

## Critical Data Routing (CDR) for Intra Wireless Body Sensor Networks

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### Abstract

*The life critical and real time medical application of Wireless Body Sensor Networks (WBSNs) requires the assurance of the demanded Quality of Service (QoS) both in terms delay and reliability. This paper proposes Critical Data Routing (CDR) that categorizes the sensory data packets as critical and non-critical data packets. Along with the heterogeneous natured data, it also addresses the high and dynamic path loss and the temperature rise issues caused by postural movement of the human body and electromagnetic waves absorption respectively. The simulation results show that the proposed CDR scheme achieves its designed objective of forwarding the critical data packets within certain time limits and with highest reliability while reducing the temperature rise of the in-body sensor nodes.*

**Keywords:** wireless body sensor networks (WBSNs), routing, QoS, critical, temperature, path loss

### 1. Introduction

In WBSN – used for continuous and remote healthcare monitoring [1], the tiny, lightweight, cost effective and low-power Bio-Medical Sensor Devices (BMSDs) are deployed on and/or inside the human body to sense and analyze the vital sign data of the human body. It has a three-tiered architecture in order to send the sensory data to the final destination [2],[3]. In the first tier i.e. Intra-WBSN, the tiny BMSDs send the vital sign data to on-body base station called as Body Coordinator (BC). In the second tier i.e. Inter WBSN, the BCs are responsible to forward the received vital-sign data towards the sink(s) using other BCs and/or regular infrastructure like wireless local area network. Finally, in the third tier, it's the responsibility of the sink(s) to send the received vital-sign data to the final destination which could be a physician, health-care sever and/or emergency control room, using regular infrastructure such as internet.

As WBSN deals with the human body and due to structure, nature and behavior of the human body, it faces some unique challenges along with the traditional constraints of Wireless Sensor Networks (WSNs). A range of BMSDs, like blood pressure, Electroencephalography (EEG), temperature, Electrocardiography (ECG) and many more, are deployed for different applications, which make WBSN heterogeneous in nature. Due to its heterogeneous nature it generates different categories of data, where different QoS parameters are among the key requirements. Similarly, due to saline-water nature, the human tissues absorb the electromagnetic waves carrying the information in wireless communications. This electromagnetic waves absorption along with the energy consumption during the operations of the BMSDs result in temperature rise of the BMSDs. In case of the implanted BMSDs, this temperature rise might affect and/or damage the human tissues if remain for long time [4],[5]. In addition to these, the postural movement of the human body along with the electromagnetic waves absorption results in dynamic and high path loss while exchanging information with other implanted BMSDs and/or BC. Due to this high and dynamic path loss the conventional path loss models of wireless communication are not applicable for intra WBSNs.

Different people have tried to address these challenges of WBSNs and proposed various routing protocols. The high and dynamic path loss issue of intra WBSN due to postural movement of human body has been addressed in [6]–[9]. In [6] Quwaider and Biswas have proposed a routing scheme by partitioning the sensor field into different partitions and uses store and flood mechanism to route the sensory data towards BCI While in [7] the same authors

have called intra WBSN as Delay Tolerant Network (DTN) using store and forward approach. Similarly, in [8] the same partitioning approach is being used as in [6] and uses store and forward mechanism. In [8], the authors have used Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) mechanism to forward the generated and/or received data packets toward BC. All the aforementioned schemes use non real time routing mechanism by storing the packets at several intermediate nodes which makes them unrealistic for critical medical applications. Furthermore, they do not consider the heterogeneous natured data and the thermal effects of the implanted BMSDs.

Temperature Aware Routing Algorithm (TARA) [5] is the first routing protocol that aims to decrease the thermal effects of the implanted BMSDs. Each node observes the communication activities of its neighbor nodes and estimates their temperature. A neighbor node having temperature rise greater than certain threshold is declared hotspot node, which increases the delay and energy consumption. The shortcoming of TARA has been addressed in Least Temperature Rise (LTR) [10] where a hop-count is associated with each data packet. The data packet is discarded if the hop-count reaches beyond the threshold value, which results in low packet delivery ratio. Another temperature aware routing scheme named as Adaptive Least Temperature Rise (ALTR) proposed in [10], where instead of dropping the data packets it uses Shortest Hop Algorithm (SHA) to send the data packets towards BC. Least Total Route Temperature (LTRT) presented in [11] is designed to focus on the entire route instead of individual nodes and high hop-count. All the aforementioned temperature aware routing schemes address the thermal effects of the implanted BMSDs while completely ignore the QoS parameters demanded by heterogeneous natured data and the high and dynamic path loss of Intra WBSNs, due to which these are not suitable and practically implementable for Intra WBSNs.

