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A Practical Traffic Scheduling Scheme for Differentiated Services of Healthcare Systems on Wireless Sensor Networks

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Abstract Wireless sensor networks have recently been extensively researched due to the flexibility and cost savings they provide. One of the most promising applications of sensor networks is human health monitoring: wireless sensors are placed on the human body to form a wireless body network where the sensor node can continuously monitor real-time physiological parameters or human activities (motion detection). However, along with the flexibility, many problems arise due to a number of factors, including the bad quality of transmission media and the scarcity of resources. Moreover, sensor networks have different characteristics such as a variety of devices, different generated data, etc. From a quality of service (QoS) point of view, the healthcare domain can be seen as a real-time application demand to consider application requirements. Healthcare domains principally have stringent delay and loss requirements. Thus, considering different capabilities and ensuring time data delivery become necessary. Because wireless body area networks (WBAN) deal with human life, any delayed or lost data can endanger the user's life. This paper proposes a differentiated traffic and scheduling scheme for WBAN. It is based on patients' data classification and prioritization according to their current status and diseases. Through queue scheduling and path choice issues, the urgent data are delivered on time to provide a QoS guarantee for WBAN. Finally, it is shown that the proposed scheme is efficient for timely data transfer in WBAN.

Keywords WSN · Quality of service · Real-time · Dynamic data differentiation

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1 Introduction

The rapid advances in electronics and wireless communication technologies have enabled the development of wireless sensor networks (WSN), which offer economically viable solutions for numerous applications such as home security, military reconnaissance, target tracking, pollutions levels monitoring, healthcare monitoring, and freeway traffic. Particularly, the area of WSN has been applied in the healthcare domain, where wireless body area networks (WBAN) efficiently administer healthcare delivery to arrange services [1]. This provides better services to a large number of people in the hospital, their homes, or their workplaces using limited financial and human resources. WBAN consists of a network of multiple body sensors attached or implanted in the human body where they can continuously process, exchange sensed data, and communicate wirelessly with other networks in order to monitor physiological status or body activities [2]. The medical application of WBAN aims to improve existing healthcare and monitoring services, especially for the elderly, children, and chronically ill [3]. In addition to healthcare service, WBAN is also a promising technology in other domains such as consumer electronics, athletic training, workplace safety, secure authentication, and safeguarding of uniformed personnel [4]. Although body sensors share many of the same challenges as general WSNs, a number of WBAN-specific challenges should be analyzed. One of the challenges is assuring the timely and reliable delivery of life critical medical data in a resource constrained environment. WBANs have fewer and smaller nodes compared to WSNs, which implies small batteries leading to stricter energy consummation for any activity.

In addition, WBANs support various services with different characteristics, since different devices have a different quantity of energy, generate different sized data, and have various transmission rates. Thus, using a data transmission algorithm designed for WSNs in WBANs is unsuitable.

Therefore, it has become important to provide a service differentiated real-time and reliable transmission scheme for WBANs and WSNs to provide a QoS guarantee from end to end.

In this paper, we support quality of service (QoS) for body sensor area networks through data classification and prioritization. We also use a path selection algorithm based on scheduling available routes to ensure timely delivery of WBAN data.

The rest of the paper is organized as follows. In Sect. 2, we discuss the related work. In Sect. 3, we present the proposed scheme. In Sect. 4, we analyze the performance of the proposed scheme. Finally, in Sect. 5, we conclude the paper and discuss future works.

2 Background and Related Work

This section introduces WBANs, provides the QoS concepts, and describes some of the related work that has been done in the area of QoS support in WBANs.

2.1 Wireless Body Area Network

A wireless body area network (WBAN) is a type of wireless sensor network that consists of body sensors attached on or inside the human body for health monitoring, i.e. control of physiological status by measuring the temperature, blood pressure, heart rate, electrocardiogram (ECG), electroencephalogram (EEG), respiratory rate, and saturation of peripheral oxygen (SpO2) levels. It is used to control body activities, i.e. motion detection.

