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Energy-aware Peering Routing Protocol for indoor hospital Body Area Network Communication

Zahoor Khan[a],*, Nauman Aslam[b], Shyamala Sivakumar[c], William Phillips[d]

[a,d]Faculty of Engineering, Dalhousie University, Halifax, Canada
[c]Saint Mary's University, Halifax, Canada
[b]Northumbria University, UK

Abstract

The recent research in Body Area Networks (BAN) is focused on making its communication more reliable, energy efficient, secure, and to better utilize system resources. In this paper we propose a novel BAN network architecture for indoor hospital environments, and a new mechanism of peer discovery with routing table construction that helps to reduce network traffic load, energy consumption, and improves BAN reliability. We have performed extensive simulations in the Castalia simulation environment to show that our proposed protocol has better performance in terms of reduced BAN traffic load, increased number of successful packets received by nodes, reduced number of packets forwarded by intermediate nodes, and overall lower energy consumption compared to other protocols.

Keywords: Body Area Network, Hospital BAN communication, Peering framework, Energy-aware Peering Routing Protocol;

1. Introduction

The monitoring of physiological and biochemical parameters in the human body is very challenging for Wireless Sensor Networks (WSN). These challenges [1] include the high level of data reliability required for critical information, the small size of implantable nodes, access to nodes due to difficult sensor replacement, context awareness due to the sensitivity of body physiology, power supply to implanted sensors, and mobility of nodes. These challenges are addressed in the new sub-field of WSN known as Body Area Network (BAN).

The IEEE 802.15 Task Group 6 is working to develop a low power and low frequency short range communication standard protocol for BAN. The goal is to optimize BAN operations related to inside or outside of the human body but also to be compatible with other medical and consumer electronics devices [2]. Several projects such as SMART [3], CareNet [4], AID-N [5], and ALARM-NET [6] are proposed to monitor patient data. The goal of these projects is to collect and analyze BAN data. The general BAN architecture used in these projects is to send the data to the central database for monitoring. Also displaying in real-time BAN data in hospital environment is not addressed. Traffic congestion and database server or link failure can cause delay or stop displaying the patient's data which can affect the patient's treatment. The mobility of the patient in the hospital may require a change to the dedicated

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* Zahoor Khan. Tel.: +1-902-494-1876.
  E-mail address: Zahoor.Khan@dal.ca.

display unit used to display patient data. In order to resolve these problems, a new BAN network architecture and a routing protocol is required.

Our proposed BAN peering framework and routing protocol are designed to display in real-time BAN data, avoid a fully centralized system, and discover the dedicated BAN data display unit dynamically. Both centralized and distributed approaches are used in the proposed scheme. Only the central computer holds the information of BANs and display units which helps to improve privacy and better control BAN communication. The BAN data is displayed on the display unit in a distributed manner which reduces traffic load and helps to improve patient mobility.

The remaining part of the paper is organized as follows. Related work is discussed in section 2. The proposed BAN peering framework and Energy-aware Peering Routing protocol (EPR) are given in sections 3 and 4 respectively. Section 5 presents performance evaluation of the proposed BAN architecture and conclusions are presented in section 6.

2. Related Work

Typically, in BAN, the body implant and wearable sensors send their data to a central device known as the coordinator. The coordinator is a computationally more powerful device and behaves as a router in BAN networks. BAN communication factors include the combination of reliability, short range transmission, low data rate, less energy consumption, and noninterference. The current Personal Area Network (PAN) standards do not support BAN communication [8]. However the IEEE 802.15 task group 6 is working to develop a standard for BAN which should be compatible with the low transmission range of 3 meters, data rates of up to 10Kbps, and support for QoS [2].

