A Secure IoT Framework for Remote Health Monitoring Using Fog Computing

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***Abstract*— This paper presents a secure IoT framework for remote health monitoring using fog computing, tailored for the Jordanian healthcare context. The proposed Remote Health System (RHS) addresses critical challenges in healthcare IoT applications, including latency, security, and bandwidth consumption. By integrating IoT wireless sensor networks with fog and cloud computing, our framework overcomes limitations prevalent in cloud-only solutions. The architecture leverages fog computing layers to provide local storage, real-time data processing, and preliminary analysis, acting as decision-makers and security checkpoints before relaying data to the cloud for complex functions. We incorporate advanced threat detection mechanisms and secure protocols to protect sensitive health data throughout its lifecycle. The performance and security of the proposed framework were evaluated using FogNetSim++ and OMNeT++ 4.6 simulations. The paper uses fog security and ZigBee communication protocols which implemented in the proposed framework. Results demonstrate the system's ability to reduce latency, energy consumption, and end-to-end delay while maintaining high security levels. CPU usage, memory consumption, and end-to-end delay were analyzed for various node configurations. The framework shows promise in enhancing healthcare delivery in Jordan, particularly in remote and underserved areas, by leveraging the strengths of IoT, fog computing, and cloud infrastructure. This work contributes to the evolving landscape of e-health systems in Jordan, by proposing a scalable, efficient, and secure solution that addresses the unique challenges of the country's healthcare sector.**

***Keywords*— Internet of Things (IoT), Fog Computing, Remote Health Monitoring, FogNetSim++, Jordanian Healthcare, Cybersecurity, Electronic Health Records (EHR).**

I. Introduction

The increase of new technologies such as the Internet of Things (IoT), Cloud Computing (CC), Wireless Sensor Networks (WSN), Fog Computing, and advanced network topologies have revolutionized numerous smart applications [1]. These innovations have paved the way for a new generation of IoT applications, each presenting unique cybersecurity challenges [2].

The Internet of Things (IoT) represents an interconnected network of devices, from smartphones and smartwatches to various appliances, all exchanging data within single or multiple networks [3]. This connectivity has facilitated the development of applications that enhance quality of life and serve humanity. However, the integration of IoT with CC systems, while providing scalable tools and high-scale data storage, also introduces significant security concerns [4].

The dynamic nature of many IoT applications generates vast amounts of data, with frequent exchanges between cloud and node [43]. Factors such as system component heterogeneity, massive object usage, and distributed system architecture contribute to this data generation [5][41][45]. This scenario necessitates robust cybersecurity measures to protect sensitive information throughout its lifecycle [6].

Fog Computing has emerged as a solution to reduce power consumption and delay, offering better support for low latency, location awareness, scalability, and mobility in large-scale IoT applications [7]. It efficiently handles numerous heterogeneous objects and devices distributed across wide geographical areas [8]. However, the security implications of fog computing in IoT ecosystems, particularly in sensitive domains like healthcare, requires thorough exploration [9][36].

While research on IoT in Jordan has focused on its implementation in hospital sectors. In particular, during the COVID-19 crisis [10], the security aspects of fog platforms in this context remain underexplored. Fog computing, introduced by Cisco in 2012, complements rather than substitutes CC, using similar resources (networking, computing, and storage) [11]. This complementary nature necessitates a comprehensive security strategy encompassing both fog and cloud layers [12][38].

IoT applications interact with various life sectors, including healthcare, agriculture, and industry, significantly impacting overall quality of life [13][31]. In healthcare, particularly in Jordan, the integration of IoT and fog computing with cloud systems can potentially enhance patient safety and reduce emergency room congestion [14]. However, this integration also introduces new security vulnerabilities that must be addressed [15].

The Jordanian healthcare system, encompassing both public and private sectors, faces increasing demands due to population growth and disease spread [16]. Some organizations have implemented electronic health systems to connect public hospitals across Jordan, maintaining records and facilitating access to patient information [17]. However, these systems must be fortified against cyber threats to ensure data integrity and patient privacy [18].

Home healthcare in Jordan, primarily provided through the private sector, remains limited due to cost constraints [19]. This paper explores the potential of a secure third-party system leveraging IoT, fog, and CC to assist patients and doctors, with a particular focus on cybersecurity measures to protect sensitive health data [20][30]. By addressing these security challenges, we aim to develop a framework that not only improves healthcare delivery but also ensures the confidentiality, integrity, and availability of critical medical information in the increasingly connected healthcare ecosystem [21][26].

