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Schedule communication routing approach to maximize energy efficiency in wireless body sensor networks

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Abstract. E-Health allows you to supersede the central patient wireless healthcare system. Wireless Body Sensor Network (WBSN) is the first phase of the e-Health system. In this paper, we aim to understand e-Health architecture and configuration, and attempt to minimize energy consumption and latency in transmission routing protocols during restrictive latency in data delivery of WBSN phase. The goal is to concentrate on polling protocol to improve and optimize the routing time interval and schedule communication to reduce energy utilization. In this research, two types of network models routing protocols are proposed – elemental and clustering. The elemental model improves efficiency by using a polling protocol, and the clustering model is the extension of the elemental model that Destruct Supervised Decision Tree (DSDT) algorithm has been proposed to solve the time interval conflict transmission. The simulation study verifies that the proposed models deliver better performance than the existing BSN protocol for WBSN.

Keywords: Wireless Body Sensor Networks; e-Health; energy efficient routing protocol; polling protocol

1. Introduction

1.1 Overview of e-Health application

Traditional healthcare systems are designed and implemented to respond to symptoms or to manage medical conditions. Advances and wide acceptance of communication and information technologies has enabled the delivery of medical services over a distance, also known as telemedicine (Ko *et al.* 2010). Information and communication technologies have introduced changes in clinical practices, such as electronic medical records and healthcare information systems. Moreover, new developments in sensors, wearable computing, and communications has enabled wearable physiological monitoring, which can provide clinicians and users with tools and environments to gather physiological data over extended periods of time. Continuous monitoring can enable healthcare providers to focus on disease prevention and early intervention. Moreover, it can facilitate more efficient management of chronic conditions such as diabetes or heart failure.

e-Health enables wireless transfer of the medical information platform, where the patient's physical status is monitored and shared with others. e-Health can be defined as a medical information technology that allows doctors to perform medical consultations, diagnoses and analyses away from patients. Specifically, doctors and physicians can examine patients remotely by monitoring any sensation or change in bodily function that is experienced by patients with a particular disease, through sensors and sound devices, and gather physiological data over telecommunication.

As characteristic of e-Health, the patient is equipped with one or several medical sensors and wearable devices. These sensors are used for monitoring and recording the patient's physical status and forwarding that information to the medical server and, in necessary situations, to the emergency medical server. At the medical server, all monitored information such as pulse recording, heart and breathing rate, blood pressure and motion data ultimately exposes the patient's real-time situation by using special software (Ukil *et al.* 2015). Once an irregular signal has been noticed, doctors or nurses (physicians) may undertake additional activities for that specific patient. In practice, Electrocardiograph (ECG) signals perform a very significant role for the e-Health structure. Each part of an ECG record transmits substantial medical information (Ukil *et al*. 2015). One significant fact is that data error or loss is not accepted. Continuous and steady transfer of vital signals in the e-Health system is essential.

2. e-Health architecture

The idea of health monitoring is defined, in which an individual's health factors are routinely monitored at home without disturbing their daily activities. In the wireless healthcare framework, two parts of the traditional telemedicine systems, which used wired connections will be replaced by the wireless network connectivity. The first is a connection between medical peripheral devices, and the second is the connection between local aggregator that will

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collect patients' vital information through multiple medical peripheral, and an active phone line (Vazquez *et al.* 2015). By developing wireless networks, these two parts structures can be reconfigured.

The first is to employ wireless connectivity between the local base station of the telemedicine sensor and existing smartphone. In this configuration, the portability of telemedicine sensor will be enhanced to allow medical physicians to carry them to patients' homes and make medical consultations away from the telemedicine facilities. In this configuration, patients are comparatively free from the wires connected to the local main station, when within range of the radio transmission, they can easily move around without disturbing the data sampling. The routing connectivity will be established by IEEE 802.15.1 or IEEE 802.15.4 (Piette *et al.* 2012). The wireless transmission ranges will be shorter than Wireless Local Area Networks (WLAN).

The routing architecture of the e-Health application is divided into two phases:

Phase One: Wearable Physiological Sensors (WBSN Phase)

The first phase is mainly responsible for sampling the patient's vital signals. In this phase, wearable medical sensors, such as a wearable pulse oximeter, ECG sensor, and blood pressure sensor are used (Said and Tolba 2012). These vital sensors that are integrated with a mote continuously monitor the patient's physiological signals and transmit them in real-time to the local client devices, such as PDAs, which are integrated with the receiving mote. Basically, the local client devices are locally used by the medical practitioners. In addition, these wearable sensors have onboard memory, so that one practitioner can temporally store the Patient Care Record (PCR) and another practitioner can access these records when taking over the patient (AbuKhousa *et al.* 2012).

It is also responsible for data communications with the medical server or base station and the database at the hospital. One of the goals of phase one is to achieve the aggregate of data from the medical sensors, human manual input, flexible user interface configuration, and rule-based user input (Francis *et al*. 2015). Phase one usually deploys a variety of local client devices, such as PDAs and tablet or PCs, which run the personal server that is designed to achieve the aforementioned prospects and has a user-friendly interface that transacts physiological signals and communicates with the medical server (the base station).

