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RESEARCH ARTICLE

RELIABLE ROUTING OF EMERGENCY DATA IN WIRELESS BODY AREA NETWORKS UNDER STATIC AND MOBILE SCENARIOS

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Abstract

Timely intervention can help save precious lives of people who are at risk from chronic diseases or fatal diseases such as cardiac arrest, heart diseases to mention a few. These are the major causes of disability and death across the globe. Continuous monitoring of vital body parameters can be useful in timely intervention which can save the lives of the patients suffering from chronic diseases which can be life threatening, also improve the quality of life. This can be done using Wireless Body Area Networks (WBAN) with sensors placed on human body. This network uses routing protocol to transmit the sensed data packets to the destination node. if the detected information falls into the category of emergency data, It is critical for sensor nodes to transmit data in a reliable and timely manner while consuming as little energy as possible. Existing protocols propose routing methods that classify traffic and prioritize emergency data transmission. However, apart from traffic classification, robust measures to reduce the loss of emergency packets at various levels during transmission have not been adequately addressed. This can reduce the reliability of emergency data, also increasing the traffic load and energy consumption in forwarder nodes. This shortcoming drives us to propose a routing protocol EER-QR (Energy Efficient Routing with QoS and Reliability) which uses specialized modules with measures for a specific task. Experimental results have demonstrated that EER-QR is Capable of reliably transmitting emergency data, minimizing network load and therefore extending network lifetime. This can help with proper diagnosis in such critical situations resulting in timely intervention and treatment saving the lives of patients.

Introduction:-

Patient monitoring involves data from sensors, which should be transmitted without delay. Data from sensors on the human body is transmitted to the monitoring station using sink nodes. Transmission of data in a reliable fashion and effective energy utilization are important considerations when patients are being monitored in real time. We need efficient mechanisms that can handle data, which is critical to delay. The new routing mechanism should efficiently distinguish between normal packets (NP's) and packets that are critical to delay [1], [2], [3]-[9].

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This network can experience problems in the form of congestion of packets or failure of links due to body movement. We need to develop a system that can overcome all these issues and deliver data in a reliable fashion. This can help in timely decisions and save patients' lives. The network topology of the WBAN network changes frequently because of changes in posture during mobility. This can result in the connection between the sensor nodes being lost. The connection needs to be reestablished, taking into consideration the topology of the network at that instance [18]. Along with the issues discussed above, the protocol should also take into consideration energy consumption, loss of packets, and network lifetime [6]-[8].

The proposed routing protocol, Energy Efficient Routing with QoS and Reliability (EER-QR), has mechanisms to distinguish and transmit packets in a reliable and energy efficient way. EER-QR takes into consideration the reliability requirements of data that needs to be transmitted in real time. The mechanisms proposed as part of routing provide an improvement over its contemporary protocols with high throughput, less traffic and packet timeouts under static and mobile scenarios. This has been demonstrated using the OMNeT++ based Castalia simulator.

The most important contributions of this work are listed below.

1. Improvised algorithms for choosing the forwarder node based on key criteria such as connection quality, sensor node type, energy level, and the node's current position.
2. Separating the data into emergency and periodic for transmission across reliable path in the network.
3. A modular architecture with robust measures to prevent emergency packets from being lost at various points and different stages in the network.

The paper is organized as follows: Section 1 introduces the EER—QR protocol, Section 2 reviews relevant literature, and Section 3 proposes EER-QR routing protocol which is time critical and sensitive to delay. Performance **analysis of EER-QR is given in Section 4.**

Literature Review:-

The WBAN implementation situation is exceptional when compared to other wireless networks. Routing protocol research focuses on providing timely and energy-efficient data transport to network endpoints. This section introduces several routing strategies that were adopted by different researchers to achieve packet transmission in a reliable and energy-efficient manner.

Transmission of data in a reliable fashion and effective energy utilization are important considerations when patients are being monitored in real time. We need efficient mechanisms which can handle data which are critical to delay. The literature has been examined for work done by scholars with a focus on handling emergency packets and packet categorization. The fuzzy based routing protocol for emergency data EARP(Energy Aware Routing Protocol) proposed by Xintong Wang , et al. [3] uses Fuzzy approach by considering QoS requirements of the packet and link quality to make decisions. Data is classified into periodic and emergency data. The fuzzy rules are formulated depending in the relationship between the input and output which is fuzzified. The emergency data is assigned with the highest priority by Yating Qu, et al. [9] and will be transmitted with high reliability. The periodic data is categorized as continuous or discontinuous. Compared to emergency data, the priority of periodic data is low. Yousaf, et al. [11] proposed CE Mob, Critical Transmission in Emergency with Mobility support in WBAN. When transmitting normal packets, the protocol uses single hop approach. During transmission of emergency packets, single hop approach is used where data is transferred to the sink directly.

A framework that can segregate and prioritize delay sensitive data with normal data in applications related health care was proposed by K. Hasan, et al. [15]. The Software Defined Networking (SDN) framework would manage traffic which is application specific. The experimental results have demonstrated high throughput and low latency for emergency traffic in the network. The criticality index have been proposed by S. Misra, et al. [16] using pricing model for improving the packet delivery and network throughput in a cloud-enabled WBAN platform Authors have also considered the to provide services for emergency patients in real-time. Analytical models have been proposed for improving the QoS in the network.

Transmitting critical information using IEEE 802.15.6 super frame structure was proposed by A. K. Jacob, et al. [19]. Authors had observed that during emergency situation, data from multiple nodes need to be transmitted. This can result in repeated collision. This issue has been addressed by using polling mechanism. However polling can result in network overhead.Reducing network delay for emergency packet can improve the efficiency of the network.Aarti Sangwan, et al. [5] proposed a mechanism capable of handling delay. The network has been modeled in a three level heterogeneous network depending on the energy levels. Nodes with more energy are selected as cluster heads which can be active for a longer duration. The cluster head selects the best path based on delay requirements of the data and energy efficiency. Reliable transmission of emergency packets is the main theme of WBAN networks with medical applications. Along with this, other factors such as network throughput, network load , energy consumption, average end-to-end delay etc also play an important role in deciding upon the efficiency of the network. The routing protocol aware of QoS considerations can manage the requirements.MIQoS-RP: Multi-Constraint Intra-BAN, QoS-Aware Routing Protocol for Wireless Body Sensor Network proposed by Fatima Tul Zuhra, et al. [23] is a multi-faceted routing metric that optimises route selection while taking into account reliability, throughput, delay, and link quality limitations.

Along with the issues discussed above, routing protocols must be able to distinguish between ordinary packets and emergency packets. The protocol should also take into consideration energy consumption, loss of packets and network lifetime. The literature given henceforth explores the work done by scholars with a focus on packet categorization. The traffic priority based delay-aware and energy efficient path allocation routing protocol for wireless body area network (Tripe-EEC). Here the traffic has been classified as normal, on request and emergency traffic. The authors have proposed an efficient prioritization mechanism for transmitting emergency traffic with low and high threshold values generated simultaneously. The Priority-based Congestion-avoidance Routing Protocol (PCRP), the emergency packets are scheduled before normal packets by attaching priority number. The authors have also proposed multiple queues, data aggregation and filtration process to reduce delay and processing for priority data. Avoiding transmission of redundant normal packets can reduce the network traffic. The routing protocol Critical Data Routing Code by A. K. Sagar et al. [14] tries to aim at this by classifying packets and transmitting the ones which are critical and above specified threshold. The sensor nodes have been strategically placed to reduce packet forwarding by the nodes [25].

EER-QR Reliable Routing Protocol For Time Critical Packets

WBAN relies heavily on the timely delivery of essential data. Many of the existing QoS protocols take the reliability of the neighboring node into account.[1], [19], [20]. This neighbor node may lack a reliable upstream node to send the packet. Furthermore, the network traffic is increased when hop-by-hop reliability is used, and end-to-end reliability is not guaranteed.