II. Ease of Use

A. Selecting a Template (Heading 2)

In the field of CC and health systems, numerous applications and modules are being developed to connect to patients' bodies through wearable or non-wearable devices. These systems use various communication methods to send patient information in real-time to doctors for diagnosis. Most proposed topologies consist of a three-tier framework: a wireless connection network, wearable sensors, and the cloud [1].

Many existing systems rely on sending data directly from sensors to the cloud, which can lead to congestion issues. For instance, self-monitoring blood glucose (SMBG) systems for diabetes patients have been improved by using Continuous Glucose Monitors (CGM) to address previous drawbacks [2]. Babu et al. (2013) proposed a framework using wearable sensors to measure parameters like blood pressure and body temperature, transmitting data to a gateway via Bluetooth and then to a cloud server for storage and specialist access [3]. Similarly, Rolim et al. presented a cloud-based medical data server accessible to medical staff via internet-connected content service applications [4].

In Jordan, the study [32] proposed a four-tier health application system using fog computing in addition to CC, demonstrating higher throughput and reduced delay compared to cloud-only solutions.

B. Health Infrastructure in Jordan

Jordan has been making significant strides in developing its e-health infrastructure. The Ministry of Health (MoH) launched the Hakeem Program in 2009, aiming to computerize the public healthcare sector [6]. This national e-health initiative connects public hospitals and health centers across the kingdom, facilitating electronic health records (EHR) and improving healthcare service delivery [7][33]. Major hospitals involved in the e-health initiative include:

- King Abdullah University Hospital (KAUH) in Irbid
- Al-Bashir Hospital in Amman
- Prince Hamzah Hospital in Amman
- Queen Alia Hospital in Amman [8]

These hospitals have implemented various levels of electronic health systems, including computerized physician order entry (CPOE) systems and electronic medical records (EMR) [9].

The Jordanian government has recognized the importance of cybersecurity in healthcare. The National Information Technology Center (NITC) plays a crucial role in developing and implementing cybersecurity strategies for the healthcare sector [10]. Key initiatives includes:

- The National Cybersecurity Strategy 2018-2023, which addresses healthcare as a critical infrastructure sector [11].

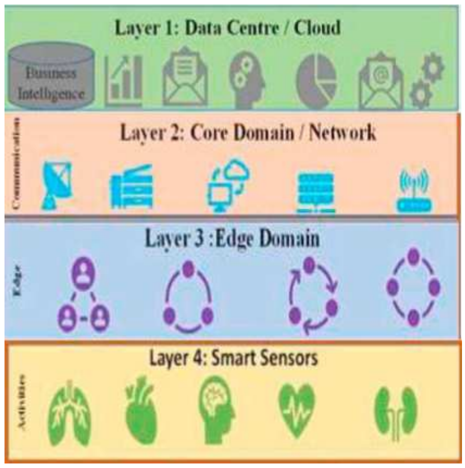

Fig 1. Transmission data Flow Diagram

- Implementation of the Health Insurance Portability and Accountability Act (HIPAA)-inspired regulations for protecting patient data [12].
- Establishment of a Computer Emergency Response Team (CERT) to handle cybersecurity incidents in critical sectors, including healthcare [13].

Despite these efforts, challenges remain in fully securing the e-health infrastructure. A study by Al-Nassar et al. (2020) highlighted the need for improved cybersecurity awareness and training among healthcare professionals in Jordan [14].

Recent research has focused on integrating IoT and fog computing with existing e-health systems in Jordan. For instance, Alzboon et al. (2021) proposed a secure IoT-based health monitoring system for Jordanian hospitals, incorporating fog computing to enhance data processing and security [15]. Furthermore, the COVID-19 pandemic has accelerated the adoption of telemedicine and remote health monitoring in Jordan [37]. The Ministry of Health, in collaboration with the Private Hospitals Association, launched several telemedicine initiatives to reduce hospital visits and manage the spread of the virus [16].

While Jordan has made significant progress in developing its e-health infrastructure and implemented cybersecurity measures, there is still room for improvement, particularly in integrating advanced technologies like IoT and fog computing. Future research should focus on enhancing the security and efficiency of these systems while addressing the unique challenges of the Jordanian healthcare context.