To address the challenges related to the management of patients' medical information, an intelligent monitoring of BAN data in hospital environment is required [9]. The projects [3-4] use two communication tiers to send the data from body sensors to the web server or database server. Only outdoor BAN communication is considered in [5] which uses a GPS module. ALARM-NET [6] introduces an automatic monitoring system by using WSN. In [7], the store and display idea is to send the BAN data to the database and then from the database, the healthcare devices can be used to display it. The network architectures used in existing projects [3-7] consider only centralized approach for monitoring the patients' data. However, as mentioned previously no mechanism is provided for displaying the BAN data when there is no connectivity of healthcare system with the central database.

A routing protocol is required to implement our proposed BAN peering framework. In [10], a routing protocol is proposed in which different packet classes are handled differently depending on their QoS requirements. [10] considers BAN communication in which the next hops in the network are only BAN coordinators. The BAN environment in a hospital has different requirements including different device types as next hops. In [11], the proposed BAN network architecture explains the mechanism of combining or splitting a BAN in inter-BAN communication. It seems a reasonable idea for internetworking of BANs however it does not consider the real time display of BAN data in hospital environment. There are other ideas [12-19] for efficient routing in WSN but these do not consider the requirements of BAN communication in a hospital scenario.

3. Proposed BAN Peering Framework

A general BAN communication framework is shown in Fig. 1. It is a hierarchical model with three communication tiers [9]. In tier 1, the implanted and wearable sensors send data to the BAN coordinator. The possible next hop of a BAN coordinator can be any device shown in tier 2. The communication devices with the exception of BAN coordinator in tier 2 forward the BAN data to tier 3 communication devices. The two possible BAN communication scenarios are indoor and outdoor. The BAN in the hospital and at home are considered as indoor scenario. There are two kinds of communication, point-to-point and point-to-multipoint. Point-to-point (p-p) means the BAN coordinator sends data packets to the next hop for a single destination. Point-to-multipoint (p-mp) is when the BAN coordinator sends data packets to the next hops for multiple destinations.

The requirements of BAN communication in indoor-hospital environment are different from the

outdoor or indoor-home BAN communication. In the hospital environment, typically, every patient's BAN needs a Medical Display Coordinator (MDC) for displaying the patient's data. Normally this device is placed within 3 meters of BAN coordinator. For example, when a patient comes to the hospital in Emergency Room (ER) the BAN data is displayed on the MDC of the ER. Thereafter the patient may be transferred to the Operation Room (OR), Patient Room (PR), or Intensive Care Unit (ICU) for further treatment. It is now required to display the BAN data on the new MDC.
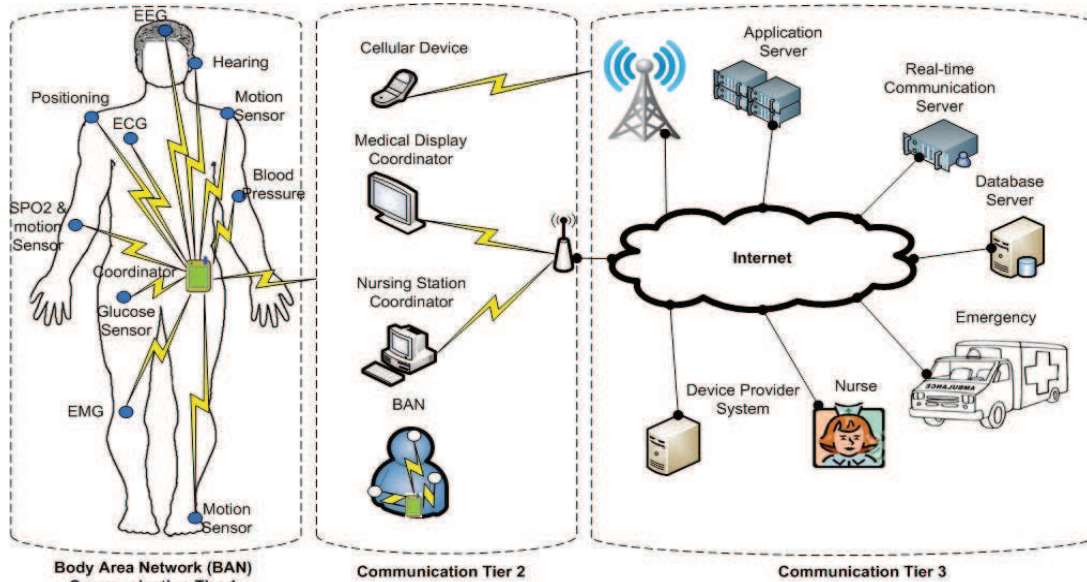