In [12], the authors divide the vital sign data into four categories. (1) Critical Data (CD) – need to be transmitted with least delay and highest reliability. (2) Delay Sensitive Data (DSD) – require least delay and can tolerate some packets loss. (3) Reliability Sensitive Data (RSD) – need highest reliability and can accept some delays. (4) Regular Data (RD) – do not demand for any QoS parameter. It uses two sinks – primary and secondary, for each patient. Each data packet is forwarded towards both sinks, which results in increase network traffic. DMQoS proposed in [13] uses the same categories of data as in [12] that aims to provide the demanded QoS parameter based on the nature of data packets. It uses hop-by-hop where the source node is completely dependent upon a single node in terms of latency and/or reliability. This localized hop-by-hop approach does not ensure the successful delivery of the data packets. QPRD [14] and QPRR [15] are two other QoS aware routing schemes designed to display the patient's vital information. QPRD classifies the generated traffic into DSD and ND while QPRR divides it into RSD and ND. All the aforementioned QoS-aware routing schemes consider inter WBSNs communication and completely ignore the unique challenges i.e. high and dynamic path loss and temperature rise issues of intra WBSNs.

To the best of the author's knowledge, TMQoS [16] and RAR [17] are the QoS-aware routing schemes in the existing literature, that is designed for intra WBSNs. TMQoS considers thermal effects of the implanted BMSDs along with the heterogeneous natured data packets. It divides the patient's vital information into four classes same as in [12],[13]. TMQoS performs well in order to provide the demanded QoS parameters as compared to other state-of-the-art schemes given in [5], [11]. While routing the critical data packets, it sends two copies of each data packet simultaneously, one to the neighbor node having least delay while other to the one having highest reliability. Redundant data packets delivery results in high network traffic, more network congestion and thus reducing delivery success ratio. Similarly, it also causes more energy consumption and high temperature rise of the implanted BMSDs. Furthermore, it is also not paying any attention towards the high and dynamic path loss of intra WBSNs. RAR considers the temperature rise issue of the implanted BMSDs along with dynamic and high path loss of intra WBSNs and divides the data packets containing the vital signs information into reliability constrained data packets and normal data packets. It does not consider the critical data that need to be transmitted with least delay and highest reliability.

To the best of the authors' knowledge, no such scheme exist in the literature that ensures the provision of the demanded QoS parameters and considers the high and dynamic on and in-body path loss while maintaining the temperature of the implanted BMSDs at an acceptable level for critical data packets. In this paper, we have proposed Critical Data Routing

(CDR) for Intra WBSNs that aims to provide best routes for critical data that need to be transmitted within certain time frame and highest possible reliability. Besides latency and reliability, it also addresses the path loss and temperature issues of the implanted BMSDs. It focuses on end-to-end path latency, reliability and temperature without maintain end-to-end path, where each intermediate sensor node is involved in route selection process. Its uses modular based approach where each module has assigned its duty. We evaluated and compared our proposed CDR scheme in terms of delivery failure ratio due to high and dynamic path loss, delivery success ratio, on-time delivery success ratio, energy consumption and temperature rise with other state-of-the-art schemes.

The rest of this paper has been organized as follow: Section 2 presents the research method used, while the proposed Critical Data Routing (CDR) is being discussed in Section 3. In Section 4, we present results and discussion and finally Section 5 concludes this paper.

## 2. Research Method

### 2.1. Network Model

Connectivity graph can be used to model the different implanted BMSDs and on-body BC with replaceable power source, as given in equation (1).

$$G = (V, E) \quad (1)$$

Where  $V$  corresponds to the set of  $N$  implanted BMSDs and BC, i.e.  $V = \{s_1, s_2, s_3, \dots, s_n\} \cup \{BC\}$  while  $E$  corresponds to  $M$  possible wireless links between any two BMSDs and/or a BMSD and BC i.e.  $E = \{e_1, e_2, e_3, \dots, e_m\}$ . The assumptions made are: all BMSDs exercise the same and low transmission power during communication with other BMSDs and BC. Secondly, the BMSDs might play the role of source node as well as forwarding nodes.

### 2.2. Classification of Data

Considering the critical medical applications of WBSNs, the observed patient's vital information can be categorized as Critical Data (CD) and Non-Critical Data (NCD). The CD packets need to be transmitted within certain time frame with highest possible reliability while NCD packets do not demand any such QoS parameters.