III. Methodology

The Proposed Patient Monitoring System using Fog Computing and Internet of things in Jordan is Smart automation system related to healthcare. There are communication gaps between clients and medical practitioners is critical issues and many people need to visit hospitals, clinics or pharmacies just to do normal checkup [24][34]. Replacing traditional way in Jordanian health care system need to be managed in a high performance architecture, to manage huge data gained from patients. Consequently, this cannot work without high-speed internet connection and computing analyses tools by applying fog computing. Fog computing is an emerging technology that proposes intelligent connection networks between IoT devices on one hand and cloud platforms on the other hand. IoT node could be use CC in aim of improve the performance and availability of applications [10]. Fog computing is an extension of CC at the edge of network [17] [35] [39]. In this section, we have discussed the structure of IoT-Fog Healthcare solution to optimize the cloud-based system called RHS [22][25].

Communication Technology	Device used	Layer name
Dedicated high-bandwidth LAN and WLAN IEEE 802.11	Cloud (CDC)	Cloud Computing
Dedicated high-bandwidth LAN and WLAN IEEE 802.11	DC (Health Care Unit)	Fog Computing Tier 1
High speed LAN ,WLAN and WPAN 3G,4G LTE ,Wi-Fi	Fog Instance (Mobile and Fog Station)	Fog Computing Tier 2
Bluetooth , Zigbee	Edge device (Sensors)	Edge Devices

Fig 2. Technology

A. *Data Transmissions Flow*

Figure 1 illustrates the proposed framework architecture for remote Health system that is composed of four main layers: Sensor Network (IoT), Fog layer1, health care unit as Fog layer 2 and cloud layer. The figure captured the transmission of data from layer 4 passing to layer 3 and second layer finally to layer number 1. All previous models are found to offload the jobs of the cloud to the edge of the network to enhance the quality of services, lift the performance, decrease the latency, boost the connectivity, and support different types of projects which are sensitive to the time and critical cases [27].

B. *Communication Technology Architecture*

Figure 2 shows technology associated with each layer:

1. Zigbee: Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. Hence, Zigbee is a low-power, low data rate, and close proximity (i.e., personal area) wireless ad hoc network

2. Bluetooth: is a short-range wireless technology standard that is used for exchanging data between fixed and mobile devices over short distances using UHF radio waves in the ISM bands, from 2.402 GHz to 2.48 GHz, and building personal area networks (PANs).[3] It was originally conceived as a wireless alternative to RS-232 data cables. It is mainly used as an alternative to wire connections, to exchange files between nearby portable devices and connect cell phones and music players with wireless headphones. In the most widely used mode, transmission power is limited to 2.5 milliwatts, giving it a very short range of up to 10 meters (30 feet). Bluetooth is managed by the Bluetooth Special Interest Group (SIG), which has more than 35,000 member companies in the areas of telecommunication, computing, networking, and consumer electronics. The IEEE standardized Bluetooth as IEEE 802.15.1.

3. WIFI: is a family of wireless network protocols, based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access, allowing nearby digital devices to exchange data by radio waves. These are the most widely used computer networks in the world, used globally in home and small office networks to link desktop and laptop computers, tablet computers, smartphones, smart TVs, printers, and smart speakers together and to a wireless router to connect them to the Internet, and in wireless access points in public places like coffee shops, hotels, libraries and airports to provide the public Internet access for mobile devices.

4. GSM: Global System for Mobile Communications (GSM) is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices such as mobile phones and tablets. It was first deployed in Finland in December 1991.

C. *Data flow Diagram*

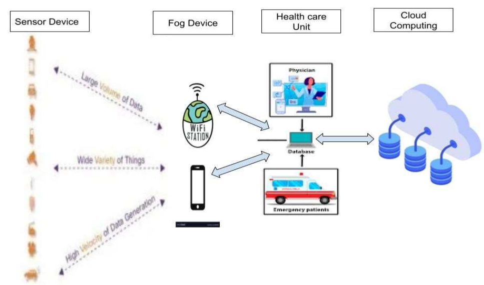

Fig 3. Data Flow Diagram

As Figure 3 explain the application Patient Monitoring System consists of four major modules: Patient sensor, patient mobile or fog station, Health Calculator, and cloud data center. There exists data dependencies between the models, as shown, the input for any model is the output of another model, the function of the used modules are the following:

