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*Research Article*

# Design and Evaluation of a Wearable Smart Blanket System for Monitoring Vital Signs of Patients in an Ambulance

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*Objectives*. Considering the advantages of the wearable systems (such as continuous monitoring, ease of installation, and significant efficiency), they can also be used to monitor patients in emergency situations and, particularly, in the ambulance. This study is aimed at specifying, modeling, and evaluating a wearable smart blanket system for monitoring vital signs in emergency circumstances. *Method*. At first, all the smart blanket system requirements were specified using an author-made questionnaire, and the essential requirements were specified in the software requirements specification format. Such an anticipated smart wearable blanket is then modeled by Unified Modeling Language. Finally, the most important quality attributes (*i.e.*, the nonfunctional requirements) of the proposed wearable smart blanket system were evaluated using a descriptive-analytical study. *Results*. Evaluation results of the proposed system show that using the smart blanket system could not only provide the required functionalities, but also, it improved the important quality attributes such as response time and delay in sending data packets (14% improvement), accuracy, energy consumption (18% improvement), reliability and fault-tolerance, and performance (28% improvement) in contrast to the compared related work. *Conclusion*. Using a smart wearable blanket in an ambulance instead of such in a huge ambulance cabin would be beneficial in terms of time and space, ease of use, and maybe cost while providing the required functionalities besides having proper quality attributes.

## 1. Introduction

Considering that many diseases and disabilities currently require continuous monitoring, constant care and monitoring of patients for timely intervention is an urgent need. Under emergencies, patients are unstable, and constant monitoring of their vital signs may help the healthcare team to take action without delay [1]. Today, smart systems and advanced tools have grown dramatically to monitor patients and control their conditions [2]. The ability of these smart systems to store and transfer data across different health care sectors (including telemedicine) is important. Wearable technology is one of the most recent technologies in this field [3].

Wearable systems are generally used to monitor the vital signs and symptoms of patients, as well as for their follow-up, telehealth, nursing, and healthcare surveillance systems, surgical robots, and many other systems [4]. One of the distinctive features of these systems is that they are always kept by the data-publishing subject (patient). Therefore, the physician has full-time access to their patients and information about them. Also, we may allude to the significant features and functional advantages of the wearable blanket system, such as ease and speed of installation, precision measurement and monitoring, low volume (easy to operate in small ambulances and easy handling in heavy traffic for emergency situations), and obtaining and using the blanket at home [5].

As such, one of the most important areas of application of wearable technologies in the field of health care is to monitor patients, and a critical and sensitive situation is monitoring the patient in the ambulance and under EMS conditions [6]. Emergency conditions refer to a condition in which a patient's health changes suddenly or in which physiological and biochemical parameters fluctuate

[7]. Early and managed intervention under emergency conditions could reduce the complications of the disease and prevent sudden death. Monitoring and caring for patients in emergencies requires quick and accurate decisions [8]. The main task of health care teams at ambulances is to care for and monitor patients in emergencies. Therefore, one of the goals of clinical monitoring of patients under emergency conditions in an ambulance is to get informed immediately on the life-threatening events, so that they are mitigated prior to injury or disabling the patient [9]. Therefore, speed and accuracy are two essential factors in emergency conditions (such as in ambulances), and simultaneous application of both is necessary yet tricky. Constant caring and monitoring of patients in the ambulance is crucial. So, there are modern systems in today's ambulances that provide services to patients in their beds [10, 11].

As mentioned above, time and speed of operation are critical in monitoring these patients and in emergency situations within ambulances [12]. On the other hand, attaching different devices to the patient's body in the ambulance requires a considerable amount of time, and in these conditions, time is gold! Also, the use of multiple monitoring devices to record the vital signs would occupy the small cabin of the ambulance [13].

Some of the current monitoring systems have low measurement accuracy. Accurate data recording is one of the essential parameters of monitoring [14]. The systems may occasionally incur errors in data recording. Therefore, using these systems in an ambulance causes problems such as installation difficulty, reliability, power consumption, installation time, and critical data transfer. Finally, with medical technology development, we are looking for tools to monitor vital signs in the ambulance. Mobile smart monitoring tools must have specific features [3]. These tools should be capable of recording essential parameters such as temperature, heart rate, respiratory rate, blood pressure, blood glucose, stress monitoring, and pulse oximetry [8].

## 2. Background and Related Works

With the development of computer and communication sciences, wearable sensors to monitor health-related vital biological parameters have been considered. Several articles have been written in the field of wearable systems. Some of the articles related to the wearable sensor networks are reviewed in the following. Urs Anliker et al. (member students of IEEE) presented a Wearable Multiparameter Medical Monitoring and Alert System specifically for respiratory and cardiac patients in 2003. The designed system performs continuous evaluation and monitoring of various vital signs and identifies multiple emergency parameters [15]. Eom et al. introduced a wearable smart blanket system called Smart Blanket in Japan. It was a collection of wireless body sensing units that record and transfer vital parameters only by being placed on the body [16]. The BASU Consortium brought together scientific and industrial experts from electronics, communications, and medical engineering to develop a wireless system distributed on the body. The system was designed to monitor chronic patients in health care facilities and at home. The BASUMA project was designed primarily to make progress in the treatment of patients with obstructive pulmonary diseases [17].

In our earlier paper, all the functional and nonfunctional requirements needed to design a wearable smart blanket system for monitoring patients' vital signs were extracted comprehensively. And then, these provisions were developed in a system requirements specification format. Also, based on critical requirements, all UML diagrams were drawn to present the system model. Therefore, in the previous research, the technical and physical specifications of the wearable system were identified. After the requirements extraction phase, the proposed system was simulated, which is discussed in this study. The wearable smart blanket system comprises specific characteristics such as monitoring the crucial signs, communicating with the surroundings, processing the signals instantly, and storing all critical signs. The wearable smart blanket system should also suggest some nonfunctional properties such as interactivity, easy installment and function, low energy consumption, error fault tolerance, and sign stability accuracy [18, 19].

