Traffic-Differentiated Two-Hop Routing for QoS in Wireless Sensor Networks

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This paper proposes a Traffic-Differentiated Two-Hop Routing protocol for Quality of Service (QoS) in Wireless Sensor Networks (WSNs). It targets WSN applications having different types of data traffic with several priorities. The protocol achieves to increase packet reception ratio (PRR) and reduce end-to-end delay while considering multi-queue priority policy, two-hop neighborhood information, link reliability and power efficiency. The protocol is modular and utilizes effective methods for estimating the link metrics. Numerical results show that the proposed protocol is a feasible solution to addresses QoS service differentiation for traffic with different priorities.

Keywords: Wireless Sensor Networks (WSNs), quality-of-service (QoS), two-hop neighbors, traffic-differentiation, Packet Reception Ratio (PRR), end-to-end delay.

1. Introduction

Wireless Sensor Networks (WSNs) form a framework to accumulate and analyze real time data in smart environment applications. WSNs are composed of inexpensive low-powered micro sensing devices called motes[1], having limited computational capability, memory size, radio transmission range and energy supply. These sensors are spread in an environment without any predetermined infrastructure and cooperate to accomplish common monitoring tasks which usually involves sensing environmental data. With WSNs, it is possible to assimilate a variety of physical and environmental information in near real time from inaccessible and hostile locations.

WSNs have a set of stringent QoS requirements that include timeliness, high reliability, availability and integrity. Various performance metrics that can be used to justify the quality of service include, packet reception ratio (PRR), defined as the probability of successful delivery should be maximized. The end-to-end delay which is influenced by the queuing delay at the intermediate nodes and the number of hops traversed by the data flows of the session from the source to the receiver. Sensor nodes typically use batteries for energy supply. Hence, energy efficiency and load balancing form important objectives while designing protocols for WSNs. Therefore, providing corresponding traffic differentiated QoS in such scenarios pose a great challenge. Our proposed protocol is motivated primarily by the deficiencies of the previous works (explained in the Section 2) and aims to provide better Quality of Service.

Table 1 Our Results and Comparison with Previous Results for Differentiated QoS Routing in Wireless Sensor Networks.

Related	Protocol	Considered	Estimation	Traffic	Duplication
Work	Name	Metrics	Method	Differentiation	
E. Felemban	MMSPEED	one-hop delay,	EWMA	Delay	Towards
$et \ al.,[2]$	(Multi-path	link reliability		requirement	the same
	and Multi-SPEED	and residual			sink
	Routing Protocol)	energy.			
M.M.	DARA (Data	one-hop delay	Variance-based	Critical	Towards
Or-Rashid	Aggregate	and transmission		Traffic and	different
$et \ al.,[3]$	Routing	power.		Non-Critical	sinks
	Algorithm)			Traffic	
Y. Li	THVR (Two-Hop	two-hop delay	WMEWMA	No	No
$et \ al., [4]$	Velocity Based	and residual			
	Routing Protocol)	energy.			
D. Djenouri	LOCALMOR	one-hop delay	EWMA and	Regular,	Towards
$et \ al., [5]$	(Localized	link reliability	WMEWMA	Reliability	
	Multi-objectives	residual energy		-sensitive, Delay,	sinks
	Routing)	and transmission		-sensitive and	
	_,	power.		Critical Traffic	
This paper	TDTHR	two-hop delay,	EWMA and	Regular,	Towards
	(Traffic	link reliability	WMEWMA	Reliability	different
	-Differentiated	residual energy		-Responsive, Delay,	sinks
	Two-Hop	and transmission		-Responsive and	
	Routing)	power.		Critical Traffic	

This paper explores the idea of incorporating QoS parameters in making routing decisions the protocol proposes the following features.

- Data traffic is split into regular traffic with no specific QoS requirement, reliabilityresponsive traffic; which should be transmitted without loss but can tolerate some delay, delay-responsive traffic; which should be delivered within a deadline but may tolerate moderate packet loss and critical traffic; which has high significance and demanding both high reliability and short delay.
- Link reliability is considered while choosing the next router, this selects paths which have higher probability of successful delivery.
- Routing decision is based on two-hop neighborhood information and dynamic velocity that can be modified according to the required deadline, this results in significant reduction in end-to-end PRR.
- 4. Choosing nodes with higher residual energy and minimum transmission power, balances

the load among nodes and results in prolonged lifetime of the network.

