

Article

Mobile Wi-Fi Based Scheduling of Cyber-Physical Systems in Healthcare

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Received: 14 December 2019; Accepted: 28 January 2020; Published: 2 February 2020



Abstract: Wireless Body Area Networks (WBANs) and Wireless Local Area Networks (WLANs) have been widely regarded as solution providers for future Cyber-Physical Systems (CPS)-based ehealthcare amenities. The IEEE 802.11 standard specifies media access protocols in wireless networks, along with channel access methods. WBANs are expected to improve the existing healthcare services significantly, but several research challenges also have to be tackled for apt utilization of the technology. Guarantee of Quality-of-Service (QoS) differentiation between various health parameters, such as temperature and blood pressure, during mobility is a major challenge for the provision of ehealthcare services. The scheme proposed in this paper for the Mobile Wi-Fi based connectivity of WBANs is designed to provide QoS-based priorities for ehealthcare subscribers by altering the Contention Window (CW) for different applications of patient health monitoring. The relationship between CW and QoS is utilized to achieve efficient resource assignment. Three different health parameters, i.e., ECG (Electrocardiogram), BP (blood pressure) and temperature, are monitored using medical CPS in this work. The performance evaluation results, such as end-to-end packet delay and throughput for various data traffic classes reveal that the proposed scheme improves QoS provision.

Keywords: CPS; mobile Wi-Fi; QoS; simulation; contention window

1. Introduction

The emergence of rapid advancements in wireless communication technologies and electronics has enabled the development of Wireless Body Area Networks (WBANs). The concept of Cyber-Physical Systems (CPS) implies advanced systems capable of interacting with humans to improve physical systems through computing, communicating and controlling physical or environmental parameters. The notion of CPS has promoted numerous possible solutions for different applications, such as remote healthcare monitoring. The WBAN research area has been functional mainly in the healthcare domain, where WBANs are gaining popularity by competently dealing with healthcare delivery for services provision [1]. The utilization of WBANs leads to improved services for an enormous number of people in hospitals, at their offices or in their residential premises, by utilizing limited human and financial resources. A WBAN is established by a large number of sensor-based CPSs, with sensors in the range

of hundreds or even thousands, connected to the patients' body [2]. In WBAN, a variety of challenges for the research community have been recognized with the regular usage of radio technologies such as Wireless Fidelity (Wi-Fi), 4G/5G and Mobile Wi-Fi. While working with such technologies, the Quality-of-Service (QoS) support needs to be guaranteed for the sensors with limited power as well as the narrowband real time applications of WBAN. Compared to sensor networks, WBANs deal with smaller and fewer nodes, called body sensors, implanted inside or on the body of the patient to measure vital signs such as ECG, BP and glucose level, either externally or internally. These sensors consist of small batteries with limited power. This paper addresses the scheduling issues of body sensor data traffic originating from medical CPS over WBAN. A QoS-aware scheduling approach is proposed for WBAN in this paper. The proposed scheme is based on Enhanced Distributed Coordination Function (EDCF) via MiFi connectivity at the MAC (Media Access Control) layer. The remaining paper is organized as follows. Section 2 explains the Mobile Wi-Fi device and system architecture. Section 3 represents the related work that has been done in the QoS support area. The scheme proposed is explained in Section 4. Section 5 discusses the methodology and Section 6 evaluates the resulting analysis based on experiments. Finally, Section 7 explains future work and the conclusion based on the results of this paper.

2. Mobile Wi-Fi and Cyber-Physical Systems for Ehealthcare

This paper investigates the provision of QoS through a Mobile Wi-Fi access point that acts as a relay to connect a cellular network (4G/5G, etc.) and a Wi-Fi system. The device is also used to provide mobile Internet access to Wi-Fi-enabled peripheral devices e.g., laptops or smartphones. The device provides Wi-Fi access within a range of 20 meters for up to five mobile devices and operates on 2.4GHz or 5GHz for Wi-Fi access. The CPS architecture suggested in this work for the setting up of a WBAN includes several components, such as sensor nodes, Mobile Wi-Fi device, Base Station (BS) and a medical server, as illustrated in Figure 1. The transmission of the health parameters of a patient, such as temperature or electronic images from locations under cellular coverage, could be achieved using a belt with sensors fitted in it. Such a belt could be enveloped around the wrist or chest of the patient. These body sensors sense vital signs to observe health data from the patient's body, which are ultimately transmitted to the BS from the body to where the BS is linked to the server in the hospital through the Mobile Wi-Fi device and Wireless Local Area Network (WLAN).

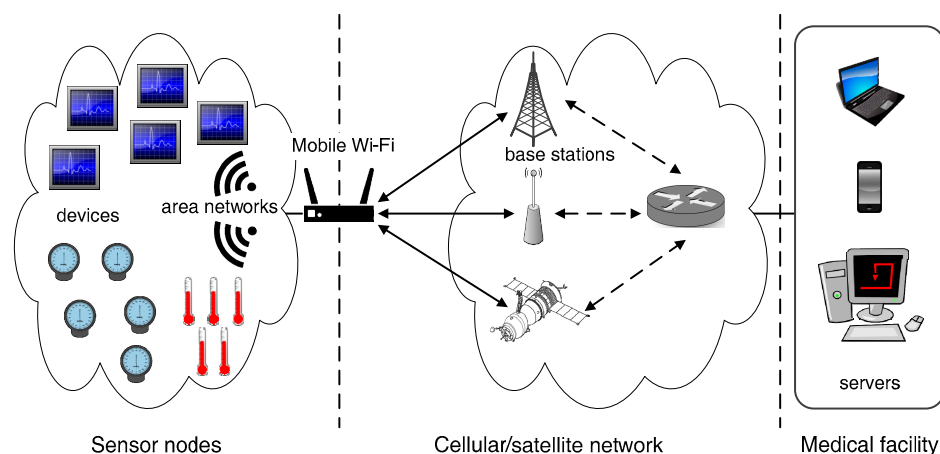


Figure 1. Cyber-physical systems (CPS) Architecture.

In WBAN, sensor nodes placed connected to a human body (or implanted) quantify vital health parameters such as heartbeat rate, sugar level and rate of respiration to monitor patient's health. Several issues, such as sensors' limited power, QoS provision and narrowband applications with real-time requirements over broadband systems, have come to the fore. Similarly, the lack of availability of DSL (Digital Subscriber Line) in far-flung areas for health monitoring is also a challenge for researchers.

3. Related Work

This section explores the work conducted by the researchers using different approaches for QoS provision in wireless networks. The authors of [3] examine the main characteristics of WSNs and the requirements of QoS provisioning in the context of a cyber-physical computing Distributed Coordination Function (DCF) extension, proposed by the authors of [4], based on the Contention Window (CW) increment, which makes use of functions with additions after shifting bits to the left. The main targets are to reduce packet loss ratio, minimize delay and increase transmission channel efficiency. In [5], authors proposed a class-based model for QoS differentiation. The model defines two flag bits added inside the MAC header to differentiate three classes of services. The algorithm proposed in [6] is designed to enhance both the delay in and throughput of IEEE (Institute of Electrical and Electronics Engineers) 802.11 DCF performance. In [7], a government-owned Wi-Fi network is used to develop a QoS model for end-to-end performance. Traffic classification takes place via the CW threshold. A CW-based scheme is proposed in [8] to achieve a high performance in terms of throughput in densely built environments. The scheme proposed in [9] analyzes the IEEE 802.11 DCF parameter effects, such as RL (Retry Limit) and CW, in industry-based applications with small packet and noisy atmosphere. Authors in [10] segregate traffic into real-time and non-real-time for QoS differentiation.

In [11], the authors present an algorithm for the improvement of QoS and energy efficiency by decreasing delays and packet collisions in data transmission of IEEE 802.11 standard. Authors of [12] present a comparative analysis of IEEE 802.15.4 and IEEE 802.15.6 standards in terms of various QoS parameters. In [13], authors propose a scheduling scheme for WBANs where duty cycles are scheduled for power and information transfers phase-wise. In [14], a mechanism based on the adaptive backoff of the contention window is proposed for the improvement of QoS. The backoff time is adjusted according to the active stations in each access category. A QoS-aware packet aggregation scheduler at MAC layer to improve voice data traffic performance at both mobile station as well as access points is presented in [15]. A qualitative QoS assessment with the help of laboratory tests and emulations for comparing various WLAN networks is presented in [16]. In [17], a mechanism for QoS provision in an asymmetric full-duplex WLAN communication system is presented. The authors of [18] present a framework based on virtualization and software-defined networking notions for QoS guarantees in 5G networks. In [19], the authors present a scheme for the management of radio resources in uplink device-to-device communications. The authors of [20] use a flying ant colony algorithm for the optimization of QoS-based web service selection issues. Approaches with a genetic algorithm for grouping and routing in sensor-based networks are proposed in [21], enhancing both the sensor's lifetime and QoS. In [22], authors propose a MAC protocol for reduced energy consumption and delay for traffic. The authors of [23] propose a mechanism for improving QoS provision in 802.11e standard. In [24], issues of resource management are addressed with consideration of QoS in WLANs for human based traffic.