The data transmission between physiologic sensors and the client devices relies on the short-range wireless local network connectivity such as IEEE 802.15.1 and IEEE 802.15.4, and this connectivity establishes the first routing data transmission (Ukil *et al*. 2015).

Phase Two: Aggregate Data Transmission Routing Protocol

To manage and aggregate patients' physiological records, a group of servers provide storage, access, backup and support in third level. This database contains patients' records and annotations of records, metadata and predefined medical rules (Said and Tolba, 2012) for automatic replies. It is designed to support effective storage, and each record contains specific information about a patient, type of sensors used to collect data, equipment expenditure for gathering data, and under which situation the information is recorded. Since wireless communication is made up by the WLANs, such as IEEE 802.11, the wireless access points must be within the range of the radio transmission. Alternatively, this wireless connection can be replaced by a Wireless Wide Area Network (WWAN). In this case, extra wireless network units, such as a modem or a particular PC card, are required to establish the WWAN connectivity. There also need to be companies to offer this connectivity.

The main goals of a wireless healthcare monitoring are nonstop monitoring of patients' physiology in their daily activity, processing of observed factors, providing a response to the patients if necessary, and transfer of data to healthcare providers. Wearable sensor may also include extra information, such as environmental factors' situations (e.g., temperature and humidity), to improve clarification of monitoring constraints. Based on the aforementioned aims, the architecture of an e-Health monitoring system is shown in Fig. 1.

The wearable sensors can be organized in various configurations depending on patients' condition, infrastructure and environment. For example, sensor monitoring, configuration of elderly persons in some nursing home or their own home is significantly different than the sensor configuration of patients or healthy persons for pulse monitoring of their daily activities.

Depending on the target population and deployment environment, infrastructure for wearable physiological monitoring can be deployed with several configurations. As an example, deployment configuration for wearable sensors of elderly persons in nursing homes, and deployment configuration for monitoring healthy individuals during their daily activity is significantly different. Even though a number of connectivity configurations are possible, Fig. 2 presents the most typical kind of configurations.

The first type of the configuration is shown in Fig. 2(a); the patient's data are collected by sensors and gathered on a portable personal device that transfers data to the medical server. There are extensive varieties of devices that can be used as a portable personal device such as smartphones, tablets and laptops. Smartphone is popularly preferred as the first choice, as nowadays its usage is increasing rapidly, apart from the fact that its affordability and improvement in performance and functionality make it an optimal solution. Furthermore, because of easy availability and popularity ofsmartphones, this structure is extensively accepted and popular.

In the second type of configuration, patient's sensors communicate with the gateway, and then the data is transmitted to the medicine server through the Internet. This configuration is illustrated in Fig. 2(b). This type is suitable for those patients who spend most of their time within the identified location in limited areas like home, hospital, or nursing home.

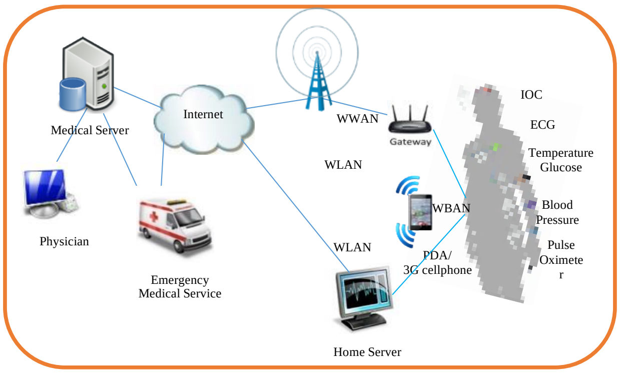

Fig. 1 Wireless healthcare (e-Health) system architecture

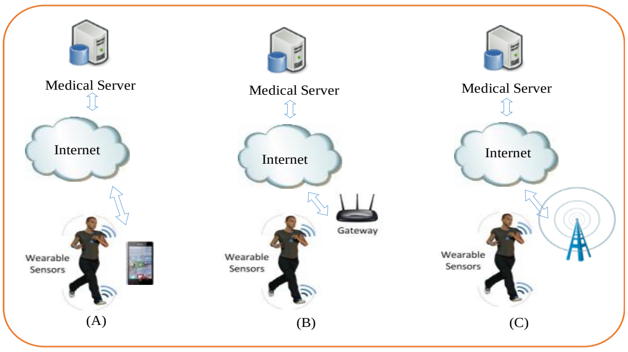

Fig. 2 Possible connectivity configuration of wearable sensor network

The third configuration is not like the other two structures, which require intermediary for connection between sensors and medical server. It communicates over the Internet directly with the medical server, as illustrated in Fig. 2(c). In this configuration, the sensors contain a modulator to send data directly. Necessary response from a physician is possible via a personal device, which receives data. This process is similar to sending messages to the patient's smartphone. Unfortunately, limited energy density of today's batteries and significant cost of communication over the cellular network are responsible for limited applicability of this configuration. However, with future technology advances, this configuration can be very successful.