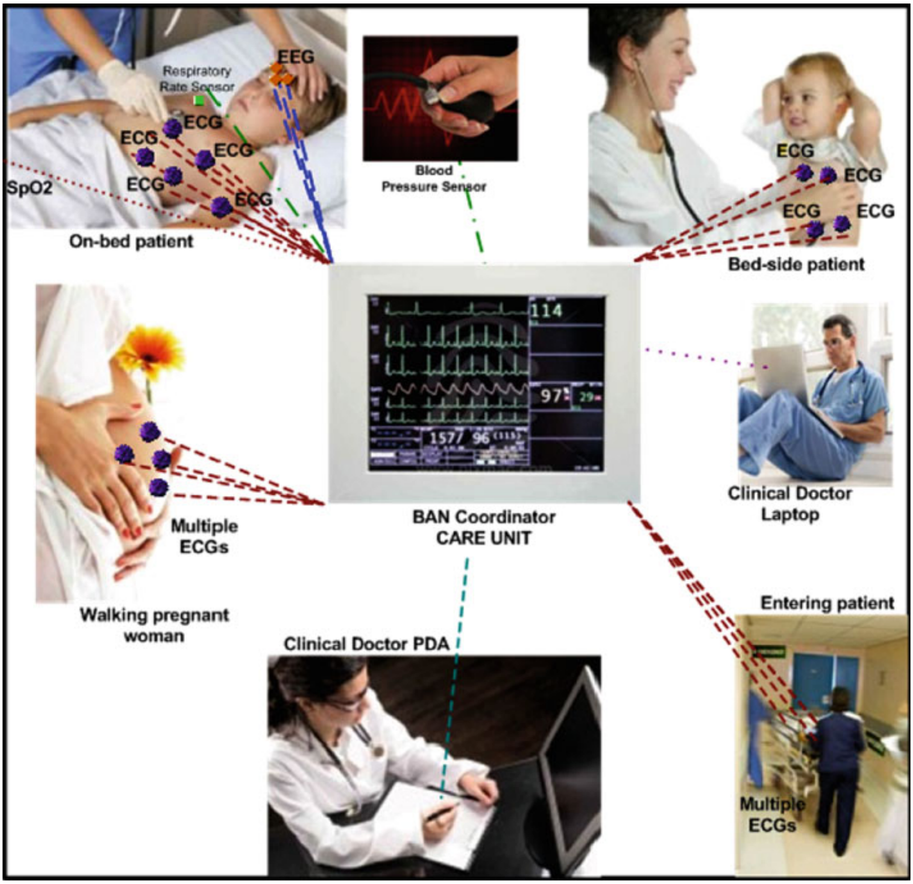

Fig. 1 WBAN example in a hospital environment [18]

WBANs are mainly utilized for smart services, including healthcare, life care, and sports entertainment. They are used to develop a smart and affordable healthcare system and can be a part of diagnostic procedures, chronic condition maintenance, supervised recovery from surgical procedures, and management of emergency events [16]. WBANs provide a data rate of 10 Kbps to 10 Mbps and a very short transmission range of at least 3 m with low power [17]. Figure 1 shows the WBAN application in healthcare monitoring.

2.2 Quality-of-Service Concepts for WBAN

Quality of service is the ability to either provide different priorities to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. For example, a required bit rate, delay, jitter, packet dropping probability and/or bit error rate may be guaranteed.

The role of QoS is the following:

- Perform effective traffic management…
  - ✓ To meet diverse application requirements.

- ✓ For delay, jitter, loss, and/or throughput.
- ✓ For range of differentiated services.

While energy efficiency is an important consideration for designing algorithms and protocols for WBANs, QoS parameters such as coverage rate, reliability, end-to-end delay, fairness, throughput, and error rates for delivery or sensing may be equally important, depending on the application objectives.

As a real-time application, WBAN has QoS requirements, where it demands a guarantee of some minimum level of the service from the network.

This raises demands in service differentiation for data belonging to different body sensors, with different characteristics carried by people having different needs in the networks. WBAN applications have varying data characteristics with different requirements and rely on the ability of the network to provide QoS guarantees with respect to delay, delay jitter, packet loss, and throughput metrics. End-to-end delay is an important design consideration factor for the medical environment.

2.3 Related Work

Various QoS methods have been studied for WBAN: [5–10] these works adopt different scheduling, service differentiation, and novel hardware techniques to optimize the emergency transmission, packet latency, and power consumption of WBANs. In [5], they propose an infrastructure for remote medical applications. In order to improve the delay and transmission time of critical vital signs, a differentiated service based on priority scheduling and data compression is presented. In this model, a patient server receives instructions from a remote hospital server and configures the patient's WBAN accordingly. The wireless sensors transmit the signals to the server. Here, each type of vital signal receives a priority level and then is transmitted to the hospital server according to its priority.

In [6], they modify the framing structure of IEEE 802.15.4 to remarkably reduce the packet delay of emergency alarms. They introduce a preemptive scheduling model to guarantee the transmission priorities of various medical data.

There are also scheduling techniques utilizing prioritized retransmission [7] and fuzzy-logic controls [8] to enhance WBAN QoS. In [9], they propose a QoS-aware routing service framework for biomedical sensor networks where they prioritize routing services and user specific QoS metrics. In [10], a service prioritization and congestion control protocol is presented for wireless biomedical sensor networks in healthcare monitoring where they discriminate between different physiological signals and assign them different priorities. Different from the above WBAN QoS solutions, our proposed scheme puts more focus on a dynamic traffic classification for service differentiation as a solution for WBAN QoS.

Previous techniques did not consider dynamic changes in received data. They provided means to prioritize ECG and heart rate data above other patient data due to their numerous parameters. The result of such prioritization is that other patient data will have delayed transmission due to dynamic changes in patient status. Thus, we propose a dynamic priorities setting based on a patient's current requirements.

