Performance Analysis of Fog and Cloud Nodes for Cognitive Internet of Things

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at BRAC University. Some parts of this thesis paper have been submitted in the book chapter titled " An Overview of Cognitive Internet of Things: Cloud and Fog Computing ", of the book titled " Secure Edge Computing: Applications, Techniques and Challenges" published by CRC Press, USA.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Abstract

Over the past decade, human interest in wireless communication has increased remarkably, and this has led to the development of the Internet of Things (IoT), Cloud, Fog, and Edge Computing. Existing wireless network models face several problems: low mobility, shortage of storage space, and slow data transfer speed due to the increased data traffic. As 127 new IoT devices are connected to the web every second, finding the solution to these problems has become a necessity. To improve the baud rate, Cognitive Radio was introduced, allowing the signals to select the shortest possible route during transmission. This paper proposes a model for CIoT-Fog-Cloud networking and the Reconfigurable Intelligent Surface (RIS) framework to resolve some of the problems. Fog-Cloud computation and Fog-Fog computation are the two situations considered to explain that storage computation would be more efficient, owning to a reduced physical distance between the Fog Nodes. The simulation results provided signs of quicker data transfer with low energy consumption and less transmission time.

Keywords: Cloud Computing; Cognitive Radio; Edge Computing; Fog Computing; Internet of Thing; Reconfigurable Intelligent Surface.

Dedication

This thesis is dedicated to our beloved parents, who have raised us to be the individuals we are today, who have always been there for us anytime we need them, and who, with their love and goodness, always encourage us.

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List of Acronyms

CIoT	Cognitive Internet of Things
CR	Cognitive Radio
RIS	Reconfigurable Intelligence Surface
Fn	Fog node
SNIR	Signal to noise interference ratio

List of Symbols

τ_{tD}^{FC}	Transmission delay between fog and cloud
R_{fog}	Data rate at the fog node
R_{cloud}	Data rate at the cloud
$SNIR_{fog}$	Signal to noise interference ratio at fog node
$SNIR_{cloud}$	Signal to noise interference ratio at cloud
P_c	Transmission power of the CIoT device
h	Channel coefficient
d	Distance between the CIoT device and the Fog node
α	Path-loss exponent
σ^2	Noise variance
I_{fog}	Interference from other CIoT devices at the Fog node
P_f	Transmission power of Fog device
h_{fc}	Channel coefficient of Fog-cloud
h_{fr}	Channel coefficient of Fog-RIS
h_{rc}	Channel coefficient of RIS-cloud
d_{fc}	Distance between Fog to cloud
d_{fr}	Distance between Fog to RIS
d_{rc}	Distance between RIS to cloud

τ_{tD}^{FF}	Transmission delay between fog and fog
h_{ff}	Channel coefficient of Fog-fog

Chapter 1

Introduction

1.1 Introduction

The electronic transmission of the data between two or more points which are not bound by the electrical device is recognized as wireless networking. Individuals, as well as other organizations, can often interact over long ranges using wireless technologies. Wireless networks are often designed to satisfy various filtering specifications. Those could be modified and reduced easily, according to the requirements of one's organization. While the unforgotten aspect of our lives is wireless technology, demand has risen more than anything because of CIoT. Cognitive IoT involves the usage of cognitive IoT technology paired with linked digital data and methodology that can be provided by such systems. These will therefore make rational judgments, evaluate expectations, examine important data and include on-demand operation. As IoT develops progress, cognitive radio-based IoT frameworks would in the long - run become crucial demands. With the transformation from IoT theory into practice, the number of IoT devices are planned to expand into a wide variety, making it challenging to provide sufficient frequency band to these gadgets. The potential challenge for spectrum regeneration is cognitive radio (CR). CR causes the signal to pick the quickest route for transmission completion. Inactive stations throughout CR and IoT system are recognized by spectrum identification.

Transportation in wireless networks is increasing at an unprecedented pace, and innovative technologies in the future networks are expected to require more high levels and increased profitability. The cloud offers flexible computing capacity and growing forms of data access. This decentralized database system has many parallels to the conventional wireless networks, which interconnects all of the modules required for detecting and local filtering. Many of the most advanced innovations become IoT and cloud computing. A vast volume of data is produced every moment by the Internet of Things (detectors, machinery and technologies). To maximize the advantage of IoT technology, cloud computing allows us to protect and analyze these data. Cloud storage often will enable organizations to extend the network of their specific requirements without requiring external equipment and resources. Besides, Cloud infrastructure often facilities to ensure data sharing and processing or a direct connection to facilitate the continuous transmission of data around computers, software and the web. As this knowledge is transmitted over a lengthy network connection for processing, authentication and monitoring, it takes even longer to analyze the information at the bottom, next to the data source. With the decline of running and maintenance expenses, cloud computing can link devices and allow system registry in a limited period, on-boarding, virtual software maintenance and virtual detection.

In particularly large server networks and general database structures, Fog computing may be interpreted, contributing to the increasing difficulties in viewing knowledge critically. In comparison to databases in network infrastructure, fog computing allows for processing resources to existing on a local network. Comparison to cloud computing, fog computing stresses accessibility to end consumers and consumer priorities, including operating expenses, protection measures, resource utilization, dispersed spatial delivery and conceptual knowledge, decrease in latency and bandwidth savings to deliver higher quality services and edge analytics mining. Fog computing creates this convenient to operate computers between end-users and infrastructure computing information centers, processing and communication services. Fog computing is the interpret from how edge computing works which allows computation, storage and networking infrastructure between end-users and cloud processing centers simpler to run. Similar to network infrastructure, edge computing does not have to be distributed through a distant cloud and other hierarchical networks. Through minimizing distance, the edge will increase the quality and efficiency of data transfer and even the system and equipment on edge through transmitting data to specific channels. Edge, computation and processing structures are situated at the edge of the part, smart device, database or individual generating the data being analyzed as quickly as feasible. The goal is to eliminate communication delay, as the data do not need to be transmitted to a local distribution device from the edge of networks and back to the edge. For edge architectural processors, the Internet of things linked tools is a straightforward usage. This would undoubtedly extend the functionality of IoT devices to have different usage cases with IoT in general through putting a micro platform like fog and edge on the IoT application to offering the software and solutions to utilize this.

1.2 Literature Review

Over the years, researchers have been investigating how to demonstrate quick, time-consuming, and well-secured network system without being disconnected. In this literature review, we have pointed out several remarkable research that has been done.

Review of Fog Computing

T.H. Dang [11] addressed several frame models for the improvement of data security and performance by increasing efficiency. He proposed a Region-Based model for secure transmission among Fog nodes, a Fog-based model for operating Fog nodes and a service development model for changing device location. They found encouraging outputs that demonstrate the suitability of their proposed model.

Therefore, R. Basir et al. [9] discussed the major operating sectors, which are the key to industrial revulsion. Hence, they pointed out the necessary solutions to the critical situation of Fog computing and IoT application.

J. Li et al. [15] proposed a unique forwarding scheme that can maximize the delivery rate while maintaining low latency and efficiency. The experiment verified that the proposed scheme could perform better than many other well-known forwarding models in terms of routing performance and security issue.

Multiple Fog nodes are preferable for building a robust, reliable network system because a single Fog node may get busy and block the whole system. Based on cross-domain IoT function, the authors of [16] proposed a Fog-based framework that shares services at the network edges by using several layers and launched a superior Fog structure for a stable, continuous service.

H. Lu et al. [17] presented an overall discussion of the framework of Cognitive Internet for self-directed driving. Again, they discussed detailed computation of the framework to improve transmission rate through Cognitive Internet of Vehicles and finally came with a cross-domain IoT model for autonomic driving based on Cloud/Fog Computing scheme.

Similarly, M. R. Anawar et al. [18] elaborated the importance of researching Fog Computing infrastructure to gain a more precise concept about significant IoT data computation as Fog Computing is on the rising stage. Thus, they discussed the obstacles while implementing Fog network and pointed out the possibilities in the aspect of ample IoT data research.

P. Verma [19] focused on the problem of unpredictable time delay, which occurs while processing distant health tracking service through Cloud. Hence, the author suggested a preferable solution by utilizing the principle of Fog Computing, including modern methodology. Moreover, correct action taking feature on accurate time made the proposed model more convenient.

S. Ali [20] researched on how to enhance the response duration of heart attack patient, connection of specific transport, and to avoid transport clash during emergency time. In the research field, E-health concept in IoT structure is the advanced section of attention for the researchers. The authors presented an outstanding infrastructure, performance of tasks and classification of the structure to prevent heart attack crisis through voice and gesture monitoring smart devices.