This paper's main contribution is the following: A brief reference to the design requirements and the intended model in the published article is provided (detailed in [19]). A comprehensive and mathematical evaluation/simulation of a wearable smart blanket system for monitoring vital signs in the ambulance is then given.

## 3. Research Method

At the first stage, a survey was used to extract the functional and nonfunctional requirements of the wearable smart blanket system. Next, an author-made questionnaire was designed to extract modeling capabilities and requirements. The major inquiries of the questionnaire were the functional features of the system software, structural features of the smart blanket platform and patient portable unit, and the nonfunctional requirements of the system software. The validity of the questionnaire was confirmed by groups of IT specialists and EMS physicians. The questionnaire, with 60 proper items, was distributed among 20 EMS physicians and ambulance technicians by a nonprobability convenient sampling. Items with a score above 80 are at a modeling priority. Data were analyzed using SPSS. The Cronbach's alpha value of the designed questionnaire is 0.82. Therefore, the reliability of the questionnaire is confirmed.

All requirements derived from the previous steps were formulated in the standard SRS (Software Requirements Specification) document [20]. Thus, the design and modeling of the wearable smart blanket system were performed based on the document format. UML (Unified Modeling Language) was used for designing and modeling [18].

Finally, a descriptive-analytical study evaluates the wearable smart blanket system. In order to evaluate the mentioned system, the simulation method was used in NS2 (network sensor) simulator environment. The architecture simulation method uses applied architecture implementation. In this method, the main components of the architecture are implemented, and the other components are

Table 1: Data elements of the wearable smart blanket system.

| No. | General specifications of capabilities | Subsets |
|---|---|---|
| 1 | Functional—possibility of inclusion and exclusion into and from the physician assistant system | Registration, inclusion, exclusion |
| 2 | Functional—possibility of registering age and gender in the system software by the physician | Entering diagnoses, editing, saving, final approval, submitting therapeutic suggestions |
| 3 | Functional—possibility of receiving medical signals by installed sensors and to call out the ambulance technician | Noninvasiveness of sensors, number of sensors, type of sensors, correct location of installation of sensors |
| 4 | Functional—possibility of local recording and storage of vital data and obtaining data from sensor systems (portable patient unit) by system software | Documenting and storing signals such as electrocardiograms, respiratory rate, and heart rate |
| 6 | Functional—possibility of interpreting and processing vital data | Extracting acceptable knowledge and information, analyzing symptoms, providing instant feedback, and alerting system |
| 7 | Physical requirements | Ideal size and weight, flexibility, relative stability, moisture absorption, waterproof |
| 8 | Physical requirement—precise location of sensors | Location of SPO2, BP, HR, temp sensors |
| 9 | Nonfunctional requirement | Easy maintenance and use, confidentiality, responsiveness, accessibility, encryption, entity authentication |

simulated in a final operable system. Also, the application context where the software is expected to run can be simulated at a suitable abstraction level. This implementation can then be used to simulate software behavior under different conditions. In order to perform the simulation, scenarios were defined for each experimental scenario. Also, four comparative scenarios were considered for the evaluation of the macrocriteria. In these scenarios, ideal and nonideal cases are investigated and compared.

## 4. Results

A comprehensive list of functional and nonfunctional requirements and standard SRS format and a comprehensive model of the wearable smart blanket system is provided in a previous article [19]. In this article, to reiterate the findings of previous research, functional and nonfunctional requirements and the proposed model of the wearable smart blanket are reviewed. The general functional requirements of the software of wearable smart blanket system are as follows: (a) possibility of registration, inclusion, and exclusion; (b) possibility of registering age and gender in the system software by the physician; (c) possibility of setting a threshold for all vital signs by the physician; (d) possibility of retrieve data from sensors and displaying vital signs and signals; (e) producing alarms by the software; (f) storing of all vital signs of the patient; and (g) possibility of numerical and graphical analysis of the recorded data.

The structural properties of the smart blanket platform and sensor fibers are as follows: (a) possibility of receiving medical signals by sensors, (b) proper selection of sensors, (c) nonallergic sensors and fibers, (d) proper selection of materials of fibers and sensors, (e) proper selection of ideal size and material of blanket; (f) selection of fibers and sensors with suitable relative conductivity, and (g) accurate installation of sensors and fibers on the anatomical areas of the body.

Nonfunctional features of the software of wearable smart blanket system include the following: entity authentication, encryption techniques, response time and message latency, accuracy of recording vital signs, interactivity, accessibility, possibility of chronological storage and retrieval of data, energy consumption, and reliability. Table 1 summarizes the data elements and possibilities of the wearable smart blanket and the functional and nonfunctional features.

*4.1. System Model in UML Diagrams.* According to the requirements outlined in previous researches [11], in order to create a uniform understanding, UML (Unified Modeling Language) diagrams have been used to create a suitable model for a wearable smart blanket system.

UML represents the structure and behavior of the system by diagrams. A system is modeled as a set of separate objects that interact with each other to achieve the ultimate goal of the system.

For example, the following are all classes related to the wearable smart blanket system, which shows several different classes such as database, master system, smart blanket server, patient, and physician, as well as their relationships. In Figure 1, we can see the main classes of our system.