It is evident from the literature survey that either QoS requirements are not considered when resource allocation is performed in wireless networks, or computationally intense and complex schemes are designed. The distinct natures of human-based traffic and sensor-based traffic are also not reflected in the literature. In this paper, delivering QoS-based services in ehealthcare-based CPS is the issue discussed. The peculiarities of sensor data traffic are considered when devising the QoS differentiation mechanism in this work.

4. Mobile Wi-Fi Features

To establish a connection between the sensor nodes and mobile networks, such as a 5G network, a wireless access point known as a mobile Wi-Fi device is deployed. The mobile Wi-Fi device can be used to access 5G network services with the help of a SIM (Subscriber Identity Module). Hence, ehealthcare services could be offered even when the patient is not at home or in hospital. To provide outdoor monitoring services to patients, the use of a smartphone with a mobile hotspot could also be a very handy option as a Wi-Fi access point for CPS. An arrangement involving a mobile hotspot

offers mobility support and also helps in achieving the high data rates tendered by the future mobile networking systems. The sensor nodes in the vicinity of the mobile hotspot capable of communication via Wi-Fi access point could avail the services of high-speed internet. Smartphones provide the feature of a mobile hotspot where an LTE-A access network is used to link the backhaul traffic to LTE-A broadband internet, whereas Wi-Fi services are provided to sensor nodes in the Wi-Fi coverage area. Such a smartphone or mobile Wi-Fi device comprises a Wi-Fi protocol stack towards the access link side and an LTE-A protocol stack towards the backhaul link side (Figure 2).

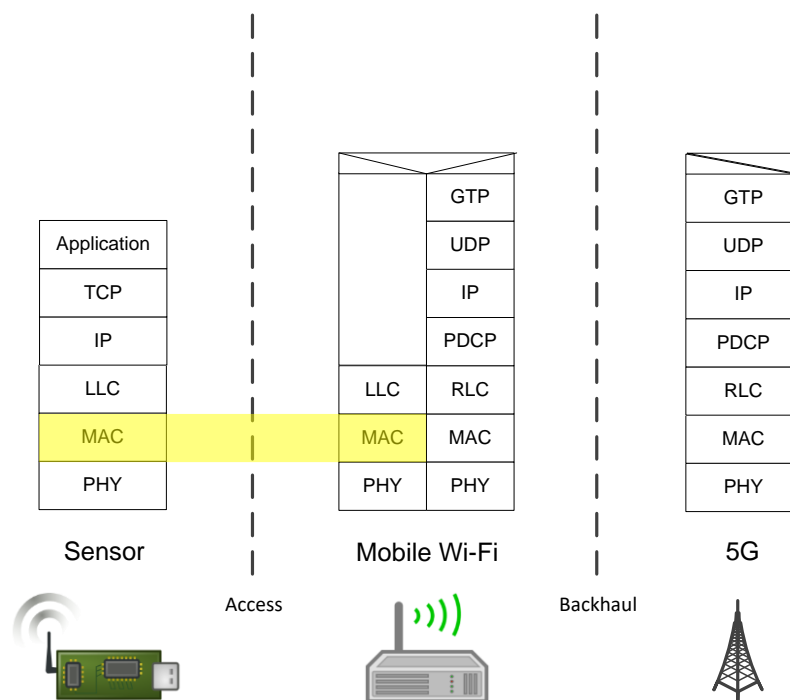


Figure 2. Mobile Wi-Fi protocol stack.

5. Data Traffic Types and Prioritization

In this research work, three types of data sensors with varying QoS requirements are considered. These sensors are actually biosensors and used to generate data that are acquired with the help of healthcare equipment to determine various health parameters. The three data traffic types that are cogitated in this work are ECG (Electrocardiogram), blood pressure (BP) and temperature. These sensor types generate data traffic that can be associated with different priority levels. Generally, the highest level of priority among the three traffic types is given to ECG traffic, then BP is considered less delay sensitive as compared to ECG data traffic, whereas temperature data traffic is the most delay-tolerant type of data traffic [23]. Each of these traffic types generate data traffic with different inter-arrival times and are allocated various access categories. The traffic classes ECG, BP and temperature are modelled as video, best effort and background data traffic types, respectively, for the sake of prioritization and differentiation.

6. Distributed Coordination

The Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) are access mechanisms associated with the MAC layer of the Wi-Fi protocol stack, or, more precisely, the IEEE 802.11 MAC. Distributed coordination has to be made available mandatorily in all nodes, whether in an infrastructure or ad-hoc setup. Carrier sensing is the primary feature of distributed coordination. If the energy from signals in the available bands is above a certain level, the medium is presumed to be busy and considered not available for transmission. Coordination in a distributed fashion utilizes a

backoff mechanism, where nodes ready for transmission sense the medium. If the medium is declared as busy, the sensing node is required to postpone the transmission. A DCF Interframe Space (DIFS) time of medium inactivity is ensured, after which the nodes randomly generate a backoff time, expressed as number of slots. The generated period also has to be added to the waiting time for the node before occupying the medium. The randomization reduces chances of collision in the contention period. The backoff period is determined by finding the product of single slot duration and an integer value. Backoff period is expressed as follows

$$T_{backoff} = CW * \text{uniform}(0, 1) * T_s \quad (1)$$

where $T_{backoff}$ is the time the node must wait after a lapse in the DIFS duration of free medium, CW is an integer value between maximum CW size (CW_{max}) and minimum CW size (CW_{min}), while T_s is the time duration of a single slot. The parameter CW initially assumes the value of CW_{min} and, after each failure in the transmission attempts, a new value of CW is generated. The new value cannot exceed CW_{max} . The value is higher than the previous value of CW . The new CW value is generated as follows

$$CW = 2^x - 1 \quad (2)$$

where the value of x is incremented after each unsuccessful transmission attempt.

7. Enhanced Distributed Coordination Function

Distributed Coordination can be advantageous when medium access is desirable for nodes with equal priorities. All stations can compete with equal likelihood to achieve channel access. However, it may not be beneficial in cases when nodes belong to different priority classes. Enhanced Distributed Coordination Function (EDCF) can provide differentiation of traffic types by stipulating multiple access categories. Each access category is associated with a set of values of parameters, such as Transmit Opportunity (TXOP), CW_{min} , CW_{max} and arbitration interframe space (AIFS) number (AIFSN), where TXOP is the duration of time transmission can be done by a node after acquiring contention and AIFSN is dependent on its access category. Here, AIFS is a mechanism used to prioritize access categories (Figure 3). The mechanism is achieved through AIFS number (AIFSN). The value of the AIFSN for each access category is used to find the AIFS duration of that respective category. AIFS duration is determined as

$$T_{AIFS} = T_{SIFS} + AIFSN \times T_s \quad (3)$$

where T_{AIFS} is the AIFS duration and T_{SIFS} is the Short Interframe Space (SIFS) duration.