As a result, the packets may be dropped. In addition, the source node may get erroneous acknowledgment of packet delivery. Before picking a path, several WBAN protocols evaluate end-to-end dependability. However, redundant pathways are found and packets are sent to ensure that the packet reaches its destination [10], [12], [13].

The proposed protocol EER-QR solves these issues by utilizing a low transmit power of -25dBm for both fixed and moveable nodes and, more crucially, by selecting the next hop node based on the most reliable end-to-end path(s) between the source and destination nodes. Along with achieving reliability, the EER-QR also demonstrates improved performance in limiting the number of packets forwarded by the intermediate nodes, the number of packets transmitted successfully and also achieving energy efficiency.

The proposed routing protocol for reliable routing of time critical packets (EER-QR)

All feasible pathways between the source and destination nodes are discovered. In addition, among all of the pathways, the most reliable one is chosen for transmission. The routing table stores the network information. The node sends the time critical packet to the next hop node if the computed reliability is better than the reliability requirement of the packet. If such a path is not available, the system identifies the two most reliable paths from the source to the potential destination and transmits duplicate packets. Despite the redundancy, this method provides better end-to-end dependability for time-sensitive packets.

Data from crucial BANs may be reliably delivered to their final destinations thanks to the suggested technique. To demonstrate the improved performance of the proposed modifications to the routing protocol, extensive simulations have been carried out in the OMNeT++-based simulator Castalia 3.2. In both fixed and moving patient scenarios, improved reliability is evidenced by greater transmission success rate, decreased network routing traffic (Hello packets), and lower end-to-end delay (latency).

Architecture of EER-QR Protocol

The proposed architecture with the following modules are part of this architecture.
(i) Transmitter and Receiver
(ii) Packet Delay Module (PDM)
(iii) Classifier for Packets (CP)
(iv) Hello Protocol (HP)
(iv) Routing Management (RM)
(v) QoS Management (QM).
(vi) Link Reliability Module (LRM)
Detailed description of each module is given below.

(i) Transmitter and Receiver

Hello packets and data packets are received or transmitted by the MAC receiver or transmitter respectively.

(ii) Packet Delay Module (PDM)

Network layer needs the following information to calculate the node delay that will be experienced by the packet. The information includes,
1. Time taken for acquiring the channel (DAC)
2. Time for transmitting a packet (DTP)
3. Delay experienced in buffer/queue (DQ).
This information is obtained through the packet delay module (PDM).

(iii) Classifier for packets (CP)

The data packets and hello packets from the receiver (MAC) are separated and forwarded to the appropriate Modules. The **Routing Management (RM)** Module which is in charge of selecting the path receives the data packets. . The **Hello Protocol Module** receives the Hello Packet. The information in the Hello Packet is utilized to build the Neighbor table, which is used to dynamically build and update the Routing table.

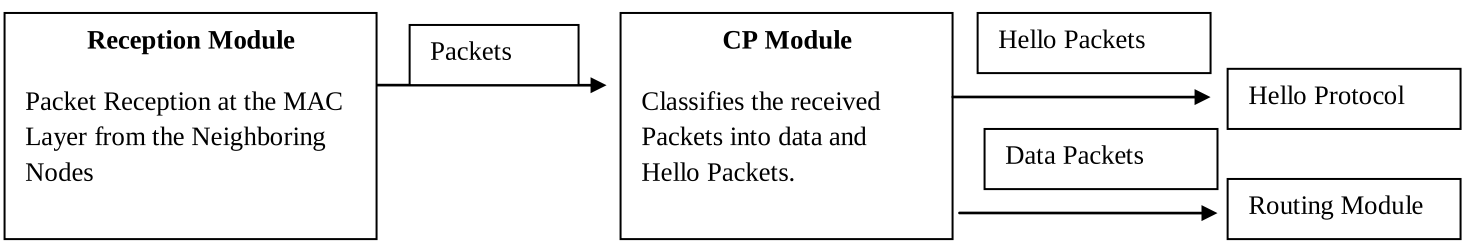

Figure 1:- Classification of the received packets.

(iv) Routing Management (RM)

The data stream generated from different sensor nodes should be classified and segregated. This is done by the PC-QoS i.e Packet Classifier based on QoS which is responsible for identifying the type of data packet and grouping the packets. The RMM has the following sub modules (i) Classifying packets based on QoS needs. (ii) Table constructor for routing (iii) Packet grouping into Time Critical Packets (TCP's) and Normal Packets (NP's). (iv) Selection of path. The RMM chooses the most appropriate path based on the requirements of each category of packet. For any packet, consider the path delay PD(X, DEST) where X is the source and DEST is the destination. If the path delay is less than the delay requirement of the time critical packet, the corresponding path is chosen for sending the packet.

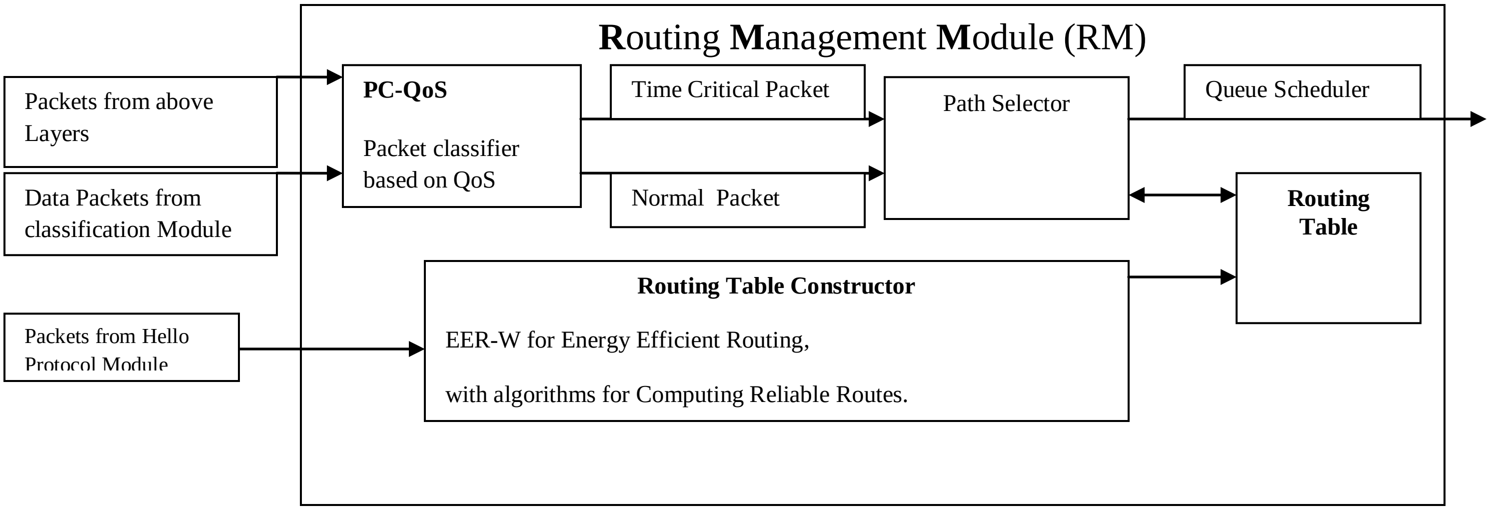

Figure 2:- RM Module for selecting routing path based on packet requirement.

The physiological parameters like as glucose level, SPO2, and body temperature as PH, blood pressure (BP), electrocardiography (ECG), and electroencephalography (EEG) are taken into consideration for determining the health of an individual [17]. The EER-QR selects the next hop device based on the energy level, location, and device type. **Normal Packets (NP's)** includes data such as glucose level, SPO2, and body temperature. **Time Critical Packets (TCP's)** carry vital data such as PH, blood pressure (BP), electrocardiography (ECG), and electroencephalography (EEG). EER-QR separates BAN data into two types and provides a technique for determining the optimum route for both data types taking QoS into account. The algorithms proposed in our previous work, Energy Efficient Routing for WBAN (EER-W) are used to determine the most energy-efficient way to use while transmitting NPs [24]. The benchmark protocols, on the other hand, do not include any robust techniques for reliable transmission of Time Critical Packet's from the source to the destination.