Based on the routing phases of the e-Health application, the first level contains, one or more intelligent wearable sensor nodes, such as electrocardiogram, pulse oximeter, body temperature, blood pressure, intraocular pressure, acceleration, humidity, and atmospheric pressure. These vital sensor networks optimized for a particular continuously monitor the patient's health and physiological signals, body motion, and environmental situation; and transfer data in real-time to the patient's personal devices or gateway that is incorporated with receiving node. The network communicates with the clients' personal devices, which enclosed of a personal application, to send data to the medical server and receive necessary information or alarm from a physician. Moreover, sensor networks depend on a network coordinator to configure and manage the network nodes, and retrieve the data from the nodes.

The second level of communication is different and depends on the configuration of the sensor network. In a situation that sensors are connecting to the gateway, this level of communication happens when most of the patient's time is spent in a particular area; in such cases, this level contains the gateway that sends the data to the medical server. Thus, feedback alarm or communication from physicians is sent through SMS or call to the patient's smartphone. In the other configuration, this level contains the specific GUI applications running on the patient's personal device. The applications have a particular feature, such as user interface, data logging, data analysis, health parameters; data is retrieved from sensors, which includes patients' information status with a real-time feedback. Furthermore, these applications send the collected data from sensors to the medical server. In another configuration, when the patient uses the sensor network with GSM modulator, the retrieved data is sent directly to the server without intermediate device, and like the first configuration, in case of essential communication from physician's side, physicians' feedback is sent to the patients' smartphone.

In the e-Health application, discrete sensors have different characteristic functions, and mostly the sensors work in a heterogeneous architecture with various hardware proficiencies and structures. One of the most important considerations for heterogeneity data collection and data transmission to the base station is a communication protocol. Along with that potential activity, reliability could be different among sensors to reach to a particular convinced Quality of Service (QoS) in communication with minimum energy consumption. Consequently, the essential of Body Sensor Network architecture is a communication protocol that could deliver adequate quality with minimum energy utilization. In the following section, some basic techniques used in this research have been discussed.

3. Wireless body sensor network data transmission protocol

In the e-Health application, discrete sensors have some different characteristic functions, and mostly the sensors work in a heterogeneous architecture with various hardware proficiencies and structures. One of the most important considerations for heterogeneity data collection and data transmission to the base station is a communication protocol. Along with that potential activity, reliability could be different among sensors to reach to a particular convinced Quality of Service (QoS) in communication with minimum energy consumption. Consequently, the essential of Body Sensor Network (BSN) architecture is a communication protocol that could deliver adequate quality with minimum energy utilization. In the following section, some basic techniques used in this research have been discussed.

Most of the researchers are working on generic protocols data transmission, in terms of BSNs Medium

Access Control (MAC) protocols. Recently, some wireless healthcare systems have been established for elder care (Wood *et al*. 2008), patient monitoring (Ko *et al.* 2010, Fayn and Rubel 2010, Lee and Chung 2014, González *et al.* 2014), and disaster recovery (González *et al*. 2014, Tia *et al.* 2007, Chenji *et al.* 2013). The basic function that these systems support is monitoring vital signs. Some of the wireless medical systems support peer-to-peer communication (Jie *et al.* 2013, Chenji *et al.* 2013). Many e-Health systems use smartphones (Hwa-Chun et al., 2010, Yuechun and Ganz, 2004), 802.11 standards (González *et al*. 2014, Tia *et al.* 2007, Pawar *et al.* 2012), and 802.15.4 standards (Dor *et al.* 2012, Wood *et al*. 2008, Subramanya *et al*. 2013) for wireless monitoring method. The estimation of these systems naturally does not concentrate reliability, and usually performed at small scale in a laboratory. In different systems, different design decision must be made, and the effort must support real-time communication in network architecture with ability to handle patient mobility. Based on the study, along with the medium access mechanism, BSN data communication schedule has significant impact on energy consumption. Further, the schedule must consider parameters of WBSN such as number of sensors, resource availability of sensors, and required latency of the application.

Contention based protocols supports real-time communication through adapting of the CSMA/CA parameters such as contention window or initial back off, and works on probabilistic differentiation (Rambim *et al.* 2011, Wang 2013, Tran *et al.* 2011, Mur *et al.* 2012). To control the overload condition in contention-based rate, admission protocols have been proposed (Sarikaya *et al*. 2012, Han *et al*. 2010, Wan *et al*. 2011, Antoniou *et al*. 2013). However, contention-based approaches have drawbacks that make them inappropriate for high data rate and real-time applications. Due to random back off method, communication latency has high variability. Also, because of extreme channel conflicts, there are significant drops under heavy load.

A concept of the operation for selecting the most feasible value of a specific set of quantities or variables is known as optimization problem (Burger *et al.* 2014). The selected values satisfy assumed set of the firm requirements and specifications, which maximizes preferred efficiency and minimizes the cost. The convex optimization problem is a type of general optimization problem. Assigning a problem as a convex problem generally translates into ability to indicate problem efficiency. Several methods have been developed to solve convex optimization problem. Therefore, formulating a problem as a convex optimization problem indicates ability to clarify the problem efficiently. One type of optimization problem is geometric program, which is used in this research.