A. Kanyilmaz [21] gave insights of how to operate smart home function without any interruption using multiple Fog nodes. Because of poor internet connection and power restriction problem of devices, designing confidential Fog networking model became a necessity for computation of data processing. The authors provided a Fog Computing frame with remote node to apply in a smart home, which resulted in data privacy and diminished internet usage.

J. Wang [22] provided a great analysis of the mixed computing system regarding the selection process and implementation serial in a task queue. Thus, for solving the challenges, the authors proposed three different method-based models for accurate time operation and performance issues to demonstrate the reliability and the productivity of the structure in industrial IoT service.

Apart from this, L. Lu et al. [23] introduced a music intelligence system based on machine learning methods to link up the music and automatically grade the music. For identification purpose of the melody, concealed Markov model and Gaussian mixture model are executed in cloud servers. The authors found useful outputs that provide support to originate melody grade and a way for future research in music cognition field.

N. Moustafa et al. [24] proposed a model that executes reasonable run time during emplacement of task by using an execution log to select appropriate Fog for quick data transmission. The framework contains a depository of Fog behaviour details which preserved in a standard log pattern to decrease the latency of the whole simulation system.

J. Ma et al. [8] researched the complication of Cloud services that use up a vast quantity of space in the network infrastructure and take huge time to execute data transportation due to distant source. Therefore, the authors came up with a several level Fog Computing schemes based on IoT using a specific algorithm to provide a solution to those limitations and diminish power usage of the terminal layer.

C. Mouradian et al. [25] experimented a framework that uses accidental spot movement of Fog nodes to experience the required real-time and operation cost. Based on that, the authors then constructed a model using elements emplacement specific algorithm to discover non-optimum emplacement, which developed the desired timespan and operation implementation charge of the overall frame.

F. Jalali et al. [26] surveyed high tech circumstance in the network structure, operation layer and system dematerializing which maximize or minimize power usage of an IoT infrastructure. Furthermore, the authors pointed out techniques to control the power efficiency of IoT operation and facilities using Fog computing.

Additionally, N. Khumalo et al. [27] investigated the benefits of using Fog Computing to balance the financial limitations of users by maintaining local transmission, storage, association, supervision, policy-making and thus allow excellent quality facilities for users that can provide the necessary solution to overcomes the cost issue in 5G deployment. The proposed structure operated better than cloud deployments structure based on energy efficiency and time duration in the advanced agriculture scheme.

Again, L. Velasco et al. [28] reviewed a secured, extremely distributed Fog computing architecture including three major construction part consists of the scalable node for integration purpose, controller for monitoring and services to perform at the Edge of a wireless network. The system architecture provided a solution to perform budget-friendly 5G services.

R. Shahzadi et al. [29] proposed a three-tier Fog system based on the alternate identifying process including challenges like source allocation, confidentiality, unavailability of system architect, software verifying, and support for the diversified networks.

Furthermore, M. S. Elbamby et al. [30] researched the problem of task allocation and active Edge caching in fog networks. The authors proposed a structure that includes user nodes for edge computing, Cloudlets for proactive computation and cached memory transmission with the target of achieving low latency and authenticity limitations.

E. Balevi [31] determined the ideal nodes which need to have extra transmission ability by transforming themselves to Fog nodes for achieving maximum performance rate by minimizing computation delay. Only the maximum transmission capable Fog nodes should be elected in order to avoid path loss for heavily deployed systems.

H. Yildirim, [32] worked on the most appropriate benefit of utilizing RISs for overall ins-out application with various frequency bands. A basic operational structure with a specific RIS was experienced, and the improvement of the elements on the maximum presumed allotment of the forwarded signal and illusion behave was noticed.

Review of Cloud Computing

S. Dillon et al. [10] aimed to point out the limitations and difficulties of Cloud computing while discussing the paradigm of service bashed and grid-based model to relate them with Cloud. The authors focused on exchangeability aspects including IaaS, PaaS, SaaS for future research and improvement.

Bonomi et al. [12] looked upon new operation and facilities produced from Cloud computing paradigm executed by Fog computing. The authors also researched the interconnection between the Fog and the Cloud while determining the limitations of Cloud computing. Thus, they claimed critical behaviour made the Fog the perfect stage for challenging IoT services and applications.

S. Prabavathy et al. [33] gave the insights of identifying the threat at a fast rate for IoT operation by allocating local Fog nodes in cloud observation. The experiments of the proposed system verify to be time-efficient and accurate in allotment while it enhances the distributed interruption selection mechanism with expandability, adaptability and compatibility.

C. Fiandrino et al. [34] evaluated application distribution for mobile cloud computing by developing a model based on the android application and introduced implementation time behaviour of several allotment aspects. The results uncovered infrastructure that lies between the prototype and devises pattern for appropriate power supervision of the service-based operation.

Similarly, N. Moustafa [35] provided a remarkable analysis that defines Fog as a lookalike system of Cloud consisting of a similar operation, software, interface and service structure Cloud. Hence, the authors suggested a scheme that explains the correlations between IoT, Fog and Cloud for the proper execution of security limitations, resolution and future instruction.

R. Vilalta et al. [36] validated the idea of TelcoFog infrastructure including three major participation blocks consist of the scalable node for continuous integration, controller for facilities allocation and services to ensure proper monitoring of the suggested structure and to enable them to drive above any telecom system architecture.

P. Bellavista et al. [37] discussed in their paper the real-life drawbacks consist of container-based dematerialized sources and association of IoT access which exposed advantage of the proposed unified infrastructure to support 5G service, Edge-Fog combined capabilities and focused on most appropriate and clear professional difficulties.

M. A. Rahman et al. [38] presented a transmission structure between mobile users- fog nodes, and between fog nodes-cloud, which can sustain smart facilities such as seeking lost person in the populated area, indicate high health risk areas, place-based information of interest and monitoring emergency time to make a long-lasting, energy-efficient Big IoT data model.

A. Mebrek et al. [39] introduced an ideal model including three specific energy-efficient ways including different line models and the combinational game between Fog nodes with the objective of reducing the overall performance charge of IoT operations.

S. Sthapit et al. [40] introduced a sensor network using chains of network and linear operating method when Cloud and Fog are not available in the platform. The proposed method has experimented in a different situation containing maximum and minimum range, one-sided association, and various value of statistics interchanges to investigate the strengths and weaknesses of the proposed algorithms.

Review of Edge Computing

A. Yousefpour et al. [6] gave the insights of Fog computing and its similar computing prototype, containing their standard features and dissimilarities. Hence, they classified the contribution to Fog computing and identified differences among several access to the edge computing, cloudlet to overcome the privacy and real-time response issue in the IoT server.

Besides, H. E. Sayed et al. [7] comprehensively surveyed the edge schemes and provided a comparative study of cloud computing to confirm productivity and inventiveness of Edge computing. After researching several network characteristics in the scheme, the result demonstrated that Edge performs better than Cloud computing structure.

K. Dolui et al. [13] researched on how to take off distance issue between Cloud performance and users in order to reduce real-time delay while transmitting a signal. Thus, the authors discussed three unique execution method consist of Fog Computing, Cloudlet and Mobile Edge Computing based on a group of variables which can be chosen automatically to complete secured operation successfully.

R. Ullah et al. [14] provided a remarkable analysis that defines enabled NDN with Edge computing is an ideal way to diminish latent time, major network trade, the capacity of manufacturing massive data within a short time and returning the outcome to the users in physical duration.

K. Peng et al. [41] presented an extensive survey of mobile Edge computing service approval by giving an overall summary including specification, infrastructure and facilities of Edge computing. The study also includes two different taxonomy, Edge server-based supply, expert guide, Edge emplacement, source allotment and open issues for a better understanding of the edge service adaptivity.

N. Abbas et al. [42] presented an all-inclusive survey to understand the progress of mobile edge computing sector containing denotation, superiority, framework and operation reign in terms of data assurance and confidentiality.

F. A. Salaht et al. [43] mentioned that Fog was innovated to supplement Cloud Computing for operating various IoT function with the low latent period, fast delivery, wide range, regional allotment which is a demanding model in real life. Therefore, the authors surveyed on emplacement problem in Edge Computing based on modern organization aspect and specified limitation which should be solved.

