Journal of Biomedical Informatics 116 (2021) 103731

Contents lists available at ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

Original Research

IoT-based GPS assisted surveillance system with inter-WBAN geographic routing for pandemic situations

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ARTICLE INFO

Keywords:
COVID-19
Internet of Things
Inter-WBAN Communication
Geographic Routing

ABSTRACT

Background: Worldwide pandemic situations drive countries into high healthcare costs and dangerous conditions. Hospital occupancy rates and medical expenses increase dramatically. Real-time remote health monitoring and surveillance systems with IoT assisted eHealth equipment play important roles in such pandemic situations. To prevent the spread of a pandemic is as crucial as treating the infected patients. The COVID-19 pandemic is the ongoing pandemic of coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

Methods: We propose a surveillance system especially for coronavirus pandemic with IoT applications and an inter-WBAN geographic routing algorithm. In this study, coronavirus symptoms such as respiration rate, body temperature, blood pressure, oxygen saturation, heart rate can be monitored and the social distance with 'mask-wearing status' of persons can be displayed with proposed IoT software (Node-RED, InfluxDB, and Grafana).

Results: The geographic routing algorithm is compared with AODV in outdoor areas according to delivery ratio, delay for priority node, packet loss ratio and bit error rate. The results obtained showed that the geographic routing algorithm is more successful for the proposed architecture.

Conclusion: The results show that the use of WBAN technology, geographic routing algorithm, and IoT applications helps to achieve a realistic and meaningful surveillance system with better statistical data.

1. Introduction

COVID-19 is an infectious disease triggered by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It was first recognized in December 2019 in Wuhan, Hubei, China, and has resulted in an ongoing pandemic [1]. More than 80 million cases have been reported across 188 countries and territories with more than 1.75 million deaths; more than 45.11 million people have recovered as of December 26, 2020 [2]. Today, the threats continue and the effects of coronavirus vary from person to person. In such pandemics without a complete cure, maintaining social distance among persons and wearing protective clothes, masks, etc. has to be observed.

Persons have no choice but to be close to each other at work, class, home, etc. They must be aware of how the pandemic spreads and must take the necessary precautions. In addition, patients who screen positive for high-risk features should be isolated immediately to avert further contact with other patients and health care personnel. To assist in this process, eHealth monitoring and surveillance systems can be utilized before and after infection. With eHealth systems, the patients' vital signs and environmental conditions can be sensed and monitored remotely. The vital signs that have to be displayed vary according to illness and pandemic. Furthermore, persons with the same infection may have different symptoms, and their symptoms may change over time. COVID-19 symptoms are not specific because they are also seen in some other diseases, with fever being the most common symptom [3]. The other symptoms are cough, fatigue, shortness of breath or breathing difficulties, and loss of smell and taste [4]. As a new disease many of the details of COVID-19 s spread are still under investigation [5,6].

Currently, Wireless Body Area Network (WBAN) architecture is the most popular eHealth system with IoT (Internet of Things) and IoMT (Internet of Medical Things). The body signs like temperature, blood pressure, oxygen saturation, to name a few, can be gathered and transported for remote monitoring. IEEE 802.15.6 standard has been proposed for more realistic and accurate communications in WBAN

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https://doi.org/10.1016/j.jbi.2021.103731
Received 23 September 2020; Received in revised form 26 February 2021; Accepted 27 February 2021
Available online 9 March 2021
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environments. According to the priority of body signs and opportunistic access of wireless ISM (Industrial Scientific Medical) bands CSMA/CA medium access control (MAC) protocol with priority access specifications has been developed. WBANs can be utilized for example in military, health, education applications in the community, for some specific tasks.

Geographical routing is a form of routing based on geolocation information [7]. It is mainly recommended for wireless networks and is based on the idea that the source node sends a message to the geographic location of the destination node rather than using the network address. Geo-routing requires each node to be able to determine its location and the source node to be aware of the destination node's location. With this information, a message can be directed to the target without prior knowledge of the network topology or a route discovery.

In order to navigate the coordinator nodes in WBANs based on geographic information, each coordinator node must be aware of its geographic location and inform its neighbors. For this reason, a WBAN architecture has been designed in which coordinator nodes will have a Global Positioning System (GPS) hardware. The coordinator can get coordinate information with the help of GPS.

In this study, we have proposed an IoT based WBAN architecture with a geographic routing algorithm for pandemic situations. The IoT based WBAN with all protocols and routing algorithm has been developed in Riverbed Modeler software. Also, IoT software; InfluxDB for database processes, Node-RED for visual programming of interconnecting hardware devices, Application Programming Interfaces (APIs), and online services, and Grafana for analytics and monitoring solutions for every database have been used in the proposed architecture. Our surveillance system will be implemented for COVID-19 pandemic and it has been equipped with eight body sensors for sensing of symptoms and social distance and 'mask-wearing status' of persons can be monitored.

One of the most important novelties in our study is the use of the GPS-based geographical routing algorithm for inter-WBAN communication using the CSMA/CA-based IEEE 802.15.6 protocol for the first time in the literature. However, with a more holistic approach, architecture has been developed for real-time monitoring with IoT software (Node-Red, Grafana, and InfluxDB). The monitoring with Node-RED is proposed for COVID-19 and for this reason the patients' remote control unit is capable of monitoring all data about COVID-19. The data are stored in an InfluxDB database for use in the future and analyzing statistics.