1) **Layer 1:** *Sensor network and IoT device*

Sensor network and IoT device To collect the patient information that reflects his activity and medical state, several types of sensors are needed such as medical sensors, activity sensors, Medical sensors include Electro Cardio Gram (ECG) sensor, Electro Encephalo Gram (EEG) sensor, Electro Myo Graphy (EMG) sensor, pulse oximeter sensor, temperature sensor, respiration rate sensor and glucose level sensor. Sensor's elements are responsible for detecting the presence of the patient, capturing his image, collecting readings and sending it to the fog devices via wireless network [46] or ZigBee communication protocols. Sensors must be in all positions that the patient can move to it.

2) *Fog* Layer

Fog layer consists of smart mobile devices or Wi-Fi stations, called gateways. A gateway is a device with computing, storage and network connectivity that is distributed in residuals area. Both fog nodes handle four issues: 1) receiving patient data from sensors, 2) analyzing these data to make a decision of the health state of the patient, 3) communicating with health unit Local data processing is added to the fog for adding the intelligence to it in order to enhance the system by increasing its reliability, decreasing latency, overcoming the internet disconnection and speedup the decision especially at emergency situations after passing data to fog layer 2 fog device in layer 1 should send simple massage about the statues and if any immediately action should be taken for example if blood pressure so high should to visit emergency room as soon as possible module can

Fig 4. Omnet and Fognetsim++

collect the physiological and environmental data from various wireless sensors embedded at different locations at home and from elderly patient and convert it to adequate form for analysis. Data filtering, preprocessing and noise removal are implemented in this stage. This unit consists of a simple database simple algorithm because we don't load any more complexity in the layer. The monitoring system to detect and measure the pain of the monitored patient. Pain can be detected through uses the vital signs as temperature, blood pressure and blood glucose which are collected from the wearable sensors that reflect the vital measures of the body.

3) Fog Layer2 Healthcare Unit

This layer consist of central device in health unit such hospital or pharmacy, 24 emergency room and so on when this layer received data from fog layer 1 then immediately proceed it and take an action in addition to send report to fog device 1 about the statues of patient, it also tells the patient if an action is required; time of medicine, quantity of medicine, a specific food must eat, and any other desired instructions to follow. it could send an ambulance to patients' location if needed, the notification may be a message, voice telephone call. Finally, this layer should pass the processed data to cloud to more processing, The patient data must be sent to the cloud for storage, diseases prediction, risk amount assessment and long-term analysis. We present this layer as first decision maker and front data center so it should have capability more than fog layer device in tier 1, This layer should have a private local storage which stores the incoming data on a local repository to perform functions as data security and data analysis. Moreover, the data that could not be transmitted to the cloud due to network problems is stored temporally in the health care devices as backup and redundancy copy [8].

4) Cloud Layer

Finally, the Cloud layer which consists of distributed resources, servers that are located at far place. And repositories, cloud management is the responsibility of the cloud manager who integrates them to receive process and store all data related to the patient. The doctor use processed data to fulfill long-term evaluate and analysis the status, history of patient health. It is responsible for big data storage and analysis, Diseases Prediction, the system notifies responsible persons about the patient health status if an emergency situation occurred. The system saves a backup of patient's health data locally in case of a connection problem with the cloud, a passive component which provides data storage services to storing the patient's data [23]. It consists of a cloud server and fog. The fog stores recently and frequently requested PHI while cloud stores non recent and least frequently requested PHI.

IV. IMPLEMENTATION

A. System Model

As Figure 3 demonstrates, the application RHS consists of four major components:

1. Sensor (wearable and implanted sensor).
2. Client (Broker1): The client module interfaces (wearable and implanted device). filter the signals and send them to the Health Unit to get the current health status of the patient.
3. Health unit (Broker2): The health unit is responsible for calculating the health state of the patient based on the collected signal data, this part sends a report to the Client about the health state.
4. Data Center Cloud: A cloud data center moves a traditional on-prem datacenter off-site. Instead of personally managing their own infrastructure, an organization leases infrastructure managed by a third-party partner and accesses data center resources over the Internet. Under this model, the cloud service provider is responsible for maintenance and updates.

B. Experimentation Tool

Simulation is a essential process for validating the quality of the proposed system and modeling sensor behavior. Our framework integrates two widely-used network simulators: OMNeT++ 4.6 and FogNetSim++. This integration facilitates the exchange of patient information between the middleware and simulator, allowing us to test and demonstrate the reliability of our approach for IoT application validation [1].

