J Ambient Intell Human Comput
DOI 10.1007/s12652-013-0195-6

ORIGINAL RESEARCH

A new patient monitoring framework and Energy-aware Peering Routing Protocol (EPR) for Body Area Network communication

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Received: 10 December 2012 / Accepted: 17 May 2013

Abstract The recent research in Body Area Networks (BANs) 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 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. The three scenarios with fixed and variable number of packets sent by source nodes are considered for better analysis. Static nodes are considered in first and second scenarios whereas mobile nodes are used in third scenario. We have performed extensive simulations in the OMNeT++ based Castalia-3.2 simulation environment to show that our proposed protocol has better performance in terms of reduced BAN traffic load, increased successful transmission rate, reduced number of packets forwarded by intermediate nodes, no packets dropped due to buffer overflow, and overall lower energy consumption when compared with a similar protocols.

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Keywords Body Area Network · BAN · Hospital BAN communication · ZK-BAN · ZK-BAN peering framework · EPR · Energy-aware Peering Routing Protocol

1 Introduction

The monitoring of physiological and biochemical parameters in the human body using Wireless Sensor Networks (WSNs) is a challenging problem. Some of these challenges discussed in Ko et al. (2010) are high level of data reliability, 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 patient. 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 (IEEE 2007). Several projects such as SMART (Curtis et al. 2008), CareNet (Jiang et al. 2008), AID-N (Gao et al. 2007), and ALARM-NET (Wood et al. 2006) are proposed to monitor patient's 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. However, these projects have not addressed the displaying in real-time of BAN data in hospital environment. 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 of the dedicated 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 Zahoor Khan BAN (ZK-BAN) peering framework and routing protocol (EPR) 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. The central computer only holds the information of BANs and display units thereby improving privacy and helps better control on BAN communication. However, 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 Sect. 2. The proposed BAN peering framework (ZK-BAN) and the associated Energy-aware Peering Routing protocol (EPR) are given in Sects. 3 and 4 respectively. Section 5 presents performance evaluation of the proposed BAN architecture and conclusions are presented in Sect. 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 with other devices. The current Personal Area Network (PAN) standards do not support BAN communication (Zhen et al. 2011). However the IEEE 802.15 task group 6 is working to develop a standard for BAN which should be compatible with a low transmission range of 3 m, data rates of up to 10 Kbps, and support for QoS (IEEE 2007).

To address the challenges related to the management of patients' medical information, an intelligent monitoring of BAN data in hospital environment is required (Chen et al. 2010). Motion recognition using sensors in hospital environment is discussed in the literature (Ugolotti et al. 2013; Amoretti et al. 2013). Security-enhanced ambient assisted living supporting school activities during hospitalization is given in (Antón et al. 2012). The projects (Curtis et al. 2008; Jiang et al. 2008) use two communication tiers to send the data from body sensors to the web server or database server. SMART (Curtis et al. 2008) provides a monitoring system for indoor hospital environment but it only covers the emergency rooms. The patient data is displayed on the PDAs of the patient and healthcare professional. SMART (Curtis et al. 2008) is not implementable in the areas like ICU, ORs where highly sensitive equipment is used. This is due to the possible disturbances of high transmitting power devices, such as PDAs, on the highly sensitive hospital devices. IEEE 802.15.6 is newly proposed standard for BAN. The transmission range of BAN is 3 m. Our proposed BAN peering framework provides a solution for the whole hospital and it is compatible with BAN standard. Only outdoor BAN communication is considered in (Gao et al. 2007) which uses a GPS module. It uses the approach of first sending the data to the server and then the authenticated users analyze the patient data from the servers. The link or server failure can stop the monitoring process. On the other hand, our proposed monitoring system provides a real-time monitoring system in indoor (hospital) environment. ALARM-NET (Wood et al. 2006) introduces an automatic monitoring system by using WSN. ALARM-NET combines the environmental and wearable sensors to provide a solution of continuous monitoring for assisted-living and residential monitoring. Heterogeneous devices are used with the integration of mobile body networks, wireless environmental sensors, and IP-networks. The goal of this project (Wood et al. 2006) is to collect and analyze BAN data. The general BAN architecture used in this project is to send the data to the central database for monitoring. However the display of 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. Our proposed BAN peering framework emphasizes the real-time display of BAN data and discusses the different scenarios in hospital environment.

In Agarwal et al. (2010), the store and display idea is used 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 (Curtis et al. 2008; Jiang et al. 2008; Gao et al. 2007; Wood et al. 2006; Agarwal et al. 2010) consider only centralized approaches 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.

In Kim and Cho (2009), 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 (Chen et al. 2006, 2007, 2008, 2009; Liang et al. 2008; Huang and Fang 2008; Felemban et al. 2006; Razzaque et al. 2008) for efficient routing in WSN but these do not consider the requirements of BAN communication in a hospital scenario.

A routing protocol is required to implement our proposed BAN peering framework. In Razzaque et al. (2011), a routing protocol is proposed in which different packet classes are handled differently depending on their QoS requirements. Hello packets are used to broadcast the information of a node to its neighbor nodes. After receiving the Hello packets, a node updates its routing table with the help of the information received by Hello packets. However, a disadvantage of the method used for broadcasting the Hello packets increases network traffic which results in higher BAN energy consumption. The next hops considered by DMQoS in the BAN communication are only BAN Coordinators (BANCs) and every node broadcasts its Hello packets after a certain period of time. In a real BAN communication scenario, the next hop can be a different device like Nursing Station Computer (NSC), Medical Display Coordinator (MDC) or BANC. The features and requirements of NSC, MDC and BANC are different in a hospital environment. Our proposed routing protocol EPR addresses these shortcomings, with the consideration of all possible next hop devices (i.e. NSC, MDCs and BANCs) in the hospital environment, by controlling the broadcast of Hello packets.

3 Proposed BAN peering framework (ZK-BAN)

A general BAN communication framework is shown in Fig. 1. It is a hierarchical model with three communication tiers (Chen et al. 2010). 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 is considered to be an 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. In point-to-multipoint (p-mp), 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 m of BAN coordinator. For example, when a patient comes to the hospital's 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 then required to display the BAN data on the new MDC.

Due to the availability of 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 the centralized mode, the BAN will connect to the Nursing Station Coordinator (NSC) to obtain 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 Point-to-point communications in ZK-BAN

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. Figure 2a 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. 2b.

Three steps shown in Fig. 2a are given below.

1. My Peer(s)? Communication type (p-p or p-mp)?
2. Look NSC peer table and send info to B_1.
3. Look B_1 routing table and send data for MDC_1.