To the best knowledge of the authors;

- CSMA-CA based IEEE 802.15.6 standard first use for COVID-19 pandemic.
- The geographic routing algorithm is used for inter-WBAN communication and compared to AODV, which is popular in the literature.
- Real-time monitor and surveillance systems are proposed with IoT tools.
- Riverbed Modeler, Node-RED, InfluxDB, and Grafana software are performed simultaneously for realistic performance analysis.
- The efficiency of the proposed architecture in overcoming mobility constraints of persons has been evaluated via Riverbed Modeler simulation.
- The proposed approach protects persons outdoors from pandemic situations.

The following section summarizes the related works, simulation environment with software attributes is given in Section 3. The simulation results are presented in Section 4, and the last section gives the conclusions.

2. Related works

A search of relevant literature did not find any study which combined WBAN, IoT software, COVID-19 pandemic monitoring system, and geographic routing for inter-WBAN communication together. The main network architecture in our study is inter-WBAN communication with the proposed routing algorithm for IoT assisted eHealth monitoring and surveillance systems. Intra-WBAN consists of eight nodes with various priorities and a coordinator node (HUB), inter-WBAN consists of several intra-WBANs with some cooperative techniques like clustering, routing, etc.

The first suggestions for geographic routing were put forward as Greedy Routing and Face Routing [8]. Together, these two algorithms form the basis of many later approaches. Greedy routing is a simple form of geographic routing in which packets are forwarded to the nearest neighbor to the destination every time they travel across the network. The Greedy approach is simple to understand and implement as well as being efficient. However, greedy manipulation has a major drawback; when a node cannot find a neighbor closer to the target than itself, it must destroy the packet. Face routing is a simple method of routing in wireless ad hoc networks. It only uses the position information about the nodes to make routing, and it demonstrably guarantees message delivery in statically linked plane graphs. However, it is often difficult to obtain a statically linked plane graph in a realistic wireless network. The geographic routing algorithms in the literature were generally developed for wireless ad hoc networks and later for wireless sensor networks [9–11].

The authors in [12] studied Industrial Information Integration (III) networks and its trends. They proposed that the III of industrial sectors should be supported to prevent the spread of COVID-19. In their study, the gravity model and social network analysis have been utilized to determine the important variables such as industrial sectors' information distance and quality for constructing information integration networks of industrial sectors.

A review study has been proposed in [13] about robotics applications in the COVID-19 pandemic. The authors presented a comprehensive review of the literature to identify robots' potential applications in the management of epidemics. They also identified robot applications to serve patients under quarantine for food and medicine delivery. In [14], the authors proposed a review study about telemedicine applications for the COVID-19 pandemic. They discussed the telemedicine technology with its benefits.

The authors in [15] discussed additive manufacturing in pandemic situations. Different additive manufacturing techniques have been explained with their roles in bridging the supply chain gap in the medical industry. 3D printing technology has been investigated in pandemic emergencies for medical supplies.

In [16], 4D printing technology use in the COVID-19 pandemic has been discussed. Eleven important 4D printing technologies have been identified which provided solutions to problems during the pandemic. The authors of [17] studied and discussed the capabilities of Medical 4.0 for healthcare during the COVID-19 crisis and ten significant Medical 4.0 applications have been reviewed. In [18], wireless medical sensor networks and their roles have also been studied in the context of COVID-19. Some applications of wireless medical sensor networks have been identified with deploying of sensors to accomplish quality healthcare.

Health information technologies have been investigated in the course of the COVID-19 pandemic in [19]. The authors explained the effects of health information technology services such as medical decision support, e-patient portals, etc. The differences in our study can be summarized as follows. A geographic-based routing for inter-WBAN communication is developed and IoT software is utilized for the monitoring systems. The proposed surveillance system can be used as a tool to monitor and respond to the COVID-19 pandemic.

3. The proposed surveillance system

The proposed system consists of two main components. The first component has been modeled in Riverbed Modeler. This component

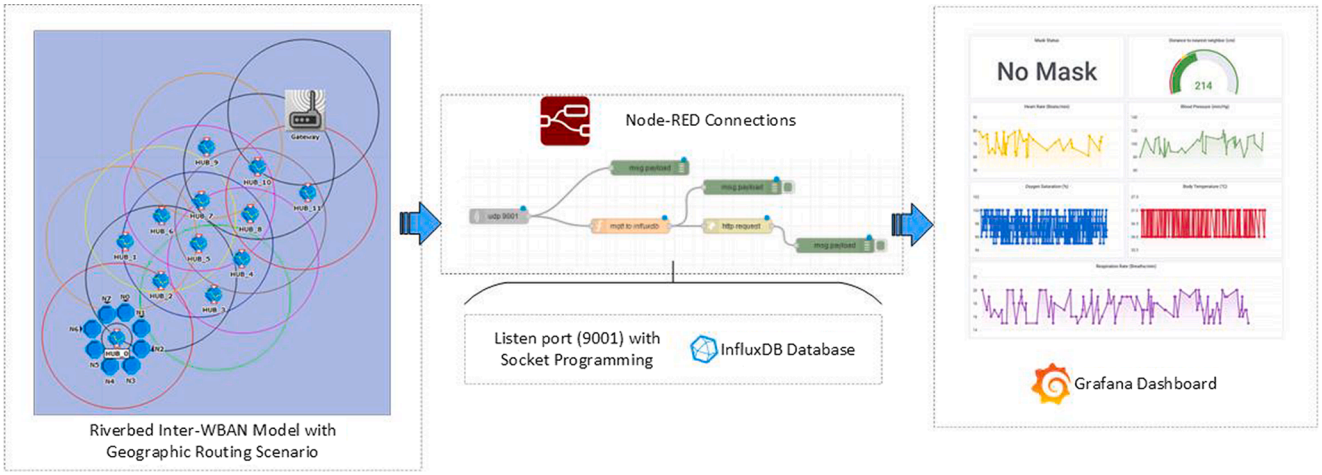


Fig. 1. The network simulation and IoT software parts of the proposed system.