In natural form, the geometric problem (Burger *et al*. 2014) is not convex. Transformation of geometric problem to convex problem is provided in (Dor *et al.* 2012), as it is discovered best solution by using interior-point approach, so, there is no need to have initial guess of the result. In this research, the polling schedule protocol will be used to find optimal energy-efficient routing model, and the geometric problem has been used to model the problem of calculating optimal polling schedule for wearable sensor communication in the e-Health application. Polling protocols are already being used in body area network and provide good performance (Khan *et al.* 2012). Thus, the proposed model is accordingly developed for communication schedule as an optimal polling schedule protocol to minimize energy consumption and respected to BSNs potential activities. In this model, at particular time intervals, the base station sends inquiries to collect data, and with a powerful base station, even with the limited number of sensors, the required data report is collected. In this paper, the experiment spans e-Health application on personal area networks such as Bluetooth (IEEE 802.15), which delivers enhancement and better performance by implementing polling protocol to find ideal time-interval performance and minimizing energy consumption of sensors.

4. Network model

To design an optimal model for the e-Health network based on polling protocols, the following important parameters are considered for optimizing energy efficiency:

(a) *Utilizations of high respond sensors with optimized energy:* One of the notable facts in wearable sensors is their energy consumption. The selected BSNs for this research are the sensors with tiny battery size and less energy constraints.

(b) *Powerful gateway with rechargeable battery and solid connectivity:* The implemented sensors should utilize minimum battery and, on the other hand, they are a highly responsible device in the e-Health network communications; in this regard, a cellphone device is highly recommended. Again, due to the main idea of power saving in sensors, reducing the transmission distance is assumed. In this case, the goal is to utilize a high-power gateway with a high-response activity to establish asymmetric connectivity that limits sensors to consume the lowest energy transmission that they can, and give a high response to e-Health network.

(c) *Sensor architecture:* According to the e-Health functionality, which works on heterogeneous network, this is important to reach to a significant data collection by considering memory size (based on the power consumption), and also power capability.

(d) *Data collection:* Based on a specific time interval, every WBSN collects particular data and sends it to a gateway, and finally stores the data on the server. Relying on this data collection, it can be estimated that approximately how much data is going to be collected, and then take decisions about storage capacity and transfer rate.

(e) *Medical alert reporting:* This is to estimate irregular activity in the proposed model. However, alerts could be occasionally triggered, but should be reported up to the maximum 2 seconds.

Considering the aforementioned parameters, two types of networks are proposed. In the first one (elemental), sensors are connected directly to the base station, whereas in the second type (clustering), as the numbers of sensors are extended, all sensors communicate with the base station through the cluster head. The aim is to reach to the optimal and feasible solution to satisfy the sensitivity of an e-Health application.

Interval time based polling protocol is assumed for the body sensor networks. The data communication method of polling protocol is based on the time division, also consider a distance interval for communicating to the base station. All the notations are summarized in Table 1.

Every sensor is given time interval division, and data update time to polling, which is essential for the different number of distance time interval, and total set over the polling interval. To minimize the energy consumption of network model, two essential elements are considered. The first element is considering the alert of the system, which take place rarely. The report of alert is required for the acknowledgment and reaction of physicians. Second is reducing the idle status at the sensors by wake-up trigger mechanism, to moderate the long-time listening and keep sensors awake to the online mode.

The polling time intervals of the body sensors are between $P_1 ... P_n$ intervals. The data latency is dependent on sensors' data collection time interval and transfer data to the base station.

Data latency is defined as the time between data collection at the sensor and receipt by base station. So, the following problems must be considered in data transmission schedule:

Table 1 List of notations (WBSN)

Notification	Description	Notification	Description
SN	Sensors	**Dt**	Total Data Transmission
C	Clusters	**b**	Buffer between two Updates
LCH	Cluster Head	**EUb**	Energy Utilization
t	Distance Time Interval	**TC**	Total Cost
dt	Data communication	**wl**	Weight of Latency
Pi	Polling Interval	**We**	Weight assign to sensor energy utilization
TP	Total set of Ps	**DSDT Algorithm Factors**	
Alt	Alert of the system	**DS**	Data-Set
Piu	Upper time limit Polling Interval	**TPS**	Transition Probability Set
ds	Size of collected data	**L**	Label for output
Freq	Frequency	**A**	Attribute for input
Buff	Buffer Size	**P**	Number of entity in TPS
EO	Expense Operating (Overhead)	**BP**	Best-Pick
Tr	Data Transmission Rate	**ABP**	Chosen Attribute with minimum error

(1) The set of polling time interval must satisfy trade-off between data transmission latency and energy consumption. The method must be allowed to select between these two quantities and achieve a sufficient trade-off. (2) Discovering the optimum polling time interval that satisfies constraint parameters of sensors is a sensitive task. (3) Based on application requirements, sensor settings and parameters change over time. Therefore, changes to individual sensor parameters of polling schedule have been studied. The next sections discuss the design of proposed network models.

4.1 Network model type one (Elemental)

In the elemental model, all the sensors are connected directly to the base station. In this part, according to the physician requirements and based on data communication of the e-Health network, convex cost for particular BSNs specification is formulated.