Fig. 1. BAN Communication System

As there are many MDCs in the hospital we need a mechanism to display in real time BAN data on the MDC dedicated to the patient. For this we propose a hybrid peering method. In this method the BAN will be peered with a display device (MDC). The BAN communication has two modes: centralized and distributed. In centralized mode, the BAN will connect to the Nursing Station Coordinator (NSC) to get the peering information and in the distributed mode it will discover and send data to its peer. The mechanism is explained below by considering the different possible communication scenarios.

3.1. Hospital BAN point-to-point Communication: In the hospital, initially the BAN communication is in a centralized mode and no data is displayed on any MDC. The BAN coordinator will try to connect to the Nursing Station Coordinator (NSC). The purpose of this connection is to obtain the information about its peer (MDC) and communication type (p-p or p-mp).

The NSC is a centralized system that holds the peering and communication information in its NSC peer table for all BANs in the hospital. By keeping this information on the NSC, the privacy of the data is ensured. The Nurse/operator is responsible for entering the peering (MDC) and communication (p-p or p-mp) information of BAN on the NSC. After getting the peering information from the NSC, the BAN coordinator will immediately switch to a distributed mode and will start searching for its peer. After discovering its peer MDC, the data will be displayed on the MDC. Each MDC is also connected with a wireless access point which can transfer patient data to tier 3 communication devices. As the communication type is p-p, the BAN coordinator sends data packets to its respective peer. Fig. 2(a) explains the process when BAN B_1 in steps 1 and 2 gets the information from NSC about its peer (i.e. MDC_1) and communication type (i.e. p-p). In step 3, the BAN coordinator will discover MDC_1 and display the data on it. The data from B_1 will always be displayed on MDC_1 even when B_1 moves away from MDC_1. The timing diagram of this process is shown in Fig. 2(b).
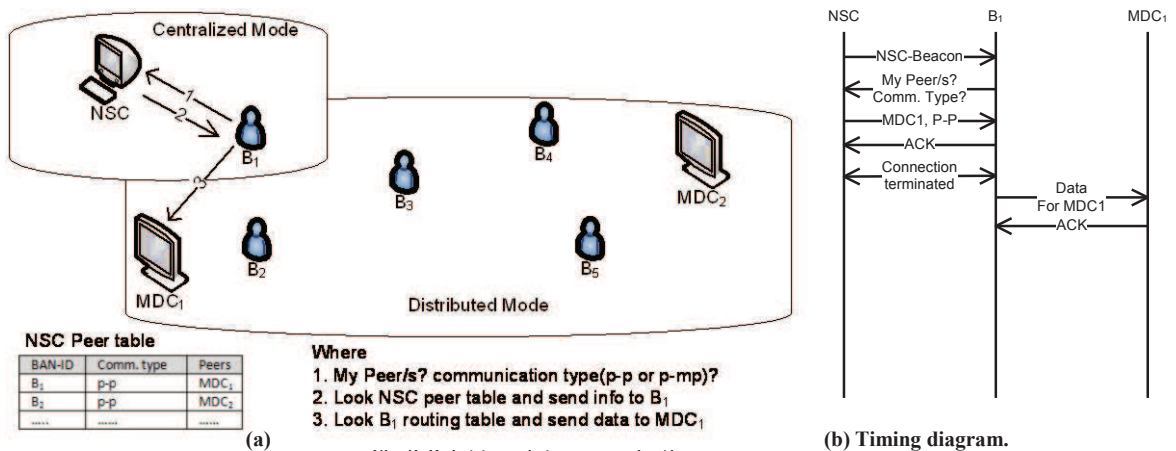
(a)

(b) Timing diagram.

