Privacy-Aware Energy-Efficient Framework Using the Internet of Medical Things for COVID-19

Fadi Al-Turjman and BD Deebak

Abstract

SARS-CoV2 has caused a coronavirus disease known as COVID-19. It has become a pandemic all over the world that highly demands proper data interpretation to expand research findings. In the medical and healthcare systems, the Internet of Medical Things devices play a crucial role to gain the autonomous operation that provides an eco-friendly condition to medical practitioners and patients. In an emergency, healthcare-related data including heart rate, blood pressure, oxygen level, and temperature are transmitted to assess the condition of patients. It deploys low-power sensor nodes on the patient's body that periodically generates an analysis report to the medical center through the mobile sink. However, it is still challenging to analyze security risk and energy consumption. In the issue of unbalanced energy consumption, the low-power sensor nodes may degrade the delivery time of data transmission to the remote data centers. Therefore, this article presents a privacy-aware energy-efficient framework (P-AEEF) protocol to secure the medical information of the patient. The prime objective is to minimize the communication cost to improve the security features and energy efficiency against unauthentic access. The simulation result reveals that the proposed P-AEEF provides ~88.25 percent better performance efficiency than the other state-of-the-art approaches.

Introduction

Of late, a spread of severe acute respiratory syndrome coronavirus 2, so-called SARS-CoV2, has widely been distributed over an area that primarily manifests as a pandemic disease. An illness of the lower respiratory tract is associated with significant morbidity and mortality across the globe. This contagious disease may generally be transmitted through respiratory droplets, while the airborne diffusion may also exist in the possibility of an aerosol-generating procedure (e.g,. bronchoscopy). This procedure applies a viewing tube to examine the nature of the patient's lungs and airways that include branches of bronchi, voice box, vocal cord, and trachea. This is usually associated with asthma and bronchitis to expose the health risk and severity rate. As a result, proper protection and patient welfare are mainly preferred:

1. To ensure the survival rate
2. To protect healthcare personnel from infectious disease
3. To endorse the health condition of communities

With the existence of living standards and upgrading societal essentials, people demand better healthcare services using m-Health. It provides medical services and collects information through mobile technologies, namely smartphones and tablets. Smart devices effectively integrate the technologies to offer medical assistance including rehabilitation, disease assessments, medical examination, and treatment. This medical assistance could be made available to people under home quarantine or stranded on the road. Providing physical relief comprising treatment, medical cost, disease prevention, and diagnosis, m-Health has become more attractive in academia and industry [1]. With the wide recognition of electronic transmission, the individual tasks may involve a strong impact to protect the privacy rights. The advanced technologies including mobile computing, desktop, and storage devices have been utilized for the potential use of data analysis and information processing [2].

In the past, several studies have been initiated for the classification of COVID-19 symptoms that report various laboratory findings such as mild and clinical procedures [3]. As a result, it may be difficult to manage the risk of infection to classify the key features such as gender and age. To analyze the key features, predictive analysis is extremely essential in determining the risk levels. The important factors include clinical resources and tools such as medical beds, respirators, hospital capacity, and protective equipment. Since medical diagnostic tools and resources are very limited, healthcare providers are forced to make an early diagnosis with past patient histories. To provide a timely decision, artificial intelligence (AI) is highly recommended. In the healthcare system, clinical decision support is applied that uses machine learning (ML) to interpret medical data effectively. Key findings such as heart rhythm, and nerve and muscular disease are involved to predict the infection rate of COVID-19. Additionally, deep learning (DL) is exploited to learn the biological studies that design a suitable prediction system to measure the performance of the DL application models.

Digital Object Identifier: 10.1109/IOTM.0001.2000123

Drug Discovery and Vaccine Clinical Trials

The rapid growth of COVID-19 is not showing any sign of protection to restrict the mortality rate in comparison to other viral diseases like influenza. As a result, it is more essential to discover the vaccines and anti-viral medication over SARS-CoV2. In 2019, the National Institute of Allergy and Infectious Disease (NIAID) patronized the United States to carry out clinical trials using AI. At first, the scientists of Flinders' University successfully developed a synthetic chemist using an AI program that has millions of synthetic compounds to extract insightful features [2]. Importantly, the modern approach may make the development process shorter than originally intended. From the clinical trial, the efficacy of the SARS-CoV2 vaccination is still unknown. To understand the mutation period of SARS-CoV2, an AI-based prediction algorithm could be employed as a potential adjuvant. It may be useful to find new compounds while screening them on a layer basis. Moreover, it could understand the acceleration process of the vaccine to develop the antivirals to engage in the treatment process of COVID-19. It uses COVID-19 datasets to screen the mutation process, which may be useful to discover a predictive model. Of late, the IBM supercomputer has equipped the AI intelligence for the treatment process of SARS-CoV2 that uses a spike computation model (Protein S) to provide an interaction with the ACE2 receptor of the human.

