoPTS world will have a "Personal cluster," most likely centered around their smartphone or another smart device and this would act as a "hub" for connecting to another cluster [17]. Another cluster could be smart shopping mall, smart airport etc.

This concept is further enhanced to form cluster-based applications in which the group of devices (cluster) will define services depending on the information they sensed. Clusters should advertise the services to make users aware of the availability of services to benefit the users.

In this research, services are advertised by a beacon based approach similar to the Physical Web [18] which is an interaction layer between IoT device and user. In the physical web, service URL is advertised using Eddystone URL frame format. The nearby smartphone can get notification of URL without downloading any specific app, and the user can simply tap on the URL and access the service.

A mobile user would then carry around with the personal cluster and dynamically connect to such clusters using beacons in order to benefit from the services they offer, e.g., in smart airport, at the check-in desk, a beacon will notify the user that due to a technical snag the flight is delayed by a couple of hours and lunch e-vouchers are provided by the airline.

The next section provides the motivation and the impetus to achieve cluster-based approach of IoPTS.

1.3. MOTIVATION

The IoPTS vision looks very fascinating, however, to bring it to fruition is very challenging. This needs to have seamless interaction between the user, a cluster of devices, and services with the help of appropriate communication technologies. To achieve this, it is very important to understand the requirements of the IoPTS system. Some of the requirements derived from above discussions are enumerated below:

1: ***Organizing IoT Devices***

In the application mentioned above i.e. beacons in retail, Amsterdam IoT Living Lab, IoT devices may be heterogeneous, some devices may be mobile and resource constrained in nature. Hence, it is very challenging to organize them systematically and to collect information from them.

2: ***Energy Efficient Service Advertisement***

In the IoPTS, the cluster of devices offers services to the user. However, it is more important to make users aware of the presence of these services. Moreover, making advertisements and conveying these notifications in an energy efficient manner is needed in IoPTS because available notifications are large in a number and device (smartphone) on which user is getting a notification is battery powered. Hence, service advertisement should be done in an energy efficient and user-centric way [19].

3: ***Personalized Service Discovery***

In IoPTS scenarios, there can be a vast number of IoT applications resulting in a large number of services available to the user. However, every time users may not be interested in all types of services offered. They may be interested in specific services. Therefore, personalized service discovery is required. Personalized service discovery facilitates user-centric framework.

To accomplish above-mentioned requirements, there is a need to follow a systematic approach to organize IoT devices, to form services and to make user aware of preferred services. Hence, it is vital to have a user-centric framework for IoPTS system [20].

From the above discussion, we need to fulfill aforementioned requirements to deploy IoPTS applications. However, there are some challenges need to be addressed to fulfill above-mentioned requirements [21]. The challenges are discussed below, and some challenges are focused in this thesis.

Mobility: IoT system consists of different types of devices. Every IoT device has some fundamental functionalities, e.g. sensing the current temperature, air humidity, position, etc. and more complex functionalities require the collaboration of more devices. Hence, it is necessary to organize an IoT devices efficiently. However, due to the mobility of IoT devices, it is very difficult and challenging to organize them.

Heterogeneity: IoT devices are heterogeneous in several aspects. The IoT devices differ in size, computational capability, functionality, communication interface, energy source and many more parameters. The major challenge for any IoPTS system is to form IoT services with the help of such diverse devices.

Scalability: The number of IoT device deployment has increased tremendously and will continue to increase in the future as mentioned in the introduction section. Most IoT applications need a collection of a large number of heterogeneous devices and it is possible that a number of devices in the application may change dynamically. The IoT system needs to support scalability to organize, connect and manage such a large number of devices.

Energy Efficiency: In the IoT, most of the devices are battery powered. Devices need more amount of energy for data sensing, data transmission, data processing and to take actions based on the sensed data. IoT systems should be energy efficient to increase the life of the IoT devices.

Security: IoT systems are tremendously vulnerable to attacks due to numerous reasons. First, most of the times devices are unattended and consequently, it is easy to physically attack them. Second, most of the communications are wireless, which makes it extremely simple for an adversary to attack. Lastly, most of the IoT objects are constricted by finite resources like a battery, computational power and memory and hence complex security techniques cannot be implemented.

The above-discussed requirements and challenges of the IoPTS motivated to research energy efficient and user-centric clustering framework for IoPTS.

1.4. PROBLEM STATEMENT

The problem statement of the thesis is formulated from the above stated findings of the background study and literature survey about IoPTS applications and its requirements, discussed in Chapter 2. The thesis aims to deliver a mechanism for a seamless user-service interaction by providing solutions to the research questions mentioned below.

1.4.1. RESEARCH QUESTIONS

The research question addressed by this thesis is:

> ***"How can the future Internet of People, Things and Services (IoPTS) be organized in order to advertise services to the end users, using a cluster framework approach?"***

The research question is further divided into subquestions for a detailed study about each aspect of research question and analysis of each subquestion is done in the thesis:

- **How to organize IoT devices in a systematic manner to define services on the basis of the data they collect?**

  In the IoPTS, a cluster of IoT devices provides services to the user. IoT devices should be organized systematically to achieve cluster-based approach. The different parameters should be considered while organizing devices. i.e., the type of device, cluster type and the method of user-cluster interaction.

- **How to make users aware of the availability of IoT services in their vicinity?**

  In the IoPTS, infrastructure devices may provide the services to the user. When a user comes to an unfamiliar place, it may be more important for them to know about the services present at that location.

- **How to discover IoT services based on users' roles, preferences and requirements?**

  In the IoPTS, many clusters will be available, which results in a large number of services offered at particular premises. Though a large number of services are available to the user, the user may not be interested in each service. The users should get services according to their roles, preferences and requirements.

1.4.2. RESEARCH OBJECTIVES

The main objective of this research is to develop a generic cluster framework for IoPTS system and it is achieved by designing a seamless user-cluster interaction with objectives to develop:

- A mechanism to organize devices efficiently based on clustering.

  To deploy different IoT applications, there is a need to collect data from IoT devices. The IoT devices are heterogeneous in size, energy source, memory, computational capability and communication capability. This identifies the need for a mechanism to organize these devices systematically.

- Energy efficient and a profile-aware proactive approach for service advertisement using BLE.

  The user should get additional information about the services that are advertised by the IoPTS cluster without connecting to the cluster. The user can take a decision to use these services based on the additional information. This recognizes the need of profile aware service advertisement mechanism.

  The IoPTS cluster may have significant number of services to provide benefit to the user. Hence the advertiser device needs to advertise multiple services. The advertiser device could be battery powered and this leads to the need of energy efficient service advertisement mechanism.

- Personalized service discovery mechanism.

  In the IoPTS, beacon-based service advertisement mechanism uses the broadcast approach to advertise the services. The service advertisements may not be directed to the specific user. Hence, the user gets notifications of all services advertised by the cluster, these may include nonpreferred services. The personalized service discovery mechanism is needed to discover preferred services for the user.

- A generic cluster framework for IoPTS.

  Currently, IoT frameworks are designed from an application perspective and not from the perspective of the user preferences and the contexts. Therefore, this makes it imperative for researchers to address the objective to develop an efficient and generic framework for IoPTS.

1.5. LIMITATIONS

In this thesis, there are still many aspects of cluster framework that are not addressed. We have limited our research to provide a possible solution for the organization of devices, service advertisement and discovery. There is a scope for improvement in the following aspects of cluster framework:

1. The research provides a device organization mechanism for self-healing clusters. However, cluster framework needs to be scalable for another type of clusters, i.e., heterogeneous and user-driven on-demand cluster. The user-driven on-demand cluster needs a GW that has the capability to select specific devices among the cluster of devices based on the user requirements. This research does not provide a mechanism to form user-driven and heterogeneous cluster.

2. In this framework, it is assumed that data is collected from sensors, and services are defined. The research does not address how to collect the data from sensors and converting them into services.

The data sensed by the IoT devices are heterogeneous in size, format, real-time or non-real-time, etc.; hence, a specific mechanism is required to process and manage such heterogeneous data. Further services are advertised using beacons stuffed with service URL. The different vendors could use different formats for specifying service URL which leads to interoperability and scalability issues. Hence, there is a need to have the standard for writing the URL of services. In this research, standard formats are not used while writing the service URL.

3. In the cluster framework, the personalized service discovery is done on the basis of the service advertisement frame and user preferences. In this research, the focus is given to propose the service advertisement frame, however, configuring and retrieving the user profile attributes are not addressed.

   Further, the user profile could be created based on the service usage. Hence, there is a need of mechanism to update the user profile dynamically.

1.6. CONTRIBUTION OF THIS THESIS

The research contributes in improving the performance of IoPTS framework by addressing different aforementioned challenges. The contributions of this research are as follows:

1.6.1. CONTRIBUTION 1: MOBILITY-AWARE CLUSTERING SCHEME

The first contribution of the research is a Mobility-Aware Clustering Scheme (MACS) for efficient organization of IoT devices. The Particle Swarm Optimization (PSO) [22] is a basis of MACS mechanism. MACS treats every IoT device as a sensing device. It forms a cluster based on device position and fitness value that is calculated through PSO.

The MACS is simulated using Network Simulator-2 (NS-2). The performance of the MACS is evaluated based on parameters like energy consumption, delay, and control overheads with a varying number of nodes. The measured parameters show the performance and suitability of MACS algorithm for IoPTS scenarios [19].

1.6.2. CONTRIBUTION 2: PROFILE-AWARE PROACTIVE SERVICE ADVERTISEMENT

The second contribution of this research is a Profile-Aware Proactive Service Advertisement (PAPSA) mechanism. The service profile is created and based on the service profile BLE advertisement frame is configured for respective service.

The PAPSA facilitates to filter and rank services based on the user preferences and requirements. The proposed work modifies a BLE advertisement beacon format in order to perform a profile-aware service advertisement [19].

1.6.3. CONTRIBUTION 3: PERSONALIZED SERVICE RANKING

The third contribution of this research is a Personalized Service Ranking (PSR) algorithm. The PSR mechanism filters IoT services by matching attributes of the user profile and IoT service profile. Profile information about IoT service is retrieved from the BLE advertisement beacon.

Further, a list of services obtained from the filtration process is ranked depending on the context and usage history of the user. Finally, the user gets notification list of preferred IoT services [19].

1.6.4. CONTRIBUTION 4: CLUSTER FRAMEWORK FOR IOPTS

The fourth contribution of the research is a clustering framework for IoPTS. The proposed framework gives high-level service depiction of IoPTS. The components of the framework are clustering mechanism for grouping of devices, service advertisement for making users aware of IoT services, service discovery with service ranking and filtering mechanisms based on user preferences. The proposed framework helps to enable the user to be notified and take advantage of the services provided by a cluster of IoT devices. This framework is a step towards realizing IoPTS system [19].

1.7. RESEARCH METHODOLOGY

The choice of appropriate and demonstrated methodology is a basic prerequisite of every research. The research of designing a cluster framework for IoPTS involves exhaustive information and comprehension of the elements that influence the working of IoPTS systems. Hence, the work carried out under this research considers a blend of qualitative and quantitative research methodology [23] which includes the literature review, simulation and system design. In particular, this work defines the term IoPTS, differentiating it from existing IoT approach in the context of the user-cluster interaction. The need of cluster framework for seamless user-cluster interaction in the view of IoPTS is recognized.

The very first requirement is an organization of IoT devices to achieve cluster framework for IoPTS. This requirement arises due to heterogeneous nature of IoT devices. The detailed literature survey of the type of IoT devices is done to classify IoT devices. The classification of the IoT devices helps to select different types of device organization methods, i.e., self-healing, heterogeneous and user-driven on demand. The different methods of organization of self-healing clusters are analyzed by systematic literature survey. The different parameters like mobility, energy efficiency and scalability have been evaluated from the literature analysis. These parameters are taken as design parameters to develop clustering algorithm. The proposed clustering algorithm is simulated in NS-2 [24] for performance evaluation.

The service advertisement is the second requirement to achieve cluster framework for IoPTS. This requirement arises due to the need of making the user aware of IoT services and hence different service advertisement methods are analyzed to select the parameters for profile aware service advertisement. The service discovery is the third requirement to achieve cluster framework for IoPTS. This requirement arises due to the availability of a large number of services around the user. The different methods of service discovery and ranking are analyzed to select parameters for personalized service discovery. The performance of proposed service advertisement and discovery mechanism is evaluated by designing the system. This research defines, develops, implements/simulates and analyzes the cluster framework modules, i.e., device clustering, service advertisement and service discovery. We promote an approach to achieve seamless user-cluster interaction.

To summarize, Requirement gathering – Analysis – Design – Verify is applied as a research methodology in this thesis.

The requirement gathering and analysis is done by systematic literature review. A literature review is the process of searching, evaluating and analyzing relevant research documents. According to Cronin et al. [25], a literature review is of four types, traditional/narrative, systematic, meta-analysis and meta-synthesis. In this thesis, systematic literature review methodology is used. The cluster framework for IoPTS is verified by system design and simulations. According to Davis et al."Simulation is a method for using computer software to model the operation of real-world processes, systems, or events [26]." Simulations are used to understand system behavior in a specific environment and initial conditions and to do so simulation tools allow researchers to set system parameters. It is used in the research to verify system correctness where execution of algorithms/mechanisms in real time is not feasible and systems with the complex mathematical base. System performance could be verified by running simulation multiple times and changing initial conditions [27]. The performance of the clustering mechanism is verified by rerunning simulation for different scenarios.

System design is the scientific research methodology to design a system using design science [28]. The system is evaluated with different initial conditions and parameters, depending on the system behavior conclusions are presented. In the thesis, research question has been evaluated by developing service advertisement and discovery mechanisms by considering cluster framework of IoPTS.

The outline of research methodology is depicted in figure 1-1, which shows the development of the research from challenges to the outcome, using literature review, simulation, and system design methodologies. The Research Question (RQ) is refined after the literature review, and this leads to the research challenges and objectives. The activities in the orange color are the research contributions that are simulated and implemented in the research using simulation and system design methodologies.

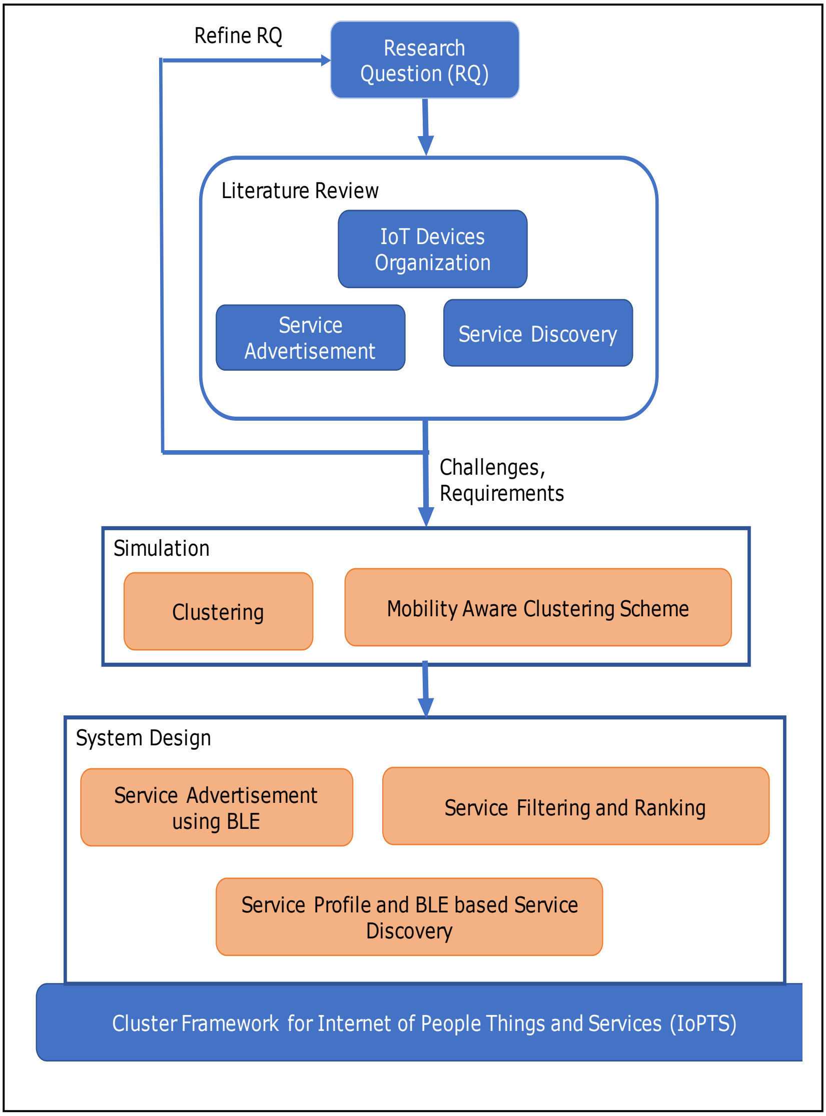

Figure 1-1 Evolution of research

1.8. PUBLICATIONS

The different contributions of this research have been peer-reviewed and published in journal and conference proceedings or are in the process.

1. **Gitanjali Shinde** and Henning Olesen, "**Cluster Framework for Internet of People, Things and Services (IoPTS)**," *IEEE Indicon YASHADA*, Pune, India, December 11, 2014.

2. **Gitanjali Shinde** and Henning Olesen, "**Interaction between users and IoT clusters: Moving towards an Internet of People, Things and Services (IoPTS),"** *WWRF 34th meeting*, 21st -23rd April 2015, Santa Clara, CA, USA, Apr. 2015.

3. **Gitanjali Shinde** and Henning Olesen, "**Survey on Service Discovery Mechanisms**," *International Conference on Intelligent Computing and Communication ICICC – 2017*, August 2-4, 2017, Pune, India.

4. **Gitanjali Shinde** and Henning Olesen, "**Service framework for Internet of People, Things and Services (IoPTS),**" *WWRF 36th meeting*, Beijing China, 2nd -3rd June 2016.

5. **Gitanjali Shinde** and Henning Olesen, "**Beacon based cluster framework for Internet of People, Things and Services (IoPTS)",** In process for journal submission, International Journal of Ambient Computing and Intelligence (IJACI).

1.9. THESIS ORGANIZATION

The thesis is organized into seven chapters. After problem formulation in Chapter 1, the background study of the problem statement is done in chapter 2. On this basis, the thesis is divided into two parts. The first part of the thesis deal with the need of the device organization and proposed clustering mechanism. This part includes chapter 3 and 4. The second part of the thesis deals with user-cluster interaction. In this part mechanisms for service advertisement, service discovery and the cluster framework for

IoPTS are proposed. This part includes chapter 5 and 6. A brief about each chapter is given below, and interconnection of thesis chapters is depicted in figure 1-2.

Chapter 2: Approaches of Internet of People, Things, and Services

The first part of this chapter introduces IoT and different IoT definitions. Subsequently, the concept is elaborated by discussing the IoT applications. Next section proposes the need for IoPTS and explains the IoPTS vision.

The second part of this chapter provides different approaches of service utilization. In the next section, various types of clustering approaches of IoPTS are discussed. This chapter proposes a need for clustering framework for IoPTS.

Finally, the various challenges of the clustering framework are elucidated in the vision for the realization of the IoPTS applications.

Chapter 3: Organization of IoT devices

The aim of this chapter is to give a detailed overview of the organization of IoT devices. This chapter starts with the need of an organization of devices. The device organization mechanisms may vary based on the type of devices. The next section provides the classification of the devices. In chapter 2, we discussed different types of approaches for clustering of IoT devices, i.e., self-healing homogeneous, heterogeneous and user-driven on-demand clusters.

This research focuses on the details of self-healing homogeneous clusters. The next section provides the detailed literature survey of the clustering mechanisms for self-healing clusters. The design parameters for clustering algorithm are discovered from the analysis of the literature work. The chapter is summarized with the selection of design parameters for the proposed clustering algorithm.

Chapter 4: Proposed clustering mechanism

This chapter aims to propose mobility aware clustering mechanism. The device may change their location due to mobility, hence a self-configurable clustering algorithm is required. This section of the thesis provides a proof of concept of the proposed clustering algorithm. The last section of this chapter presents results and concluding remarks about clustering algorithm. Results are drawn using NS-2 tool.

Chapter 5: Service advertisement and discovery

Chapter 5 aims to discuss the overview of service advertisement and service discovery mechanisms. The different communication technologies used for service advertisement are analyzed and based on this analysis BLE is used in the proposed work.

In the next section, the details of the BLE advertisement frame is presented. In the second part of the chapter, service discovery process is discussed and different service ranking mechanisms are evaluated. The need of personalization for service discovery is identified based on this evaluation.

Chapter 6: Proposed service advertisement and discovery mechanisms

The aim of chapter 6 is to propose a mechanism for seamless interaction between user and cluster to get the benefit of the IoT services. The generic cluster framework is proposed to achieve a seamless user-cluster interaction. Two modules of this framework are presented in this chapter, i.e., service advertisement and service discovery.

In the first part of the chapter, the PAPSA mechanism and PSR mechanism are proposed. In the next part of the chapter experimental results of PAPSA and PSR mechanisms are discussed.

The chapter is summarized by proposing the cluster framework for the IoPTS, it includes three modules, i.e., device organization, service advertisement and service ranking.

Chapter 7: Conclusions and Future Work

This Chapter summarizes the research work with concluding remarks and provides directions for future research.

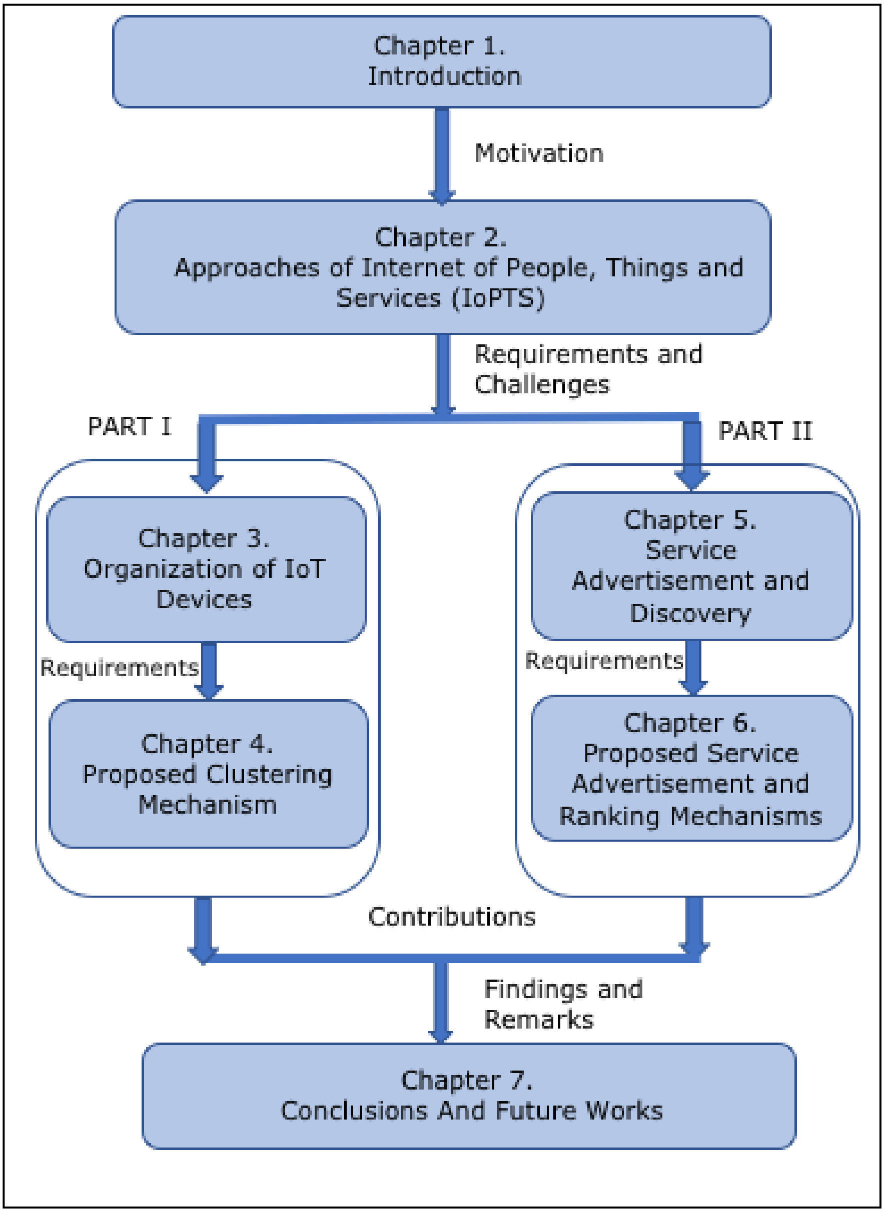

Figure 1-2 Thesis organization

1.10. REFERENCES

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CHAPTER 2. APPROACHES OF INTERNET OF PEOPLE, THINGS, AND SERVICES

The first part of this chapter introduces IoT and different IoT definitions. Subsequently, the concept is elaborated by discussing the IoT applications and also proposes the need for IoPTS and IoPTS vision.

The second part of the chapter provides different approaches of service utilization of IoPTS and its various types of clustering approaches. This chapter also proposes a need for cluster framework for IoPTS. Finally, the various challenges of the clustering framework are elucidated in the vision for the realization of the IoPTS applications.

2.1. OVERVIEW OF THE IOT

In the era before IoT, the World Wide Web, Internet, Web 2.0 and social media made people’s life more comfortable by providing web services and facility to access personal data irrespective of their location. Further, to save time and improve efficiency, there is a need for machine to machine communication, automation and ubiquitous access to personal devices. This need gave birth to the concepts of “Ubiquitous Computing” and “IoT”.

The phrase ‘Ubiquitous Computing’ coined by Mark Weiser in 1988 meaning to provide access to anything, at anytime from anywhere [1]. The term IoT was introduced by Kavin Ashton in 1999 [2] at Massachusetts Institute of Technology's Auto-ID lab in the realm of supply chain. In the literature IoT is defined in different ways.

As per CASAGRAS EU project [3], IoT is a

“*A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object identification, sensor, and connection capability as the basis for the development of independent cooperative service and applications.*

These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability."

International Telecommunication Union defined IoT as,

"*A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies* [4] ."

According to the Internet Engineering Task Force [5], IoT is,

"*The basic idea is that IoT will connect objects around us (electronic, electrical, non-electrical) to Provide seamless communication and contextual services rendered by them. Development of RFID tags, sensors, actuators, mobile phones makes it possible to materialize IoT which interact and cooperate each other to make the service better and accessible anytime, from anywhere*."

In the literature, many authors have also defined IoT with different aspects. According to Dorsemaine et al. [6], IoT is a

"*Group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate*."

Botterman [7] defined IoT as,

"*Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts*."

According to Rayes and Salam [8] IoT is,

"*The network of things, with clear element identification, embedded with software intelligence, sensors, and ubiquitous connectivity to the Internet*."

From the above different IoT definitions we could say that despite the various definitions, the concept of IoT is similar i.e., it is a network of interconnected objects that connects objects/things around us to the internet to access them ubiquitously, e.g. smart home: Smart phone app is used to control the entire home appliances. Home appliances are programmed and customized according to user preferences, e.g. programmable thermostat used to control temperature based on occupancy, Automated door locks are configured in such a way that these doors unlock based on user identity. The user has the RFID card with its attributes and doors have RFID reader, doors open only for the authorized user after reading the RFID tags.

Human activity is tracked using a surveillance camera and a passive infrared sensor to secure home, support children's safety by setting off an anti-theft burglar alarm. Devices like air conditioning, lighting, washing machine and heater are automated to a predefined schedule/controlled remotely.

The sensors are deployed outside the window to sense the presence of allergic particles in the garden/outside the home. If presence is found then the windows of the home will automatically close.

If the kid in the house has an eyesight problem e.g. myopia, he can have an RFID chip with his identification. The TV will have an RFID reader which reads the RFID chip and adjusts to the new settings as per his preferences for viewing TV. From the cloud/server the TV is enabled with new settings i.e. the subtitles are in a bigger font size and screen color changes accordingly.

As discussed above smart home examples we can say that IoT consists of mainly three basic elements: First, things/object/devices, second, data (information), and third, communication technologies [9] discussed as follows:

The primary component of the IoT- Things, could be any physical/virtual element around us, i.e., sensors, actuators, objects with RFID tags, objects in the home, office and so on. The physical object is anything around us that are characterized by unique identification. Virtual objects exhibit proxy relation with the physical object. Sensors are the type of objects which sense environmental, physical and chemical parameters. The actuator is the object that controls motion or functioning of the system based on sense parameters. Things in IoT may also be associated with Personal Area Network (PAN), vehicular network and delay tolerant network, where time and space isolation between geographical space and virtual space can be eliminated which results into human-to-environment relationship. IoT devices are heterogeneous in size, computational capabilities, and energy source. Devices have a unique identification, sensing and communication capabilities.

The second element – Information, is those parameters sensed by the IoT devices, which may be environmental parameters or user-health parameters and any other depending on the domain. It may differ in size and format. These parameters must be stored, processed and converted to appropriate services to provide its benefit to the user.

The third element -Communication technologies connect devices to the user and this is the backbone of IoT. It is a medium for data transmission from device to the server, server to the user, user to user and device to device [10]. Depending on the capability of the IoT device, communication between them varies i.e., communication without Gateway (GW), communication via a GW. Communication technologies are heterogeneous in structure, energy demands, transmission range and addressing capability, e.g. RFID, Bluetooth, Near Field Communication (NFC), ZigBee, Local Area Network (LAN), Wi-Fi, Cellular networks, WiMAX, LoRaWAN [11] and many more.

The term IoT has spread rapidly with the advancements in technologies, it is used widely in different domains [9], some application domains of the IoT are explained below:

Smart City: The Smart City is a smart infrastructure to provide IoT services to the citizens to improve the quality of their life. This is achieved by using resources efficiently. Services in the smart city are smart grid, intelligent public transport, e-governance, smart watering, waste disposal, smart parking, smart surveillance, and so on. Nowadays, construction of Smart cities has attracted the IoT market. "Padova Smart City" [12] is one of the examples of such innovation.

Smart Home: An ability to control home equipments from anywhere or control them remotely is the core functionality of a smart home. Further, in a smart home, equipments take decisions through machine learning techniques based on environmental parameters. Hence, manual setup is not required to setup temperature of air conditioners, adjust light brightness, turn on the music mode, and so on. In the IoT paradigm, the electricity source is an important aspect to be considered. Smart homes provide facilities to save electricity i.e. after leaving home all electric equipments like lights, air conditioners, fans, heaters, etc. are automatically switched off [13]. In the literature, considerable work is done in the field of a smart home for controlling home devices remotely [14][15], efficient energy consumption [16], and home security [17].

Smart Watering: Water management is a grave issue due to the scarcity of water. Efficient distribution and consumption of water is required to maintain water resources. Current water management systems need to be improved by deploying IoT to check leakages, distribute water supply, check the purity of water and for several other purposes [18].

Intelligent Transport: In this era, to save fuel and time an intelligent transport system is required. Vehicles can communicate with each other and with road infrastructure for safety. Services like road status, traffic information, refueling services on the road, and so on can be provided through IoT [19].