G. Premsankar et al. [44] addressed that data produced by detector, actuators, and other equipment in IoT has considerably improved in the present time. Again, the authors surveyed edge computing structure to identify benefits, permitting methodology to present mobile gaming and lastly source comprehensive 3D operation to investigate time duration.

F. N. Nwebony et al. [45] surveyed on how low latent period, the low cost can be gained by imposing Edge computing prototype and proposed a technology for e-Health conventions, e-Health advantages from superior transmission model, to transfer health details and provide health facilities based on edge-cloud and additional prototype.

S. Muhammed et al. [46] addressed a scheme with mathematical execution of three elements and four-level including medical care system model, UbeHealth, intense learning, high-efficiency computing to overcome the limitations such as response time, wideband, and authenticity. Three broadly used group of info are utilized to determine the UbeHealth function.

X. Sun et al. [47] proposed a significant model to compute at the Edge for the IoT structure, edge IoT to handle the media stream at the mobile Edge in order to solve the expandability problem of the usual IoT. The authors modified the model by adding proxy VM migration system to reduce the transit delay and fog computing structure to maintain flexibility while ensuring user safety.

T. Nguyen et al. [48] mentioned that Mobile edge computing is imposed to discharge tasks from cloud computing to provide services to mobile IoT devices. However, several crucial difficulties occur like suggested services effectiveness on the desired MEC node and identifying ongoing services in nearby MEC. The authors indicated a content-based networking service arranged in every reign following a three tired graded network to guarantee the quality of service.

M. A. Rahman et al. [49] suggested a Blockchain-based architecture to provide safety and confidentiality services for the long-lasting IoT confirmed distributed financial state in smart industries. The model contains a long-term technology which can supremely promote protected smart city facilities, such as contributing economic state, smart agreement, and digital interrelationship with chain and IoT operations.

1.3 Motivation

Cognitive Internet of Things has tempted a massive curiosity from various terms and segments because of their extensive range of utilization through fog, cloud and edge computing. CIoT can provide an expanded range of results to most of the communication threats while merged with telecommunication networks. Moreover, it can also return a positive outcome to various groundbreaking technologies related to the swift network system. Because of real-time computation of fog, storage capabilities of clouds and reliability of edge computing, they are beneficial to operate together for better throughput in CIoT technologies. The prominent feature of CIoT is their improved data speed which is conducted through fog nodes, Reconfigurable Intelligent Surfaces (RIS), clouds as well as unlicensed devices. The implementation of CIoT based wireless communication offers the best possible solution to slow data transmission, lack of flexibilities and storage problems. The main motive of our thesis was to construct a system model in order to accelerate data transmission with maximum energy efficiency and also introduce preferable output. The accurate framework can analyze the performance of the infrastructure for the given wireless transmitted data with low bandwidth. We have imposed cognitive IoT based simulation to compute the data rate equation, whereas simulation models are usually used for a broadscale view of the transmission layout.

Simulations are significant enough for pointing out appropriate positions of IoT devices, transmission power acknowledgement, data rate comparison and transmission delay comparison between CIoT devices to get better performance shortly.

1.4 Background of Fog, Cloud and Edge Computing

1.4.1 Introduction

Cloud storage is a retrieval type in which information is processed and retrieved electronically from various servers. Furthermore, with the help of fog and edge computing, the processing efficiency has been enhanced by enabling end-users to display narrower comprehensive data instead of saving information in an extensive, cloud-based archive, alongside data that they will never have to use. We will address the context details concisely for fog computing, cloud computing, and edge computing in the following sections.

1.4.2 Fog Computing

Fog computing is designed to provide reliable acknowledgment of the Internet of Things. Fog is a distributed platform for the storage and analysis of customer and cloud information. Fog computing depends on a specification that combines computation mechanisms and contextual application advantages for sensor nodes. A fog processing methodology contributes to a simulated world in which the person stores and manages the data. Fog computing reduces the distance between the cloud and IoT devices, enabling the calculation, encoding, communication, and control of channel nodes in IoT devices' vicinity. The 'horizontal' fog computation configuration allows computing operations via many frameworks and entities and encourages spent deployment via a vertical structure. Fog computing is defined as a "horizontal framework" who is user-friendly, storage, management, and networking through a seamless cloud to all platforms. Fog computing allows for real-time data processing, promoting data collection as rapid as our network in our immediate community.

1.4.2.1 Characteristics of Fog Computing

1. It uses less energy.
2. It increases the efficiency of the network.
3. There is also no internet required.
4. Fog is similarly suited to be viewed for the immediate future.
5. A large number of fog nodes are necessary.
6. Enhanced utilization of the power of Fog nodes of IoT interfaces also increases.
7. Nodes need a great deal of capacity to interact with nodes at more extensive ranges.
8. Data is scattered through nodes. So, the whole structure would not fail if anything goes incorrect.

1.4.3 Cloud Computing

Cloud computing, on-demand wireless network connectivity, facilitates data collection without explicit, direct user intervention. Telecommunications companies are required to provide their cloud management and maintenance capabilities in collaboration with their heterogeneous data and delivery systems to deliver Software-Defined Networking (SDNs), Network Virtualization (NFV), Mobile Edge Computing (MEC), and Cloud Access Networks (C-RANs) for future 5 G services [36]. Cloud computing offers a realistic solution through the utilization of advances in network technologies. The Cloud storage paradigm not only focuses on data centers designed to handle large data sets but also on their service. Groundwork, applications, and software (IaaS, PaaS, SaaS) are used as a Cloud resource. Infrastructure as a Service (IaaS) allows cloud users to connect to the IT system to distribute storage, memory, and networking [10]. Using optical networks, these data centers are often interconnected together in a manner that offers a particular terminal benefit, providing data center networks with low latency links between data centers [11].

1.4.3.1 Characteristics of Cloud Computing

1. The storage space is significant.
2. The computing power is much more sophisticated, and the computations are complicated.
3. It is sufficient for long-term analyzes.
4. It helps minimize the affordable cost of resources by minimizing the use of expenditures in hardware devices.
5. If the Internet is available, it has the advantage of working from all over the world.
6. Big system piles on a cloud server lead to mounting and congestion delays.
7. The difficulty of sophisticated agreements when it comes to accessing the platform complicates cloud infrastructure.
8. Security is a crucial concern since the cloud is available to the public around the world.
9. Requires continuing Internet for more substantial operation.

1.4.4 Edge Computing

We live in an era dominated by revolutionary cloud computing technologies, and billions of individuals were utilizing personal cloud storage to use the Internet to store their information. Excess latency and bandwidth consumption have become a concern nowadays due to the growing number of users. An idea called 'Edge Computing' came as an addition to the Cloud to exploit 5 G wireless technology that would allow for real-time responsiveness, lower latency, to more straightforward maintenance. Edge Computing acts as an intermediary layer between the server and the end-users, allowing information to be processed, interpreted, and exchanged at the edge of a networking structure. For possible interpretations of the systems functioning as the intermediate Edge nodes, the transmitting protocols and framework used by the Edge layer, and the Edge layer's assistance, the Edge layer is performed in the center of end-users and the Cloud. There are three groups to classify the edge layer architecture: Mobile Edge

Computing (MEC), Fog Computing (FC), and Cloudlet Computing [13]. Edge computing will, however, be incorporated as a groundbreaking Edge infrastructure in cellular and wireless networking contexts, integrating software and hardware devices positioned in the proximity of end-users at the edge of the network. The fundamental idea of edge computing is to introduce comfort to the network's edge, such as processing and speed. In order to limit data congestion and response delay, the storage capacity is taken adjacent to IoT devices and to facilitate space-intensive IoT applications [14]. The data generated by the end devices will work at the edge nodes, and for further processing, only a particular portion of the information will be sent to the Cloud. Thus, it is possible to decrease the backbone network and the connectivity load. There are some major features of Edge Computing which are described below:

1) QoS and Latency: Although edge devices are useful, many of them lack sufficient ability to meet the delay-sensitive needs. With immense computational capacity and physical space, cloud infrastructure provides resource-enhanced technology. Most IoT systems are, however, vulnerable to delays. All these systems are available via the WAN, which creates a lag in comparison to cloud versions. Thus, traditional clouds do not fix problems such as connectivity and real-time requirements. Apart from where the end-user is situated, different network hops would be programs that need more operational potential and storage resources that cannot be built competently with cloud technology. Operating services are required to achieve high QoS at the edge of the network. For example, in autonomous vehicles, the information collected from the camera needs to be evaluated efficiently to fulfill the real-time QoS criterion. The combined cloud servers obstruct the user interface due to inadequate Internet capacity and WAN delay. The general latency will be reduced if the databases are installed adjacent to the end network. The high efficiency of the local area network (LAN) and a comparatively limited number of demands are the advantages of servers nearest to the users.