3.2 Point-to-multipoint communications in ZK-BAN

In some cases we need to display the BAN data on more than one display units. When a doctor wants to see the

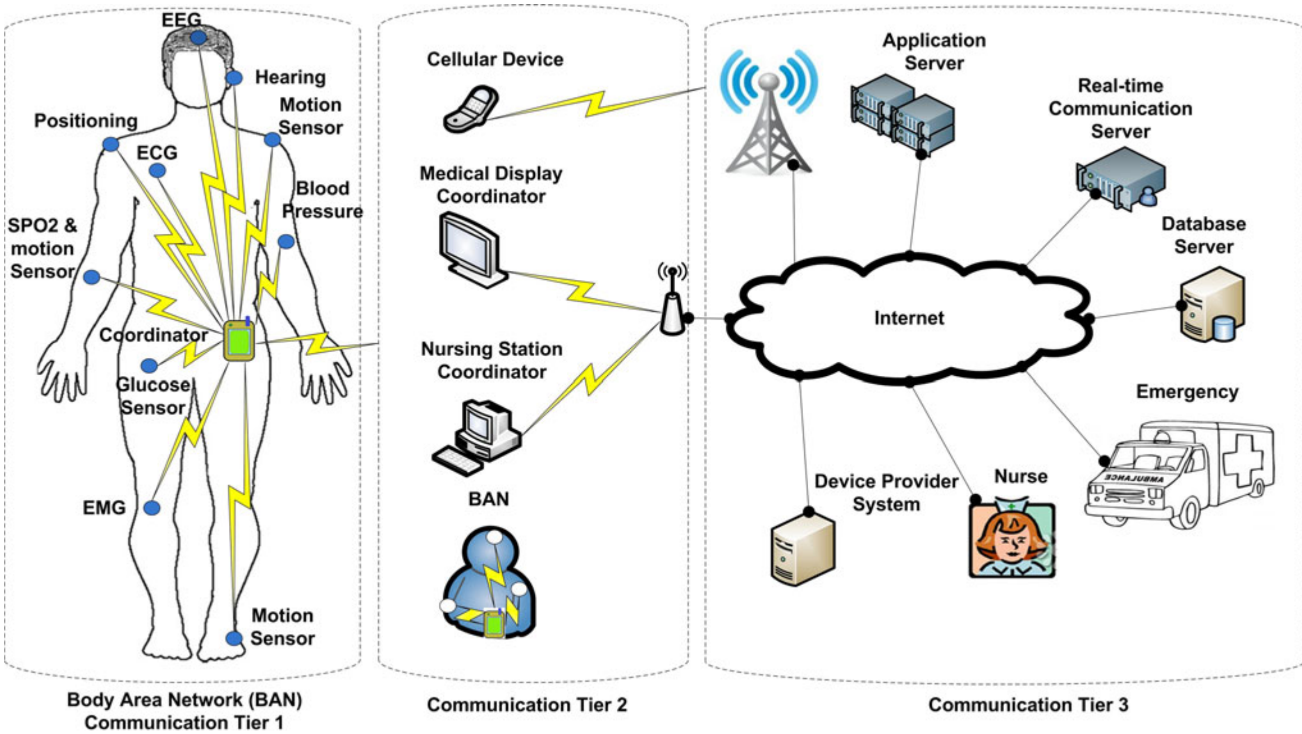

Fig. 1 BAN communication system

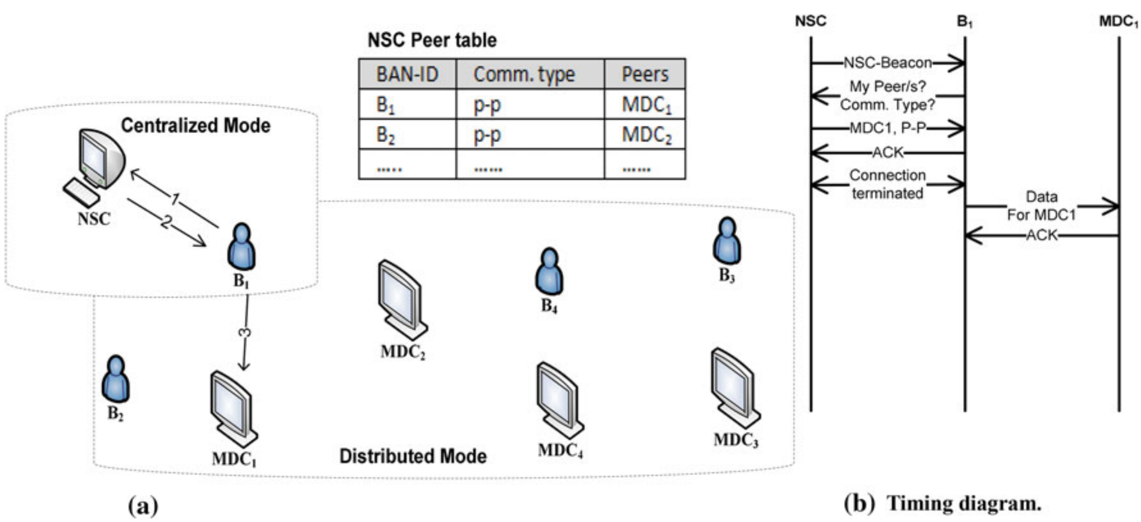

Fig. 2 Point-to-point communication

patient's data on his/her office MDC, we need p-mp as communication type and MDC_1 and MDC_2 as its peers. The operator should enter these changes in NSC. The B_1 will send two copies of data packets, one for MDC_1 and other for MDC_2. The below scenario explains it clearly. B_1 will first contact to NSC and gets information about its peers and communication type. It will then send two copies of data packets for both MDC_1 and MDC_2 after searching these peers. This process can summarize in three steps as shown in Fig. 3.

1. My Peer(s)? Communication type (p-p or p-mp)?
2. Look NSC peer table and send info to B_1.
3. Look B_1 routing table and send data for MDC_1, MDC_2.

3.3 Peer unreachable in ZK-BAN

When B_1 is displaying its data on its peer MDC1 and suddenly MDC_1 is unreachable, B_1 will change its mode to centralized from distributed. It will immediately stop sending the data to MDC_1 and search the NSC. After

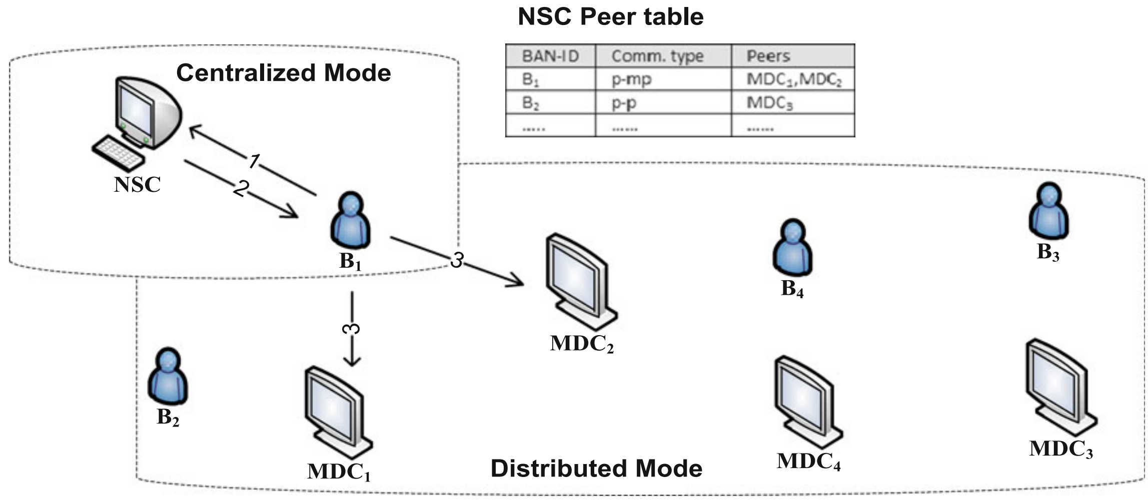

Fig. 3 Point-to-multipoint communication

getting connection with NSC, it will send peer unreachable message and again ask for peering information, as shown in Fig. 4 steps 2 and 3. B_1 will wait for new peering and communication information from NSC and will continue the process which is explained in Sects. 3.1 and 3.2. The three steps used in Fig. 4 are given below.