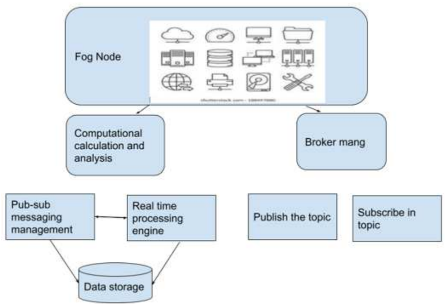

Fig 5. Fog Node components

The simulation process utilizes OMNeT++ version 4.6 [44] and the FogNetSim++ package. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily designed for building network simulators [2]. FogNetSim++ is an extension for OMNeT++ specifically developed for fog computing simulations [3]. Both OMNeT++ and FogNetSim++ are open-source, providing the ability to simulate networks and incorporate built-in modules that emulate real network devices [40].

Figure 4 illustrates the design of our proposed framework. The FogNetSim++ is integrated with OMNeT++, creating a comprehensive simulation environment. This environment includes:

- Medical sensors
- Fog nodes
- A central fog node, which is the main component of the fog network

The central fog node performs two primary functions:

a) Broker functionality

b) Data analysis and computation

The broker is responsible for managing the fog nodes through two main operations: subscribe and publish. These operations will be discussed in detail in the following section.

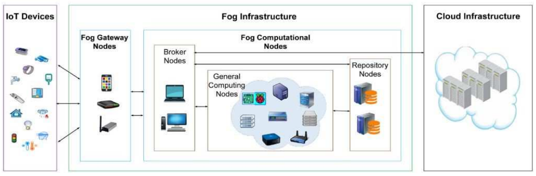

Fig 6. High level view of integrating IoT-Fog and Cloud through FogBus framework

This simulation setup allows us to accurately model and evaluate the performance of our proposed healthcare IoT system, with a particular focus on the fog computing layer and its interactions with sensors and other network components.

C. Extermination simulation

The FogNetSim++ package offers a flexible design, allowing users to model, simulate, and evaluate various realistic fog scenarios. It provides functionality to create network environments supporting both static and dynamic nodes and enables the use of multiple fog protocols [29].

Our proposed system can support sensor devices (d) and M fog nodes. Mobile devices can communicate with fog nodes, which may be mobile devices or stationary fog stations. In our system, we refer to these collectively as fog nodes. A typical fog node might include:

- A distributed messaging system
- A data processing engine
- Data storage
- A load monitoring component

Recent years have seen the development of several publish-subscribe message broker implementations. Among these, Kafka stands out as an advanced open-source distributed messaging system capable of efficiently handling data streams in a scalable manner. Kafka is well-suited for real-time applications such as sensor communication, data stream analysis management, and network monitoring [7].

The main objective of our simulation in FogNetSim++ is to design a framework supporting different sensors. Figure 5 shows the graphical user interface of FogNetSim++.

The architecture components include fog nodes, brokers, and end devices. The broker manages resources, while other parts of the fog node provide computational services. End devices are the actual sensors that can move during communication with fog nodes. Figure 6 provides a high-level view of the system, while Figure 7 shows a snapshot of the running OMNeT++ architecture [28].