We test the performance of our proposed approaches by implementing our algorithms using ns-2 simulator. Our results demonstrates the performance and benefits of TDTHR over earlier algorithms.

The rest of the paper is organized as follows: Section 2 gives a review of related works. Section 3 and Section 4 explain the network model, notations, assumptions and working of the algorithm. Section 5 is devoted to the simulation and evaluation of the algorithm. Conclusions are presented in Section 6.

2. Related Work

Stateless routing protocols which do not maintain per-route state is a favorable approach for WSNs. The idea of stateless routing is to use location information available to a node locally for routing, *i.e.*, the location of its own and that of its one-hop neighbors without the knowledge about the entire network. These protocols scale well in terms of routing overhead because the tracked routing information does not grow with the net-

work size or the number of active sinks. Parameters like distance to sink, energy efficiency and data aggregation, need to be considered to select the next router among the one-hop neighbors.

SPEED (Stateless Protocol for End-to-End Delay)[6] is a well known stateless routing protocol for real-time communication in sensor networks. It is based on geometric routing protocols such as greedy forwarding GPSR (Greedy Perimeter State Routing) [7][8]. MMSPEED (Multi-path and Multi-SPEED Routing Protocol) [2] is an extension of SPEED that focuses on differentiated QoS options for real-time applications with multiple different deadlines. It provides differentiated QoS options both in timeliness domain and the reliability domain. For timeliness, multiple QoS levels are supported by providing multiple data delivery speed options. For reliability, multiple reliability requirements are supported by probabilistic multi-path forwarding. The protocol provides end-to-end QoS provisioning by employing localized geographic forwarding using immediate neighbor information without end-to-end path discovery and maintenance. It utilizes dynamic compensation which compensates for inaccuracy of local decision as a packet travels towards its destination. The protocol adapts to network dynamics. MMSPEED does not include energy metric during QoS route selection.

Sharif et al., [9] presented a new transport layer protocol that prioritizes sensed information based on its nature while simultaneously supporting the data reliability and congestion control features. Rusli et al., [10] propose an analytical framework model based on Markov Chain of OR and M/D/l/K queue to measure its performance in term of end-to-end delay and reliability in WSNs.

Koulali et al., [11] propose a hybrid QoS routing protocol for WSNs based on a customized Distributed Genetic Algorithm (DGA) that accounts for delay and energy constraints. Yunbo Wang et al., [12] investigate the end-to-end delay distribution, they develop a comprehensive cross-layer analysis framework, which employs a stochastic queuing model in realistic channel environments. Ehsan et al., [13] propose energy and

cross-layer aware routing schemes for multichannel access WSNs that account for radio, MAC contention, and network constraints. Geographical routing protocols have been proposed, such as GREES (Geographic Routing with Environmental Energy Supply) [14], DHGR (Dynamic Hybrid Geographical Routing) [15], and EAGFS (Energy Aware Geographical Forwarding Scheme) [16].

DARA (Distributed Aggregate Routing Algorithm) [3] considers reliability, delay, and residual energy in the routing metric, and defines two kinds of packets: critical and non-critical packets. The same weighted metric is used for both types of packets, where the only difference is that a set of candidates reached with a higher transmission power is considered to route critical packets. For delay estimation, the authors use queuing theory and suggest a method that, in practice, needs huge amount of sample storages.

All the above routing protocols are based on one-hop neighborhood information. However, it is expected that multi-hop information can lead to improved performance in many issues including message broadcasting and routing. Chen et al., [17] study the performance of 1-hop, 2-hop and 3hop neighborhood information based routing and propose that gain from 2-hop to 3-hop is relatively minimal, while that from 1-hop to 2-hop based routing is significant. Li et al., [4] have proposed a Two-Hop Velocity Based Routing Protocol (THVR). Shiva Prakash et al., [18] propose a Link Reliability based Two-Hop Routing protocol which achieves to reduce packet deadline miss ratio while considering link reliability, two-hop delay and power efficiency.

Djenouri et al., [5] propose a new localized quality of service (QoS) routing protocol (LO-CALMOR) it is based on differentiating QoS requirements according to the data type, which enables to provide several and customized QoS metrics for each traffic category. With each packet, the protocol attempts to fulfill the required data-related QoS metrics while considering power efficiency. The protocol proposed in this paper is different from LOCALMOR it considers two-hop transmission delay and queuing delay for select-

ing the optimal path.