They use *SUMMIT* to act out the virtual screening process to observe the nature of the small molecules, which may either bind the protein-receptor to make the course more complex or reside in the protein alone. In pursuit of system modeling, the abilities of the small molecules could be well studied to restrict the viral recognition in the host cell or to interrupt the interaction of the host virus for prompt identification. It is evident that AI-based modeling may hasten the testing process even if trillions of molecules are likely to be tested.

Cloud Management and IoT Devices

A model known as "Trace-Test-Treat (TTT)" has been named as a delivery tool for the large-scale computation resources over public/private networks. Nowadays, it is becoming a promising model for the cloud computing paradigm that mitigates the overall cost of infection. This specific characteristic attracts a number of individuals and corporations to let out the cloud service to carry out the application systems. Cloud computing (CC) has infrastructure as a service (IaaS), which provides higher-layer services such as platform as a service (PaaS) and software as a service (SaaS) [4]. Amazon EC2 and IBM Smart Cloud Enterprise [5] are popular providers of IaaS that allow users to let out computation resources in the form of virtual machines (VMs). Cloud providers can offer several VM types that are characterized by machine configuration, pricing model, and quality of service (QoS). Amazon EC2 is the most typical representation, offering three kinds of pricing models: on-demand, reserved, and spot [4]. As IaaS providers have random arriving users and their requests are aperiodic, the different types of VMs and instances are very tough to predict.

Thus, there may be some instances in which a cloud service provider may have received several massive requests that cannot be satisfied with its computation resources to guarantee the QoS. A proactive solution for a cloud service provider is to purchase some computation resources in advance, which is cost-ineffective [4]. An alternate solution is the cloud federation [3], which allows cloud providers to deal with the resources through the act of federation agreement. This paradigm overcomes the resource limitation of cloud providers to outsource the member requests in the federation. However, this federation is not easily exercised at present due to a lack of standard interoperation and customer motivation [5]. Various research domains such as bioinformatics, physics, astronomy, and Earth science use a complex large-scale scientific application to simulate and analyze real-world entities. Khan *et al.* [6] introduced energy-efficient routing that provides a reliable solution to stabilize the energy consumption. Sagar *et al.* [7] designed an energy-aware wireless body area network (WBAN) to the healthcare systems. It uses critical data routing to optimize the energy consumption and to improve the network lifetime. Mu *et al.* [8] improved the systematic procedures of route request and response to optimize the routing cost. However, the above existing protocols could not be adopted in a mobility environment to secure the transmission.

As a result, global healthcare protection cannot utilize the existing mechanisms to provide secure data aggregation. It is seeking a technological solution that may initiate the initial screening to check the spread of SARS-CoV2. This screening process is very essential to medical professionals to treat the patient remotely. It may involve professionals to offer medical treatment in containment zones [9]. To address the issue effectively, the technological advancements including the Internet of Things (IoT), peer-to-peer networks, and AI are converged in digital form. Nowadays, it is managing the clinical problems of SARS-CoV2 [10]. In the digital age, the IoT development and the evolution of the 5G network include AI to provide a long-term solution. However, it applies ML, DL, data analytics, cloud computing, and blockchain technology to enhance the medical diagnosis, treatment, and prevention strategies. These assistive technologies handle the user data at remote locations using dedicated IoT devices. It is equipped with AI and data analytics to provide a decision making process, which includes data interpretation, system modeling, data analysis, and forecasting. It uses cloud computing to store the analytical data that integrates the blockchain technology to secure the communication platforms.