## 3. Proposed Critical Data Routing (CDR) for Intra WBSNs

Figure 1 given below illustrates the network architecture of the proposed CDR, which is a cross-layered modular based approach. It's the job of *MAC Receiver* to receive the data and/or Hello packets from neighbor nodes and/or BC and forward them toward *Packets Classifier* where the incoming packets are classified as data and Hello Packets. After classification, the Hello and data packets are routed to routing module and data packets classifier respectively. Upon receiving the data packets either from packets classifier or from upper layers, the *Data Packets Classifier* classifies them as CD and NCD and sends them to QoS-aware next-hop selector. On the other hand, the *MAC Transmitter* forwards the data and/or Hello packets towards other BMSDs and/or BC. The detailed description of the remaining modules is given in the following sub-sections.

### 3.1. Delay Estimator

At any node  $n_i$ , the estimation and calculation of the delay is done by delay estimator using equation (2) given below, where  $QD_{ni}$  is the queue delay and  $TD_{ij}$  is the delay caused by transmitting the packet  $P$  from node  $n_i$  to node  $n_j$  over link  $L_{ij}$ . Processing and propagation delays are other delays experienced by a packet  $P$ , but these are negligibly small and can be ignored.

$$ND_{n_i} = QD_{n_i} + TD_{i,j} \quad (2)$$

Queue Delay  $QD_{n_i}$  at node  $n_i$  is the time for which the packet  $P$  remains in queue before transmission and is considered only for CD packets in our proposed CDR. It can be calculated by using Exponentially Weighted Moving Average (EWMA) formula same as in [18], given in equation (3). The value of smoothing factor constant  $\alpha$  ranges between 0 and 1 and we choose  $\alpha = 0.2$  in our simulation same as in [13],[14],[16]. Initially  $QD_{n_i}$  is the queue delay experienced by first CD packet.

$$QD_{n_i} = \alpha QD_{n_i} + (1 - \alpha) QD_{n_i} \quad (3)$$

Transmission Delay  $TD_{i,j}$  is the time for which the packet  $P$  remain in the MAC layer of node  $n_i$  before either successfully transmitted to node  $n_j$  over link  $L_{i,j}$  or dropped. it can be calculated using the formula given in [14] as in equation (4), where  $DR_{bits}$  represents the data rate in bits,  $SP_{bits}$  represents the size of packets in bits and  $NP$  is the number of transmitted packets in time interval  $\delta t$ .

$$TD_{i,j} = \frac{1}{DR_{bits}} \times \frac{\sum_{z=1}^{NP} SP_{bits}(z)}{NP} \quad (4)$$

### 3.2. Reliability Estimator

The responsibility of the reliability estimator is to estimate and calculate the  $LR_{i,j}$  – the average reliability of the link  $L_{i,j}$  from nodes  $n_i$  to node  $n_j$ . Is  $NP_{successful}$  is the number of the packets that are successful transmitted and  $NP_{total}$  is the total packets transmitted, then  $P_{average}$  given in equation (5) is the average probability of the successful transmission over link  $L_{i,j}$  during time interval  $\delta t$ . Window Mean with Exponentially Weighted Moving Average (WMEWMA) formula same as in [19], can be used to calculate  $LR_{i,j}$  i.e. the average link reliability of link  $L_{i,j}$  between the transmitting node  $n_i$  and the receiving node  $n_j$ , given in equation (6). The value of the weighting factor  $\beta$  ranges between 0 and 1 and we choose  $\beta = 0.4$  in our simulation, same as in [13],[15],[16].

$$P_{average} = \frac{N_{successful}}{N_{total}} \quad (5)$$

$$LR_{i,j} = LR_{i,j} \times \beta + (1 - \beta) \times P_{average} \quad (6)$$

### 3.3. Path Loss Estimator

The estimation and calculation the path loss  $PL_{i,j}$  of the wireless link  $L_{i,j}$  between the transmitting node  $n_i$  and receiving node  $n_j$  is carried out by path loss estimator. The derived version of Friis formula [20], know as semi-empirical formula [21], can be used to model  $PL_{i,j}$  as a function of the distance  $d_{i,j}$  between the transmitting node  $n_i$  and the receiving node  $n_j$ , given in equation (7), where  $PL_0$  denoted the reference path loss at the reference distance  $d_0$ .