3. Problem Definition

The topology of a wireless sensor network may be described by a graph G = (N, L), where N is the set of nodes and L is the set of links. The objectives are to,

- Maximize the Packet Reception ratio (PRR).
- Reduce the end-to-end packet delay.
- Improve the energy efficiency (ECPP-Energy Consumed Per Packet) of the network.

3.1. Network Model and Assumptions

In our network model, we assume the following:

- The wireless sensor nodes consists of N sensor nodes and a sink, the sensors are distributed randomly in a field. The nodes are aware of their positions through internal global positioning system (GPS).
- The N sensor nodes are powered by a nonrenewable on board energy source. All nodes are supposed to be aware of their residual energy and have the same transmission power range.
- The sensors share the same wireless medium each packet is transmitted as a local broadcast in the neighborhood. We assume any MAC protocol, which ensures that among the neighbors in the local broadcast range, only the intended receiver keeps the packet and the other neighbors discard the packet.
- Like all localization techniques, [6][2][19] each node needs to be aware of its neighboring nodes current state (ID, position, link reliability, residual energy etc), this is done via HELLO messages.
- In addition, each node sends a second set of HELLO messages to all its neighbors informing them about its one-hop neighbors.
 Hence, each node is aware of its one-hop and two-hop neighbors and their current state.

Table 2 Notations Used in Section 4

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Symbol	Definition
N	Set of Nodes in the WSN
D	Destination Node
S	Source Node
dist(x, y)	Distance between a node pair x, y
$N_1(x)$	Set of one-hop Neighbors of node x
$N_2(x)$	Set of two-hop Neighbors of node x
$F_1^{+p}(x)$	Set of node x 's one-hop favorable forwarders providing positive
	progress towards the destination D
E^{+p}	Set of node x's two-hop
$F_2^{+p}(x,y)$	favorable forwarders
	Estimated hop delay between x and
dt_{xy}	y
dq_x	Estimated queuing delay at node x
	Time deadline to reach Destination
t_{req}	D
V_{req}	Required end-to-end packet delivery
	Velocity for deadline t_{req}
V_{xy}	Velocity offered by $y \in F_1^{+p}(x)$
$V_{xy\to z}$	Velocity offered by $y \in F_2^{+p}(x,y)$
S_{req}	Node pairs satisfying $V_{xy\to z} \geq V_{req}$
=	Transmission power cost from node x
$T_a(dist(x,y)^{\alpha})$	to node y
E_u	Remaining energy of node y
	Packet Reception Ratio of link relay-
prr_{xy}	ing
	node x to node y
β	Tunable weighting coefficient for prr
ρ	estimation
γ	Tunable weighting coefficient for
I	queuing and
	transmission delay estimation

 Nodes are assumed to be stationary or having low mobility. The network density is assumed to be high enough to prevent the void situation.

4. Algorithm

TDTHR has the following components: a link reliability estimator, a queuing and transmission delay estimator, a node forwarding metric incorporated with the two-hop dynamic velocity assignment policy and a queuing controller. The proposed protocol LRTHR implements the modules for estimating queuing and transmission delay and packet delivery ratios using efficient methods. The packet delay is estimated at the node itself and the packet delivery ratio is estimated by the neighboring nodes. These parameters are updated on reception of a HELLO packet, the

HELLO messages are periodically broadcast to update the estimation parameters. The overhead caused by the 1-hop and 2-hop updating are reduced by piggybacking the information in ACK, hence improving the energy efficiency. The notations used in this paper are given in Table 2. The protocol is based on the following parameters: (i) Link Reliability Estimation; (ii) Queuing and Transmission Delay Estimation; (iii) Node Forwarding Metric; and (iv) Queuing Controller

4.1. Link Reliability Estimation

The Packet Reception Ratio (PRR) of the link relaying node x to y is denoted by prr_{xy} . It denotes the probability of successful delivery over the link. Window Mean Exponential Weighted Moving Average (WMEWMA) based link quality estimation is used for the proposed protocol. The window mean exponential weighted moving average estimation applies filtering on PRR, thus providing a metric that resists transient fluctuations of PRR, yet is responsive to major link quality changes. This parameter is updated by node y at each window and inserted into the HELLO message packet for usage by node x in the next window. Eqn. 1 shows the window mean exponential weighted moving average estimation of the link reliability, r is the number of packets received, m is the number of packets missed and $\beta \in [0,1]$ is the history control factor, which controls the effect of the previously estimated value on the new one, $\frac{r}{r+m}$ is the newly measured PRR

$$prr_{xy} = \beta \times prr_{xy} + (1 - \beta) \times \frac{r}{r + m}$$
 (1)