1. Look B_1 routing table and send data for MDC_1 if MDC_1 is not responding, switch to centralized mode.
2. Peer is unreachable, My Peer/s? Communication type (p-p or p-mp)?
3. Look NSC peer table and send info to B_1.

3.4 Peer/communication type update in ZK-BAN

Another important case is when there is any change on NSC peer table about the B_1 peering information then NSC sends a "peer update" message. After receiving this message, B_1 will immediately stop sending data to its peer(s) and change its mode to centralized. It will ask NSC about the change. After getting information from NSC, B_1 will terminate its connection from NSC and continue the process of displaying data on its peer. This process is summarized in below five steps as shown in Fig. 5.

1. Look B_1 routing table and send data for MDC_1. If NSC sends an update, B_1 will switch to centralized mode.
2. "Peer update" message from NSC to B_1.
3. My Peer/s? Communication type (p-p or p-mp)?
4. Look NSC peer table and info to B_1.
5. B_1 sends data to MDC_2 (new peer).

3.5 NSC unreachable in ZK-BAN

In centralized mode, the BAN connects with the NSC. If the NSC is unreachable then BAN coordinator will search

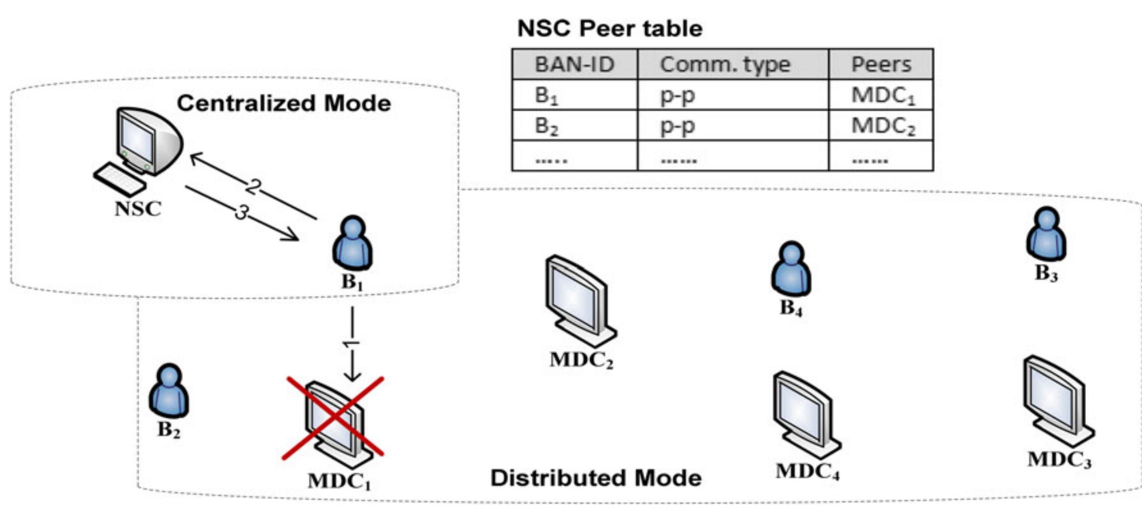

Fig. 4 BAN peer unreachable

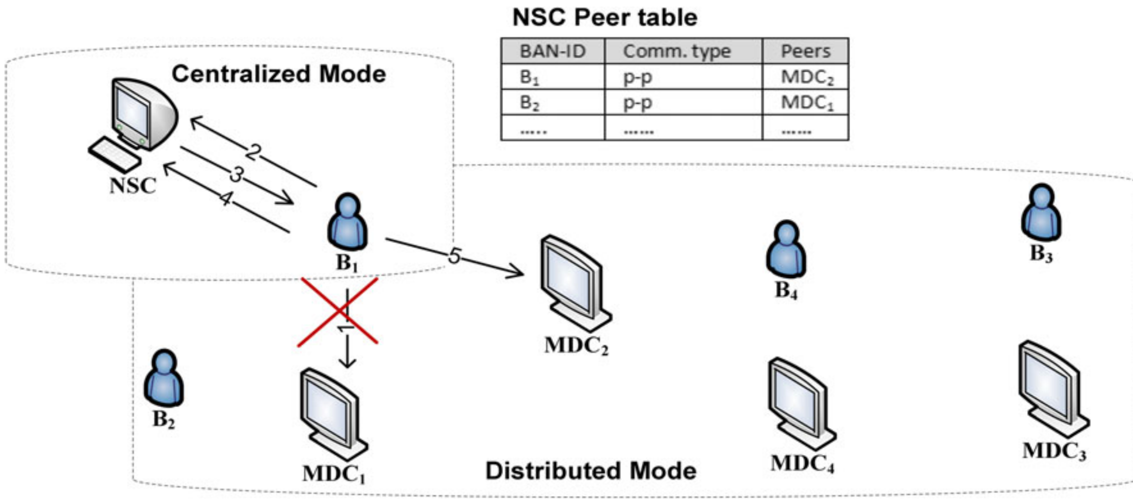

Fig. 5 Peer/communication type update

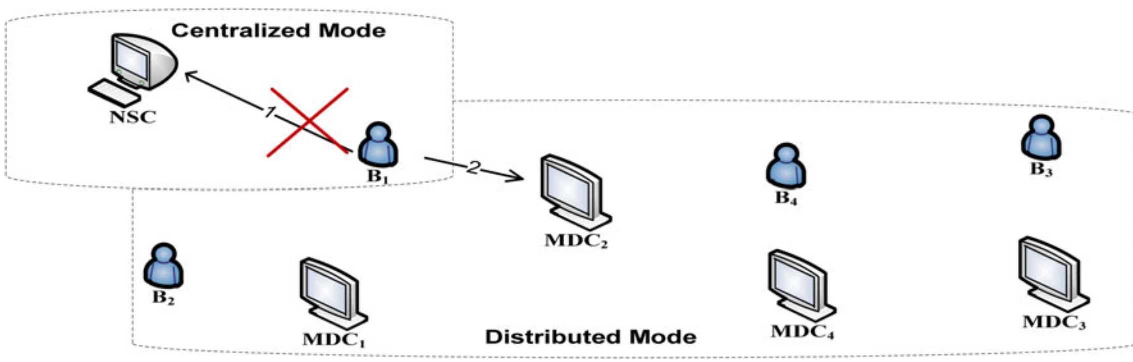

Fig. 6 NSC unreachable

for an alternate path to the geographically closest MDC. All MDCs and NSC are connected via Wi-Fi as shown in Fig. 1. BAN sends the NSC unreachable message to the central server.