*4.2. Evaluation of the Proposed System.* Various parameters such as accuracy, throughput, energy consumption, and others were evaluated and calculated to analyze the qualitative factors affecting the performance of the wearable smart blanket system. As such, it can be argued that the main purpose of evaluating the wearable smart blanket is to determine the factors affecting its performance. In this regard, the sensors mounted on the smart blanket were simulated. Therefore, to simulate the proposed system, a number of small-scale wireless sensors with relatively low operational and computing power are included in the wearable smart blanket system, which are tasked with transferring data to the outside world. Sensors are divided into different categories, each with specific tasks. Some of these sensors are for transferring body temperature data, some for transferring heart rate data, some for transferring blood pressure data,

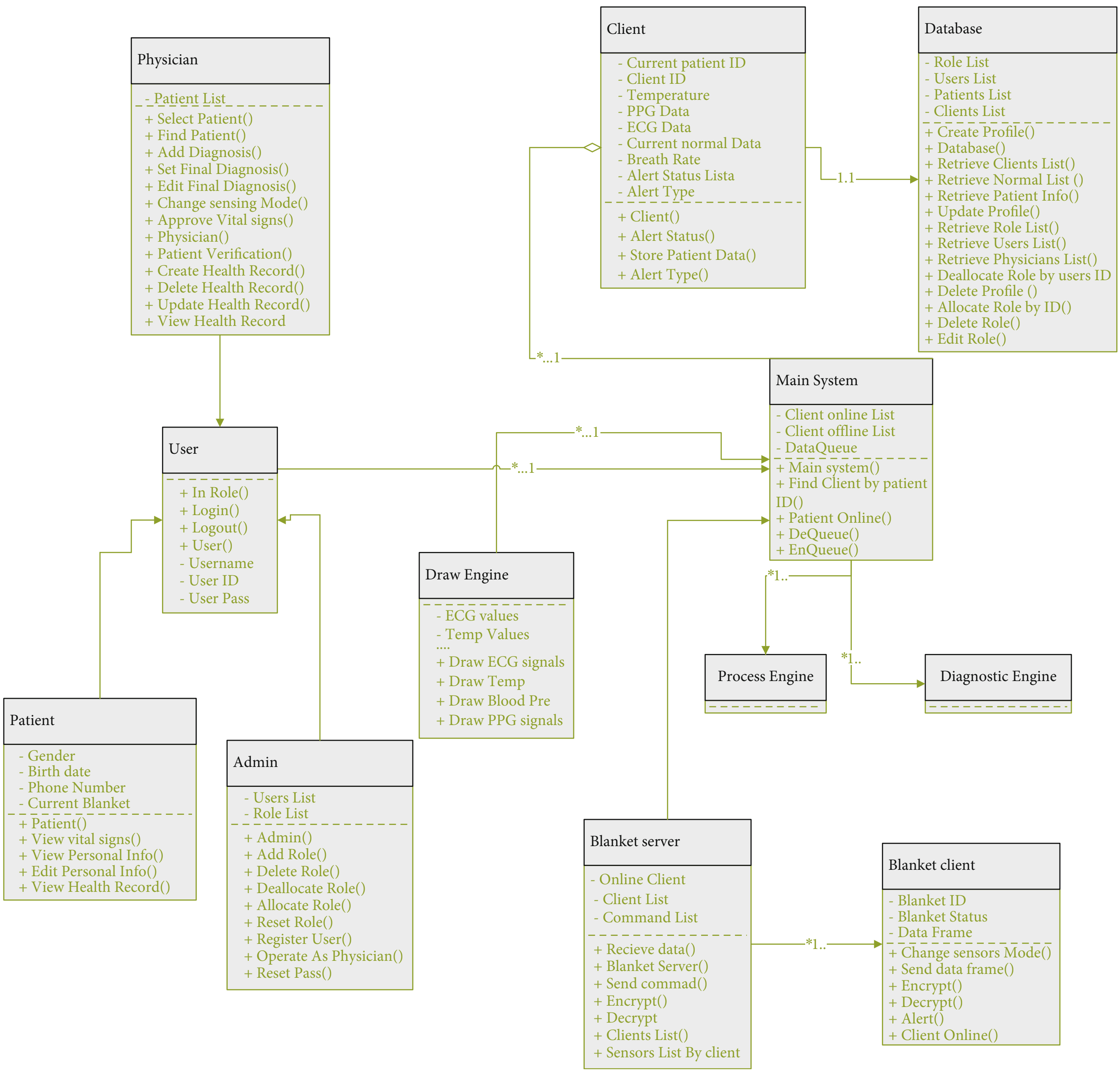


Figure 1: Class diagram.

and so on. A sensor is responsible for collecting these data, which is called the sink node. The sink node transfers collected data to the relevant physician or nurse system, which continually monitors the patient's conditions.

*4.2.1. Evaluation Settings.* In order to simulate the wearable blanket, we used the Mannasim development in the simulator [21]. This allows us to use body sensors in the simulation. In the NS2 simulator, the wearable blanket sensors are easily simulated and used, transfer parameters are adjusted, and the graphical representation is displayed. In the next step, the simulation tests of the number of sensors were used to compare and evaluate the proposed system, with the tests having 5, 10, 15, 20, 25, 30, 35, and 40 sensors. Also, four comparative scenarios were considered for the evaluation of the macrocriteria. In these scenarios, ideal and nonideal cases were investigated and compared. For this purpose, simulation criteria including measurement accuracy, throughput, data delay, total power consumption, reliability, average power consumption for each number of sensors, and scenarios are studied separately. The simulation results of the proposed system for our research (WSBS) are presented in the following diagrams, and the values obtained from the simulation are compared with another system (Flexible Blanket) presented in the basic article [16]. The evaluation results section discusses the evaluation scenarios and the results of each of them. In order to evaluate the proposed system, scenarios are presented for the following macrocriteria:

Table 2: Simulation parameters and values.