For the two types of packets, the routing table includes separate entries. The neighbor table entries from the Hello Protocol Module are used to build the routing table.

Energy Efficient Path:
The Forwarder Node, or FN_E, is a low-energy next-hop node. This node may send Normal Packets (NPs) to the target. Using the remaining energy in the node and the node's location, the energy aware algorithm EER-W calculates this information.

Reliable Path:
For the data packets which are time critical (TCP) packets, the EER-QR algorithm takes the reliability factor into consideration and selects the path from the routing table to meet the reliability requirement of the packet or data stream. To meet the reliability, the EER-QR algorithm uses redundant path. The path with the highest reliability factor and its corresponding forwarder node is stored for each of the intended destination.

Notations:
1. $\mathbf{FN_{RR1}}$**:** Forwarder node across reliable Path-1 between source to destination.
2. $\mathbf{FN_{RR2}}$**:** Forwarder node across reliable Path-2 between source to destination.
3. $\mathbf{RP_{C1}}$ **:** Choice of Reliable Path-1 between source to destination.
4. $\mathbf{RP_{C2}}$ **:** Choice of Reliable Path-2 between source to destination.
5. $\mathbf{FN_{R}}$**:** Forwarder node to the destination.
6. $\mathbf{PR_{Req}}$**:** Reliability Requirement of the packet.

Two reliable path entries are made in the routing table with its corresponding FN_{RR1} , FN_{RR2} where,
FN_{RR1} is the forwarder node for the first choice for reliable path with notation RP_{C1}
FN_{RR2} is the forwarder node for the alternate choice for reliable path with notation RP_{C2}

The redundant path increases the traffic in the overall network, but considering the importance of time critical packets, this tradeoff is tolerable. The experimental results have demonstrated a minor increase in the network traffic because of introducing redundant paths.

Algorithm 1 for generating routing table for data packets that must be reliably transmitted. The source node that wants to reliably send data to the desired destination examines the neighbouring table for information about the node with the identification IDENTDst. This data is saved in the variable FN_R. The FN_R is empty if no forwarder node is available. If the packet contains time-critical data, the node passes it directly to the sink node.

If the paths to the destination node are available, the information between the source to the destination is stored in the decreasing order of reliability. That is, the first entry will be the path with the highest reliability followed by paths which are of low reliability.

Algorithm 1 Routing Table building Algorithm for transmitting data packets reliably

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INPUT: Next hop records between node i to the destination $NEXH_{(i, DST)}$, $\forall$ DST $\in$ {BAN}
1. **for** every possible destination DST $\in$ {BAN} **do**
2. FN_R ={ All neighbor nodes j $\in$ $NEXH_{(i, DST)}$ }
3. if (FN_R ==NULL) then
4. add 0 to FN_{RR1}, FN_{RR2}, RP_{C1}, RP_{C2}
5. Else
6. Order the records in FN_R in decreasing order of reliable paths (RP_{C1} and RP_{C2})
7. FN_{R1} = the node with the highest reliability $\in$ FN_R .
8. RP_{C1}= The path with the first highest reliability among the 2 best paths.
9. RP_{C2}= The path with the second highest reliability among the 2 best paths.
10. end if
11. end for

Algorithm 2 Route chooser algorithm for Time Critical Packets (TCP's)

INPUT: Next hop records between node i to the destination in the routing table $NEXH_{(i, DST)}$, $\forall$ DST $\in$ {BAN }
1. **for** every segregated packet $\in$ { NP's, TCP's } **do**
2. **if** the segregated packet is Time Critical Packet (TCP)
3. **if** (RP_{C1}> PR_{Req})
4. Forward the packet to $\mathbf{RP_{C1}}$
5. **else if** (RP_{C2}> PR_{Req})
6. Forward the packet to $\mathbf{RP_{C2}}$
7. **else** forward the packet to $\mathbf{RP_{C1}}$ and $\mathbf{RP_{C2}}$
8. **end if**
9. **else if** segregated packet is Normal Packet(NP)
9. forward the packet to E_{NH}
10. **else**
11. discard the packet
12. **end if**
13. **end for**

The algorithm 2 validates the packet need in terms of reliability and selects the best next hop node based on the need of the packet. If the packet is a Time Critical Packet (TCP), and the most reliable route RP_{C1} at that time has reliability greater than the reliability needed for the packet PR_{Req}, the packet is sent through that path. If this is not the case, as previously mentioned, the algorithm transmits packets through both RP_{C1} and RP_{C2} pathways to increase the likelihood of the packets being successfully delivered to the destination. If the packet is normal, the algorithm passes it to an energy-efficient next hop node. If a packet cannot locate a next hop node, it is dropped from the network. This is to prevent the network from being overwhelmed.

(v) QoS Management (QM).

The Routing Management Module (RMM) finds the best next hop node for each packet or stream of packets and sends them to the EER-QOS QR's aware module, which divides data packets into two categories and queues each kind separately. The Time Critical Packet (TCP) queue takes precedence over the Normal Packet (NP) queue. The highest-priority TCP queue sends all of its packets first. Packets from the lower priority NP queue are only forwarded when the TCP queue is empty. The TCP queue has a certain amount of time to send all of its data to the MAC layer. However, the NP queue transmits its data for a defined amount of time before returning to serve the TCP queue if the TCP queue fails to submit all of its data within this time. The QoS Aware Queue Scheduler also prioritizes the recent packets for accurate estimation.

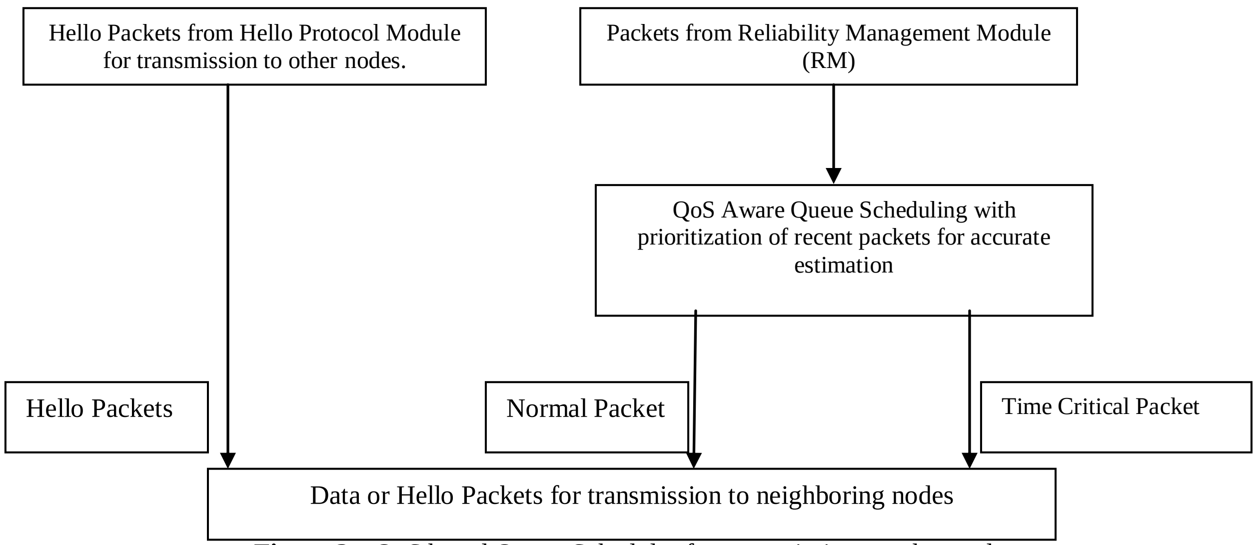

Figure 3:- QoS based Queue Scheduler for transmission to other nodes.