The PRR estimator is updated at the receiver side for each w (window size) received packets, the computation complexity of this estimator is O(1). The appropriate values for β and w for a stable window mean exponential weighted moving average are w = 30 and $\beta = 0.6[20]$.

4.2. Queuing and Transmission Delay Estimation

The nodal delay indicates the time spent to send a packet from node x to its neighbor y, it is comprised of the queuing delay (delay_Q), con-

tention delay (delay_C) and the transmission delay (delay_T).

$$delay_{node} = delay_O + delay_C + delay_T$$
 (2)

The queuing delay constitutes the time the packet is assigned to a queue for transmission and the time it starts being transmitted. During this time, the packet waits while other packets in the transmission queue are transmitted. Every node evaluates its queuing delay dq_x for the various classes of queues used, i.e., Critical-Queue, Delay-Responsive-Queue, Reliability-Responsive-Queue and Regular-Queue, each packet class has a different estimation of dq_x for the queuing delay, i.e., $dq_x < packet.class >$. Eqn. 3 shows the EWMA (Exponential Weighted Moving Average) update for queuing delay estimation, dq is the current precise queue waiting time of the respective packet and $\gamma \in [0,1]$ is the tunable weighting coefficient.

$$dq_x < packet.class >= \gamma \times$$

$$dq_x < packet.class > (3)$$

$$+ (1 - \gamma) \times dq$$

The transmission delay represents the time that the first and last bits of the packet are transmitted. If t_s is the time the packet is ready for transmission and becomes head of transmission queue, t_{ack} the time of the reception of acknowledgment, BW the network bandwidth and size of the acknowledgment then, $t_{ack} - sizeof(ACK)/BW - t_s$ is the recently estimated delay. Eqn. 4 shows the EWMA (Exponential Weighted Moving Average) update for transmission delay estimation, which has the advantage of being simple and less resource demanding.

$$dt_{xy} = \gamma \times dt_{xy} + (1 - \gamma) \times (t_{ack} - sizeof(ACK)/BW - t_s)$$
 (4)

 dt_{xy} includes estimation of the time interval from the packet that becomes head of line of x's transmission queue until its reception at node y. This takes into account all delays due to contention, channel sensing, channel reservation (RTS/CTS) if any, depending on the medium access control (MAC) protocol, propagation, time slots etc. The computation complexity of the estimators are O(1). The delay information is further exchanged among two-hop neighbors.

Algorithm 1: Traffic-Differentiated Two-Hop Routing (TDTHR)

```
Input: x, D, F_1^{+p}(x), F_2^{+p}(x), lt

Output: Node y providing positive progress towards D

V_{req} = \frac{dist(x,D)}{lt}; for each \ y \in F_2^{+p}(x) do

V_{xy \to z} = \frac{dist(x,D) - dist(k,D)}{dq_x < packet.class > + dt_{xy} + dq_y < packet.class > + dt_{yz}}; S_{req} = \{F_2^{+p}(x) : V_{xy \to z} \ge V_{req}\}; if (|S_{req}|) = 1 then

Return y \in S_{req}; else

if packet.class == delay.responsive then

for each \ y \in S_{req} do

Return y with max \ E_y \ min

T_a(dist(x,y)^{\alpha}); else

if packet.class == critical then

for each \ y \in S_{req} do

S_c = \text{Return } y \text{ with } max \ prr_{xy}; if (|S_c|) = 1 then

Return y \in S_c; else

for each \ y \in S_c do

Return y \text{ with } max \ E_y \ min

T_a(dist(x,y)^{\alpha});
```

4.3. Node Forwarding Metric

In the wireless sensor network, described by a graph G = (N, L). If node x can transmit a message directly to node y, the ordered pair is an element of L. We define for each node x the set $N_1(x)$, which contains the nodes in the network G that are one-hop i.e., direct neighbors of x.