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Simulation time | 100 sec | Transport layer protocol | TCP |
| Area | 500 × 500 | Routing protocol | AODV |
| Transmission range | 300 m | Antenna type | Omni antenna |
| Number of sensor nodes | 5-40 | Network interface | Phy/WirelessPhy |
| Max. UTRAN uplink channel bit rate | 2 Mbps | MAC interface | Mac/802_11 |
| Max. UTRAN downlink channel bit rate | 2 Mbps | Distribution sensor | Uniform |
| Application | FTP | Data rate | 512 kb |
| Initial energy | 10 J | — | — |

accuracy, performance, and reliability. Table 2 shows the parameters and simulation elements. The number of blanket nodes varies from 5 to 40 sensors. The antenna model employed is omniantenna. Rod-shaped antennas that emit radiation in all directions are called omnidirectional; dipole antennas are omnidirectional antennas. In the basic article, which we will discuss in the next section, the dipole antenna has been used. The range mentioned in Table 2 is for the transmission range that this system's sensors can send their information up to a distance of 300 meters. In routing, we applied the AODV protocol, AODV (Ad_hoc On Deman Distance Vector), the most popular reactive routing protocol designed for ad hoc mobile networks and other wireless networks. This protocol can find paths between nodes and can perform both unicast (sending packets for one node) and multicast (sending packets for a specific group). In the MAC layer (data connection layer), the 802_11 protocol was utilized. A uniform method has been used to distribute the simulation sensors. The energy of these nodes is limited, and some of the sensors' energy decreases with each data transfer or reception. We considered the initial energy value of the sensors to be 10 joules. In Figure 2, the sensor structure employed in the wearable smart blanket system is displayed.

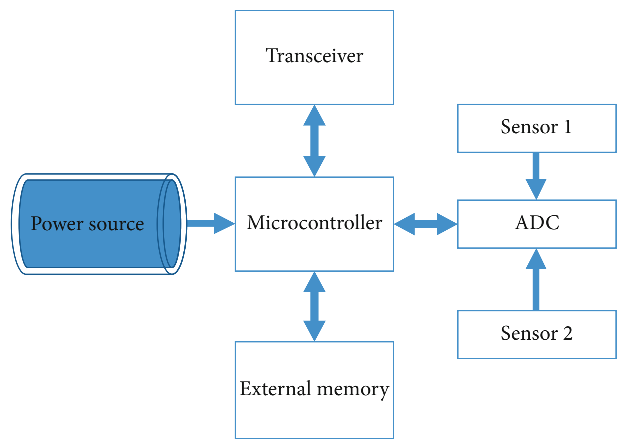


Figure 2: Sensors structure.

*4.2.2. Evaluation Results*

*(1) Accuracy*. The measurement accuracy should be evaluated at different distances of the system to the patient's body. Also, the monitoring accuracy of different sensor collections is evaluated by changing the number of sensors. Therefore, to measure the sensing accuracy of each node, the amount of sensed data and the data dissemination rate of each individual sensor have been obtained. As we know, a sensor is responsible for sensing and disseminating its data. For example, a heart rate sensor should sense the heart rate data using electronic components and disseminate the data after sensing. The monitoring accuracy of the system is calculated using the following equation [22]:

$$\text{Precision} = N/E. \tag{1}$$

where $N$ is the number of packets received divided by the amount of power consumed by each node [22]. As noted, the following is the measurement accuracy evaluation of the test scenario of the distance of sensors to the patient's body.

(i) Investigating the accuracy of the proposed system measurement by testing the sensors' distance to the patient's body. Figure 3 shows the measurement accuracy of the sensors at multiple distances

Figure 3 shows the accuracy of sensor measurements at different distances from the patient's body. Suppose the distance between the electrodes and the sensors mounted on a patient's body is gradually increased from zero to 3 cm. In that case, the measurement accuracy of the sensor collection will be reduced, and it will be 0 at 3 cm. As can be seen in the figure, as the distance of the sensors from the patient's body increases, monitoring is still performed, but there is insufficient accuracy.

The sign recording accuracy will maximize when the sensors' distance from the patient's body is kept to a minimum.

(i) Investigating the accuracy of the proposed system measurement by testing the change in the number of sensors [23].

In this experiment, the monitoring accuracy of vital signs was evaluated by changing the number of sensors mounted on the smart blanket platform. That is, varying the number

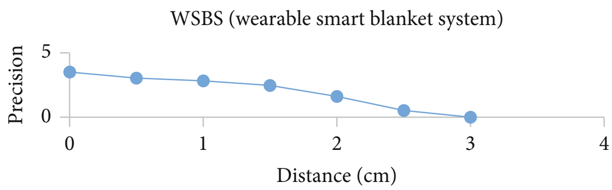


Figure 3: Effect of the distance of wearable smart blanket sensors on the accuracy of sing measurements.

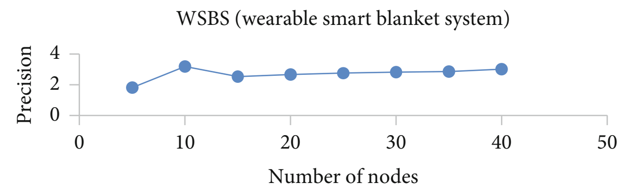


Figure 4: The effect of increasing the number (scale) of sensors in the proposed system on the accuracy of vital signs measurement.

of sensors used in this system varies its measurement accuracy. As shown in the simulated experiments section, the desired number of sensors is 5, 10, 15, 20, 25, 30, 35, and 40, and the simulation results are discussed in the following diagram.

Figure 4 shows the accuracy of each sensor (number of sensors: 5, 10, 15, 20, 25, 30, 35, and 40) after simulation. In order to measure the measurement accuracy of each node, the amount of the sensed data and the data disseminated by each sensor were obtained. As we know, a sensor is responsible for sensing and disseminating its data. For example, a body temperature sensor should sense the body temperature data using electronic components and disseminate the data after sensing. As shown in the diagram, the measurement accuracy is maximal in the node collections with 90 nodes. Considering Eq. (1), with the increase in the energy consumption of the node collection, the monitoring precision decreases.