(iv) Hello Protocol (HP)

The Hello Packets, which are control packets, carry node information. This information must be sent to other network nodes so that reliable and energy-efficient pathways may be found and utilised to forward packets to their destination. The Hello Protocol Module is in charge of processing the Hello Packets. The EER-QR protocol lowers the number of hello packets in the network by permitting only Type-1 nodes (which may be directly charged) and nodes with higher energy levels to send hello packets. This prevents nodes with lower energy levels from being part of a possible route in the network, preventing energy loss in such nodes.

$IDENT_{Dst}$	LOC_{Dst}	$IDENT_j$	LOCj	DIST(j,Dst)	REj	DTj

$IDENT_{Dst}$	LOC_{Dst}	$IDENT_j$	LOCj	DIST(j,Dst)	DIST(i, j)	Cj	Tj	$DEL_{Node(i)}$	E2EDL Path(i,Dst)

Figure 4:- Hello Message packet format.

The neighbour table building algorithm is used by the Hello protocol module to generate the neighbour table. For the purpose of creating the tables given above, the information from the Hello packets and the Link Reliability Module is pooled. The updates from the hello packets are used by the table construction algorithm to re-compute and update the following information.(1) Node delay which is hop to hop $DEL_{Node(i)}$ (2) Delay between the two ends $E2E_{DL}$ Path(i, Dst). Delay at node i, $DL_{Node(i)}$ is computed by summation of delay incurred by packet due to processing, queuing, capturing the channel and finally transmitting. This is shown in below equation.

$$DEL_{node(i)} = DEL_{processing} + DEL_{queue+ ChannelCapturre} + DEL_{transmission(i)} \qquad (1)$$

Table 1:- Notations and their Description.

Field ID	Description
ND_i	Node sending packets
ND_j	Neighbor node of i

ND_{DST}	Node receiving the packets.
$IDENT_{Dst}$	Identification of the receiver.
LOC_{Dst}	Location of the receiver.
$IDENT_j$	Identifier of Neighbor node.
LOC_j	Location of node J(Neighbor).
$DIST_{(j,Dst)}$	Node j to destination distance.
RE_j	Energy remaining in node j.
DT_j	The type of device i.e $Node_j$
$DIST_{(i,j)}$	Node i to j distance.
$NEXH_{(i, DST)}$	The Next node which can be used as a hop between node i and the destination Dst.
E_{NH}	The next hop node which is Energy-aware.
D_{NH}	The next hop for time critical packets.
PD(i,Dst)	Delay between the node i to the destination Dst.
TDnode(i)	The internal delay within the node i
PD_{DSP}	Path delay for time critical packets sensitive to delay.
PR_{Req}	Reliability Requirement of the packet.
$H2H_{DL}$ Node(i)	Delay between Hops.
$E2E_{DL}$ Path(i,Dst)	Path delay between nodes.

The path delay between any nodes in the network to the destination is computed using the following equation.

$$PD(i,Dst) = TDnode(i) + PD(j,Dst) \quad (2)$$

In the above equation 2, PD (j, Dst) =0 when j is the destination, that is j=Dst.

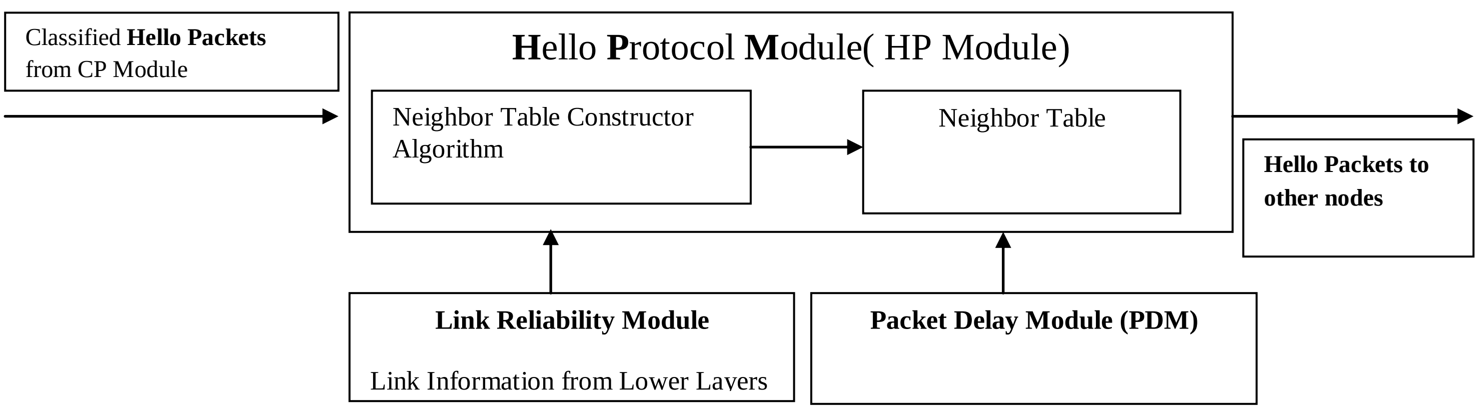

Figure 5:- HP Module for processing Hello Packet Information.

(vi) Link Reliability Module (LRM)

The reliability module keeps track of how many packets are sent to the neighbour node j and how many acknowledgements are received. The reliability module sends information from the MAC layer to the network layer about data packets that have been successfully sent and acknowledged. This information is used to figure out how reliable a connection is between node i and its neighbor, node j.

Link Reliability Estimation Technique

The technique used for estimating the reliability of the link for constructing the routing table is as given below. The equations have been taken from the following sources [1], [21], [22].

Link Reliability for any node i, $LR_i = \frac{\mathbf{T_{sucess}}}{\mathbf{T_{Total}}}$ (3)

Where $\mathbf{T_{Total}}$ = Total Number of Packets sent (including retransmission) (4)

$\mathbf{T_{sucess}}$ = Total Number of Packets successfully transmitted (5)

For each node i belong to WBAN i.e $i \in$ WBAN, the MAC layer computes the link reliability separately for each node. This module counts the number of transmission attempts Ta required. This also includes the number of retransmission attempts. This is counted against the number of packets successfully transmitted Ts. This ratio is used to estimate the reliability of the link.

To estimate the link reliability, Window Mean with Exponentially Weighted Moving Average (WMEWMA), the mathematical model as given in (3) has been used to calculate $LR_{i,j}$ i.e. the average link reliability of link $L_{i,j}$

$$\mathbf{LR_{i,j} = LR_{i,j} \times \beta + (1 - \beta) \times LR\ i} \qquad (6)$$

The average link reliability LR_i between the transmitting node NDi and the receiving node NDj is given in the below equation (3). The value of the weighting factor β ranges between 0 and 1 and we choose β = 0.4 in our simulation, as given in (6)

Result Analysis:-

The proposed EER-QR algorithm is compared with Multi-Constraint QoS-Aware Routing Protocol (MIQoS-RP) for Wireless Body Sensor Networks and RR (Random Routing).The RR algorithm does not take into consideration the delay requirement of the packets and are randomly forwarded. In order to see if EER-QR based routing is better than noRouting in terms of end-to-end reliability, a comparison is made to noRouting. Simulations show that the route reliabilities of EER-QR technique are more successful.

Experimental setup

1. The number of packets successfully received at the destination nodes.

Table 2:- Metrics with Configuration information.

	Area	Scenario 1 and 2 : 8M × 8M
Deployment	Deployment type	All nodes are static in Scenario 1. Nodes are dynamic in Scenario 2.
	Nodes Deployed	8 nodes(6 BANs,2 Relay Nodes)
	Initial node energy	
	Size of the Buffer	32 packets
	Transmission rate at the Link Layer	250kbps
	Transmission power used	-25dBm
Task	Type of Application	Event driven
	Maximum size of packet.	32 Bytes
	Type of traffic.	CBR Traffic.
MAC Layer	IEEE 802.15.4	Values which are default.
Simulation	Time	2000 Sec with set uptime as 3 seconds. Result of simulation is the average of three rotations.