Smart Agriculture: In many countries, agriculture is the principal source of income for the majority of the population, e.g., India. Traditional methods of agriculture need improvement with the help of IoT. Plant monitoring, checking soil quality, attention to plant diseases- all this could be done efficiently using IoT resulting in improvement of crop growth. The quantity and quality of agriculture products could be improved by using IoT methods [20], which will boost the country's economy.

E-health: Health always has been an area of concern as health issues need urgent attention and delay in getting medical treatment could prove fatal. In the health domain, IoT plays a significant role to provide facilities that could improve health care methods and help to save valuable human lives. The literature indicates that tremendous work is done in the e-health domain for functions like ECG monitoring [21], patient tracking [22], smart ICU [23], hospital data management [24] and remote patient monitoring [25]. Using sensors the body temperature, the oxygen level in blood, heart rate and other health parameters could be monitored remotely. This improves the quality of life to a great extent. Many advancements are happening in the domain of e-health, e.g., IoT wearable devices for diabetic patients monitors the blood sugar level by which the patients need not worry about checking their sugar levels. In any critical situation, the users may get a warning from IoT wearable to change their diet plan or to take an insulin dose [26].

Enterprise*:* Machine to machine communication with minimum user intervention is required in the enterprise domain. In the enterprise, many applications have the precise deadlines, delay of few milliseconds can result in hazardous consequences and in few applications manual observation recording in the adverse area is not possible. In all these cases IoT plays an important role. Many industries like GE, Cisco, and Huawei started using IoT to manage asset remotely and for its maintenance. According to World Economic Forum Industrial Internet Survey (2015), 79% of the industries are using IoT to optimize use of assets as well as control cost and increase the revenue [27]. In oil and gas companies IoT is used for the safety of the workers by minimizing their exposure to hazardous chemicals and gasses [27].

From the above discussion of IoT application we can say that generally present IoT applications are app/web based. In this approach, IoT architecture facilitates the method to provide the IoT services to the user irrespective of the time and location. IoT is mainly used to save and control cost, improve the efficiency of the system and to enhance user's lives.

However, App based approach may face hurdles due to increasing IoT application deployment. Since to benefit from IoT services, user needs to install an app for each specific application, i.e., the user needs to install a separate app each for home, office, supermarket, airport, hospital and so on, hence this is not a scalable approach and therefore there is a need for a framework of user-IoT service interaction without installing the specific app.

This brings up the need for IoPTS, because it is an interconnection of people with services provided by the things.

Eloff et al. [28] defined IoPTS as

"*The vision where people, things (physical objects) and services are seamlessly integrated into the networks of networks as active participants that exchange data about themselves and their perceived surrounding environments over a web-based infrastructure*."

Previously, Eloff et al. [28] has proposed the term IoPTS and has also discussed the importance of trust, security and privacy for IoPTS. In this research, we are referring the term IoPTS but with different aspect.

2.2. PROPOSED IOPTS VISION

Thinking about the future of IoT, IoPTS will maximize value associated with IoT applications by making users aware of services offered by infrastructure. IoPTS is the extension of the IoT, as defined in chapter one. IoPTS is a cluster-based service approach where people are connected to a services offered by cluster of IoT devices.

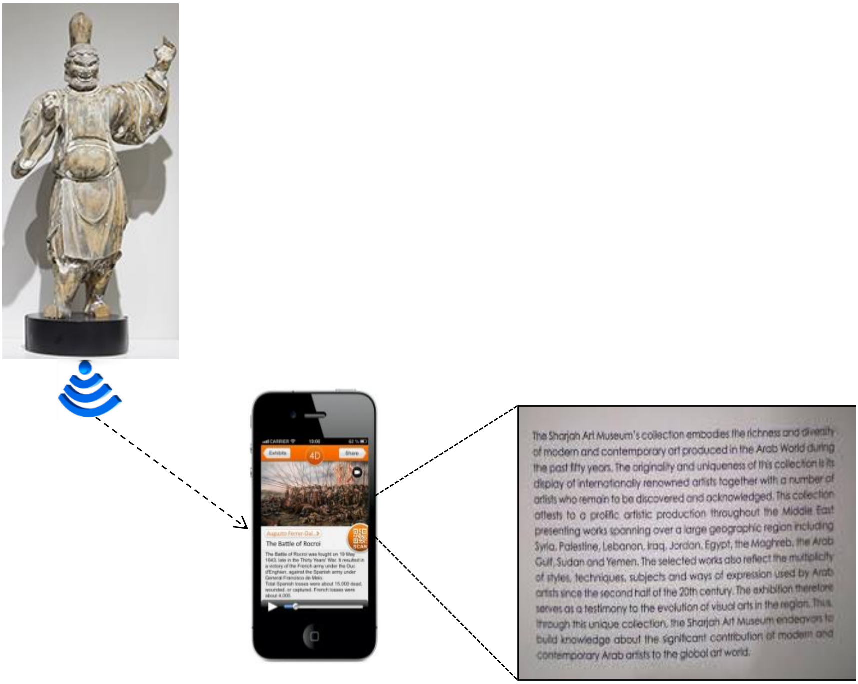
In the IoT, user accesses IoT services using APP installed on a smart phone or GUI for web services. IoT is based on the concept that the user can access anything at anytime from anywhere. As in the IoT, services are accessed through specific app hence there is no need to advertise these services to the user. However, in the IoPTS, IoT services need to be advertised to the user. We can say IoPTS is more about making the user aware of services provided by the surrounding premises unknown to the user. To achieve this, different dedicated service advertiser mechanisms are required like the physical web in which the services are advertised using Eddystone BLE advertisement frames [29]. To elaborate the IoPTS concept further the museum scenario is discussed as follows:

***Museum*:**
Traditionally information about the object/art is written on the boards or images are displayed. Many times, the native language is used to write information and route direction. The tourist may not be familiar with the native languages and face difficulty in understanding the history of the art while taking a tour of the museum. To overcome these hurdles researchers started using IoT technology [30][31][32]. The below-mentioned scenario provides the experience of a tourist’s visit to an IoT enabled museum.

The beacons are deployed for service advertisement at every section of the museum. The traveler gets notification of the floor plan and the map of the museum.In the museum, each art is attached with the beacon containing the information about it. The traveler can use this beacon to know the information about art in the form of text, audio or video format as per his requirements as shown in the figure 2-1.

The ultrasonic and motion sensors are deployed to regulate the crowd by detecting the traveler's presence and movements in the proximity of the exhibit.

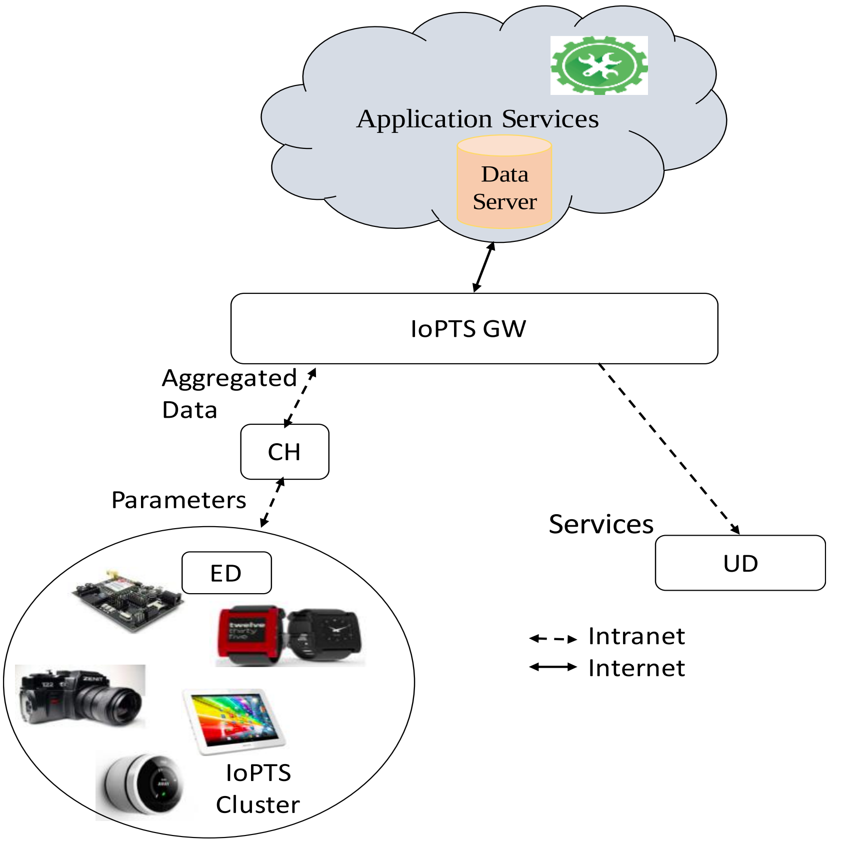
From the discussion of the museum scenario, we can say that IoPTS deals with how humans and things can connect for shaping a smarter world.



Beacon is connected to each art of the museum advertising information about it, User's smart phone scan the available beacons in his vicinity and using beacon he gets historical details about the art.

Figure 2-1 The museum scenario

IoPTS helps to answer many different questions such as: will the cooperation of sensors, the intelligence of cloud and humans help to do things differently? How will these smart things change the perspective of human life? It is necessary to follow some specific strategy to make IoPTS beneficial. The strategy should be well thought out, not only taking into consideration the social and personalized behavior of people and things, but also the proactive nature of heterogeneous devices and predictability of interactions. The IoPTS refers to the collection of different services available on the internet and provided through an IoT framework. The general flow of IoPTS system is shown in the figure 2-2, where End Devices (ED) which can be sensors, actuators, RFID tags etc. are grouped in the cluster. These are connected to the IoPTS GW through Cluster Head (CH) (forming cluster and selecting CH is discussed in the later part of this chapter). The communication between ED, CH and GW is done through local intra-cluster communication protocol e.g. BLE. IoPTS GW then processes data and forward it to the server/cloud. At the server, the data is further processed and IoT service formation is done. The IoPTS GW advertise IoT services using beacon-based approach (discussed in the next section) to make user aware about the presence of services.



ED: End device, it could be any IoT device, the multiple ED are grouped in the IoPTS cluster. CH: CH collects information from IoPTS cluster of ED and aggregates the data. IoPTS GW: GW defines services and stores data on the cloud/server and advertises services. UD: user device, e.g., smart phone, smart watch, laptop, etc. used for service utilization.

Figure 2-2 IoPTS architecture

2.3. SERVICE UTILIZATION APPROACHES

From the discussion of IoT applications and IoPTS vision, we can conclude that in the IoPTS, services can be utilized using two types of mechanisms as follows:

2.3.1. APP BASED

In the above discussed IoT applications devices are accessed through dedicated smartphone App [33]. In the App based approach, app developer gathers data from multiple data services. Generally, data services use same standards, i.e., Restful approach, https for security and JSON for data format. Though the data services use same standards, these are defined in different formats, e.g. the company providing an app for the building automation can organize services in the format "user/building/room/temperature" and the company providing an app for office can organize services as "/user/hub/devices". In such systems, the developer is required to write a code for an app that understands the specific data format. This approach is not scalable as a large number of services will be present in the IoT and developer will need to write multiple codes e.g. an application having ten services will be needed to be written in ten different codes to develop one app.

Further, in the IoT, thousands of apps would be required, leading to an unwieldy complexity of app-based approach. Since, an app cannot discover new services automatically, interoperability is again an important hurdle in the app-based approach. App developer will need to write separate apps for different operating platforms, e.g., ios, android and windows

HyperCat alliance developed the solution to overcome the interoperability issue of the IoT, i.e., HyperCat. HyperCat is a lightweight, open and JSON based service discovery format for IoT [34][35]. HyperCat provides the interoperability, as each device would understand other device data without bothering about the data format and operator. It arranges each device data into a common set of categories to make it easier for service discovery.

HyperCat is the catalog of URLs; and each smart device has a unique URL. Developer need not worry about writing code for service discovery but makes services as machine browsable. Semantic service discovery is provided by keeping a catalog of URL in RDF format on the server. These catalogs are cumulated and knowledge graph is drawn at the client side to fire the query. Hypercat supports Restful architecture and provides security by working over https.

2.3.2. CLUSTER/BEACON BASED

In this approach, devices in particular premises are grouped to form a cluster. In this cluster, devices may provide one or more services, however service advertisement and user-service interaction is not handled by the individual devices, as some of the devices in the cluster may be resource constrained i.e. limited energy, limited computational capabilities. Hence each cluster is associated with a beacon device to advertise services and to handle user-service interaction. User can use services by beacon supported browser e.g., Google Chrome or Nearby Notifications.

In this approach, services are advertised using beacon devices, e.g., ibeacon [36] and physical web. Apple has invented ibeacon technology to advertise the services using BLE. It provides UUID for identification of service.

Physical Web: It is the project by Google for discovering and interacting with IoT devices using BLE [37][38]. It is a lightweight interaction layer between IoT device and user. The physical web is like "*Walk up and use anything"* i.e., every smart device broadcasts URL of service and the nearby smartphone can get notification of URL without downloading any specific App. In this, notifications can be scanned by beacon supported browser e.g., Google Chrome or Nearby Notifications. URL is used to advertise service as per application, in few cases it will give a web page with small information, in other cases it could be linked to complicated services.

The user can simply tap on URL and access service e.g., at the bus stop, URL could give a schedule of the bus and route service, the office coffee machine may offer different types of coffee and pricing, speaker of the conference can broadcast URL for his presentation using physical web and the conference audience can download the presentation using URL. The function of an advertiser device is only to broadcast URL hence any number of devices can receive the URL with little or no conflict. Physical web supports the user usage privacy as service advertiser device is unaware of the user using the services.

Presently physical web uses BLE Eddystone frame format for advertising the URL of the smart device. Advertisement frame format includes service UUID and service URL to provide information about service provided by the IoT device. The advertisement frame format allows few bytes to embed in the URL, hence physical web uses encoding technique like NFC Data Exchange Format. In this URL suffix i.e. "http://www." and prefix i.e. ".com" is converted into the single character [39] .

Additionally, the ranking of the services is provided based on the received signal strength. The service with high signal strength will be given high priority.

The advertiser device can use other technology than BLE for service advertisement e.g., Wi-Fi, Wi-Fi Direct.

In the Wi-Fi network service advertisement could be done using mDNS approach. This approach provides few benefits over BLE as in this URL length is not the limiting factor. Any size of URL can be fitted and it provides security as only users logged in Wi-Fi network will get the notification [40].

The Wi-Fi direct can be used to advertise services, this facilitates the device to device connection without an access point. Moreover, devices can connect to peer to peer approach instead of the internet. This provides benefits over the BLE and mDNS approach as the device can get data without internet connectivity [41].

This approach suffers from a few limitations such as URL is in plain text format hence it can't be used to advertise services of the domain that deals with sensitive data. Physical web approach could be made secure by using encrypted URL, web authentication mechanisms, using mDNS and by reducing transmit power of the advertiser device.

The cluster/beacon based is not the replacement of the app based approach. Installing an app for each smart object or for each application is not scalable and therefore, in such an environment the cluster/beacon based could be the generic solution to advertise all services in the cluster.

To deploy different IoT applications and different approaches of IoT service utilization, there is need to collect data from IoT devices. The IoT devices are heterogeneous in size, cost, energy source, memory, and communication capability. These can be installed at favorable or remote/inaccessible locations. In the latter case, these operate autonomously with secure remote management. Hence, in such applications the device requires long battery life capabilities to avoid battery replacement due to lack of accessibility to mounting locations. Further, this raises the requirement of a method to organize these devices and forward data to the server/cloud. IoT devices need to be categorized based on their capabilities. The next section describes the different approaches of organizing devices in the cluster/group.

2.4. IOPTS CLUSTERING APPROACHES

The service utilization approaches discussed above gave rise to the vital question "how to connect people with a cluster of IoT devices?". Subsequently, ”what are the types of clusters and how to form the clusters?”. The research proposes the different types of clusters in the IoPTS. Depending on the type of cluster, the cluster formation and interaction between the user and the cluster differs. The type of IoPTS clusters are as follows:

- Self-healing homogeneous cluster
- Heterogeneous cluster
- User-driven on-demand cluster

2.4.1. SELF-HEALING HOMOGENEOUS CLUSTER

In this type of cluster, the IoT devices may or may not be organized by human/administrator e.g., sensors could be deployed using helicopters in the dense forest area for sensing environment parameters [42] . In such a scenario, random deployment is done. In this type of cluster, devices may be mobile or stationary and most of the devices are resource constrained i.e small in size, limited computational capabilities, less memory and battery powered. This type of clusters are used in the Wireless Sensor Network(WSN) [43].

Due to physical damage, battery drain or mobility, the devices may leave or join the cluster. Hence cluster should be able to make necessary changes for functioning i.e. clusters should be self-healing. In this type of cluster devices have similar communication interface. Devices may not have IP connectivity and due to an energy constrained these are clustered and parameters are forwarded to the server using CH and GW.

To form the cluster, GW sends joining request to each device in the cluster. After receiving joining request, devices reply with their attribute parameters with identification. GW forms a table of active devices that are in the network. Then using the specific clustering algorithm clusters are formed and CH are selected dynamically using different CH selection algorithms. CH prepares a schedule to collect data from group members of the cluster and broadcasts the schedule to the cluster members. Cluster members transmit data in assigned slots and during other times these are in sleep mode to reduce energy consumption. CH aggregates the data collected from cluster members and forwards these aggregated data to the GW in the single or multi-hop approach. The user can access services offered by devices through GW. For self-healing, GW updates active device table periodically. Administrator intervention is not required for such purposes.

The user can get the benefit of the services offered by the cluster by interacting with the GW. The user personal cluster is connected to the GW for service utilization. User personal cluster includes devices like smart phone, laptop, smart watch and so on. In this type of clusters service utilization can be done using the app-based approach discussed in the section 2.3.1.

2.4.2. HETEROGENEOUS CLUSTER

In heterogeneous cluster, devices are heterogeneous in the view of communication interface i.e. devices may have ZigBee, Bluetooth, Wi-Fi, Profibus, Highway Addresable Remote Transducer (HART) Protocols [44]. Based on the distance and communication interface, devices are organized in the clusters and CH is selected as per different CH algorithms. To deploy such clusters, the administrator is required for field installation as clusters are formed based on the distance and similar communication interface. As per traditional approach, each cluster will require one GW with a similar communication interface. This approach is not scalable as a large number of GW will be required thereby increasing the cost of deployment of the application. Hence, GW with heterogeneous communication interface is required.

This approach of forming a cluster is used in applications which have a high density of heterogeneous devices and the deployment area is large. Depending on the density and area of the application, formation of heterogeneous cluster varies. In applications which have less number of devices and small deployment area the functionality of GW and CH can be combined in the GW.

In heterogeneous cluster approach, the GW plays a major role and has additional capabilities than GW in self-healing scenario. The GW has the capability to receive data from multiple CH over different communication interfaces and forwards it to the server/cloud. The user can benefit the services offered by heterogeneous cluster by connecting to the GW.

In this type of clusters, service utilization can be done using app based, beacon/cluster-based approach discussed in the section 2.3.2. The beacon-based approach makes user aware about the services offered by the cluster of the devices.

2.4.3. USER-DRIVEN ON-DEMAND CLUSTER

In user-driven type of cluster, the initial setup of the cluster is done by the administrator similar to the heterogeneous cluster. It is a type of heterogeneous cluster with some advancements. It has the same configuration as that of the heterogeneous cluster.
Here, two different clusters may meet and connect for a limited time span to finish a particular task e.g. user enters at some unknown premises and needs to complete the task based on the information sensed by the devices at the premises. There is a need to form a cluster of user personal devices and a few devices among all devices of the heterogeneous cluster without the administrator intervention.

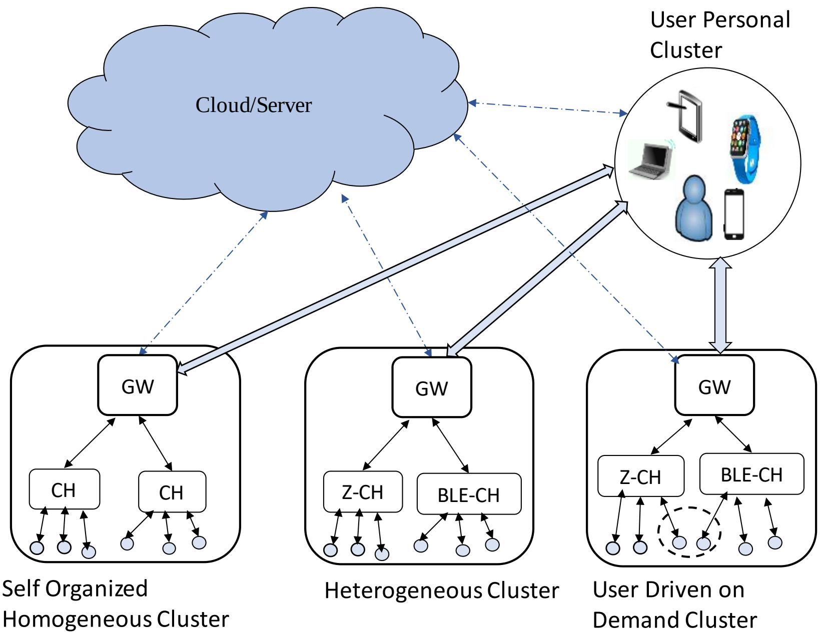
Such type of clusters are formed based on user demand and to form such clusters, GW needs to have more special capabilities than GW of the heterogeneous cluster. GW should be capable of selecting devices of the cluster based on user requirements, forming and maintaining cluster for limited time span to perform the required task. GW should have a mechanism to not only organize devices as per user requirement, but also have the capability to understand user requirements.

In this type of clusters service utilization can be done using the HyperCat [35] approach discussed in the section 2.3.1. The selection of the device and forming the cluster will be effortless using HyperCat as it maintains the catalog of services offered by devices.

The IoPTS clusters are shown in the figure 2-3. In the self-organized cluster, the devices are grouped and one CH is assigned to each group. CH of each group aggregates parameters sensed by group members and forwards aggregated data to the GW.

In the heterogeneous cluster, devices may have different communication technology. The devices with BLE communication are grouped and BLE based CH (BLE-CH) is assigned to the group. The same method is followed for other devices i.e., ZigBee based devices grouped and ZigBee based CH(Z-CH) is assigned and so on. In the case where application area and device density is small, the role of CH can be eliminated.

To form user driven cluster GW selects devices according to the user requirements. The selected devices may be from same cluster or multiple different clusters as shown in figure 2-3, two devices are selected from different clusters shown in the dotted circle.



1) self-organized homogeneous clusters 2) Heterogeneous cluster 3) User driven on demand cluster.

Figure 2-3 IoPTS clusters

In each of the above-mentioned approaches, the role of grouping of devices and GW is needed. Since it is not ideally possible that each device has IP connectivity, some devices may have IP connectivity but exposing the IoT device may lead to few hurdles. It will require strong security measures to be applied on device. Also applying strong security measures on IoT devices is not a feasible solution due to less computational capabilities and more energy consumption. Another limitation for such scenario is the maintenance of network with diversified devices i.e. devices with IP connectivity and devices without IP connectivity.

Devices with the low computational capability and heterogeneous communication interfaces are grouped together, and one GW is allocated to each group. GW has different communication interfaces to connect to all devices of the group. The user can access these services at anytime from anywhere through GW using the app or the web-based approach.

2.5. ROLE OF GW IN THE IOPTS

GW mainly works in a scenario where communication protocol of device is not the same as the protocol used at the network layer. GW has different functionalities, first, it acts as protocol translator as most of the sensors may have BLE communication interface due to increase in beacon applications, few may have ZigBee interface and so on. Due to such diversified protocols GW acts as the point of contact between local intra-cluster of IoT devices and external internet. It increases the scalability by connecting a group of devices to the internet.

Second, it collects the data from heterogeneous devices. The data may differ in size and format. Data may be redundant and forwarding such data may reduce network efficiency and degrade system performance. Hence, data processing and aggregation is required. GW processes and aggregates data before forwarding it to the server, hence IoT device need not required to process the data which results in lowering energy consumption of device and cost of deployment.

Third, GW provides security to the IoT devices. The strong security measures could not be applied to the IoT devices due to the resource constrained nature. GW has sufficient computational capability and energy source; hence strong security measures could be applied on GW. Devices are secure as these are behind the GW and not directly exposed to the external network.

Fourth, GW can update the firmware of IoT devices. The manufacturers may release new firmware version. In the network without GW there is a need to manually update firmware in each device which is not the scalable approach. GW receives new firmware version from server/cloud and it updates all related devices.

Fifth, GW provides formation of the user driven cluster. As discussed in the section 2.4.3 user driven cluster needs a selection of specific devices. GW has the capability to select devices from different clusters and form the new cluster for a limited time. GW maintains and monitors newly formed cluster by preparing the communication schedule for data exchange. GW resolves the cluster after allocated duration.

2.6. REQUIREMENTS OF CLUSTERING FRAMEWORK FOR IOPTS

As discussed in the sections above, different types of organization of devices is required in the IoPTS i.e. self-organized, heterogeneous and user-driven on-demand. Further to utilize IoT services beacon-based approach and GW with specific capabilities are required. A new clustering framework is required to develop user driven and beacon based IoPTS application.
IoPTS system needs to address the requirements listed below:

- Devices must be organized systematically. Group of IoT devices should be formed based on some logical connection between them. The process of organizing the devices faces difficulties due to heterogeneity, resource constrained and mobility of the IoT devices.

- Among all devices, a device with strong capabilities should be selected as a group head/CH to collect data from group members and forward it to the server through GW.

- IoT services are defined based on real-time data which is processed by the server. The server should have a mechanism to process and manage data sensed by IoT devices. In IoPTS application number of services will be large hence these should be organized using approaches like HyperCat.

- For users to take advantage of IoT services provided by a group of devices, the advertisements of the services offered should be done in a user-friendly format which is easily comprehended by the user i.e. using the beacon-based approach.

- In the IoPTS user will be surrounded with a large number of service notifications using beacon-based approach however the user may not be interested in all services. Hence filtering and ranking of services based on user preference is required. Presently physical web rank services based only on signal strength and it is not sufficient [45]. The context aware and user centric ranking of services is required in IoPTS. Mechanism is required to retrieve user preferences and context information to achieve user centric approach.

2.7. SUMMARY

With the burgeoning use of connected devices, application of IoT is penetrating in every use of the real world. This chapter presents IoT vision with respect to the ubiquitous machine to machine communication and gives an overview of IoT. In the next section of this chapter, definitions of IoT coined by various global stakeholders are presented and discussed. This chapter also discusses IoT applications to clarify the concept further.

The subsequent section discusses the need for the IoPTS vision and the concept is elaborated by presenting a scenario exemplifying this vision. The different IoT service utilization approaches are proposed i.e. app based and beacon based. To improve efficiency and support interoperability for the app-based approach, the HyperCat mechanism is further discussed. Beacon based approach is elaborated by presenting details of the physical web mechanism.

In the further section, different IoPTS clustering approaches are proposed. These clustering approaches are defined based on the method of cluster formation and cluster management. The IoT devices are grouped in the clusters for efficient user-service interaction. Depending on the type of cluster, the suitability of protocols for inter-cluster, intra-cluster and user-cluster communications may vary.

The role of the GW is discussed in detail for deploying the different type of IoPTS clusters i.e. self-organized, heterogeneous, user-driven on-demand.

Requirements of cluster framework of IoPTS are presented and discussed in this chapter. In this research, few requirements i.e. IoT device organization, to make users aware of the availability of services in their vicinity and personalized service discovery are discussed.

On the basis of these requirements, this research proposes the clustering framework for IoPTS with its components i.e. clustering module, service advertisement module and service discovery module. The framework is divided into two parts. The first part focuses on device organization i.e. functionalities behind the GW and the second part concentrates on the functionalities of user-service interaction i.e. Service utilization. The research proposes the device organization algorithm in the first part of the thesis and in the second part of the thesis beacon-based service advertisement and personalized service discovery mechanisms are proposed.

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CHAPTER 3. ORGANIZATION OF IOT DEVICES

The aim of this chapter is to give a detailed overview of the organization of IoT devices. This chapter starts with the need of organization of devices. The next section provides the classification of the devices and the device organization mechanisms which may vary based on the type of devices. In chapter 2, we discussed different types of approaches for clustering of IoT devices, i.e., self-healing homogeneous, heterogeneous and user-driven on-demand clusters. This research focuses on the details of self-healing homogeneous clusters. The next section provides the detailed literature survey of the clustering mechanisms for self-healing clusters. The design parameters for clustering algorithm are finalized from the analysis of the literature work. The chapter is summarized with the selection of design parameters for the proposed clustering algorithm that is presented in the next chapter.

3.1. DEVICE ORGANIZATION

From the discussion in chapter 2, we can say that the device organization is the first step to deploy IoT applications. This section provides the need for clustering of devices. Clustering of devices depends on the type of devices, clusters and topology used in the network.

3.1.1. NEED OF CLUSTERING

Clustering of devices is a formation of a group of devices based on the specific parameters, e.g., distance. The network without clustering i.e. unorganized network is depicted in figure 3-1. In such a network, user-device communication may vary depending on the capability and type of the device. Here, most of the devices are not using IP connectivity hence, they are connected to the user via GW. Some devices with IP connectivity may be directly connected to the user through the internet. However, exposing IoT device to the external network without GW is not an advisable solution as discussed in chapter 2. Mostly, devices in the self-healing network are battery-powered and resource-constrained. In figure 3-1, devices are constrained in energy, memory and computational capability. These devices can’t store big routing tables due to insufficient memory. Though devices may have sufficient memory to store the routing table however frequent updation of the routing tables may not be feasible. In unorganized networks, the flooding mechanism may used for data transmission.

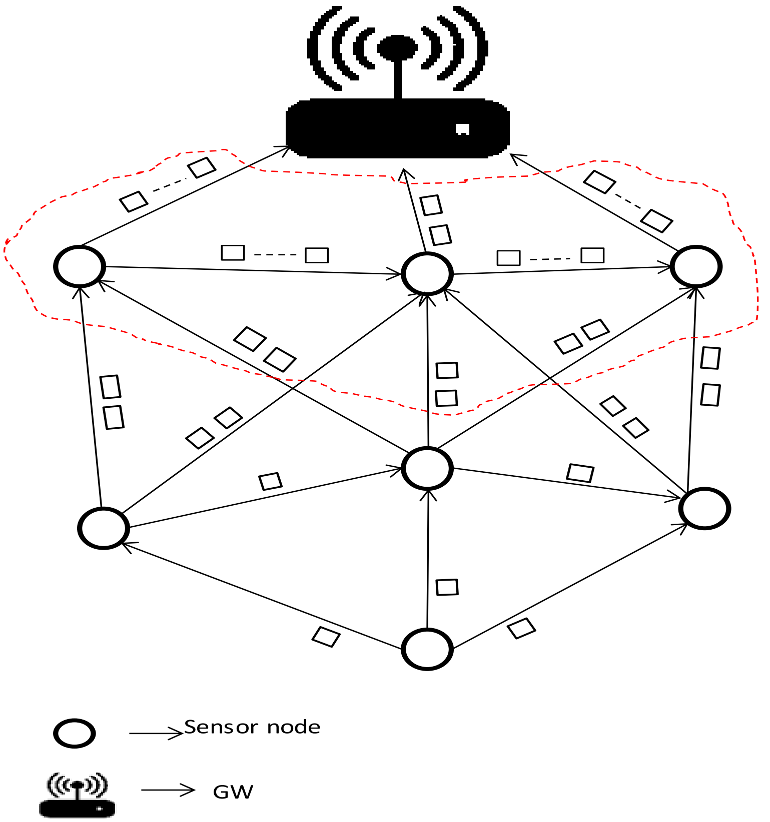
Limitations of the unorganized networks are discussed as follows [1][2]:

Network life time: Network life time is the time difference between the time when the network is deployed and the time when the first node becomes dead due to energy drain [3]. The unorganized networks have less network life time because in such networks data transmission is done using traditional flooding method [4]. In flooding method, every device forms the data packet with sensed parameters and the GW address as the destination address. The device broadcasts the data packet in the network to it's neighboring devices which then rebroadcasts the same packet to it's neighbors and so on. Due to this mechanism, GW receives multiple copies of the same packet. Device energy is more consumed due to redundant data transmission that leads to reducing network life time. Clustered network approach increases the network life time as CH sets the data transmission paths to avoid the data redundancy.