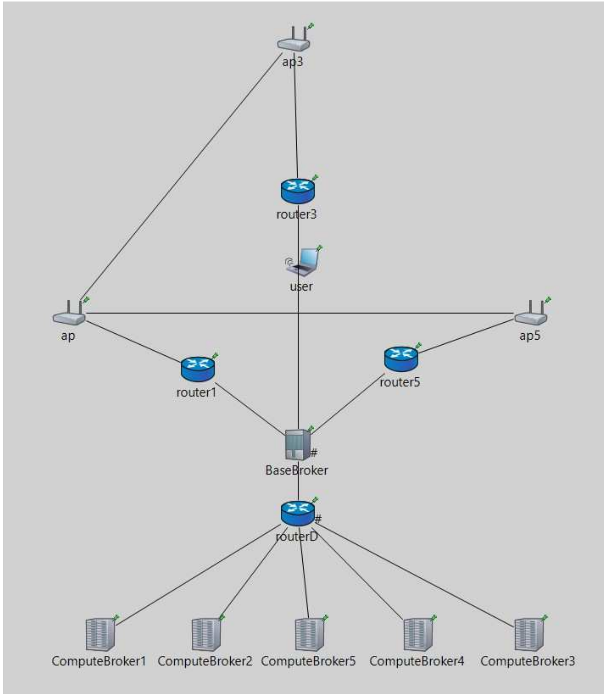

Fig 7: OMNeT++ architecture

The broker receives subscription requests from devices to perform requested computations. It must then dispatch data to the devices requiring it, implementing a publish-subscribe mechanism. Any mobile device or station can register with the broker as a subscriber (needing data), a publisher (providing data), or both. The broker tracks subscriber locations and shares updates with all of them.

The broker sends data to the computational part for offline processing. At this stage, we can incorporate various algorithms at the fog node to support task execution. Calculations at the fog layer may not be as complex as main computations but can include alert messages. The fog layer is finally connected to the cloud data center.

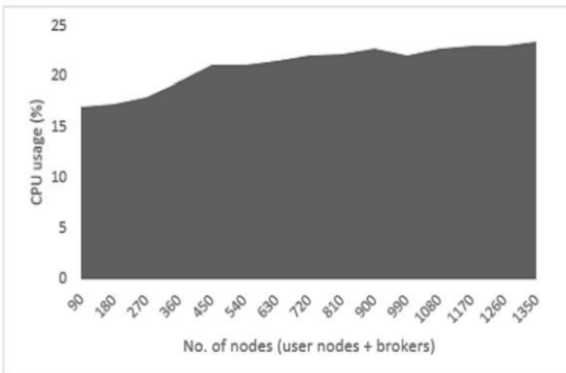

Fig 8. Fognetsim++ CPU usage

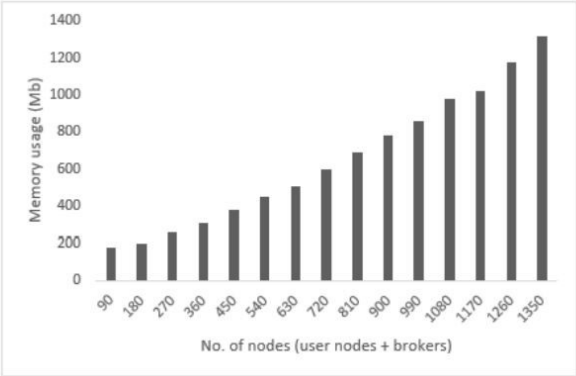

Fig 9. Fognetsim++ Memory usage

FogNetSim++ supports heterogeneous systems and fog node applications that can execute concurrently over each node, catering to the needs of subscriber devices.

D. Testing And Performance Evaluation

FogNetSim++ provides comprehensive insights into network details and supports a wide range of configurations. The system specifications used to run FogNetSim++ in our experiments are outlined in Table 1.

TABLE I. SYSTEM SPECIFICATIONS FOR FOGNETSIM++ SIMULATION.

Component	Specification
CPU	4 Cores
Memory	16 GB RAM
OS	Windows 11, 64bit
OMNeT++ Version	4.6

V. RESULTS AND DISCUSSIONS

After running simulations for the system, we obtained the following results.

- CPU Usage: As shown in Figure 1, the CPU usage increases gradually with the number of nodes, reaching approximately 23% for 1350 nodes. This demonstrates the system's efficiency in handling a large number of devices, which is crucial for widespread deployment in healthcare scenarios.
- Memory Consumption: Figure 2 illustrates the linear growth in memory usage, reaching approximately 1300 MB for 1350 nodes. This linear relationship indicates predictable resource requirements as the system scales, which is essential for planning and resource allocation in healthcare IT infrastructure.

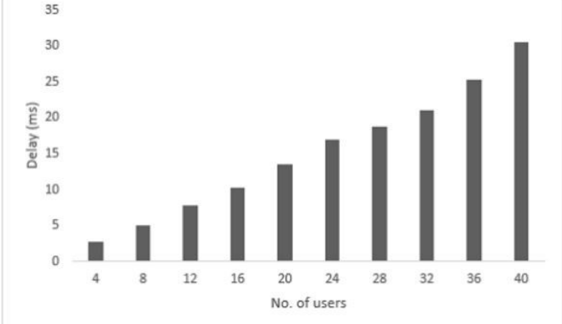

Fig 10. Fognetsim++ end-to-end Delay

- End-to-End Delay: Figure 3 demonstrates that the end-to-end delay increases with the number of users, reaching about 30 ms for 40 users. This highlights a potential challenge in maintaining low latency as the system scales. While these delays are manageable for many healthcare applications, they underscore the need for optimization in time-critical scenarios.