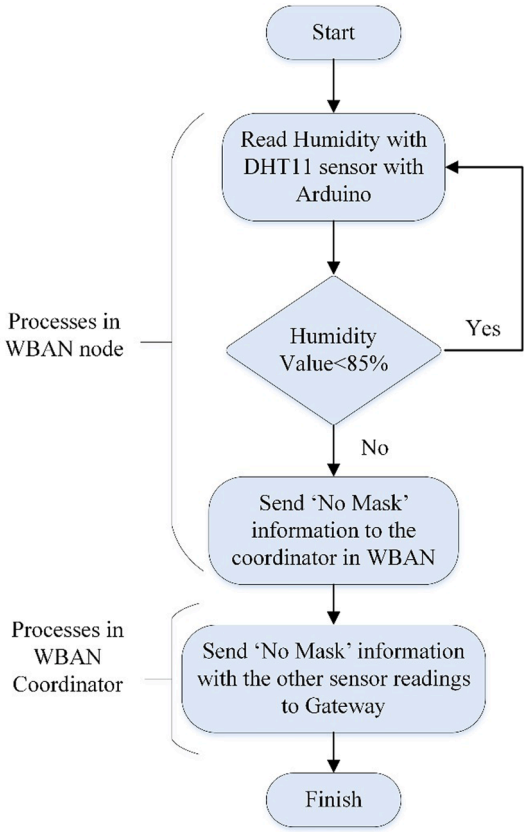


Fig. 2. The mask detection algorithm.

composes the network part of the system and has IEEE 802.15.6 protocol based WBANs with a developed geographical routing algorithm. The second part consists of InfluxDB, Node-RED, and Grafana IoT software. The gathered data from the first component of the system are saved in a database using InfluxDB and Node-RED, the data in the database from the network is then visualized on Grafana. Two components have been joined with socket programming. Therefore these components can run simultaneously for more realistic performance analysis. The relationship between components is illustrated in Fig. 1.

The flow diagram of the mask detection algorithm we developed is given in Fig. 2. There is no standard for detecting a mask, but image processing has been widely used in the literature. We have experimented with some sensor applications with a temperature and humidity sensor (DHT11 sensor with Arduino). The experiment was conducted with and without a mask. Without a mask the temperature and humidity near a person's mouth were measured at about 32 °C and 50%, respectively. Whereas with a mask, the temperature and humidity near a person's mouth were about 34 °C and 95%, respectively. The ambient room temperature and humidity were 28 °C and 58%, respectively. When the measured sensor results are investigated, the difference in humidity is the dominant factor in identifying mask-wearing status. So, we use the humidity of a persons mask for detecting mask status.

3.1. Intra-WBAN architecture

In the first component, intra-WBAN and inter-WBAN communication have been designed with CSMA-CA based IEEE 802.15.6 and geographic routing algorithm. Various body sensor nodes with a coordinator as HUB communication create the intra-WBAN architecture. All nodes and the HUB use the IEEE 802.15.6 protocol based on CSMA/CA MAC. Each sensor node has a priority and the HUB is aware of these priorities for transmitting data to the remote centers. For example, the heart rate vital sign is more important than the others. So, the delay and throughput results of such signs have to be more crucial. In Fig. 1, the body sensor nodes are shown as N0, N1,…, N7 because of having eight different priorities low to high. In the middle of these nodes, the HUB is placed with a GPS unit. The common coronavirus symptoms; respiration rate, body temperature, blood pressure, oxygen saturation, heart rate signs which are sensed by the body nodes are taken into consideration in the proposed intra-WBAN architecture.

CSMA/CA MAC is a multiple access technique developed for the IEEE 802.11 standard. This technique has sensing mechanisms that allow nodes to detect the events in the shared medium on the network. The sensors can listen and sense the shared wireless medium. A node listens to the medium before transmitting its sensed data. If the medium is not busy, the node can send data. If the medium is busy, the node will wait in the backoff period for a random time to send its data, and then try again. This approach tries to lessen the collisions that happen in each node.

CSMA/CA used in the IEEE 802.15.6 standard includes some modified stages for intra-WBAN architecture. Firstly, IEEE 802.15.6 has the Alternative Binary Exponential Backoff (ABEB) procedure. The node that has a packet to be sent to the HUB holds the contention window (CWmin, CWmax) values and the backoff counter (BC) between [1, CW] for a new conditional time slot. CWmin and CWmax values can be selected according to the priority of the nodes. The highest priority has a small CW value that increases the possibility of access to the channel in order to transmit emergency events to the target with the least delay. Contending nodes to send packets set the backoff counter with a random