Fig. 2. Point to point communication

3.2. Hospital BAN point-to-multipoint communication: In some cases we need to display the BAN data on more than one display unit. For example when a doctor wants to see the patient's data on his/her office MDC too, the nurse/operator needs to change the BANs communication type as p-mp, and the corresponding peers IDs in the NSC peer table. The BAN will now send two copies of data packets, one for each MDC.

3.3. Hospital BAN Peer Unreachable: When BAN is displaying its data on its peer MDC, and if the MDC is unreachable, the BAN will change its communication mode from distributed to centralized. This will immediately stop the BAN from sending data to the unreachable MDC and search for the NSC. The BAN coordinator will send a peer unreachable message to the NSC and again asks for peering information.

3.4. Hospital BAN Peer/communication type update: Another important case is when there is any change in the NSC peer table about BAN peering information, in such a case, the NSC sends a "peer update" message. On receiving this message, the BAN will immediately stop sending data to its peer(s) and switch to centralized mode. The BAN coordinator will query the NSC about the change. Upon reception of new peering information from the NSC, the BAN will switch to distributed mode and send the data to the new peer(s).

3.5. Hospital BAN NSC Unreachable: In centralized mode, the BAN connects with the NSC. If the NSC is unreachable then BAN coordinator will search for an alternate path to the geographically closest MDC. All MDCs and NSC are connected via Wi-Fi as shown in Fig 1.

4. Proposed Energy-aware Peering Routing Protocol (EPR)

   The proposed routing protocol is intended to be employed in the indoor hospital environment for BAN communication. The data-centric multi-objective QoS-aware routing protocol proposed in [10] is used to select the next hop node and forwards data packets by taking into consideration the QoS requirements of the data. The higher residual energy and geographic position were the two important factors used for choosing the downstream hop. Network traffic is differentiated into different classes including Ordinary Packets (OP), Critical Packets (CP), Reliability-driven Packets (RP), and Delay-driven Packets (DP) according to their generated data types. The reliability and delay control modules introduced in [10] result in better performance than several state-of-the-art approaches [12-19] in terms of lower bit error rates, traffic load, and operation energy overload. However, a disadvantage of [10] is that the method used for sending the Hello packets and creating the routing table results in increased network traffic, thereby increasing BAN energy consumption. In [10], every node broadcasts its Hello packets after a specific period of time. In this paper we address these shortcomings, by controlling for who broadcasts the Hello packets, when the Hello packets are broadcast, thereby reducing the number of Hello packets broadcast.

Unlike [10], only NSC and MDCs broadcast Hello packets periodically and the BAN broadcast the Hello packet only at the reception of Hello packets having the NSC or MDC information. The proposed methodology consists of three parts: 1) the new hello protocol, 2) neighbor table construction and 3) routing table creation based on the geographic and energy information in neighbor table. In our BAN peering framework, a BAN coordinator needs to have a connection with the NSC for getting its peering information, and a connection with the MDC as peer for displaying its data, as discussed in section 3. An indirectly connected BAN coordinator must use another BAN as its next hop only if the other BAN can help its transmission to reach the MDC or NSC. A BAN that does not have a connection to NSC or MDC will not broadcast its Hello packets, and any neighboring nodes will not consider such a BAN coordinator as its next hop. In the proposed Hello protocol, initially nodes do not broadcast any Hello packets. First the MDCs and NSC will broadcast their Hello packets to their neighboring nodes. Assume a node i that receives MDCs or NSC information in the Hello packet will create its neighbor table and routing table, and then start broadcast its own Hello packets. Node i will stop broadcasting Hello packets if it fails to receive Hello packet at any time, and remove all the entries from its neighbor and routing tables.