Generally, according to the patient's health and condition of monitoring, the physician configures the interval time for data collection and updates P_i from sensors SN_i, and sets the upper time limit of communication P_{iu}. Optimal asset value is determined between the polling intervals of $P_1, ... P_n$, and is defined as follows

$$0 < P_i \le P_{iu} \,; \qquad i = 1 \, ... \, n \tag{1}$$

Throughout the time of polling P_i can define the size of collected data ds_i, based on different frequency $Freq_i$ and reach to two other factors. These two factors are the buffer size $Buff_i$ for each BSN that is required for each sensor to utilize gap of updates and expense operating *EO* that has all the issues such as synchronization, error correction, security and preliminary of overheads, and is defined as follows

$$(P_i \times Freq_i \times ds_i) \le Buff_i \times b_i \tag{2}$$

During the data collection, the base station must be informed about the empty buffer of each sensor, and also about the data transmission rates *Tr* and total of data transmission *Dt*, which is calculated as follows

$$(EO + P_i \times Freq_i \times ds_i) \le Dt \times Tr \tag{3}$$

Consequently, the complete number of interval times constructs the constrain structure, in which all time interval distance *t* is defined by the base station, and results in $1/t$ for a single time interval. Meanwhile, every sensor resided at $1/P_i$ polling interval, so for every distance period, there could be the maximum one sensor to link. With merging all the aforementioned scenario, formulation will be as follows

$$0 < P_i \; and$$
$$P_i \le \min\left(P_{iu}, \frac{Buff_i \times b_i}{Freq_i \times ds_i}, \frac{Dt \times Tr - EO}{Freq_i \times ds_i}\right); \tag{4}$$
$$i = 1, \dots, n$$

$$\sum_{i=1}^{n} \frac{1}{P_i} \le \frac{1}{t} \tag{5}$$

Based on the given Eqs. (2) and (3), it should be ensured that the buffer capacity between two updates is not full, which will result in an overflow and won't allow the sensor to communicate. In this regard, defining b_i to calculate buffer capacity between two updates is necessary. As it is calculated in Eq. (3), the energy utilization EUb_i for a sensor at the time of communication is the product of sensor frequency and data size in sensor and also multiplication of the polling interval, with the overhead added and divided by transmission rate.

Total cost *CT*, estimation is the summation of the energy consumption and the latency of sensors in transmission data. In this way, the related weight of latency wl_i is to indicate the priority of sensors to send their data, and also we_i is weight assign to the sensors during calculation of total energy utilization. The value of wl_i and we_i are between 0 and 1, which shows the most closely related weight value to the one that has the superior priority, and force energy, respectively. The associate value to energy and latency to show the related weight at the time of data collection as well as power consumption is α. Therefore, the total cost calculation is

$$\sum_{i=1}^{n} \frac{1CT = \sum_{i=1}^{n}\left(we_i \times \frac{EUb_i \times EO}{Tr} \times \frac{1}{P_i} + \alpha \times wl_i \times \frac{P_i}{2}\right)}{P_i} \le \frac{1}{t} \quad (6)$$

The network model is proposed to work with polling protocol in optimization problem. The total cost of energy consumption for each sensor will be formulated by using Eqs. (4)-(6). The result is shown in Eq. (7), as follows

$$CT_i = we_i \times \frac{EUb_i \times EO}{P_i \times Tr} + \alpha \times wl_i \times \frac{P_i}{2} \quad (7)$$

This value exposes sensors' cost of the total cost and function of individual sensor can be defined as the negative of this cost.

4.2 Network model type two (Clustering)

In the second type of the proposed network model, as the number of BSNs are extended, the cluster-head collects all the sensors' data and then transfers data to the base station. The assumption is that the sensors' connectivity to the base station is asymmetric. Suppose, if SN_i is a leaf node. At the duration of P_i seconds, it polls data, and all the leaves send their data to the cluster-head. The cluster-head in $P_i+1^{'th}$ interval communicates with the base station. The aggregations of data from multiple extensive sensors are through the particular cluster-head.

In this type of network, the cost function includes the complete power utilization and data latency for overall a body sensor network. However, the communication between the base station and sensors is through the chosen cluster-head. The appointed cluster-head has the duty of data management in the buffer and hand over of discrete buffers for sensors' data transaction. In this case, the resulted equation will be the same as Eq. (4); therefore, for the buffer part $Buff_i$ and the separation of sensors, data is forwarded by an additional polling distance interval to make it capable of communication with base station, which is concluded in following equation

$$0 < P_i \le P_{iu} - \mathrm{t}\,; \qquad i = 1 \dots n$$
$$P_i \le min\left(\frac{Buff_i \times b_i}{Freq_i \times ds_i} \times \frac{Dt \times Tr - EO}{Freq_i \times ds_i}\right) - t \quad (8)$$

Hence, the sensors' data transmission time intervals and polling protocol intervals must be same. These two parameters for the extension sensors could derived by merging the aforementioned related functions and give the following result

$$\sum_{i\in CT} \frac{1}{P_i} + \sum_{i\in CT} \frac{2}{P_i} \le \frac{1}{t} \quad (9)$$

The main dilemma for the second proposed network model is facing unfitting between the time interval and polling protocol. Suppose in the first batch of assigning the polling interval, (2, 4, 7, 10, …) slot number is given for a sensor, and the second batch gets the (1, 3, 4, 6, …) for another sensor. In such conditions, there will be time interval conflict to resolve. Generally, the solution, which is used for this condition, is to give the first priority to the first taken sensor, and the next sensor should again get the unassigned intervals. As the typical solution is not applicable for the body sensor networks due to their sensitivity and also energy consumptions, conversely, the proposed solution for conflicts is according to the calculation and managing the priorities.