The two steps shown in Fig. 6 are explained below.

1. B_1 sends data to the NSC. B_1 does not receive any response in case of if NSC is unreachable.
2. Look B_1 routing table and send data for NSC via closest MDC.

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 Razzaque et al. (2011) 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 (OPs), Critical Packets (CPs), Reliability-driven Packets (RPs), and Delay-driven Packets (DPs) according to their generated data types. The reliability and delay control modules introduced in Razzaque et al. (2011) result in better performance than several state-of-the-art approaches (Chen et al. 2006, 2007, 2008, 2009; Liang et al. 2008; Huang and Fang 2008; Felemban et al. 2006; Razzaque et al. 2008) in terms of lower bit error rates, traffic load, and operation energy overload. However, a disadvantage of (Razzaque et al. 2011) 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 Razzaque et al. (2011), the next hops considered in the BAN communication are only BAN coordinators and every node broadcasts its Hello packets after a specific period of time.

In reality, the BAN communication in a hospital environment has different requirements including different device types (i.e. NSC, MDC, BAN) as next hops. In this paper we address these shortcomings with the consideration of all possible devices (NSC, MDCs and BANs) in the hospital environment by controlling the broadcasts of the Hello packets. Our mechanism provides the details of who and when the Hello packets are broadcasted which results in reduced number of Hello packets broadcast. Unlike Razzaque et al. (2011), only NSC and MDCs broadcast Hello packets periodically and the BAN broadcast its Hello packet only at the reception of other nodes' Hello packets which contain the NSC or MDC information. The interval of Hello packets broadcasted by NSC or MDCs depends upon the probability of the new addition of BANs. For example, the new patients are coming more frequently in emergency room which demands lower amount of time between the broadcast of the Hello packets from NSC and MDCs. In our experiments, NSC and MDCs broadcast their Hello packets after every 30 s. 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 the neighbor table. In our BAN peering framework (ZK-BAN) as discussed in Sect. 3, 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. 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 to broadcast its own Hello packets. Node i will stop broadcasting Hello packets if it fails to receive Hello packet at any time, and removes 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) send Hello packets periodically. The Hello packet fields of node j are shown in Fig. 7. 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).

The residual energy (E_j) is the remaining node j energy. The $D_{(j,Dst)}$ is calculated by using Eq. (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.

$$D_{(j,Dst)} = \sqrt{\left(X_j - X_{Dst}\right) + \left(Y_j - Y_{Dst}\right)}. \tag{1}$$

4.2 Neighbor table construction algorithm

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. 8. 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	$D_{(j,Dst)}$	E_j	T_j

Fig. 7 The Hello packet format

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

Fig. 8 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. $D_{Dst}(ht) < D_{(j,Dst)}$.

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

$$C_j = \frac{\left(T_j \times D^2_{(i,j)}\right)}{E_j}. \tag{3}$$

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. It is assumed that the locations of NSC and MDCs are known. The values of X_i, and Y_i of the node i are calculated by the RSSI localization technique given in Xu et al. (2010). 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. The neighbor table constructor calculates the communication cost and updates the neighbor table periodically after receiving every new Hello packet.

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

INPUT: Hello Packet

$D_{(i,Dst)} = \sqrt{(X_i - X_{Dst})^2 + (Y_i - Y_{Dst})^2}$
  if $\left(D_{(j,Dst)}(hp) < D_{(i,Dst)}\right)$ **then**
    (add a new record for the Dst's information in the neighbor table)
    $ID_{Dst}(nt) \leftarrow ID_{Dst}(hp)$
    $ID_j(nt) \leftarrow ID_j(hp)$
    $L_j(nt) \leftarrow L_j(hp)$
    $D_{(j,Dst)}(nt) \leftarrow D_{(j,Dst)}(hp)$
    $E_j(nt) \leftarrow E_j(hp)$
    $T_j(nt) \leftarrow T_j(hp)$
    $D_{(i,j)}(nt) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$
    $C_j(nt) = \frac{(T_j\,(nt) * D^2_{(i,j)}(nt))}{E_j(nt)}$
  end if
(add a new record for the neighbor node j's information in the neighbor table)
    $ID_{Dst}(nt) \leftarrow ID_{(Dst)}(hp)$
    $ID_j(nt) \leftarrow ID_j(hp)$
    $L_j(nt) \leftarrow L_j(hp)$
    $D_{(j,Dst)}(nt) = 0$
    $E_j(nt) \leftarrow E_j(hp)$
    $T_j(nt) \leftarrow T_j(hp)$
    $D_{(i,j)}(nt) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$
    $C_j(nt) = \frac{(T_j\,(nt) * D^2_{(i,j)}(nt))}{E_j(nt)}$

4.3 Routing table construction algorithm

There are many records in the neighbor table for the same destination. The 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. 9. 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).

Algorithm 2 Routing Table Construction algorithm

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

for each destination Dst $\in$ {NSC, MDC, BAN} **do**
  if ($ID_j(nt) == ID_{Dst}(nt)$) **then**
    (add a new record for the Dst's information in the routing table)
    $ID_{Dst} \leftarrow ID_{Dst}(nt)$
    $L_{Dst} \leftarrow L_{Dst}(nt)$
    $NH \leftarrow ID_{Dst}(nt)$
  else
    if ($C_j == \min_{k \in NH_{(i,Dst)}} C_k$) **then**
      (add a new record for the Dst's information in the routing table)
      $ID_{Dst} \leftarrow ID_{Dst}(nt)$
      $L_{Dst} \leftarrow L_j(nt)$
      $NH \leftarrow ID_j(nt)$
    end if
  end if
end for

ID_{Dst}	L_{Dst}	NH

Fig. 9 Routing table structure

5 Performance evaluation

The performance of our proposed routing protocol is compared with the DMQoS routing protocol (Razzaque et al. 2011) using simulations performed in the OMNeT++ based Castalia-3.2 simulator (NICTA 2011). We also compared the performance of energy-aware based routing "EPR" with no energy-aware based routing "noRouting". In noRouting, the data packets are forwarded to random next hop devices instead of algorithm's next hop based on energy-aware routes. The comparison of EPR with noRouting is used to verify whether sending the packets to a random next hop device results in a better successful transmission rate than our proposed energy-aware routing protocol. The network parameters used in our simulations are shown in Table 1.

The total area used in DMQoS (Razzaque et al. 2011) is 2,000 m $\times$ 2,000 m = 4,000,000 m^2 and each coordinator is placed in 63.3 m $\times$ 63.3 m = 4,000 m^2 which is not feasible for indoor-hospital environment considered in this paper. Typically, an MDC is placed within 3 m of the patient's bed. We consider a typical hospital scenario in which NSC, MDCs and BAN coordinators are used within an area of 9 m $\times$ 9 m = 81 m^2. The overall energy consumption during construction and update of the routing tables are shown in Table 2.