An experimental network setup with OMNet++ based Castalia simulator has been used.BAN nodes have been classified as Type 1 and Type 2 nodes. Our Model classifies the devices into 3 types. The sink which may be mobile phone or PDA which can be recharged regularly is Type 1.The nodes/relay nodes with easily replaceable batteries are considered as Type 2 and other BAN nodes including nodes which may be implanted with limited battery power and also which is difficult to replace the battery is considered as Type 3. For experimental purposes, power for transmission is -25 dBm. The data from the source has to go through other nodes to reach the destination. To validate the rate of successful data transmissions, traffic in the network, and the number of packet time out in the network, 20K Time critical packets have been considered with varying rates. Until 4K packets, the above observations are made for every 1K packets and later it is 4K packets.

Static and dynamic nodes have been considered in scenarios 1 and 2 respectively. With an average of 3 runs simulated for every experiment, the overall performance of EER-QR is analyzed considering the following.

(i) Dropout rate of packets because of buffer overflow.
(ii) Timeout of packets because of the required delay for time critical packets.
(iii) Number of packets in the network at any given point of time.

(iv) Packets reaching the destination successfully (Throughput).

The packets generated in the network and the packets discarded are reduced because of the end to end delay mechanism introduced. This has resulted in lower network traffic and higher throughput.

Scenario 1 – Static Nodes

The first scenario has been planned and deployed considering all the nodes as static.

1a. Packet Throughput

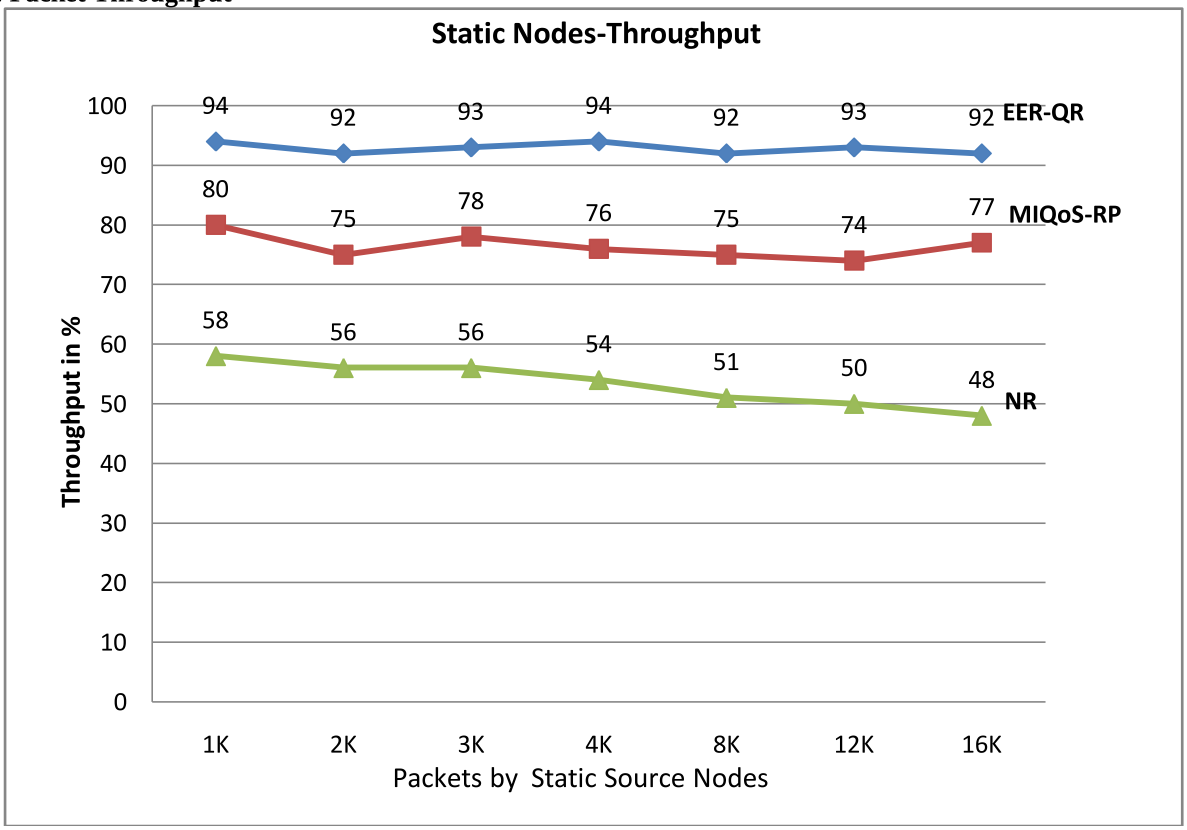

Figure 6:- Number of Packets sent as Load vs Throughput.

The packet throughput in Figure 6 shows that EER-QR provides a consistent throughput of 92%.Random routing of packets has a throughput of 58%. The benchmark MIQoS-RP[23] protocol has a throughput of 77%. The reduced throughput in the MIQoS-RP protocol is because of the selection mechanism for the best next-hop which cannot guarantee the required latency for the packet, resulting in packet time out and packet drop. This also increases network traffic. Selecting the best next-hop based on hop count cannot guarantee lower delay. EER-QR will address this gap by taking into consideration end to end path delay. The benchmark MIQoS-RP protocol results in increased energy consumption and traffic congestion at nodes near sink node because of forwarding the packets frequently. This is avoided in our EER-QR protocol.

1b. Packets Forwarded by Intermediate Nodes.

The number of packets that are sent to the destination using other nodes as intermediate nodes is shown in Figure 7. The proposed protocol EER-QR uses intermediate nodes when the nodes are within the range or if the energy levels in the battery are low. If the intermediate nodes are not available and if it is a TCP, the EER-QR protocol transmits the packets directly to the destination. This is because of the time critical nature of the data. The benchmark protocols MIQoS-RP and NR uses other sensor nodes to forward the packets. This can drain the energy levels of other nodes in the network.

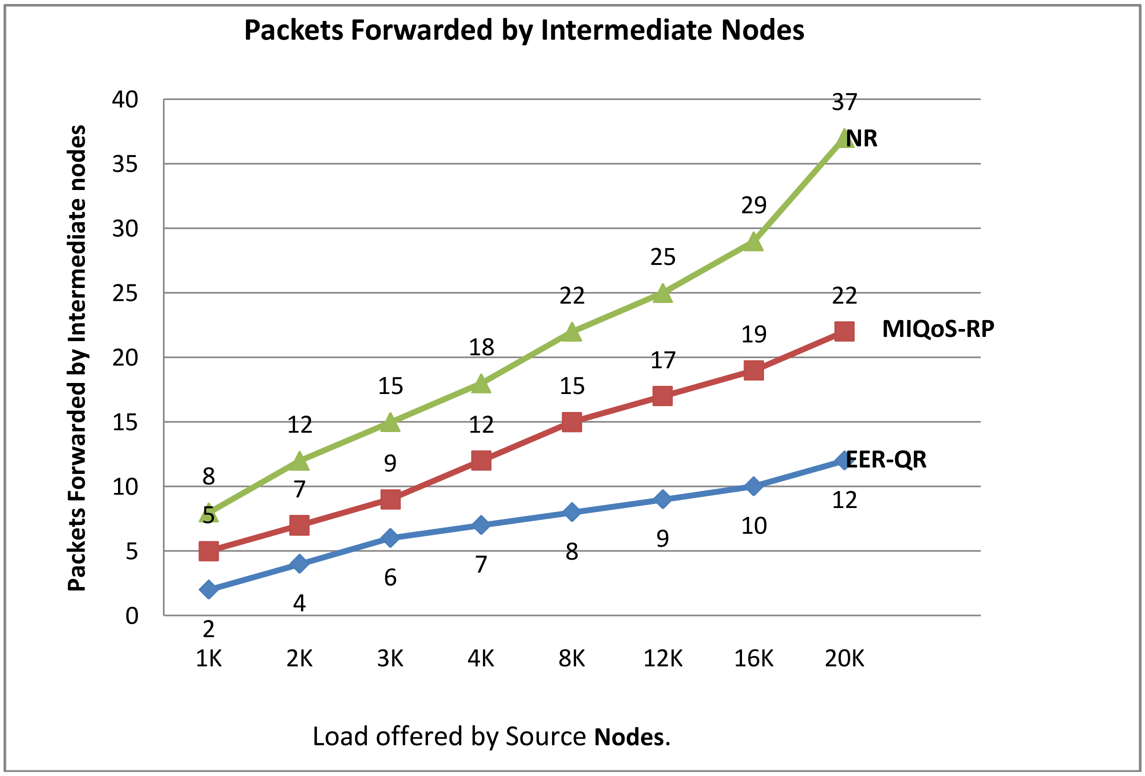

Figure 7:- Packets Forwarded by Intermediate Nodes.