$$N_1(x) = \{ y : (x; y) \in E \text{ and } y \neq x \}$$
 (5)

Likewise, the two-hop neighbors of x is the set $N_2(x)$ i.e.,

$$N_2(x) = \{z : (y; z) \in E \text{ and } y \in N_1(x), z \neq x\}$$

(6)

The euclidean distance between a pair of nodes x and y is defined by dist(x,y). We define $F_1^{+p}(x)$ as the set of x's one-hop favorable forwarders providing positive progress towards the destination D. It consists of nodes that are closer to the destination than x, i.e.,

$$F_1^{+p}(x) = \{ y \in N_1(x) : dist(x, D) - dist(y, D) > 0 \}$$
(7)

 $F_2^{+p}(x)$ is defined as the set of two-hop favorable forwarders *i.e.*,

$$F_2^{+p}(x) = \{ y \in F_1^{+p}(x), z \in N_1(y) : \\ dist(y, D) - dist(z, D) > 0 \}$$
 (8)

We define two velocities; the required velocity V_{req} and the velocity offered by the two-hop favorable forwarding pairs. In SPEED[6], the velocity provided by each of the forwarding nodes in $(F_1^{+p}(x))$ is.

$$V_{xy} = \frac{dist(x, D) - dist(y, D)}{dt_{xy}}$$
(9)

As in THVR[4], by two-hop knowledge, node x can calculate the velocity offered by each of the two-hop favorable forwarding pairs $(F_1^{+p}(x), F_2^{+p}(x))$ as shown in Eqn. 10. Furthermore, we include queuing delay at both the current (dq_x)) and the next hop (dq_y) nodes, with the two-hop transmission delay (dt_{xy}) and dt_{yz} , this distinguishes the proposed protocol from LO-CALMOR[5].

$$V_{xy\to z} = \frac{dist(x, D) - dist(z, D)}{dq_x < pak.class > + dt_{xy} + dq_y < pak.class > + dt_{yz}}$$
(10)

Where, $y \in F_1^{+p}(x)$ and $z \in F_2^{+p}(x)$. The required velocity is relative to the progress made towards the destination [21] and the time remaining to the deadline, lt (lag time). The lag time is the time remaining until the packet deadline expires. At each hop, the transmitter renews this parameter in the packet header i.e.,

$$lt = lt_p - (t_{tx} - t_{rx} + sizeof(packet)/BW)$$
 (11)

Where lt is the time remaining to the deadline (t_{req}) , lt_p is the previous value of lt, $(t_{tx} - t_{rx} + sizeof(packet)/BW)$ accounts for the delay from reception of the packet until transmission. On reception of the packet the node x, uses lt to calculate the required velocity V_{req} for all nodes in $(F_1^{+p}(x), F_2^{+p}(x))$ as shown in Eqn. 12.

$$V_{req} = \frac{dist(x, D)}{lt} \tag{12}$$

The node pairs satisfying $V_{xy\to z} \geq V_{req}$ form the set of nodes S_{req} , if the packet class is delay.responsive then the node with the maximum residual energy and minimum transmission power cost is chosen from the set S_{req} . However, if the packet class is critical then the node with the highest packet reception ratio (PRR) is selected from S_{req} , but if more than one node has the same maximum PRR, a node with maximum power efficiency is picked.

The Traffic-Differentiated Two-Hop Routing is shown in Algorithm 1, the computation complexity of this algorithm is $O(F_2^{+p}(x))$. Our proposed protocol is different from LOCALMOR, as it considers two-hop neighborhood information that will provide enhanced foresight to the sender in identifying the node that can offer the required QoS and route the packets in real-time.

Algorithm 2: Queuing Controller

```
Input: Packet, Queues

for each Packet in node do

if packet.class == critical then

Place Packet in Critical-Queue;

else

if packet.class == delay.responsive then

Place Packet in

Delay-Responsive-Queue;

else

Place Packet in

Reliability-Responsive-Queue;

Start Timer;

for each Timer Expire do

Shift packet to Critical Queue;

for each Packet Transmission do

Stop Timer;
```

4.4. Queuing Controller

The queuing controller helps accomplish low delay when routing critical and delay-responsive packets, higher precedence should be given to these packets in channel contention than the normal packets (regular and reliability-responsive Additionally, critical packets need packets). higher priority than delay-responsive packets. This can be accomplished by implemented the queuing controller module as detailed in Algorithm 2 [5]. Three queues are used to send packets from the highest priority queue to the lowest one. The highest priority queue, Critical-Queue, is used by critical packets, the second highest priority queue, Delay-Responsive-Queue, is used by delay-responsive packets, and the least priority queue, Reliability-Responsive-Queue, is used by regular and reliability-responsive packets. The number of critical and delay-responsive packets is usually small, and there would be instances where their corresponding queues are vacant, else higher priority traffic may hinder lower priority traffic. Hence, a timer for each packet is employed to move it to the highest priority queue.