Both Cloud and Fog frameworks complement each other in providing high-quality service, offering benefits in storage capacity, control, and communication links. Table 1 outlines the comparison between Cloud and Fog computing characteristics.

These results demonstrate the viability of our fog-based approach in managing the computational and communication demands of a large-scale healthcare IoT system. The fog layer effectively reduces the burden on cloud infrastructure while providing localized processing capabilities, crucial for timely decision-making in healthcare contexts.

The comparison between cloud and fog computing characteristics (Table 2) reveals the complementary nature of these technologies. Fog computing's ability to operate with intermittent internet connectivity and its distributed nature make it particularly suitable for the Jordanian healthcare context, where internet reliability may vary across different regions.

TABLE II. CC VS FOG COMPUTING

Characteristics	Cloud	FOG
Bandwidth and internet connectivity	requires full connectivity during service from clients to get services, bandwidth required depends on total amount of data to be processed	It more flexible because it operates with or without Internet, the data send later when Internet become available.
Size	large amount of data has to be processed at a time and each typically contains tens of thousands of integrated servers	a fog node in each location can be small or as required to meet another fog node for customer or client demands.
Operation	It operates in specific selected domain environment with well-trained technical experts	framework the environments primarily decided by the customer's requirements
Deployment	It requires highly qualified and suitable strategically planning	It requires minimal planning for deployment but challenges is to connect with one fog node to other intermediate fog node.
Server locations	central server in a small number of big data centers distributed environment	It often requires distributed servers in many locations and over large geographical areas, closer to users along with fog-to-fog range or cloud-to-thing range. Distributed fog nodes and systems has been controlled either in centralized or distributed manners depending upon the clients/fog node.

Our approach addresses several key challenges in implementing e-health systems:

- Cost-effectiveness: By leveraging consumer-grade devices like smartphones and Raspberry Pi, we propose a solution that could be more accessible to a broader population in Jordan.
- Performance and Availability: The multi-tiered architecture ensures high availability and performance, critical for healthcare applications where delays could have serious consequences.
- Data Management: The proposed system balances local processing at the fog layer with long-term storage in the cloud, addressing both immediate data needs and long-term record keeping.

CONCLUSION

This research presents a comprehensive framework for a secure and efficient remote health monitoring system using IoT, fog computing, and cloud infrastructure. Our proposed architecture addresses critical challenges in healthcare IoT applications, particularly in the context of Jordan's evolving healthcare landscape. The results of our study demonstrate the potential of fog computing in enhancing the performance and efficiency of healthcare IoT systems. By effectively distributing computational tasks between fog nodes and the cloud, our framework shows promise in reducing latency, optimizing resource utilization, and improving overall system responsiveness. The scalability of our proposed system, as evidenced by the CPU and memory usage patterns, suggests that it could be effectively deployed across various scales of healthcare operations, from small clinics to large hospitals. This scalability is crucial for the diverse healthcare needs of Jordan. However, the increasing end-to-end delay with user count highlights the need for continued optimization, especially for time-sensitive healthcare applications. This challenge presents an opportunity for future research and development in load balancing and task distribution algorithms. Our work contributes to the evolving landscape of e-health systems by proposing a scalable, efficient, and potentially cost-effective solution tailored to the needs of Jordan's healthcare sector. By leveraging the strengths of IoT, fog computing, and cloud infrastructure, our framework paves the way for improved healthcare delivery, particularly in remote and underserved areas.

Looking forward, this research opens several avenues for future work: Prototype Development: Implementing a low-cost prototype will provide real-world validation of the system's performance and usability in Jordanian healthcare settings. Advanced Modeling: Developing stochastic models will enhance our understanding of system availability and help identify potential bottlenecks. Security Enhancements: Given the sensitive nature of healthcare data, future work should focus on implementing advanced security measures tailored to the fog-cloud ecosystem. AI/ML Integration: Exploring the integration of artificial intelligence and machine learning techniques at the fog layer could significantly enhance data analysis capabilities and enable predictive healthcare interventions.

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