Energy consumption of nodes near GW: In the network without clustering, nodes can transmit information to the GW via multi-hop, i.e., flooding data transmission mechanism, hence nodes near to the GW need to transmit more packets than nodes away from the GW. This results in faster and additional energy drain of nodes near to the GW.

Control overhead: Control overhead is the number of control packets that are required to transmit for managing the network. Control packets are used for flow control to avoid loss of data packets. Forwarding such packets consumes more energy of nodes. In clustering approach, control packets are needed in less numbers as the network is managed at the local/cluster level.

Delay in data transmission: Delay is the time difference between the packet sent from the source device to the time it is received at the destination. The overall delay in such a network increases due to congestion occurring near the GW.



Organization of IoT devices without clustering: the data transmission is done using flooding approach. The GW receives multiple copies of the single packet through multiple routes. More energy is consumed by devices near the GW and congestion may occur near GW, shown in the red color.

Figure 3-1 Organization of IoT devices without clustering

Network Management: Devices may leave or enter the network due to mobility or drained battery power. These changes should be updated for network functioning. Network management is difficult in the unorganized network because all the changes in the network need to be managed by GW. Local level network management is required to update the changes. In a clustered network, it could be done by CH at the local level.

Data transmission capacity: The number of packets transmitted through the network increases due to the absence of data aggregation. It may happen that geographically close nodes deliver same data packets and therefore redundancy of packets is not verified. Transmitting redundant packets leads to the improper utilization of the data transmission capacity. The local level data aggregation is required to drop redundant packets from the transmission.

Congestion: Network traffic increases due to transmission of the redundant packets and the nodes near GW may flood with more data packets than it's buffer capacity, which leads to the congestion in the network.

Scalability support: Scalability refers to how well the network performs with increasing network density i.e. number of nodes in the network. In the network without clustering, energy consumption, control overhead, delay may increase with increasing number of nodes in the network that may results in low network life time. Hence this approach is not scalable.

We can say that there is a need of forming clusters to overcome above-discussed limitations. It is required to classify IoT devices because based on the type of devices cluster formation may differ.

3.1.2. DEVICE CLASSIFICATION

IoT devices are different from each other, concerning size, communication interface, computational capability, energy source, etc. IoT Devices could be categorized depending on different parameters [5][6][7] as follows:

Sensing Capabilities: IoT devices may sense environmental parameters such as temperature, humidity, etc. Different applications may require a different type of devices. Devices could be categorized depending on the sensing capability as:

- Sensing capability devices, e.g., temperature sensor
- Devices without sensing capabilities, e.g., Actuators, RFID tag

Data Handling: Some IoT devices are intended to sense different parameters and information. Devices could be categorized based on the type of data it handles, as mentioned below, e.g.:

- Environmental parameter
- Audio data

- Video data
- Health parameter

Energy Source: Energy source of IoT devices is an important design parameter of any IoT application. Some devices may be battery powered and others may have uninterrupted power supply, energy harvesting mechanism [8] and so on. IoT devices could be categorized depending on the energy source of the device as follows:

- Battery powered
- AC powered
- Energy harvesting

Size, Computational Capabilities: Most of the IoT devices are constrained in size and computational capability. Some devices may have more computational capability than other devices. The basic functionalities, i.e., sensing and forwarding parameters are assigned to resource-constrained devices. Devices with more computational capability may assign with extra functionalities like data processing and take actions based on the sensed data. Depending on their constrained nature, devices could be categorized as:

- Constrained devices
- Non-Constrained devices

Communication Capabilities: IoT devices are heterogeneous concerning the communication capabilities. Every IoT device may not have IP capability to connect it to the Internet. An organization of devices differs based on the communication capabilities. IoT devices could be categorized as:

- Devices with IP connectivity
- Devices not using IP connectivity

Mobility: Mobility is an important parameter for designing clustering algorithm. Organization of mobile devices is complex than the static devices. IoT devices could be categorized as:

- Stationary
- Mobile

IoT application may have a collection of devices from different categories and hence, organizing heterogenous devices needs a systematic clustering process. In the research, devices with sensing capability are considered to sense environmental parameters. In many IoT applications, IoT devices could be moving hence in the research work, mobile devices are considered.

The second factor that affects IoT device organization is the cluster topology. Cluster topologies are used to reduce energy consumption and congestion in the cluster.

3.1.3. CLUSTER TOPOLOGY

Topology is the way of connecting devices to CH and GW. The topology may affect the performance of the cluster to a great extent. Presently, star, mesh, hierarchical and tree topologies are used to organize devices in the network [9][10][11], so in IoPTS. These topologies are depicted in the figure 3-2.

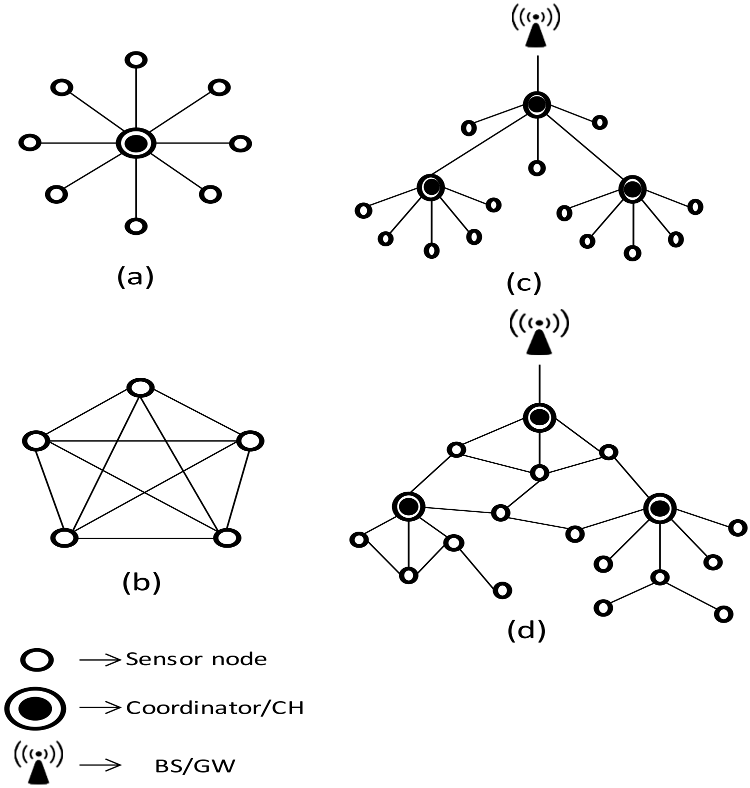
Star Topology: In this type, one central device works as coordinator (PAN head/CH) of all devices in the cluster. Devices cannot communicate directly with each other. Devices are only connected to the coordinator device on a single hop distance. This type of organization is suitable for applications where devices have low range transmission capabilities, and the cluster density is low. The coordinator device must have an uninterrupted power supply and member devices may have battery power supply. This cluster follows the client-server architecture and coordinator acts as the server. However, if the PAN coordinator fails the complete network will be down. This topology is not suitable for a network having high device density. The cluster members are connected to the coordinator by a single communication path. The functioning of the device may stop because of the failure of a link between the coordinator and member device.

Mesh topology: In the mesh topology, every device is connected to each other on a single or multihop distance. One device in the network works as a coordinator to transmit sensed data to the cloud/server. This is a reliable communication topology as every device can communicate to each other. In this topology, packet reception ratio is more as single link failure doesn't affect the working of the cluster. Network life time is higher because less energy is consumed for data transmission due to load balanced nature. This type of topology is difficult to deploy for the high-density network because it is difficult to reconfigure. Mesh topology suffers from the higher latency as each node does store data and then forwards it to the next node.

Hierarchical Tree Topology: In this type of topology, devices are arranged in hierarchical levels. At each level, devices are connected to the coordinator device similar to a star topology. Coordinators of each group are connected to the Base Station (BS) following a tree structure. This type of topology can be used in the high-density network, but it suffers from limitations similar to a star topology.

Clustered Hierarchical Topology: In the clustered hierarchical topology devices are arranged in hierarchical levels similar to a hierarchical tree topology. However, devices at a similar level can communicate with each other. In each level, one device is selected as a CH. The CH is used to manage the network at the cluster level. The CHs of all levels are connected to each other and to the BS. This is a widely used type of topology as it has combined the advantages of mesh and hierarchical tree topology. The scalability limitation of mesh topology is overcome by clustered hierarchical topology by using CH.

From the above discussion, we can say that the clustered hierarchical topology is well suited for the high-density network. In the proposed clustering mechanism, clustered hierarchical topology is used.



a) Start topology b) Mesh topology c) Hierarchical tree topology d) Clustered hierarchical topology

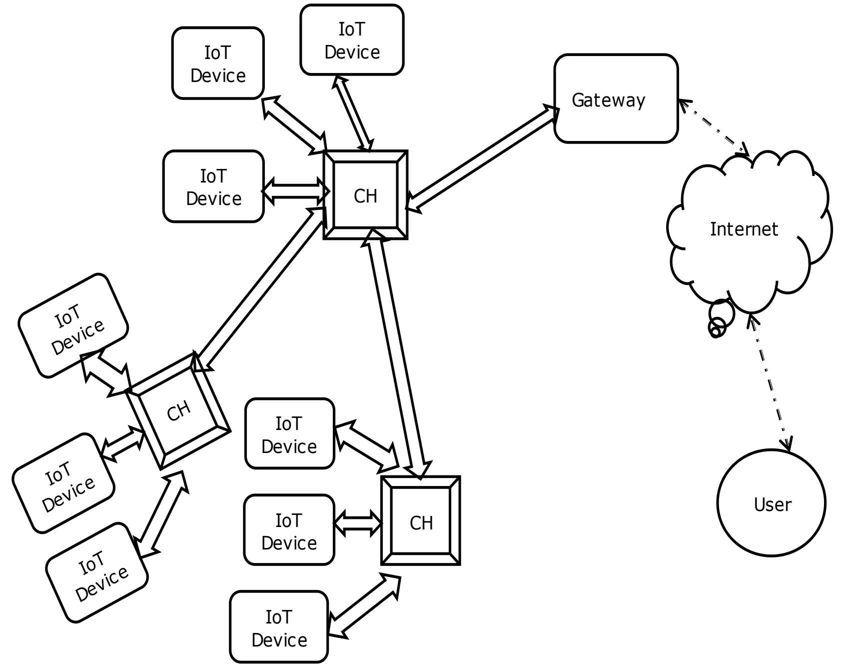
Figure 3-2 Cluster topology

3.1.4. CLUSTERING PROCESS

Devices could be organized systematically based on some sort of logical connection between them. The cluster formation and management process may vary depending on the different type of devices, topology and clusters. The different type of the clusters, i.e., self-healing homogeneous, heterogeneous and user-driven on-demand cluster are presented in chapter 2, section 2.3.2. The cluster formation and management of the heterogeneous clusters could be done by the administrator. The location and number of devices in the self-healing homogeneous and the user-driven on-demand cluster may vary. Hence, cluster formation and management is a complex task. These types of clusters require clustering mechanism that could manage and update cluster without the intervention of the administrator. In general, the process of clustering of devices in WSN is as follows [12], The network with clustering of devices is depicted in figure 3-3:

Cluster Formation: Cluster formation is the process to form a group of devices depending on the specific parameters, e.g., distance, location, type of data sensed, and the energy of node.

CH Selection: The device with strong computational and communication capability is selected as the head of a group. Information sensed by cluster members is forwarded to the data center/cloud through the group head/CH because all devices are not capable of transmitting sensed data to the data server.



Devices are grouped in the cluster and strong node among the cluster is selected as CH. The user is connected to devices through CH and GW.

Figure 3-3 Organization of IoT devices with clustering

Discovering neighboring nodes and setting communication link between them are the major functions of cluster formation process. The selection of CH is the crucial task of the clustering process after formation of the cluster. The CH aggregates the data received from all cluster members, and the aggregated data is forwarded to the BS/GW.

3.2. LITERATURE WORK OF CLUSTERING MECHANISM

The detailed survey of literature work in the domain of clustering is done to understand the different mechanisms of organizing devices.

In the clustering process, a new node is added to the cluster by pairing it with an existing node in the cluster. Clustering of devices could be done based on the parameters like node mobility, location awareness, cluster overlapping, energy efficiency, CH selection overhead, delay, hop count, the distance between CH and BS, and uniform CH distribution [13][14][2]. The sensor nodes can also be clustered according to sensing parameters, hardware capabilities, processing capabilities and communication interface, as well as their natural environment.

A High Energy First clustering algorithm is proposed by Cheng et al. [15]. This work is targeted for the hard network lifetime scenarios. The hierarchical topology is used in this mechanism. Energy consumption of CH nodes and non-CH nodes is analyzed and the highest residual energy node is selected as CH. From the analysis of this mechanism, we can conclude that the **high residual energy** of the device should be considered as the primary selection parameter for the CH.

Krill herd based clustering algorithm is proposed by Shopon et al. [16], it works in two stages to form a cluster and selection of CH. i.e., setup stage and steady stage. In the setup stage, all nodes transmit residual energy and location of the nodes to the BS. BS selects CH depending on the residual energy. In each round, number of CHs are selected. The CH main task is to aggregate data from cluster members and forward it to the BS. The energy of CH node is consumed more than the non-CH node and hence, the algorithm keeps rotating the role of CH. The simulation is done for 100 nodes and results are compared with standard clustering algorithms like Low-Energy Adaptive Clustering Hierarchy (LEACH), LEACH-C, and PSO. Simulation results show that it works better than these algorithms with respect to the energy consumption required for clustering. This algorithm maximizes the lifetime of the network by selecting CH uniformly in the simulation area. Uniform CH selection is done by taking distance from non-CH members and high residual energy as criteria. The uniformity in the CH selection improves the average energy consumption of the network. The simulation is executed for some number of rounds till energy of nodes is exhausted to prove the scalability of an algorithm. Here, the single hop data communication approach is used which limits the scalability of the network. This work shows that the **uniformity in CH distribution** can also be one of the important parameter to form a cluster.

Packet discarding based clustering is proposed by Halim et al. [17]. The algorithm is focused on reducing an energy consumption which increases due to congestion in the network. Packets are discarded by CH node to reduce network congestion. It works into two phases: clustering phase and packet discarding phase. Initially, CH is selected randomly. Consequently, CH receives packets from non-CH nodes of the cluster and aggregate the packets and forwards it to the BS. During data aggregation CH discards packets whose time to live reaches to zero and packets with size more than 60 bytes. WSN packets are in the range of 30-60 bytes. The simulation results show that with increasing number of CHs the delay and energy consumption reduces as CHs performs the packet discarding. In this approach, extra functionality of verifying packet length is assigned to the CH, this computation may increase the energy consumption of the CH. From the analysis of this algorithm, we can say that the clustering algorithm should have a strategy to minimize traffic **congestion** in the network to reduce energy consumption.

Hierarchical clustering algorithm for heterogenous WSN is proposed by Awan and Saleem [18]. In these, two types of nodes are considered. One, basic nodes which are not capable of energy renewing capability and two, energy harvesting node which has the energy renewing capability. Energy harvesting nodes are treated as a CH. In this network, the area is divided into three types: regular grid, minimax grid and k-medoids. In the regular grid, the network is divided into the square-shaped cells, and energy harvesting node is placed at the center of the cell. Hence, a number of cells is dependent on the number of energy harvesting nodes and so for scalability it is a limiting parameter. In the minimax grid, initially energy harvesting nodes are deployed at the center of the cell for efficient energy consumption. Location of energy harvesting nodes is updated at the center of the smallest circle which encloses all nodes in the cell. Like regular grid, in minimax grid selecting the number of energy harvesting node is a limiting factor. To overcome this in k-medoids, BS is deployed at the center. Nodes which are in the range of BS can directly communicate with the BS and do not require energy harvesting node for communication. The network is divided into cells for remaining nodes. Using these three ways, the clustering is done and these approaches are compared with LEACH protocol. The mobile and heterogeneous nodes were considered in this algorithm. This work indicates that the **GW location** can be one more important parameter for efficient clustering algorithm.

Quantum-inspired Particle Swarm Optimization (QPSO) clustering algorithm for the capillary network is proposed by Song et al. [19]. It is assumed that all nodes are aware of their location and energy. In this algorithm, nodes are mobile and homogenous. QPSO works on the rotation angle and quantum bit technique. The algorithm is focused on both intra-cluster and inter-cluster energy consumption. Selection of CH is done depending on the fitness value. The node with highest fitness value is selected as CH. The fitness value is calculated based on the location and residual energy of a node. Every CH forwards data collected from cluster members to the GW. GW has two interfaces, one for connecting CH and other for the outside world. In the simulation, QPSO is compared with PSO, binary PSO, and quantum genetic algorithms. This algorithm indicates that the **inter-cluster communication** should be energy efficient to reduce the average energy consumption of the network.

Clustering for fault monitoring in the IoT network is proposed by Zhou et al. [20]. In this, CH selection is done based on the Traveling Sales Man problem, i.e., the node which is connected to a maximum number of nodes (node association) with minimum distance is selected as CH. CH works as a monitoring node for fault identification. Stationary and homogenous nodes are considered for clustering. Simulation results show the energy efficiency of the algorithm as communication cost is minimum using Traveling Sales Man technique. This algorithm indicates that the **node association capability** is also the designing parameter for a clustering algorithm.

Energy efficient clustering for WSN is proposed by Tsai and Chen [21]. The algorithm works in five following stages (1) virtual Id selection, (2) CH selection, (3) cluster setup, (4) schedule creation and (5) data transmission phase. In the first phase, virtual ids are allocated to each node. In this algorithm, all devices are GPS enabled for location information. CH is selected based on the residual energy and energy consumption required for data routing. Virtual Id is required to self-promote a CH. Stationary and heterogenous nodes are considered in the network. Simulation results compared with LEACH protocol and results show that energy consumption for clustering is less than LEACH protocol. This approach is not suitable for high node density networks as due to GPS requirement cost of the network will be high.

The joint clustering method for WSN is proposed by Xu et al. [22]. This joint clustering method uses a back-off timer and gradient routing for clustering. In this CH selection is dependent on the gradient information which helps inter-cluster communication, i.e. selected CH forms well-organized cluster and best path for inter-cluster communication. Here the static and homogenous nodes are considered for the clustering. Initially, all nodes transmit gradient information. The route is setup towards BS direction with the help of gradient information. Cluster diameter is dependent on the transmission range. Simulation results show that due to simultaneous CH selection and multi-hop routing, energy consumption is reduced thereby increasing the life of the network. This approach persists the limitations of gradient routing. This work indicates that the energy consumption could be reduced by using backoff timer. The **routing information** can be used as the parameter for CH selection.

Group-based mobility clustering mechanism is proposed by Kim and Lee [23]. In this work, homogeneous devices, i.e., devices having same characteristics are considered to form a cluster. Relay device, termed as mesh point, is used to extend network coverage. This work is targeted for IoT network. To realize IoT network practically and for flexibility, the clustering algorithm should support mobility. Hence, in this work, mobile mesh points are considered, but nodes are considered as stationary. Simulation results show the algorithm provides reliability, scalability and good coverage for mobile IoT network. This work concludes that the **mobility** is the primary parameter for clustering of the devices.

Distance-aware clustering protocol for WSN is proposed by Gautam and Pyun [24]. In this, the network is divided into two tiers: primary and secondary tier. The node with the highest energy and nearest distance from BS is selected as CH. CH of the primary tier collects data from non-CH nodes and CH nodes of the secondary tier. To increase network lifetime, the role of CH is kept rotating. Some number of CHs are selected depending on the residual energy of nodes. The decision to choose the number of CH needs to be selected dynamically depending on the number of nodes alive. The stationary and homogeneous nodes are considered for clustering. Simulation results show that the selected CH which is nearest to BS results in less energy consumption. The **distance between the CH and GW** can be a crucial parameter for clustering of the devices.

Cooperative clustering protocol for mobile and homogeneous devices is proposed by Vambase and Mangalwede [25]. The CH of Bluetooth PAN acts as a gateway between low-power Bluetooth network and high-power WLAN. The algorithm does not require any infrastructure changes because of this reason it is applicable to the practical scenarios. The implementation results show that the energy consumption is minimized using cooperative clustering protocol as Bluetooth is used for the intra-cluster communication. This approach limits the data transmission speed up to 2Mbps. The **energy consumption** parameter is used for the clustering of the devices.

Adoptive-parent-based clustering framework for ZigBee network is proposed in Huang et al. [26]. Cluster tree topology is suitable for low-power Zigbee network, but this topology couldn't satisfy the maximum data transmission requirement. To resolve the issue, in this work an adaptive parent-based clustering approach is proposed. The algorithm provides maximum data transmission capacity to the network nodes. When ZigBee router suddenly initiates data transmission, then it requires more data transmission capacity. Router asks for more data transmission capacity from adjacent relay and parent relay nodes to complete requirement. The analysis of this algorithm indicates that the **data transmission capacity** is also one of the design parameters for the clustering algorithm.

3.3. EVALUATION OF CLUSTERING MECHANISMS

In the literature, many promising mechanisms of clustering are presented for the WSN and IoT network. The focus of each mechanism is kept on one or two parameters of the clustering among the parameters: efficient energy consumption, prolonging network life time, reducing transmission delay and scalability support.

The clustering algorithm should consider one or more following design parameters while forming the cluster as these parameters greatly affect cluster formation and management. Among these some of the design parameters are selected based on the application requirement. Following design parameters have been evaluated from the literature analysis.

- **Residual Energy**: The energy consumption is the primary design parameter for the clustering algorithm. Most devices in the network can be battery powered hence clustering algorithm should not consume more energy of the devices. The energy of the CH degrades faster than other nodes because it is assigned to perform extra functionalities. The higher residual energy should be the parameter for the CH selection.

- **Uniform CH distribution**: Cluster formation using residual energy may result in the non-uniform distribution of the CH nodes. It may be possible that nodes having high residual energy may belong to the nearby locations hence one section of the network may get more number of the CH than the other section. The non-uniform CH distribution may lead to the less network life time.

- **Congestion**: The clustering algorithm should avoid congestion in the network. The CH of the cluster is required to perform data aggregation and verification of packets. The dead and big packet should be dropped to avoid congestion in the network. Lower node density clusters should be formed to reduce the computation burden and energy consumption of the CH.

- **Location of CH**: The location of the CH plays very important role in the cluster functioning. The CH should be equidistant or should be reachable in minimum distance from each member of the cluster. The CH situated at the corner/one end of the cluster may degrade energy of the nodes placed at the other end of the cluster.

- **Inter-cluster communication**: The inter-cluster communication, i.e., communication between CHs affects the average energy consumption and congestion in the network. The individual CH may connect to the GW/BS in the single/multi-hop approach. The more number of CHs should be selected in the section of the network near to the GW/BS to reduce congestion and energy consumption.

- **Node association capability:** The node having high node association capability with minimum distance should be selected as CH to reduce the average energy consumption of the network.

- **Routing information**: The clustering algorithm based on the routing information may reduce the average energy consumption by providing better inter-cluster communication.

- **Data transmission capacity Requirement**: The optimized usage of data transmission capacity is required in the high-density node networks. The clustering algorithm should fulfill the data transmission capacity requirement for low latency and efficient data transmission.

- **Mobility:** Mobility parameter focuses on the dynamic change of location of the nodes in the cluster. Cluster management is difficult for the clusters having mobile nodes because mobile nodes may leave or enter cluster at any time. Hence the clustering algorithm should support self-healing techniques.

- **Scalability:** Scalability shows the ability of the algorithm to work "efficiently" with increasing number of nodes in the cluster. By efficiently means, energy consumption, control overhead, and delay parameters should not increase abruptly with increasing number of nodes in the cluster.

3.4. SUMMARY

This chapter proposes the need for the organization of the devices. The type of the devices and cluster topology are also important parameters for designing the clustering algorithm as these affects greatly on the performance of the cluster. In the next section, the process of the clustering is discussed.

The analysis of different clustering algorithms in the literature is done to discover the design parameters for clustering algorithm. To achieve scalable, energy efficient and well-managed network the clustering algorithm should consider some design parameters like mobility, energy consumption, inter-cluster communication, uniform CH selection, the location of the CH, node association capability, data transmission capacity and the cost of the deployment.

In the research, energy consumption, uniform CH selection, node association capability and data transmission capability are considered as design parameters for clustering algorithm. The proposed algorithm is targeted to the network with mobile nodes because stationary nature of the nodes could limit the scope of the applications.

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CHAPTER 4. PROPOSED CLUSTERING MECHANISM

The proposed MACS algorithm and results of MACS for varying number of nodes in section 4.3.4 are presented in the article [5] (list of publication). In this chapter detail explanation of the MACS is done and results are extended.

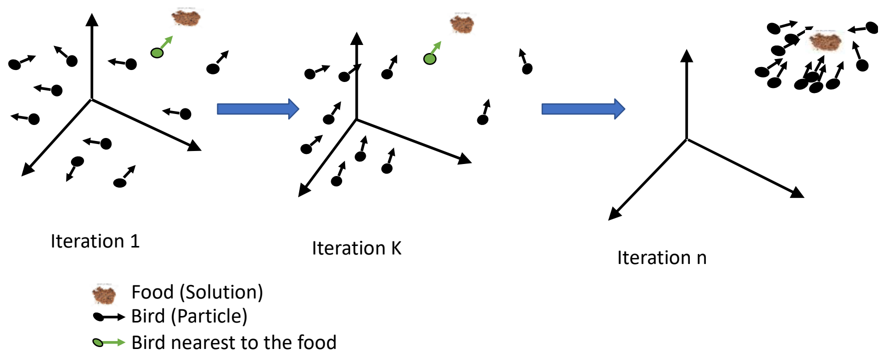
This chapter aims to propose mobility aware clustering mechanism. The devices in the network may change their location due to mobility hence, a self-configurable clustering algorithm is required in such environment. This section of the thesis provides details of the proposed clustering algorithm. The last section of this chapter presents results and concluding remarks about clustering algorithm. The results are drawn using NS-2 simulation tool.

4.1 MOBILITY-AWARE CLUSTERING SCHEME

In the initial phase, WSN was used to monitor environmental parameters like temperature, humidity, pressure and to respond accordingly [1][2]. However, with advancements in technologies, WSN is also used in the military surveillance [3][4][5], wild animal observation [6][7], forest surveillance [8][9], marine applications [10][11]. In some applications the deployment of devices/sensors, forming and managing clusters by the human is unfavorable e.g., sensors deployed in the dense forest area for collecting environment parameters. In such cases, the self-healing clustering algorithms are required. The critical evaluation of literature clustering mechanisms is done in Chapter 3, which concludes that there is a need for scalable, energy efficient and mobility aware clustering algorithm as these are fundamental requirements of the future network. In this research work, we propose the MACS to address the scalability, mobility, and energy consumption issues. The proposed clustering algorithm is based on PSO.

PSO technique is based on the birds flocking/fish schooling proposed by Dr. Eberhart and Dr. Kennedy [12]. The PSO analogy is similar to the behavior of birds to find the food. In the bird flocking scenario, the group of birds searching for food in the search area. The search area is with only one food being searched. All birds search the food by following the bird which is nearest to the food. All birds change their location and velocity according to the bird nearest to the food.

In the above scenario, the bird is a "particle" in the search area, searching for the solution, i.e., "food" by following the optimal path. The optimal path is calculated by updating their position and velocity. The solution is achieved in few iterations, as shown in figure 4.1. In each iteration, fitness of the particle is calculated and based on the fitness value particle updates it's velocity and position using the two best values i.e., *pbest and gbest*. The *pbest* is the best value that particle achieved so far, and *gbest* is the best value achieved by any particle in the search area. The fitness of particle is calculated using objective function i.e. the function which aims to find a solution.



The birds (particles) in the search area updates their position and velocity with respect to the particle nearest to the solution. After some iterations birds find a solution. The first, intermediate i.e k^{th} and last iteration i.e. n^{th} are shown in figure.

Figure 4-1 PSO working

The basic PSO works as follows [13]:

Step 1: Particle Initialization: the particles of the PSO are initialized with initial values i.e. position, velocity and memory to store pbest.

Step 2: Fitness Evaluation: fitness of the particle is calculated based on the objective function. The objective function is defined depending on the problem domain for which solution needed to be searched.

Step 3: Update personal and global best: based on the fitness value pbest and gbest are updated if current values are better than the previous values.

Step 4: Velocity and position update: the velocity and position of the particle is updated based on new values of the pbest and gbest using equation 4.1 and 4.2

Step 5: The step 2 to4 are repeated till solution is found or maximum iterations are achieved.

Step 6: The solution is achieved.

The velocity (displacement) of the particle is updated using the formula as follows [13]:

$$\vec{V}_{id}(t+1) = \vec{V}_{id}(t) + c_1 \times r_1 \times (pbest_{id}(t) - present_{id}(t)) + c_2 \times r_2 \times (gbest_d(t) - present_{id}(t)) \text{ ------------------ } (4.1)$$

where $\vec{V}_{id}(t)$ and $present_{id}(t)$ are the velocity and position of particle "i", in "d" dimensional space at time step "t" respectively.

The $pbest_{id}(t)$ is the best position of i^{th} particle in "d" dimensional space until time step "t". The $pbest_{id}(t) - present_{id}(t)$ is the cognitive component that keeps the best position of the particle and hence in the iterations particle can return back to its best position [13].

The $gbest_d(t)$ is the best position of the any particle in the group in "d" dimensional space until time step "t". The $gbest_{id}(t) - present_{id}(t)$ is the social component, that keeps the best position of the particle in the group that is nearest to the solution.
The individual particles can move towards the solution with the help of the social component and cognitive component.
The cognitive and social components are weighted using c_1 X r_1 and c_2 X r_2 [13]. The r_1 and r_2 are random number between (0,1) and c_1, c_2 are learning factors.