5. Performance Evaluation

To evaluate the proposed protocol, we carried out a simulation study using ns-2 [22]. In this study the proposed protocol (LRDTHR) is compared with LOCALMOR, DARA and MM-SPEED. The simulation configuration consists of 900 nodes located in a 1800 m^2 area. Nodes are distributed following Poisson point process with a node density of $0.00027 \text{ node}/m^2$. The primary and secondary sink nodes are located in the region (0,0) and (1800, 1800) while the source node is located in the center of the simulation area, equidistant from both the sinks. The source generated a CBR flow of 1 kB/second with a packet size of 150 bytes. Critical and regular packets are used in the simulation for comparing our protocol with LO-CALMOR, DARA and MMSPEED, while delaysensitive and reliability-sensitive packets are used for comparing with LOCALMOR only. The deadline requirement was fixed in this simulation to 300ms for all class of packets.

The MAC layer, link quality and energy consumption parameters are set as per TelosB³ (TPR2420) mote [23] with CC2420 radio as per LOCALMOR. Table 3 summarizes the simulation parameters. LOCALMOR, DARA and MM-SPEED are QoS protocols and a comparison of PRR (Packet Reception Ratio), ECPP (Energy Consumed Per Packet *i.e.*, the total energy expended divided by the number of packets effectively transmitted), packet average end-to-end delay (mean of packet delay) and the network lifetime are obtained.

Table 3 Simulation Parameters.

Simulation Parameters	Value
Number of nodes	900
Simulation Topology	1800m x 1800m
Traffic	CBR
Critical Packet Rate	From 0 to 1
Regular Packet Rate	1 - CPR
Payload Size	150 Bytes
Transmission Power Range	100m
Initial Battery Energy	2.0 Joules
Energy Consumed during Transmit	0.0522 Joule
Energy Consumed during Receive	0.0591 Joule
Energy Consumed during Sleep	0.00006 Joule
Energy Consumed during Idle	0.000003 Joule
Propagation Model	Free Space
Hello Period	5 seconds
PRR - WMEWMA Window	30
PRR - WMEWMA Weight Factor (β)	0.6
Queuing/Delay - EWMA Weight Factor (γ)	0.5

In the first set of simulations the critical packet rate was varied from 0.1 to 1 and the remaining rate to 1 represents regular packet rate. Figure 1 and Figure 2 illustrates the efficiency of the TDTHR algorithm in increasing the PRR with respect to regular and critical packets. TDTHR, LOCALMOR and DARA linearly increase their performance as a function of critical packet rate, while performance of MMSPEED is relatively constant. The high reliability of TDTHR, LOCALMOR and DARA is due to the use of efficient re-duplication towards different sinks, compared to MMSPEED that uses a multi-path single-sink approach, this results in packet congestion either at the final sink or intermediate nodes.

In Figure 2 the linear increase of the packet reception ratio for TDTHR, LOCALMOR and DARA with the increasing critical packet rate can be explained by the subsequent increase of

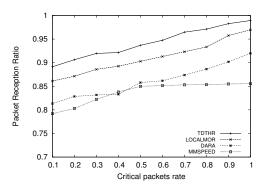


Figure 1. Packet Reception Ratio - Regular Packets

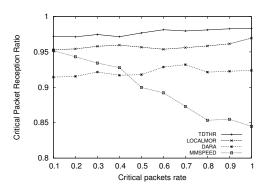


Figure 2. Packet Reception Ratio - Critical Packets

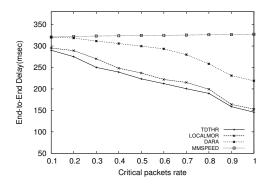


Figure 3. End-to-End Delay - Regular Packets

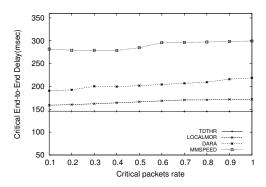


Figure 4. End-to-End Delay - Critical Packets

re-duplications (addressed only to critical packets). Hence, the larger the number of critical packets we have, the more the packets are duplicated, which eventually increases their reception ratio. In TDTHR the two-hop based routing and dynamic velocity of the TDTHR algorithm is able to aggressively route more packets to the sink node, hence it is observed that TDTHR has higher PRR than the others in general.