The physician could define the sensors with highest priority according to the health status of the particular patient or a critical condition notification among sensors, which the most important monitoring part of the patient should indicate as the highest priority. For this new task, the individual order IO_i, function status *FS* should consider. The *FS=1*, if the data is abnormal or out of range, otherwise *FS=0*. Also, the availability of buffer and available energy for every BSNs is assumed. Based on the effectiveness of the parameters, the priority of every sensor SN_i and timing is estimated.

Available buffer *AB* at the time *t* is predictable by the base station, which has identified buffer size and sampling rate. Furthermore, sensors could state available energy *AE* from time to time. This feature is evaluated by proposing a method, called Destruct Supervised Decision Tree (DSDT) approach. This feature identifies the highest order to be the root, which is based on the right or left child, and every sensor finds its own priority.

In the first scenario, the power consumption is relayed on a communication between nodes to the base station, but in case of second scenario, the data collection from the child nodes to the cluster-head and transmit data to base station must be estimated. For this scenario evaluation, Eq. 10 is used, where TP_i is the particular element to calculate the energy consumption.

$$TP_i = \left(\frac{1}{P_i} \times EUb_i \times \left(\frac{P_i \times Freq_i \times ds_i + EO}{Tr}\right)\right)$$
$$= \left(\frac{EUb_i \times Freq_i \times ds_i}{Tr} + \frac{EUb_i \times EO}{Tr \times P_i}\right) \quad (10)$$

Eq. (10) can be rewritten as follows

$$TP = \left(\frac{1}{TP_i} \times \frac{EUb_i \times EO}{Tr}\right) \quad (11)$$

The cluster-head should receive all the data from child nodes with the aforementioned definition, and this process should take place for all child nodes connected to their particular cluster-head. This assumption can be denoted in the Destruct Supervised Decision Tree (DSDT) algorithm.

Decision tree has various applications, especially when a particular attribute is chosen, which could result in an even output (pair leaf). However, supervised learning is a machine learning task and technique to train certain data and label them for evaluation of the suitable predicted output result. The complete evaluation takes place when we assume that the hypothesis can lead the algorithm to a good estimation, even give predictions for unseen instances. The purpose of DSDT is to maximize the training data accuracy and, with reasonable techniques, implement hierarchical model and obtain distinct function.

Each decision for a single node from an input is divided into two leaves that continuously develop further branches recursively, until the optimum outcome is achieved. Nevertheless, the best tree is the one that keeps all the attributes and develops a tree relatively small.

The proposed DSDT is taking set of various attributes *{1… N}*. The function is computed and returns the label that is certain with most of the attributes from the training set under the main root.

Destruct Supervised Decision Tree (DSDT) Algorithm

DSDT (DS, A_i)
For set of Labels do
If L is a label for all elements of Data-Set (DS)
Return L as new child

For illustration of Labels in Data-Set do
\\ To choose attribute with minimum error within suitable time
P_L = Number of label entity in Transition Probability Set (TPS)

$$Entropy_L = -\sum_{L} P_L \log_2 P_L$$

$$BP_i = \sum_{i=1}^{A} P_i \ (Entropy_L \ for \ A_{BP} = i)$$

Return A_{BP} \\ Chosen attribute

For all elements in set of attributes
TPS = Set of Best-Pick chosen attribute A_{BP}

If TPS set is empty
Return generality A_i as new child
Else
Return (A_{BP}, DSDT (TPS, A_{BP1}),…, DSDT (TPS , A_{BPn})) as new child
End
End
End

Fig. 3 Destruct Supervised Decision Tree (DSDT) algorithm

Table 2 Energy consumption and performance time for tasks of sensor module platform

Task	Energy Consumption (mJ)	Performance Time (s)
Generate a Pulse	106.9	7.1
Filtering	52.4	3.5
Peak Detection	3.1	0.2
Calculation of Systole and Diastole Width	0.075	0.005
Normalize Average Beat	8.8	0.6
Ratio Calculation	4.7	0.3

The goal of this algorithm is to achieve a tree with the minimum error and that is only based on selecting suitable attributes in the algorithm at the suitable time. The main algorithm is developed, and by the core function, decision of the attribute selection is made. The goal of proposed DSDT algorithm is to find the highest priority.

The proposed DSDT algorithm considers various attributes, such as available buffer, available energy, individual order, function status, and frequency. Nevertheless, some parameters such as frequency, buffer size of nodes and data size do not distress the dynamic priority for a BSN. The rest of the features are arranged in descending order. Subsequently, critical situation of a patient, achieves the maximum rank status, whereas, the rest of influences can be arranged by the sensors' emphasis and specifications.