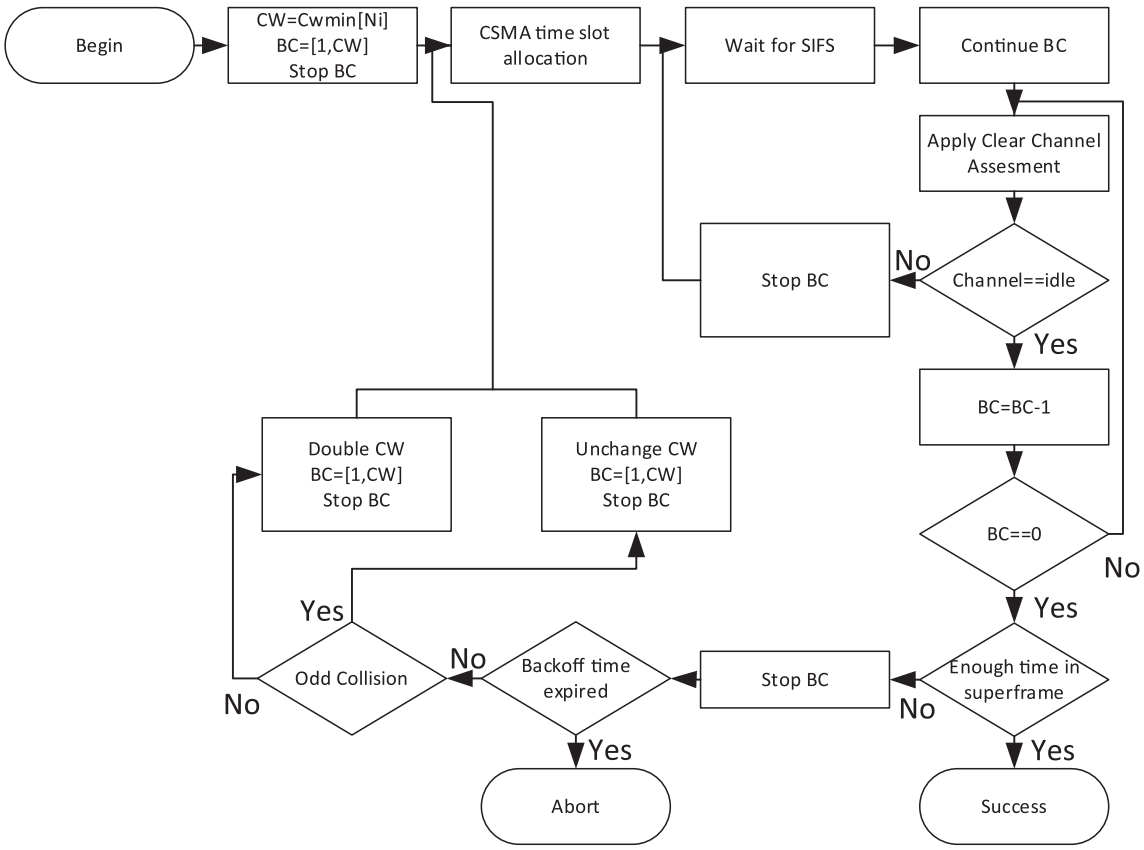


Fig. 3. CSMA/CA-based IEEE 802.15.6 data transmission flow diagram.

integer over an evenly distributed interval [1, CW] to minimize the probability of collision. All process steps of the IEEE 802.15.6 are shown with the flow diagram in Fig. 3.

3.2. Inter-WBAN architecture

Each WBAN uses the aforementioned CSMA/CA-based IEEE 802.15.6 protocol in itself. When WBANs want to communicate with each other, only HUBs can transmit the data to other HUBs because of data security. This type of communication, called inter-WBAN communication, can be enabled with routing algorithms and some permissions. In our proposed system, the HUBs can sense the other HUBs and transmit data to the others in full-duplex.

In our simulation scenario, we assume that the WBAN users are placed in the outdoors like soldiers, trainers, students, workers, etc. The persons in the simulation are equipped with WBAN devices, the body signs are sensed by nodes and transmitted to the HUB. Inter-WBAN communications run after the HUBs receive packets from the nodes connected to them. All HUBs have GPS modules and their locations can be determined with the GPS. The proposed routing algorithm in this study has been designed on the location of HUBs. HUBs share their location information at certain times. The distance between HUBs has been calculated using this information. Therefore, HUBs can know the distance of their neighbors. Each HUB that has data to transmit to the remote gateway sends the data to the nearest neighbor. Then, a HUB which has the data from the previous HUB, delivers them to its neighbor. The delivery of the data continues in this way until the data reaches the destination gateway. The aforementioned data delivery is called

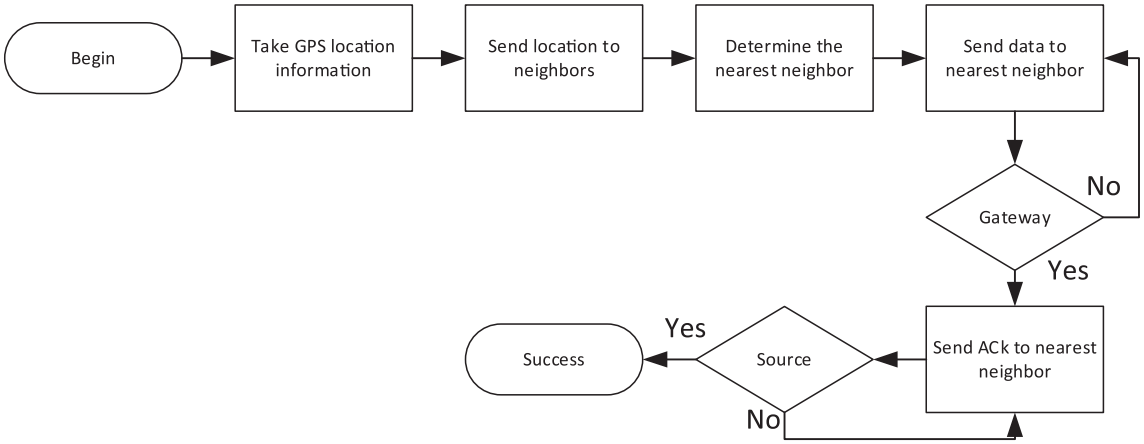


Fig. 4. Geographic routing flow diagram.