Figure 3 and Figure 4 illustrate the packet endto-end delay of regular packets and critical packets respectively, performance of LRTHR is better that the other protocols. LOCALMOR and

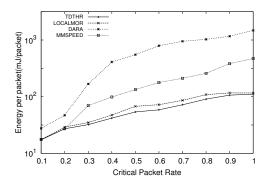


Figure 5. ECPP vs Packet Rate

DARA consider one-hop transmission delay and queuing waiting time, while TDTHR considers dynamic velocity, two-hop transmission delay and queuing waiting time hence the selected paths from source to sink will be shorter and aid in reducing the end-to-end delay. MMSPEED also considers queuing and transmission delays, but on the other hand, the use of multi-path singlesink transmissions causes congestion and thus results in several retransmission of packets before successful reception, which explains the relatively higher delay. In Figure 4 we notice a stable endto-end delay for all protocols, which indicates the strength of the routes selected for critical packets that are clearly not affected by the rise in rate of critical packets.

As depicted in Figure 5 the energy consumption per packet (ECPP) successfully transmitted, ascend as the critical packet rate increases. The energy consumption has similar tendency in both TDTHR and LOCALMOR but DARA has a higher energy utilization. In LOCALMOR the energy consumption per packet smoothly increases as packet rates become higher. LOCALMOR balances the load among nodes that ensure delivery within the deadline and have high reliability. DARA performs inadequately in terms of energy, as it does neither use any traffic balancing approach nor any probabilistic allocation.

In TDTHR the two-hop based routing will en-

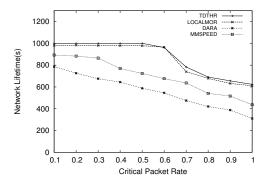


Figure 6. Network Lifetime vs Packet Rate

sure shorter paths between source and sink, by selecting links providing higher PRR on the route to the sink, the energy consumption of the forwarding nodes can be minimized, due to lower number of collisions and re-transmissions and help in traffic balancing. Furthermore, in the proposed protocol the link delay and packet delivery ratios are updated by piggybacking the information in ACK, this will help in reducing the number of feedback packets and hence reduce the total energy consumed. The impact of efficient energy utilization and traffic balancing on network lifetime is depicted in Figure 6, TDTHR and LOCALMOR show good performance compared to DARA and MMSPEED.

Last, we study the performance of TDTHR and LOCALMOR with respect to delay-responsive and reliability-responsive traffic. The QoS traffic is varied in the same way as critical packets were varied in the earlier simulations, *i.e.*, each QoS traffic varies from 0.1 to 1. Figure 7 and Figure 8 examines the results. This comparison is important because we need to ascertain the positive effect of two-hop delay incorporated in TDTHR over the one-hop delay used in the LOCALMOR. The delay-responsive traffic are routed through more delay efficient links, while reliability-responsive traffic, considers only reliable links. From Figure 7 and Figure 8 it is clear that the performance of TDTHR is bet-

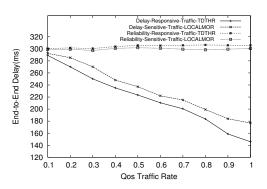


Figure 7. TDTHR vs LOCALMOR - End-to-End delay

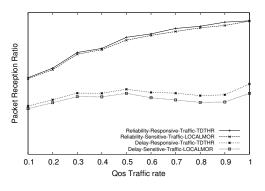


Figure 8. TDTHR vs LOCALMOR - Packet Reception Ratio

ter than LOCALMOR for delay-responsive traffic due to two-hop information and has similar performance for reliability-responsive traffic.