When considering energy levels of BAN devices, the devices used in our BAN network model can be divided in three types. The NSC is considered to be a type 1 device which is connected directly to the power source. The MDCs is considered to be a type 2 device which requires the replacement of its batteries periodically. The BAN coordinator is a type 3 device because of its limited energy availability. The device type, distance from neighbor to the node, and neighbor residual energy are important factors in building the routing table. The neighbor with shorter distance, lower device type, and higher residual energy is preferable as the next hop. The benefit of considering these factors is to balance the traffic load and energy consumption within the network. Our proposed energy-aware peering routing protocol is explained below.

4.1 Hello Protocol: We assume that each type 1 and type 2 device (NSC or MDCs) sends Hello packets periodically. The Hello packet fields of node j are shown in Fig. 3. The destination (Dst) can be a NSC or any MDC, or BANC. The Hello Packet contains information about the destination device ID (ID_{Dst}), destination location (L_{Dst}), sender's ID (ID_j), distance from sender node j to the destination ($D_{(j,Dst)}$), residual energy (E_j), and device type (T_j).

ID_{Dst}	L_{Dst}	ID_j	L_j	$D_{(j,Dst)}$	E_j	T_j

Fig. 3. The Hello packet format

The residual energy (E_j) is the remaining node j energy. The $D_{(j,Dst)}$ is calculated by using equation 1. Upon reception of the Hello packets from the node j, the receiver node i will store the information in its neighbor table for further processing. Moreover the node i adds its own information to the received Hello packet and broadcasts it. If the next Hello packet from the same sender is not received within a certain time period, it means the sender has moved away or has broken down. All the entries in the neighbor table associated with that sender will be deleted and the routing table will be updated.

$$D_{(j,Dst)} = \sqrt{(X_j - X_{Dst})^2 + (Y_j - Y_{Dst})^2} \qquad (1)$$

4.2 Neighbor Table: We assume that node j is the neighbor of node i which is located in between node i and destination node Dst. The neighbor table structure of node i is shown in Fig. 4. It contains the information about the destination device ID (ID_{Dst}), destination location (L_{Dst}), neighbor ID (ID_j), neighbor location (L_j), distance from neighbor to the destination ($D_{(j,Dst)}$), distance from neighbor ($D_{(i,j)}$), neighbor residual energy (E_j), neighbor device type (T_j) and communication cost (C_j).

ID_{Dst}	L_{Dst}	ID_j	L_j	$D_{(j,Dst)}$	$D_{(i,j)}$	E_j	T_j	C_j

Fig. 4. Neighbor Table structure

After receiving a hello packet, the node i's neighbor table constructor algorithm will compare the distance from neighbor to the destination (D_{Dst}(hp)) with the direct distance of node i to the destination

$D_{(i,Dst)}$. It will add a record if D_{Dst} from Hello packet is less than the distance between the node i to the destination i.e. $D_{Dst}(ht) < D_{(i,Dst)}$.

$$D_{(i,j)} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \qquad (2)$$

$$C_j = \frac{(T_j * D_{(i,j)}^2)}{E_j} \qquad (3)$$

The algorithm for Neighbor Table Constructor for node i is shown in Algorithm 1. We assume that node i receives a Hello packet from neighbor node j. The *hp* and *nt* used in this algorithm stand for hello packet and neighbor table respectively. X_i, Y_i represent the X, Y coordinates of node i. X_{DST}, Y_{DST} stand for the X, Y coordinates of the destination. The other fields of the neighbor table have the same meanings as in Hello packet. $D_{(i,j)}$ and C_j are calculated by using formula 2 and 3. The values of T_j, $D_{(i,j)}$ and E_j are used to find the communication cost (C_j). The shorter distance ($D_{(i,j)}$), lower device type (T_j), and higher residual energy (E_j) will generate a lower communication cost (C_j). The node j with lowest value of C_j is the best choice for next hop.