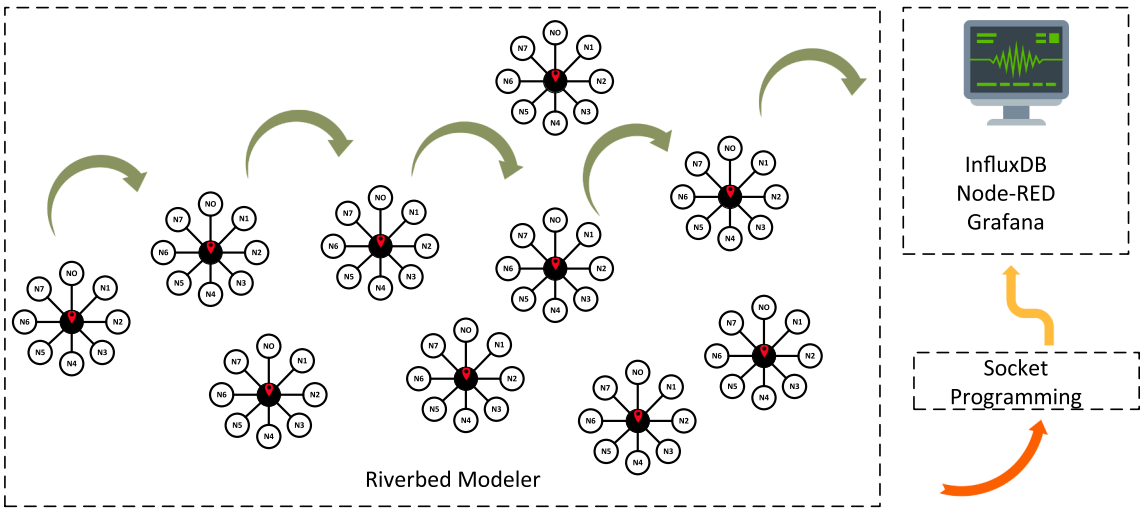


Fig. 5. An example of the simulation scenario.



Fig. 6. IoT software interface on Grafana.

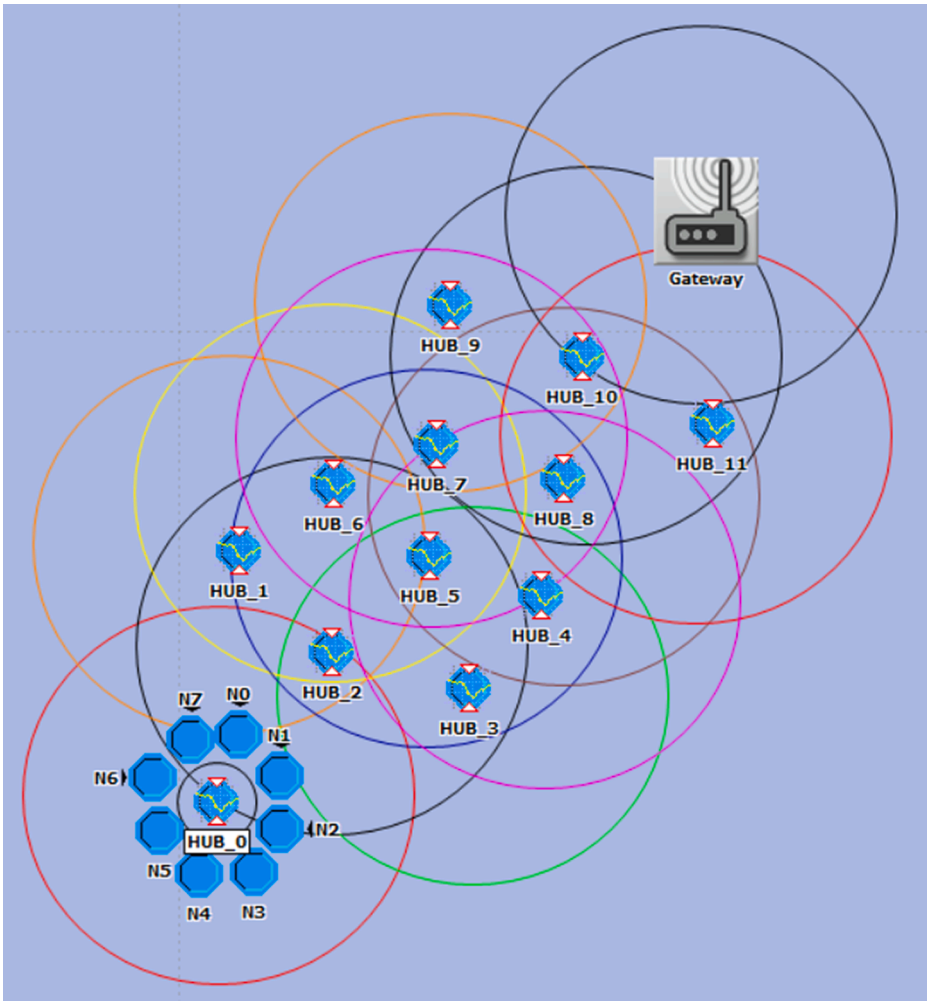


Fig. 7. The proposed network project editor in Riverbed Modeler.

geographic routing in ad hoc wireless networks based on location information assisted by GPS. The chain of operations in our study starting from the intra-WBAN communication and continuing with inter-WBAN communication aims to protect persons outdoors from the pandemic situations and warn the remote centers for unwanted scenarios. The details and working conditions will be explained in detail in the next section. All process steps of the proposed geographic routing are shown with the flow diagram in Fig. 4.

Table 1
Simulation parameters.