$$PL_{i,j} = PL_0 + 10n \log \frac{d_{i,j}}{d_0} \quad (7)$$

However, due to dynamic postural movements of the human body, the path loss of intra WBSNs is dynamic in nature. Zero-mean Gaussian random variable  $X_\sigma$  with standard deviation  $\sigma$  can be used to formulate equation (7) as in equation (8). The quality of the link  $L_{i,j}$ , denoted by  $LQ_{i,j}$ , between the transmitting node  $n_i$  and receiving  $n_j$  can be calculated using equation (9) derived from equation (8) same as in [21] with transmitting power of  $P_{trans}$ , path loss of  $PL_{i,j}$  from equation (8) and threshold level of  $LQ_{thre}$ . Furthermore, the transmitting node  $n_i$  can only

communicate with the receiving node  $n_j$  if the quality of the link  $L_{i,j}$  between them, denoted by  $LQ_{i,j}$ , is greater than or equal to the pre-define threshold level. In our proposed CDR scheme, we use the whole body path loss model proposed in [21], which covers the different path loss models proposed for intra WBSNs.

$$PL_{i,j} = PL_0 + 10n \log \frac{d_{i,j}}{d_0} - X_\sigma \quad (8)$$

$$LQ_{i,j} = \frac{1}{2} - \frac{1}{2} \operatorname{erf} \left( \frac{-P_{Trans} + PL_{i,j} + LQ_{thre}}{\sqrt{2\pi\sigma}} \right) \quad (9)$$

### 3.4. Temperature Estimator

The job of the temperature estimator is to estimate and calculate the temperature rise occurred at any implanted BMSD  $n_i$ . As discussed earlier, the human tissues absorb the electromagnetic waves during the wireless communication among the implanted BMSDs. The rate at which the human tissue, with density of  $\rho$  and electric conductivity of  $\sigma$ , absorb the electromagnetic waves, having induced electric field of  $E$ , per unit weight as [5]:

$$SAR = \frac{\sigma |E|^2}{\rho} \quad (10)$$

The second reason that causes the temperature rise of the implanted BMSDs, is the energy consumption required to carry out the different operations, denoted by  $P_c$ , which can be measured by dividing the power consumed by volume of the implanted BMSD. Finally, the rate at which the temperature of the implanted BMSDs rises can be calculated by using Pennes Bioheat formula [22], given in equation (11). Table (1) provides the explanation of the different parameters of equation (11) while their values are obtained from [23].

$$\frac{dT}{dt} = \frac{KV^2T - b(T - T_b) + \rho SAR + P_c}{\rho C_p} \quad (11)$$

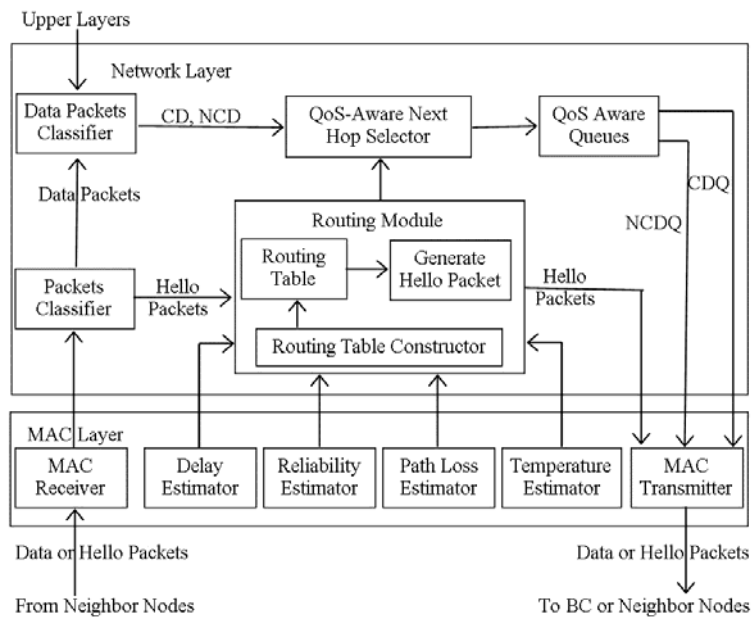


Figure 1. Network Architecture of the Proposed CDR

Table 1. Description of the Parameters used in Equation (11)

Parameter	Description
$dT/dt$	Rate at which rise temperature occurs
$K\nabla^2T$	TR due to tissue's thermal conductivity
$b(T-T_b)$	TR due to blood perfusion
$\rho SAR$	TR due to electromagnetic wave absorption
$P_c$	TR due to power consumed by nodes' operation
$\rho$	Mass density
$C_p$	Tissue's specific heat