*(2) Performance*. The performance itself includes three basic subsets of delay (response time), throughput, and energy consumption that must be evaluated in order to meet the performance criterion.

Delay of a system refers to the sending time of the bits received per unit of time. The following equations (2) and (3) are used to calculate the response time and delay of the proposed system:

$$D_T = N/R, \tag{2}$$

where $D_T$ is the transmission delay in seconds, $N$ is the number of bits, and $R$ is the transmission rate [24, 25].

$$\text{Response time} = \text{Stime} - \text{Rtime}, \tag{3}$$

which is equal to the time of sending the package minus the time of receiving the package.

Throughput of any system is usually measured in seconds and sometimes in data packets per second or data packets over time intervals. System throughput or total throughput is the sum of data delivered to all terminals over a network. In other words, the throughput in the proposed system is calculated by the following equations (4) and (5):

$$\text{Throughput} = \text{Bandwidth} \times \text{RTT/RTT}, \tag{4}$$

where RTT is the send and returns the time of a packet [26].

$$\text{Packet drop} = \text{Generated packets} - \text{Received packets} \tag{5}$$

The packages produced are minus the packages received [27].

Calculation of the energy consumption of each node: the following criterion can calculate the average energy consumed by each node for sending data from source node to destination node. This criterion can be calculated by the following equations (6) and (7) [28]:

$$E_a = \frac{\sum_{i=1}^{M} \left(e_{i,\text{init}} - e_{i,\text{res}}\right)}{M \sum_{i=1}^{S} \text{data} N_j}, \tag{6}$$

where the parameter $M$ represents the number of nodes in the network. The parameters $e_i$, $e_{\text{res}}$, and $e_{\text{int}}$ represent the initial and residual energy in the $n^{\text{th}}$ node, respectively. The parameter $s$ is the number of destination nodes and the parameter Nj is the data received by the destination node $j$.

$$\text{ER(k)} = k * E\text{elec}, \tag{7}$$

where $\text{ER}(K)$ energy consumption $K$ bits and $E$elec energy consumption of a node to send and receive a bit [29].

(i) Investigation of the response time (delay) of the proposed system by testing and the routing protocol changing scenario

In this case, packet transmission times should be evaluated in the simulation environment and the data transfer delay has to be compared by the node collection. Since routing protocols greatly affect network performance, we need to provide a routing algorithm tailored to the proposed system.

Ideally, the proposed solution uses the AODV routing protocol. In AODV, no specific routes will be assigned to any possible destination on the network; however, when the source node has a packet to send, routes are set up as needed. Therefore, when a message arrives requesting a new route, flooding is not performed in the network, as each node can only send packets to the destinations in its routing table. In order to prevent loops during routing, AODV uses a sequence number at each destination to identify current routing information. This sequence number will be carried by all routing packets until it reaches the destination.

DSDV routing protocol was used to evaluate and compare the performance of the routing protocol in the proposed solution. DSDV routing falls into the category of routing tables, where each node has a routing table in its memory that contains information about different nodes. The outputs show that due to the increase in latency and the memory consumed; this protocol does not fit the proposed solution. Also, as the routing process in the DSDV protocol requires frequent routing tables, the response time is significantly reduced. The DVSD routing protocol diagram is shown versus the AODV routing protocol diagram are shown below to compare the ideal and nonideal cases. Figure 5 shows the average delay of the proposed system and the base article system, in which the amount of latency of the whole system is divided by the number of node sets to calculate each of the averages. As can be seen, the average data transmission delay has a rising trend due to the increase in the number of nodes, and at point 40, the delay rate of both systems has a maximum value.

Figure 5 shows the delay time of the two methods in milliseconds. Comparing the two methods, it is clear that WSBS has less delay than the basic paper solution, i.e., Flexible Blanket. The delay is highly dependent on the time and method of sending and receiving the packet. Therefore, according to the results, with the increase in the number of sensors, the delay in sending data packets is maximum at point 40 (40 sensors). It can be concluded that the AODV routing protocol is appropriate to reduce packet transmission delay and increase the responsiveness of the wearable smart blanket.

(i) Investigation of the throughput of the proposed system by changing the transmission rate (rate of appropriately delivered packets)

The sensor network throughput depends on the packet delivery rate (PDR). If the transmission is successfully completed, the throughput of the sensor collection will be optimal. Considering the importance of this issue, the throughput of the sensor collection for the smart blanket has been evaluated and compared. In order to investigate the performance in the nonideal case, the high packet delivery rate was used. The results show an increase in the number of dropped packages. Due to the memory limitations of the existing nodes as well as the limitations of packet queuing, many of the packets will be dropped. As a result of the increase in dropped packets, the throughput is also reduced. In order to compare the ideal and nonideal cases, the average delivery rate will be analyzed against the high delivery rate, as shown in Figure 5. The average delay of the proposed system and the basic article system is presented in Figure 6.

Figure 7 shows the throughput of the two methods in kilobyte per seconds. As the number of sensors increases, the network throughput also increases. The basic paper solution shows that its throughput is very close to the WSBS, and almost the same at some points such a 5, 10, 15, and 20. As shown, with the increase of the nodes in the proposed system, the throughput increases suddenly, but due to energy limitations, fewer nodes need to be placed on the system.

In order to compare the ideal and nonideal cases, the average delivery rate will be analyzed against the high delivery rate. Therefore, as the packet transfer rate increases, the number of dropped packets increases, and the throughput of the smart blanket decreases sharply. Therefore, if the packet transfers and delivery rates are chosen in such a way that the number of dropped packets is less, the throughput of the wearable system will be higher.