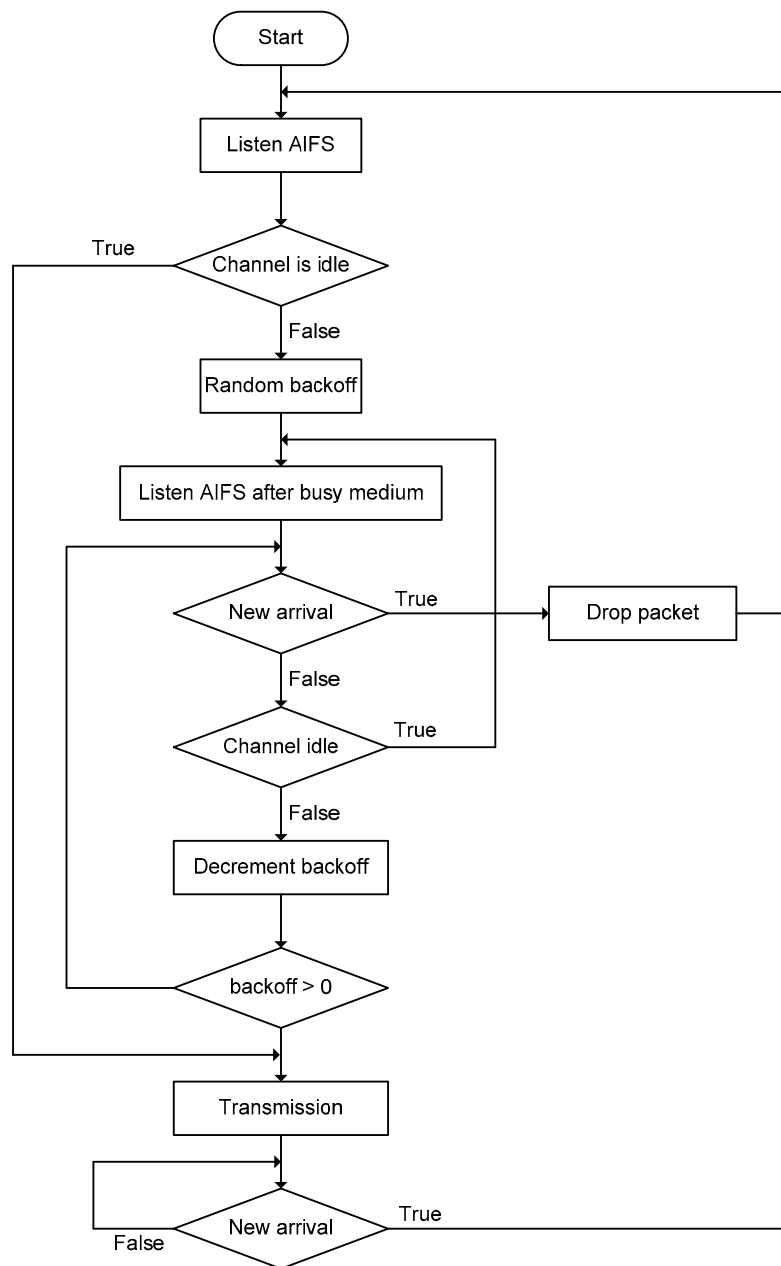


Figure 3. AIFS-based procedure.

8. Proposed Scheme

The default CW_{max} and CW_{min} values for each access category have been determined in the IEEE 802.11e standard documentations (as given in Table 1). In this work, a slight modification to the values in Table 1 is presented and then evaluated for soundness. For the access category associated with the highest traffic class of sensor data (ECG), the default values of CW_{min} and CW_{max} are adopted. For the other categories (BP and temperature), the values suggested are given in Table 2. These values have been formulated in light of a sequence of exhaustive sensitivity analyses via simulations [24]. The default parameters were determined primarily for traditional human-based data traffic involving file transfer data or web browsing-related data. The proposed values set are the extract of the essence of sensor type data patterns with significantly different traffic models as compared to human-based traffic. Furthermore, this configuration also allows ECG data traffic to have a much higher probability

of accessing the medium in contrast to other traffic types. The proposed CW_{min} value for temperature is the largest, resulting in the lowest priority to the access category.

Table 1. Default Enhanced Distributed Coordination Function (EDCF) parameters.

Access Category	Sensor Type	CW_{min}	CW_{max}	AIFSN	TXOP
Video	ECG	15	31	2	6.016 ms
Best effort	BP	31	1023	3	3.264 ms
Background	Temperature	31	1023	7	3.264 ms

Table 2. Revived EDCF parameters.

Access Category	Sensor Type	CW_{min}	CW_{max}	AIFSN	TXOP
Video	ECG	15	31	2	6.016 ms
Best effort	BP	127	1023	3	3.264 ms
Background	Temperature	255	1023	7	3.264 ms

The aim here is to squeeze the CW sizes for high priority and release for low priority traffic. The sensor node connected to the body performs medium sensing when it is ready to transmit. The transmission is initiated upon sensing the medium as available. If an acknowledgement of this transmission is received, the data transmission is deemed successful. Sensor data of all access categories are sent to the mobile Wi-Fi access point, where it can then be forwarded to the ehealthcare medical facility even from remote locations. Data servers at the medical facility maintain databases of patients' health history which can be retrieved if and when required by the physicians. Database access to own records are also provided to patients for possible future reference.

9. Simulation Setup

In this paper, the design, implementation and evaluation of a WBAN-based scheme for data traffic prioritization is achieved with the help an OPNET Modeler-based [25] simulation environment. The simulation model primarily consists of three domains, i.e., the Wi-Fi based access domain, the 5G based backhaul domain, and the 5G core network. The access domain consists of the mobile Wi-Fi device access protocol stack and sensor nodes deployed in the Wi-Fi coverage area. The backhaul domain consists of the mobile Wi-Fi and base station with their 5G air interface protocol stacks. The 5G core network consists of a 5G gateway labelled as a server in the simulation environment. The gateway node works as a sink for uplink data, and all the uplink packets originating from sensor nodes are destroyed here. The 5G gateway is connected to the 5G base station via router and Ethernet links, with 20ms as mean delay. All nodes consist of protocols such as Internet Protocol (IP) and User Datagram Protocol (UDP), along with Ethernet in the core network and wireless protocols in the access and backhaul domains. The protocols in the backhaul domain also include Radio Link Control (RLC), Medium Access Control (MAC) and Packet Data Convergence Protocol (PDCP). The information related to sensor nodes' mobility and channels is kept in the form of a database at the node labeled 'global_node_list,' which is accessible from all the nodes in the simulation environment. All the node-related parameters are initialized in the 'global_node_list' at the start of each simulation run. The simulation environment and protocol stack for the sensor node are depicted in Figures 4 and 5, respectively.

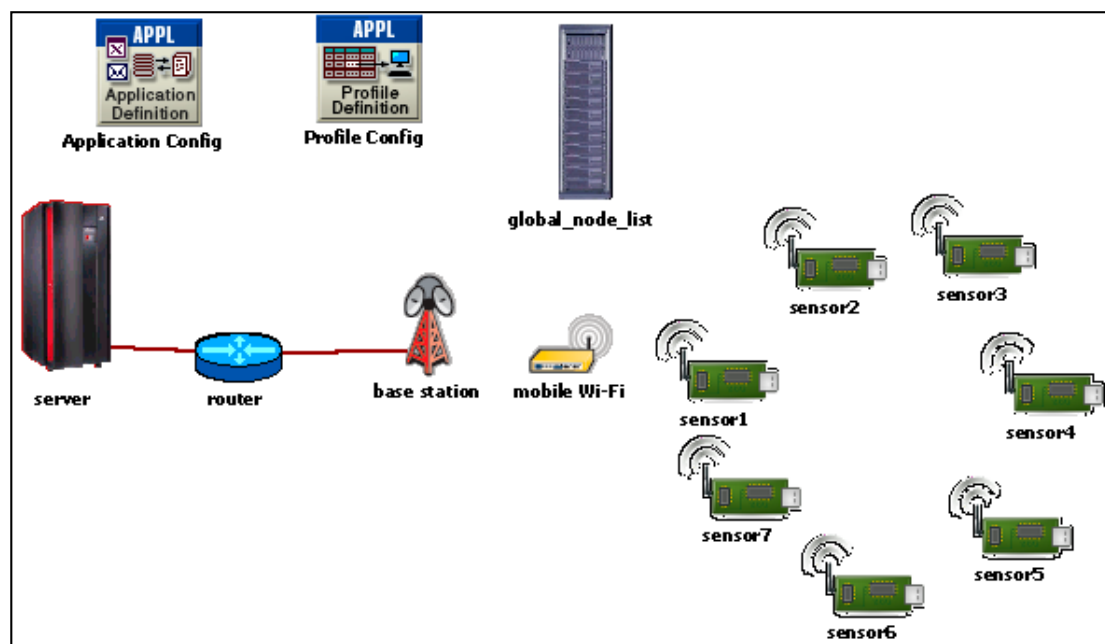


Figure 4. OPNET simulation environment [25].

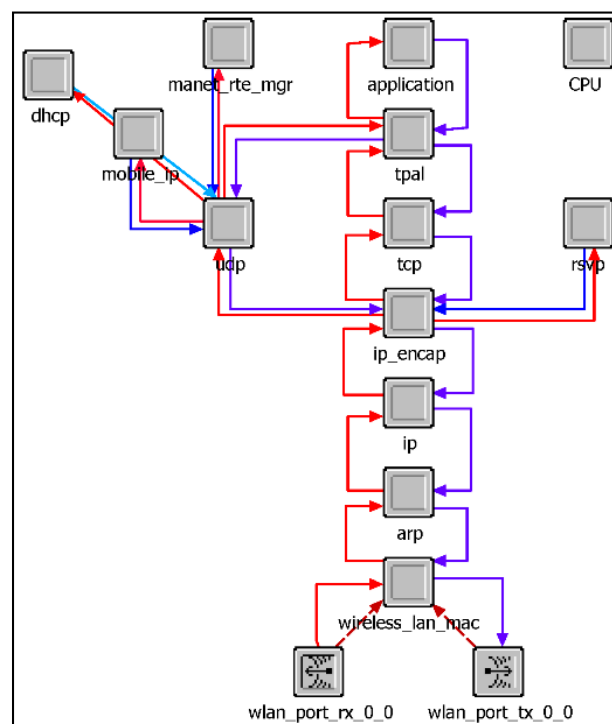


Figure 5. OPNET node model with protocol stack for sensor nodes.