Parameters	Values	
Simulation Time	600 s	
Frequency	2400–2483.5 GHz	
The body sensor and HUB numbers	12 HUB + 8 node + 1 gateway	
Bandwidth	1 MHz	
Data Rate	971.4 kbps	
Packet Size	100 byte	
Packet Inter-arrival Times	N7 = 0.2 sec.	N3 = 2 sec.
	N6 = 0.5 sec.	N2 = 5 sec.
	N5 = 1 sec.	N1 = 10 sec.
	N4 = 1 sec.	N0 = 20 sec.
Energy Consumption Parameters (MicaZ values)		
Battery	2 AA (3 V)	
Initial Energy	34,600 Joule	
Packet Transmission	0 dBm = 17.4 mA	
Packet Receive	27.7 mA	
Idle	35 μA	
Sleep	16 μA	

4. The simulation scenario and results

We propose the surveillance system for pandemic situations, especially for COVID-19. The WBAN nodes generate the coronavirus symptoms respiration rate, body temperature, blood pressure, oxygen saturation, and heart rate signs' packets and send them to the HUB in the intra-WBAN communication. The priorities are categorized from highest to lowest as respiration rate, body temperature, blood pressure, oxygen saturation, and heart rate, respectively. Additionally, the humidity level of a person's mask and location information of the nearest neighbor node are gathered and transferred with the aforementioned COVID-19 symptoms. The limited coverage radius of WBAN nodes necessitates the use of a relay node to reach their destination. Therefore, the inter-WBAN data transmission to the gateway has occurred with the geographic routing algorithm. An example of the architectural view we propose is shown in Fig. 5. The gateway as a healthy person, doctor, or supervisor displays all data as shown in Fig. 6. The results are shown for a person equipped with WBAN in Riverbed Modeler simulation software.

We use current IoT software in our simulation with InfluxDB, Node-RED, and Grafana. InfluxDB [20] is an open-source time-series database. We use it for database operations in our simulations and the aforementioned data from Riverbed Modeler are saved in InfluxDB. We utilize socket programming to import data from the Riverbed Modeler. Node-RED programming tool as a browser-based flow editor is used for wiring the software. InfluxDB and Grafana connections are provided through Node-RED that is user friendly and the processes can be

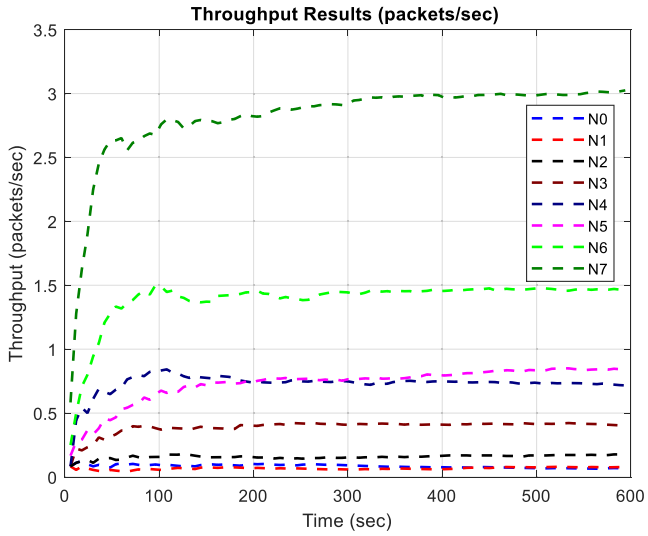


Fig. 8. The throughput results.

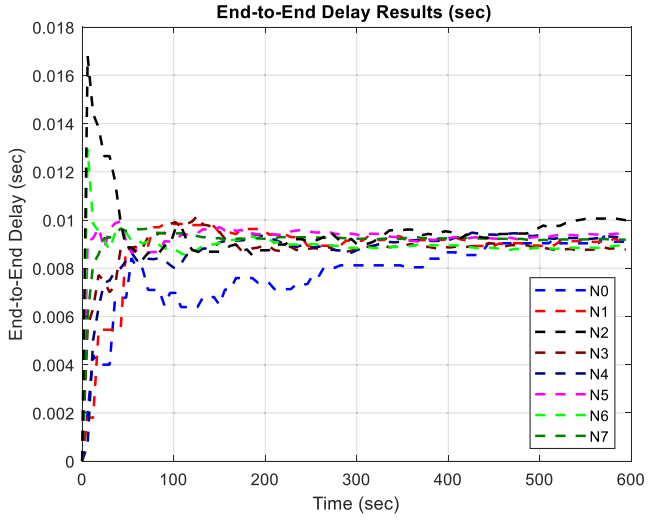


Fig. 9. The end-to-end delay results.

deployed to its runtime in a single-click [21]. Finally, the visualization has been facilitated in Grafana as can be seen in Fig. 6. Grafana allows us to query, visualize, alert on, and understand data stored in the database [22].

The proposed network consists of intra-WBAN and inter-WBAN that is modeled in Riverbed Modeler. Riverbed Modeler is a network programming tool which serves all network interfaces and protocols. Wireless/Wired, Ad-Hoc/Infrastructure, Mobile/Stationary networks with their components can be programmed professionally [23]. Riverbed Modeler project editor can be seen in Fig. 7.

We show the only body sensors connected to the HUB_0 for simplicity and there are a total of twelve HUBs in the simulation environment. HUB_0 wants to send its intra-WBAN data to the gateway and the gateway is the destination that has the aforementioned monitoring system as shown in Fig. 7. The simulation parameters are given in Table 1. Each body sensor as N0, …, N7 has different packet inter-arrival times and the simulation duration is 600 s.