3 Proposed Scheme

The basic idea of our scheme is to classify and prioritize patient vital signs dynamically. We also use a queue scheduling and path choose scheme to ensure timely delivery in real

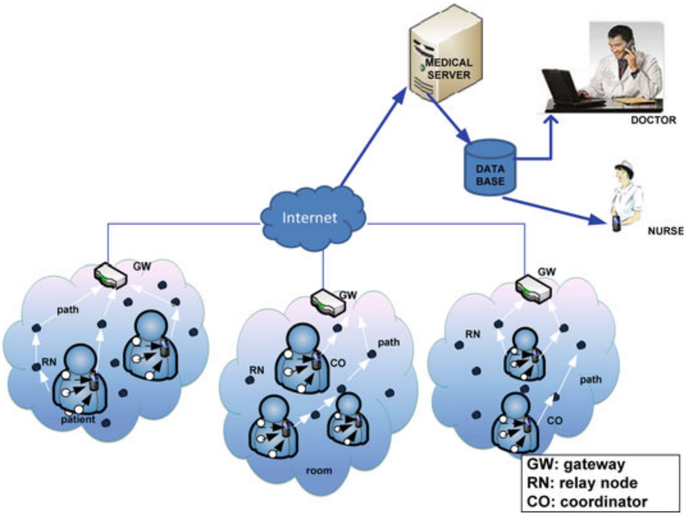

Fig. 2 System architecture

time traffic. In this section, we present the proposed scheme in detail by providing the system architecture, application scenario, data classification, and data transmission based on scheduling.

3.1 System Architecture

The system architecture consists of groups of sensors attached to a patient's body: a coordinator (CO), relay node (RN), and gateway (GW) as illustrated in Fig. 2. Body sensors collect and send data to the CO, which in turn follows data to a GW (base station) through RNs if necessary.

The GW save patients' data into the hospital database where they can be accessed by hospital staff in real-time.

The overall procedure consists of 6 steps and is outlined briefly as shown in Fig. 3.

Step 1: After each sensor node(***Source Node***) senses data from patients, it classifies data into two phrases: Event or Normal. And it sends data to the CO. (Described in Sect. 3.3.1)

Step 2: ***Coordinator*** decides patient status as "Normal/Moderate/Urgent" data. Traffic Scheduling, path selection and data transmission processes are handled considering patient status. (Described in Sects. 3.3.2 and 3.4)

Step 3: ***Relay node*** relays the data to *Gateway*

Step 4: ***Gateway*** transfers the data to *Medical Server* using wired network, Internet.

Step 5: ***Medical Server*** handles the user request and provide services to user. Furthermore, *Data Manager* stores the data and supports the data searching and matching using Metadata.

Step 6: ***User*** accesses the ***Database*** with the service provided by *Service Manager* in Medical Server

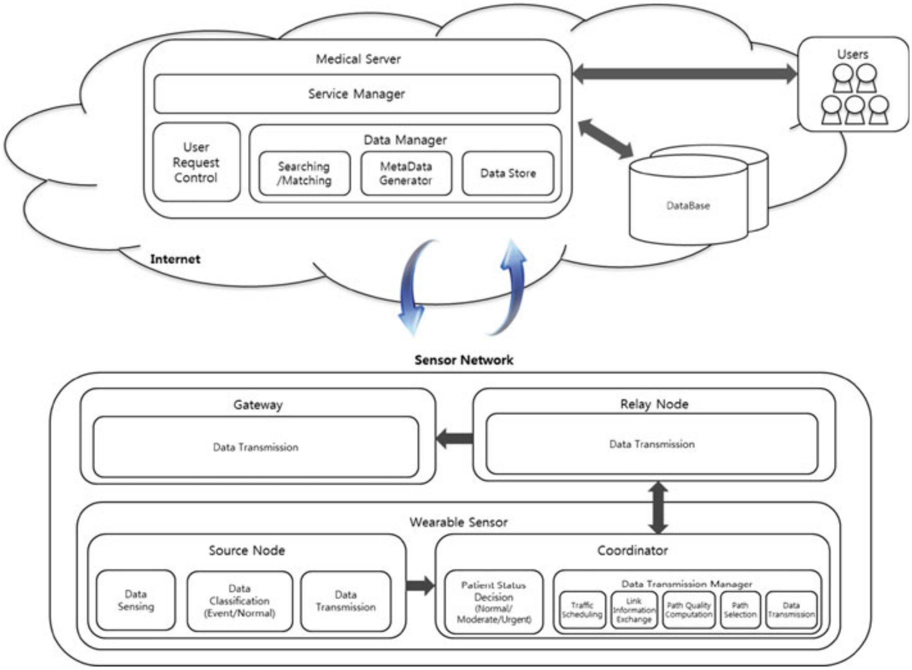

Fig. 3 System framework

Table 1 Diseases characteristics

Vital signs	Diseases		
	Sepsis	Sleep apnea	IDH
ECG	–	–	✓
Pulse	✓	✓	✓
Blood pressure			
Systolic	–	–	✓
Diastolic	–	–	✓
Temperature	✓	–	–
SPO2	–	✓	–
Breathing frequency	✓	–	–

✓ corresponding vital sign
– no corresponding vital sign

3.2 Application Scenarios

We first give an application scenario that will be used throughout this work. We consider a hospital environment where patients with various diseases are controlled by employing a ubiquitous sensor network to handle vital sign delivery, including ECG tracings, heart rate, blood pressure, blood sugar, SPO2, and temperature.

We mainly focus on three diseases: sepsis [11], sleep apnea [12], and intradialytic hypertension (IDH) [13]. Table 1 summarizes the disease characteristics considered in the motivating example.