10. Parameters for Simulation and Traffic Models

Simulations are performed, where the main objective is the evaluation of the scheme proposed in this work along with a comparison with conventional approaches. The parameters and traffic models for simulations are given below in Table 3.

Table 3. Parameters and traffic models for simulations.

Parameter	Value
Layout	1 base station, 1 Wi-Fi access point
Base station radius	375 m
Short Interframe Space (SIFS)	0.01 ms
DCF Interframe Space (DIFS)	0.05 ms
Slot length	0.02 ms
Wi-Fi capacity	11 Mbps
Physical features	Direct sequence
Short Retry Limit	7
Long Retry Limit	4
ECG frame interarrival time	0.001 s
Blood Pressure (BP) frame interarrival time	0.0015 s
Temperature frame interarrival time	5 s
Frame Size	2 bytes
Simulation runs with different seeds	10
Simulation length	1000 s

Additionally, all the simulations are performed with ten different seeds and the simulation runtime length is set as 1000 s. The 95% confidence intervals for results are established using obtained results, and statistical significance is realized. The simulations are performed for three different scenarios with varying traffic loads. In each scenario, three schemes are compared in terms of the performance parameters throughput and packet end-to-end delay. The three schemes are denoted here as No QoS (NQ), Default QoS (DQ) and Proposed QoS (PQ). The NQ scheme operates without enhanced coordination, the DQ scheme works under the enhanced coordination mechanism, whereas the PQ scheme incorporates enhanced coordination along with proposed modifications.

11. Results

The results presented in this work are divided into four scenarios. The main difference between the scenarios is the varying traffic load in these scenarios. In each scenario, the performance of the three schemes—NQ, DQ and PQ—is compared in terms of throughput and packet end-to-end delay.

11.1. Scenario 1

In the first scenario, the performance of the NQ, DQ and PQ schemes is compared in terms of average packet end-to-end delay and throughput. In Scenario 1, sensors' deployment in the simulation environment is done in such a way that there are two ECG sensor nodes in each sub-scenario (Table 4). The number of temperature sensor nodes in the first sub-scenarios is 20. The number of nodes is increased stepwise in subsequent sub-scenarios by adding five additional nodes. Therefore, the number of temperature sensors in the four sub-scenarios can be given in the form of a sample space as {20, 25, 30, 35}. The average values of results obtained from simulation runs for each parameter are illustrated in the graphs along with the 95% confidence intervals, determined using ten seeds, shown as error bars. If an error bar is missing, this would imply that the confidence interval is almost zero in that specific case.

Table 4. Deployment of sensors in Scenario 1.

Sensor Type	Number of Nodes			
	Sub-scenario 1	Sub-scenario 2	Sub-scenario 3	Sub-scenario 4
Temperature	20	25	30	35
BP	0	0	0	0
ECG	2	2	2	2

The results in Figure 6 show that, with the PQ scheme, superior end-to-end delay results with proper QoS differentiation could be achieved when compared to DQ and NQ schemes. The PQ scheme provides the low end-to-end delay to ECG devices and high-temperature devices. Moreover, a high ECG throughput in the PQ scheme is achieved in comparison to the ECG throughput performance of other schemes, as depicted in Figure 7.

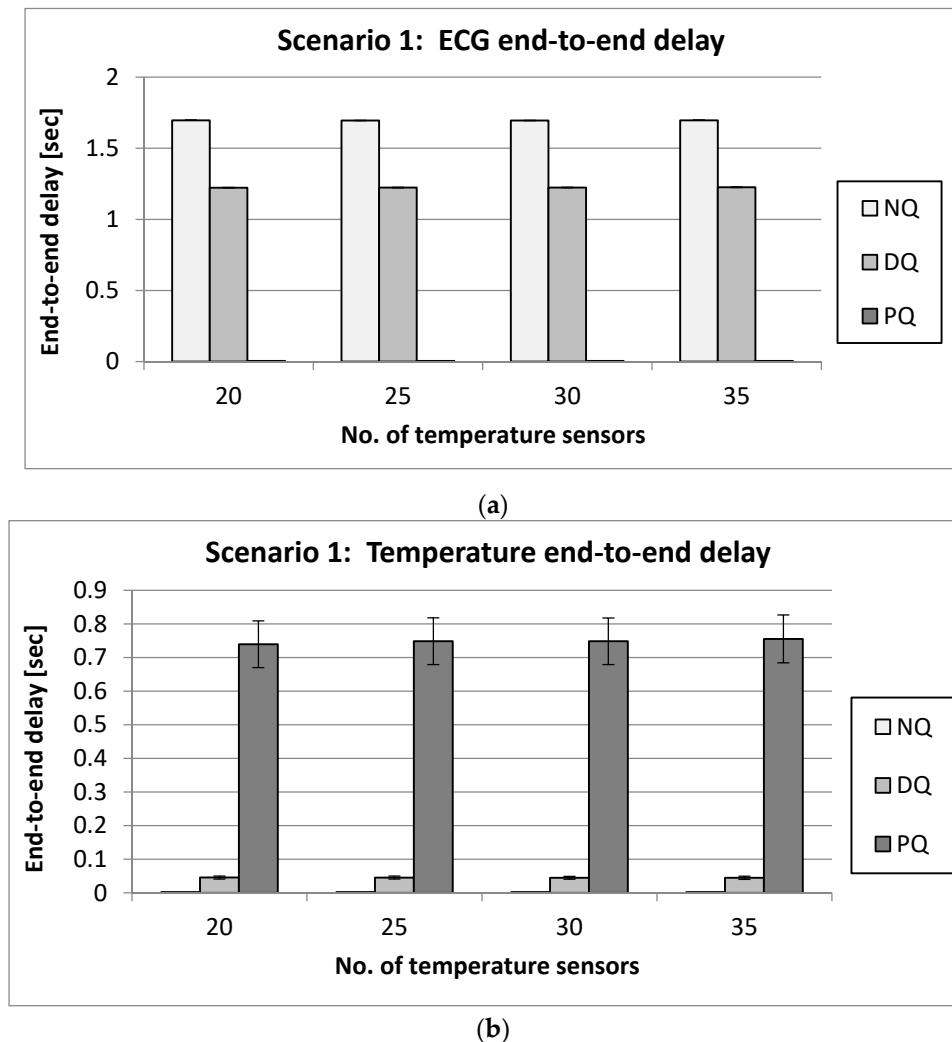


Figure 6. Average end-to-end packet delay results comparison for various data traffic types.

The results for ECG end-to-end delay show that, in the case of the PQ scheme, ECG data traffic is treated with high priority, hence small end-to-end delays, as compared to DQ and NQ schemes, are achieved. Temperature devices accomplish end-to-end delay results in such a way that, in the case of the PQ scheme, high end-to-end delays are noticed as compared to DQ and, eventually, NQ schemes. In Figure 7, it is seen that the PQ scheme achieves better throughput as compared to DQ and NQ schemes. The evident reason for this performance is the high priority scheduling that the PQ scheme renders to ECG nodes. Consequently, the transfer of large volumes of ECG data to the network with improved spectral efficiency can be accomplished, and the overall system performance in terms of cell throughput can be enhanced. In contrast, the mean temperature throughput stays unchanged for all three schemes in all sub-scenarios because of the higher ECG priority.