Firstly, we investigate the throughput results of the proposed network. Throughput results show the successfully transferred data to the gateway. The aforementioned data are generated by N0, …, N7 body nodes in HUB_0 intra-WBAN. As can be seen in Fig. 8, the highest throughput belongs to N7 which is the highest priority node and it has

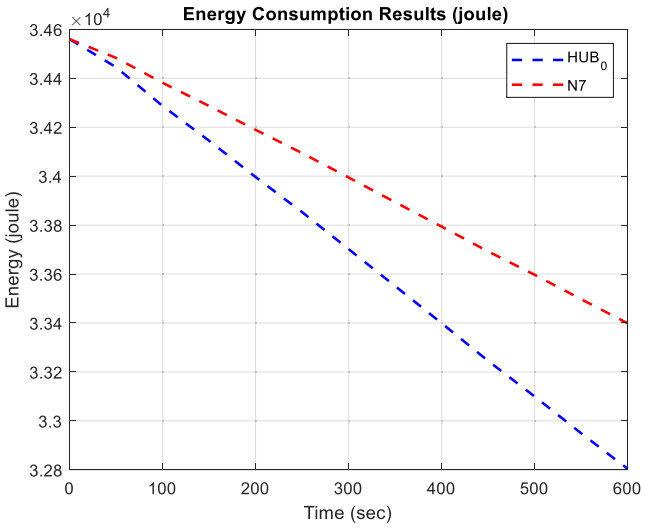


Fig. 10. The energy consumption results.

the minimum packet inter-arrival time. The lowest throughput belongs to N0 which is the lowest priority node and it has the maximum packet inter-arrival time. Differences between packets are due to packet inter-arrival times assigned for priorities. The throughput results are consistent as expected. In the proposed architecture, throughput is very important in terms of following the vital conditions of people or patients. For this reason, packets are expected to reach their destination without any loss. In order to achieve this goal, geographical routing protocols with different priority and high-performance CSMA/CA-based IEEE 802.15.6 have been used. The results show that the aforementioned technical capabilities are quite appropriate for eHealth surveillance system.

Secondly, we investigate the end-to-end delay that is an important parameter for performance analysis results. End-to-end delay (EED) is a delay that holds the time between the generation process time of a packet at the source and arrival time at the destination. The EED results are shown in Fig. 9 as averages. As can be understood from simulation parameters in Table 1 the packet inter-arrival times are not equally distributed, for example, N7 generates five packets in a second, while N0 generates one packet in twenty seconds. In addition, the packet size is hundred bytes with exponential distribution. Therefore, as can be seen in Fig. 9, the EED results are very close. In addition, the packets travel on several HUBs and various inter-arrival times to the HUBs. The average EED result for all packets is about nine msec. The proposed architecture is delay-sensitive. The collection, storage, processing and analysis of the data should be done as soon as possible due to the rapid increase in health data. These data may be obtained from different sources and formats. The data must reach the destination with minimum delay. Fatal consequences can occur in the case of high latency vital packets.

Lastly, the energy consumption results are given in Fig. 10. Only HUB_0 and N7 node energy consumption results are given for simplicity, because the energy consumption results of nodes are very close to each other. The energy consumption of the nodes is calculated according to sending, receiving, idle and sleep modes. For these reasons, we give one node and one HUB results. The nodes generate the packets, sense the medium, and transfer the data to the HUB. HUBs collect the data from the nodes, sense the medium, run the routing protocol, and send the data to the nearest neighbor. Finally, the HUB consumes more energy than the nodes. This can be seen in Fig. 10.

Most routing protocols require neighborhood tables of nodes to make routing decisions. These tables are usually constructed using routing beacons (packets). These packets broadcast regularly and are received by all nodes within the coverage area. The main problem with routing algorithms using beacons is that neighborhood information is not always

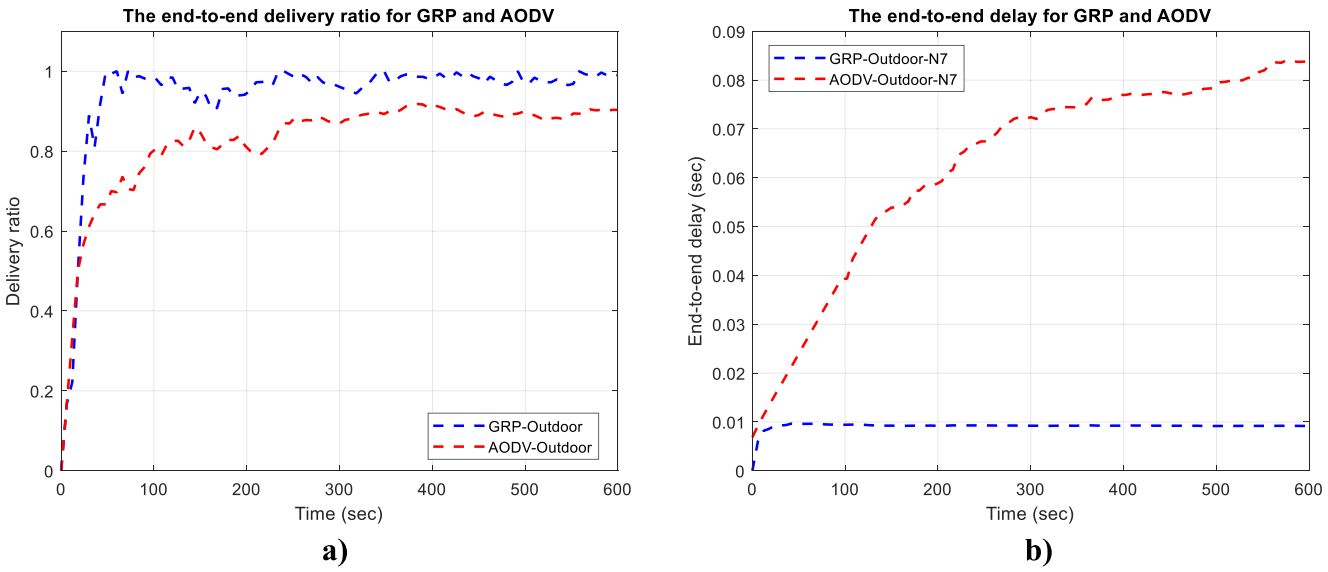


Fig. 11. **a)** The end-to-end delivery ratio and **b)** delay of N7 for GRP and AODV.