We used different values of transmit power i.e. −10, −15 and −25 dBm in our simulations. Three scenarios are considered: in the first scenario a fixed number of packets are sent and all nodes are static, in the second and third scenarios a variable number of packets are sent. Scenario 3 is similar to scenario 2 but has movable BANs. The results are then observed and compared. We measure the successful transmission rate, buffer overflow, packets forwarded by intermediate nodes, traffic load, and overall energy consumption for the three scenarios by sending a fixed number of packets and a variable number of packets from 4 to 80 K range. The results of these scenarios are discussed below.

Scenario 1: In this case, each BAN coordinator sends 1,000 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 (Razzaque et al. 2011), 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. Figure 10a shows the number of packets forwarded by the intermediate nodes. It is seen from Fig. 10a that 332 data packets go through the intermediate nodes before reaching to the

Table 1 Parameters information

Deployment	
Area	9 m × 9 m
Deployment type	Case 1 and 2: All nodes are static
	Case 3: NSC and MDCs are fixed but BANs are movable
Number of nodes	4 BANs, 3 MDCs, 1 NSC
Initial node locations	NSC (0,1), MDC_1 (0,5), MDC_2 (0,3), MDC_3 (1,3), B_1 (2,3), B_2 (3,5), B_3 (3,0), B_4 (6,3)
Initial node energy	18720 J (=2 AA batteries)
Buffer size	32 packets
Link layer trans. rate	250 kbps
Transmit power	Different transmission power (−10, −15, −25 dBm)
Reception power	7 dBm
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	2003 Seconds including 3 s for nodes initialization (simulation results are the average of three rotations)

Table 2 Overall energy consumption during construction and update of the routing tables

Transmit power (dBm)	EPR (mJ)	DMQoS (mJ)
−25	10,930	10,928
−15	11,016	11,013
−10	11,033	11,043

destinations in EPR when the transmit power is −25 dBm. For transmit power of −15 and −10 dBm, there is no any packet which goes through the intermediate nodes in EPR because the destinations are in range due to the high transmit powers. In comparison, there are 2,526, 3,922, and 3,849 packets forwarded by intermediate nodes in DMQoS for the transmit powers of −25, −15, and −10 dBm respectively. The packets forwarded by intermediate nodes in noRouting are 4,553, 6,497, and 6,838 for transmit powers of −25, −15, and −10 dBm respectively. Due to the reduced numbers of broadcast Hello packets and fewer data packets forwarded by intermediate nodes, EPR results in reduced network traffic load and overall energy consumption as shown in Fig. 10b and c respectively. Figure 10b shows that the traffic load reduction in EPR as compared to DMQoS is 40, 47, and 47 % when the transmit power is −25, −15, and −10 dBm respectively.

The network traffic load in noRouting is almost double than the EPR for all three transmit powers. The saved energy by all nodes in EPR is 93, 201 and 216 mJ for the transmit power of −25, −15 and −10 dBm respectively as shown in Fig. 10d. The buffer overflow due to traffic congestion is negligible in EPR when compared to DMQoS and noRouting as shown in Fig. 10e. 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 (i.e. successful transmission rate) is shown in Fig. 10f. The successful transmission rate in EPR as compared to DMQoS is increased by 6, 11 and 13 % when the transmit power is −25, −15 and −10 dBm respectively. EPR delivers 19, 40, and 39 % more packets than noRouting for transmit power of −25, −15, and −10 dBm respectively. We observed that EPR delivered more packets successfully than DMQoS and noRouting.

Scenario 2: The devices (BANs) B_1, B_2, B_3, and B_4 are considered as source nodes and devices (NSC and MDCs) are the destination nodes. B_1 sends packets to MDC_1, B_2 sends packets to MDC_2, B_3 sends packets to MDC_3, and B_4 sends packets to NSC. The data of B_4 has to go through the other devices to reach NSC. The source nodes send a total of 80 K packets. The successful transmission rate, buffer overflow, packets forwarded by intermediate nodes, traffic load, and overall energy consumption are calculated after every 4,000 packets until 28 K are transmitted and thereafter when 40, 60, and 80 K packets are sent by all BANs. Figure 11 shows that the EPR provides better results of the successful transmission rate for all the three transmit powers i.e. −25, −15, and −10 dBm.

From Fig. 11a it is observed that for low transmit power of −25 dBm, EPR maintain its throughput from 67 to 76 % whereas DMQoS provides throughput from 61 to 67 % and noRouting has 47–51 %. When transmit power is −15 and −10 dBm, as shown in Figs. 11b and c, EPR provides consistently successful transmission rate of 95 %. Whereas DMQoS has a successful transmission rate ranging from 83 to 88 % and 82 to 88 % for the transmit power of −15 and −10 dBm, respectively. The successful transmission rate of noRouting is 56–66 % for both transmit powers (i.e. −15 and −10 dBm).

Figure 12 shows the number of packets forwarded by intermediate nodes. In EPR protocol, when the transmit power is −25 dBm and for 4–80 K packets sent from source nodes, 332–7,843 packets are forwarded by the intermediate nodes. In comparison, the intermediate nodes in DMQoS and noRouting forward 2.5–55.5 and 4.5–97.7 K packets respectively as shown in Fig. 12a.