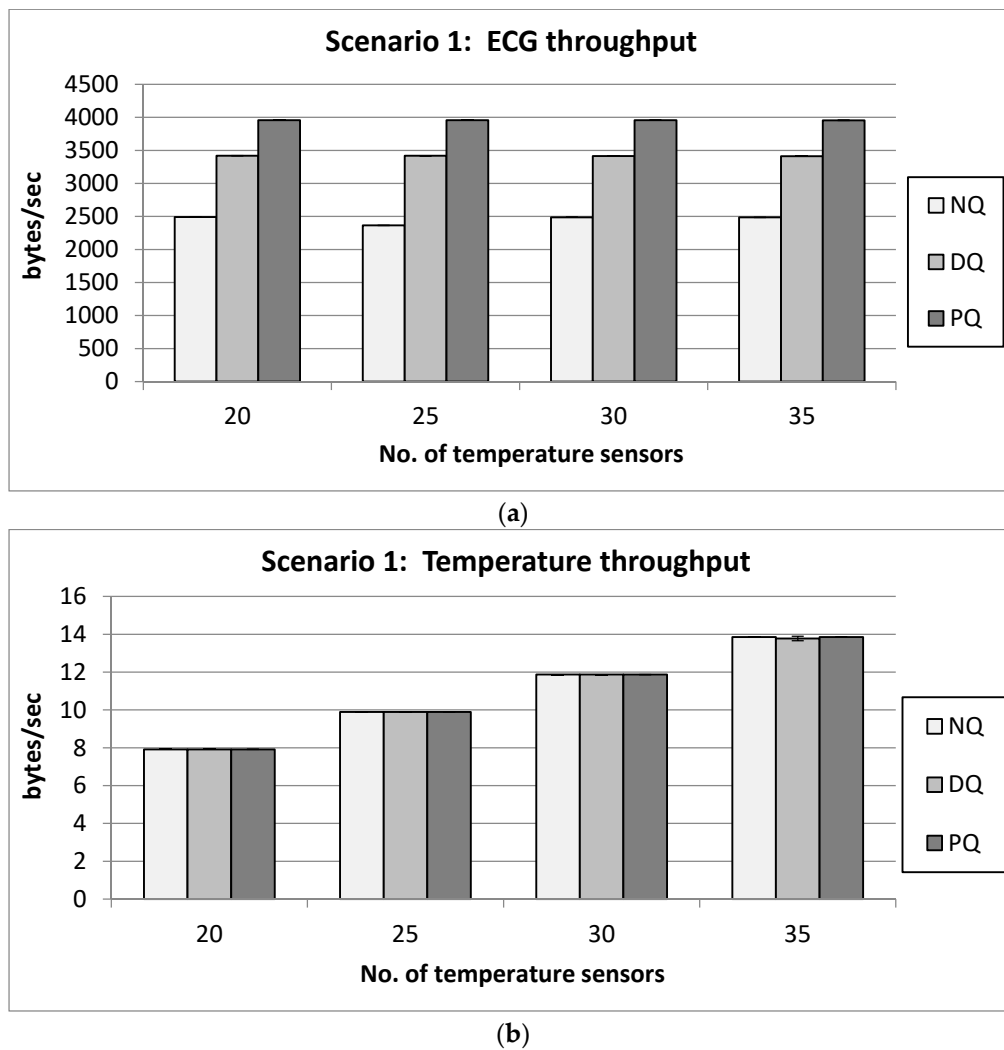


Figure 7. Average throughput results comparison for various data traffic types.

11.2. Scenario 2

In the second scenario, the traffic load deployed in the simulation environment can be explained in such a way that, on the one hand, 20 sensor nodes are deployed for transmitting temperature type data traffic in all sub-scenarios (Table 5) and, on the other hand, the number of ECG nodes in the first sub-scenario is two. The number of nodes is incremented in each of the subsequent sub-scenarios to 3, 4 and 5, respectively.

Table 5. Deployment of sensors in Scenario 2.

Sensor Type	Number of Nodes			
	Sub-scenario 1	Sub-scenario 2	Sub-scenario 3	Sub-scenario 4
Temperature	20	20	20	20
BP	0	0	0	0
ECG	2	3	4	5

The evaluated schemes, NQ, DQ and PQ, are appraised in terms of performance for QoS parameter, the end-to-end packet delay, and also throughput. Here, Figures 8 and 9 portray the results obtained for the second scenario. The ECG nodes with PQ scheme achieve a low average end-to-end delay with a

low traffic load but the delays increase when the load is increased in terms of ECG nodes. The reason for the higher delays is that when the nodes are in a highly loaded traffic environment, sufficient resources are not consistently available for each node to be facilitated. In the case of temperature end-to-end packet delay results, the increase in ECG nodes causes the temperature nodes to suffer high delays. The justification for these higher delays is the small ECG frame inter-transmission interval that produces a highly loaded traffic environment. A high load results in delays in temperature traffic and, with the PQ scheme, sufficient resources could not be provided all the time for every temperature sensor. The sensors under superior channel conditions would get frequent chances to be served consistently.

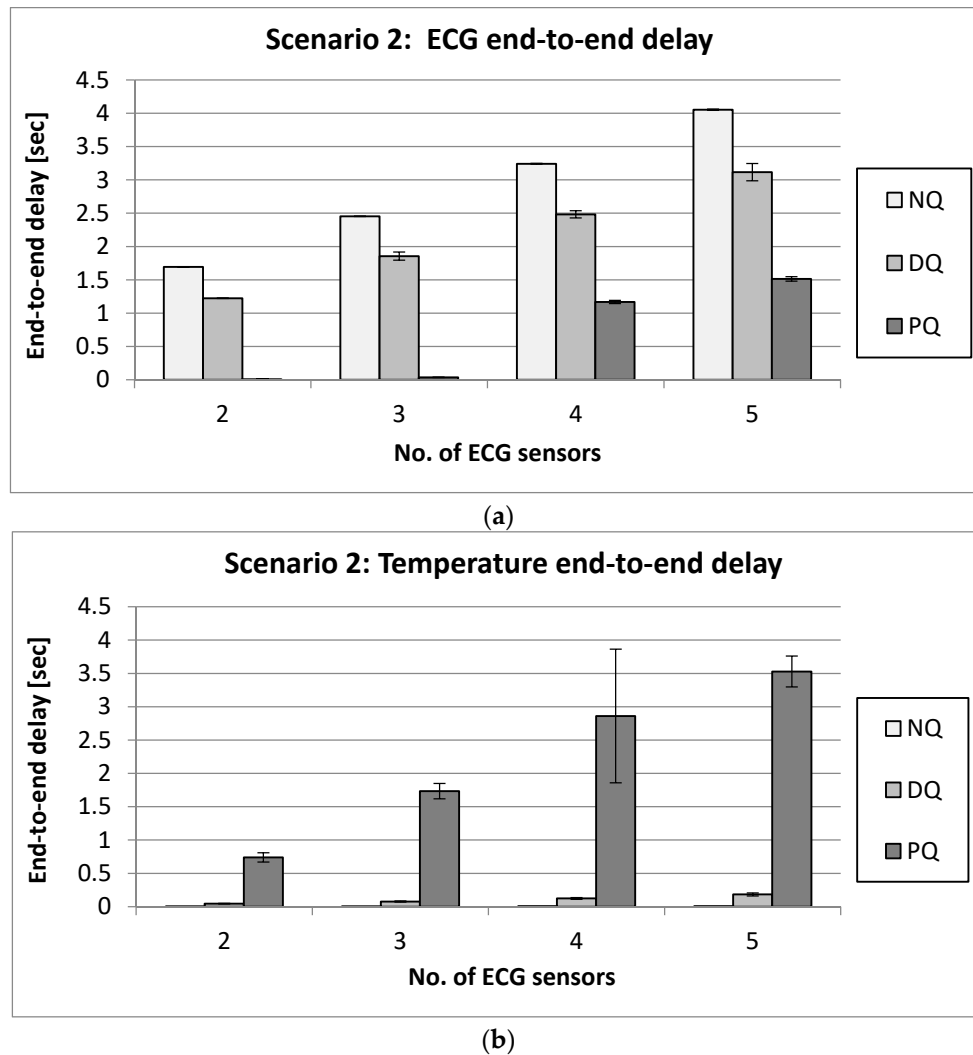


Figure 8. Average end-to-end packet delay results comparison for various data traffic types.

Increasing the number of ECG sensors causes the mean PQ based throughput for ECG data traffic to increase until the number reaches four sensors, where the channel reaches maximum capacity and throughput would not improve further even if the nodes for ECG are increased. The justification for such a behavior is that the rise in number of ECG nodes would result in the intensification of ECG traffic, but only until the highest achievable level of throughput is reached. The mean PQ throughput for sensor nodes with temperature data traffic remains unchanged for all the schemes even if the ECG nodes increase in number. This behavior is due to the fact that the number of temperature nodes in all sub-scenarios would not change. Therefore, the traffic from temperature nodes towards the access point remains persistent in the three sub-scenarios.