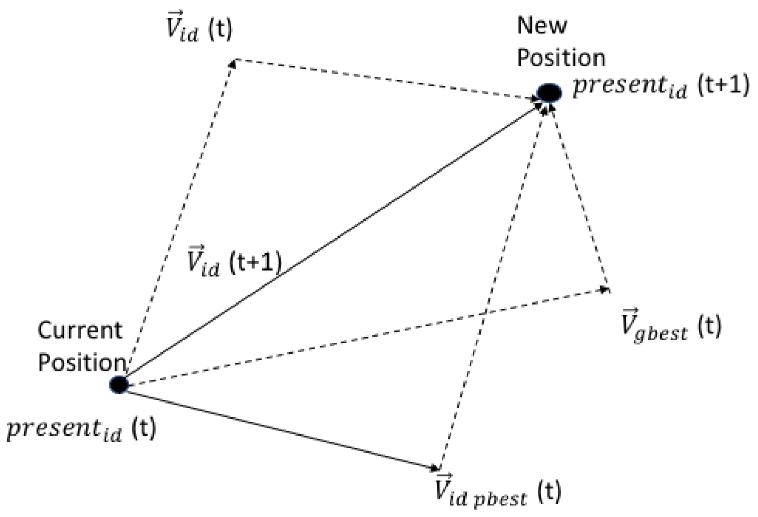
Position shift $\vec{\Delta}_{id}$ is the displacement during unit time T, it can be calculated as follows:

$$\vec{\Delta}_{id} = \vec{V}_{id}(t+1) * T$$

The position of the particle is updated using the previous position and position shift as follows [13]:

$$present_{id}\ (t+1) = present_{id}\ (t) + \ \vec{\Delta}_{id} \text{------------} \ (4.2)$$

where the $present_{id}$ (t+1) and $\vec{V}_{id}\ (t+1)$ are the new position and velocity of the i^{th} particle in "d" dimensional space in the time step t+1. Figure 4.2 shows the concept of PSO particle position change in the graphical format.



The PSO particle updates its position based on the its own best velocity i.e. $V_{id\ pbest}$ and velocity of the particle nearest to the solution i.e $V_{gbest.}$

Figure 4-2 Position update

PSO has been used widely in the field of WSN [14][15][16][17]. Different variations of PSO have been evaluated by Kulkarni and Venayagamoorthy [18] in which advantages and limitations of PSO are presented. PSO can be useful for resolving issues of WSN i.e. node localization, data aggregation, energy efficient clustering, etc.

In the proposed MACS, PSO is used to organize devices in the cluster with a few assumptions as follows:

Assumptions:

1) The devices are assigned with initial values for a few parameters: initial energy, location, transmission power, reception power.
2) Devices are considered as mobile.
3) Gateway is considered as stationary.

Devices are grouped into the clusters depending on the position and the fitness value. The objective function calculates fitness value of the device based on the Node life time (NLT), the Residual Link Data transmission Capacity (RLDC) and Link association time (LAT). In MACS, PSO is used to find the device with higher NLT, RLDC and LAT.

In the literature, different clustering algorithms are proposed. The literature PSO based clustering algorithms have used different parameters for clustering e.g. distance between nodes [16] link quality, node residual energy, network coverage [15], number of nodes in the cluster, distance between CH and BS [19]. In the MACS NLT, RDLC, LAT are used for clustering, the efficient energy consumption of the network can be achieved using parameter LAT and RDLC parameter improves the packet delivery ratio of the network. These parameters are discussed in the next section

4.2 MACS PHASES

The MACS works in two phases: an initial setup phase and a cluster formation phase.

Initial setup phase: The devices are assigned with initial values for a few parameters: Energy, location, and velocity. Each device has a memory to store its location and all other parameters. Initially, each node broadcast *"hello packet"*, this packet contains node id, location and velocity. After receiving "*hello packet*" nodes create the neighbor table, in this neighbor node's id, location i.e. x and y coordinates and velocity are stored. The "hello packets" are periodically exchanged i.e after "*hello interval*" and the neighbor table is refreshed by removing/adding nodes, as nodes may change their location due to mobility or may die due to power drain. Subsequently, GW node broadcast it's location and ID in the network and all nodes store details of the GW. After fixed period i.e. "*clustering interval*" all nodes in the network creates association messages, it contains node id, it's location, velocity, NLT, RDLC and LAT. Each node broadcast association packet in the network and stores the details of association messages transmitted by other nodes, i.e. "*node_list_table*". Every node calculates the NLT, RDLC and LAT after "hello interval" i.e. t and updates these parameters. These parameters calculated as follows:

RDLC computation: Initially the data transmission capacity is assigned to each device in the network i.e. link Capacity (LC) [20][21]. The RDLC is calculated from the link capacity used by current data transmission and LC of the device.

The link capacity used by current data transmission i.e. consumed link capacity (CLC) is estimated as follows:

$$CLC_t = \frac{N \times L}{T}$$

Where N is the number of Packets,

L is the length of packet in bits

T is the unit Time

The RDLC of link is calculated as follows:

$$RDLC_t = max(0, LC - CLC_t)$$

NLT computation: The device energy is consumed mainly due to the data transmission/reception. The node is said to be alive till it has sufficient energy to operate. Otherwise, it is a "dead" node. The NLT is the time from when it is deployed to the time till node is dead [22]. NLT can be calculated depending on the remaining energy of a node and the node's Energy Reduction Rate (ERR).

In the real-time scenario, some operations are performed by a device which consumes energy, i.e., sensing, transmitting, receiving parameters, switching from active to the sleep mode and vice versa. The amount of energy required to switch between Active mode to sleep mode is represented by EA_s. The amount of energy required to switch between sleep mode to Active mode is represented by ES_A. The amount of energy required for parameter sensing, transmitting and receiving operations are represented by E_S, E_T, E_R respectively. The Energy Consumption (EC) of the node can be calculated as follows:

$$EC = EA_s + ES_A + E_S + E_T + E_R$$

The Residual Energy (RE) of node can be calculated based on initial energy (IE) and energy consumed as follows:

$$RE_t = IE - EC$$

In MACS, E_T is initialized as 0.02mW and E_R is initialized as 0.01mW [23]. The EA_s, E_S, and ES_A are not considered or assumed to be negligible [24].

The NLT of the node depends on the ERR, it is the energy consumed by the node per unit time (T) and is calculated as follows:

$$ERR = \frac{(IE - RE_t)}{T}$$

The NLT is calculated as follows:

$$NLT_t = \frac{RE_t}{ERR}$$

LAT computation: In the IoT applications, devices may be stationary or mobile. In latter case, devices can make/break the connection among them based on the distance and velocity. LAT is the time spent by the device being associated (linked) to another device. LAT is calculated based on how much time devices can be connected to each other despite the mobility. LAT is calculated for each neighbor (connection) the node has and it is calculated using neighbor node direction, distance the node can travel and the relative speed between both nodes, as follows:

The node direction can be estimated using velocity vector of the node. It can be decomposed into a parallel and a perpendicular component. The direction can be find by the component of the neighbor velocity vector that points in the same (or opposite) direction of the node velocity. The distance that nodes can travel is calculated using the euclidean distance *formula and the* node coordinates that are stored in the *node_list_table. The Relative Speed (RS) is calculated based on the direction of the nodes.* If both nodes have same direction, then relative speed can be calculated by taking speed difference of both nodes and in the case of different direction relative speed can be calculated by taking sum of speed of both nodes, as follows:

$$RS = \begin{cases} Nspeed - NGspeed & if\ nodes\ have\ same\ direction \\ Nspeed + NGspeed & else \end{cases}$$

The LAT is calculated as follows:

$$LAT_t = \sum_{i=0}^{CN} \frac{Distance_i}{RS_i}$$

Where CN is the total number of neighbor nodes

NG is a neighbor node

N_{speed} is the speed of the node

NG_{speed} is the speed of the neighbor node

$Distance_i$ is the distance node can travel

Finally, the average LAT for node is calculates as follows:

$$LAT_{avg} = LAT_t/CN$$

Cluster formation phase*:* In this phase, clusters are formed on the basis of device position and fitness value. The fitness value of the node represents the capability of the node with respect to it's residual energy, the node association capability and the available data transmission capacity. Every node is initialized with the swarm particles i.e. every node has the *node_list_table* and PSO is applied using objective function of MACS. The nodes update their velocity and position using pbest and gbest that are achieved in the iterations.

The fitness values (FV) are calculated using the objective function of the MACS in each iteration "k" is as follows:

$$FV_k = (\alpha_1 \times NLT) + (\alpha_2 \times RDLC) + \left(\alpha_3 \times LAT_{avg}\right) \text{------ (4.3)}$$

Where α_1*,* α_2 *and* α_3 *are* weight values and values of the LAT, NLT and RDLC are retrieved from the association messages.

The node has attribute "*pbest*" holding best fitness value got so far and "*gbest*" attribute holds best value got by any node in the iteration. In each iteration, if the new calculated FV is better than previous value then the "*pbest*" of the corresponding node and "*gbest*" are updated. The position and velocity of the particles are updated in each iteration based on equation (4.1) and (4.2), here c1=c2=2 [25][26][26][27]. *The MACS aims to find node with higher* *fitness value i.e. node with high link association capability, residual energy and available bandwidth. In the fitness function,* weight values α_1, α_2 *and* α_3 *are used to maximize the objective parameters i.e., NLT, RDLC, LAT respectively and* the summation of the weight values are kept as 1 [28]*. In the MACS, the NLT parameter is considered as major affecting factor in clustering than LAT and RDLC, as network life time is dependent on the node life time. Hence, weight value for NLT is taken higher than LAT and RDLC. To summarize, the objective of equation 4.3 is to maximize the performance parameters viz. NLT, LAT and RDLC, therefore they are being multiplied in the order of higher to lower as* α_1, α_3 *and* α_2 *i.e.,* $\alpha_1 = 0.4$, $\alpha_3 = 0.33$, *and* $\alpha_2 = 0.27$ *respectively.* The simulation is rerun with different variations of weight values for α_2, α_1 *and* α_3 the values providing best results are finalized. These values may vary depending on the network environment parameters.

After the end of all iterations, nodes with best fitness values are selected. Few nodes among these are selected as a CH, based on their location to achieve uniform distribution of the CH.

The algorithm of clustering devices using MACS is summarized below, and the flow of events is depicted in the figure 4-3. Initially, GW node broadcasts its location and id, all nodes in the network store this information. The association packets will be created by each device in the network. Further, each node in the network broadcasts the association packet and stores the parameters forwarded by other nodes in the network i.e. node_list_table. The node is initialized with particles using node_list_table and PSO is applied. The fitness value is calculated using objective function i.e. equation 4.3 based on these parameters, i.e., NLT, RDLC, LAT. The pbest, gbest are updated if the new values are better than the previous ones. This process is repeated for some iterations to find the node having the highest fitness value. Finally, the list of nodes is sorted with highest to lowest fitness value. The node with highest fitness value forms the cluster of nodes under its coverage. The Cluster Members (CMs) of newly formed cluster are removed from the sorted list to achieve uniform CH distribution and to avoid overlapping clusters. Hence it may be possible that a node with higher fitness value becomes CM due to its position. Then the sequentially next node in the sorted list (list with removal of CMs) forms the cluster of nodes under its coverage and process continues till all nodes gets clustered.

The number of clusters i.e. value of "p"depends on the fact that no node or less number of nodes remain un-clustered. Hence, the value of "p" varies based on the number of nodes in the network, CH location and density of nodes under coverage of selected CH. The clusters are formed for each CH and cluster information is broadcasted to all CMs. Acronyms used in the figure 4-3, *K: number of iterations, P: number of clusters to form*.

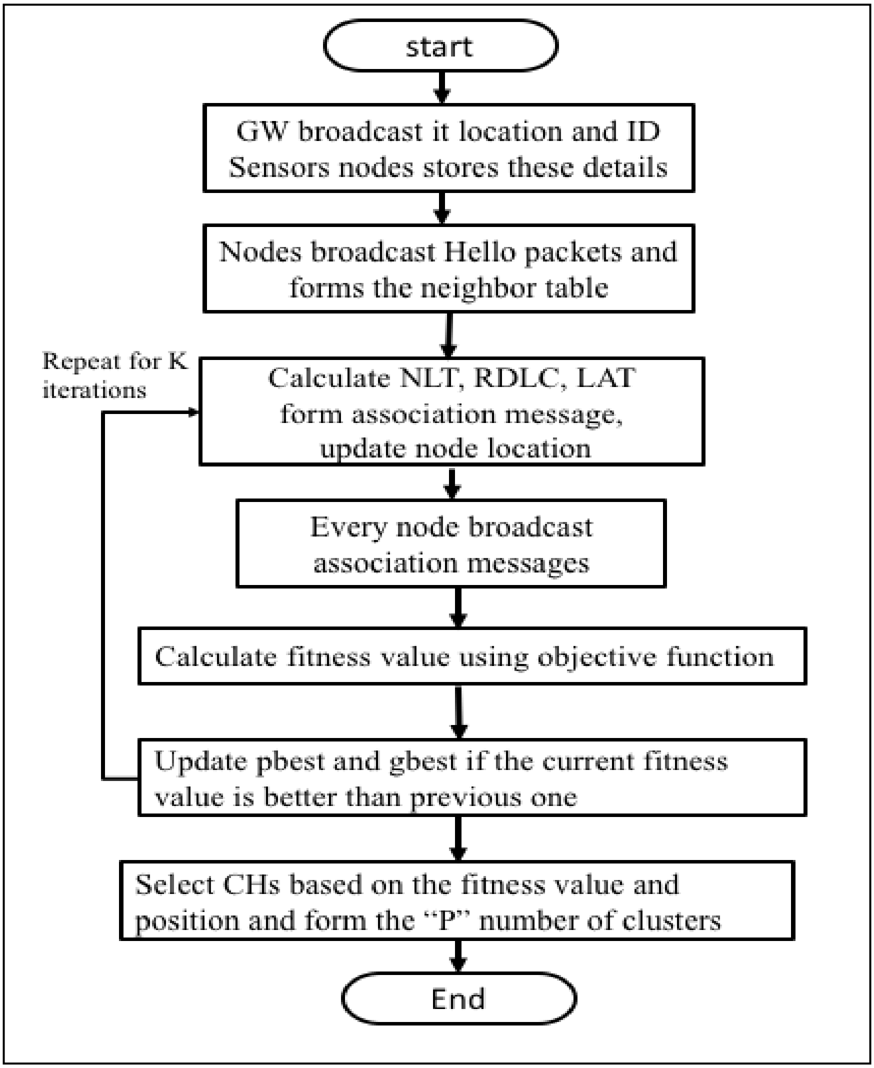


Figure 4-3 Clustering of algorithm - flow of events

4.3 RESULTS AND DISCUSSION

Simulation tools are useful to analyze the behavior of the system under different conditions. In simulation, we can set initial values for sensor nodes and different network parameters. The MACS algorithm is simulated using the NS-2 simulator tool. In NS-2 we can configure parameters for devices, e.g., device location, initial energy, the energy required for transmission and reception. We can also configure network environment parameters, e.g., data packet size, the protocol used in MAC layer, queue length, simulation area, simulation time, transmission coverage, etc. Algorithms can be executed using the simulation for different parameters and scenarios to verify its performance.

4.3.1 NS-2 SIMULATION TOOL

NS-2 has five components: script file, scenario file, main code file, output trace file and an animation file [21].

Script files: These are with the extension ".tcl" and provide the parameters to the main code file, i.e., simulation area, the number of devices, simulation time, type of data packets, queue length, time to start and stop the simulation.

Scenario file: The initial location of devices is specified in this file, and it is taken as an input file for simulation execution. Simulation can be rerun for different configuration by varying scenario files.

Main Code file: This file contains the implementation code. It has an extension of a programming language, e.g., ".cpp".

Output trace file: The output file is generated after execution of the simulation that contains the trace of simulation. The trace file contains a log of the simulation. The log contains: the time when a packet is sent from the device, type of a packet, energy of the device, location of the device and so on. This file has the extension ".tr". We can verify the performance of the algorithm by calculating throughput, data transmission delay, and other performance parameters based on the log [29].

Animation file: This file is generated with an extension ".nam". This file is the graphical representation of the algorithm. Devices are displayed using circles with it's id. We can visualize and verify the algorithm behavior using this file.

4.3.2 PERFORMANCE PARAMETERS

MACS performance is verified for parameters like delay, Energy Consumption (EC), Packet Delivery Ratio (PDR) and Control Overhead (COH) [21].

Delay*:* Delay is the time difference between the packet sent from the source device to the time it is received at the destination. Delay should be minimized for better performance of the system. The throughput of the network will be reduced with increase in the delay.

EC*:* The device energy is consumed mainly due to the data transmission/reception. Energy consumption of devices should be minimized to increase the lifetime of the network.

PDR*:* Data packets are dropped due to congestion in the network that results in system performance degradation. PDR is based on the number of packets received out of a number of packets sent. PDR is expected to be high for better performance of the system.

COH*:* The two types of packet are transmitted in the simulation i.e. data packet and control packets. The control packets are transmitted to manage the network e.g. "association packets" broadcasted by GW containing its location and node id, "hello" packets broadcasted by each node and GW for refreshing routing table entries, link failure message packets, route request packets etc. These consume the node energy and network bandwidth which results in the overhead. COH should be minimized for better system performance.

4.3.3 SIMULATION RESULTS

The proposed MACS algorithm is executed for four different scenarios as follows:

1. Varying number of nodes: The number of devices in the simulation is changed and simulation is executed to verify the scalability support of the MACS algorithm.
2. Mobility: Device mobility makes cluster organization difficult and affects the cluster performance. In this, two scenarios are analyzed and compared to verify the effect of mobility i.e., scenario with stationary devices and scenario with mobile devices.

3. Varying GW location: The location of the GW immensely affects the performance of the system. The correct location of GW could be finalized for better performance by verifying the performance of the MACS for different locations of GW. It will help to deploy GW in real time. In this, two scenarios are analyzed and compared to verify the effect of GW location i.e., scenario with GW at center of network and GW at the corner of the network.
4. Proposed MACS is compared with one of the clustering protocol based on the PSO i.e. Particle Swarm Optimization Protocol for Hierarchical Clustering (PSO_HC). Both protocols are simulated for similar parameters and results are verified.

Simulation is done with following simulation parameters, shown in table 4-1:

The simulation area is taken 500 X 500m to verify the scalability support of the MACS. Simulation is executed for 200 seconds as in this duration significant changes are observed in the network. In simulation, a random mobility model is used, i.e. random speed in the range of 1-5 m/s are used for mobility of nodes. For setting wireless network, the communication channel is considered as a wireless channel, the two-ray ground type of radio propagation and constant bit rate traffic model with UDP protocol are used [30][31][32][33]. The 802.11 is used as MAC protocol and a queue length of 50 packet size is considered.

Simulation Parameter	**Value**
Simulation Area	500 x 500 m
Simulation Time	200 s
Mobility Model	Random
Number of Nodes	50,75,100,125
Radio Propagation model	TwoRayGround
Channel	WirelessChannel
Transport layer protocol	User Datagram Protocol (UDP)
Traffic model	Constant Bit Rate (CBR)
Initial Energy	100 J
Transmitting Power	0.02 mW
Receiving Power	0.01 mW
Queue Length	50
MAC Protocol	802.11

Table 4-1 Simulation parameters

4.3.4 RESULTS FOR VARYING NUMBER OF NODES

Initially, the MACS is executed for 50 devices with hierarchical network topology and its performance is verified by analyzing parameters like delay, PDR, COH and EC. In the IoPTS environment, a large number of devices will be deployed. Hence MACS' performance should not be degraded with the increasing number of devices in the network. To verify the scalability support, MACS is executed by varying number of nodes in the network, i.e., 75, 100 and 125 with simulation parameters as Table 4-1.

The delay, EC, PDR and COH are calculated by applying the equations in Appendix A on the "out.tr" file. When increasing the number of nodes, the number of data and control packets will increase which results in higher EC, COH and delay. However, simulation results of the MACS mechanism show that EC, delay, and

COH do not increase dramatically with increasing number of nodes, a small increment is observed. PDR is not degraded significantly with increasing number of devices in the network, only a small decrease in the PDR is observed. Simulation results show that the performance of MACS is consistent even though the number of nodes is increased. Simulation results are represented by plotting the graphs:

In figure 4-4 to 4-7, the number of nodes is on the x-axis and delay, EC, COH and PDR on the Y-axis, respectively.

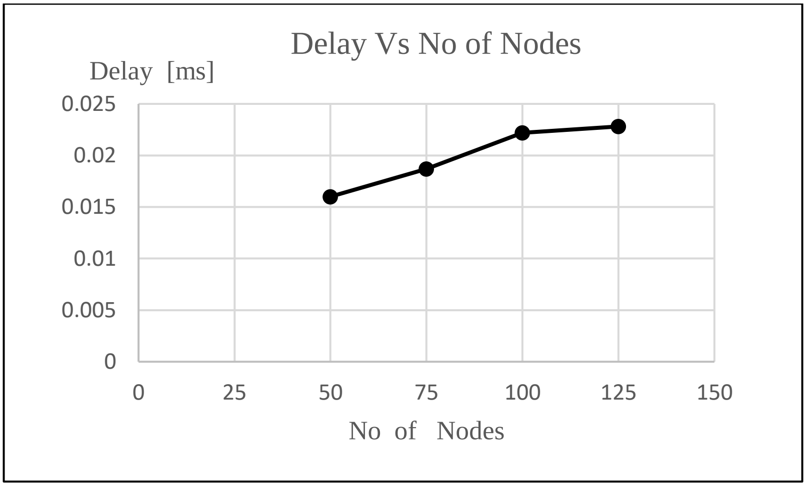


Figure 4-4 Delay Vs Number of nodes

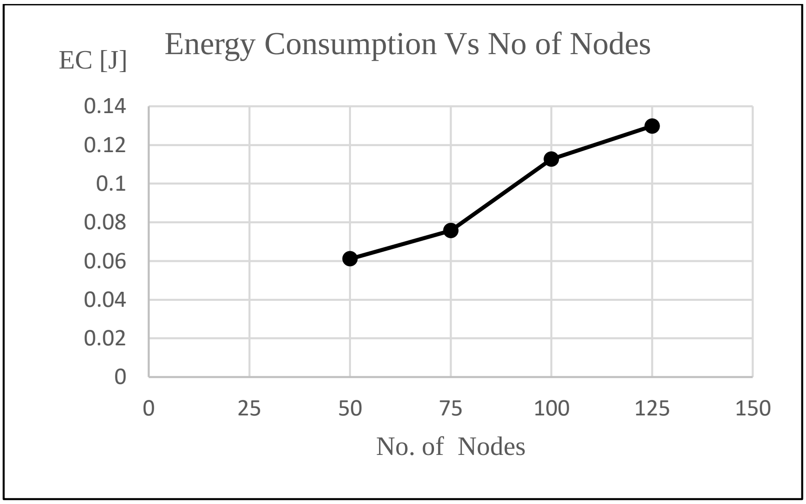


Figure 4-5 Energy consumption Vs Number of nodes

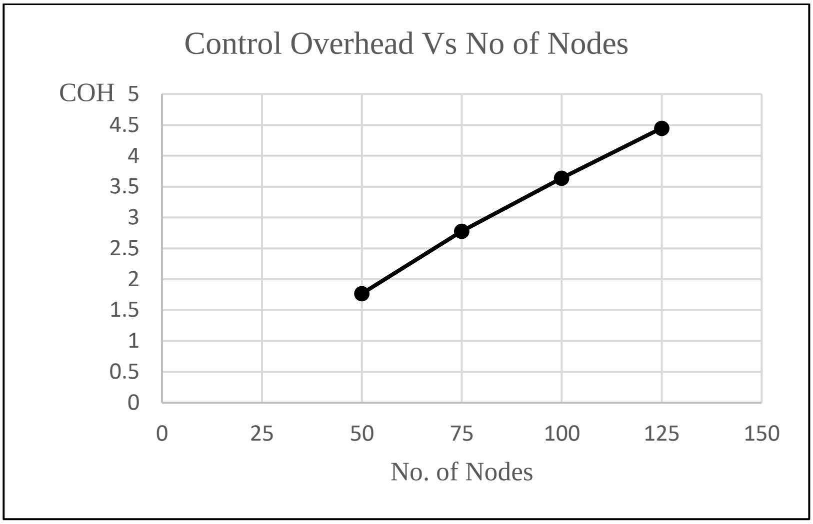


Figure 4-6 Control overhead Vs Number of nodes

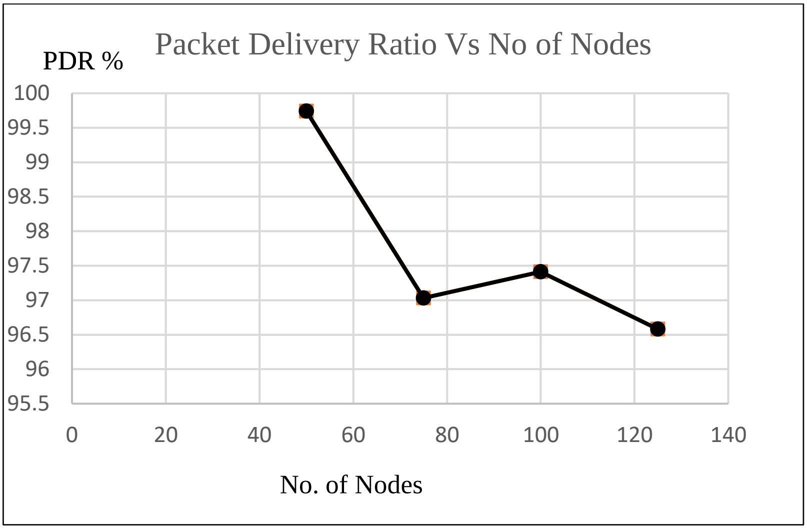


Figure 4-7 Packet delivery ratio Vs Number of nodes

4.3.5 RESULTS FOR STATIONARY VS MOBILE NODES

Simulation is executed for the case of stationary nodes and results are compared with mobile devices scenario. Simulation parameters are presented in Table 4-1, for the mobile node scenario random mobility is used and for stationary scenario nodes are considered as stationary, i.e. no mobility. Simulation is re-run by varying the number of devices in the network: 50, 75, 100 and 125. The simulation results compared by calculating parameters delay, EC, COH and PDR are explained in the above section. Simulation results show that the MACS works more efficiently in the network with stationary devices than a network with mobile nodes. In the scenario with stationary devices, LAT of node is based on the node density near the node, it may be possible that some nodes are having larger number of the neighbor nodes than other ones. In the scenario with mobile nodes, rerouting may be required frequently due to change of node location, it will lead to an increase in packet drop, COH, EC, and delay. However, simulation results show that comparatively, MACS performance does not degrade too much with mobile devices. This shows the suitability of MACS in the mobile IoPTS scenario. Simulation results are shown as follows:

In figure 4-8 to 4-11, the number of nodes is on the x-axis and delay, EC, COH and PDR on the Y-axis respectively.

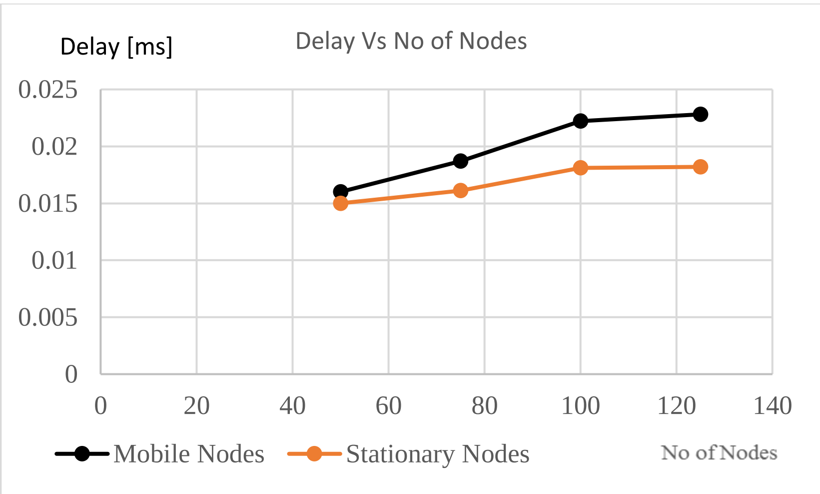


Figure 4-8 Delay: Stationary Vs Mobile devices

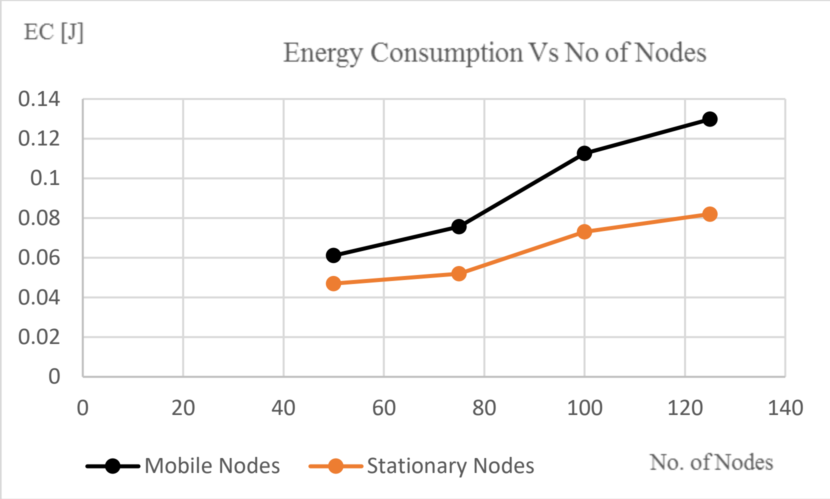


Figure 4-9 Energy consumption: Stationary Vs Mobile Devices

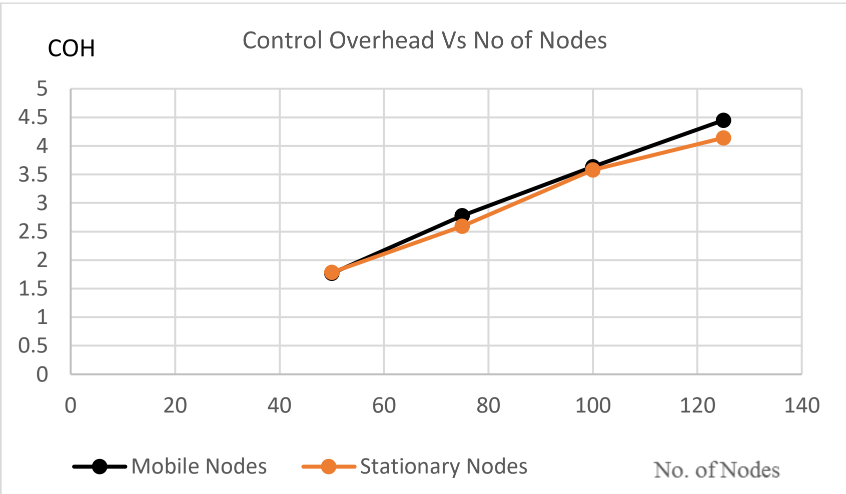


Figure 4-10 Control overhead: Stationary Vs Mobile Devices

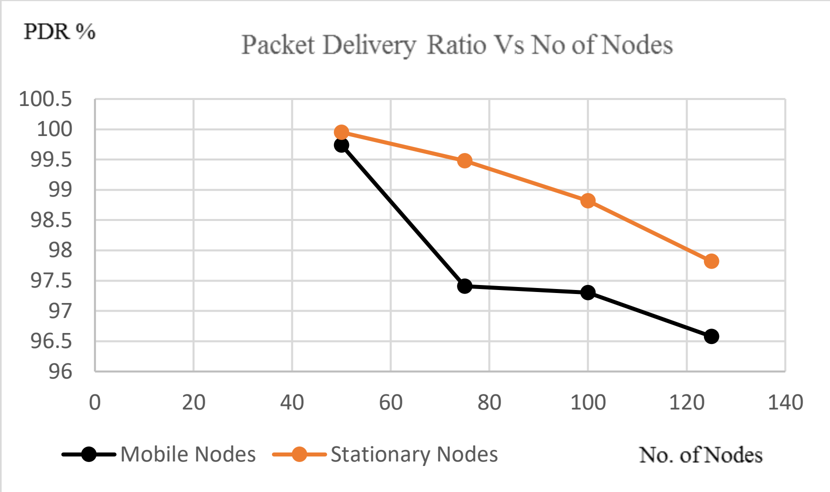


Figure 4-11 Packet delivery ratio: Stationary Vs Mobile Nodes

4.3.6 RESULTS OF VARYING LOCATION OF GW

GW location affects the network performance. If GW is situated at a long distance from the CH, then the CH will degrade its energy faster as long-distance data transmission will consume more energy. Simulation is run for two different scenarios: GW is located at the center of the network and at the corner of the network. Simulation parameters are presented in Table 4-1, Simulation results show that MACS performs better in the scenario where GW is situated at the center as it is approximately equidistance from all CH. Simulation results are shown as follows: In figure 4-12 to 4-15, the number of nodes is on the x-axis and delay, EC, COH and PDR on the Y-axis respectively.