### 3.5. Routing Module

The three sub-modules of the routing module are: routing table constructor, Hello packets constructor and routing table. The responsibility of the routing table constructor is to construct and periodically update the routing table based on the information obtained from various parameters estimators and other BMSDs in neighborhood. After obtaining the required information equations (12), (13), and (14) can be used to calculate the end-to-end path delay  $PD_{i,j}$ , reliability  $PR_{i,j}$ , and temperature  $PT_{i,j}$  from the transmitting node  $n_i$  to  $BC$  through the intermediate node  $n_j$  respectively. The routing table parameters are given in Figure 2, while Table (2) describes these parameters. Once the routing table is constructed or updated, it provides information to Hello packets generator to generate the Hello packet in order to inform other BMSDs in its neighborhood.

$$PD_{i,j} = PD_{i,j} + ND_{ni} \quad (12)$$

$$PR_{i,j} = PR_{i,j} \times LR_{i,j} \quad (13)$$

$$PT_{i,j} = PT_{i,j} + NT_{ni} \quad (14)$$

### 3.6. QoS-Aware Next-Hop Selector

The responsibility of QoS-aware next-hop selector is to select the desired next-hop based on the demanded QoS parameters. Upon receiving the data packets  $P$  from data packets classifier module, our proposed critical data routing algorithm, given below, searches the routing table ( $RT$ ) for only those nodes in the neighborhood whose link quality ( $LQ_{i,j}$ ) is greater than or equal to the pre-defined threshold level ( $LQ_{thre}$ ) and place them in  $NN_{LQ}$  (lines: 2–4). The data packet  $P$  is discarded immediately in case of empty  $NN_{LQ}$  (lines: 5–6). Otherwise, in case of  $P$  belonging to  $CD$ , Delay Aware Procedure is called with inputs  $NN_{PD}$  and  $P$  (lines: 7–8). While in case of  $P$  belonging to  $NCD$ , the desired next hop ( $DNH$ ) is the node belonging to  $NN_{LQ}$  with least end-to-end path temperature ( $PT_{i,j}$ ) (line: 9). Once delay aware procedure is called, it selects only those nodes belonging to  $NN_{LQ}$ , whose end-to-end path delay ( $PD_{i,j}$ ) is less than or equal to required delay ( $PD_{req}$ ) and place them in  $NN_{PD}$  (lines: 10–12). In case of empty  $NN_{PD}$ , the data packet  $P$  is discarded immediately (lines: 13–14). If there is a single node in  $NN_{PD}$  then that node is selected as  $DNH$  (lines: 15–16). Otherwise reliability aware procedure is called with inputs  $NN_{PD}$  and  $P$  (line: 17). Upon calling reliability aware procedure, it selects only those nodes whose end-to-end path reliability ( $PR_{i,j}$ ) is greater than or equal to the required reliability ( $PR_{req}$ ) and store them in  $NN_{PR}$  (lines: 18–20). If none of nodes fulfills the required reliability demand then the  $DNH$  is the node belonging to  $NN_{PD}$  having highest  $PR_{i,j}$  (lines: 21–22). If there is a single entry in  $NN_{PR}$  then that node is selected as  $DNH$  (lines: 23–24). Otherwise, the node belonging to  $NN_{PR}$  with least  $PT_{i,j}$  is selected as  $DNH$  (line: 25).

## Critical Data Routing Algorithm

Inputs: Data Packet P, and RT

1. **for** each data packet P **do**
2.   **for** each node  $n_i \in RT$  **do**
3.     **if**  $LQ_{ij} \geq LQ_{thre}$  **then**
4.       store node  $n_i$  into  $NN_{LQ}$
5.     **if**  $NN_{LQ} = NULL$  **then**
6.       discard P immediately
7.     **else if**  $P \in CD$
8.       call Delay Aware Procedure
9.     **else**  $DNH = n_j \in NN_{LQ}$  with least  $PT_{ij}$

## Delay Aware Procedure

10. **for** each node  $n_i \in NN_{LQ}$  **do**
11.   **if**  $PD_{ij} > PD_{req}$  **then**
12.     store node  $n_i$  into  $NN_{PD}$
13.   **if**  $NN_{PD} = NULL$  **then**
14.     discard P immediately
15.   **else if**  $NN_{PD} = 1$  **then**
16.      $DNH = n_j \in NH_{PD}$
17.   **else** call Reliability Aware Procedure