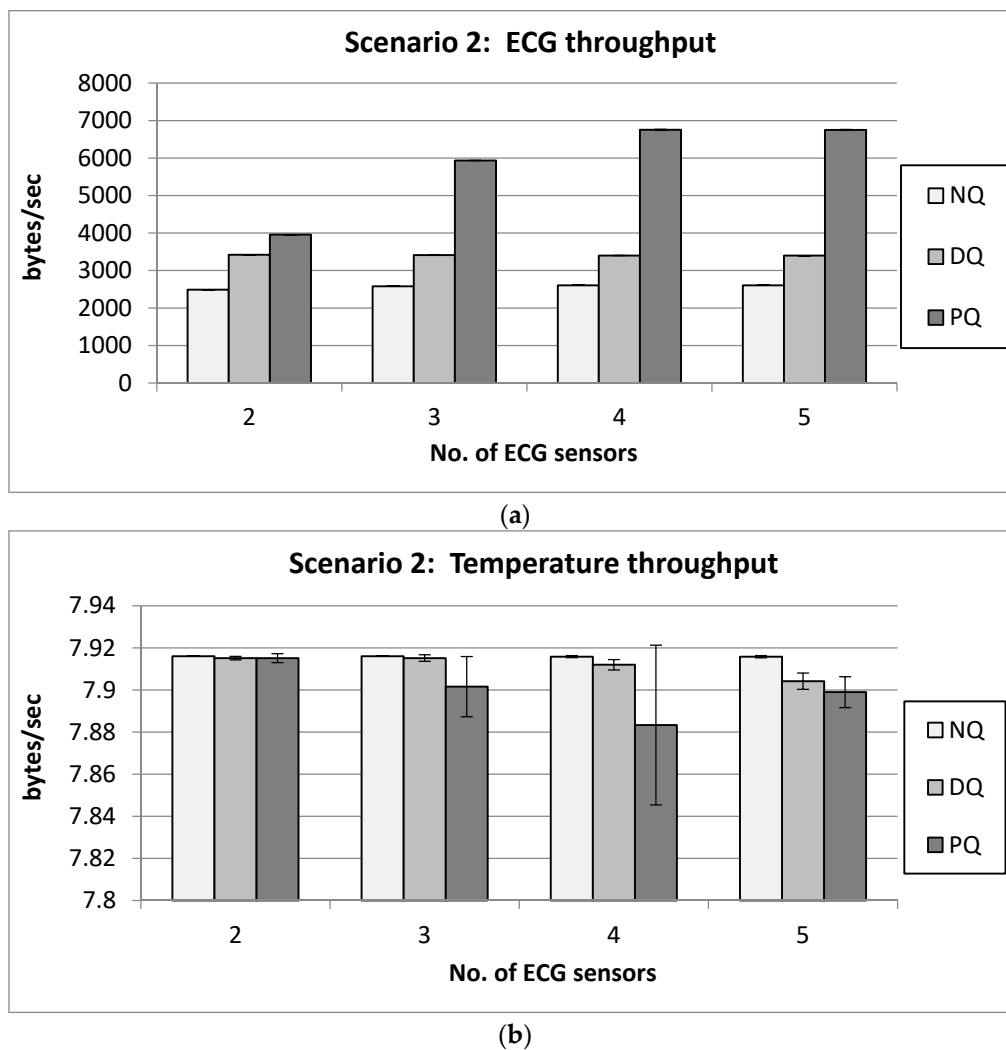


Figure 9. Average throughput results comparison for various data traffic types.

11.3. Scenario 3

In the third simulation scenario, the simulation environment is now loaded with BP sensors as well (Table 6). Therefore, the environment boasts all three types of sensors. The network scenario consists of two ECG sensors and four BP sensor nodes in all sub-scenarios. The number of temperature sensor nodes varies in all the sub-scenarios. The temperature nodes in various sub-scenarios are 3, 4, 5 and 6, respectively. Yet again, the simulations are performed in the given traffic loads for evaluation of end-to-end delay and throughput for NQ, DQ and PQ scheduling schemes.

Table 6. Deployment of sensors in Scenario 3.

Sensor Type	Number of Nodes			
	Sub-scenario 1	Sub-scenario 2	Sub-scenario 3	Sub-scenario 4
Temperature	3	4	5	6
BP	4	4	4	4
ECG	2	2	2	2

The three scheduling schemes are reevaluated for performance in terms of throughput and end-to-end delay. In this scenario, the results for BP traffic are also presented. Figures 10 and 11

illustrate the results obtained in the third scenario. The results reveal that the performance of the PQ scheme is better than the other schemes when it comes to QoS differentiation. The proposed scheme provides low end-to-end packet delay results for ECG nodes, high end-to-end delay for BP nodes and even higher delays for temperature traffic nodes. Moreover, high throughput is noticed in the case of ECG sensors, low in the case of BP nodes and lowest in the case of temperature nodes.

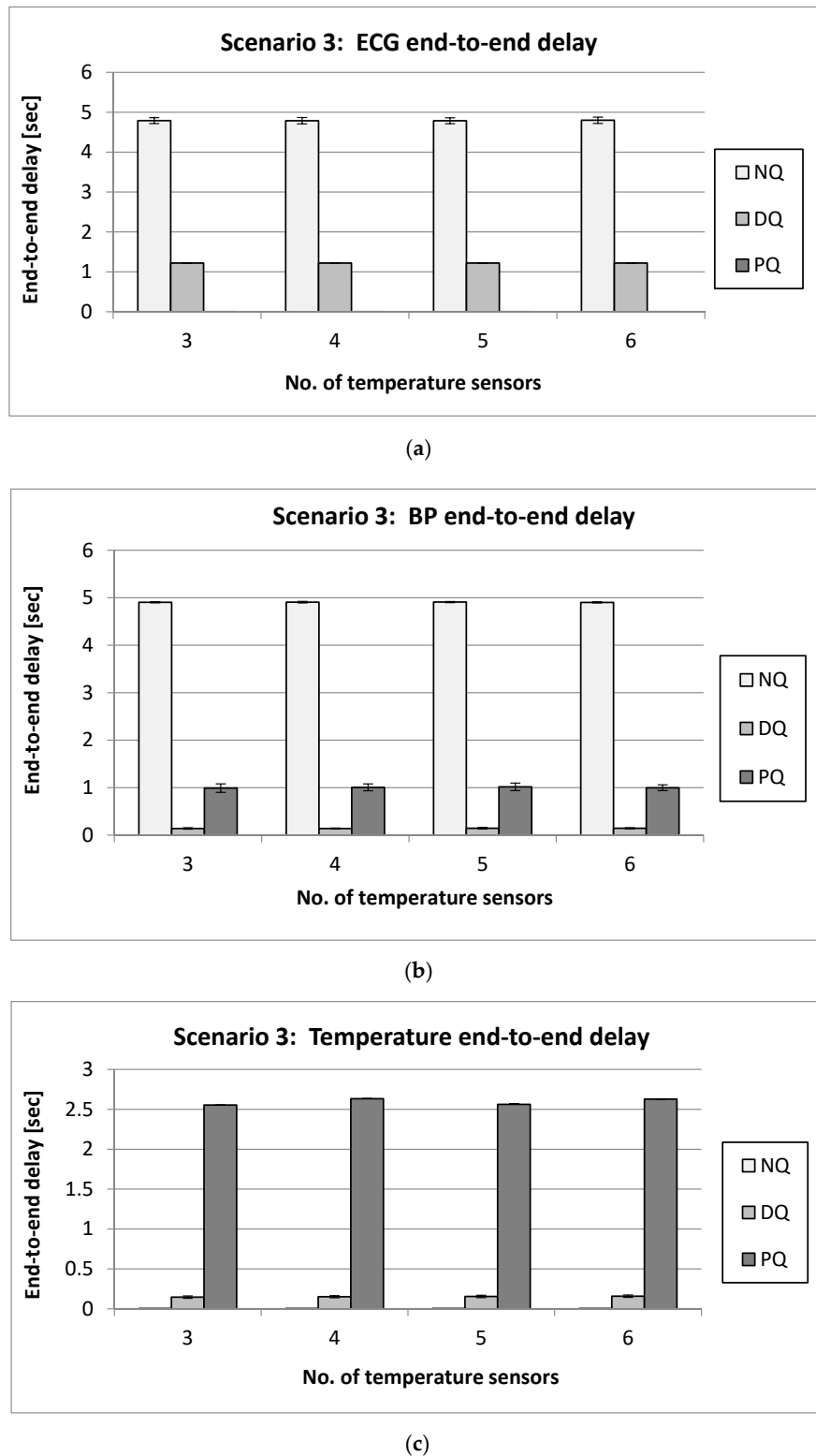
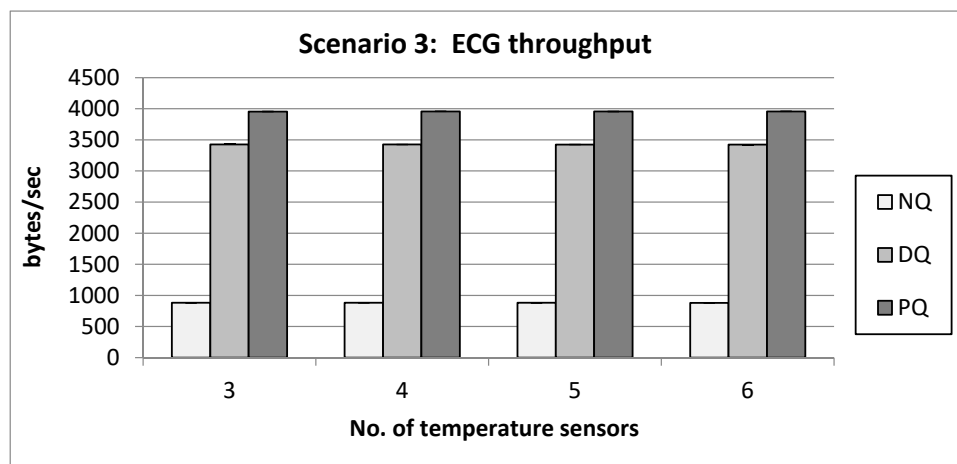
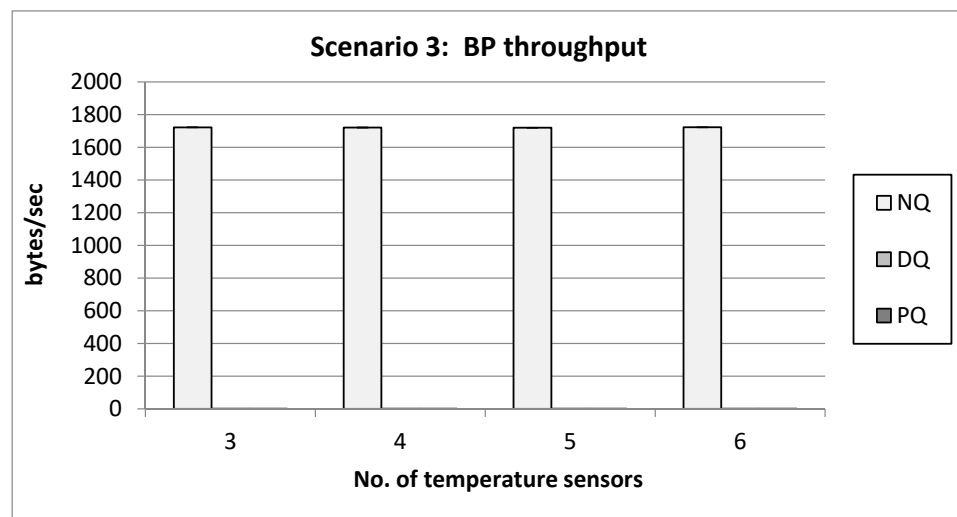