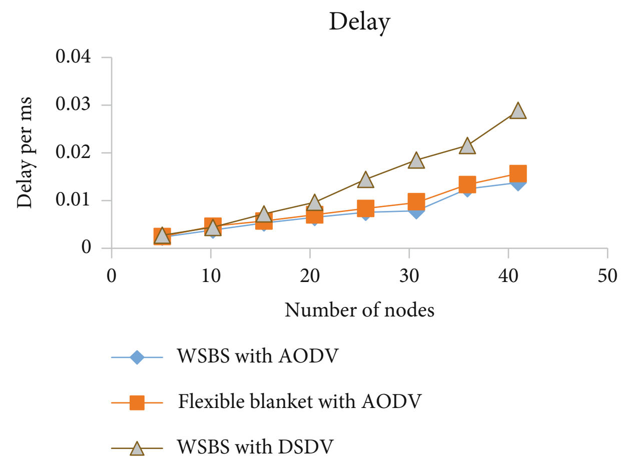


Figure 5: Comparison of the delay rate with the increasing number of sensors.

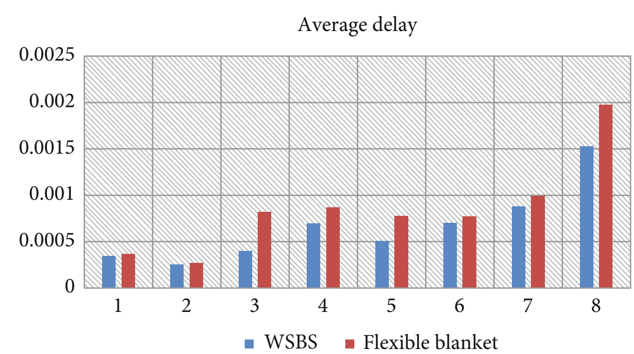


Figure 6: Average delay of the proposed system and the basic article system.

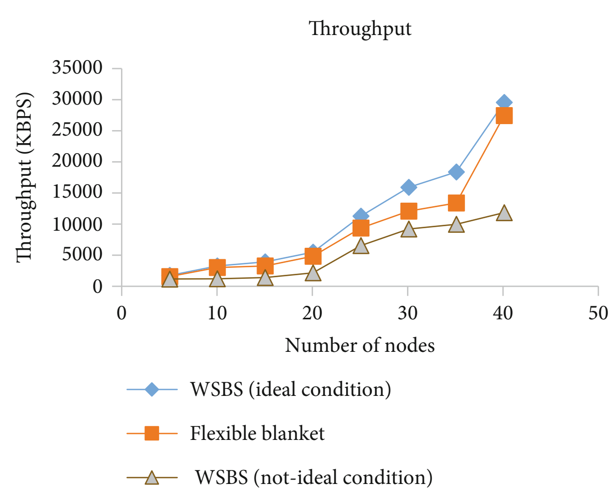


Figure 7: Throughput of the proposed system.

Figure 8 shows the number of dropped packets for the ideal and the nonideal cases in the proposed system network.

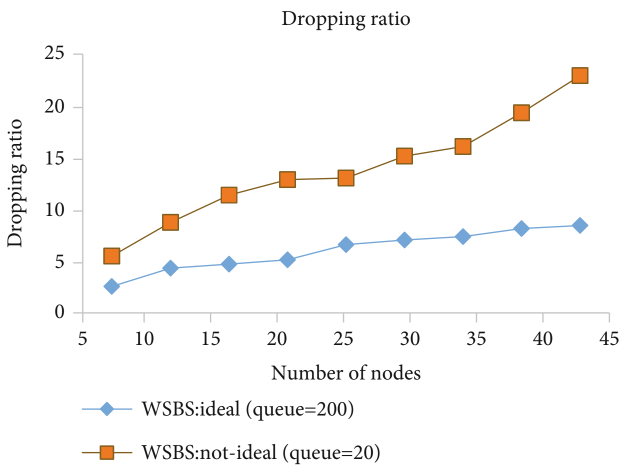


Figure 8: Comparison of the dropped data for the average transfer rate and the high transfer rate.

As it can be seen, in the ideal case, the average transmission rate has been used and the number of dropped packets is less, because the computational overhead is less and the packet queue limitation will not be incurred [30]. However, in the nonideal case, if the data transmission rate is high, the computational overhead of the nodes will also increase. This operational overhead requires sufficient memory, but due to the limitations in the memory and the packet queues, the number of dropped packets will increase significantly, which will affect the network throughput.

(i) Investigation of the energy consumption of the proposed system by evaluating the scenario of changing the number of sensors

Investigation of the energy consumption of every node in the smart blanket system network is an important issue. For this purpose, by changing the number of nodes installed on the smart blanket platform, the mean energy consumption and total energy consumption of the node collections were calculated by Eq. (6) and (7); comparing diagrams are also given.

Figure 9 shows the average energy consumption in the current research methods and the basic article. WSBS is a simulation of the present study model, and the Flexible Blanket is the basic article model. The basic article solution is based on a wearable blanket or clothing, on the surface of which the sensors are randomly distributed. Each sensor is made of polystyrene and is thin, flexible, and planar. The frequency used in the basic article is 1.5 GH, and a dipole antenna has been used. Considering the information obtained by the simulation of the proposed solution, it has been attempted that the simulation and parameters are as close as possible to each other. As it is clear, in WSBS, with the increase in the number of sensors up to 25, the average energy consumption will have an increasing trend. Above 25 sensors, the average energy consumption reduces proportionally. Therefore, based on the basin article results, the average energy consumption is more stable than WSBS. Comparing the two methods, it is clear that WSBS consumes less energy than the basic article because the average energy

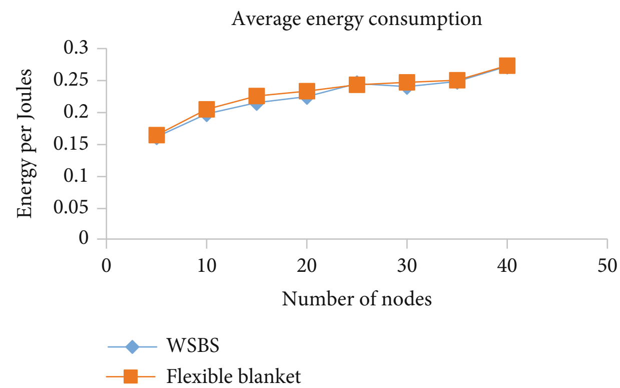


Figure 9: Average energy consumption.