## Reliability Aware Procedure

18. **for** each node  $n_i \in NN_{PD}$  **do**
19.   **if**  $PR_{ij} \geq PR_{req}$  **then**
20.     store node  $n_i$  into  $NN_{PR}$
21.   **if**  $NN_{PR} = NULL$  **then**
22.      $DNH = n_j \in NN_{PD}$  with highest  $PR_{ij}$
23.   **else if**  $NN_{PR} = 1$  **then**
24.      $DNH = n_j \in NH_{PR}$
25.   **else**  $DNH = n_j \in NN_{PR}$  with least  $PT_{ij}$

Table 2. Description of the Parameters used in Figure (2)

Parameter	Description
$ID_{Dest}$	Destination (body coordinator) ID
$Loc_{Dest}$	Coordinates of the body coordinator
$ID_{nj}$	ID of the neighbor node $n_j$
$LQ_{ij}$	Link Quality between nodes $n_i$ , and $n_j$
$PD_{ij}$	End-to-end path delay from node $n_i$ to BC through node $n_j$
$PR_{ij}$	End-to-end path reliability from node $n_i$ to BC through node $n_j$
$PT_{ij}$	End-to-end path temperature from node $n_i$ to BC through node $n_j$
$Loc_{nj}$	Coordinates of the neighbor node $n_j$

$ID_{Dest}$	$Loc_{Dest}$	$ID_{nj}$	$LQ_{ij}$	$PR_{ij}$	$PD_{ij}$	$PT_{ij}$	$Loc_{nj}$
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Figure 2. Routing Table Parameters

## 3.7. QoS-Aware Queues

Two independent queues – Critical Data Queue (CDQ) and Non-Critical Data Queue (NCDQ), are used. Once the desired next hop is being selected, the data packet is sent to QoS-aware queue, where CDQ is at higher priority than NCDQ. The CD packets wait in CDQ before transmissions while NCD in NCDQ. The data packets waiting in NCDQ are transferred to CDQ after specific time period in order to prevent them from indefinitely blocking.

## 4. Results and Discussions

Network Simulator version-2 (NS2) is being used to carry out the simulation and performance evaluation of our proposed CDR scheme. In our simulation, the BMSDs can be used as sources and/or relaying nodes. Some of the BMSDs generate CD packets while others generate NCD packets. We have taken the average results by changing the BMSDs generating CD and NCD packets. We have compared our proposed CDR scheme with TMQoS [16] and LTRT [11]. The network parameters used in our simulation are given in Table (3).

Average packet loss ratio against different link qualities by considering different data generation rates is shown in Figure 3. It can be seen that the proposed CDR results in lower packet loss ratio as compared to TMQoS [16] and LTRT [11], while LTRT [11] shows poorer performance among all. The reason behind their poor performance is that they completely ignore the high and dynamic path loss issue of implanted BMSDs which we have addressed in our proposed CDR scheme.

Table 3. Simulation Network Parameters

	Area	3m x 2m
	Number of Nodes	14 BMDSs and 01 BC
	Initial Energy	100 Joule
Deployment	Buffer Size	60 Packets
	Transmission Range	40 cm
	Transmission Power	$1.8467e^{-12}$
	Bit Error Rate	$10^{-2} - 10^{-4}$
Tasks	Application Type	Event Driven
	Propagation Model	TwoRayGround
	Network Interface Type	WirelessPhy
	Traffic Type	Constant Bit Rate (CBR)
MAC	IEEE 802.15.4	Default Values
Simulation	Time	1000 Seconds

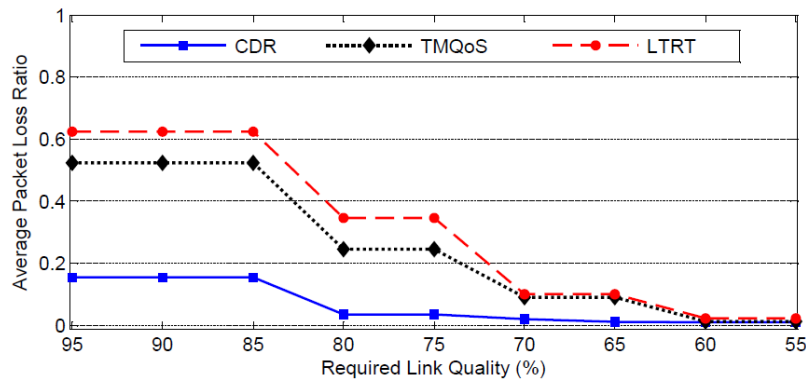


Figure 3. Average Packet Loss Ratio Vs Link Quality at Different Data Generation Rates

Figure 4 shows the impact of the data generation rates over the packet success ratio by considering different link qualities, where the packet success ratio is decreasing slightly with the increase in data generation for all schemes that might be due to congestion. Figures 5(a) and 5(b) illustrate the average packet success ratio against different demanded reliabilities by considering different link qualities at low and high data generation rates respectively. Similarly, the impact of the time constraint on the average on-time packet delivery ratio by considering different link qualities, when the data is generated at low and high rates is shown in Figures 6(a) and 6(b) respectively. It is clear from Figures 4, 5, and 6, that the proposed CDR scheme outperforms the other state-of-the-arts while TMQoS [16] shows better performance as compared to LTRT [11].