The tree will start developing with the first feature, and the importance of the sequential features is measured for the set of inconsistent BSNs until a distinctive priority BSN is recognized. Moreover, every leaf situation is found on an individual feature from the main root to a derived leaf. The outcome of a leaf has always two branches, and only one can be identified as the maximum. The data transmission in the proposed model is in convex optimization problem for optimum time scheduling, which proposed algorithm results in minimum time interval. This algorithm is shown in Fig. 3.

5. WBSN simulation study

An important performance metric in patients' vital signs monitoring is transmission energy, and data transmission is a main factor in sensors' energy consumption. Subsequently, transmission energy consumption is directly proportional to the size of data being transmitted, thus methods can use the density ration as an indication of reduction of transmission energy. To enable density of proposed models and compare the performance to the existing BSN scheme, a similar ratio for proposed model defined as

$$Density\ Ratio = \frac{Total\ Sensed\ Data}{Data\ transmitted\ by\ proposed\ model}$$

The function was implemented in MATLAB, and to calculate density ratio for a set of patients' vital signal the code ran for five different subjects, using 16 bits/sample, the total data is around 10 MB. The processing and feature calculation takes to occur once very 5 second. Implementation of the sensor module on existing sensor platforms has been done, and energy consumption and performance time has been investigated.

The data used for evaluation consist of data collected from 10 patients using wearable photoplethysmogram (PPG) sensor from Data.gov (Wei 2014, Ranck 2016) and PhysioNet (Silva and Moody 2014) databases. The signals of both databases are sampled at 125 Hz and buffer size is 5 second at sensors. The measure of performance time and energy consumption vales for each task are given in Table 2.

Based on typical clinical application datasets, heart rate, pulse height, systolic width and diastolic width considered for diagnostic features of wearable PPG sensor. The accuracy of the proposed model is calculated by comparing these features over time. The average of features' errors over all patients in the PhysioNet and Data.gov databases are shown in Table 3. The observation of errors is similar for both models, and result is within accepted limits.

Table 3 Energy consumption and performance time for tasks of sensor module platform

Task	Energy Consumption (mJ)	Performance Time (s)
Generate a Pulse	106.9	7.1
Filtering	52.4	3.5
Peak Detection	3.1	0.2
Calculation of Systole and Diastole Width	0.075	0.005
Normalize Average Beat	8.8	0.6
Ratio Calculation	4.7	0.3

Table 4 Average density ratio and features error for elemental and clustering model for PPG signals using PhysioNet and data.gov databases

Model	Database	Density Ratio	Percentage (%) of Features Error			
			Heart Rate	Pulse Height	Systole Width	Diastole Width
Elemenal for PPG	Data.gov	230.6	4.3	4.4	5.4	8.2
	PhysioNet	407	5.6	3.5	4.3	4.8
Clusterig for PPG	Data.gov	178.1	4.4	4.6	5.5	8.4
	PhysioNet	262.9	5.7	3.5	4.3	4.8

Table 5 Trade-off between density ratio or energy saving and features error for different threshold values

Threshold	Database	Density Ratio	Percentage (%) of Features Error			
			Heart Rate	Pulse Height	Systole Width	Diastole Width
Close	Data.gov	204.3	4.3	4.5	5.5	8.3
	PhysioNet	335.2	5.7	3.5	4.3	4.8
Average	Data.gov	430.1	6.1	4.6	5.8	8.2
	PhysioNet	985.6	6.4	4.1	4.5	6.1
Relax	Data.gov	980.7	9.7	4.9	6.7	8.5
	PhysioNet	2405.1	6.6	4.2	4.6	6.9

Table 6 Values of parameters performed in WBSN simulation

Variable	Value
n (No. of sensors)	10
Pi (Polling Interval)	1 Sec.
EO (Overhead)	120 bit
B (Buffer between two Updates)	0.6
Buff (Buffer Size)	[80, 16, 16, 16, 32, 48, 32,16, 32, 8] KB
Freq (Frequency)	[256, 20, 20, 20, 15, 256, 20, 128, 64,32] Hz
Ds (Size of collected data)	[4, 2, 2, 2, 2, 4, 1, 1, 4, 2] bytes
Wl (Weight of Latency)	1/8

The threshold values used in the sensor for deciding when to send feature updates or raw signal updates, and it can be sent during operation of the system or set a prior. Selecting *close* threshold values would lead to more frequent updates from sensors, and it reduces the features' error, but it increases energy consumption. However, selecting *relaxed* threshold values provides higher-energy conservation at the cost of increasing features error. This trade-off has been shown in Table 4 for two databases. As it has been presented, a density ratio as high as 2405.1 can be achieved at less than 10% features' error. By give a radio energy consumption of 0.05 mJ per sample, it reduces the power consumption from 6.25 mW to 2.6 μW, that makes the sensor to continue the support of proposed models.