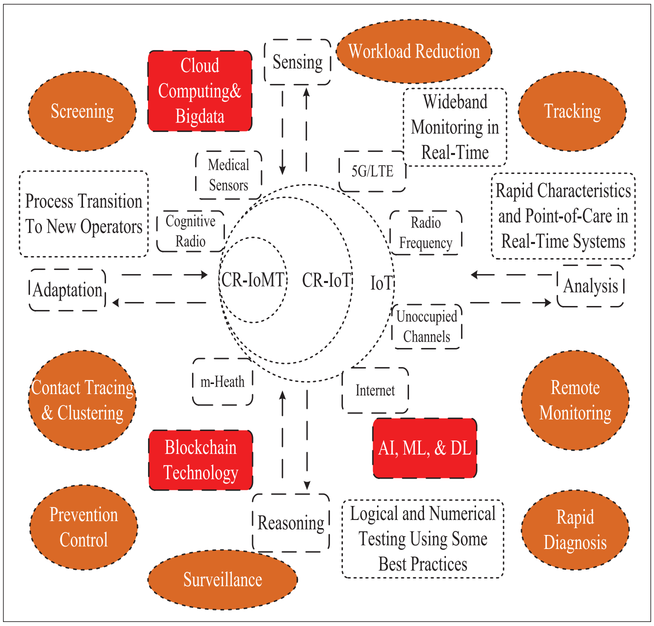

FIGURE 1. Cognitive-radio-based Internet of Medical Things with cyclic technological processes.

The remaining sections are as follows. The following section discusses the cognitive-radio-based IoT (CR-IoT) using IoMT. Next, we present the proposed P-AEEF protocol. Then the protocol performance is demonstrated using NS-3. The final section concludes the study work.

CR-IoT Background

Figure 1 shows the cognitive-radio-based IoMT (CR-IoMT) with cyclic technological processes, which enable physical entities to exchange sensitive information. However, it highly recommends data privacy to ensure guaranteed QoS. CR-IoT supports machine-to-machine (M2M) interaction to accommodate more networking devices that utilize dynamic spectrum allocation to meet the massive user requirements. As for the medical industry, CR-IoT derives its representative as CR-IoMT. It plays a significant role in the development of smart healthcare. IoMT reads the physiological data of the patient such as blood pressure, oxygen level, body temperature, heart rate, and glucose level to manage the treatment process of COVID-19. IoT generally refers to a network of interlinked physical objects such as medical sensors, monitoring devices, home appliances, and autonomous driving. The connective objects are massively enabled to sense, process, and share data. It provides data intelligence to automate human activity and interaction. It is currently increasing data traffic, which is expected to reach 4394 EB by 2030 [11]. To meet the requirement of bandwidth, a promising technique known as CR-IoMT is highly preferred. It utilizes the scarce spectrum dynamically to interconnect the physical objects in the highly dense environment. As a result, this technological purpose suits this pandemic situation as people are connected and monitored over a huge public network. Due to nation-wide lockdowns and restrictions in crowd movements, most people's activities are going online, including commerce, e-learning, telemedicine, smart metering, surveillance, and so on. These real-time activities are ensured over wireless networks, which demand more bandwidth utilization. Therefore, CR-IoMT is widely recommended to generate or transmit short packets through opportunistic searching to identify the unallotted channels, whereby resources such as bandwidth and spectrum may certainly be saved.

IoMT for Covid-19

At present, COVID-19 is referred to as a pandemic to highlight the activities of medical research. In the past, technological advancements have been a panacea for a world crisis. To

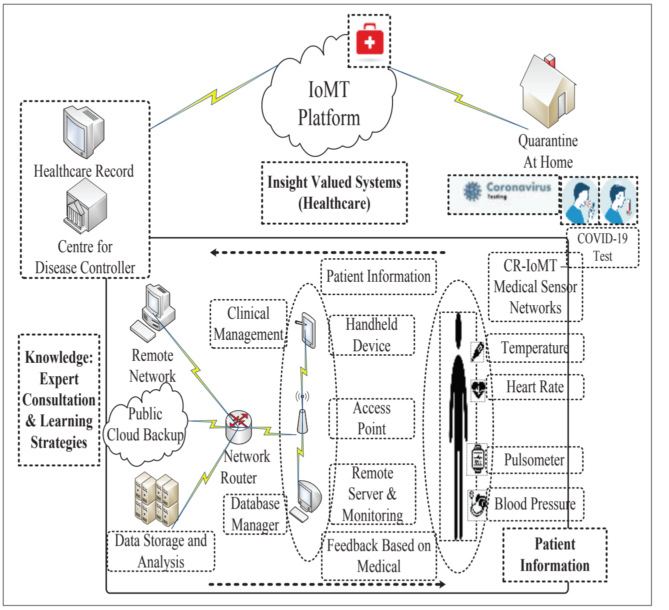

FIGURE 2. Medi-logic implication of CR-IoMT.