Algorithm 1 Neighbor Table Constructor Algorithm, at each node i.

INPUT: Hello Packet

1. $D_{(i,Dst)} = \sqrt{(X_i - X_{Dst})^2 + (Y_i - Y_{Dst})^2}$

2.   **if** $\left(D_{Dst}(ht) < D_{(i,Dst)}\right)$**then**

3.   (add a new record for the Dst's information in the neighbor table)

4. $ID_{Dst}(nt) \leftarrow ID_{Dst}(hp)$

5. $ID_j(nt) \leftarrow ID_j(hp)$

6. $L_j(nt) \leftarrow L_j(hp)$

7. $D_{(j,Dst)}(nt) \leftarrow D_{(j,Dst)}(hp)$

8. $E_j(nt) \leftarrow E_j(hp)$

9. $T_j(nt) \leftarrow T_j(hp)$

10. $D_{(i,j)}(nt) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$

11. $C_j(nt) = \frac{(T_j(nt) * D_{(i,j)}^2(nt))}{E_j(nt)}$

12.   end if

13.   (add a new record for the neighbor node j's information in the neighbor table)

14. $ID_{Dst}(nt) \leftarrow ID_{(Dst)}(hp)$

15. $ID_j(nt) \leftarrow ID_j(hp)$

16. $L_j(nt) \leftarrow L_j(hp)$

17. $D_{(j,Dst)}(nt) = 0$

18. $E_j(nt) \leftarrow E_j(hp)$

19. $T_j(nt) \leftarrow T_j(hp)$

20. $D_{(i,j)}(nt) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$

21. $C_j(nt) = \frac{(T_j(nt) * D_{(i,j)}^2(nt))}{E_j(nt)}$

4.3 Routing Table: There are many records in the neighbor table for the same destination. The novel routing table construction algorithm filters the neighbor table, and only chooses entry with the lowest communication cost. The routing table structure of node i is shown in Fig. 5. It contains destination ID (ID_{Dst}), destination location (L_{Dst}), and next hop (NH). As shown in algorithm 2, a new record is added in the routing table for each destination Dst $\in$ {MDC, NSC, BAN}. If the destination (Dst) and node i are

directly connected with each other, the next hop (NH) will be the destination ID (ID_{Dst}). Otherwise neighbor node j with the lowest communication cost (C_j) will be selected as next hop (NH).

ID_{Dst}	L_{Dst}	NH

Fig. 5. Routing Table structure

Algorithm 2 Routing Table Construction algorithm

INPUT: Neighbor table, i's neighbor table records $NH_{(i,Dst)}$, $\forall$ Dst $\in$ {MDC, NSC, BAN}

    1.   **for** each destination Dst $\in$ {NSC, MDC, BAN} **do**
    2.   **if** ($ID_j(nt) == ID_{Dst}(nt)$) **then**
    3.   (add a new record for the Dst's information in the routing table)
    4. $ID_{Dst} \leftarrow ID_{Dst}(nt)$
    5. $L_{Dst} \leftarrow L_{Dst}(nt)$
    6. $NH \leftarrow ID_{Dst}(nt)$
    7.   **else**
    8.   **if** ($C_j == min_{k \in NH_{(i,Dst)}} C_k$) **then**
    9.   (add a new record for the Dst's information in the routing table)
    10. $ID_{Dst} \leftarrow ID_{Dst}(nt)$
    11. $L_{Dst} \leftarrow L_j(nt)$
    12. $NH \leftarrow ID_j(nt)$
    13.   **end if**
    14.   **end if**
    15. **end for**

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5. Performance Evaluation

The performance of our proposed routing protocol is compared with the DMQoS routing protocol [10] using simulations performed in the Castalia-3.2 simulator [20]. The network parameters used in our simulations is shown in Table 1.