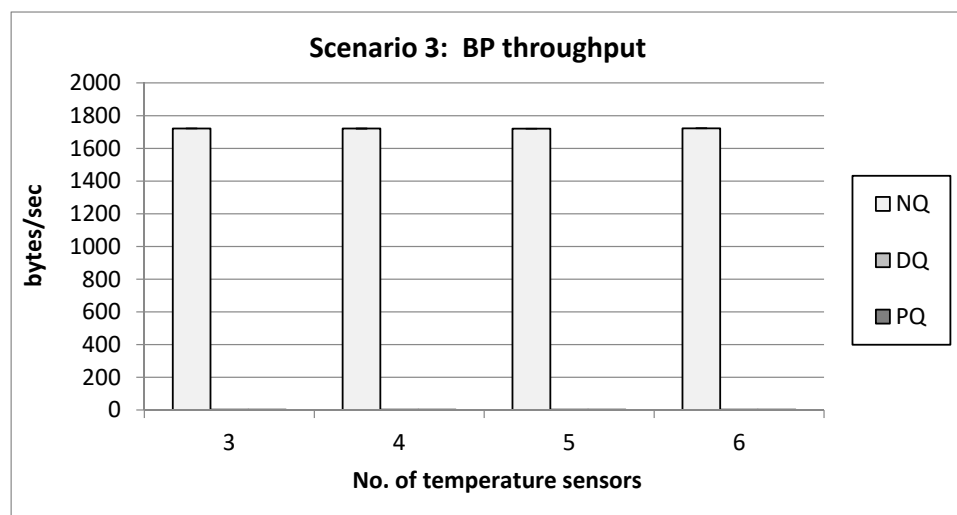
Figure 10. Average end-to-end packet delay results comparison for various data traffic types.



(a)



(b)



(c)

Figure 11. Average throughput results comparison for various data traffic types.

The mean end-to-end packet delay graphs for ECG nodes of NQ, DQ and PQ scheduling schemes show that, in the PQ scheme, ECG data on the access point with the highest priority among all the schemes and end-to-end packet delays are small as compared to the DQ scheduler, as the end-to-end packet delays are high. Moreover, the PQ scheme results for the end-to-end delay of ECG and BP traffic are not influenced significantly by increasing the number of temperature nodes. The mean BP end-to-end delay results of NQ, DQ and PQ schemes show that the PQ end-to-end packet delay for BP is higher as compared to DQ and NQ. Hence, ECG data traffic is treated on a priority basis.

Because of the larger interarrival time between temperature frames, the PQ scheme would not prolong the ECG, BP and temperature packet end-to-end delays. In contrast to NQ and DQ schemes, the ECG nodes in PQ scheme perform well, with an increase in temperature traffic nodes. The NQ scheduler gives priority to nodes with helpful channel conditions without any consideration of QoS. The average ECG throughput with the PQ scheme remains unchanged in all sub-scenarios, as the number of temperature nodes increases. The reason for this behavior is that the PQ scheduler offers a better scheduling opportunity for ECG nodes.

The average throughput of temperature nodes remains unchanged for all the schemes. The throughput of temperature nodes goes up if the number of temperature nodes is increased. In spite of the fact that guaranteed bit rate traffic flows are provided, with consistent resources ahead of the non-guaranteed bit rate traffic, there are enough resources to serve even the non-guaranteed bit rate traffic. Furthermore, large interarrival periods for packets from temperature nodes mean that an increase in the number of temperature nodes would not have a significant impact on throughput.

11.4. Scenario 4

The fourth scenario features a simulation environment that is arrayed with sensing nodes. Here, three nodes are deployed for ECG activity monitoring in the first sub-scenario and the number of nodes is incremented gradually in each successive sub-scenario up to six ECG devices (Table 7). Additionally, four of the deployed nodes are used for the BP monitoring of patients and three nodes examine the temperature of the patients. The QoS parameter of average end-to-end packet delay and throughput are appraised for NQ, DQ and PQ schemes in succession.

Table 7. Deployment of sensors in Scenario 4.

Sensor Type	Number of Nodes			
	Sub-scenario 1	Sub-scenario 2	Sub-scenario 3	Sub-scenario 4
Temperature	3	3	3	3
BP	4	4	4	4
ECG	3	4	5	6

Figure 12 describes end-to-end delay results obtained for all the sub-scenarios of the fourth scenario. The results illustrate that the PQ scheme performs better than DQ and NQ by accomplishing lower end-to-end delays for ECG nodes, then higher delays for BP devices and even higher delays for temperature devices. Moreover, improved ECG throughput is realized in comparison to ECG throughput achieved by other schemes, as illustrated in Figure 13. It is shown in these results that, in the case of the PQ scheme, ECG data traffic is transmitted with high-level priority, thus these nodes achieve low end-to-end delays when compared to DQ and NQ schemes, where end-to-end delays are larger. In the case of the PQ scheduler, the BP devices have greater end-to-end delays in comparison to the DQ scheme. The reason for this relatively poorer performance is that the scheme focuses on providing better services to ECG devices, while BP data traffic is considered more tolerant of delays. Delays of up to several minutes are acceptable in case of BP traffic. In case of temperature data traffic delays, the PQ scheme performs poorly as well, with higher delays noticed as compared to NQ and DQ schemes. However, even temperature delays of the order of minutes are considered to be acceptable

and temperature data traffic is not as delay-sensitive as ECG. In throughput results, the PQ scheme accomplishes a high ECG throughput when compared to NQ and DQ schemes, as PQ provides higher transmission rates of data. In case of DQ and NQ schemes, data on transmission rates are low because PQ gives a high priority to ECG devices, and consequently succeeds in transferring more data of ECG sensors with enhanced spectral efficiency, resulting in an improvement in the cell throughput. In the case of the PQ and DQ scheduler, BP throughput becomes very low, due to the increase in ECG traffic, whereas temperature throughput when compared with ECG and BP devices is very low.