Table 2 Disease identification of sepsis

Criticality level	Event type		
	Temperature >38.3 °C or <36 °C	Pulse >90 c/min	Breathing frequency >20 c/min
Normal	No	No	No
Medium	Yes	No	No
	No	Yes	No
	No	No	Yes
High	Yes	Yes	No
	No	Yes	Yes
	Yes	No	Yes
	Yes	Yes	Yes

Table 3 Disease identification of sleep apnea

Criticality level	Event type	
	Pulse rate <60 beats/min or >100 beats/min	SPO2 <90 %
Normal	No	No
Medium	Yes	No
	No	Yes
High	Yes	Yes

Table 4 Disease identification of IDH

Criticality level	Event type	
	Systolic blood pressure >20 mmHg	Decreasing mean arterial pressure >10 mmHg
Normal	No	No
Medium	Yes	No
	No	Yes
High	Yes	Yes

3.2.1 Disease Identification

In this section, we shortly describe each disease. We also show disease identification using Tables 2, 3 and 4.

In these, 'event type' means a vital sign in an abnormal range. 'Criticality' signifies a level of emergency/risk.

a) Sepsis

Patients who suffer from sepsis become urgent if two of the following criteria occur at the same time [11]:

1) Temperature >38.3 °C or <36 °C

2) Pulse >90 c/min
3) Breathing frequency >20 c/min

Possible levels of criticality for sepsis patients are shown in Table 2. A normal level corresponds to normal sensed data, a medium level corresponds to one event type where the patient might need care, and a high criticality level exists when any two event types happen at the same time. For the high level, the patient requires immediate treatment.

b) Sleep Apnea

Patients who suffer from sleep apnea become urgent if they meet two of the following criteria at the same time [12]:

1) Pulse rate <60 beats/min or >100 beats/min (for adults)
2) SPO2 <90 %

Possible levels of criticality for sleep apnea patients are shown in Table 3 where a normal level means that there is no event in the sensed data, a medium level signifies one event type, a high criticality level signifies two event types happened at the same time.

c) Intradialytic Hypertension (IDH)

Patients who suffer from IDH become urgent if they have two of the following criteria at the same time [13]:

1) Systolic blood pressure >20 mmHg
2) Decreasing mean arterial pressure >10 mmHg

The possible levels of criticality are shown in Table 4, where a normal level refers to normal data, a medium level indicates one event type, and a high criticality level refers to two event types that happen at the same time.

3.3 Data Classification

In general, the sensed data are transmitted to the GW through a coordinator. In WBAN, multiple events often occur; thus, specifying each node to a corresponding role is necessary to schedule the events based on their criticality. In the following section, the role of each node is described in detail to handle important events properly.

3.3.1 The Role of the Source Node

When a sensor node senses data, it immediately compares it with the defined threshold and then decides if there is any event.

An event occurs when the data crosses the threshold where the data type bit is considered to be true, otherwise the data are normal and the data type bit is filed as false. This is illustrated in Fig. 4.

After that, data are delivered to the CO, which performs data classification and sends it to the GW through multipath based on the criticality level.

3.3.2 The Role of the Coordinator Node

The coordinator node has a criticality table that is used to classify and categorize patients based on the received data from the source nodes. Data arrive classified as event or normal

Fig. 4 Event notification by the source node algorithm

```
Input:
Threshold for vital sign $x$: thrshld   $x$
Data(s): current sensed data
Output: QoS requirements fulfilled
begin
    for every period do
        for every vital sign $x$ do
            if (data(s) > thrshld   $x$ then
                category x ← event.
                Set the data type to true
        else
            category $x$ ← normal
        Set data type to false
            end if
        end for
    end for
end
```

data, and a copy of information containing packet criticality level is added to the CO's criticality table. Thus, upon receiving the data, the CO can use its criticality table to classify the data and make decisions as follows:

- If data come from the source node categorized as events and there is a corresponding event type stored before in the critical table, the patient status will be designated critical.
- If data come from the source node categorized as events and there is not a corresponding event type in the critical table, the patient status will be designated as normal. In addition, the CO will add a copy of the information related to the new event to its critical table before sending the data.
- If data come from the source node categorized as normal, the patient status will be designated normal.

Each event notification has a unique ID. The uniqueness of an event notification is achieved by its timestamp. From this, we categorize patients as normal, moderate, or urgent based on the sensed data and their criticality level as shown in Tables 2, 3 and 4.

- **Normal**: A patient status is set as normal when the coordinator node does not find any disease criteria/events.
- **Moderate**: A patient status is set as moderate if the coordinator node perceives any one of the disease criteria, which designates the criticality level as medium.
- **Urgent**: A patient status is set as urgent if the coordinator node identifies two of the disease criteria or all disease criteria simultaneously, meaning the criticality level is high. Figure 5 outlines the patient categorization process in detail.