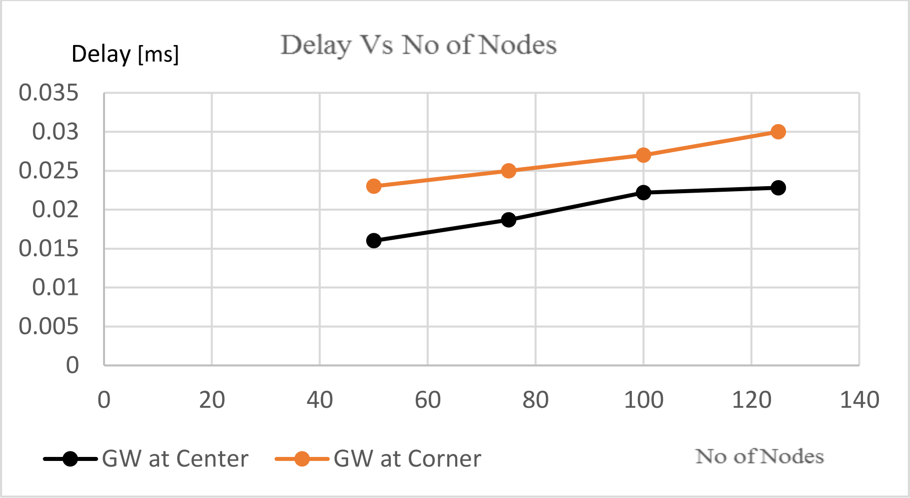


Figure 4-12 Delay: GW located at center of the network Vs at corner

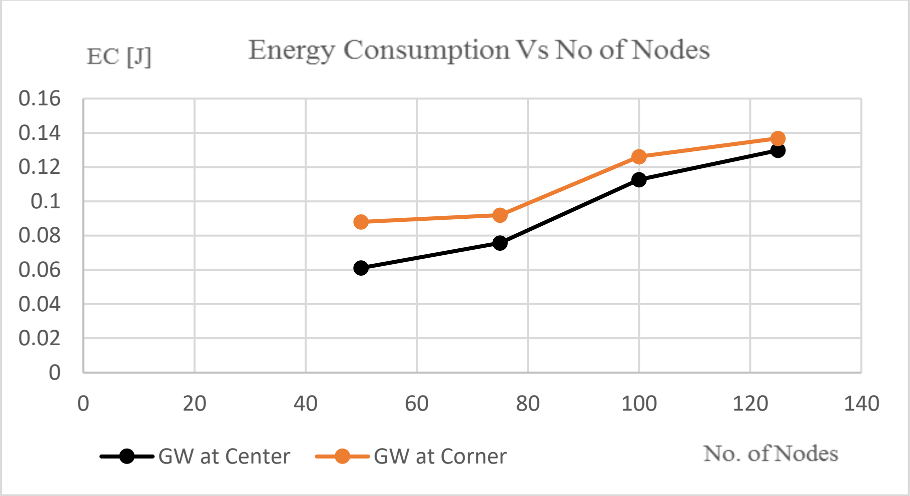


Figure 4-13 Energy consumption: GW located at center of the network Vs at corner

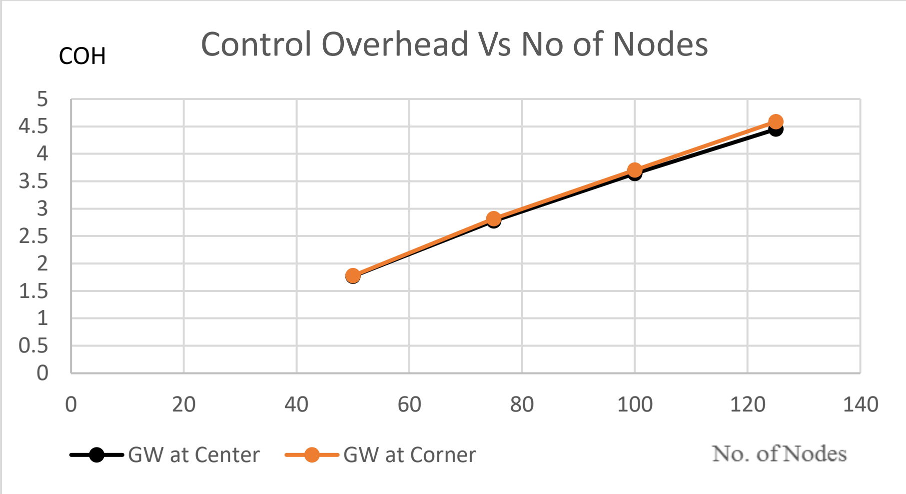


Figure 4-14 Control overhead: GW located at center of the network Vs at corner

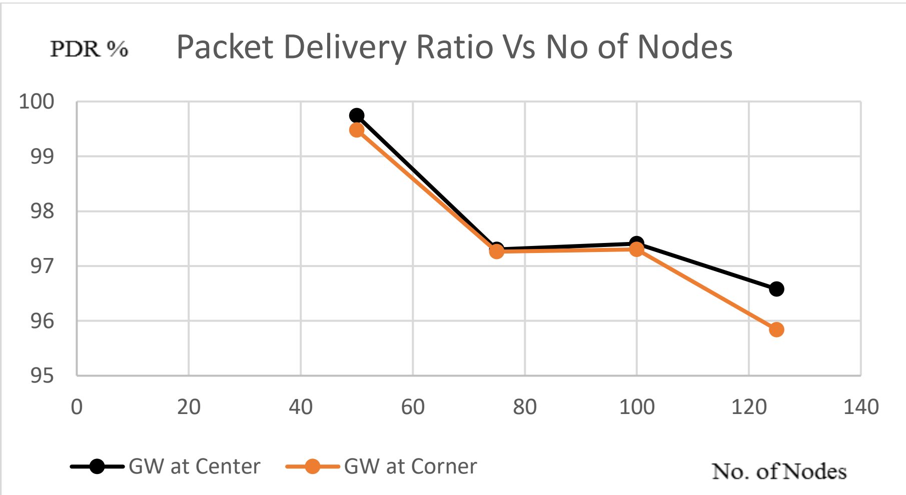


Figure 4-15 Packet delivery ratio: GW located at center of the network Vs at corner

4.3.7 COMPARISON OF MACS AND PSO_HC

The performance of the MACS mechanism is compared to the Particle Swarm Optimization Protocol for Hierarchical Clustering

(PSO_HC) [34], a centralized PSO-based hierarchical clustering protocol for WSNs. The PSO_HC minimizes average energy consumption by selecting the optimal number of CHs. As the CHs are constantly active and hence minimizing the number of CHs can reduce the energy consumption and increase the network lifetime. Furthermore, PSO_HC maximizes scalability and the network coverage by two-hop clustering to resolve the limited transmission range problem. In PSO_HC, the fitness value is calculated based on the two parameters i.e. energy efficiency by minimizing the number of CHs, and link quality.

In the PSO_HC protocol, the energy efficiency (EE_p) and cluster link quality (CQ_p) are used as parameters in the objective function to select the CH. The objective function of the PSO_HC is as follows:

$FV = \left(wc_1 \times EE_p\right) + \left(wc_2 \times CQ_p\right)$-------- (4.4)

In PSO_HC, it may be possible that multiple devices with high residual energy belong to the same section of the network. Hence, it may result in a non-uniform distribution of CHs that leads to more energy consumption of the network. However, in the MACS, uniform distribution of CH is achieved as CH selection is done on the basis of location and fitness value. Therefore, the distance between CH and CM nodes is less. In the MACS protocol, EC is reduced due to short distance packet transmission as the distance between CH and CMs is shorter. Moreover, in PSO_HC the link association time is not considered hence more packet loss may occur as compared to MACS.

The simulation is run for both clustering algorithms i.e. PSO_HC and MACS with 50, 75, 100 and 125 devices. Simulation results are shown in figures 4-16 to 4-19. Simulation results show that the MACS is more efficient concerning EC, PDR, delay and COH than PSO_HC protocol. Simulation graphs are as follows:

In figure 4-16 to 4-19, the number of nodes is on the x-axis and delay, EC, COH and PDR on the Y-axis respectively.

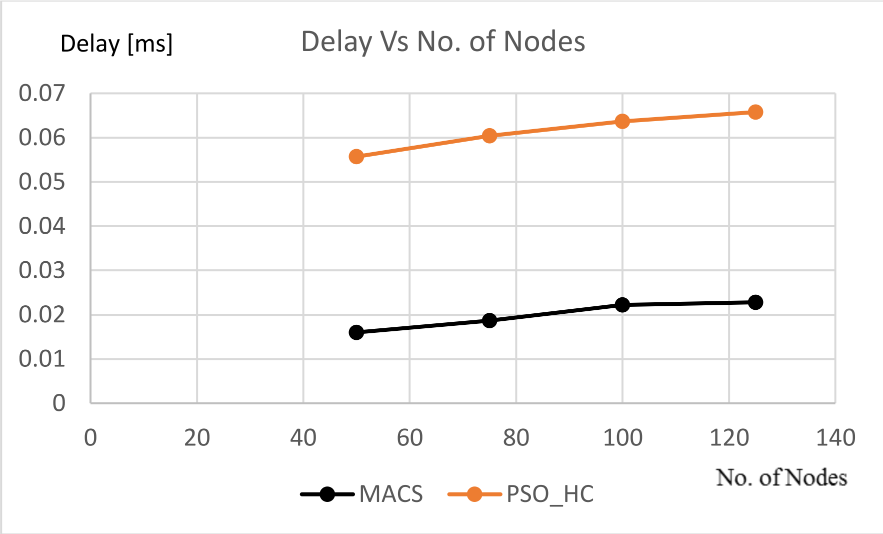


Figure 4-16 Delay: MACS Vs PSO_HC

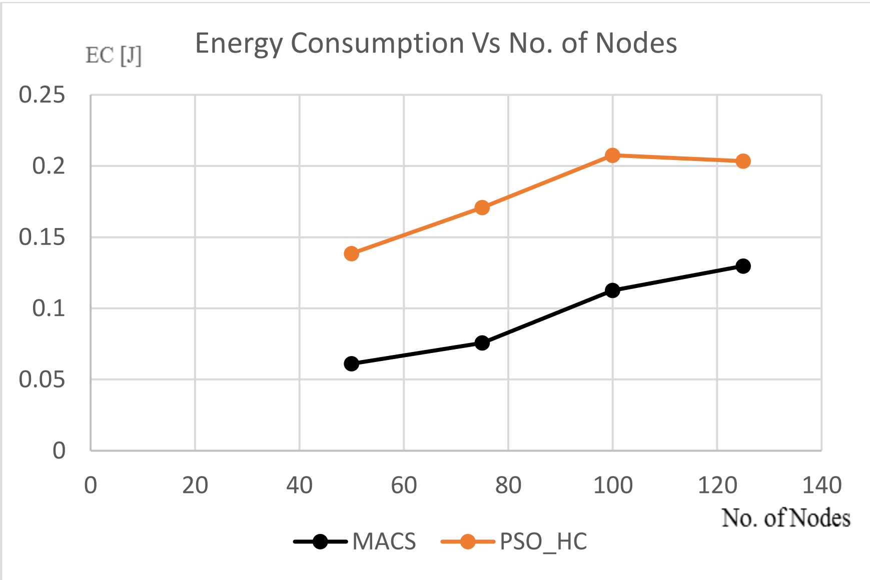


Figure 4-17 Energy consumption: MACS Vs PSO_HC

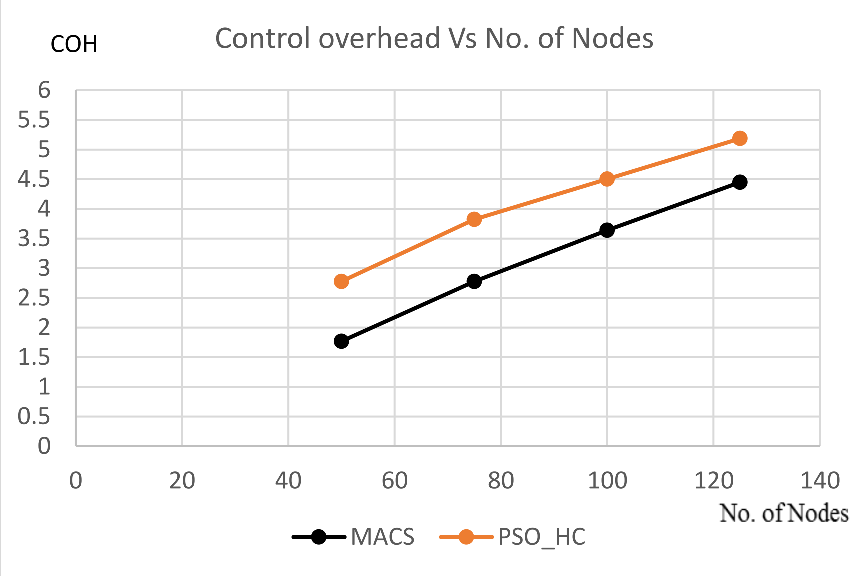


Figure 4-18 Control Overhead: MACS Vs PSO_HC

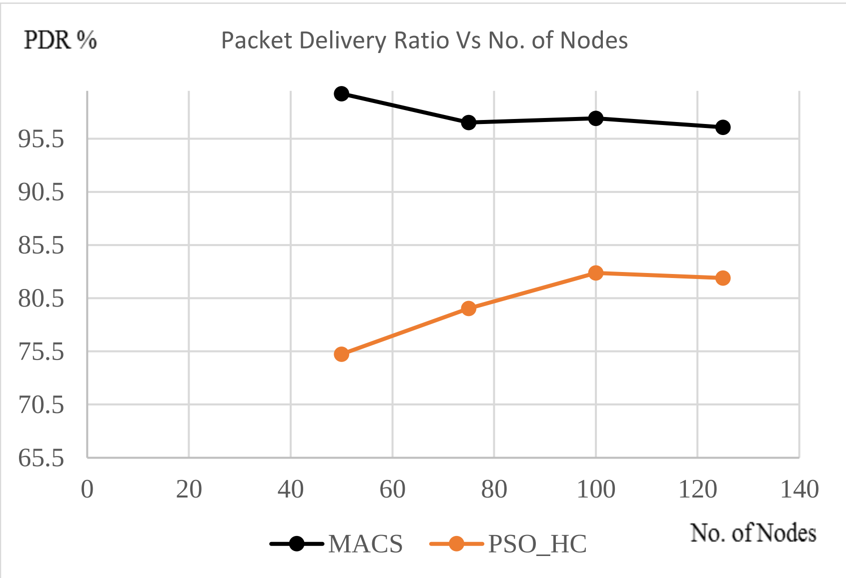


Figure 4-19 Packet Delivery Ratio: MACS Vs PSO_HC

4.4 SUMMARY

Organization of mobile devices is a difficult process and hence it is a big challenge to develop a mechanism to support mobility. Approaches evolved so far for clustering of devices suffers from one or more anomalies, and hence the problem of designing scalable, mobility aware and energy efficient clustering is far from being resolved.

The MACS is proposed in this chapter to address scalability, mobility and energy consumption issues of the network with resource-constrained devices. The proposed MACS scheme is based on the multi-variable fitness function for cluster formation. The performance of MACS is verified by four different scenarios for scalability and mobility support. The location of the GW plays an important role in the network and hence the MACS performance is verified by changing the location of the GW.

The simulations results show that the MACS scheme support mobility, and it is an energy efficient mechanism for clustering devices.

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CHAPTER 5. SERVICE ADVERTISEMENT AND DISCOVERY

The BLE advertisement frame format in section 5.2.1 is published in the paper [4] (list of publications) where BLE frame format was discussed to design service advertisement mechanism for IoPTS. In this chapter, we discuss two different BLE frame formats, i.e., ibeacon and Eddystone for designing proposed profile aware advertisement mechanism. The part of literature survey of service discovery mechanisms in section 5.3.2 is published in the paper [3] (list of publications). In this chapter, we also analyzed literature of service ranking mechanisms.

This chapter aims to discuss the overview of service advertisement and service discovery mechanisms. The different service advertisement mechanisms are evaluated based on the communication technology and energy efficiency. BLE is used in the proposed work based on this analysis. In the next section, the details of the BLE advertisement frame is presented. In the second part of the chapter, service discovery process is discussed and different service ranking mechanisms are evaluated. The need of personalization for service discovery is invoked based on this evaluation. The different design parameters for service advertisement and discovery are finalized based on this evaluation.

5.1. SERVICE ADVERTISEMENT

In the beacon/cluster-based approach, services are advertised using BLE device and the user must discover these services to get the benefit of them. In this, BLE device discovery process is used for service discovery. The device discovery is a two-way process in which the IoT device must announce its existence, and user device should discover services by scanning the advertisement frames [1]. The detailed survey of service advertisement mechanisms is done in the next section to understand the pros and cons. This review of different mechanisms will guide to choose appropriate service advertisement parameters for IoPTS application.

5.1.1. LITERATURE OF SERVICE ADVERTISEMENT MECHANISMS

In the literature, communication technologies like Wi-Fi [2], Wi-Fi aware [3], Zigbee [4], Bluetooth and BLE [5] are used to advertise services. In the literature, most of applications used Wi-Fi for service advertisement due to long range transmission capability. Wi-Fi enabled devices can connect to the internet using access point or hotspot. It operates at ISM 2.4GHz and 5GHz frequencies and the data rate for communication is 54Mbps [6][7]. The typical communication range is 50m for indoor applications and 100m for the outdoor applications. Wi-Fi is a cost-effective and most popular solution due to Wi-Fi alliances to run an interoperability programs on devices. It uses star topology where the center node is the internet GW.

Wi-Fi device scans other devices to establish a connection. Two types of scanning methods are used in Wi-Fi, i.e., passive and active scanning. In the passive scanning, the device scans for probe request or beacon frame from another device/AP. In active scanning device transmit probe request and waits for a probe response from the AP. Probe request may be unicast/broadcast. In both types of scanning, active scanning is faster; however, it consumes more energy than passive scanning.

The Wi-Fi passive scanning based device advertisement is proposed by Lu et al. [8]. Wi-fi operates in two modes: ad hoc and infrastructure mode. In this work, ad hoc operating mode is used as it doesn't require infrastructure support. The device broadcasts beacon to announce their existence. Here stuffed beacons are used and the information about the application running on the devices is stuffed into the beacon. A peer could get information of application on the device without connecting to it, i.e., profile awareness is supported by this mechanism. The peer device can decide on setting data connection with the advertiser device depending on the application information. This work indicates that advertisement process should have a mechanism to provide additional information about the service, depending on the service information user can decide to use the service. This additional service information can be used by user while selecting services among the available ones.

Wi-Fi based device discovery for the vehicle to pedestrian communication is proposed by Fujikami et al. [9]. In this collective scanning and extension receiving method is used to improve scanning time. The scanning time of collective scanning is compared with the scanning time of traditional IEEE 802.11 and results of comparison indicates that collective scanning performs better than the traditional approach. In this approach, advertisement frame doesn't provide additional information about the service.

Wi-Fi direct based device discovery mechanism is proposed by Sun et al. [10] Listen Channel Randomization (LCR) scheme is used to improve find phase of device discovery. Results show that 72% of delay is reduced by using LCR over legacy find phase. Network topology influencing device advertisement is discussed by Ccori et al. [11]. In this scheme three types of network topologies are analyzed namely, centralized, distributed and hierarchical. The analysis is done based on parameters like network traffic, discovery time, reliability and server-side infrastructure. The analysis concludes that the hierarchical topology works better with respect to the discovery time.

Wi-Fi is used in many applications however, Wi-Fi devices require a large amount of power as compared to ZigBee, Bluetooth and LoRaWAN. Hence in the applications with energy constrained devices ZigBee, LoRaWAN and Bluetooth could be used for service advertisement.

ZigBee is used in Wireless Personal Area Network (WPAN). Every ZigBee network must consist of at least one coordinator who is responsible for handling, storing, receiving and transmitting the data. The coordinator is used for formation of a network tree. The router acts as a mediatory device that is used to pass the data to the coordinator. End device is a low power device with limited functionalities to communicate with the parent node. The typical communication range is 30m for an indoor and 100m line of site for outdoor application. Each ZigBee network can have a 64K number of nodes [12]. ZigBee device discovery is initiated by transmitting it’s 64bit address. After joining ZigBee network, the device receives 16-bit address, i.e., PAN ID. The device can transmit commands to other devices on the same network. Typically, ZigBee can be used in home automation system [13] however, it can't readily use with a smartphone.

LoRaWAN is a protocol for low power wide area network developed by the LoRa alliance. It supports mobility, low powered and bidirectional communication, hence it is suitable to use in the IoT network. It supports a data rate of 0.3kbps to 50 kbps [14][15]. LoRaWAN minimizes the energy consumption of end devices using adaptive data rate scheme and improves the network capacity. It follows the star topology where the gateway is the relay node to transfer messages from end devices to the central server. It uses a frequency band of 2.4GHz and 5GHz like that of Wi-Fi. End devices are connected to the server by initiating join procedure. Join procedure consists of two MAC messages, join request and join accept. The researchers have started using LoRaWAN in the IoT applications e.g., EU project Worldwide Interoperability for Semantics IoT (Wise-IoT) [16]. However, this technology in the initial stage may face some challenges [17].

Hence, the service advertisement method based on the Bluetooth communication technology is evaluated further.

Bluetooth is the short-range wireless communication medium which uses radio frequency 2.4GHz ISM band. Bluetooth operates in 2400 to 2483.5 MHz with 79 channels of 1MHz each. The range of Bluetooth communication is 10 meters. Bluetooth uses master-slave or client-server configuration for device communication. Bluetooth devices can send data in full duplex mode with 64Kbps data rate [18]. Bluetooth devices need to pair each other for data communication. A piconet is a network of devices connected using Bluetooth. In a piconet, seven devices can be connected to master station. An additional device can be attached in Parked or Hold state. Piconets are established dynamically when Bluetooth devices enter and leave radio proximity. In Bluetooth communication, one device acts as a master and other as a slave.

Bluetooth based device discovery protocol, ”eDiscovery” is proposed by Han et al. [19]. In this, energy consumption of the device is reduced dynamically by changing duration and interval of Bluetooth device discovery based on a number of peers discovered. This protocol achieves minimum energy consumption based on the two parameters: the threshold number of devices discovered and Bluetooth window. If the discovered number of devices is more than the threshold value, then next Bluetooth window is smaller in size. Hence, the device will spend less time in scanning which leads to minimum energy consumption. A prototype implementation is done on Nokia N900, and results are compared with literature protocols. In this approach, advertisement frame doesn't provide additional information about the service. Results show the efficient energy consumption as compared to other protocols.

Though Bluetooth required less amount of the power than Wi-Fi technology, most Bluetooth devices are battery powered. This needs more energy efficient technology. BLE was discovered to resolve the problem of high current consumption of the Bluetooth. BLE consumes approximately 15mA current which is very low compared to classical Bluetooth with a current consumption of 30mA. BLE reduces implementation cost, enhance communication range, and multiple vendor interoperability. BLE is more reachable due to a lower implementation cost and interoperability. BLE is a subset of classic Bluetooth and not backward compatible with Classic Bluetooth devices. There are two types of devices single and a dual mode. Unlike single mode in dual mode, devices can operate as Bluetooth and BLE device. BLE devices should establish a connection among them to communicate with each other. Advertisement process is the first step to establish a connection. This advertising process enables BLE device to be visible to the outside world [20]. In advertisement phase, a peripheral device transmits advertising data to multiple central devices.

BLE-based device advertisement is proposed by Liu et al. [21]. In this BLE is used for Wireless Body Area Network (WBAN) application and two important parameters are considered: device discovery latency and connection setup latency. The contention and conflicts problems may arise due to increase in the number of advertisement frames and this results in network access latency and increases the energy consumption. In the proposed algorithm, BLE scanner learns network contention and adjust the parameters accordingly for efficient energy consumption. Simulation results show that the device discovery latency is reduced significantly. In this approach, advertisement frame doesn't provide additional information about service. Here the mechanism for efficient energy consumption of the scanner device is focused.

The quantitative analysis of energy consumption of BLE advertisement is presented by Lui et al. [22]. Evaluation of BLE advertising frame is done on Texas CC2541 node. The energy model is proposed and after evaluation of energy model, few observations are mentioned for efficient energy consumption. The observation being BLE scanner, window should be set larger than advertising interval. Fast device discovery protocol is proposed by Huang et al. [23]. In this, group of devices advertise their existence to a group hence, device energy consumption will be reduced as the period required to advertise is reduced. For this Wi-fi is used for advertisement in which the neighborhood devices form a group and in a synchronized way advertisement is done. In this approach, a new device is added to a group by broadcasting join window before beacon transmission. Mobility is also supported in this work as when the device leaves the group, then the group information is adjusted and forwarded to a group of members. In this approach, advertisement frame doesn't provide additional information about service. Simulation results show the energy efficiency of the algorithm.

BLE-based device advertisement is proposed by Takalo-Mattila et al. [24]. Each device is assigned a ubiquitous code (ucode) for unique identification. In the BLE beacon, ucodes are embedded and are broadcasted to advertise. Semantic ontology is used for service description provided by devices, and here OWL ontology is used. BLE beacons are treated as a tag for each device. User's smart phone receives the BLE beacons of devices present in the location and ucode is retrieved from BLE beacon. The service URL is associated with each ucode.

The literature work analysis and research recommend that the BLE is suitable for location-based applications that require low range, less energy consumption, and low data rate communication. BLE provides a facility to modify the advertisement frame. The service information can be embedded into the BLE advertisement frame. The end user can get information about services provided by the cluster without connecting to it, which will facilitate personalized service discovery. BLE is more suitable for IoT applications that require small data and short-range transmission [25][26]. The literature analysis is done to understand the methods to advertise services and to provide additional information about services in the advertisement frame.

5.1.2. EVALUATION OF SERVICE ADVERTISEMENT MECHANISMS

In the IoPTS, infrastructure devices (cluster) provide the services to the user. When the users come to an unfamiliar place, it may be very important for them to know about the services present at that location. Location-based services are advertised using Wi-Fi, Bluetooth, and BLE. To choose appropriate communication technology for service advertisement, evaluation of literature work is done based on parameters, as follows:

Communication technology: The communication technology used for service announcement has a huge effect on the energy consumption of the system. Wi-Fi, Bluetooth and BLE technology are mostly used for service advertisement. Algorithms in the literature are analyzed based on this parameter for energy efficient discovery in IoPTS system.

Profile awareness: While service advertisement, advertisement mechanism could add some information about services running on the devices. This facilitates getting information about service without connecting to the device. The decision about connecting devices can be taken efficiently depending on the requirements and available services. Literature algorithms are analyzed based on this parameter.

From the discussion of the service advertisement mechanisms, we can say that only few mechanisms support the profile awareness for service advertisement. The literature work focuses more on the mechanisms to reduce the energy consumption of the scanner device than advertiser device. BLE is used in the proposed research work based on the physical web [5] approach to advertise service URL to the users.

5.2. BLE ADVERTISEMENT

In the IoPTS environment, a large number of clusters are available which results in a large number of services offered at particular premises. Selecting appropriate service as per user requirements among such large number of available services may consume more time and energy of the user device (smart-phone). Hence service advertisement mechanism should provide a mechanism to facilitate personalized service discovery.

Most of the IoT applications started using the BLE enabled devices e.g., wearable devices and up to 2021, Bluetooth will be used in 60 percent of overall wireless devices [27]. Further advancements like Bluetooth 5 making it a promising technology for the IoPTS. Bluetooth 5 is revised version for the IoT. It provides 2Mbps data rate, i.e., two times more than BLE. It also gives four times more transmission range than BLE by increasing transmission power level to +20dBm. Furthermore advertisement capacity is improved eight times more than BLE using features like secondary advertisement channels, periodic advertisement and longer URL [27]. This section provides details regarding BLE advertisement frame format and advancements in BLE for service advertisement.

BLE has 40 physical channels in the 2.4GHz ISM band that are separated by 2MHz bands. BLE defines two types of transmission, i.e., advertisement and data transmission. There are 3 advertisement channels 37 (2402 MHz), 38 (2426 MHz) and 39 (2480 MHz) [28]. These channels are selected to minimize interference from other services. BLE device transmits advertisement packet on these three channels for a fixed time interval. BLE defines a single packet format for advertisement and data packets. The BLE device transmits advertisement data to allow another device to find and connect with it. Multiple services can be advertised by changing the advertisement data dynamically.

5.2.1. ADVERTISEMENT PROCESS

BLE device uses advertising mode to broadcast advertisement data periodically over the advertising channel, the advertisement process depicted in the figure 5-1.