Table 1. Parameters information.

Deployment	Area	9 m X 9 m
	Deployment type	NSC and MDCs are fixed but BANs are movable
	Number of nodes	4 BANs, 3 MDCs, 1 NSC
	Initial nodes locations	NSC(0,1), MDC1 (0,5), MDC2(0,3), MDC3(1,3), B1(2,3), B2(3,5), B3(3,0), B4(6,3)
	Initial node energy	18720 J (= 2 AA batteries)
	Buffer size	32 packets
	Link layer trans. Rate	250 Kbps
	Transmit power	Different transmission powers ($-10dBm, -15dBm, -25dBm$)
	Reception power	7dBm
Task	Application type	Event $-$ driven
	Max. packet size	32 *Bytes*
	Traffic type	CBR (Constant Bit Rate)
MAC	IEEE 802.15.4	Default values
Simulation	Time	123 Seconds including 3s for nodes initialization

The total area used in DMQoS [10] is 2000m X 2000m = 4,000,000 m^2 and each coordinator is placed in 63.3m X 63.3m = 4000 m^2 which is not feasible for indoor-hospital environment considered in this paper. Typically, an MDC is placed within 3 meters of the patient's bed. We consider a typical hospital scenario where NSC, MDCs and BAN coordinators are used within an area of 9m X 9m = 81 m^2. The overall energy consumption during construction and update of the routing tables are shown in Table 2.

Table 2. Overall energy consumption during routing table construction

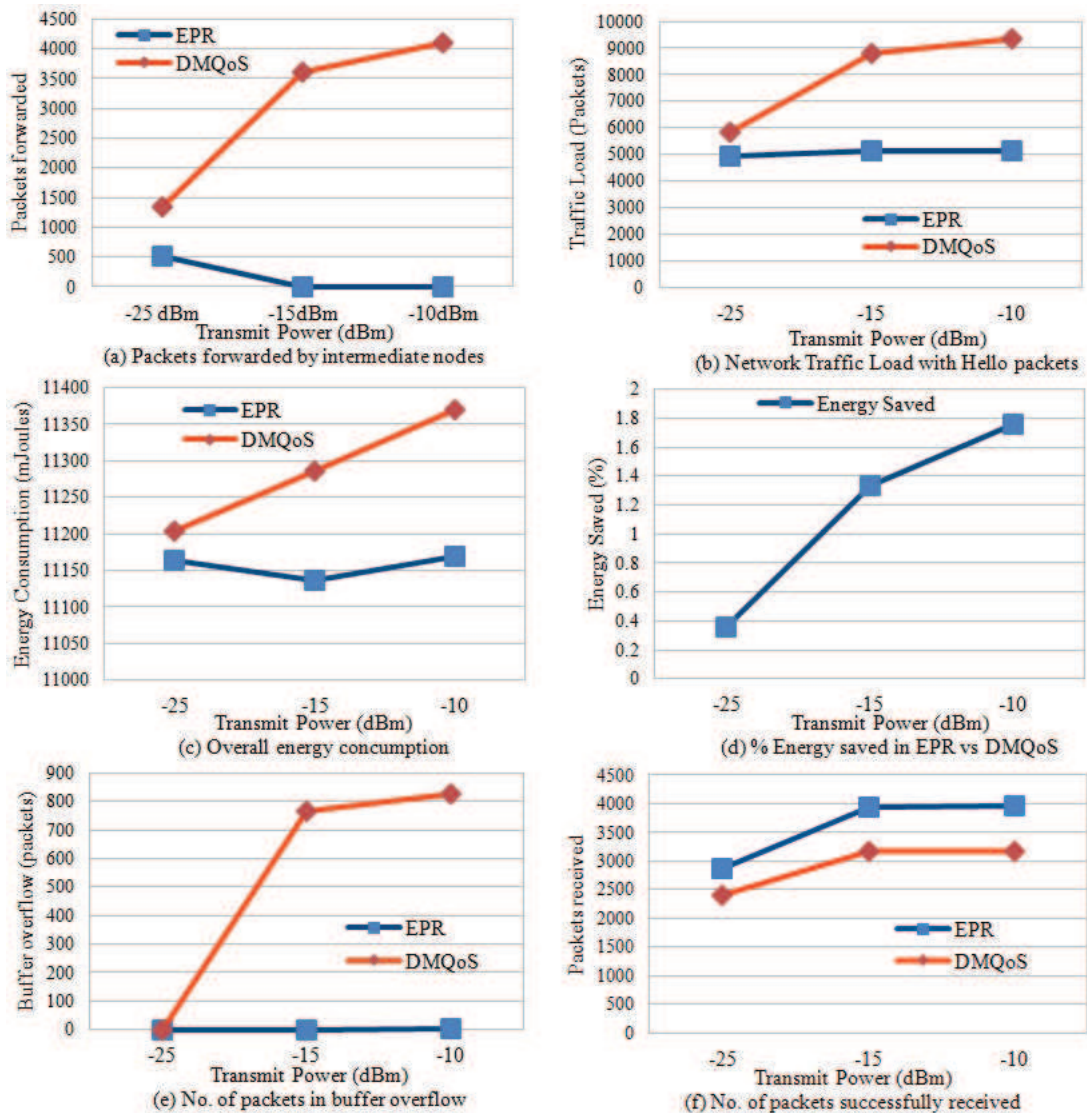| Transmit power (dBm)	EPR (mJ)	DMQoS (mJ)
-25	10930	10928
-15	11016	11013
-10	11033	11043