To evaluate the performance of the proposed model and adjusting BSN model, the simulation study is performed by using the MATLAB simulation tools. In the simulation, the CVX package has been used to achieve convex optimization. The proposed model implemented on 10 body sensor networks to have a complete e-Health network for monitoring, simulating and optimization. These sensors are 1 EEG sensor, 1 IOP, 1 ECG, 3 accelerometers, 1 Temperature, 1 Glucose, 1 Blood Pressure and 1 Pulse Oximeter sensors. Table 5 shows the typical values for the assumed parameters and the sensor specification according to the TI CC2520 Zigbee datasheet.

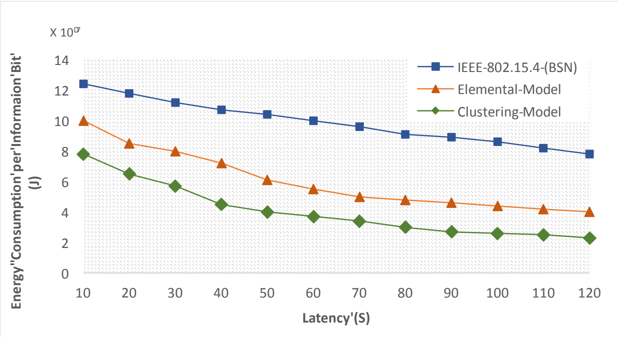

Fig. 4 Trade-off between energy consumption and latency of BSN model

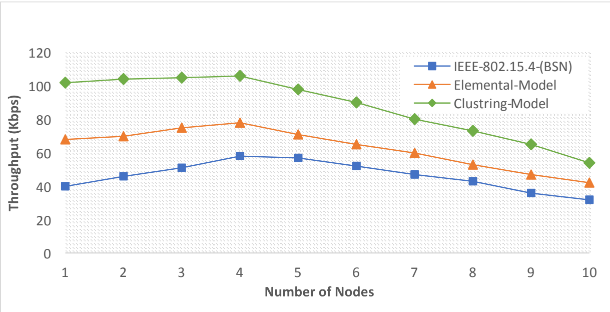

Fig. 5 Implementation of throughput per delivery packet in the number of nodes

The data and network model validate the feasibility of the constraint and control the estimate variables, which always helps to evaluate the feasibility of the model and get the optimal values at the time of implementation. In this case, initially without giving any value to α function and getting the zero value (if constrains are feasible the CVX returns zero value otherwise +Inf), showing the feasible constraint and values, required reformulation of the presumed values.

The configuration or parameters of each individual sensor may change dynamically based on patient health or application requirements through physician. Therefore, in the proposed model, with observe cost function (Eq. (6)) and it is increasing function of individual sensor cost. The only constraint that presents interdependence between sensors is Eq. (5). So, as long as Eq. (5) is satisfied for constraint the optimization problem can be solved for each sensor individually. Thus, changes to sensor parameters affect polling time interval P_i of the particular sensor and can be recalculated through simple 1-variable optimization problem. Therefore, the proposed convex model formulation was an effective and efficient polling schedule for elemental model in WBSN.

To investigate the rarely error, which is practically the result of rounding off the polling time interval P_i between distances, a minimum percentage should be considered. In this evaluation, an ordinary value of 0.97% per 100 simulations is resulted; average error up to 3% is generally acceptable.

The optimization problem is simulated for each sensor to find the polling time interval of the particular sensor; finally, total calculation based on the functions is verified the total problem functions, which shows the efficiency of this model and capability of simplifying the computation in case of changes in sensor parameters and constraints. However, the discrete value of each sensor setting could be altered based on the patients' health and situation and by the physicians.

Fig. 4, shows the optimization of models after running the simulation. The energy consumption becomes minimum in the trade-off of the latency. The higher priority becomes infected with decreasing energy consumption that influenced increase in latency. In the implementation of throughput that is shown in Fig. 5, the clustering model has better performance, where all peripheral nodes connect to the aggregator that has tolerance for high throughput. The elemental model in the both implementations, demonstrates better performance in comparison with the BSN model and support simplified routing. The proposed clustering routing model through proposed DSDT algorithm proves the premium performance of energy consumption and data throughput in compare to the BSNs and elemental routing.

6. Conclusions

In this paper, the routing architecture of the e-Health application is divided into two phases, and focus has been maintained on phase one, which is communication between sensors that are attached to the patients and the gateway or their PDA/smartphones. This phase known as Wireless Body Sensor Network (WBSN) phase and works on IEEE 802.15. A premium polling interval time schedule protocol has been established for wireless body sensor networks. Therefore, elemental and clustering network models have been developed, which consider the high response to sensors with optimized energy consumption and conflict-free data collection with consideration of medical alert reporting. The proposed DSDT algorithm will solve time interval schedule conflict in data transmission. The proposed routing models will have intelligent control over sensor operations for sensed data transmission, to improve the lifespan of body sensor network, and accurate schedule and alert detection of data monitoring.

The work developed as part of this research can be the basis of significant future research. Currently, the developed algorithms have been validated through simulation. The proposed protocols can be expanded and deployed as part of a real system. Another research topic can be understanding the correlation between the sampling rate and the accuracy of predicting a clinical deterioration for the patient monitoring in a hospital. It is also possible to add more sensors like breading rate to provide a valuable set of measurements.

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