3.4 Transmission Procedure

In addition to the steps of data classification and prioritization (traffic differentiation), we consider traffic scheduling over a multiple paths scheme to support real-time data delivery. Figure 6 illustrates the entire proposed mechanism. Each part is presented in more detail in this section.

```
Input:
1. data type
2. tbl_event: related data in the criticality table (1or 0)
3. p:patient
4. time T:maximum time of event validity
Output: assign classes to patient based on type of the flow.
Begin
    For every receive data from the source node  do
    while (time T not expired) do
        if(data type == event)&&( tbl_event==1)
        then
                Status $p$ ← URGENT
                        else
            if(data type== event)&&(tbl_event==0)
                then status $p$ ← MODERATE
                                else
            if(data type == no event) then
                status $p$ ← NORMAL
                    end if
                end if
        end while
    end for
    end
```

Fig. 5 Patient classification algorithm

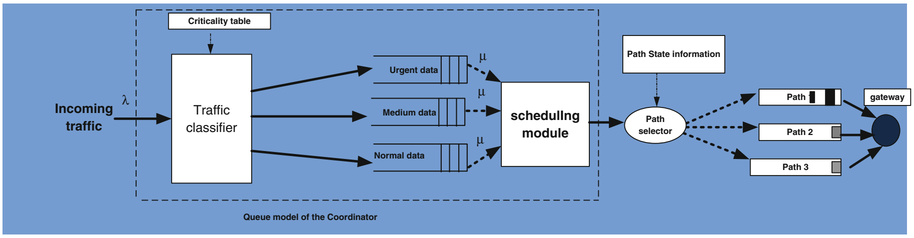

Fig. 6 Transmission procedure

3.4.1 *Traffic Scheduling*

Our scheme aims to enhance real-time delivery using differentiated service, traffic scheduling, and multipath transmission. In this subsection, traffic scheduling is presented. When data packets are received by the CO, it uses the classifier module to classify them based on the criticality table as detailed in Sect. 3.3.

After the data classification phase, data are distributed in separate queues depending on the type of traffic and related class. Thus, data traffic is added to a queue corresponding to its class.

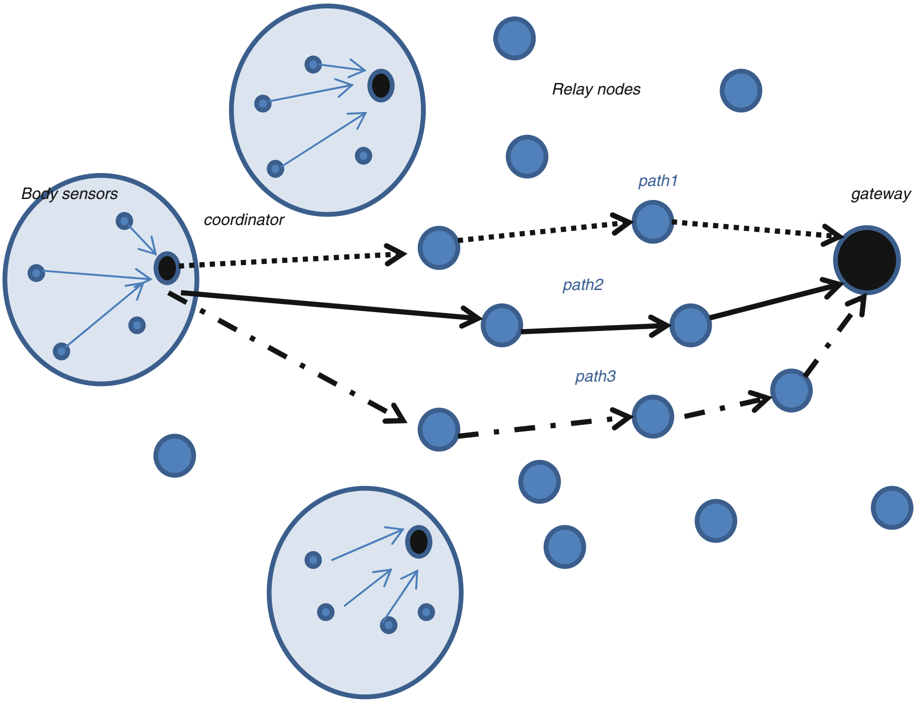

Fig. 7 Multipath example in WBAN

Next, the scheduling module is used to select data from the queue referring to traffic priority. Data in a queue is scheduled only when there is no data in other queues that has a higher priority.

After this scheduling phase, data are sent to the path selector that refers to the path state information and dynamically distributes classified packets among multiple paths. Figure 5 illustrates the mechanism of packet scheduling and path choice.

3.4.2 Parameter Obtaining Steps

Network Model We consider a medical environment where the WBAN is composed of a body sensor network, CO, RN, and GW deployed on different patients' bodies in a star topology (as described in Sect. 3.1). The communication from the body sensor to the coordinator is done in a single hop transmission, and we focus on the communication from the CO to the GW (interBAN). Figure 7 shows the multipath example in WBAN.

Link Information In order to perform multipath data transmission, we estimate the current path state by first indicating the link quality information. This uses the received signal strength indicator (RSSI) between neighbor nodes' residual energy and path delay.

The RSSI is a function of the distance between two nodes and can be computed as follows [14]:

$$\mathrm{RSSI(d)} = \mathrm{RSSI\,(d_0)} - 10\,\mathrm{n}\log(\mathrm{d}/\mathrm{d_0}) \tag{1}$$

where

- RSSI(d) is the receiving signal strength in *db* at a distance d from the source,
- RSSI(d_0) is the receiving signal strength at a distance d_0 from the source, and
- *n* is the attenuation exponent.