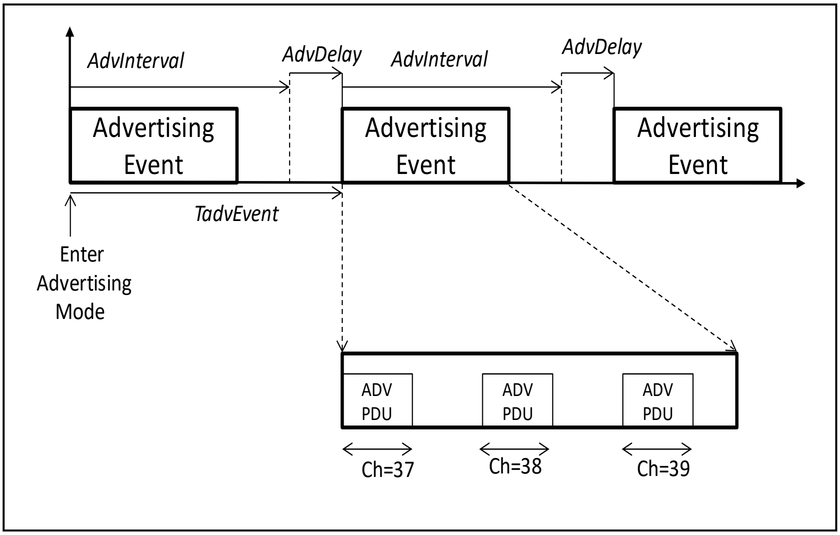

Figure 5-1 BLE advertisement process

Advertisement Interval: The advertisement process repeats after the specific interval (*TadvEvent*) shown in the figure 5-1. The time between the start of two consecutive advertising events, i.e., *TadvEvent* is calculated by the computational sum of *AdvInterval* and *AdvDelay* parameter. The *AdvInterval* should be an integer multiple of 0.625ms. It should be in the range of 20ms to 10.24s.

The *AdvDelay* is pseudo-random value with a range of 0ms to 10ms. This randomness helps to reduce the possibility of collisions between advertisements of different devices [1].

Advertisement Types: in the BLE different ways of advertisements can be done. Specific data packets are used for each type of advertisement, discussed as follows: -

- Connectable undirected: This type of advertisement is not intended for specific receiving device. The devices in scanning mode can receive the advertisement frame and it can request advertiser for additional information. Based on this additional information scanner can take the decision to connect to the BLE advertiser device. The scanner and advertiser devices can connect for data transfer, and they can transfer maximum 31 bytes of data.

- Connectable directed: This type of advertisement is intended for specific receiving devices. In this type, the scanner device can't request advertiser for additional information. The directed advertisement uses 6 bytes of the device address for connection.

- Scannable undirected: This is undirected advertisements which don't have a specific intended receiver. In this type scanner can ask for additional information about advertisement. Advertiser device transmits scannable advertisement packet of 31 bytes.

- Non-Connectable undirected: Advertiser transmit non-connectable advertisement packet with a maximum data length of 31 bytes, which cannot be connected and not intended for any specific receiver device. In this type, the scanner device can not request advertiser for additional information.

The advertisement method is used as per the application requirements. The advertisement packet is formed based on the frame format as shown in figure 5-2 as follows, it is 47B in length:

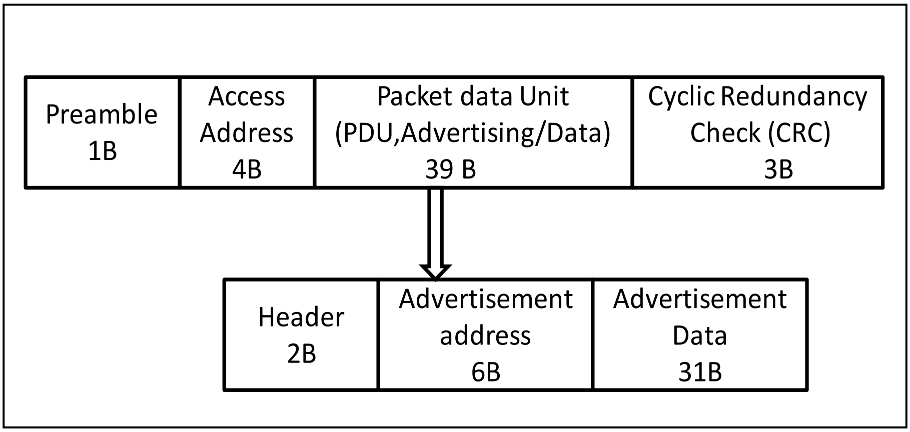

Figure 5-2 BLE Advertisement frame format [29]

- Preamble: This is 1Byte of information used for internal protocol management.
- Access Address: The access address is different for each data frame, and it contains the address of devices to be connected. However, the access address value is the same in each non-connectable advertisement frame, as it does not connect to any device.
- PDU: The PDU format is same for both type of communication, i.e., advertisement and data, but the information it carries is different. In the advertisement type of communication, the PDU packet contains information about the services it is advertising. As mentioned above, according to the BLE standard, 39 bytes are allocated to the PDU. The PDU contains 2 bytes of header and 6 bytes of advertisement address and 31 bytes of payload, i.e., data about service. The header defines the type of PDU, i.e., connectable, non-connectable, scannable and length of the payload. Advertisement address holds the MAC address of the device that broadcasting the advertisement frame.
- CRC: The CRC bytes are commonly used for error check.

5.2.2. IBEACON AND EDDYSTONE ADVERTISEMENT FRAME FORMAT

BLE is used by Google and Apple to advertise the services. Apple has invented iBeacon technology to advertise services using BLE, and it is widely used in many application areas. The Apple and Google modified 31 bytes of payload and designed frame format for service advertisement.

iBeacon has fixed frame format with identifiers to broadcast the services [30]. An app is needed to discover iBeacon. iBeacons supports iOS and android operating system. In the iBeacon frame format, the first 9 bytes are allocated to the prefix and 2 bytes for Tx power. The remaining 20 bytes are allocated to three major values that identify the particular beacon, i.e., UUID, a major number and minor number. The frame format of iBeacon Shown in figure 5-3:

- Universally Unique Identifier (UUID): This is a unique identification of iBeacon and it is a mandatory field in the frame. It is a 128bit value used for unique identification, e.g., store McDonald that has worldwide branches could use one UUID.

- A major value: It is used to identify different beacons with the same UUID. e.g. McDonald Store may have the same UUID. However, it may use different major values for each branch at different country/City, i.e., branches of McDonald at Mumbai it may have major value 10, Paris 25, etc. It is 16 bit and an optional value.

- A minor value: It differentiates particular beacon between beacons with same UUID and major values. e.g. different service at McDonald store as waiting number, placing orders and paying the bill may have same UUID and a major value but have a unique minor number. It is a 16bit value, and it is optional.

The combination of unique UUID, a major number and minor number can provide information about specific service present at the particular location to the user.

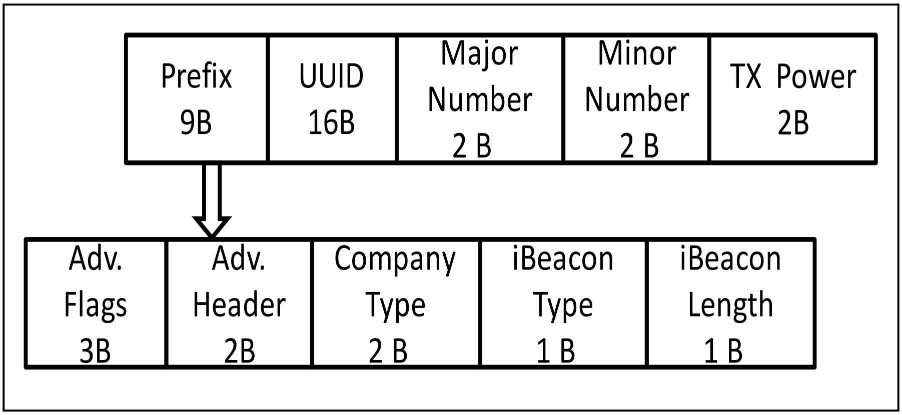

Figure 5-3 iBeacon frame format

Google proposed the open BLE beacon format called Eddystone [31], it is more secure and cross-platform. Eddystone uses the three frame formats to broadcast information about the services provided by the device in the particular area, the advertisement frame format is shown in figure 5-4.

- UUID frame: Eddystone UUID frame works same as iBeacon frame and the app is needed to discover this beacon. It is 20 bytes frame. The first byte indicates the type of frame format, i.e., UUID value is 0x00. The second byte is allocated for Tx power. It is the received power at 0 meters measured in dBm. The next 16 bytes consist of 10 bytes of namespace and 6 bytes of instance. Last 2 bytes are kept reserved for future expansion.

- Universal Resource Locator (URL) Frame: URL frame is used to broadcast the URL of the service. It is 6-20 bytes frame. The first byte indicates the type of frame format, i.e., URL value is 0x10. The second byte is allocated for Tx power. The next byte is assigned for URL prefix, i.e., http://www, https://www. The next 17 bytes are allocated for URL. The specific app in not required to discover this beacon, the beacon supported browser can track URL frame e.g., Google Chrome or Nearby Notifications [32].

- Telemetry (TLM) Frame: TLM frame is used to provide the status of the beacon, i.e., battery voltage, beacon temperature. It is 14 bytes frame. TLM frame can be broadcasted after a particular time interval to know the status of the beacon. It is used for fleet management of the beacons. It is advertised less frequently than the other two types of the beacons i.e. URL and UUID.

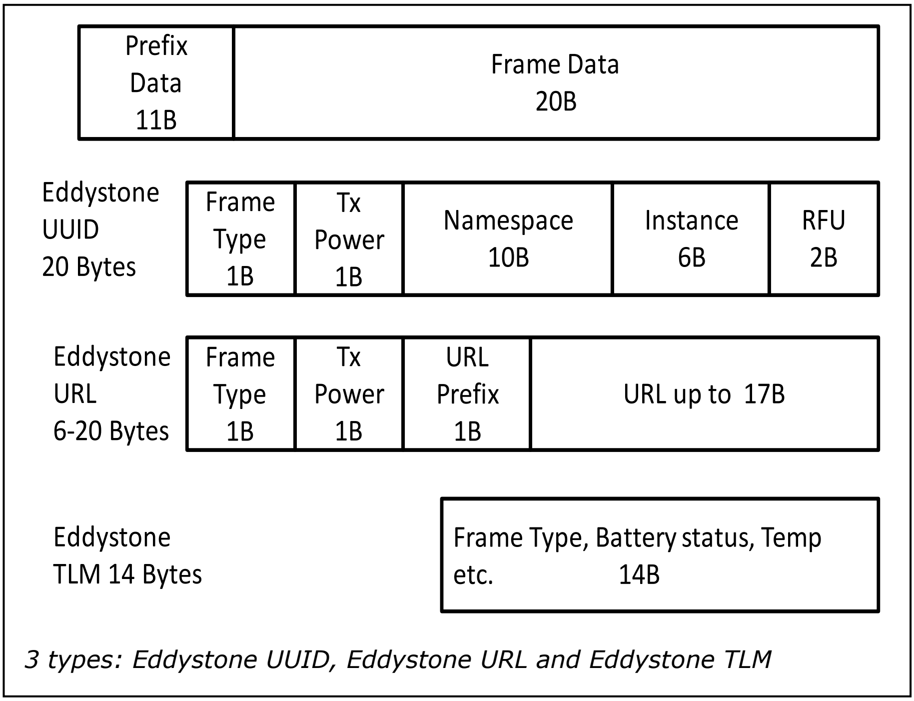

Figure 5-4 Eddystone frame format

Using these three types of frames Eddystone beacon provides additional information about services than traditional beacon frames. The approach is similar to the linked data, it is method of publishing structured data using Uniform Resource Identifier (URI). The things name can be used for the URI; hence user gets more information about the resource. Further the URI are linked with the other URI to provide more information [33]. After service advertisement, service discovery and recommendation are the important steps of any service architecture, due to the availability of a large number of services.

5.3. SERVICE DISCOVERY AND RANKING

Service discovery means finding out services as per user requirements. It is done based on the similarity between the user request and service description. Service discovery can be done through different ways however, the common approach is that the service provider registers services provided by them to Universal Description Discovery Integration (UDDI). The user request is matched with service descriptions registered with UDDI and matching service is provided to the user. In this, Service descriptions may be written using Web Service Description Language (WSDL), JavaScript Object Notation (JSON).

This approach of the service discovery is not applicable to the beacon based IoPTS applications. In the beacon-based approach services are discovered using the beacon advertisement and scanning procedure.

5.3.1. BEACON SCANNING PROCEDURE:

A device in scanning mode which is listening on an advertisement channel for the specific duration, is called *ScanWindow*. In each scan window, the device should scan on different advertising channels. The device scans an advertisement channel after a specific interval, i.e., the *ScanInterval*. The *ScanInterval*, is the interval between the start of two consecutive scan windows. The *ScanWindow* and *ScanInterval* parameters should be less than 10.24s [1].

There are two types of scanning: passive and active scanning. In the passive scanning mode, the device should only receive packets from the advertisement device on advertisement channels i.e. channel 37,38 and 39. In this mode, the device can't transmit any packets to the advertisement device. The passive scanning process is depicted in figure 5-5.

In active scanning, the device should listen for advertisement data and depend on the advertisement packet type it may request an advertiser to send additional information using a scan request. After transmitting a scan request to the advertiser, the device should listen for a scan response from the advertiser. The advertising device gives a response to scan request with the requested data. If the scan response was not received from that advertiser, it is considered as a failure otherwise it is considered a success. The scanning procedure can be used while it has been connected to other BLE devices in the piconet.

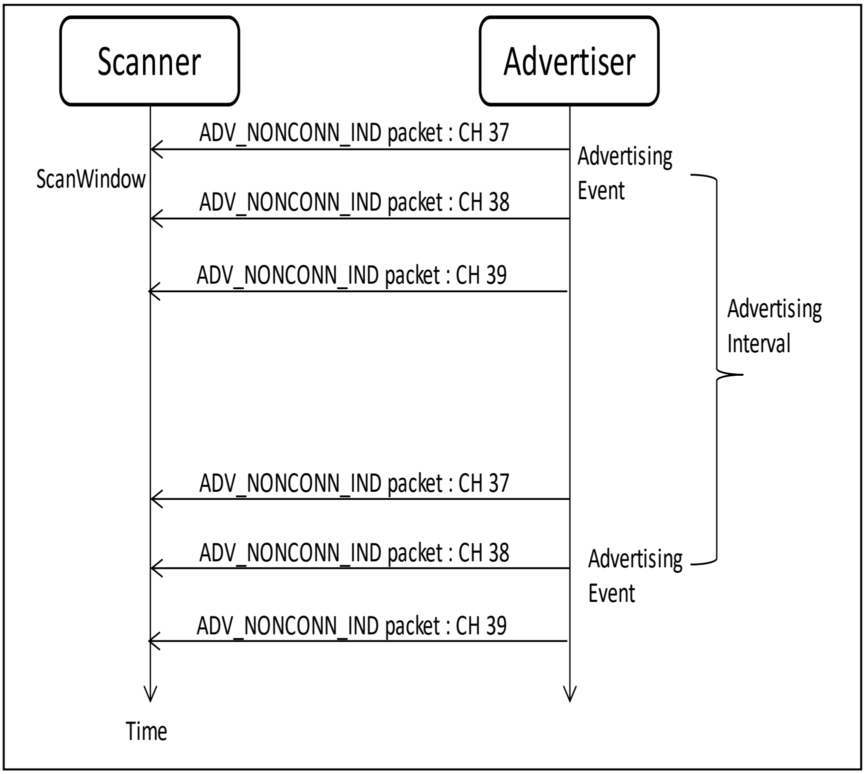

Figure 5-5 BLE scanning process

In the IoPTS a large number of the beacon will be deployed at a different location like an airport, shopping mall, bus stops, restaurant, movie theatre and so on. The user's smartphone will be flooded with beacon notifications. It may happen that user is interested in specific notifications. Moreover, the user needs to check a list of notifications manually for required notification. Hence, service ranking is required to provide precise services to the user among a large number of available services. The need of ranking of the services is depicted in the figure 5-6, it is published in the research article [34]. The detailed survey of literature work is done in next section to understand the different ways of service ranking.

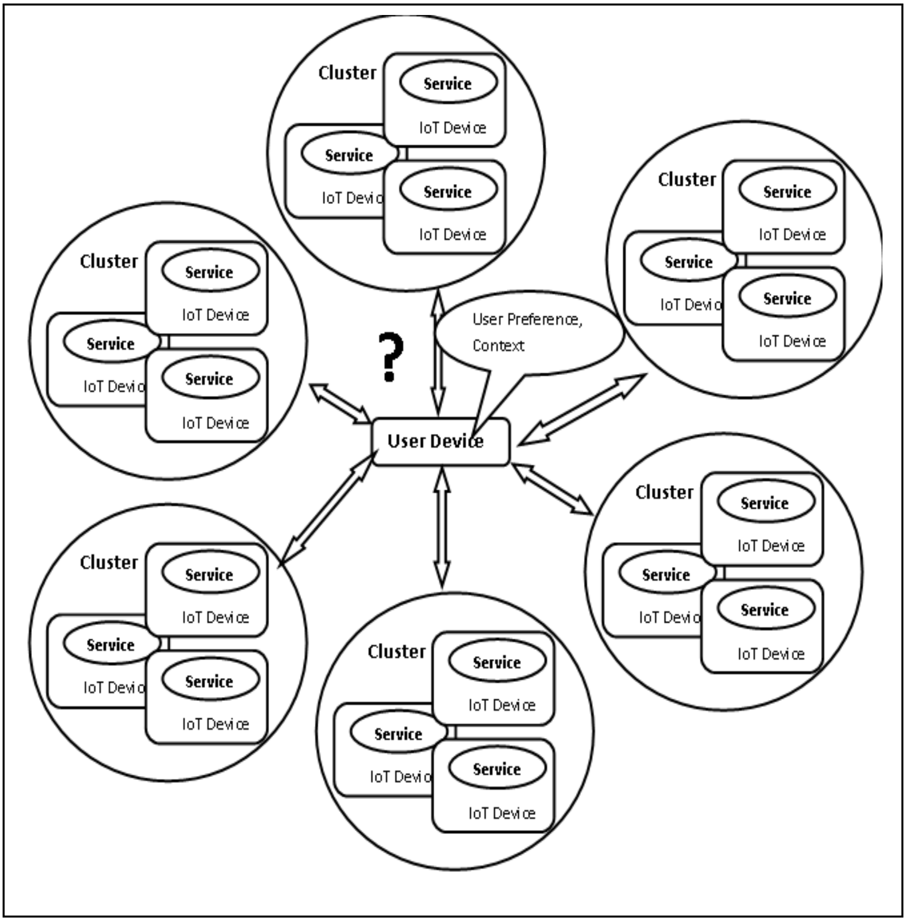

Figure 5-6 Need of user preference and context-based service discovery [34]

5.3.2. LITERATURE OF SERVICE RANKING MECHANISMS

In the physical web [35], service ranking is done based on RSSI, however RSSI is not sufficient parameter for the service ranking. Hence in this section few service ranking mechanisms are discussed.

User preference based service discovery for IoT is proposed by Wand and Chow [36]. User's smartphone is able to notify the user about nearby available services depending on user preferences. The object name service (ONS) and Physical Markup Language (PML) is used for service discovery. ONS stores the mapping between devices and services. Users' smart phone scans nearby devices and searches its entry in ONS. It provides corresponding IP address of the service to the user. The services are filtered based on the user preferences before providing IP address to the user. The system presented is the novel framework for IoT service discovery. However, it comes with assumptions that smartphone has RF scanner and capacity of optical code reading. This system may not support scalability as a large number of IoT devices are available. The system performance may degrade due to storing and searching services in ONS.

Profile-based service discovery is proposed by Meditskos et al. [37]. The services are advertised using service profile. Ontology is used to create a service profile. In this approach service request is also converted in the form of a profile. Service discovery is done based on the similarity between service profile and request profile. This mechanism indicates that the service advertisement mechanism should have the facility to provide service information, i.e., service profile. The service ranking could be done by matching user preferences and service profile.

In the literature user preference [38], context information [39] and history of usage [40][41][42][43][44] parameters were taken to improve the efficiency of service ranking and to find out appropriate service as per the user's need. These parameters of the ranking could be applied to beacon-based approach.

From the above discussion user preference, context information and history of usage parameters are taken as design parameters for proposed service ranking mechanism.

Context awareness: Context information is considered in the ranking mechanism to enhance performance of service ranking mechanism. The context could be defined as information that helps to define the situation, e.g., time, date, location. Context can be classified into different types, e.g., social, environmental, physical.

User Preference: User preference parameter improves the ranking process. In the service discovery process, it may happen that few discovered services are similar to the user request. Among these services, appropriate service should be filtered based on user preference. User preference gives more precise results of the discovery process.

Usage history: Service usage history of the user helps to develop user's profile and based on the profile, appropriate services can be provided to the user.

5.4. SUMMARY

In this chapter, different communication technologies for service advertisement are discussed based on the parameters like communication range, energy consumption, support for the facility to provide additional information about the service. From the analysis, BLE is selected as the communication technology for service advertisement. BLE consumes less energy for service advertisement. It can provide additional information about the services and doesn't require any additional infrastructure hence suitable for beacon-based approach.

The different service advertisement mechanisms are discussed to understand the methods of providing additional service information. The analysis provides the direction for research work. The profile-based service advertisement is taken ahead in the research to provide additional information about the service.

Though plenty of IoT services are offered by the IoPTS cluster, it is more important to select appropriate service for the user as per user's requirement. The need of the ranking of the service in the IoPTS is discussed in this chapter. In the literature, a ranking of services in beacon-based approach is done based on the RSSI, however it is not sufficient for IoPTS. The evaluation of service ranking mechanisms is done to find out parameters for efficient ranking. In the research, user preference, service usage history and context information parameters are taken for ranking of the services.

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CHAPTER 6. PROPOSED SERVICE ADVERTISEMENT AND RANKING MECHANISMS

The proposed profile based BLE advertisement frame in section 6.1 is published in the paper [4] (list of publications), where profile aware service advertisement is proposed based on service profile attributes, i.e., major, minor and profile bytes. In this chapter, the sub-profile attribute is added in the advertisement frame to achieve personalized service ranking. The algorithm of service ranking and results in section 6.2 and 6.4 are published in the paper [5], in this chapter results are extended.

The aim of this chapter is to propose a mechanism for seamless interaction between user-cluster to get the benefit of the IoT services. The generic cluster framework is proposed to achieve a seamless interaction. Two modules of this framework are presented in this chapter, i.e., service advertisement and service ranking. In the first part of the chapter, the PAPSA mechanism and PSR mechanism are proposed. In the next part of the chapter experimental results of PAPSA and PSR mechanisms are discussed. The chapter is summarized by proposing the cluster framework for the IoPTS, it includes three modules, i.e., device organization, service advertisement and service ranking.

6.1 PROPOSED PROFILE-AWARE PROACTIVE SERVICE ADVERTISEMENT MECHANISM

The research work is based on the features of Eddystone and iBeacon BLE advertisement frame format [1][2]. The proposed PAPSA mechanism works in the three stages as shown in the figure 6-1. In the first stage, IoT service profiles are generated for each service provided by the cluster. In the second stage, profile-based BLE advertisement frames are created for each IoT service using the attributes of service profile. In the third stage, multiple services are advertised by the single BLE device. The service advertisement provides additional information about service. The user can decide to connect the service as per his requirements.

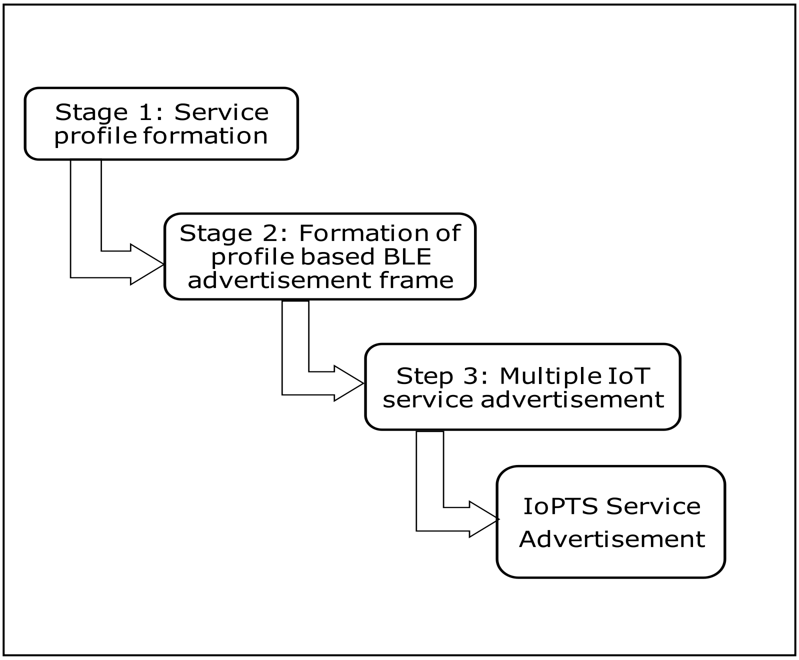


Figure 6-1 Stages of profile aware proactive service advertisement

Stage 1: Service profile is created for each service to be advertised. The service profile is created based on cluster and service attributes as follows:

- Type of the domain: This attribute provides information about the type of the cluster, i.e., healthcare, transport, food, educational, etc.
- Type of service: Every domain has different types of the services, e.g., health care domain may include services like Doctor's visiting hours, way to the laboratories. The educational domain may include services like conference schedule, seat availability, etc.
- IoT device information: This attribute provides information about IoT device which provides the services, e.g., an area where the device is deployed.
- Service URL: This attribute provides the URL of the service.

Stage 2: In the research work, BLE advertisement frame format (figure 5-2) is modified in order to realize a profile-aware service advertisement. This modification is based on Google's Eddystone URL beacon frame format (figure 5-4). The proposed BLE advertisement frame provides URL of IoT service with additional information.

BLE has 39B payload, out of the 39B, 2bytes are allocated to header and remaining 37 bytes are payload (figure 5-2). Out of 37 bytes, 13B are allocated to the Adv address, Manufacturer's ID, length, battery voltage and frame type. Remaining 24 bytes are modified to provide information about IoT services offered the by cluster, it is published in the research article [3]. This 24B are modified as follows and presented in figure 6-2:

- *Major and Minor Number*: Provides the location of device. For example, the major number can provide information about the department of the university and the minor number can provide information about a particular section in the department. 1B is allocated to each.

- *RSSI*: 1B is allocated for the RSSI level. The frames with the RSSI value lower than the threshold are ignored.

- *Profile*: 2B are allocated to provide information about the domain of service advertised by the beacon. This gives room for 2^{16}= 65535 profiles. In the IoPTS, a large number of domains will be required because IoPTS application deployment is increasing tremendously. This field differentiates services domain wise e.g.

    - Transport: This profile is for services related to transport. e.g., "*bus schedule"* service.
    - Educational: This profile specifies that services are related to the educational domain. e.g., "*conference room availability"* service.
    - Commercial: This domain is for services related to the retail market. e.g., shop/mall offer services, coffee machine.
    - Food: This is for the services related to food items/restaurants, e.g., *"Menu-card"* service.

- *Sub Profile*: 2B are allocated for customized sub-profiles. 1B is allocated to the information about the type of the service and second byte is allocated to the associated type of user.

- *URL Prefix*: 1B is allocated for URL prefix, i.e., http://www or https://www.

- *URL*: 16B are allocated to provide the URL of IoT service. The user can access services using the URL. An URL provides the reference to the corresponding service web page/web resource, e.g., http://www.SmartCampus.com/ConferenceRoom.html". This URL represents web page for a conference room in the smart campus. The last byte among 16B is allocated for the URL suffix.

As per IoPTS application, above parameters are defined and using modified BLE advertisement frame user could get detailed information about services offered by the cluster.

Major Number 1B	Minor Number 1B	RSSI 1B	Profile 2B	Sub Profile 2B	URL Prefix 1B	URL 16B

Figure 6-2 Profile based BLE advertisement frame [3]

Stage 3: Traditionally, BLE device is used to advertise single service frame. However, this scenario may not be suitable in the IoPTS environment. In the IoPTS a single cluster may require advertising few services. Hence, in the proposed work BLE device advertise multiple services instead of a single service. BLE device changes advertisement frame data dynamically and multiple services are advertised. The services are advertised after the advertisement interval as shown in the figure 6-3 where advertisement frames for services 1 to "n" are advertised, i.e., the number of services to be advertised is "n". The BLE advertisement interval is kept as 100 milliseconds, i.e., next service is advertised after 100ms of previous service advertisement, it can be set between 100ms to 10sec.

This approach of multiple service advertisement minimizes the energy consumption and deployment cost of IoPTS application. The BLE "*service counter*" is kept same as a number of IoT services to be advertised by BLE device. Transmission power can be set -40dBm to +4dBm and BLE device should keep in the non-connected mode.

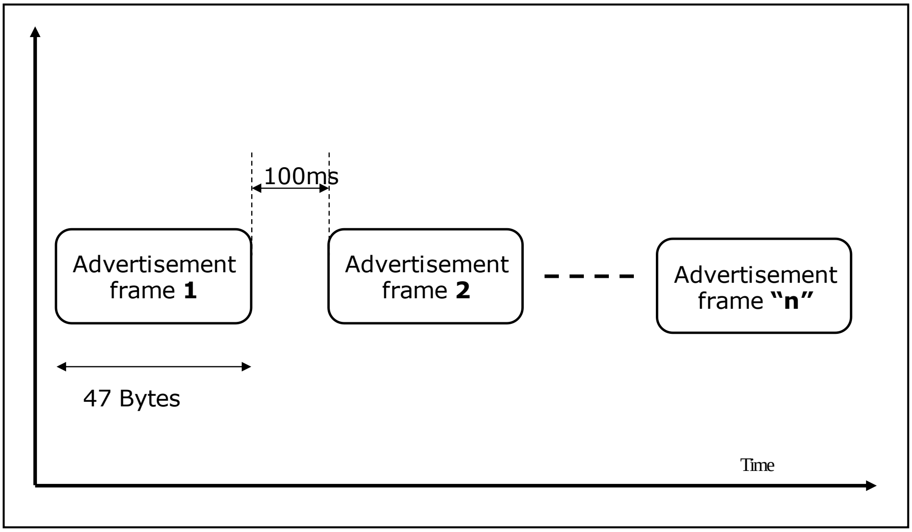


Figure 6-3 BLE: Multiple IoT service advertisement

6.2 PROPOSED SERVICE RANKING ALGORITHM

In the proposed PSR mechanism, the user requirements and preferences are retrieved from the user profile and matched with the IoT service profile to achieve personalized service discovery. Further, the "context" is considered as a design parameter of IoPTS service framework to improve the service discovery. The context plays an important role in the IoPTS as depending on the context, priority of service may change. The user's history of service usage and context information are taken as parameters for service discovery to achieve context awareness.

The flow of the events of PSR algorithm is presented in figure 6-4. The BLE device advertises the services offered by the cluster of devices using profile-based BLE advertisement frame.

The scanner devices scan the service advertisement frames i.e., all advertised services (Max). The service advertisements are embedded with the additional information about the service profile. The different attributes like profile, sub-profile, major and minor bytes are retrieved from the BLE advertisement frames. Users have their profile with it's different attributes. The algorithm works in two stages, the first stage services are filtered according to the user role and in the second stage filtered services are ranked as per user context, history and other profile attributes. Here, we take time and location as context information. The service profile matched with user role, the matching services are kept in the list of high priority services i.e. Ranked List (RL), and other services are discarded. The RL is further sorted by matching user preferences, context information, service usage history with the major, minor bytes of the service advertisement frames [3].