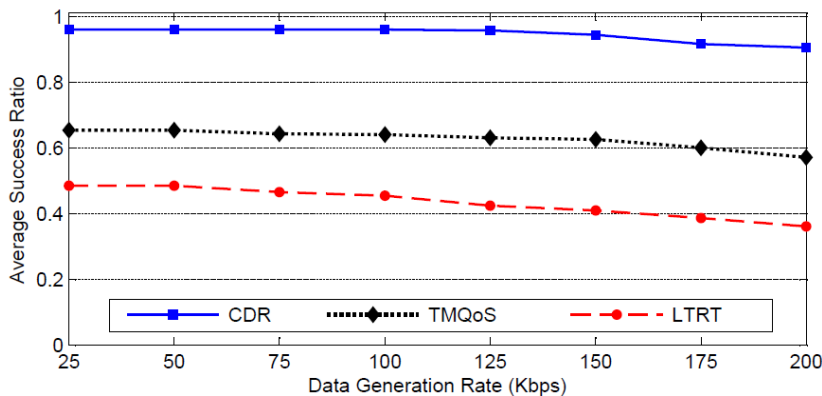
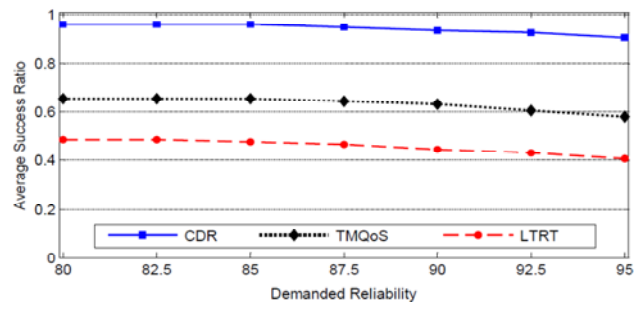
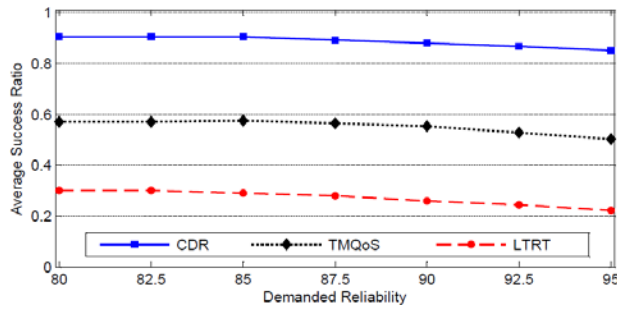


Figure 4. Average Packet Success Ratio Vs Data Generation Rate at Different Link Qualities



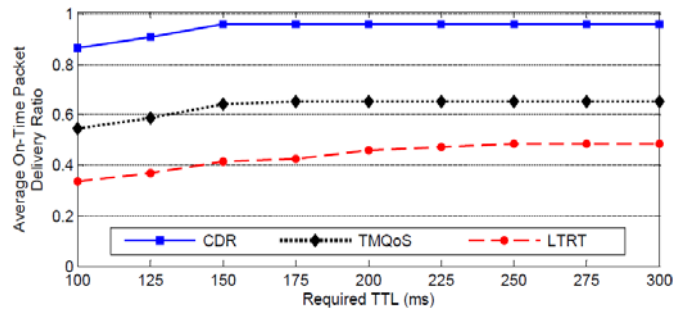


(a)

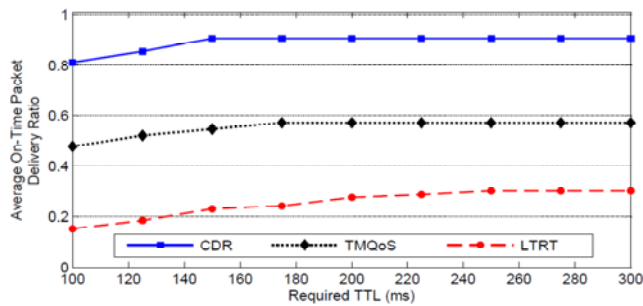


(b)