2) Reduction of Core Network Traffic: The number of devices will generate an incredible amount of raw information that can be processed and stored due to IoT. According to [14], every month, 15 petabytes of traffic is generated. Due to the lack of storage space on cloud servers, allowing the entire traffic to be distributed to the cloud network would cause cloud servers to overloaded. The data must be stored on the edge servers to mitigate bandwidth consumption and reduce latency on the core network. In this way, billions of end-users can be managed to solve data traffic and latency on edge servers. The edge computing solution will also play a prominent part in restricting traffic on the entire networking infrastructure.

3) Expandability: It is known that a significant number of IoT devices may potentially lead to a significant scalability problem in the future. Consequently, the transmission of massive volumes of information to cloud servers can result in data blockage. Cloud storage would also no longer work successfully in this situation. Edge server virtualization can provide an opportunity to promote expandability in this scenario. Cloud service overload can be overcome as this information is stored on the Edge nodes since a very minimal data volume is sent to the Cloud servers.

Shortly, the tech sector will soon be dominated by limitless sensors, computer devices, and Internet-based smartphone applications. A reliable edge computing system should be developed to meet the enormous requirements, which can accommodate both computation and communication effectively, making it an automated system.

1.4.4.1 Characteristics of Edge Computing

1. Edge computing occurs near the devices where the sensors are linked. As a result of the shorter distance from the end devices, the data is processed quickly and gives us a real-time response [13].

2. As data is stored locally on the computer consumers use [6], Edge Computing is more reliable.

3. As the data is stored on the local area network (LAN), an internet connection is not needed.

4. In Edge Computing, the service level is better than in the Cloud since the connected devices do not have to wait for the connection.

5. They can reduce their costs by reducing the bandwidth required, according to the organizations.

6. Since it is the closest one to the user, so it is the most secure.

7. It has less processing power since it is performed near the source of information.

8. Instead of getting the full information from the Cloud, Edge Computing gathers and handles only a subset of data. As a consequence, it is possible to lose any required information.

9. More local hardware is required for Edge Computing.

1.5 Objective of the Thesis

This study aims to build a networking model for improving energy performance, the latency of data and enhance high-power processing. For this, we are incorporating the idea of cloud, fog and edge computing along with CIoT. The primary targets were identified to achieve this goal.

1. The Edge computing has been designed to cope with the connectivity of node devices closest to the consumer end and collect data efficiently while providing everyone with a solution in high definition.
2. Fog computing is not only used for collecting external data but also for storing all user data while keeping the systems confidential.

3. Mostly to do all complex calculations that are impossible with Fog and Edge, we have introduced Cloud infrastructure.
4. We also introduced RIS to avoid traffic congestion problems that may occur if a solitary Fog node is often used more than just the desired user, and even if the Cloud network is overwhelmed with applications.

1.6 Organization

This thesis has been divided into four chapters that comprise of all the details of necessary information of CIoT, Fog, Cloud and Edge computing, with required mathematical models and equations, basic structure and simulation system. The results obtained upon simulations and a detailed summary of the entire research work done with future goals and scopes.

Chapter 1 Introduction

In this chapter, basic definition and the importance of IoT, Fog, Cloud and Edge computing are explained along with their characteristics. This chapter also discussed our motivations for considering this area of research, and informative literature analysis comprising substantial previous work on fog, edge and cloud computing and our objective of the thesis.

Chapter 2 System Model

This chapter consists of 3 parts. This chapter addresses the process of our models, a brief discussion about our network system and all the necessary computational equations, parameters and calculations.

Chapter 3 Simulation Result and Discussion

In this chapter we have discussed the simulation results which is the description of all the plots and figures that has been acquired through proper calculations. Concerning transmitted power and wavelength, we measured the effective interruption performance.

Chapter 4 Summary

The chapter ends with an explanation of a model we established for medium-bandwidth control and delivery, decreased latency and two-way networking outcomes.

Chapter 2

System Model

2.1 Introduction

The Internet of Things is a network where digital and manual machines are linked utilizing its computational capability. This offers a specific identification for each user to transfer data from one individual to another, without some human interaction. Since it is the system that is most accessible, in this paper, we find CIoT to be our edge system or user from which data is submitted and obtained. Fog node is linked to a limited number of CIoT devices to provide an adequate, stable data transmission network infrastructure. To prevent any route failure, network flow issue or spectrum bandwidth issue, RIS framework is implemented in the model where data is transmitted using real-time technologies. RISs are now seen as exciting new hardware technologies to boost wireless network coverage and energy consumption by dynamically modifying the transmission system of electromagnetic waves. Finally, we introduced the cloud infrastructure approach to get to the data quicker and better and to remove all the operational problems from the whole network. Cloud infrastructure is the on-demand provision of computer device services, in particular storing data (cloud storage) and processing capacity, without the recipient requiring immediate active control. Both edge tools and computing technologies can always ensure data security and protection. In the way of comparison, the following segment includes a more in-depth description of the prototype involving fog and cloud computing accompanied by fog and fog.

2.2 Network Description

There is a two-way contact mechanism linking the whole network. Moreover, we consider up-link as well as the downlink interface, where each device can store, transmit and receive data at the same time. Three specific levels of the network structure can be included: (1) CIoT-Fog;

(2) Fog-RIS-Cloud / Fog-Cloud; (3) Fog-Fog. Thus, we approach the idea of CIoT devices as several users linking to the Fog nodes, which are then linked to the RIS and ultimately, the network is focused on cloud storage network connectivity.

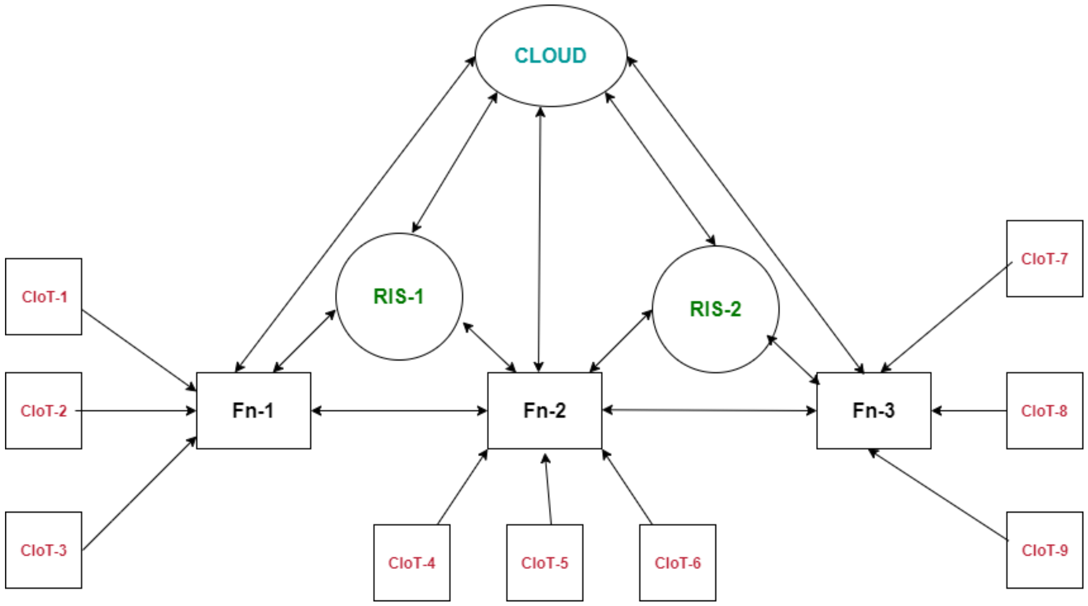

Figure 2.2.1: Illustration of the network configuration under construction

2.3 Mathematical Models

In this section, we derive the two methods taken based on the proposed system. For that, we have used the equation for Shannon's capacity theorem.

$$C = B\log_2(1 + SNR)$$

Where,

C= capacity

B= bandwidth

SNR= signal to noise ratio

We are considering SNIR, which is signal to noise interference ratio. SNIR is described as the ability of a particular desired signal divided by the sum of the power of interference (from all other interference) and the power of several background noise. If the noise power is null, then the SNIR decreases to the signal-to-interference ratio (SIR). SNIR is often used rather than SNR in wireless communication systems to measure the mathematical concepts.