provide a promising solution, IoMT is preferred. It eases the requirements such as detection, monitoring, and tracing to control the disease spread [12]. IoMT integrates medical equipment and software applications to analyze the data in the healthcare industry. It is emerging as m-Health to fight against the health emergency. Smart healthcare has integrated advanced technologies and novel applications toward a promising solution of COVID-19 that provides treatment modalities to carry out screening, monitoring, tracking, and controlling disease spread [13]. Since the pandemic is spread across the globe, it is not easy to manage the situation without the availability of live updates. CR-IoMT enables communication networks to collect the sensory information that automates the information processing to handle COVID-19. The medical emergency associates IoMT extensively with offering online medical services reliably. In addition, it establishes a medical platform to connect the telecare database to connect or track home/containment zone patients. Figure 2 shows the medi-logic implication of CR-IoMT. It connects advanced technologies including smart devices and networks to combat SARS-CoV2.

Tracking in Real Time: Worldwide, the COVID-19 cases including the number of active, cured, and death cases are being regulated using assistive technologies to track and control the patient status of various regions. Therefore, the disease severity may be analyzed to design predictive modeling using AI that provides proper decision making to the medical institute or policymakers toward control and readiness.

Remote Monitoring: As COVID-19 is highly contagious, medical professionals and healthcare assistants may easily be exposed to this disease during their services. To observe the medical data remotely, CR-IoMT provides tool assistance. It analyzes the physiological data including temperature, breathing rate, pressure level, heart rate, and so on, as shown in Fig. 2.

Rapid Diagnosis: Suspected victims including traveling histor, and migrant people may be isolated even if they do not have any clinical symptoms to observe. As a result, a proper diagnosis is highly essential to minimize the vulnerabilities. Besides, it uses AI-enabled visual sensing (AI_EVS) to diagnose the computer tomography (CT) that renders the control room able to provide live streaming. As a result, the contact-less and early detection of viruses is enabled to save the lives of frontline workers.

Contact Tracing and Clustering: To control the virus spread, contact tracing is highly necessary. It may simplify the tedious work of tracking the location histories of COVID-19 patients. Moreover, the patient information is periodically collected at the central database, governed by the healthcare authorities. The infected regions are categorized into containment, buffer, red, orange, and green zones to monitor patient activities via CR-IoMT. Region-wise histories are made available to medical professionals through IoT that uses an AI framework to enable remote checkups. In zone clustering, the central or state authorities may impose either lockdown or law and order pertaining to social distancing and wearing masks.

Screening and Surveillance: At the entryway of airports, railway stations, and public transport, a proper medical diagnosis is recommended. It may access the central database to monitor infected patients through CR-IoMT. Moreover, it may surveil suspected patients to control the virus spread.

Reducing Workload in the Medical Industry: CR-IoMT assists healthcare professionals in dealing with proper diagnosis and treatment, enabling remote monitoring to reduce the treatment workload. Hospital management may provide timely assistance to offer medical advice or to deliver telemedicine through the association of blockchain technologies.

Prevention Control: As this disease is more transmissible, the infection should be controlled promptly by healthcare authorities or through public awareness. It uses CR-IoMT to track the positive cases in the surrounding area.

Privacy-Aware Energy-Efficient Framework Protocol

The main objective of this protocol is to govern the publishing data during the process of examination and treatment. Other users are not allowed to change the choices of storage in terms of publishing the data or altering the privacy settings. However, the medical authorities are empowered to set apart the sensitive data to unveil the infection rate gradually. The proposed P-AEEF manages the medical data to influence data sensitivity by classifying the nature of the multimedia contents. The basic challenges are closeness to intra-society and separateness from intra-society that maintains the privacy of the sensitive information to intuit the preferential ratio. Besides, the proposed P-AEEF enhances the energy consumption ratio between the medical sensors to strengthen the security level of the medical data using wireless body area networks (WBANs). It ensures a reliable, efficient, and trusted technique to monitor the physical activities of the patients, which is from the mobile sink to the medical centers. Importantly, the proposed P-AEEF considers a suitable architecture to design effective modeling that equips the medical sensor to use a global positioning system (GPS), whereby the adjacent nodes are known to share the communication effectively.