Fig. 6 Performance comparisons for different parameters

We used different values of transmit power i.e. -10dBm, -15dBm and -25 dBm in our simulations. Each BAN coordinator sends 1000 packets to the corresponding MDC or NSC. The deployment of the nodes is given in Table 1. B_1 is the closest node to the NSC or MDCs. In DMQoS [10], B_1 is responsible for forwarding the data packets from other nodes to NSC or MDCs. This results in more energy consumption for B_1 and increased congestion experienced by B_1. EPR resolves these problems by choosing the most appropriate next hop. In the proposed EPR scheme, the BAN coordinator does not send data to another BAN coordinator unless it is necessary. The BAN coordinators send the data packets directly to the destinations when the transmit power is -15dBm or higher. Some of the BANs must send the data packets to the destination through an intermediate node for transmit power less than -15dBm. Fig. 6a shows the number of packets forwarded by the intermediate nodes. Due to the reduced numbers of broadcast Hello packets and fewer data packets forwarded by intermediate nodes, results in reduced network traffic load

and overall energy consumption as shown in Fig. 6b and Fig. 6c respectively. Fig. 6d shows the percentage of energy saved in EPR versus DMQoS. The buffer overflow due to traffic congestion is negligible in EPR when compared to DMQoS as shown in Fig. 6e. The consequent reduction in overall reduced BAN traffic load increases the probability of successful data transmission. The amount of data packets received by the destination is shown in Fig. 6f. We observed that EPR delivered more packets successfully than DMQoS.

6. Conclusions

In this paper we have proposed a novel BAN network architecture for indoor hospital scenario, and a new Energy-aware Peering Routing protocol (EPR) which includes three parts 1) the new hello protocol, 2) neighbor table, and 3) routing table. The new Hello protocol, and the technique used to choose the next hop that considers residual energy and geographic information of the neighbor nodes, reduce the traffic load and energy consumption while increasing the number of packets successfully received by the destinations. We have performed extensive simulations in the Castalia simulator to test our protocol. The results show that for different transmit powers the EPR reduces average traffic load by 34%, and the number of packets received successfully by the destinations has increased on average 23%. The energy saved in EPR is on average 130mJ in 120 seconds. The results signify that our proposed protocol has better performance compared to similar protocols.

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