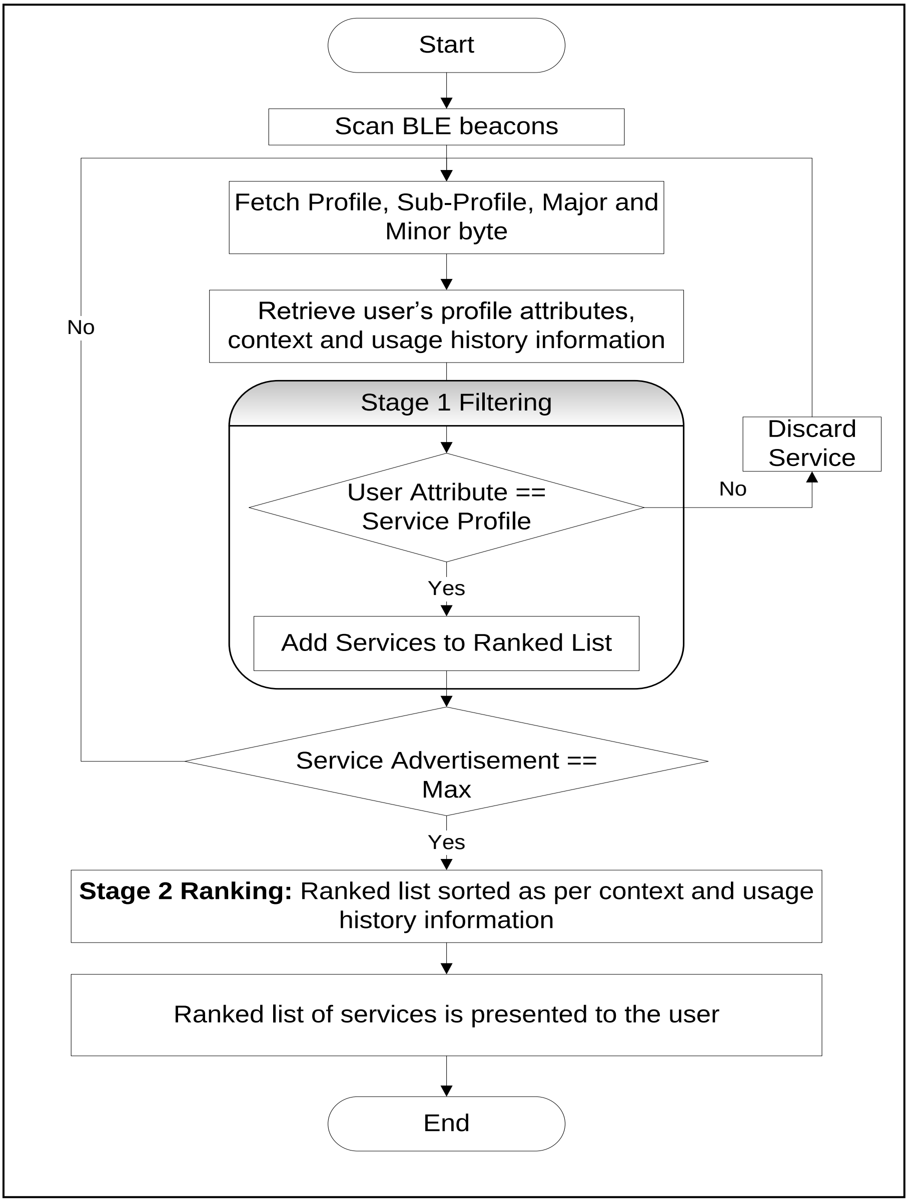


Figure 6-4 Flow of the events of personalized service discovery mechanism

6.3 IMPLEMENTATION DETAILS

The PAPSA and PSR mechanisms have been verified by implementing advertisement services for university campus application. The services are targeted to the education domain. The BLE advertiser could be deployed at the university campus to advertise the location-based services. In the literature, IoT is used to design smart campus systems for different point of views as increasing energy efficiency [4], providing location-based services [5], notifications of smart campus services [6], smart parking for campus [7] and to form smart group in the library [8] etc. The literature work for smart campus has been targeted towards automation and to save energy by minimizing energy consumption. The very few work has been targeted towards advertising location-based services, i.e., Merode et al. [6] have used beacon approach to provide the location of different sections of the campus and Antevski et al. [8] have used beacon-based approach to form a study group in the library. In this reserch, location based services are advertised.

The next section provides the selection criteria for BLE advertiser and the details of BLE advertiser used in the implementation, i.e., nRF52DK. In further sections, details of service advertisement frame, multiple service advertisement and firmware flowchart are discussed.

6.3.1 DETAILS OF NRF52DK

BLE System on Chip (SoC) is developed by the many manufactures like Texas Instruments (TI), Silabs, Cypress, microchip and Nordic, etc.

TI has developed Bluetooth wireless microcontrollers that are highly flexible, integrated and multi-year battery powered with CC2540 microcontroller based on 8051 core that supports Bluetooth 4.0 standard. It has a current consumption of 17.9mA, flash is of 128kb and 8kb RAM. Recently TI comes with CC2650 microcontroller based on the Cortex-M3 core with a current consumption of 5.9mA and supports Bluetooth 5.0 standard with the flash size of 128Kb and RAM size of 30Kb [9]. The Cypress semiconductor has developed SoC based on the Cortex M0 core that supports Bluetooth 4.2 with a current consumption 15.6mA, flash size of 256Kb and RAM size of 32Kb [10].

The Silabs Blue Gecko has developed BLE SoC with an energy efficient ARM Cortex-M4 core that supports Bluetooth 4.2 with a current consumption of 7.5mA, flash size of 256Kb, RAM size of 32Kb [11]. Microchip has developed Smart Connect BTLC1000, is an ultra-low-power Bluetooth 4.1 SoC with a current consumption of 6.5mA, flash size of 160Kb and RAM size of 20Kb [12].

Among all above BLE devices, in the research Nordic nRf52 SoC is used because it has a very low current consumption of 5.5mA which allows running application for the long term. NRF52 hardware requires a coin cell battery to run the application to broadcast services via Bluetooth. Nordic comes with an *"nRF Connect"* app which is a very helpful for testing new changes during development. This app scans nearby advertising BLE devices and discovers their services. The nRf52 provides tool *"Nordic Power Profile Kit"* for power measurement. It doesn't require a debugger to debug the code because it has an inbuilt Jlink on-board debugger which helps to debug the sample code during development [13]. Details of nRf52DK as follows:

The nRF52DK is used for BLE applications using nRF52823 SOC, shown in the figure 6-5. The nRF52DK is compatible with the Arduino Uno Rev. 3 standard. The nRF52DK contains NFC antenna to enable NFC tag functionality. It gives access to all I/O and interfaces via connectors. It supports the standard Nordic software development toolchain using Keil, IAR, and GCC. It can be programed/debugged by on-board Segger J-link.

The nRF52832 is a powerful SOC built with a 32-bit ARM Cortex-M4F processor with 512KB flash and 64KB RAM. It supports 2.4GHz transceiver, ANT, and proprietary protocol stack. The nRF52832 is a powerful SoC with ultra-low power multiprotocol which is ideally suitable for wireless applications. The output power is up to +4dBm and data rate is up to 2Mbps [13].

In the nrfDK52DK a wireless protocol stack library is used, called as Soft-Device. A Soft-Device is precompiled binary image and verified functionality according to wireless protocol specification. The Soft-Device Application Programming Interfaces (API) is available for high-level programming languages. The nRF52832 is supported by the S132 Soft-Device. It is the multi-role and concurrent Bluetooth 4.2 protocol stack [14]. The nRF52DK can be used in typical applications of BLE such as sport and fitness sensors, smart watches, health product and building automation.

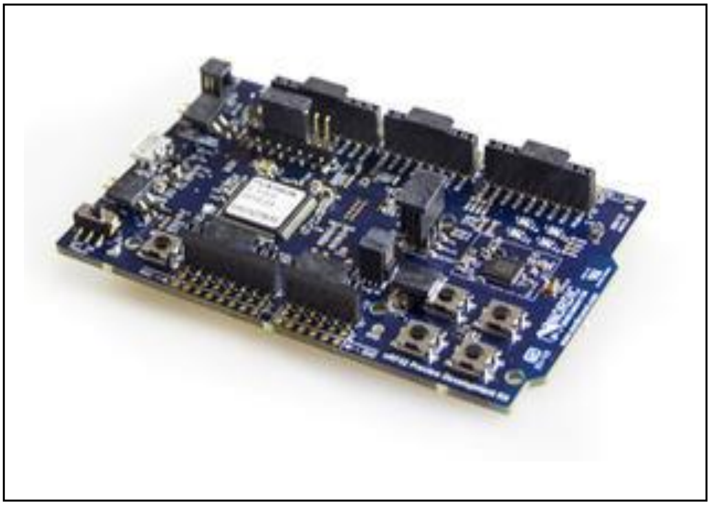


Figure 6-5 nRF52 development kit

The Keil µVison 4.0 IDE is used for coding the BLE advertisement firmware and downloaded on Nordic nrf52dk using segger Jlink on-board debugger.

6.3.2 PROFILE BASED BLE ADVERTISEMENT FRAME

A system is modeled for a university campus assuming that the university has four engineering departments, i.e., Computer, Mechanical, Civil, and Electronics, a canteen and a library for each department. It is assumed that the devices at the university are organized in the cluster and services are formed on the basis of the information/parameters sensed by these devices. All services are configured and programmed in the Nordic BLE device - nrf52DK and advertised using PAPSA. In the implementation, eight services for each department are configured in the nRF52DK, i.e., 32 services. Three roles are considered for personalized service ranking, i.e., student, visitor and professor.

The profile byte is set to the education domain, major byte specifies that service is related to the specific department and minor byte specifies that service is related to a particular section of the department. The sub-profile byte provides information about the services and associated type of the user. The eight services for each department are configured in the nRF52DK, i.e., Campus Map, Department Map, Day Schedule, Lunch/Breakfast Menu, Conference/Classroom room availability, Seat Availability, Number of students available in the conference room, Book availability in the library.

The service advertisement frames are configured with the help of above-defined profile, sub-profile, major and minor parameters. One of the implemented service advertisement frame is shown in figure 6-6, it is implemented in Keil cross compiler for the nRF52823 microcontroller.

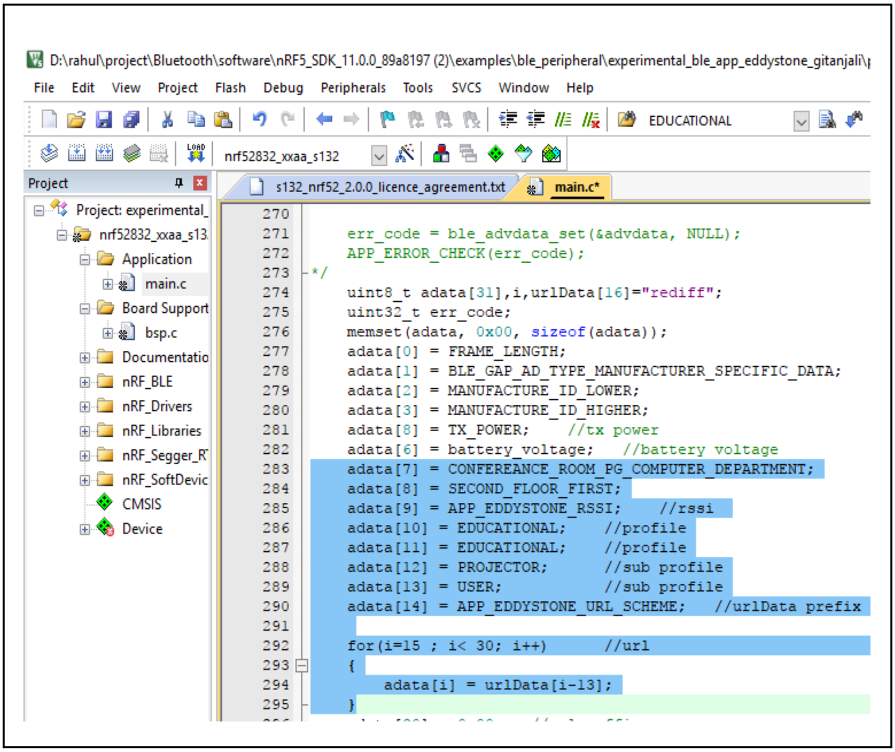


Figure 6-6 Profile based BLE advertisement frame with service

6.3.3 MULTIPLE SERVICE ADVERTISEMENT

As per the third stage of PAPSA, multiple services can be embedded in the nrf52dk. The services are advertised after advertisement interval. In the implementation, eight services per department are embedded for advertisement and advertisement interval, i.e., *"AdvInterval"* is kept as 100ms. The frame counter is kept according to the number of services to be advertised i.e. "*ble_frame_counter*" is kept 32. The multiple service advertisement is verified on the Digital Storage Oscilloscope (DSO), shown in figure 6-7. On the x-axis, time in milliseconds and on the Y-axis the current consumption during the service advertisement is presented. The peak in the waveform indicates that service is advertised after 100ms.

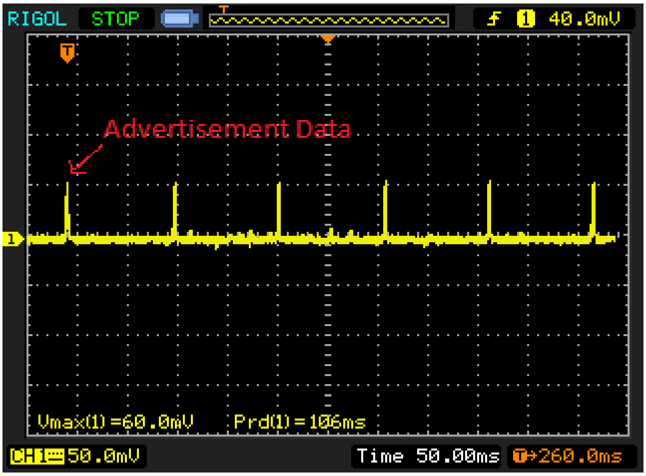


Figure 6-7 Multiple service advertisement

6.3.4 FIRMWARE FLOWCHART

The firmware flowchart is shown in figure 6-8. Upon Power on *APP_TIMER_INIT* function is used to initialize the application timer with a value of the *RTC1 PRESCALER* register. The *APP_TIMER_INIT* has two parameters *Prescale* and *buffer_size*, these are kept as zero for no prescaling and four size operation queue respectively. RTC timer is used to implement the app timer module with a clock frequency of 32.768KHz crystal oscillator.

The *bsp_init* function is used to initialize *GPIO* pin to drive the *LED* during board initialization, upon power-on *LED* is switched off. It passes timer tick value to the RTC timer to handle all the *LED* and status. Here timer tick is 100ms. *bsp_init* will start application timer in a *single shot* mode using *app_timer_create* function and assign *leds_timer_handler as* interrupt service routine which is used to show *LED* indications in different modes of BLE, i.e., Idle, Scanning, advertisement, connected and errors.

APP_ERROR_CHECK function is used to check any error condition returned by the *bsp_init* function. When *bsp_init* function initializes BSP properly, it will return *NRF_SUCESS* return code.

The *ble_stack_init* function is used to initialize Softdevice BLE stack and BLE event interrupt.

The *advertising_init* function is used to initialize the advertising functionality. It encodes the advertising data and passes it to the BLE stack. It also set *BLE_GAP_ADV_TYPES* to *BLE_GAP_ADV_TYPE_ADV_NONCONN_IND,* i.e., advertisement type is non-connectable undirected explained in the section 5.2.1. It also sets the advertising interval to 100mSec and allocates memory for advertisement data.

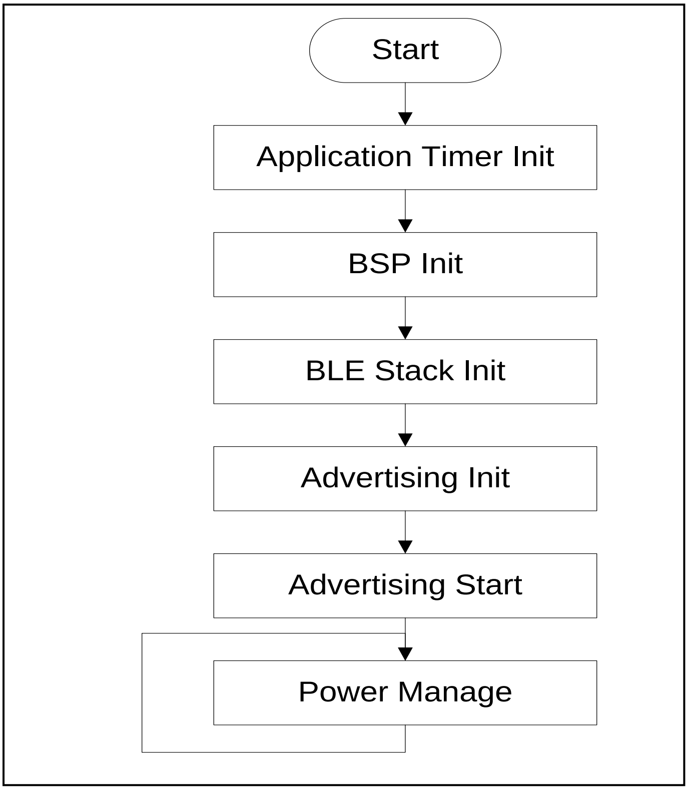


Figure 6-8 Firmware flow of events

The advertising_start function is used to start the advertisement frame, and *bsp_indication_set* function is called to blink LED0 for an indication that the advertisement frame has started. The *power_manage* function is used to manage the power consumption of the application by configuring application event and put the controller into sleep mode until some interrupt occurs.

Advertisement data is changed in interrupt routines for each service, *ble_frame_counter* keeps track of a number of service frames to be advertised.

6.4 EXPERIMENTAL RESULTS

System performance is based on the working of PAPSA and PSR mechanisms. The system performance is verified by changing a few parameters. Energy efficiency of PAPSA is evaluated by changing advertisement interval, and the consequent change in current consumption is observed. The PSR performance is evaluated by observing the behavior of algorithm with a change in user profile parameters, i.e., personalized discovery.

6.4.1 AVERAGE CURRENT CONSUMPTION

There are two parameters that affect most on the current consumption of BLE device, i.e., transmit power, Advertisement Interval. Higher Transmitting power provides a longer Bluetooth range and wide coverage area, but transmitter will draw more current from the battery of BLE advertisement device. Advertisement interval is the most important factor to determine the battery life. An advertisement device running with a BLE stack consumes more current while transmitting the advertisement data and in the advertisement interval it consumes less current, i.e., sleep time. If we increase the advertisement interval and lower the transmit power, then we can utilize the battery power more efficiently.

The equation for calculation of average current consumption [15] is as follows and parameters are depicted in figure 6-9:

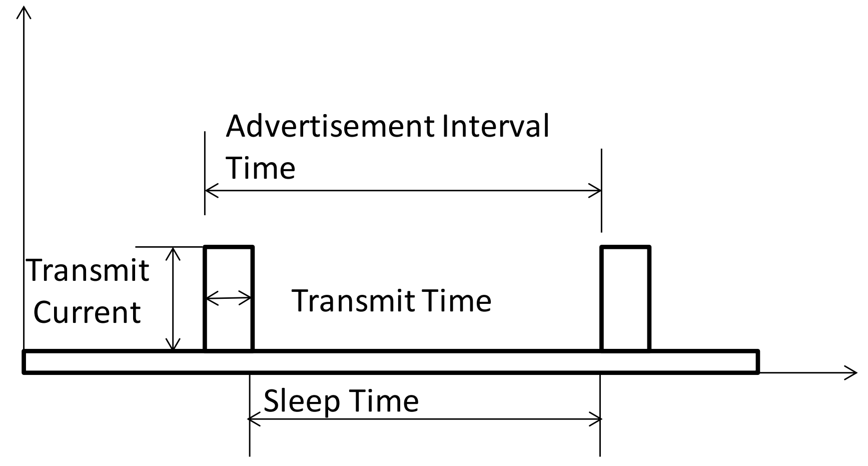


Figure 6-9 Advertisement frame parameters

$$Avr = \frac{Tr + Sr}{Avt}$$

Where *Tr is* transmit current consumption*, Sr* is sleep current consumption, *Avr is* average current consumption and *Avt is* average interval time.

Battery life can be calculated using the following formula:

$$BL = \frac{BC}{Avr}$$

Where *BL* is battery life and *BC* is battery capacity.

The CR2032 battery is used in the nRF52DK for power supply. The battery capacity of CR2032 is 230mAH.

Procedure to calculate current consumption:

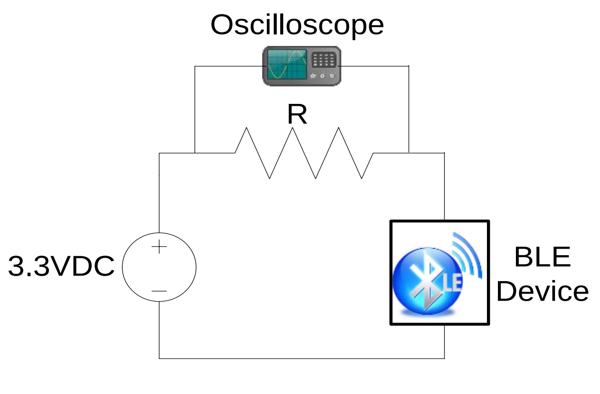
- We need to provide a power supply of 3.3Vdc externally by using coin cell battery or external power supply of 3.3Vdc to calculate the current consumption of nrf52DK. The oscilloscope circuit and BLE device must share same ground as shown in the figure 6-10.

- Install a resistance (R) in series with the nRf52DK. Here 10Ω resistance is used because the resister is a current limiting device as its value is based on the maximum value of current that can pass through the circuit. The Maximum value of expected current by the BLE device is 20mA. Voltage difference across the BLE device is 0.20V and hence R= V/ I, R = 0.20V/ 20mA, R is calculated as 10Ω

- Connect the Oscilloscope probe across the resister to observe the current consumption waveform.

Initially, the interval time is kept as 100ms for service advertisement and current consumption is observed. To evaluate the PAPSA performance, the service advertisement is done for four different scenarios by changing advertisement interval, i.e., 100ms, 200ms, 500ms, and 1000ms. With following parameters:

- Transmit power: 0dBm
- Advertisement data transmission time:2msec
- Current required for data transmission: 10mA
- Current consumption in sleep mode: 0.001mA



BLE device, Register, power supply and oscilloscope

Figure 6-10 Setup to measure current consumption

With the increasing advertisement interval, the current consumption decreases as shown in figure 6-11. The nrf52dk SoC will be in sleep mode for interval time hence with the larger interval time the current consumption of the device is decreased, and it results in improving the battery life of the device, as shown in table 6-1.

Sr.No.	Advertisement Interval time (mSec)	Sleep time (mSec)	Average current consumption (mA)	Battery Life (days)
1	100	98	0.20098	1144.39
2	200	198	0.10099	2277.45
3	500	498	0.04099	5610.30
4	1000	998	0.020998	10953.42

Table 6-1 Advertisement interval Vs current consumption and battery life

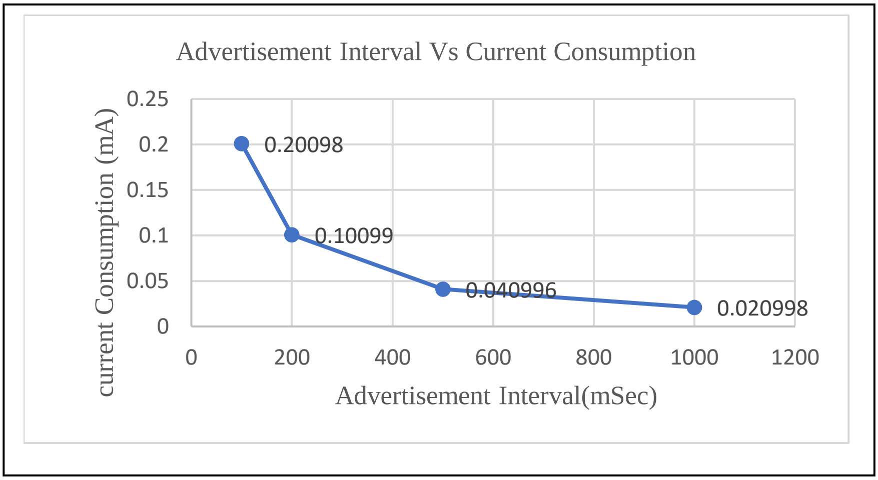


Figure 6-11 Advertisement interval Vs Current consumption

In the figure 6-11, the current consumption of BLE advertiser is observed for different advertisement interval times, the current consumption reduced while the increase in interval time. However large interval time will be annoying and it results in slower service discovery to the user. From the experimental results, we can say that advertisement interval should be 1000mSec.

The average current consumption is also observed for different scenarios by changing transmission power i.e., -40, -20, -12, -4, 0 and 4 dBm, With following parameters:

- Advertisement data transmission time:2mSec
- Advertisement interval time: 1000mSec
- Current consumption in sleep mode: 0.001mA

Although the transmission range increases with increase in transmission power but it also increases average current consumption. The results of the experiments are shown in the figure 6-12, it shows that average current consumption increases with increasing transmission power. The effect of the transmission power on the battery life of BLE device is shown in the table 6-2. The result shows that the battery life is degrading with increasing transmission power due to higher average current consumption.

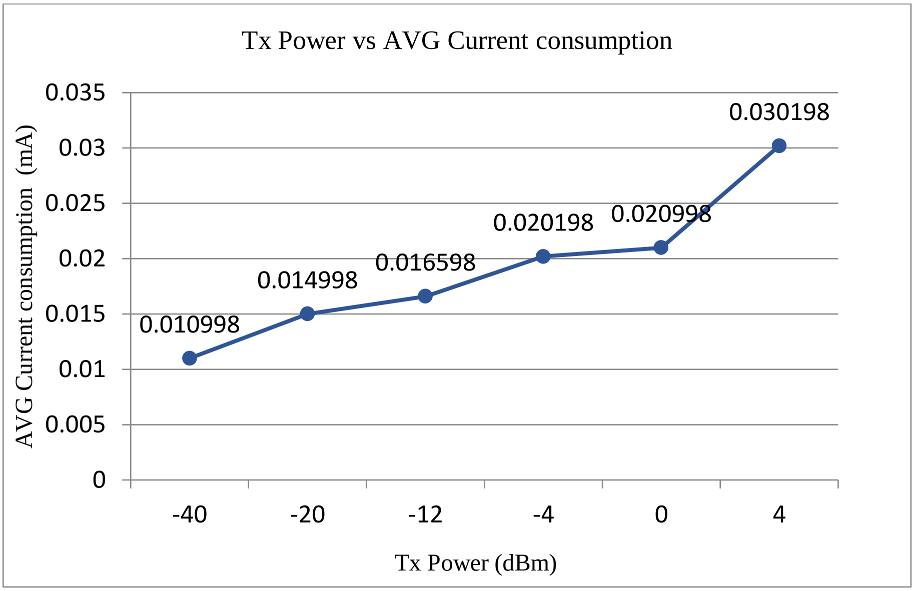


Figure 6-12 Average current consumption vs Tx power

Sr.No.	Tx Power (dBm)	Average current consumption (mA)	Battery Life (days)
1	-40	0.010998	20912.89
2	-20	0.014998	15335.38
3	-12	0.016598	13857.09
4	-4	0.020198	11387.27
5	0	0.020998	10953.42
6	4	0.030198	7616.39

Table 6-2 Tx power Vs current consumption and battery life

6.4.2 SERVICE DISCOVERY AND RANKING

The performance of the PSR mechanism is evaluated by changing the user profile parameters and discovered services list is observed. The proposed algorithm works in two stages. The first stage is filtering of the services and the second stage is a ranking of the services, as discussed in section 6.2. The evaluation of the algorithm is done for both stages. In the first stage, the results are observed by changing user role, i.e., student, professor and visitor. In the second scenario, the results are observed for the same role with different attributes.

As aforementioned, total 32 services are advertised for evaluation of the PSR, services are listed in the section 6.3.2. After applying both stages of PSR, the visitor should get four services out of 32 services based on the service configuration, similarly seven services for professor and six services for the student. However, without PSR user gets more nonpreferred services than preferred services as shown in the pie graph 6-13. In this, result of service discovery for professor is shown, the professor gets all services that are advertised, out of this 21.87% are preferred services and remaining 78.13% are nonpreferred services.

The PSR mechanism improves the service discovery result by discarding nonpreferred services in two stages, as follows:

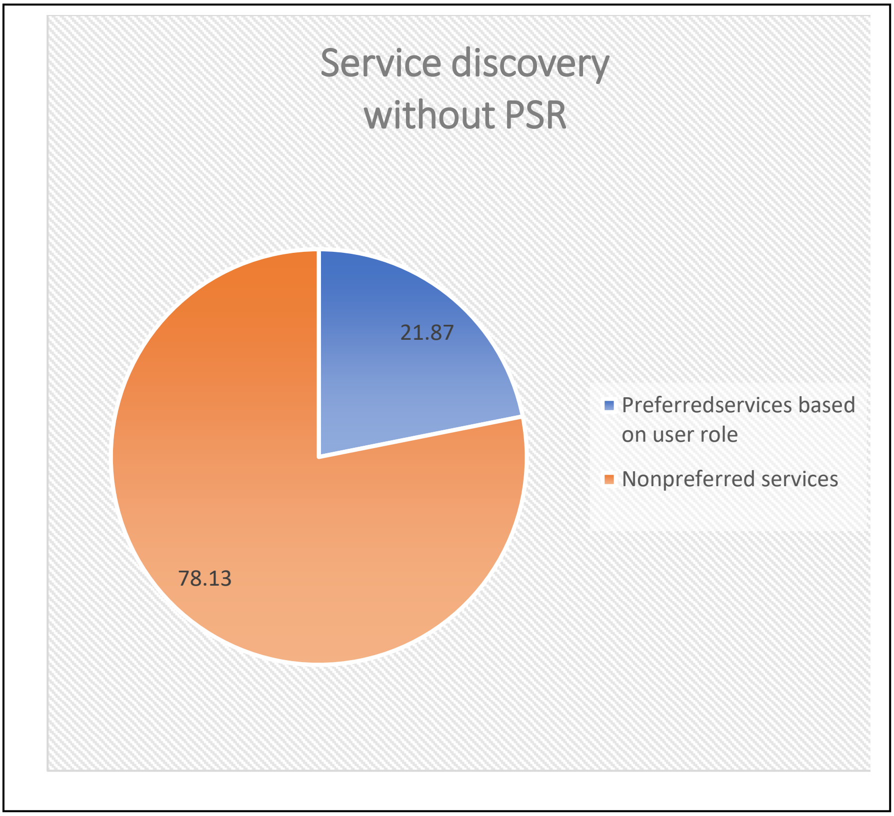
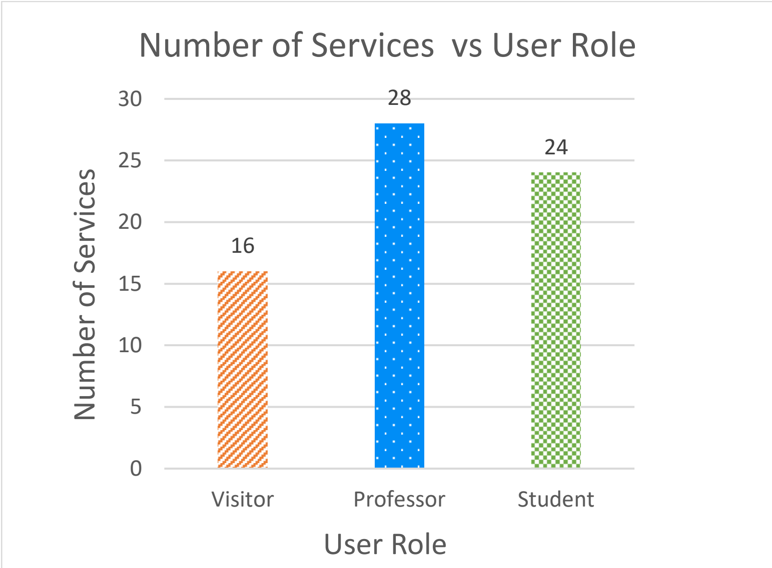


Figure 6-13 Result of service discovery without PSR for professor role

Role-specific service discovery: The PSR filters IoT services as per user role. The student should get only services that are preferred for its role among the available services, and similarly for professor and visitor role. The visitor discovered 16 services among 32 services after applying the first stage of PSR, i.e., role-specific service discovery. Similarly, 28 services for professor and 24 for the student, shown in figure 6-14.



stage 1: by changing user roles (i)visitor role (ii)Professor role (iii) student role

Figure 6-14 Role specific service filtration

The figure 6-14 shows that first stage of the PSR works efficiently, it improves service discovery performance by discarding services not related to the specific role. Hence percentage of nonpreferred services reduced as shown in the pie graph, 6-15. In this, the result of service discovery for the professor is shown. The professor gets 87.5% services out of all advertised services, out of this 21.87% are preferred services, remaining 65.63% are nonpreferred services. And 12.5% of services are discarded.