1c. Time out Packets.

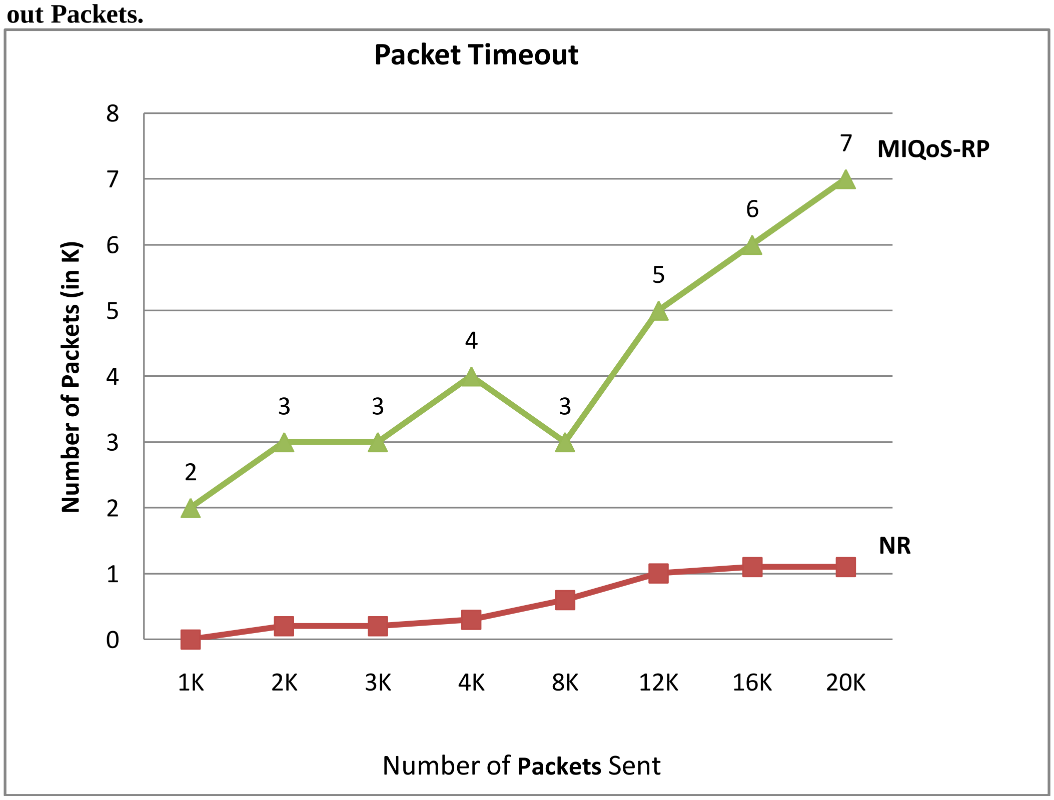

Figure 8:- Time out Packets.

EER-QR ensures majority of the packets reach the destination with few packet drops by considering delay of all nodes in the network across different path. This end to end path delay information which is available with EER-QR can be used to determine whether a packet with the needed delay requirement can reach the destination. From the **Figure 8**, we can observe that EER-QR has no packet time out compared to other benchmark protocols.

1d. Overall energy consumption

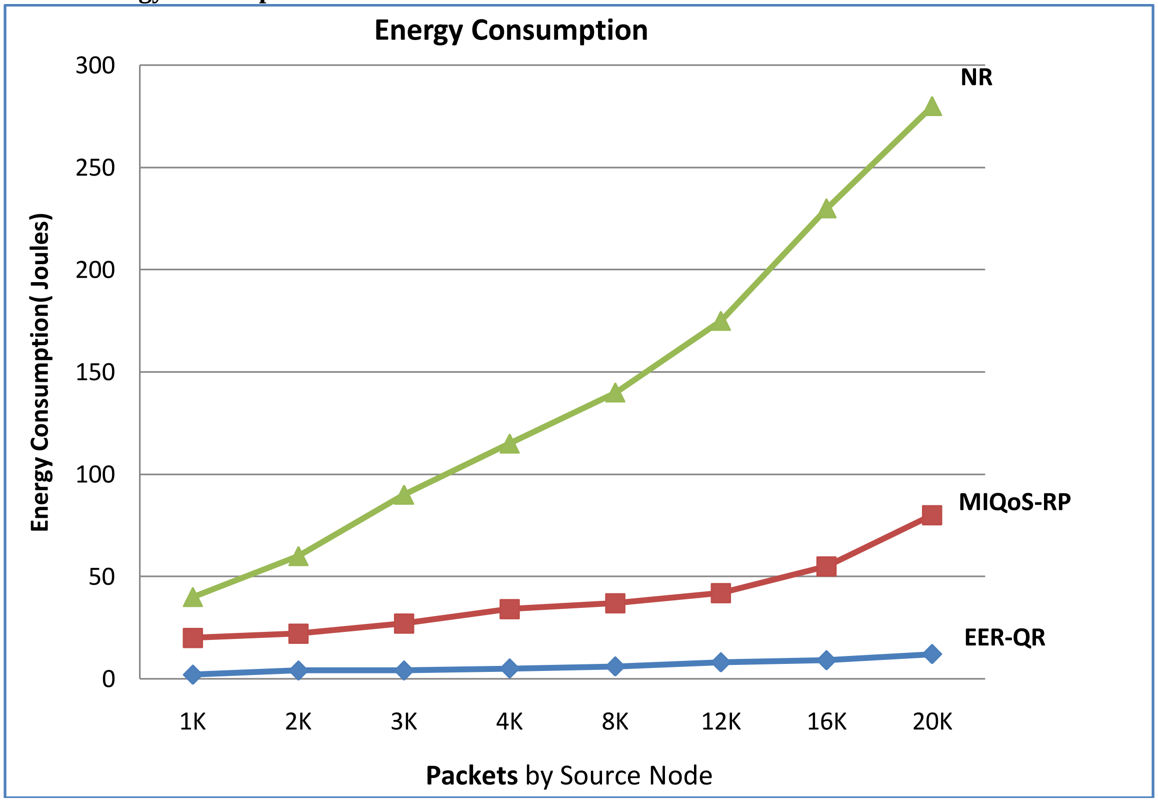

Figure 9:- Overall Energy Consumption by the nodes.

Experimental results in Figure 9 demonstrates energy utilization by nodes in the network is not being impacted by the end to end path delay mechanism of EER-QR compared to benchmark protocols. EER-QR performs end to end delay computations which may consume some energy. However, the benchmark protocols MIQoS-RP and RR demonstrate significant energy consumption because of an increase in packet forwarding and network traffic. This can also result in lower throughput as previously discussed.

Scenario 2 – Mobile Source Node

The next scenario analyses the EER-QR protocol by taking into consideration the mobility of nodes. The speed of node movement is the typical walking speed of a patient which is 3 feet in a second.