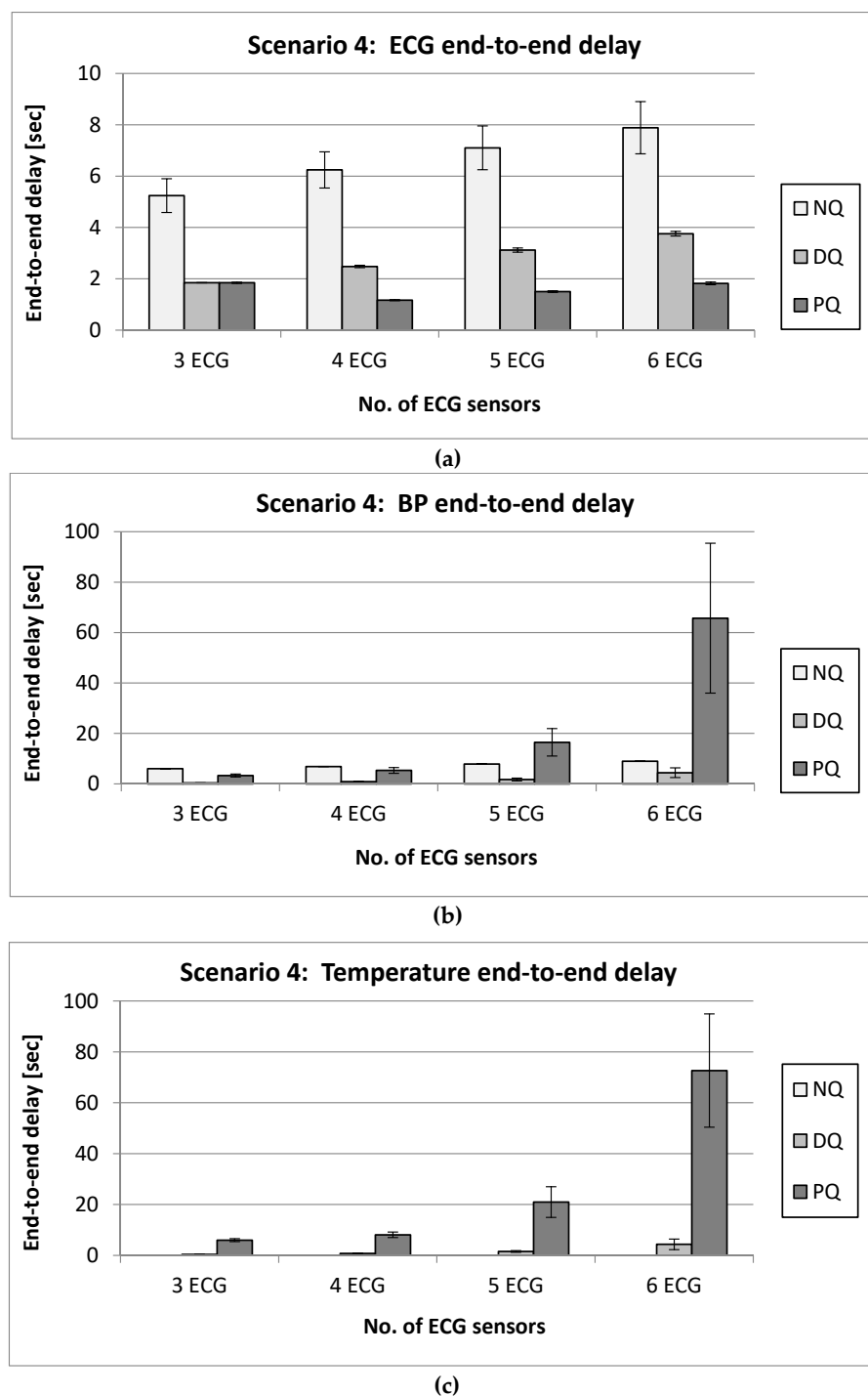


Figure 12. Average end-to-end packet delay results comparison for various data traffic types.

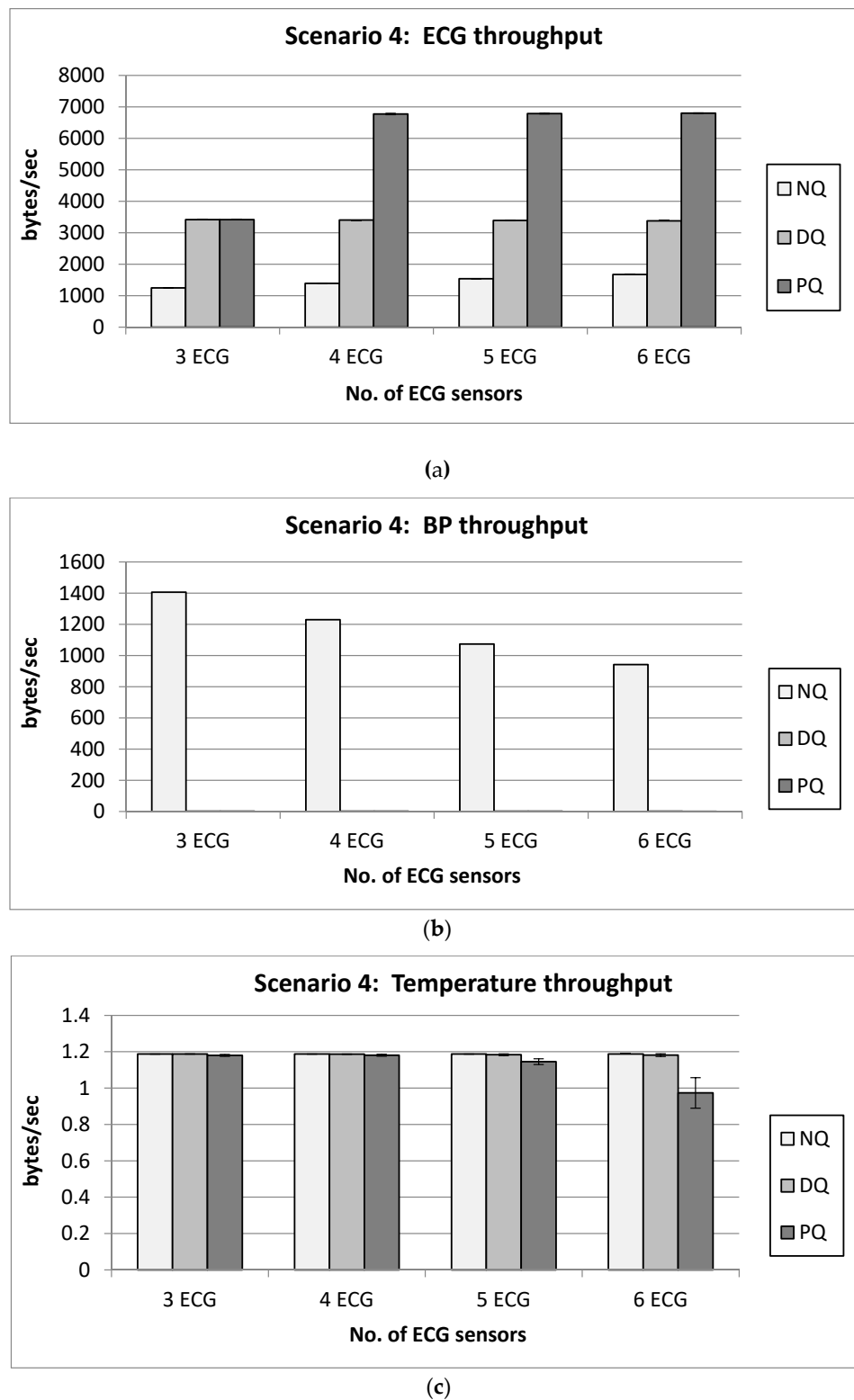


Figure 13. Average throughput results comparison for various data traffic types.

12. Conclusions and Outlook

The provision of QoS in medical CPS is an issue that has been addressed in this paper. QoS mechanisms devised in the past for conventional human-based data traffic have proven to be unsuited to sensor-based narrowband data traffic. Human-based data traffic and sensor-based data traffic have distinct characteristics. Applying QoS differentiation techniques for human-based traffic to sensor

networks can lead to adverse network performance and reduced spectral efficiency. To cope with such issues, a scheme was proposed in this paper for wireless networks with sensor-based CPS. The proposed scheme was shown to provide QoS differentiation and improve throughput performance.

The proposed scheme for the efficient scheduling of data traffic was investigated and compared with contemporary schemes. An MAC layer was devised to provide lesser contention window sizes to high-priority traffic classes. Simulation results were obtained using OPNET simulation environment to determine the performance of scheduling schemes with respect to throughput and end-to-end packet delay. The results showed that the scheme proposed in this work performs better than the other evaluated schemes in multiple traffic load scenarios. The scheme also provided better QoS diversity.

The goal in the future would be to enhance the scheme by providing service differentiation for more than three sensor types. The current work status can be improved by stretching it further to analyze mobile Wi-Fi device performance in cases of vehicular mobility where channel conditions are inconsistent. Similarly, handover issues in heterogeneous networks could be investigated as well. In this way, future research could also be in the direction of designing energy-efficient methods and the reduction of power consumption at sensor nodes.

Author Contributions: S.N.K.M. is the main contributor who conceptualized the ideas and wrote the draft of this work. A.N. designed simulation models and parameters. Y.M. performed simulation runs and determined the statistical significance of results. F.U. investigated and developed traffic models. S.A. drew figures and charts in collaboration with A.K. S.K. verified the correction of results. D.K. contributed in editing and proofreading the final draft. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Higher Education Commission of Pakistan.

Conflicts of Interest: The authors declare no conflict of interest.

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