The medical sensors form a homogeneous network to share the common properties in terms of energy, size, memory, and transmission power. However, the mobile sink does not have any resource limitations, such as energy and power, to capture the activities of patients. Medical data can periodically be monitored on a patient's body to regulate the data transmission to medical professionals through intelligent devices. However, there may be some malicious nodes that attack the network infrastructure, whereby the key properties such as data privacy, user authentication, and integrity cannot be satisfied.

Design Architecture

The designed architecture comprises two major aspects: intelligent routing and cost optimization. It interconnects the medical sensors in the form of graph G that has unique edge E between the set of sensor nodes N. In the use of parameter metrics, a weighted cost is designated to connect each edge that assigns its cost value. The cost value represents the residual energy, hop counts to the mobile sink, node distance to the neighbor nodes, and queuing factors (delay). The cost function generates a spanning sub-graps S_i in terms of minimum cost to restrict the conditional criteria:

1. There is no cyclic process in the sub-graph.
2. There are n vertices to connect (n – 1) edges in the given sub-graph.

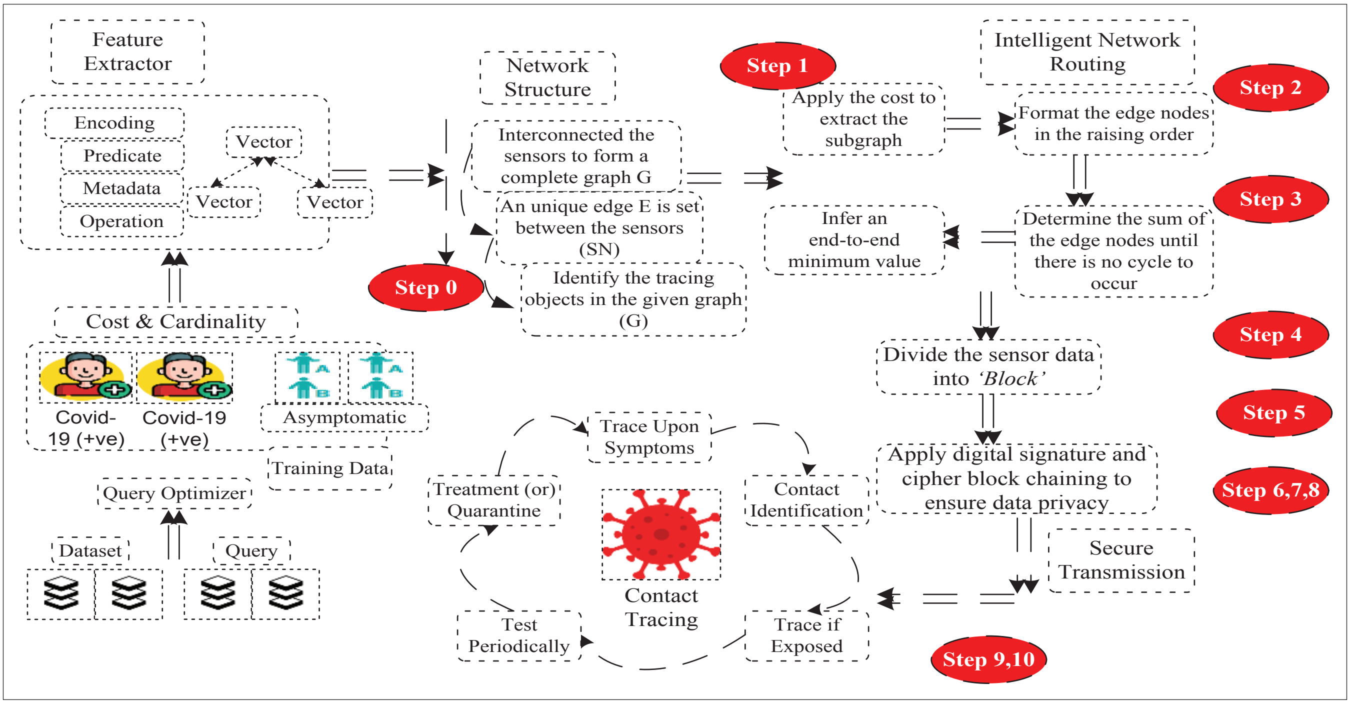

FIGURE 3. Design flow of proposed P-AEEF protocol.