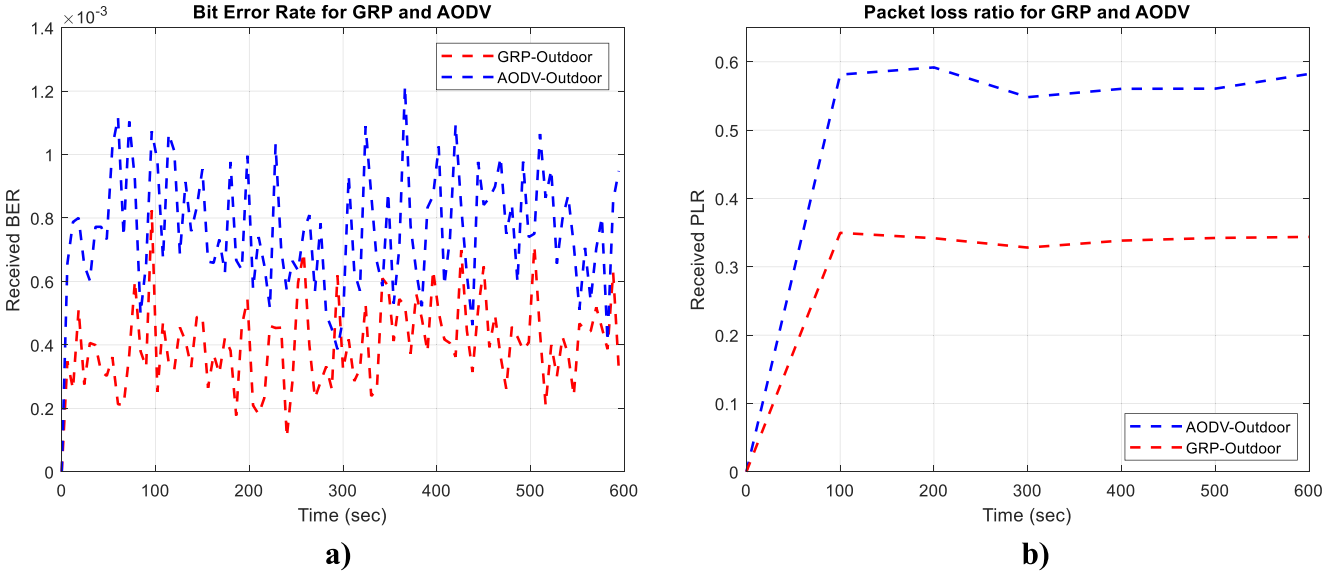


Fig. 12. **a)** Bit error rate and **b)** Packet loss ratio for GRP and AODV.

up to date. Another problem is that beacons increase network traffic and consume more bandwidth and energy. This is an important problem especially for energy-constrained networks such as WBAN. In Fig. 11-a, end-to-end delivery ratio values of geographic routing protocol (GRP) and Ad hoc On-Demand Distance Vector (AODV) routing protocols are compared for the outdoor area. In Fig. 11-b, delay analyzes for the node with the highest priority are compared for the outdoor area. The results obtained show that the GRP routing algorithm is more successful. In the light of these results, it can be said that location information in routing algorithms is important for outdoors. It is known that this difference is not significant for indoors [24,25]. However, it has been observed that routing algorithms that do not use location information for outdoors are not scalable. The results are consistent with the literature [26,27].

In Fig. 12-a, received bit error rate (BER) and packet loss ratio (PLR) values of GRP and AODV routing protocols are compared for the outdoor area in Fig. 12-b. These results obtained for outdoors show that GRP is more successful in both BER and PLR results compared to AODV. The main reason for this result is the flooding method of the AODV routing algorithm. Regardless of whether there is data to be transmitted by all nodes within the coverage area, routing beacons (packets) broadcast in the environment have become a disadvantage for both BER and PLR. The AODV uses more bandwidth by flooding method and so it uses less bandwidth for data transmission. This result causes a decrease in performance. Geographical routing algorithms utilizing small, cheap, and low-power GPS to obtain the coordinates of sensors from signal strength are an efficient approach for energy-constrained WBANs [28].

5. Conclusions

The IoT gives more powerful options for eHealth applications. With multidisciplinary studies, the efficiency of eHealth systems can be increased. In this study, intra-WBAN and inter-WBAN architectures with CSMA-CA based IEEE 802.15.6, geographic routing algorithm and AODV have been performed for pandemic situations. Various IoT software (Node-RED, InfluxDB, and Grafana) and architectures have been utilized for visualization of COVID-19 symptoms. Therefore, an IoT based eHealth surveillance system has been designed for pandemics, and the persons in the area can be monitored for health conditions, social

distances, and mask-wearing status. For the performance analysis proposed approach, throughput, delay, energy consumption values have been analyzed and the geographic routing algorithm has been compared to the AODV routing algorithm which is widely used in the literature in terms of delivery ratio, delay, packet loss ratio, and bit error rate. For future studies, we plan to use machine learning, deep learning, and cognitive algorithms for mining health data with data analytics tools.

CRediT authorship contribution statement

Seda Savaşcı Şen: Conceptualization, Methodology, Software, Validation, Data curation, Writing - original draft. **Murtaza Cicioğlu:** Conceptualization, Methodology, Software, Validation, Data curation, Writing - original draft. **Ali Çalhan:** Conceptualization, Methodology, Software, Validation, Data curation, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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