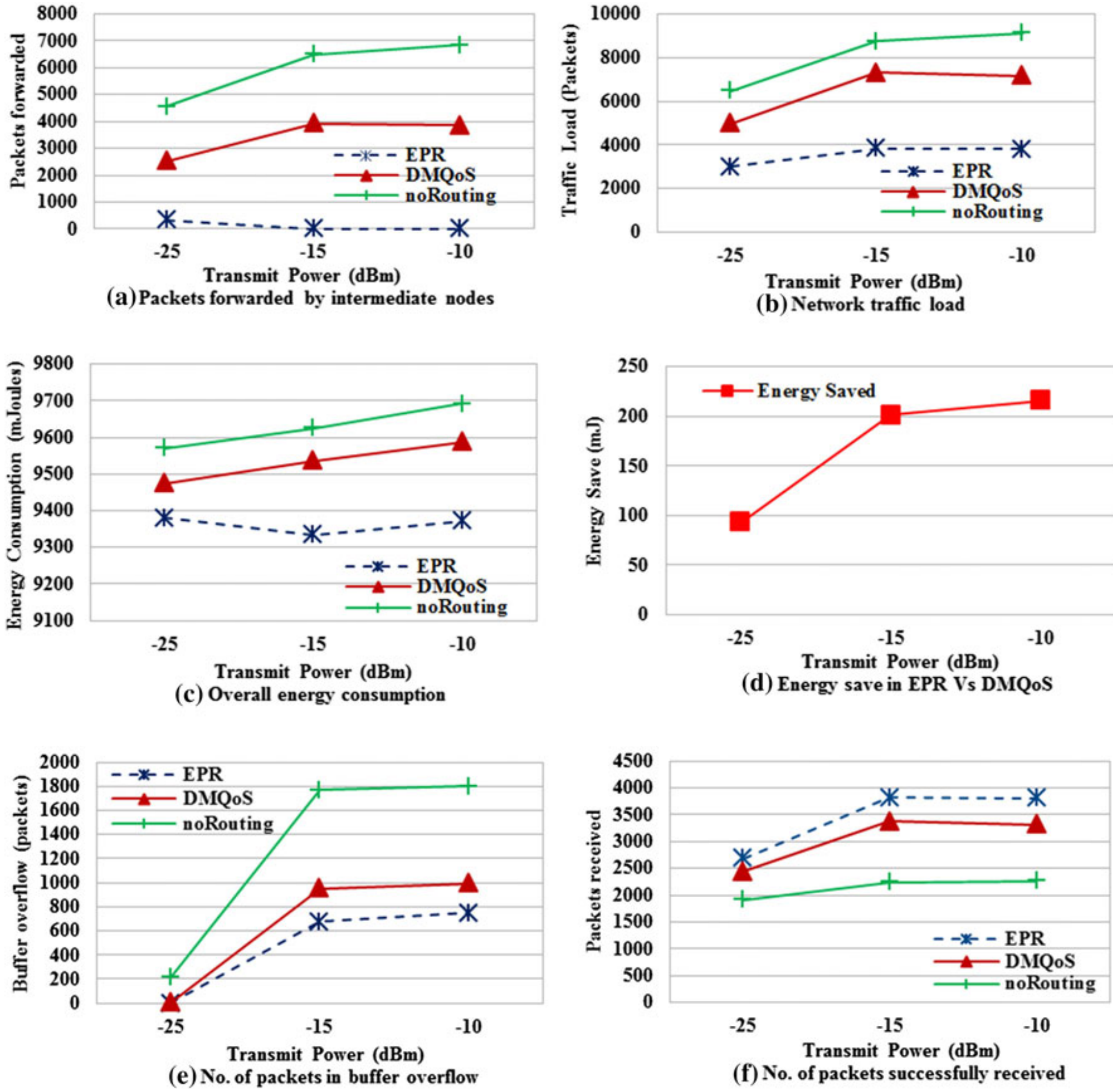

Fig. 10 Performance comparisons for different parameters

Unlike DMQoS (Razzaque et al. 2011) which sends the data to the closest neighbor node, EPR chooses the most appropriate next hop. The BAN coordinator in the proposed EPR sends data to another BAN coordinator only if it is necessary. The BAN coordinators send the data packets directly to the destinations when the transmit power is −15 dBm or higher. Figure 12b and c show that the number of packets forwarded by intermediate nodes in EPR is zero as compared to DMQoS and noRouting in which the intermediate nodes forward 4–87 K and 6.5–160 K packets respectively, for the same 4–80 K packets sent by the source nodes. Some of the BANs must send the data packets to the destination through an intermediate node for transmit power less than −15 dBm. The exchange of Hello packets is used to update the routing table of the nodes. The number of Hello packets and the number of packets forwarded by the intermediate nodes effect the total network traffic load. The mechanism of EPR reduces the number of Hello packets and data packets forwarded by intermediate nodes which results in lower traffic load than DMQoS as shown in Fig. 13.

For 80 K packets, EPR generates about 37, 52 and 52 % less network traffic when transmit powers of −25, −15 and −10 dBm are used respectively, compared to DMQoS. The network traffic load generated by noRouting is more than double of EPR generated traffic load for all transmit powers. Figure 13a compares the performance of EPR and DMQoS in terms of traffic load. It is seen that EPR has a 0–27 % lower traffic load for the low to high offered traffic when the transmit power is −25 dBm. Due to the lower transmit power; more data packets need to go through the intermediate nodes before reaches to destination node.