The sub-graphs may be constructed using Kruskal's algorithm [14] to optimize the cost functions of the mobile sink nodes. It uses the mobile sink to collect medical information that subsequently records the data to the medical centers. As a result, the proposed architecture utilizes the composite attributes to optimize the cost functions, and applies optimum learning to update the computation cost. Finally, cipher blockchaining is applied to secure the transmission of healthcare data [15].

Secure Data and Intelligent Routing

The proposed architecture interconnects the medical sensors to form an undirected graph using a cost function $f(c)$. This function is constructed using weighted residual energy, hopping distance to mobile sink $h(c)$, neighborhood distance N_d, and delay factor q_d. These factors are collectively summed to minimize the cost function by generating a spanning tree or connected graph to connect the medical sensor with the neighbor nodes. However, there must be a unique edge node between the consecutive nodes to compute the cost values using the composite parameters. In the beginning, the mobile sink advertises the current position of each sensor node, which determines the cost value of the hop count. It uses a proactive routing table to increase the packet counter, which periodically checks the identification of the neighbor nodes to classify whether the node is susceptible or not. Moreover, it computes the residual energy of the sensor nodes over a time interval Δ_t that minimizes the hop count to update the available routing table.

Assume that the medical sensor computes the consumption ratio of the energy with the available neighbor nodes.

Step 1: Each sensor node i computes the energy consumption to compare with neighbor nodes during the transmission of healthcare data involving query optimizer, cost, cardinality, and feature extractor.

Step 2: Upon successful transmission, each sensor node forwards the residual energy to a neighbor node, which stores the information in the routing table.

Step 3: In the network initialization, the content of the routing table is updated to originate the region-wise process.

Step 4: The system metrics are used, such as hopping distance and residual energy, to compute queuing delay q_d.

Step 5: Each sensor node utilizes the computation of Step 4 to optimize the cost value.

Step 6: Apply a cipher blockchain algorithm between the sensor nodes and medical centers to verify the encryption chain of the data blocks.

Step 7: In this process, the chain of data blocks uses digital authentication or public cryptography to encrypt the medical data with the pre-defined secret key s_k.

Step 8: At the sign of symptoms, $(i + 1)$ sensor nodes decrypt the data blocks using the public key of the node to verify whether the process is legal or not.

Step 9: Upon verification, confine the sensor node to identify and track close contacts.

Step 10: Finally, the chain of data blocks is periodically initiated through the mobile sink to medical centers via authorized intermediaries to route and confine the contacts, as shown in Fig. 3.

Simulation Setup

This section demonstrates the simulation analysis using NS-3. In the simulation area of 15 m^2, the medical sensor nodes are deployed. It fixes 10 sensor nodes on the patient's body, where the central node of the patient's body acts as a local coordinator or mobile sink. It is carefully weighted as a more powerful node than the medical sensors in terms of computation resources. At the initial stage, the sensor node sets the energy value, transmission range, and simulation interval to be ~1 J, 2 m, and 250 s, respectively. Most importantly, the flow of data transmission between the medical sensors and mobile sink is based on the constant bit rate (CBR). The simulation is intended to have five malicious nodes to examine the security factors of the transmission. Moreover, the size of the packet transmission is set to be 32 bits. In this work, the energy model [7] has been adopted to examine quality metrics such as link breaches (percent). To realize the significance of proposed P-AEEF, the existing mechanisms such as E-ERP [6], CRD [7], and S-EAR [8] are considered.