2a. Packet Throughput

The experimental results in Figure 10 demonstrate EER-QR gives a throughput of more than 85% for packets up to 10K and reduced to 75% when the traffic is 20K. Analysis of benchmark protocol MIQoS-RP shows a lower transmission rate and reduced throughput of 50 %. The node mobility may result in the source node moving out of coverage range. This results in packet loss because of the loss of connection with neighboring nodes. The packet loss is low and throughput is higher in EER-QR because of the source node reestablishing the connection more quickly when the nodes are within the range.

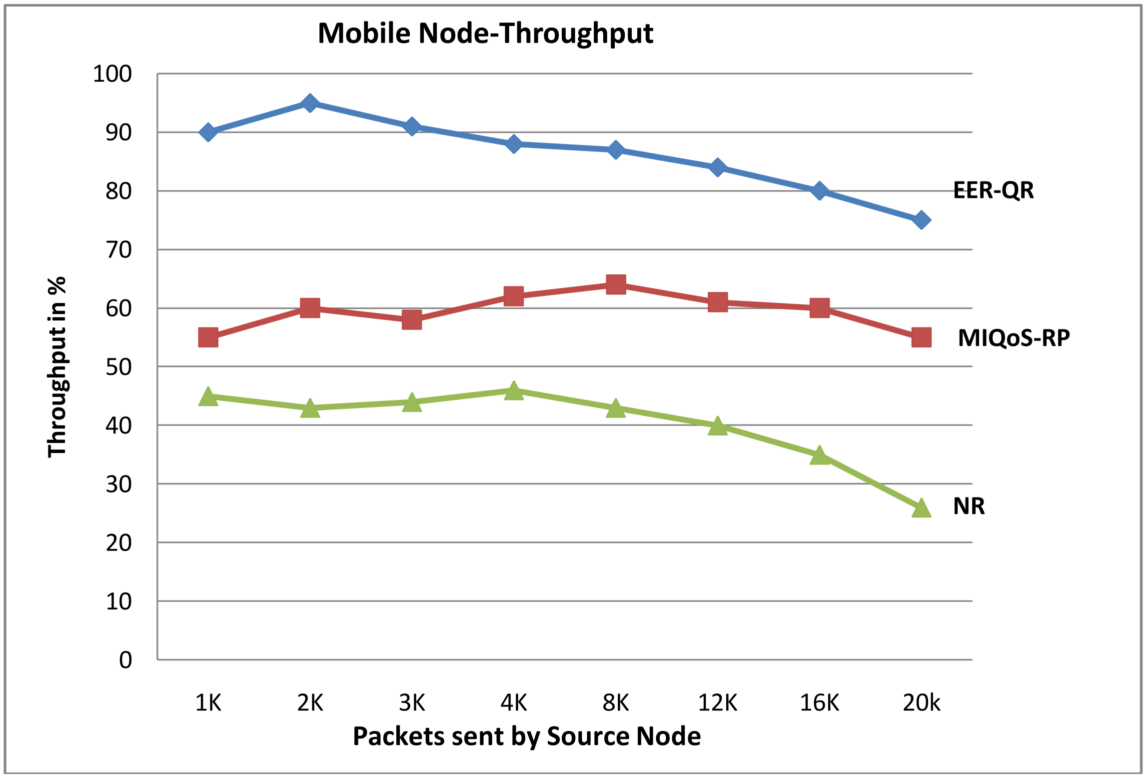

Figure 10:- Number of Packets sent as Load vs Throughput.

2b. Packets Forwarded by Intermediate Nodes.

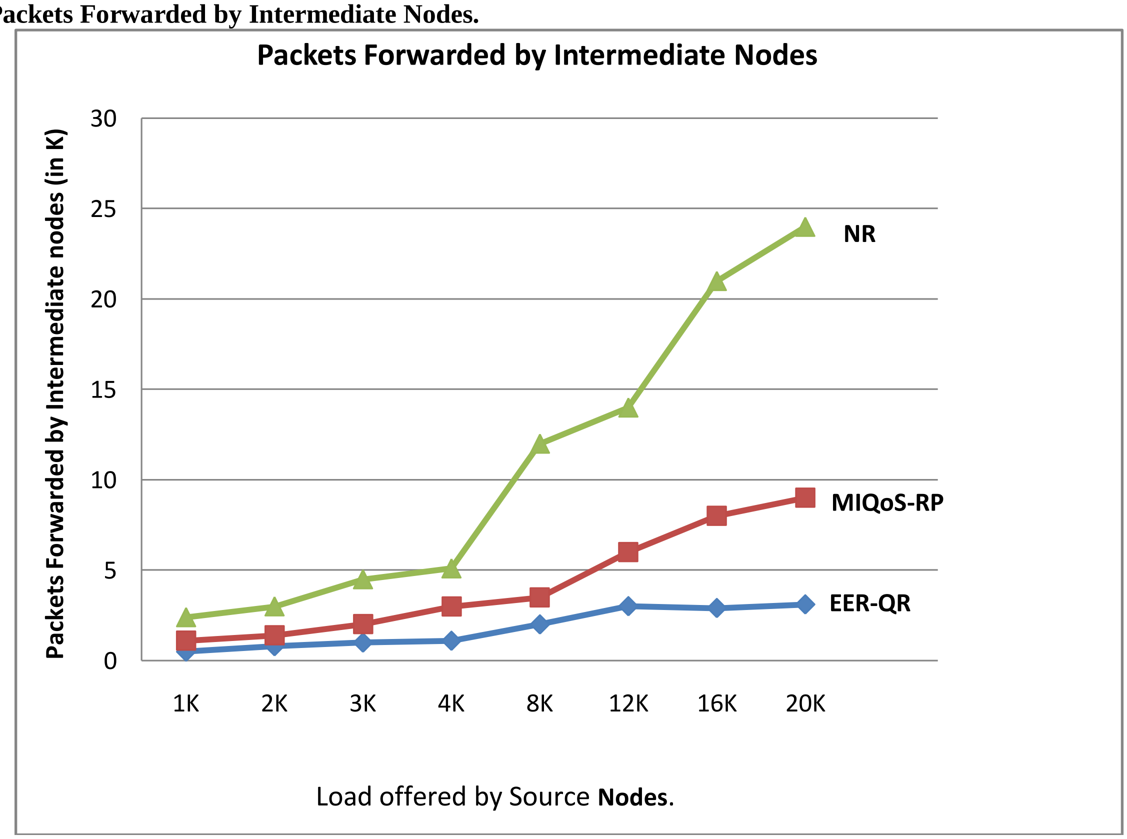

Figure 11:- Packets Forwarded by Intermediate Nodes.

From Figure 11, it can be observed that if the destination node is in range, EER-QR sends data to the destination directly. The number of intermediary nodes involved is less compared to benchmark protocols. The frequent usage of intermediary nodes increases the network traffic and drains the energy levels of the nodes.

2c. Network Traffic for the load offered when the Source Node is Mobile.