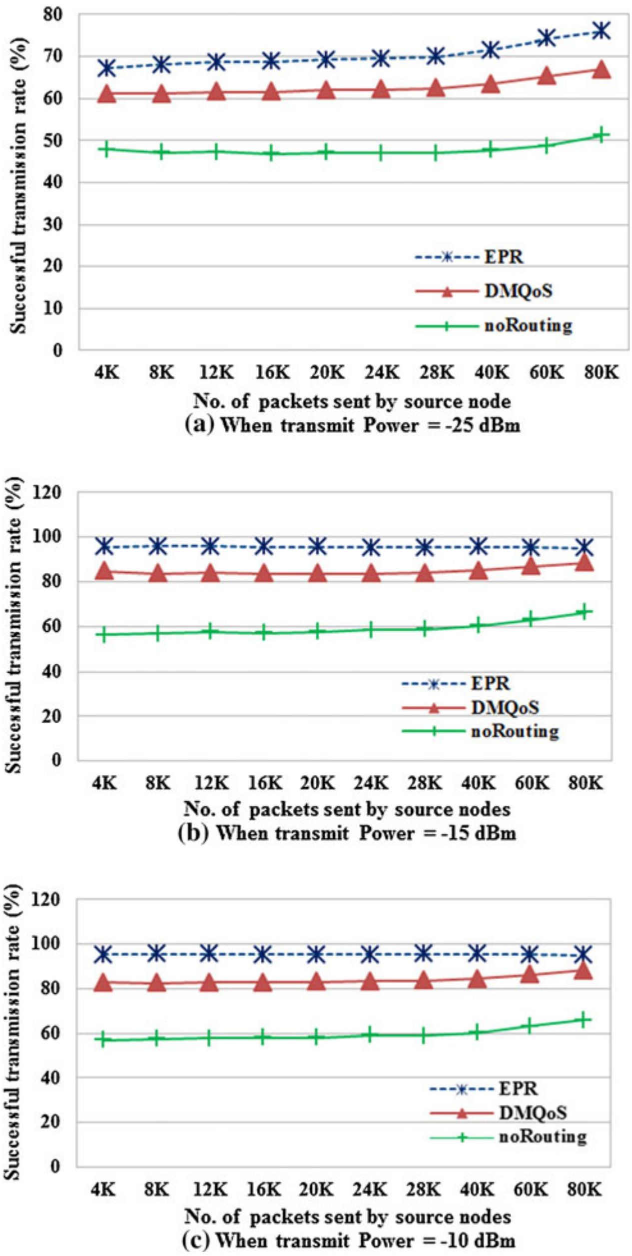

Fig. 11 Successful transmission rates as a function of offered traffic

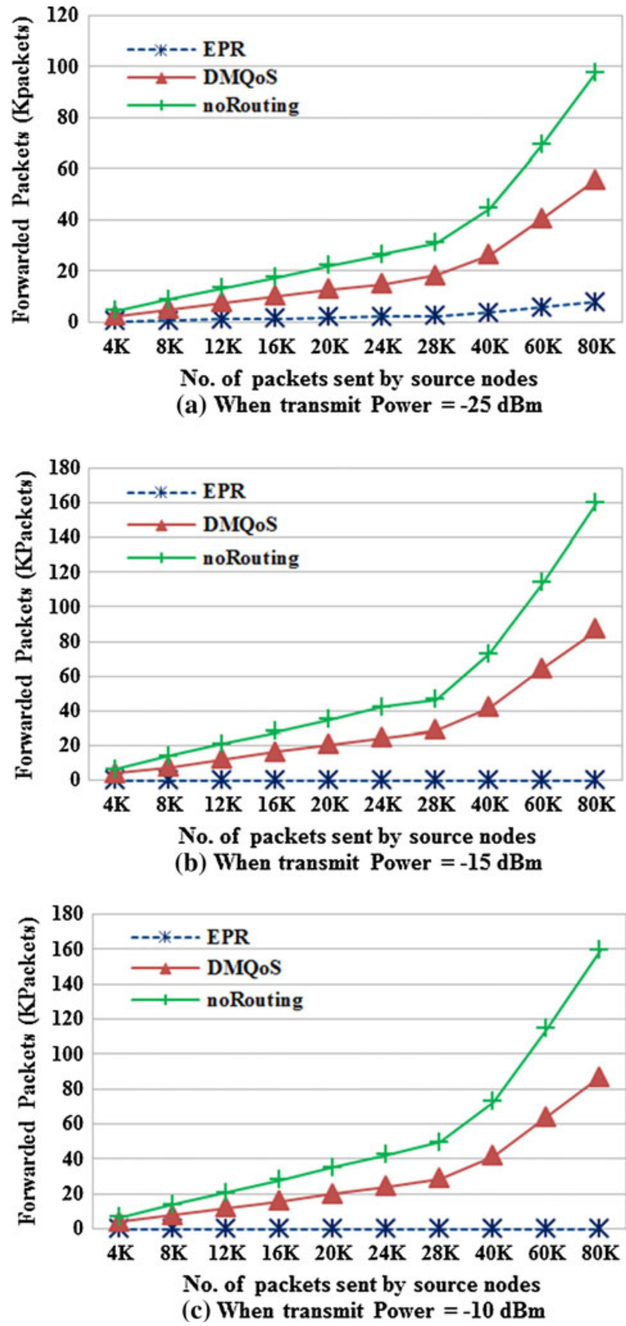

Fig. 12 Packets forwarded by intermediate nodes as a function of offered traffic

Figure 13b and c show that EPR consistently reduces the network traffic by 52 % for all offered traffic when the transmit powers are −15 and −10 dBm.

The buffer overflow as a function of offered traffic is shown in Fig. 14. The Figs. 14a shows that there is no buffer overflow in EPR for all transmit powers. DMQoS performs well for transmit power of −25 dBm by not having any buffer overflow. However, for high transmit powers of −15 and −10 dBm, due to the traffic congestion, MAC buffer overflow causes 0.7–22 K packets to be dropped in EPR and 0.9–15 K packets dropped in DMQoS as shown in Figs. 14b and c. EPR drops 16–38 % less packets than DMQoS for low to medium–high traffic load. The packets dropped in noRouting are very high for all transmit powers. EPR performs well in terms of packets dropped for low transmit power. The recommended transmit power of BAN nodes in hospital environment is −25 dBm.

Scenario 3: In this scenario, the source node B_4 is moving at the speed of 1 m/s vertically. The successful transmission rate, forwarded packets by intermediate