Figure 4 shows the experimental result of time intervals and link breaches. It is practically analyzed between the proposed P-AEEF and other existing mechanisms [6–8]. The simulation analysis proves that the proposed P-AEEF outperforms the reduction rate of the link breaches by 16, 15, and 19 percent, respectively, over other existing mechanisms [6–8]. Since the existing mechanisms failed to notice the evaluation scenario of the wireless

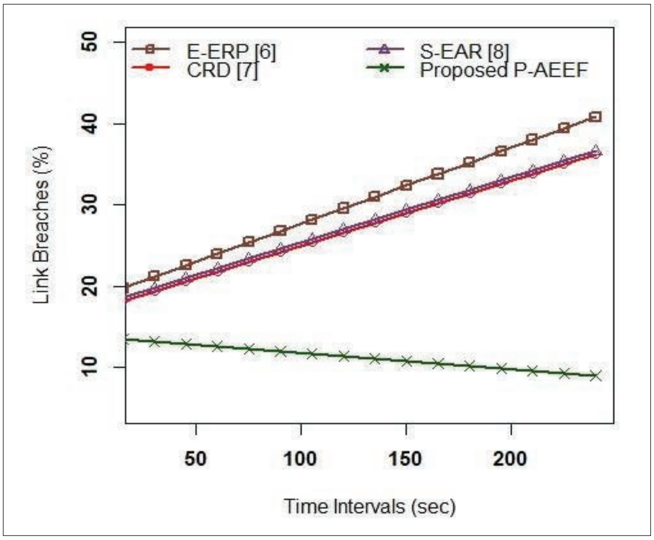

FIGURE 4. Time interval vs. link breaches.

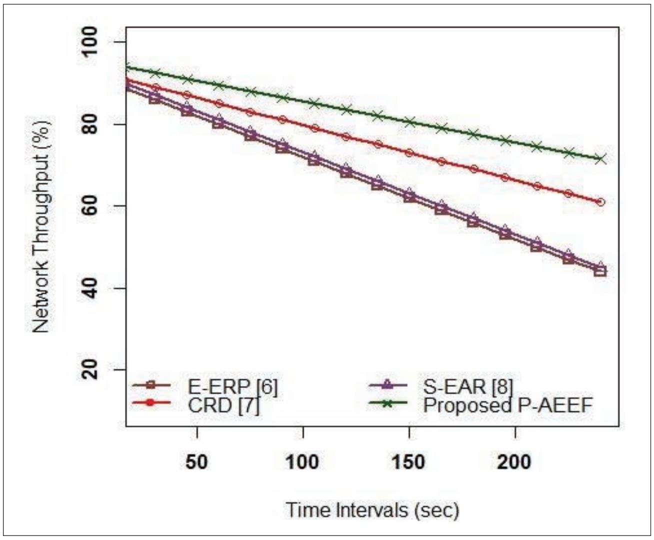

FIGURE 5. Time interval vs. network throughput.

channel and the strengths of the security level, they could not choose a trusted link to route the packets. Because of these inefficiencies, the existing mechanisms such as E-ERP [6], CRD [7], and S-EAR [8] are easily prone to link failure and frequent re-routing requests and discoveries. As a result, it may cause severe additional computation costs for the medical sensor nodes to transfer the data packets successfully. However, in the proposed P-AEEF, the integration of cipher blockchain, digital authentication, and public key cryptography guarantees reliable and secure data transmission to improve energy efficiency. Moreover, the sub-graph extraction applies the AI approach to secure the network route to compute a better cost function. Therefore, the proposed P-AEEF renders minimal call cost for the maintenance of the routing table, resulting in stable network performance.

Figure 5 shows the experimental analysis of network throughput among the proposed P-AEEF and existing mechanisms. From the analysis, it is observed that the proposed P-AEEF enhances the throughput ratio by 16, 6, and 15 percent over the dynamic time intervals in comparison with other existing mechanisms [6–8]. It is worth noting that the proposed P-AEEF applies AI techniques to exploit multihop transmission of data packets between the sensor node and mobile sink. Therefore, the network reliability and link capacity can be improved substantially to increase the energy efficiency. Moreover, the existing mechanisms could not use any intelligence to infer the false entities, resulting in the generation of more route requests and network congestion.

Conclusion

WBAN plays a crucial role in observing the health status of patients, collecting sensitive information between the mobile-sink and remote medical centers. However, due to resource constraints, medical sensors cannot provide better energy efficiency to achieve reliable data transmission. Moreover, sensitive patients' data may easily be prone to potential threats leading to security risks. Thus, this article has presented a privacy-aware energy-efficient framework using CR-IoMT for COVID-19. It utilizes Kruskal's algorithm and cipher blockchain to minimize the routing cost, whereby energy efficiency can be achieved to stabilize the network performance. In the future, the proposed P-AEEF is aimed to be deployed in the mobility environment by transforming the sensor location to track the movement of patients.

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Biographies

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