2.3.1 Fog and Cloud Notations

Assume, that the packet size is K-bits in the fog node (Fn) and the number of bits that have been partially analyzed in the packet is Q-bits. The rest are interconnected which is K-Q cloud bits. We define the transmission delay between fog and cloud as follows:

$$\tau_{tD}^{FC} = \frac{K}{R_{fog}} + \frac{K-Q}{R_{cloud}} \tag{1}$$

Where, R_{fog} and R_{cloud} are the data rate of Fn and cloud, that can be articulated as

$$R_{fog} = B\log_2(1 + SNIR_{fog}) \tag{2}$$

$$R_{cloud} = B\log_2(1 + SNIR_{cloud}) \tag{3}$$

Here, $SNIR_{fog}$ and $SNIR_{cloud}$ both symbolizes the signal to noise interference ratio at Fn and cloud. As a matter of fact, for the nth device the SNIR at the Fn, we find,

$$SINR_{fog}(n) = \frac{P_{cn}h_n d_n^{-\alpha}}{\sigma^2 + I_{fog1}} \tag{4}$$

Where, n=1, 2, 3… … N. N is the overall number of communication device. P_c stands for the transmission power of the CIoT device, h is the channel coefficient, d is the distance between the CIoT device and the Fog node. Moreover, α is the path-loss exponent, σ^2 is the noise variance and I_{fog} is the interference from other CIoT devices at the Fog node. Now, for mth

device SNIR at the cloud can be described as:

$$SINR_{cloud}(m) = \frac{P_{fm}\left[h_{fcm}d_{fcm}^{-\alpha}+(d_{frm}^{-\alpha}+d_{rcm}^{-\alpha})\sum_{i=1}^{Z}h_{fr}^{i}h_{rc}^{i}e^{j\varphi_i}\right]}{\sigma^2+I_{cloud}} \tag{5}$$

Where, m=1, 2, 3 … … M. M is the overall number of fog devices. P_f stands for transmission power of Fog device. h_{fc}, h_{fr} and h_{rc} stands for the channel coefficient of Fog-cloud, Fog-RIS, and RIS-cloud, respectively. d_{fc}, d_{fr} and d_{rc} is the distance between Fog to cloud, Fog to RIS, and RIS to cloud, respectively, and I_{cloud} is the interference strength from the other Fog nodes at the cloud. We have also discussed here the indirect interaction between fog and cloud through RIS. Combining (4) and (5) equations into (2) and (3) equations, we receive,

$$R_{fog} = B\log_2\left(1 + \frac{P_{cn}h_n d_n^{-\alpha}}{\sigma^2+I_{fog1}}\right) \tag{6}$$

$$R_{cloud} = B\log_2\left(1 + \frac{P_{fm}\left[h_{fcm}d_{fcm}^{-\alpha}+\left(d_{frm}^{-\alpha}+d_{rcm}^{-\alpha}\right)\sum_{i=1}^{Z}h_{fr}^{i}h_{rc}^{i}e^{j\varphi_i}\right]}{\sigma^2+I_{cloud}}\right) \tag{7}$$

From there, inserting the (6) and (7) equations into the (1) equation, we note,

$$\tau_{trans} = \frac{K}{B\log_2\left(1+\frac{P_{cn}h_n d_n^{-\alpha}}{\sigma^2+I_{fog1}}\right)} + \frac{K-Q}{B\log_2\left(1+\frac{P_{fm}\left[h_{fcm}d_{fcm}^{-\alpha}+(d_{frm}^{-\alpha}+d_{rcm}^{-\alpha})\sum_{i=1}^{Q}h_{fr}^{i}h_{rc}^{i}e^{j\varphi_i}\right]}{\sigma^2+I_{cloud}}\right)} \tag{8}$$

2.3.2 Fog and Fog Implementations

Again, if we assume, Assume, that the packet size is K-bits in the fog node (Fn) and the number of bits that has been partly analyzed in the packet is Q-bits. The rest are interconnected which is K-Q cloud bits. The latency between fog and fog is described as follows:

$$\tau_{tD}^{FF} = \frac{K}{R_{fog}} + \frac{K-Q}{R_{fog-fog}} \tag{9}$$

Also, here the Fog nodes obtain and record the data according to the owner.

$$R_{fog-fog} = B\log_2\left(1 + \frac{P_{fm}\left[h_{ffm}d_{ffm}^{-\alpha}+\left(d_{frm}^{-\alpha}+d_{rfm}^{-\alpha}\right)\sum_{i=1}^{Z}h_{fr}^{i}h_{rf}^{i}e^{j\varphi_i}\right]}{\sigma^2+I_{fog2}}\right) \tag{10}$$

Eventually, we consider the (6) and (10) equations to be inserted into equation (9), we find,

$$\tau_{tD}^{FF} = \frac{K}{B\log_2\left(1+\frac{P_{cn}h_n d_n^{-\alpha}}{\sigma^2+I_{fog1}}\right)} + \frac{K-Q}{B\log_2\left(1+\frac{P_{fm}\left[h_{ffm}d_{ffm}^{-\alpha}+\left(d_{frm}^{-\alpha}+d_{rfm}^{-\alpha}\right)\sum_{i=1}^{Z} h_{fr}^{i}h_{rf}^{i}e^{j\varphi_i}\right]}{\sigma^2+I_{fog2}}\right)} \quad (11)$$

So, this is the final equation for transmission delay between fog and fog.

Chapter 3

Simulation Result and Discussion

3.1 Introduction

We have set up the equations on MATLAB software after formulating the computation equations in the previous chapter and have obtained the desired results. The findings showed that our proposed system model was able to increase the baud rate and reduce the data transmission delay with lower transmission power. We have identified the numerical outcomes of our proposed model in this chapter. To illustrate how powerful this model can become to mitigate the disadvantages of slow data transfer, we have used suitable comparison figures obtained from our system model.

3.2 Plots and Explanation

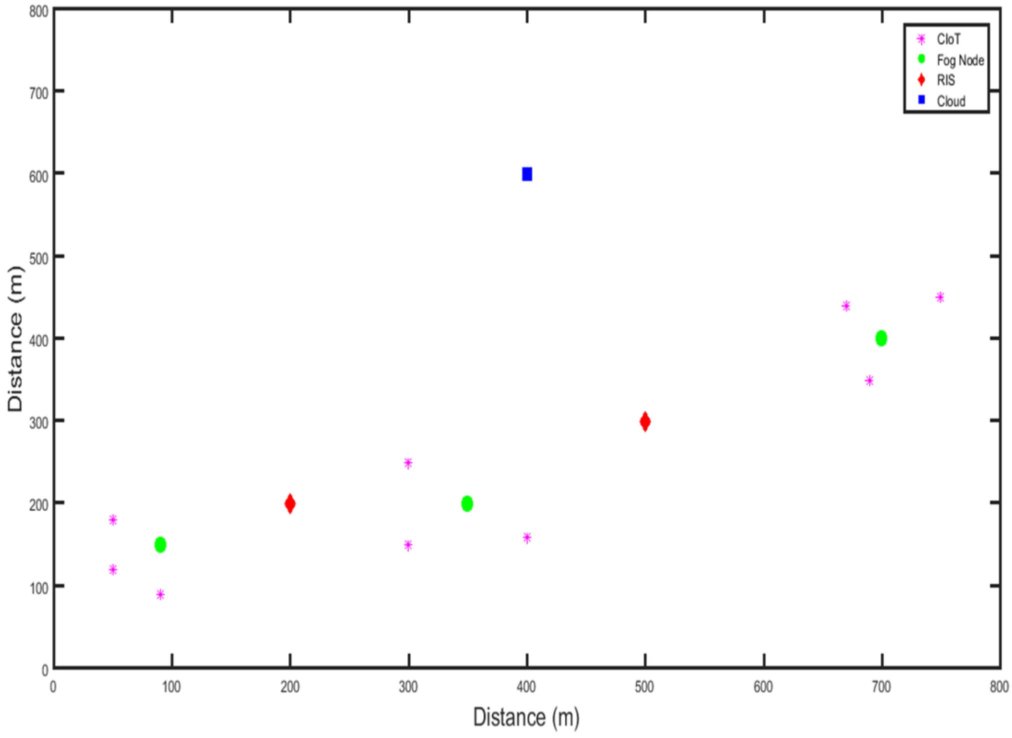

Figure 3.2.1: The CIoT, Fog, RIS and cloud approach

The above figure indicates the location of all items which exist on our system model including CIoT devices that are around 40-60 meters away from the three fog nodes. The Fog nodes are separated from each other about 260-350 meters. Every Fog node has the ability to store and process all data from the neighboring three CIoT devices. A RIS is also included which was placed between two Fog nodes at a distance of about 110-200 meters. In addition, a central cloud is also located about 200-450 meters away from the three Fog nodes which can collect and manage all the information from every CIoT devices in the network. Based on Fig. 2, simulation parameters are assumed as: B = 15 kHz, $\alpha = 4$, and $\sigma^2 = -174$ dBm. It is presumed to be Rayleigh fading for all the channels.