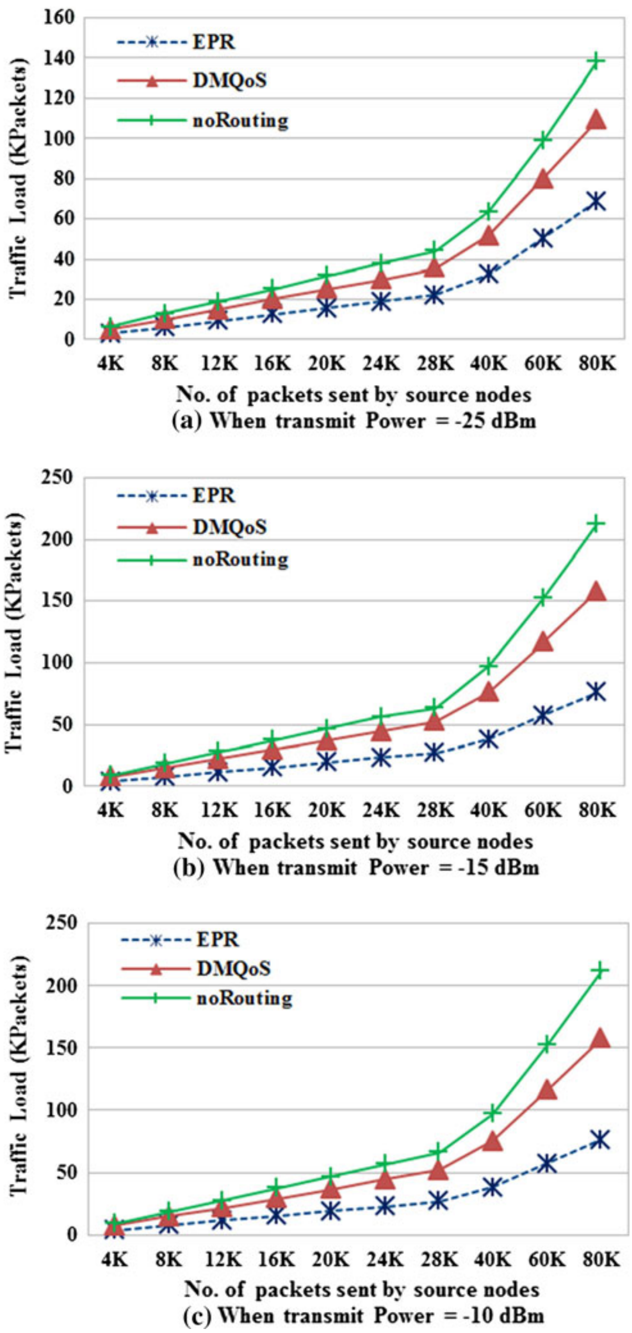

Fig. 13 Traffic load as a function of offered traffic

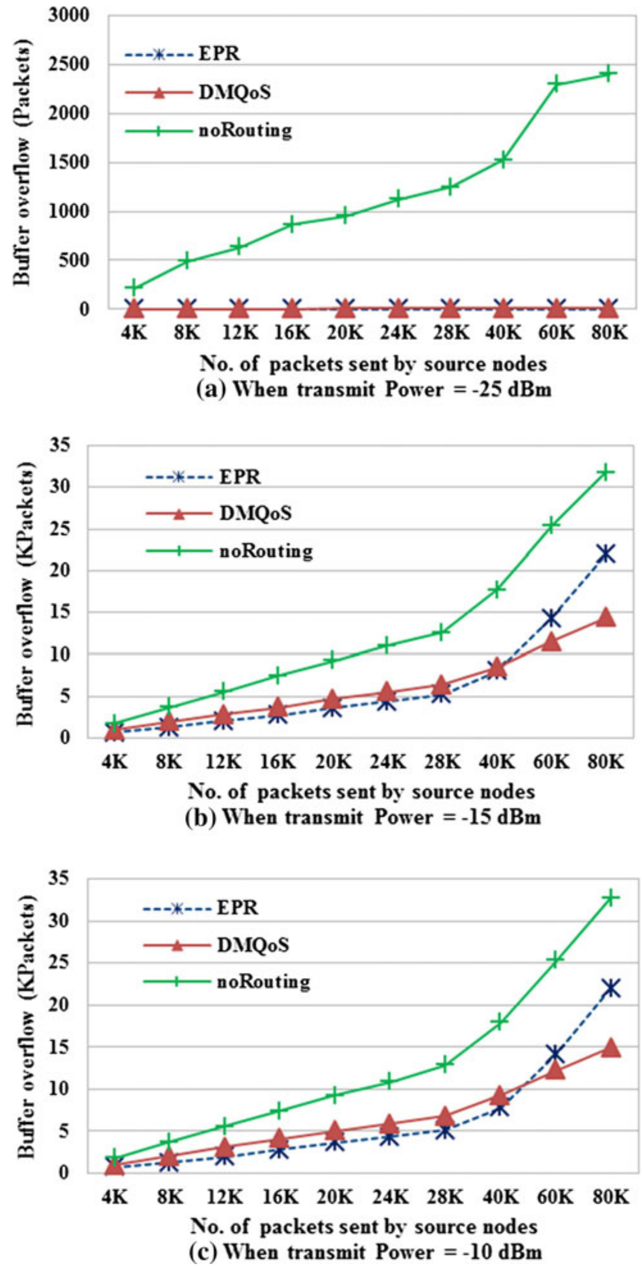

Fig. 14 Buffer overflow as a function of offered traffic

nodes, traffic load, and MAC buffer overflow are observed during the simulations of this scenario. The transmit power used for this scenario is −25 dBm. Once again, it is observed that EPR provides better results than DMQoS and noRouting in case of mobile source node. Figure 15a shows that EPR has 70–82 % successful transmission rate as compared to 63–66 % of DMQoS and 47–51 % of noRouting. In EPR, the intermediate nodes forwards very low packets which reduce the traffic load as shown in Fig. 15b and c. Figure 15d shows that there is no any packet drops due to the MAC buffer overflow. Only few packets are drops in DMQoS whereas 2.15 K packets are dropped in noRouting. In summary, EPR outer performs DMQoS and noRouting when the source node is mobile.

6 Conclusions

In this paper we have proposed a novel patient monitoring framework (ZK-BAN) for the indoor hospital BAN

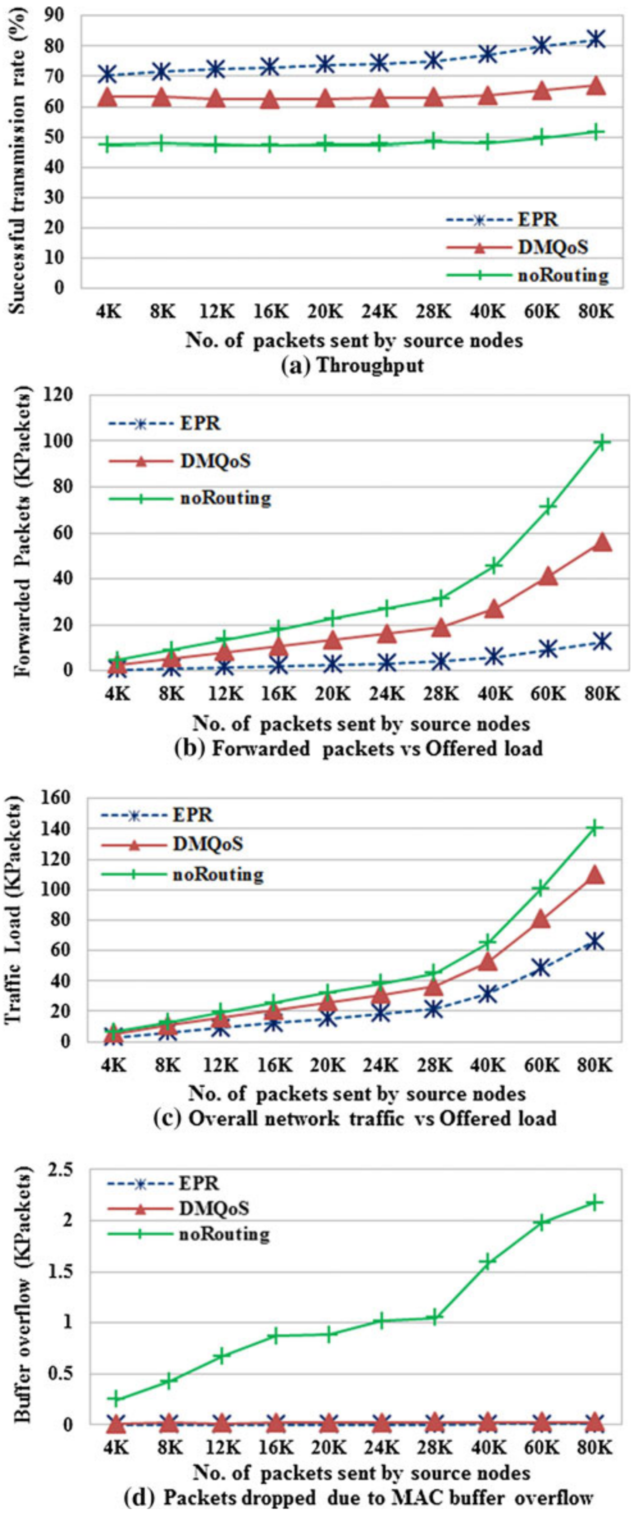

Fig. 15 Performance comparisons for different parameters when BAN is mobile

environment, and a new Energy-aware Peering Routing protocol (EPR) which includes three parts (1) the new Hello protocol, (2) neighbor table construction algorithm, and (3) routing table construction algorithm. The new Hello protocol and the technique used to choose the next hop that considers both residual energy and geographic information of the neighbor nodes, thereby reducing the traffic load and energy consumption while simultaneously increasing the number of packets successfully received by the destinations. We have performed extensive simulations in the OMNeT++ based Castalia simulator for three scenarios with fixed and variable number of packets to test our protocol. Both static and mobile patient scenarios are considered. The results show that for different transmit powers the EPR reduces average traffic load by 44 %, and the number of packets received successfully by the destinations has increased on average by 20 % for transmit powers of −15 and −10 dBm. The energy saved in EPR is on average 93, 201 and 216 mJ for the transmit power of −25, −15, and −10 dBm respectively, in 120 s. There is no buffers overflow at the intermediate nodes in EPR for very low transmit power of −25 dBm in both static and mobile scenarios. EPR consistently reduces the network traffic by 53 % for all offered traffic when the transmit power is −15 and −10 dBm. These results signify that our proposed protocol has better performance compared to similar protocols.

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