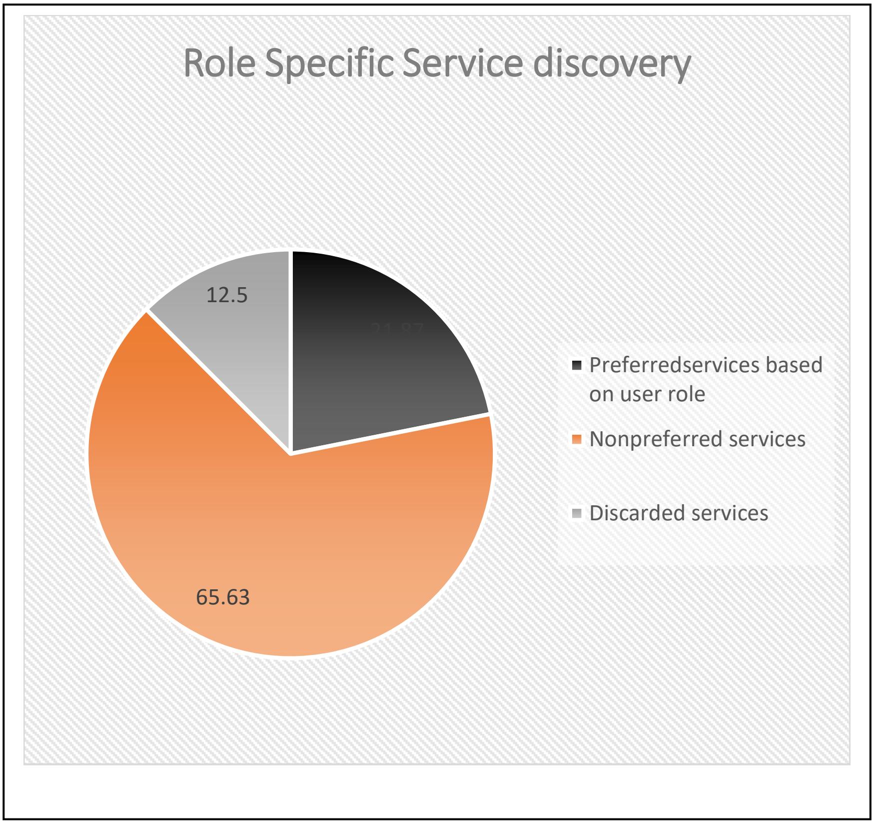


Figure 6-15 Role specific service discovery for professor role

Personalized service discovery: The first stage of PSR filters the services based on user role. However, still user is not getting services as per his preference because the same role may have a different preference.

In the second stage of PSR, the filtered services are ranked as per the user's profile attributes. The PSR performance is evaluated by changing user's profile attributes using major byte. Major byte specifies that service is related to the specific department.

The result shows that user gets a preferred list of services as per their profile attributes, as shown in figure 6-16.

After applying the second stage of PSR, the visitor discovered four services among 32 services. Similarly, seven services for professor and 6 for the student, shown in the figure 6-16.

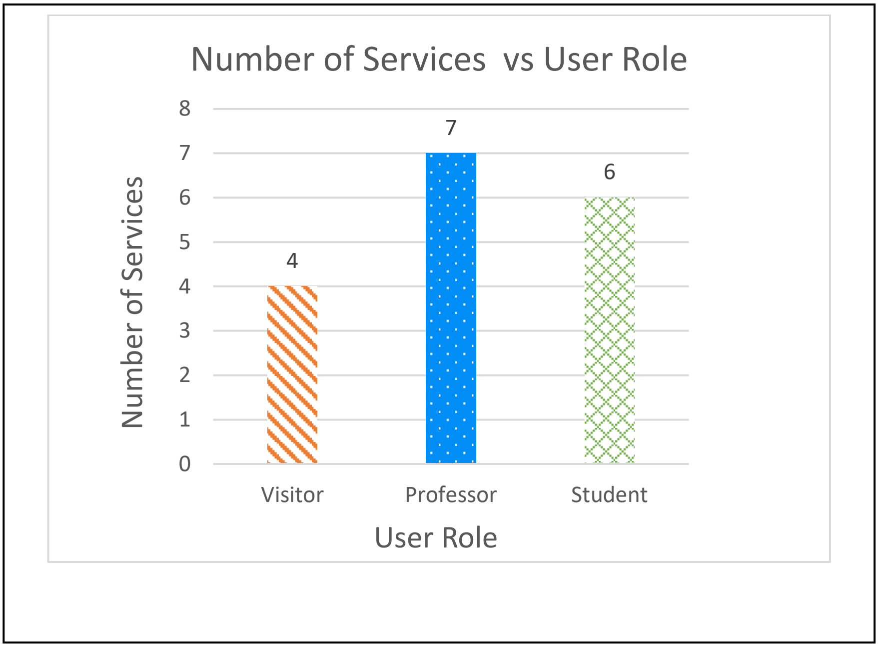


Figure 6-16 Personalized service discovery

In the pie graph 6-17, the result of personalized service discovery for a professor is shown. The professor gets 21.87% services out of all advertised services and remaining 78.13% nonpreferred services are discarded.

The above results of stage one and stage two of PSR shows that service discovery process improves significantly due to discarding nonpreferred services. The performance of the PAPSA and PSR is also verified by observing the service discovery results for different scenarios, i.e., based on context information and history of service usage.

The user gets the benefit of the IoT service using beacon/cluster-based approach, PAPSA and PSR mechanisms. We need to follow specific framework for user-cluster interaction to develop beacon based IoPTS application. In this research, the cluster framework for IoPTS is proposed for seamless user-cluster interaction.

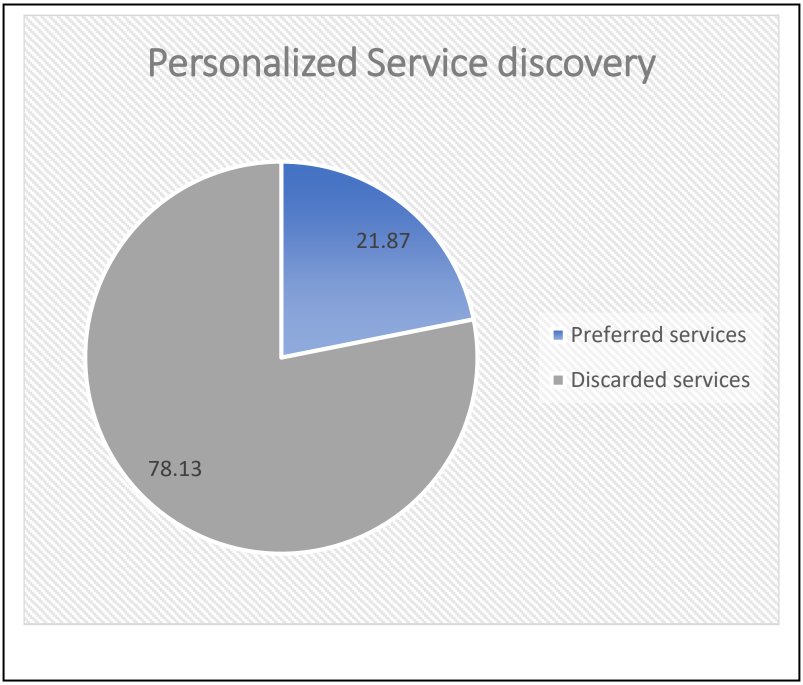


Figure 6-17 Personalized service discovery for professor role

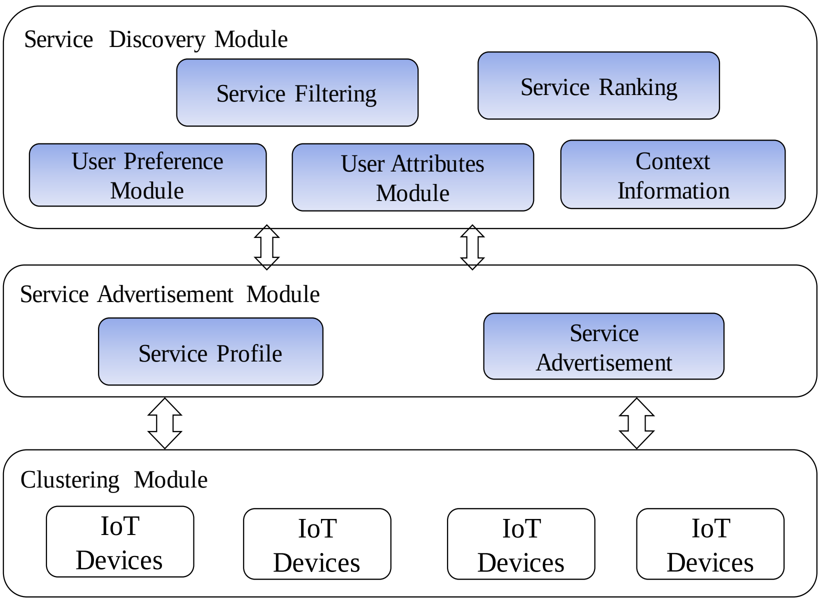
6.5 PROPOSED CLUSTERING FRAMEWORK OF IOPTS

This thesis proposes the generic cluster framework for IoPTS. The functional blocks of this framework are depicted in figure 6-18 and system architecture of cluster-based application is presented in figure 6-19. The framework consists of three modules for device organization, service advertisement and service discovery. The clustering module defines the process for device organization. The service advertisement module works based on a beacon-based approach to make aware users about the presence of the services. The service discovery module discovers preferred services among a large number of services.

In the clustering module, in IoPTS application devices are organized using the proposed MACS mechanism (presented in Chapter 4, section 4.2). The different clusters will be formed after the MACS, and each cluster will have one CH. All devices in the cluster send the sensed parameter to the CH. All CHs forward data to the GW and through GW data is stored at the server/cloud. Further, the data is processed and IoT services are defined. Hence, each cluster may have bunch of services and further these services are advertised using the beacon-based service advertisement module.

In the service advertisement module, service profiles are defined. BLE advertisements frames are generated using service profiles and proposed profile based BLE advertisement frame format. These frames are embedded into the BLE device and multiple IoT services are advertised as per PAPSA mechanism, discussed in section 6.1.

In the service discovery module, user role, preferences, context information and usage history are retrieved and similarly service attributes are retrieved from BLE advertisement frames. Services are filtered and ranked using proposed PSR mechanism for personalized service discovery.



Cluster framework consist three modules 1) Clustering module for organizing devices 2) Service advertisement module for profile aware multiple service advertisement 3) Service Discovery module for user preferred service discovery.

Figure 6-18 Cluster framework for IoPTS

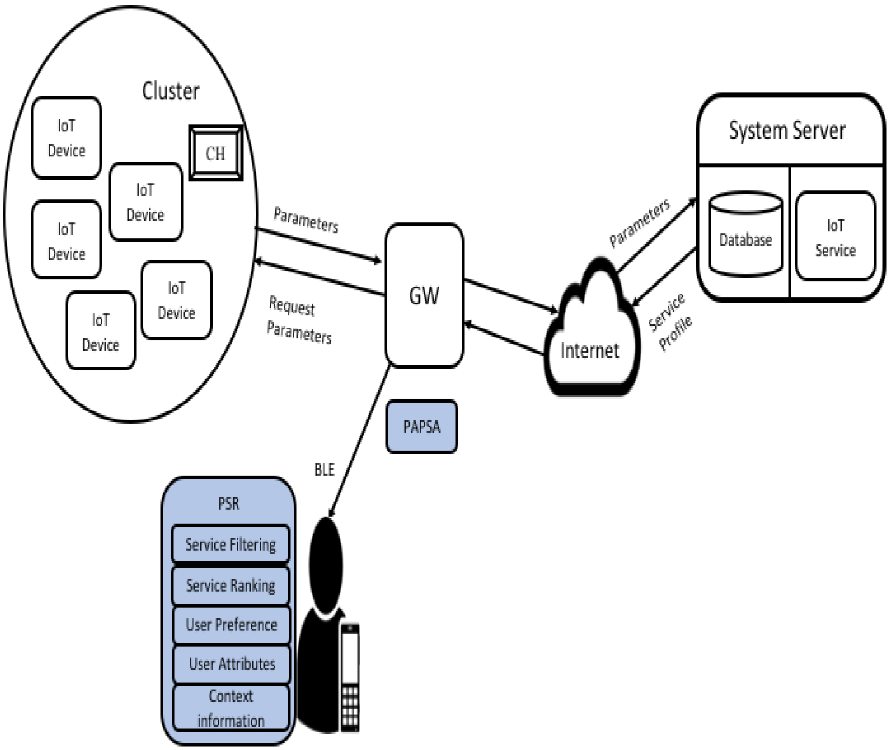


Figure 6-19 System Architecture of cluster-based application

6.6 SUMMARY

In IoPTS applications, services may be advertised using the BLE beacons by following proposed cluster framework. In the research profile based BLE beacon format is proposed, it provides facility to add more information about services.

In the PAPSA, services are advertised using Nordic BLE device, i.e., nrf52DK. IoT services are advertised by embedding service information into the BLE advertisement frame. The detailed configuration of BLE device and advertisement frames are presented in this chapter.

The multiple service advertisement by single BLE device is also proposed in the research. After advertisement interval, the advertisement frame changes its data related to the different services and advertise these services. The multiple service advertisement is needed in the IoPTS environment as every cluster is aimed to advertise some IoT services.

The user's smart-phone will be flooded with notifications due to a large number of available IoT services. This situation will be annoying for the user as he/she may be interested in the specific type of services. The research proposes the service filtering and ranking algorithm to achieve user-centric service discovery, i.e., PSR to provide user preferred services.

In the next section of this chapter, the performance of service advertisement module i.e., PAPSA is verified by estimating the current consumption and battery life. For this evaluation, thirty-two services are advertised using multiple service advertisement approach by varying the advertisement interval. The performance of the service discovery module is verified by changing user roles and attributes. Service discovery results show the user gets a list of IoPTS service as per their role, preferences, context information and usage history.

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CHAPTER 7. CONCLUSIONS AND FUTURE WORK

This chapter aims to conclude the thesis and proposes the direction for future work. The thesis addresses the challenges of the user-service interactions and proposes the cluster framework for IoPTS. In this thesis, the mechanism for the organization of IoT devices is proposed. Further, beacon-based service advertisement approach is proposed to achieve profile awareness. Lastly, the personalized service discovery mechanism is presented to offer preferred services to the user. In the thesis, proof of concept, simulation and the implementation results have been used to validate the research findings.

7.1. CONCLUSIONS

The objective of this thesis was to design cluster framework for user-cluster interaction in the IoPTS environment. To design such a framework for user-cluster interaction, we need to address some requirements of the framework, i.e., the organization of IoT devices, the method to make the user aware of the services available in the particular premises, and the service discovery according to the user's requirements. To address these requirements, our contributions are as follows:

- A mechanism to organize devices efficiently based on a MACS clustering algorithm. The IoT devices are clustered based on the location and fitness value. MACS supports mobility and provides an energy-efficient and scalable approach for organizing devices.

- An energy-efficient and profile-aware proactive approach for service advertisement is designed, i.e., PAPSA. The services are advertised using a profile based BLE advertisement frame. The energy efficiency is achieved by advertising multiple services using a single beacon device. The service advertisement frames are stuffed with service information to facilitate personalized service discovery.

- A Personalized service discovery mechanism, i.e., PSR, is designed to provide relevant services to the user. The personalized service discovery mechanism discards the services that do not match the user preferences and requirements. In this mechanism, a two-stage approach is used to provide preferred services to the user.

- A generic cluster framework for IoPTS is designed to provide functional blocks for user-cluster interaction. The cluster framework consists of three modules, i.e., device clustering, service advertisement and service discovery module to achieve the above-mentioned objectives.

The thesis has discussed various aspects of the IoPTS. The focus is given on the method of user-IoT device interaction. The need of IoPTS is derived from the different approaches of the IoT service utilizations. This thesis defined the challenges in the IoPTS which includes the device organization, making the user aware of IoT services and service discovery. In the IoPTS, devices may not be directly exposed to the external world to offer the services due to reasons as mentioned earlier. Hence, the user-service interaction will be done through the GW.

The thesis has analyzed two major phases based on the user-service interaction. In the first phase, we focused on the device - GW communication. In this phase, we defined the problem of the organization of devices, i.e., the functionality of devices behind the GW. We need to identify the type of IoT devices, the role of the devices, the different type of clusters, the method of connecting these devices to the GW and role of the GW in the cluster.

In the second part of the thesis, we focused on the user interaction with GW to get benefited from the services provided by the IoT devices. In this part, we needed to identify the methods of providing services to the user. In the IoPTS, the need of making the user aware of available services without installing the specific app is focused. Hence, different approaches of service utilization have been studied like app-based, web-based and the beacon-based approach. In the thesis beacon-based approach has been selected for further enhancement to provide a different aspect of the service advertisement. The energy efficiency of the service advertiser device plays a vital role because it may be possible that the advertiser device could be battery powered, e.g., the advertiser device may be deployed at the bus stop to offer "bus route service." The cluster of the devices may have numerous services to be provided to the user. Hence, service advertiser should have a mechanism to advertise multiple services. In this research, the focus is given to provide a mechanism for multiple service advertisement. The service advertisement in the beacon based approach is not directed to the specific user as it uses broadcast approach. The broadcast approach may not be beneficial to the user as the user may require specific service among the available services. In this thesis, the BLE advertisement frame is modified to provide additional information about the service, and hence the user can decide to use the specific service. Finally, this thesis proposes the cluster framework that consists of the organization of devices, service advertisement and service discovery modules. These modules are designed, implemented, simulated and evaluated to verify the user-cluster interaction.

7.2. SUMMARY OF CONTRIBUTIONS

In the thesis, different challenges of cluster framework are identified and some of the challenges are focused in the research. The different mechanisms, algorithms are studied and analyzed to propose the framework for user-service interaction.

The first part of the thesis provides the clustering mechanism for the organization of IoT devices. The clustering algorithm is targeted to the self-healing cluster. In this type, devices may be resource constrained, i.e., limited in energy source, memory, and computational capability. The self-configurable clustering algorithm is required in such clusters. Hence the different parameters need to be addressed to design self-configurable and energy efficient clustering algorithm. The analysis of different clustering algorithms is done to discover the design parameters. The parameters like mobility, energy consumption, inter-cluster communication, uniform CH selection, the location of the CH and node association capability are finalized from the state of the art and gap analysis.

The PSO based MACS is presented to organize devices in the self-healing cluster based on these design parameters. The MACS address the scalability, mobility and energy consumption issues of the network with resource-constrained devices. The MACS scheme is based on the multi-variable fitness function for cluster formation. The fitness function value provides the devices with high residual energy, node association capability and data transmission capacity. Further, these nodes are selected as the CH. The MACS provides the uniform distribution of the CHs to support the energy efficiency.

The MACS is simulated for the scenario with increasing number of nodes. The MACS performance is not degrading significantly with the increasing number of nodes in the network and hence it shows the suitability of MACS in a network with high node density. The MACS performance is also verified for its support to the network with the mobile nodes. The MACS works better for a network with stationary nodes. However, its performance is not degrading significantly for the network with mobile nodes and in the sequel, this shows the mobility support of MACS. The outcome of this contribution shows that the MACS provides scalability, energy efficiency and mobility support. However, MACS is not applicable to the heterogeneous and user-driven clusters. Here, heterogeneity refers to the communication interface. In this research, devices having similar communication interface are considered, however these are heterogeneous with respect to the energy source.

The clustering algorithm could be designed for the user-driven on-demand cluster. In user-driven on-demand approach, clusters should be formed based on the user requirements. The devices in the cluster that can fulfil user's requirements should be organized in the cluster to provide services to the user. It may also include devices from different clusters.

The second part of the thesis provides the mechanisms for service advertisement and discovery. In the beacon-based approach, service advertiser provides services to the user using the broadcast method. The user needs to select preferred services as per their requirement among all the advertised services. Hence, the service advertisement mechanism with additional information is required in the beacon-based approach. Further, in this approach, it is also possible that the advertiser may be battery powered. Hence, the energy efficient service advertisement mechanism is required.

The PAPSA mechanism is presented to address energy efficiency and profile awareness issues of the beacon-based approach. The PAPSA mechanism is designed based on the iBeacon and Eddystone service advertisement mechanisms. The PAPSA mechanism is implemented on nrf52DK. The performance of the PAPSA mechanism is validated by observing the energy consumption of advertiser device with different advertisement interval. The result shows that the energy consumption is reduced with increasing advertisement interval time. The outcome of this contribution shows that the proposed PAPSA mechanism is energy efficient and provides better profile awareness. However, in the PAPSA advertisement frame the length of URL is restricted up to 17 bytes which limit the scalability.

The user’s preferences and attributes should be matched with the service profile attributes for personalized service discovery. The thesis present PSR mechanism to provide personalized services to the user by matching service profile and user attributes. The PSR works in the two stages: in the first stage, services are filtered based on the user role and in the second stage, services are ranked based on the user preferences, context information and history of service usage. The PSR provides the preferred services to the user by discarding non-preferred services in these two stages. The performance of the PSR is validated by designing the system with three different roles and 32 services. The system results show that the first stage of the PSR discards significant number of services based on the user role. Similarly, in the second stage PSR discards more non-preferred services based on the user attributes. However, we have not addressed the mechanism to retrieve the user profile attributes.

The service advertisement could be done using Bluetooth 5 for long range transmission and to overcome advertisement frame length limitations. In the PAPSA, service advertisement frames are stuffed with service profile attributes and service URL. However, standard URL formats could be used to avoid the interoperability issue. In the PSR, services are ranked based on the user preferences and context information. However, the user requirements and preferences could be predicted using predictive machine learning algorithms.

This thesis proposes the cluster framework for IoPTS, extending the existing beacon-based approach to provide seamless user-cluster interaction. This framework enables organization of resource constrained and mobile devices. Further, the framework provides the energy efficient beacon-based approach to advertise services to the user and facilitates personalized service discovery. However, the framework would have another module to retrieve user preferences and to provide authorization for the authorized use of the services.

7.3. FUTURE WORK

In this thesis, there are still many aspects for improvement in cluster framework that are not addressed. We would like to discuss some open problem for future research:

The research provides device organization mechanism for self-healing clusters. However, cluster framework needs to be scalable for another type of cluster, i.e., user-driven on-demand cluster. This could be achieved by categorizing devices based on the data-centric approach to form the user-driven cluster in which GW could select the devices that can fulfil the user requirements based on the data-centric approach. For this purpose, the GW should have the capability to select devices efficiently to form the user-driven cluster. The cluster may have devices with a heterogeneous communication interface and to organize such devices the cluster should have a single CH with multiple communication interfaces or multiple CH with the different communication interface. In the heterogeneous cluster, the energy of the CH will degrade faster than the homogeneous network. As CH has different communication protocols, it needs to convert packets from the different protocol formats to a unique format for further data processing and aggregation. Hence, the clustering algorithm should have an energy-efficient way to convert packets in the similar format. The CH should have more computational capabilities to handle data in different formats.

Service URL standardization would be another interesting enhancement for cluster framework. The service providers use a different format to specify URL for services. In such systems, the developer is required to write a code for an app that understands the specific data format which leads to the interoperability problem. HyperCat is the technology that uses this approach to provide interoperability. Hence, the cluster framework could use this approach to resolve interoperability issue.

The service URL length could be the limiting factor for IoPTS, as a number of clusters offering services will be large in number. The URL length could be increased using Bluetooth 5 advertisement frame of 256 bytes. The user may need additional information about a service, and this could be advertised using multiple frames.

Security and privacy could be added to the beacon-based service advertisement. In a secure beacon-based approach, the encrypted identification value is added in the service advertisement frame to secure use of service by the authorized user. Authorized users should then have a mechanism to use encrypted service frame. The encrypted identification value could be periodically changed to achieve secure use of services.

Moreover, configuring and retrieving user profile attributes is an important direction for the future research. The user profile could be configured based on the utility provided by the cluster framework. The user's preferences and context information could be retrieved from user's service usage history and social networking. Further, the cluster framework should provide an interface to view the service notifications that are filtered and ranked based on the cluster framework, i.e., using PAPSA and PSR.

Dynamic creation of user roles will enhance the performance of cluster-based approach. This service discovery can provide more accurate results with the resultant dynamic roles.

Furthermore, authorization and access control module would be another extension to the existing cluster framework. The strong access control and authorization should be applied for secure interactions. The User Managed Access (UMA) could be applied to the cluster framework as UMA supports the dynamic addition of services and resources at runtime. In UMA, permissions of resources can also be defined at design or runtime. The UMA resource owner establishes the relation between the authorization server and service at runtime. Hence, there is a facility to have different entities to develop the authorization server and services.

APPENDIX

Appendix A. Trace File

The appendix contains the method to calculate design parameters of clustering algorithm i.e., Delay, EC, COH, PDR. These parameters, are calculated from the trace file. The trace file is the log file, in which log of simulation is stored. From these, detailed information about simulation can be retrieved: sender and receiver ID, time when a packet is sent and received, packet size, packet type i.e. control packet or data packet, device location, address, energy, etc. Following is the format of the trace file:

```
s -t 0.010269970 -Hs 59 -Hd -2 -Ni 59 -Nx 258.76 -Ny 240.81 -
Nz 0.00 -Ne 59.997203 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt
0 -Is 59.255 -Id -1.255 -It PSOC -Il 44 -If 0 -Ii 0 -Iv 1

s -t 0.010270074 -Hs 34 -Hd -2 -Ni 34 -Nx 214.27 -Ny 275.68 -
Nz 0.00 -Ne 79.999073 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt
0 -Is 34.255 -Id -1.255 -It PSOC -Il 44 -If 0 -Ii 0 -Iv 1

s -t 0.010270081 -Hs 50 -Hd -2 -Ni 50 -Nx 213.90 -Ny 221.71 -
Nz 0.00 -Ne 59.997032 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt
0 -Is 50.255 -Id -1.255 -It PSOC -Il 44 -If 0 -Ii 0 -Iv 1

s -t 35.534765542 -Hs 23 -Hd -2 -Ni 23 -Nx 459.37 -Ny 130.90 -
Nz 0.00 -Ne 79.980399 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt
0 -Is 23.255 -Id -1.255 -It PSOC -Il 44 -If 0 -Ii 0 -Iv 1

f -t 35.553215279 -Hs 41 -Hd -2 -Ni 41 -Nx 41.01 -Ny 151.62 -
Nz 0.00 -Ne 59.943876 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms
22 -Mt 800 -Is 96.255 -Id -1.255 -It PSOC -Il 44 -If 0 -Ii 0 -Iv -4
```

Trace file provides the following details about simulation, field 0 provides information about the packet status i.e. sent, received, dropped or forwarded by the device, field 1 provides the time of the event, field 2 provides next hop information. Field 3,4,5 provides node status, MAC, and IP layer information respectively.

- Field 0: shows the event type

  s: send

  r: receive

  d: drop

  f: forward

- Field 1:shows time of the event

  -t: time

- Field 2: shows the next hop node information

  -Hs: id for this node

  -Hd: id for next hop towards the destination

- Field 3: shows the Node property

  -Ni: node id

  -Nx –Ny -Nz: node's x/y/z coordinate

  -Ne: node energy level

  -Nl: trace level, such as AGT, RTR, MAC

  -Nw: reason for the event

- Field 4: shows the packet information at MAC level

  -Ma: duration

  -Md: destination node's ethernet address

  -Ms: source node's ethernet address

  -Mt: Ethernet type

- Field 5: shows the packet information at IP level

  -Is: source address. source port number

  -Id: destination address. destination port number

-It: packet type

-Il: packet size

-If: flow id

-Ii: unique id

-Iv: Time To Live (TTL) value

From these information parameters are calculated as follows:

- ***Delay:*** delay is calculated from the information in field 0 and field 1.

  Let FT is time when packet is received by the receiver

  ST is time when packet is transmitted by the sender

  If (field 0 ==" S") \\ Sender

  Then ST = field 3: time \\ transmission start time

  If (field 0 ==" r") \\ Packet received

  Then FT= field3: time \\ transmission end time

  Delay is calculated using the equation as follows:

$$\boldsymbol{Delay = FT - ST}$$

- ***EC:*** Energy consumption is calculated using the information in field 4: -Ne, node energy

  Let IE is the initial energy of device

  RE is the residual energy of device after simulation ends

  RE = -Ne ; in each iteration device energy is stored in the RE

  EC is calculated using equation as follows:

$$\boldsymbol{EC = IE - RE}$$

- ***COH:*** Control overhead is calculated from the type of packet information i.e. Field 6: -It and field 0

  Let CP is number of control packets received
  PR is Number of packets received

  \\ CP is incremented if received packet is a control packet

  If field 0 == "r" and field 6:-It == control packet

      Then CP++;
      PR++

  COH is calculated using equation as follows:

$$COH = \frac{CP}{PR}$$

- ***PDR:*** PDR is calculated based on the number of packets sent and the number of packets received. Field 1 of the trace file provides the information about packet sent or received. PDR is calculated as follows:

  Let send is the number of packets sent

  Recv is the number of packets received

  \\number of data packets send and received are calculated

  If Field 1== "S" && Field 6:-It != control packet

  Then send++;

  If field 1=="r" && Field 6:-It != control packet

  Then recv++

  PDR is calculated using equation as follows:

$$PDR = \frac{recv}{send} * 100$$

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