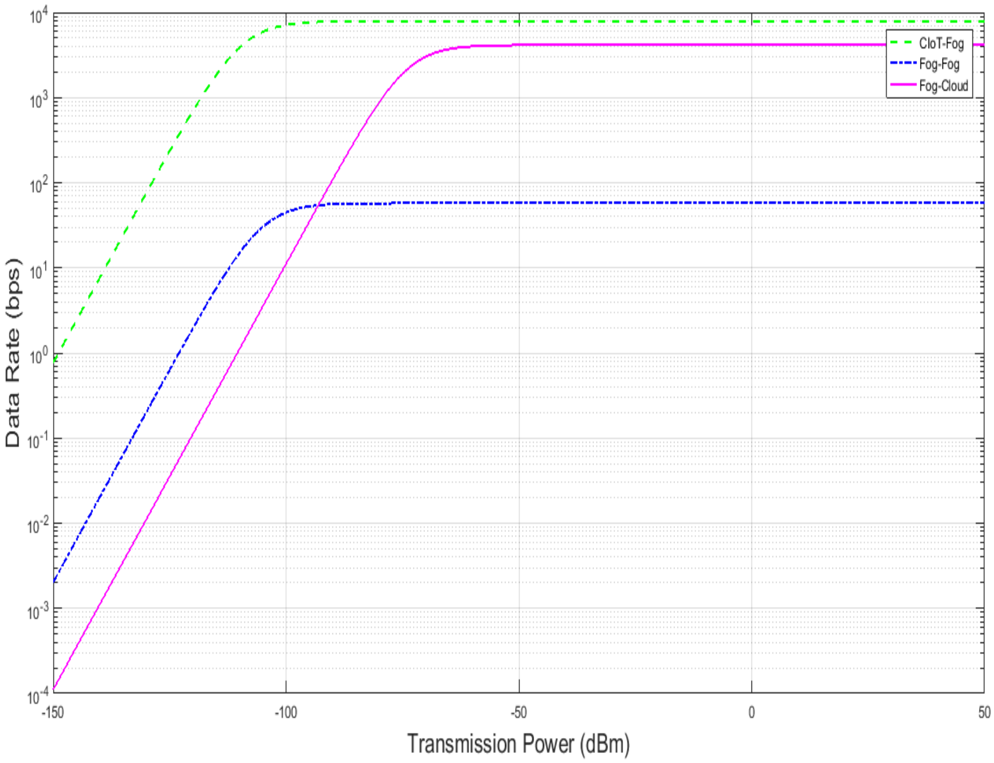

Figure 3.2.2: Comparison of data rate in bps for CIoT-Fog, Fog-Fog and Fog-Cloud

The figure shows analysis and comparison of data rate between three paths, i.e. CIoT-Fog, Fog-Fog and Fog-Cloud, where the transmission power is located along the x-axis and the data rate is located along the y-axis. The figure indicates an increment in the data rate as the transmission power increases. In contrast, when the transmit capacity is -69dBm, CIoT-Fog shows the highest data rate of 1.152e+04 bps. On the contrary, Fog-Fog displays a data rate of 91.84 bps at the same transmission capacity where the Fog-Cloud shows 4912 bps, respectively. From the above analytics, therefore, we can conclude that the CIoT-Fog path clearly shows higher efficiency for wireless network of the next generation since a higher data rate can be obtained.

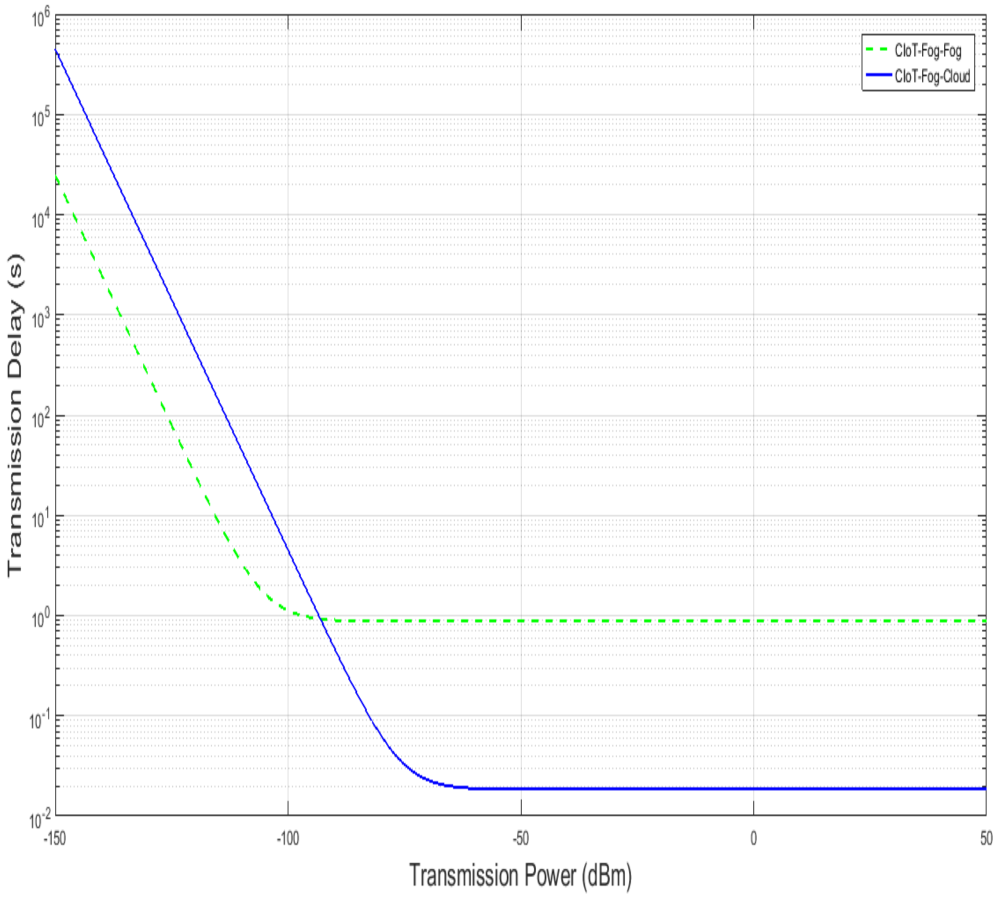

Figure 3.2.3: Comparison of the transmission time delay.

The above figure illustrates the improvement observed after a transmission power of -93 dBm in the CIoT-Fog-Cloud path. The figure distinguishes both the CIoT-Fog-Cloud and the CIoT-Fog-Fog path by their transmission delay and transmission power, of which all pathways display an exponential declining relationship with the parameters used to evaluate. The CIoT-Fog-cloud path demonstrates a least transmission delay of around 0.01228 seconds if the transmission power is -41dBm while the shortest transmission delay for the CIoT-Fog-Fog path is 0.5487 seconds if its transmission power is -67dBm. By contrast, the CIoT-Fog-cloud path has a higher transmission delay than all of the other system, as an instance, the CIoT-Fog-cloud path has a transmission delay of 2806 seconds at -130dBm transmission energy, whereas the CIoT-Fog-Fog path has a transmission delay of 155.6 seconds at the same power.

Chapter 4

Conclusion and Future Work

4.1 Conclusion

The primary objective of this paper is to boost the sensing of speed because of higher optimum and maximum transmitting capacity by proposing a fog and cloud computing with the cognitive radio network. The simple benefits of IoT indicate that the amount of linked systems and IoT applications grows that as individuals and companies are gradually implementing IoT goods. This article proposed a framework for the effective implementation of extensive data processing and network protection specifications to clarify the interrelations between IoT, cloud, RIS and Fog layers. The triple surfaces were addressed here not only for the delivery of less flexible content with less power consumption but also for very rapid data storage and calculation. For data to be processed and transferred within mere seconds and everything to be rendered more superficial, a cloud system has been used to handle both complex programming and technical studies. In this paper, we have provided a paradigm for the management and transmission of medium-bandwidth, reduced latency and two-way networking results.