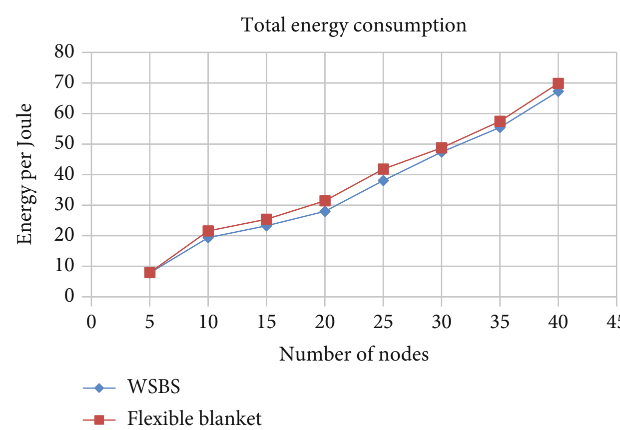


Figure 10: Total energy consumption.

consumption is highly dependent on the data transmission rate of each sensor. Figure 10 shows the total energy consumption; as shown in this figure, in both systems, as the number of sensors increases, the total energy consumption also increases. Therefore, the energy consumption of the sensor set has a completely increasing trend.

*(3) Reliability*. The concept of reliability in the physical sensor network implies that every sensor may fail or be wrecked by environmental events, such as an accident or explosion, or stop working due to the power run out. Tolerance or reliability means that node failures should not affect the overall performance of the network. In fact, we are going to build a reliable network using unreliable components. For a node $k$ with a failure rate of lk, the reliability is modeled through Eqs. (8) and (9) [28, 31].

$$R_k(t) = e^{-h_k t}, \tag{8}$$

which shows the probability of nonfailure at time $t$ provided that the node has not failed at a time interval $(0, t)$. Therefore, the probability of node failure increases over time.

$$r = \left(\frac{k}{k-1}\right) \times \left(1 - \frac{\sum pq}{\sigma^2}\right), \tag{9}$$

where $k$ is the number of nodes, $p$ is the percentage of correct transmission, $q$ is the percentage of data transmission with error, and $\sigma$ is the variance [32].

Therefore, in order to calculate the reliability and tolerance of the proposed system, the above equation is used. The comparison scenario is considered for its evaluation and is provided below along with the diagram.

If the nodes are installed on the patient's body in ideal positions and energy-saving algorithms are chosen tailored to the network when design sensor collections and routing protocols, there will be no energy constraint for data transmission, and the proposed wearable sensor network will have a long life, which in turn, increases reliability. Tolerance or reliability means that node failures should not affect the overall performance of the network. Therefore, it can be acknowledged that in the proposed wearable sensor network, one of the important issues is the lifetime of the network, which is directly related to the energy consumption balance of the sensors.

If we consider the nonideal case for this scenario (i.e., inappropriate energy storage algorithm and energy limitation), the reliability of the recorded data is reduced. As a result, failure and elimination of each node will affect the overall performance of the network due to the energy limitation, and the network lifetime is greatly reduced. In this scenario, in order to compare the relationships between energy consumption and network reliability, the error tolerances of the node collections have been calculated and are shown in the graph of these values. According to the calculations shown in the diagram, as the number of nodes increases, the total network energy consumption and average energy consumption both increase. The increase in energy consumption will reduce the reliability of each node. Suppose the number of sensors mounted on the patient's body is fewer. In that case, less amount of energy will be consumed, the tolerance of the network is increased, and the overall performance of the network and sensors is optimized. A comparison of the reliability of the ideal case (low energy consumption) with the nonideal case (energy limitation) is illustrated in the following figure.

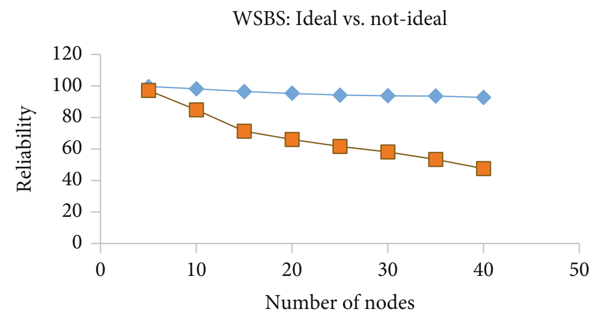


Figure 11: Reliability of the proposed system in cases of low energy consumption and energy limitation.

Figure 11 shows the reliability of each set of nodes in two cases. It can be deduced from this diagram that as the number of sensors (nodes) increases, their energy consumption increases significantly, reducing the reliability of each sensor collection. As can be seen in the figure, if the source of energy has limitations, the tolerance of the nodes decreases sharply, and the network loses its optimal performance. Therefore, in the present study, fewer nodes, i.e., 5 or 10, are considered to have sufficient tolerance for the network and make the system perform at its best. Based on the investigation, we proposed a list of appropriate parameters for our system in Table 3.