The transmission between two nodes is also proportional to their residual energy. We define R_{ab} so as to represent the link quality and the residual energy of two nodes. The RSSI of node *a* to node *b* is represented as $RSSI_{ab}$, and the RSSI of node *b* to node *a* is represented as $RSSI_{ba}$, considering symmetric transmission (e.g. ACK transmission).

The residual energy values of node *a* and node *b* are represented as res_a and res_b, respectively.

The R_{ab} is computed as follows:

$$R_{ab} = res_a \times res_b \times RSSI_{ab} \times RSSI_{ba} \tag{2}$$

where res_a and res_b are the residual energy values of node *a* and node *b*, respectively, and $RSSI_{ab}$ and $RSSI_{ba}$ are the RSSI values for node *a* to node *b* and node *b* to node *a*, respectively.

Path Quality Computation We consider the overall path quality, which is computed by the following:

$$R_{path} = \frac{\sum_n R_{ab}}{n} \tag{3}$$

where R_{ab} is the link quality and *n* is the number of links on the path.
Multipath establishment consists of the following phases:

phase 1: When body sensor nodes are first deployed, the CO discovers all possible disjoint paths to reach the GW.
phase 2: The CO broadcasts a small route request message, M_{rreq}, that has the destination address in order to find a routing path to the GW.
phase 3: The neighbor node receiving the M_{rreq} messages forwards them towards the GW after adding its ID.
phase 4: The GW replies to each M_{rreq} with the M_{rrep} message along with the ID list of M_{rreq}.
phase 5: Each M_{rrep} message follows the same path of its M_{rreq}. The coordinator node receives the M_{rrep} message along with the ID lists. Each ID list refers to a path from the CO to the GW. The M_{rrep} contains the link quality, R_{ab}, of each link and the number of hops of the path.
phase 6: The CO selects *n* paths and saves them in its local path set to the GW.

Path Selection With previous computation, CO selects the path as follows:

(1) Periodically measure the path quality with echo message and calculate R_{path} using the above formula (3).
(2) Define the scheduling probability P(a), which is the probability of assigning a traffic to a path *i*, representing the normalized value of R_{path} relative to other paths R_{path} values as

$$P_i(a) = \frac{R_{path}}{\sum_k^i R_{path}}. \tag{4}$$

We construct probability ranges for paths using the scheduling probability P(a).

Thus, for each path i, the probability range is defined as follows:

$$\left(\sum_{k}^{i-1} p_i(a), \sum_{k}^{i} p_i(a)\right); \mathrm{i} = 1, 2, \ldots, \mathrm{N}, \text{ where } p_0(a) = 0 \text{ and } \sum_{k=0}^{i} p_i(a) = 1. \tag{5}$$

(3) We use probability ranges to follow the data to the path in each interval of time. Priority is assigned to the path referring to its $\mathrm{R_{path}}$. A path with a high $\mathrm{R_{path}}$ has a higher priority. This is dynamic and changes with time.

When the CO wants to send data to the sink, it should select one path in the local set path so that the path selector generates a random number between 0 and 1. The value of the random number falls into one of the ranges defined in Eq. (5). Thus, the path with an index i related to the selected range is chosen to send the data. Therefore, lower priority paths have a lower chance than higher priority paths to follow data.

3.4.3 Mathematical Analysis

In this section, we present the analytical model used in this work. The used notations are described below.

$\lambda_{\mathrm{ur}}, \lambda_{\mathrm{m}}, \lambda_{\mathrm{n}}$ are the arrival rates of urgent, medium, and normal state packets, respectively. $\mu_{\mathrm{ur}}, \mu_{\mathrm{m}}, \mu_{\mathrm{n}}$ are the service rates of urgent, medium, and normal state packets, respectively.

$$\lambda_0 = \mathrm{N} \times \lambda_{\mathrm{ur}}. \tag{6}$$

The medium packet arrival rate is as follows:

$$\lambda_1 = \mathrm{N} \times \lambda_{\mathrm{m}}. \tag{7}$$

The normal packet arrival rate is as follows:

$$\lambda_2 = \mathrm{N} \times \lambda_{\mathrm{n}} \tag{8}$$

where N is the sensor body in the cluster.

Definition λ: total arrival rate that denotes the number of incoming packets per second at the CO. That is,

$$\lambda = \lambda_0 + \lambda_1 + \lambda_2. \tag{9}$$

μ: service rate that denotes the number of departure packets per second.

Multipath routing consists of N disjoint paths as the data arrive at the GW using multiple paths. Each path can be modeled as multiple M/M/1 queues

The packet arrival rate to each queue is a Poisson process. For a given path, the end-to-end path delay is composed of transmission delay and queuing delays. The transmission delay, which is smaller than the queue delay, is neglected.

We consider an M/M/1 queue model with non-preemptive priority. We designate three kinds of packets: urgent, medium, and normal state packets with three priorities.

The traffic intensity at the CO is computed as follows:

$$\rho = \frac{\lambda}{\mu} = \rho_0 + \rho_1 + \rho_2 \tag{10}$$

When normal packets arrive, the CO may be serving a packet for urgent or medium classes. The probability that an urgent packet finds a medium in service equals the fraction of time the node spends on medium packets, calculated as follows:

$$\frac{\lambda_1}{\mu} = \rho_1. \tag{11}$$

By Little's law [15], we have the following equation:

$$\mathrm{E(n_0)} = \lambda_1 \mathrm{E(T_0)} \tag{12}$$

where $\mathrm{E(n_0)}$ is the expected number in the queue of urgent packets, λ_0 is the arrival rate, and $\mathrm{E(T_0)}$ is the average delay time.