Figure 5. Average Success Ratio Vs Demanded Reliability Considering Different Link Qualities at (a) Low Data Generation Rate and (b) High Data Generation Rate



(a)



(b)

Figure 6. Average On-Time Packet Delivery Ratio Vs Required TTL Considering Different Link Qualities at (a) Low Data Generation Rate and (b) High Data Generation Rate

The reason behind the poor performance of LTRT [11] is that its designed objective is to minimize the thermal effects of the in-body BMSDs and it does not consider the path loss issue and the heterogeneous natured data of intra WBSNs. Similarly, TMQoS [16] completely ignores the dynamic and high path loss issue of the implanted BMSDs. Furthermore, it sends two copies of the each CD packet, which results in high congestion that may cause packet losses. On the other hand, our proposed CDR addresses these short-comings by considering high and dynamic path loss and temperature rise issues along with heterogeneous natured data.

Figures 7 and 8 show the impact of the data generation rates over the average energy consumption and average temperature rise respectively. It can be observed from the both figures that the high data generation rates result in high energy consumption and high temperature rise. From Figures 7 and 8, it is clear that LTRT [11] consumes more energy as compared to other two but out-performs the others in terms of temperature rise because its focus is to reduce the temperature rise of the implanted BMSDs and it does not consider their energy constraint. It can also be seen that TMQoS [16] consumes less energy than LTRT [11] but more as compared to CDR. Furthermore, it results in high temperature rise among all, as it sends two copies of each CD packet, which results in high energy consumption and high temperature rise of the implanted BMSDs.

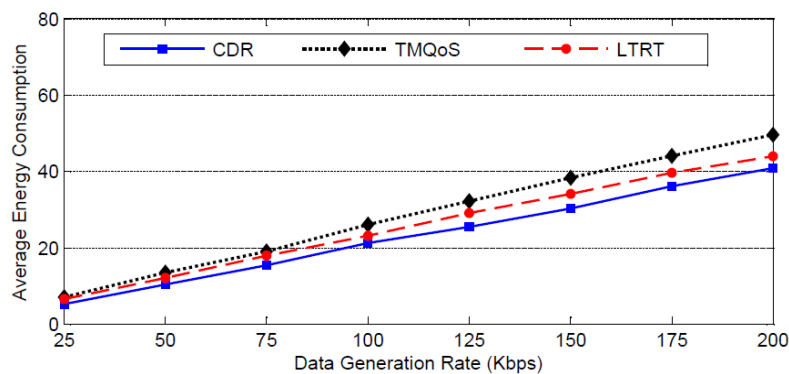


Figure 7. Average Energy Consumption Vs Data Generation Rate at Different Link Qualities

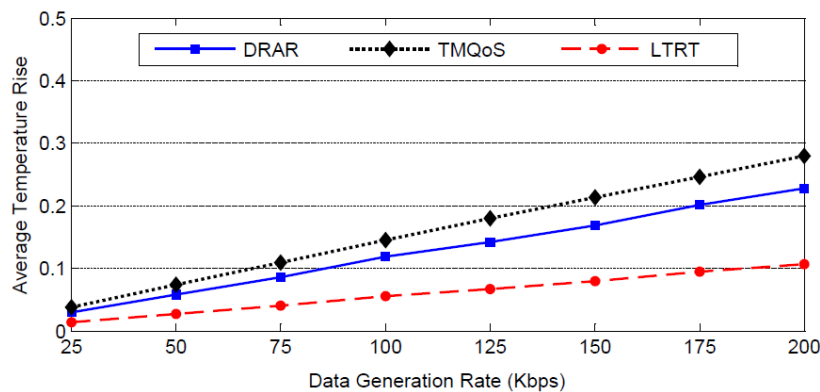


Figure 8. Average Temperature Rise Vs Data Generation Rate at Different Link Qualities

## 5. Conclusion

Critical Data Routing (CDR) scheme for intra WBSNs has been proposed in this paper. The sensory data packets are being categorized as CD and NCD packets. The designed objective of the proposed CDR is to forward the CD packets within certain time limit and with highest reliability while the NCD packets in such a way that results in lower temperature rise.

Along with the heterogeneous natured data, it also addresses the dynamic and high path loss and temperature rise issues of the implanted BMSDs. The simulation results show its better performance in terms of packet loss ratio due the high and dynamic path loss, packet success ratio, on-time packet delivery ratio and energy consumption as compared to other state-of-the-arts. However, it shows slightly poor performance in terms of average temperature rise as compared to LTRT.

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