The notable features of our work are summarized below:

i. Assuming simulation parameters to be as: B = 15 kHz, $\alpha = 4$, and $\sigma^2 = -174$ dBm, CIoT-Fog path showed the maximum data rate followed by Fog-Cloud path and lastly Fog-Fog path. The maximum data rate of 1.152e+04bps was found in the CIoT-Fog path whereas the minimum data rate was found in the Fog-Fog path, about 91.84bps.

ii. In the same scenario, at low transmission power Fog-Fog path had better performance compared to Fog-Cloud path but as transmission power increased Fog-Cloud path achieved better data rate than Fog-Fog path. However, the CIoT-Fog path always showed better data rate compared to the two other paths.

iii. In case of transmission delay, CIoT-Fog-Cloud showed to have the lowest transmission delay of about 0.01228 seconds whereas CIoT-Fog-Fog path had 0.5487 seconds along with a higher transmission power.
iv. Finally, in the same context of transmission delay, at low transmission power CIoT-Fog-Fog path had lower transmission delay but at a bit higher power CIoT-Fog-Cloud path achieved the lowest transmission delay time and showed better performance.

4.2 Future Work

The Fog-Cloud node system model for CIoT is an encouraging operating procedure in high data rate telecommunication. We have evaluated that the outcome has an extensive scope than the particular infrastructure can deliver. There is yet huge extended opportunity for our proposed systems model that need to be explored for future developments and some of them are discussed as below:

i. Due to the bounded bandwidth, progressive spectrum was utilised with an unlicensed user in a Cognitive Radio system. Friend or Foe (FoF) detection with physical-layer network can be adopted to distinguish a secondary user and a threatening malicious user in order to improve security system of CIoT [50].

ii. We have analysed the pattern of Cognitive Radio interface where base stations area located without specific location in modern networks. The cognitive radio network performance consisting of a stochastic geometry approach technique can also be implemented under frequency elective Rayleigh fading channel [51].

iii. The ideals of telecommunication radio frequency potential harvesting by operating battery gadget technique can also be designed for diminishing battery current consumption and activate eco-friendly cognitive radio network [52].

iv. A stable base station energy usage architecture with regional spectral efficiency of a CR channel using stochastic geometry strategy can be imposed to upgrade energy efficiency of the model [53].

v. The arithmetical synthesis of DASE in CWSN, activity of DASE and extended code rate for expanding DASE can also be designed for increasing spectral frequency as well as minimize energy usage and electromagnetic deterioration in digital networks [56].

vi. Cognitive UAV transmission between the UAV and the base nodes can be extended in this proposed model to establish UAV technology where mortal behavior or interaction is threaten in terms of expense and duration [57].

References

[1] X. Zhang et al., “Distributed Compressive Sensing Augmented Wideband Spectrum Sharing for Cognitive IoT,” IEEE Internet of Things Journal, vol. 5, no. 4, pp. 3234-3245, August 2018.

[2] Y. Liang, Y. Zeng, E. C. Y. Peh and A. T. Hoang, “Sensing-Throughput Tradeoff for Cognitive Radio Networks,” IEEE Transactions on Wireless Communications, vol. 7, no. 4, pp. 1326-1337, April 2008.

[3] T. Li, J. Yuan and M. Torlak, “Network Throughput Optimization for Random Access Narrowband Cognitive Radio Internet of Things (NB-CR-IoT),” IEEE Internet of Things Journal, vol. 5, no. 3, pp. 1436-1448, June 2018.

[4] H. F. Atlam, A. Alenezi, A. Alharthi, R. J. Walters and G. B. Wills, “Integration of Cloud Computing with Internet of Things: Challenges and Open Issues,” in Proceedings of IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), pp. 670-675, Exeter, 2017.

[5] A. botta, W. dedonato, V. persico, "On the Integration of Cloud Computing and Internet of Things," in Proceedings of 2014 International Conference on Future Internet of Things and Cloud, December 2014.

[6] A. Yousefpour, C. Fung, T. Nguyen, F. Jalali, A. Niakanlahiji, J. Kong and J. P. Jue, “All One Needs to Know about Fog Computing and Related Edge Computing Paradigms: A Complete Survey,” in Journal of Systems Architecture, Vol. 98, pp 289-330, September 2019.

[7] H. E. Sayed et al., “Edge of Things: The Big Picture on the Integration of Edge, IoT and the Cloud in a Distributed Computing Environment,” IEEE Access, vol. 6, pp. 1706-1717, 2018.

[8] K. Ma, A. Bagula, C. Nyirenda, and O. Ajayi, "An IoT-Based Fog Computing Model," Sensors, pp.1-17, 2019.

[9] R. Basir, S. Qaisar, M. Ali, M. Aldwairi, M. I. Ashraf, A. Mahmood, and M. Gidlund, “Fog Computing Enabling Industrial Internet of Things: State-of-the-Art and Research Challenges,” Sensors, pp. 1-38, 2019.

[10] T. Dillon, C. Wu and E. Chang, “Cloud Computing: issues and challenges” in Proceedings of 24th IEEE International Conference on Advanced Information Networking and Applications, AINA 2010, pp. 27-33, 2010.

[11] T. D. Dang and D. Hoang, “A data protection model for Fog computing,’’ in Proceedings of 2nd International Conference on Fog and Mobile Edge Computing, FMEC 2017, pp. 32-38, 2017.

[12] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, “Fog computing and its role in the internet of things,” in Proceedings of the 1st ACM Mobile Cloud Computing Workshop, MCC 2012, pp. 13-15, Finland, 2012.

[13] K. Dolui & S. K. Datta, “Comparison of Edge Computing Implementations: Fog Computing, Cloudlet and Mobile Edge Computing,” in Proceedings of Global Internet of Things Summit (GIoTS), 2017.

[14] R. Ullah, M. A. U. Rehman and B. Kim, “Design and Implementation of an Open Source Framework and Prototype for Named Data Networking-Based Edge Cloud Computing System,” IEEE Access, vol. 7, pp. 57741-57759, 2019.

[15] J. Li, X. Li, J. Yuan, R. Zhang and B. Fang, “Fog Computing-Assisted Trustworthy Forwarding Scheme in Mobile Internet of Things,” IEEE Internet of Things Journal, vol. 6, no. 2, pp. 2778-2796, April 2019.

[16] N. Chen, Y. Yang, J. Li and T. Zhang, “A Fog-based service enablement architecture for cross-domain IoT applications,” in Proceedings of 2017 IEEE Fog World Congress (FWC), pp. 1-6, Santa Clara, CA, USA, 2017.

[17] H. Lu, Q. Liu, D. Tian, Y. Li, H. Kim and S. Serikawa, “The Cognitive Internet of Vehicles for Autonomous Driving,” IEEE Network, vol. 33, no. 3, pp. 65-73, June 2019.

[18] M. R. Anawar, S. Wang, M. Azam Zia, A. K. Jadoon, U. Akram, and S. Raza, “Fog Computing: An Overview of Big IoT Data Analytics,” Wireless Communications and Mobile Computing, vol. 2018, pp. 1-22, 2018.

[19] P. Verma and S. K. Sood, “Fog Assisted-IoT Enabled Patient Health Monitoring in Smart Homes,” IEEE Internet of Things Journal, vol. 5, no. 3, pp. 1789-1796, June 2018.

[20] S. Ali and M. Ghazal, “Real-time Heart Attack Mobile Detection Service (RHAMDS): An IoT use case for Software Defined Networks,” in Proceedings of 2017 IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE), pp. 1-6, Windsor, ON, Canada, 2017.

[21] A. Kanyilmaz and A. Cetin, “Fog Based Architecture Design for IoT with Private Nodes: A Smart Home Application,” in Proceedings of 2019 7th International Istanbul Smart Grids and Cities Congress and Fair (ICSG), pp. 194-198, Istanbul, Turkey, 2019.

[22] J. Wang and D. Li, “Adaptive Computing Optimization in Software-Defined Network-Based Industrial Internet of Things with Fog Computing.” Sensors, vol. 18, 8 2509, Basel, Switzerland, 1 August 2018.

[23] L. Lu, L. Xu, B. Xu, G. Li and H. Cai, “Fog Computing Approach for Music Cognition System Based on Machine Learning Algorithm,” IEEE Transactions on Computational Social Systems, vol. 5, no. 4, pp. 1142-1151, December 2018.