When the urgent packets arrive at the CO, there are $\mathrm{E(n_0)}$ packets in the queue. As the urgent packets have higher priority, the mean time delay of the arrived packet depends on the $\mathrm{E(n_0)}$ packets, which are already buffered in the queue, plus the packets in service.

Thus,

$$E(T_0) = \frac{E(n_0)}{\mu} + \frac{1}{\mu} + \frac{1}{\mu}(\rho_1 + \rho_2) \tag{13}$$

$$= \frac{1 + (\rho_1 + \rho_2)}{(1 - \rho_0)\mu} = \frac{1}{\mu} + \frac{\rho / \mu}{1 - \rho_0} \tag{14}$$

The medium packet class has to wait for urgent packets in the queue and the medium packets that have already arrived in the queue, thus,

$$\mathrm{E(T_1)} = \frac{E(n_0)}{\mu} + \frac{E(n_1)}{\mu} + \frac{1}{\mu} + \frac{1}{\mu}\rho_2 \tag{15}$$

$$= \frac{E(n_0)}{\mu} + \frac{E(n_1)}{\mu} + \frac{1}{\mu} + \frac{1}{\mu}(\rho - \rho_0 - \rho_1) \tag{16}$$

According to Little's theorem, we have the following:

$$E(T_1) = \frac{1}{(1 - \rho_1)\mu}\left[1 + \frac{\rho}{1 - \rho_0} - \rho_1\right]. \tag{17}$$

The normal packet class has to wait for the urgent and medium packets in the queue in addition to the normal packets that have already arrived in the queue, thus,

$$\mathrm{E(T_2)} = \frac{E(n_0)}{\mu} + \frac{E(n_1)}{\mu} + \frac{E(n_2)}{\mu} + \frac{1}{\mu} + \frac{1}{\mu}(\rho - \rho_0 - \rho_1 - \rho_2). \tag{18}$$

By Little's theorem [19] we get the following:

$$E(T_2) = \frac{\lambda_0 E[T_0] + \lambda_1 E[T_1] + 1 + (\rho - \rho_0 - \rho_1 - \rho_2)}{\mu - \lambda_2}. \tag{19}$$

The expected delay in one hop is $\mathrm{E(T_i)}$. The delay between the CO and the GW can be estimated by adding up the delays incurred at each hop along the path. Thus, the total delay along the path is the summation of the individual delays at each hop, and the expected delay of a packet on the path of *k* hop is as follows:

$$\mathrm{E(N)} = \sum_{i \in P}^{k} \mathrm{E(T_i)} \tag{20}$$

where P is the set of nodes comprising the path from the coordinator to the GW.

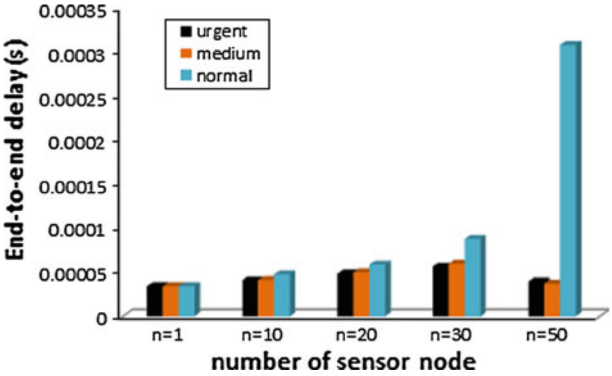

Fig. 8 End-to-end delay versus number of nodes

In addition to the data classification and prioritization steps (traffic differentiation), we consider traffic scheduling over a multiple paths scheme to support real time data delivery as illustrated in Fig. 6. The procedure details are presented in this section.

4 Performance Evaluation

In this section, we present the performance evaluation for the proposed scheme. The metrics used herein for the evaluation in terms of QoS are end-to-end delay and packet loss probability.

Average end-to-end delay is the mean delay incurred by a packet when it travels from the source to the destination.

Packet drop probability is the ratio of packets dropped due to buffer overflow.

4.1 Average End-to-end Delay

We analyzed the end-to-end delay of the different data as follows:

*Parameter values are $\lambda_{ur} = 32$ Bps (Byte per second), $\lambda_m = 128$ Bps, and $\lambda_n = 512$ Bps.

Figure 8 shows the average delay for the three classes, which varies with increases in the number of body sensors. It shows that the average end-to-end delay of urgent packets is lower compared to medium and normal classes of packets. In addition, the delay increases with an increase in the number of nodes.

Figure 9 shows the end-to-end delay for the three classes varies with different service rates. It shows that the average end-to-end delay decreases as service rate increases, that is, end-to-end delay decreases for higher service rates. Also, the queue delay of urgent packets is lower compared to classes of medium and normal packets.

We also compared the proposed scheme to a classless, shortest path approach. Figure 10 shows that urgent, medium, and normal data have a smaller delay compared to the classless, shortest path, where the latter uses common queues for all data. The results indicate that a classless, shortest path approach has a longer delay compared to the proposed scheme that uses a different queue for every data type.