Wearable technologies are among the technologies that make constant monitoring and control of patient's unstable conditions easier for medical personnel such as physicians, nurses, consultants [9]. This study is aimed at providing the characteristics, modeling, and evaluation of a wearable monitoring system designed to control the vital signs of patients in the ambulance. The wearable smart blanket system has design capabilities and requirements that enable constant monitoring of the subject's vital signs such as heart rate, blood pressure, and blood oxygen. The wearable smart blanket collects data on medical signals by sensors mounted on the blanket platform, and the data are processed and interpreted by the smart system. As a result, patient data is stored and transferred continuously without any data loss and no interruption. Based on the simulation carried out by the NS2 software, qualitative criteria such as accuracy, data transfer speed, throughput, and energy consumption have been optimized. In [29], a wireless body area network for health monitoring of elderly people was proposed. In this wearable-oriented network, routine vital signs were monitored and stored when the person gets back home. Compared to our work in which the patient was monitored in an emergency, in this project, the patients were followed by normal physiological conditions in daily life. In this work, like our article, the Network Sensor 2 simulator was used for evaluation as mentioned; the wearable smart blanket system has functional capabilities such as monitoring vital signs, recording patient medical signals, alerting medical personnel when abnormalities occur, and analyzing and extracting some data on the subject's vital signs. According to the evaluations, this system has qualitative features such as sufficient monitoring accuracy, relatively fast response time, low power consumption, relatively high reliability, optimum effectiveness, and performance. In another study which was conducted by Li et al. [30], a wearable wireless sensor network was developed for patient monitoring. In this system, physiological information, like circulatory strain and emotional patient information, are gathered by smart sensors. In line with our study, some execution parameters like Packet Delivery Ratio (PDR), throughput, and energy conception were calculated, and the project was simulated by the NS2 tool. However, in contrast with our work in this project, the Zigbee protocol was utilized for transferring data. Based on the simulation results, the measurement accuracy of the proposed system is maximal in node collections 10 nodes and zero distance. The packet transmission delay in the proposed system is less than the basic article and is less than 0.01 in node collections with 5, 10, and 15 nodes, which is very ideal. Overall, the packet transmission delay in the proposed system is almost 24% better than the basic article. The AODV routing protocol also performed better than DSDV, and there are less delay and better response time in the proposed protocol [33]. In

Table 3: Evaluation results of some parameters.

| Parameters and evaluation results for the proposed system | | Parameters and evaluation results for the proposed system | |
|---|---|---|---|
| 150-200 gr | Weight of blanket platform | AODV | Suitable protocol |
| 10 × 50 × 58 mm | Dimensions of ECG sensors | 5-10 nodes | Total number of nodes in the system |
| 25 × 25 mm | Dimensions of respiration rate sensor | $3000-5000 | Cost of manufacturing the system |
| 10 × 20 mm | Dimensions of body temperature sensor | 20 gr, total of 100 gr for 5 electrodes | Weight of ECG sensors |
| 22 × 10 mm | Dimensions of blood oxygen saturation sensor | 10 gr, total of 40 gr | Weight of respiratory rate sensor |
| 30 × 20 mm | Dimensions of blood glucose sensor | 5 gr | Weight of body temperature sensor |
| 90 × 70 cm | Minimum dimensions of the proposed system | 4 gr | Weight of blood oxygen saturation sensor |
| 190 × 90 cm | Maximum dimensions of the proposed system | 6 gr | Weight of blood glucose sensor |

this line, one study was conducted by Dang et al. [34]. In this hospital-centered project, crucial vital signs such as body temperature, blood pressure, heart rate, ECG, and EEG were monitored with wearable smart body sensors. In contrast with our work, in which we used DSDV and AODV protocol to transfer data, in this study, the vital data packets were sent to the hospital system applying the standard ZigBee MAC protocol. The throughput of the proposed system is better than the basic article. As shown in the diagrams, the throughput increases with the increase in the number of nodes. However, due to energy limitations, the number of sensors is better to be 5 or 10 at most. Also, the average energy consumption and total energy consumption of the proposed system are better than the basic article. According to the calculations, it can be said that the energy consumption of the proposed system is approximately 25% lower than the basic article. Besides, the system reliability is ideal in general. However, due to considerations of energy consumption and computational overhead, fewer nodes need to be selected to optimize the tolerance and performance of the system. The average rate of packet transmission has also been considered, which reduced both computational overheads and the number of dropped packets significantly. In another project [35], researchers developed wearable smart sensors for remote health monitoring of the elderly. The technology outlined in this paper focused on tracking person's physiological data for early detection of unique disorders. Similar to our work, extensive simulation results demonstrated the ideal performance of this system which was considered by low latency, low packets lost, and effectiveness.

## 5. Conclusion and Future Work

The use of the wearable smart blanket system will eventually allow monitoring of the subjects in a timely manner. This system allows communication with the physicians at the health center so that the EMS technician could receive specific medical and diagnostic advice when the need arises. The challenges of developing the proposed system are pointed out: because the vital signs are recorded by the sensors and decisions are made on the basis of these data, the data should have an acceptable level of reliability in the field of health care. On the other hand, the reliability of the system directly affects the quality of patient monitoring and may, at worst, result in the death of the patient due to the lack of diagnosis of threats. Considering that the sensors are of limited energy and that the node is completely eliminated as soon as the energy runs out, which creates a barrier in data transmission, so reducing energy consumption is also considered a design challenge. Patient privacy and system security should also be considered in the design of the proposed system. Another design challenge of the proposed system is the cost of various sensors. As future directions, considering the importance of recording vital signs of patients in emergencies without latency, we can implement and create a wearable smart blanket system for monitoring patients in an emergency condition.

## Data Availability

All data generated or analyzed during this study are included in this published article.

## Conflicts of Interest

The authors declare no conflict of interest.

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