[24] N. Mostafa, I. A. Ridhawi and M. Aloqaily, “Fog resource selection using historical executions,” in Proceedings of 2018 Third International Conference on Fog and Mobile Edge Computing (FMEC), pp. 272-276, Barcelona, 2018.

[25] C. Mouradian, S. Kianpisheh, M. Abu-Lebdeh, F. Ebrahimnezhad, N. T. Jahromi and R. H. Glitho, “Application Component Placement in NFV-Based Hybrid Cloud/Fog Systems with Mobile Fog Nodes,” IEEE Journal on Selected Areas in Communications, vol. 37, no. 5, pp. 1130-1143, May 2019.

[26] F. Jalali, S. Khodadustan, C. Gray, K. Hinton and F. Suits, “Greening IoT with Fog: A Survey,” 2017 IEEE International Conference on Edge Computing (EDGE), pp. 25-31, Honolulu, HI, 2017.

[27] N. Khumalo, O. Oyerinde and L. Mfupe, “Fog Computing Architecture for 5G-Compliant IoT Applications in Underserved Communities,” in Proceedings of 2019 IEEE 2nd Wireless Africa Conference (WAC), pp. 1-5, Pretoria, South Africa, 2019.

[28] L. Velasco and M. Ruiz, “Flexible Fog Computing and Telecom Architecture for 5G Networks,” in Proceedings of 2018 20th International Conference on Transparent Optical Networks (ICTON), pp. 1-4, Bucharest, 2018.

[29] R. Shahzadi et al., “Three tier Fog networks: Enabling IoT/5G for latency sensitive applications,” China Communications, vol. 16, no. 3, pp. 1-11, March 2019.

[30] M. S. Elbamby, M. Bennis and W. Saad, “Proactive edge computing in latency-constrained Fog networks,” in Proceedings of 2017 European Conference on Networks and Communications (EuCNC), pp. 1-6, Oulu, 2017.

[31] E. Balevi and R. D. Gitlin, “Optimizing the Number of Fog Nodes for Cloud-Fog-Thing Networks,” IEEE Access, vol. 6, pp. 11173-11183, 2018.

[32] I.Yildirim, A. Uyrus, E. Basar, I.Akyildiz, “Propagation Modeling and Analysis of Reconfigurable Intelligent Surfaces for Indoor and Outdoor Applications in 6G Wireless Systems,” 2019. [online] https://arxiv.org/abs/1912.07350

[33] S. Prabavathy, K. Sundarakantham and S. M. Shalinie, “Design of cognitive Fog computing for intrusion detection in Internet of Things,” Journal of Communications and Networks, vol. 20, no. 3, pp. 291-298, June 2018.

[34] C. Fiandrino, N. Allio, D. Kliazovich, P. Giaccone and P. Bouvry, “Profiling Performance of Application Partitioning for Wearable Devices in Mobile Cloud and Fog Computing,” IEEE Access, vol. 7, pp. 12156-12166, 2019.

[35] N. Moustafa, “A Systemic IoT-Fog-Cloud Architecture for Big-Data Analytics and Cyber Security Systems: A Review of Fog Computing,” [online] https://arxiv.org/abs/1906.01055

[36] R. Vilalta et al., “TelcoFog: A Unified Flexible Fog and Cloud Computing Architecture for 5G Networks,” in IEEE Communications Magazine, vol. 55, no. 8, pp. 36-43, Aug. 2017.

[37] P. Bellavista, L. Foschini and D. Scotece, “Converging Mobile Edge Computing, Fog Computing, and IoT Quality Requirements,” in Proceedings of 2017 IEEE 5th International Conference on Future Internet of Things and Cloud (FiCloud), pp. 313-320, Prague, 2017.

[38] M. A. Rahman, M. S. Hossain, E. Hassanain, and G. Muhammad, “Semantic multimedia Fog computing and IoT environment: Sustainability perspective,” IEEE Communication Magazin, vol. 56, no. 5, pp. 80–87, May 2018.

[39] A. Mebrek, L. Merghem-Boulahia and M. Esseghir, “Energy-efficient solution using stochastic approach for IoT-Fog-Cloud Computing,” in Proceedings of 2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 1-6, Barcelona, Spain, 2019.

[40] S. Sthapit, J. Thompson, N. M. Robertson and J. R. Hopgood, “Computational Load Balancing on the Edge in Absence of Cloud and Fog,” IEEE Transactions on Mobile Computing, vol. 18, no. 7, pp. 1499-1512, 1 July 2019.

[41] K. Peng, V. C. M. Leung, X. Xu, L. Zheng, J. Wang and Q. Huang, “A survey on mobile edge computing: Focusing on service adoption and provision,” Wireless Communications and Mobile Computing, Hindawi Limited, 2018.

[42] N. Abbas, Y. Zhang, A. Taherkordi, and T. Skeie, “Mobile edge computing: A survey,” IEEE Internet Things Journal, vol. 5, no. 1, pp. 450–465, February 2018.

[43] F. A. Salaht, F. Desprez, A. Lebre, “An overview of service placement problem in Fog and Edge Computing,” pp.1-43, France, 2019.

[44] G. Premsankar, M. Di Francesco, and T. Taleb, “Edge computing for the internet of things: A case study,” IEEE Internet of Things Journal, 2018.

[45] F. N. Nwebonyi, R. Martins and M. E. Correia, “Security and Fairness in IoT Based e-Health System: A Case Study of Mobile Edge-Clouds,” in Proceedings of 2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 318-323, Barcelona, Spain, 2019.

[46] T. Muhammed, R. Mehmood, A. Albeshri and I. Katib, “UbeHealth: A Personalized Ubiquitous Cloud and Edge-Enabled Networked Healthcare System for Smart Cities,” IEEE Access, vol. 6, pp. 32258-32285, 2018.

[47] X. Sun and N. Ansari, “EdgeIoT: Mobile Edge Computing for the Internet of Things,” in IEEE Communications Magazine, vol. 54, no. 12, pp. 22-29, December 2016.

[48] T. Nguyen, E. Huh and M. Jo, “Decentralized and Revised Content-Centric Networking-Based Service Deployment and Discovery Platform in Mobile Edge Computing for IoT Devices,” IEEE Internet of Things Journal, vol. 6, no. 3, pp. 4162-4175, June 2019.

[49] M. A. Rahman, M. M. Rashid, M. S. Hossain, E. Hassanain, M. F. Alhamid and M. Guizani, “Blockchain and IoT-Based Cognitive Edge Framework for Sharing Economy Services in a Smart City,” IEEE Access, vol. 7, pp. 18611-18621, 2019.

[50] S. R. Sabuj, M. Hamamura and S. Kuwamura, “Detection of intelligent malicious user in cognitive radio network by using friend or foe (FoF) detection technique,” in Proceedings of 2015 International Telecommunication Networks and Applications Conference (ITNAC), pp. 155-160, Sydney, NSW, 2015.

[51] S. R. Sabuj and M. Hamamura, “Random cognitive radio network performance in Rayleigh-lognormal environment,” in Proceedings of 2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC), pp. 992-997, Las Vegas, NV, 2017.

[52] S. R. Sabuj and M. Hamamura, “Two-slope Path-loss Design of Energy Harvesting in Random Cognitive Radio Networks,” Computer Networks, vol. 142, pp. 128-141, 2018.

[53] S. R. Sabuj and M. Hamamura, “Energy efficiency analysis of cognitive radio network using stochastic geometry,” in Proceedings of 2015 IEEE Conference on Standards for Communications and Networking (CSCN), pp. 245-251, Tokyo, 2015.

[54] E. Björnson, O. Özdogan, and E. G. Larsson, “Intelligent reflecting surface vs. decode-

and-forward: How large surfaces are needed to beat relaying?" IEEE Wireless Communications Letters, vol. 9, no. 2, pp. 1–1, February 2020.

[55] E. Basar, "Reconfigurable intelligent surface-based index modulation: A new beyond MIMO paradigm for 6G," IEEE Trans. Commun., vol. 68, no. 5, pp. 3187-3196, May 2020.

[56] S. Nazneen, M. M. J. Chowdhury and S. R. Sabuj, "Analysis of delay-sensitive performance in cognitive wireless sensor networks", Internet Technology Letters, pp. e98, John Wiley & Sons, 2019.

[57] A. R. Rahul, S. R. Sabuj, M. S. Akbar et al., "An optimization-based approach to enhance the throughput and energy efficiency for cognitive unmanned aerial vehicle networks", Wireless Network, pp. 1-19, Springer US, 2020.