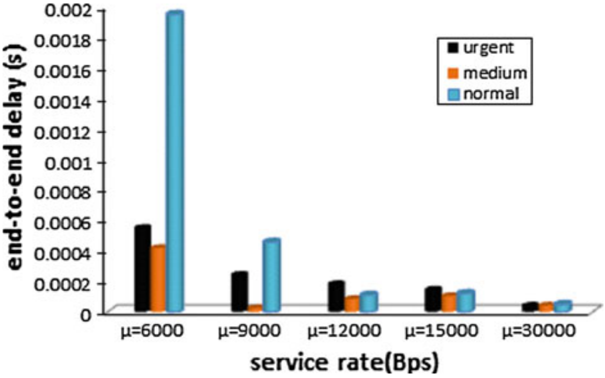

Fig. 9 End-to-end delay versus service rate

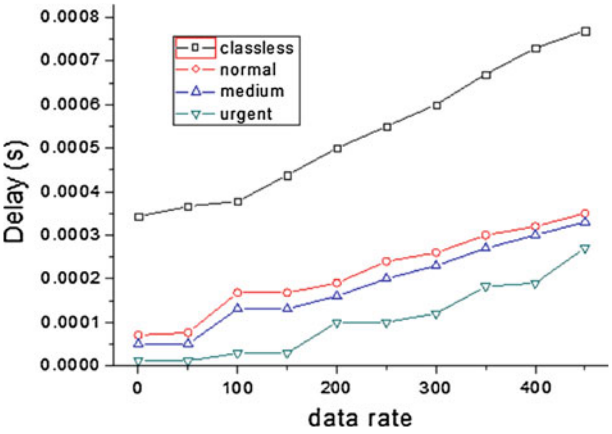

Fig. 10 Delay for the proposed scheme compared to a classless shortest path approach

4.2 Packet Loss Probability

This is defined as the probability that the number of packets in the queue is larger than the defined threshold queue length, i.e the queue overflow, where t_i represents the length of the queue. The probability, P_k, for the data of one of the three classes is given by

$$P_k = \frac{\lambda}{\mu^{t_i+1}}. \tag{21}$$

In Fig. 11, the probability of a tail for all classes increases when the arrival rate increases. In Fig. 12, it is shown that urgent data has the lowest loss, followed by medium and normal traffic. The last is classless traffic with the shortest path.

The above results show that our scheme with differentiated service quality performs better than without differentiated service in relation to low end-to-end delay and low packet loss for each traffic type.

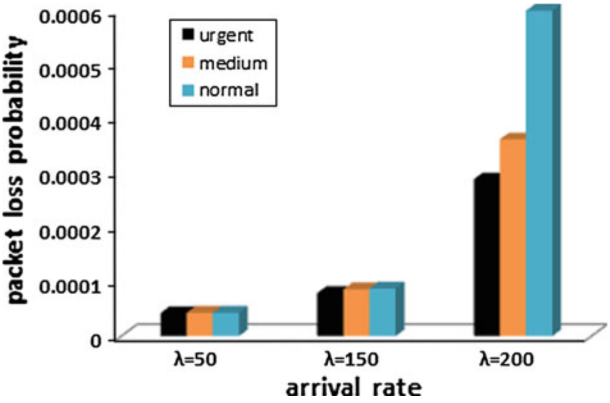

Fig. 11 Loss probability

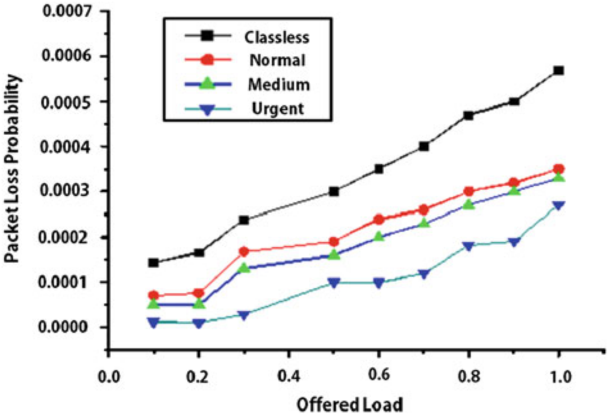

Fig. 12 Loss probability for the proposed scheme compared to a classless, shortest path approach

5 Conclusion and Future Work

Since the important data needs the high QoS, data loss must be minimized in WBAN. Here, we present the differentiation, traffic classification schemes, and traffic scheduling over multiple routes in WBAN. The work consists of two parts: in the first part we dynamically classified the patient data and assigned classes based on patient requirements. The sensed vital signs are classified and assigned different priorities based on the patient's disease and his or her current status.

The second part of the paper used multipath transmission-based scheduling to enhance reliable and timely data delivery.

The major novelty of this work rests on dynamically differentiating the patients into various classes based on their current requirements. This allows for quick data transmission based on assigned priority.

The performance evaluations of this method shows that our scheme provide low end-to-end delay and high reliability for critical data, thereby minimizing the loss probability of urgent data. For future work, more analysis and comparison with several existing approaches needs to be done. Also, consider other QoS parameters will be key way to maximize the performance.

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