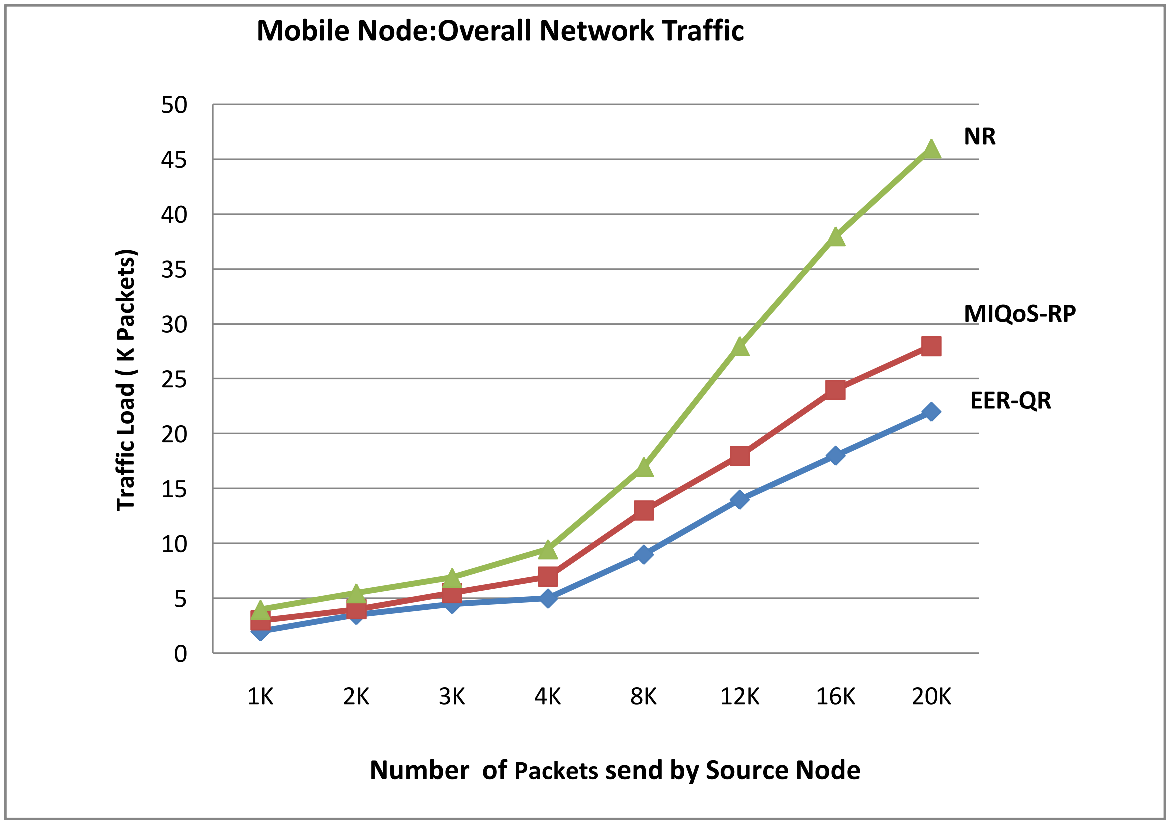

Figure 12:- Overall Network Traffic.

From Figure 12 it can be noted that the overall network traffic in EER-QR is 30% less than the benchmark protocols. The EER-QR protocol computes the end to end path delay. This information is used for selecting the most appropriate path depending on the packet requirement. Since packets are not forwarded considering the immediate next-hop node, the number of packets in the network reduces and also ensures successful packet delivery.

2d. Energy Consumption during the Mobile Node Scenario.

From Figure 13, it can be noted that overall consumption of energy by nodes using EER-QR protocol is less compared to benchmark protocols. This is because of the lower network traffic and reduced packet loss which avoids retransmission of packets.

To summarize, EER-QR demonstrates better performance compared to benchmark protocols when the source node transmitting the data is mobile. We have proposed a new protocol EER-QR which uses a modular approach with each module specialized for a specific task. For all possible paths from source to destination, EER-QR computes end-to-end path delay. This information is used by EER-QR to select the best path taking into consideration the type of packet (Ordinary or Time Critical). For time-critical packets, delay requirements will be a factor to decide on the path to be selected.

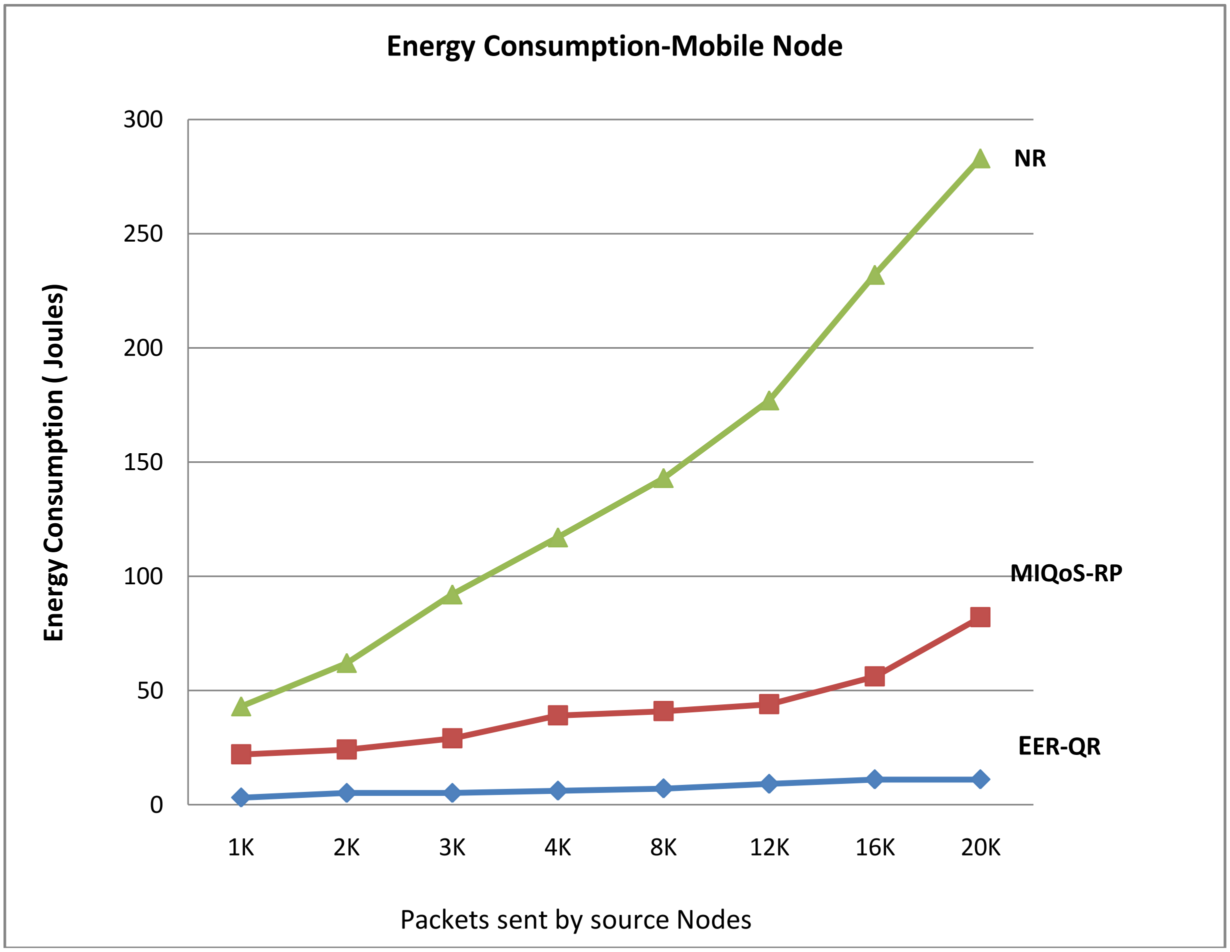

Figure 13:- Energy Consumption in Mobile Node scenario.

Conclusion:-

The WBAN s resource-constrained network has a focus on energy conservation in nodes and reliability in data transmission. This factor is a major influence in the design and implementation of health care applications related to WBAN. The nodes in this network should transmit critical information with reliability and in the shortest possible time. The major hindrance to this is congestion and packet collisions because of simultaneous transmissions by multiple nodes at the same time. As a consequence of this, emergency packets may be lost and failure to transmit this information may result in a life threatening situation for the patient who is being monitored.

The proposed EER-QR protocol uses a dynamic and modular approach to meet the crucial requirements. The strategic decision making both at the node level and the network level, taking into consideration the different routing metrics and queue management techniques, have improved the effectiveness of this protocol. A comparative evaluation against contemporary protocols of similar categories shows significant improvement in network lifetime, energy usage, throughput, and packet delivery rate, effectively addressing the reliability requirement.

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