6. Conclusions

In this paper, we propose a Traffic-Differentiated Two-Hop Routing protocol for quality of service (QoS) in WSNs, it provides a differentiation routing using different quality of service metrics. Data traffic has been sequenced into different classes according to the required

QoS, where different routing metrics and techniques are used for each class. The protocol is able to augment real-time delivery by an able integration of multi-queue priority policy, link reliability, two-hop information and dynamic velocity. The protocol is able to increase the PRR, end-to-end delay and improve the energy efficiency throughout the network. This makes the protocol suitable for WSNs with varied traffic, such as medical and vehicular applications.

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Two-Hop Routing with Traffic-Differentiation for QoS Guarantee in Wireless Sensor Networks

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This paper proposes a Traffic-Differentiated Two-Hop Routing protocol for Quality of Service (QoS) in Wireless Sensor Networks (WSNs). It targets WSN applications having different types of data traffic with several priorities. The protocol achieves to increase Packet Reception Ratio (PRR) and reduce end-to-end delay while considering multi-queue priority policy, two-hop neighborhood information, link reliability and power efficiency. The protocol is modular and utilizes effective methods for estimating the link metrics. Numerical results show that the proposed protocol is a feasible solution to addresses QoS service differentiation for traffic with different priorities.

Keywords: End-to-end Delay, Packet Reception Ratio (PRR), Quality-of-Service (QoS), Wireless Sensor Networks (WSNs), Traffic-differentiation, Two-hop Neighbors.

1. Introduction

Wireless Sensor Networks (WSNs) form a framework to accumulate and analyze real time data in smart environment applications. WSNs are composed of inexpensive low-powered micro sensing devices called motes[1], having limited computational capability, memory size, radio transmission range and energy supply. These sensors are spread in an environment without any predetermined infrastructure and cooperate to accomplish common monitoring tasks which usually involves sensing environmental data. With WSNs, it is possible to assimilate a variety of physical and environmental information in near real time from inaccessible and hostile locations.

WSNs have a set of stringent QoS requirements that include timeliness, high reliability, availability and integrity. Various performance metrics that can be used to justify the quality of service include, packet reception ratio (PRR), defined as the probability of successful delivery should be maximized. The end-to-end delay which is in-

fluenced by the queuing delay at the intermediate nodes and the number of hops traversed by the data flows of the session from the source to the receiver. Sensor nodes typically use batteries for energy supply. Hence, energy efficiency and load balancing form important objectives while designing protocols for WSNs. Therefore, providing corresponding traffic differentiated QoS in such scenarios pose a great challenge. Our proposed protocol is motivated primarily by the deficiencies of the previous works (explained in the Section 2) and aims to provide better Quality of Service.

This paper explores the idea of incorporating QoS parameters in making routing decisions the protocol proposes the following features.

1. Data traffic is split into regular traffic with no specific QoS requirement, reliabilityresponsive traffic; which should be transmitted without loss but can tolerate some delay, delay-responsive traffic; which should be delivered within a deadline but may tolerate moderate packet loss and critical traf-

Table 1 Our Results and Comparison with Previous Results for Differentiated QoS Routing in Wireless Sensor Networks.

Related	Protocol	Considered	Estimation	Traffic	Duplication
Work	Name	Metrics	Method	Differentiation	
E. Felemban	MMSPEED	one-hop delay,	EWMA	Delay	Towards
$et \ al.,[2]$	(Multi-path	link reliability		requirement	the same
	and Multi-SPEED	and residual			sink
	Routing Protocol)	energy.			
M.M.	DARA (Data	one-hop delay	Variance-based	Critical	Towards
Or-Rashid	Aggregate	and transmission		Traffic and	different
$et \ al.,[3]$	Routing	power.		Non-Critical	sinks
	Algorithm)			Traffic	
Y. Li	THVR (Two-Hop	two-hop delay	WMEWMA	No	No
$et \ al., [4]$	Velocity Based	and residual			
	Routing Protocol)	energy.			
D. Djenouri	LOCALMOR	one-hop delay	EWMA and	Regular,	Towards
$et \ al., [5]$	(Localized	link reliability	WMEWMA	Reliability	
	Multi-objectives	residual energy		-sensitive, Delay,	sinks
	Routing)	and transmission		-sensitive and	
	_,	power.		Critical Traffic	
This paper	TDTHR	two-hop delay,	EWMA and	Regular,	Towards
	(Traffic	link reliability	WMEWMA	Reliability	different
	-Differentiated	residual energy		-Responsive, Delay,	sinks
	Two-Hop	and transmission		-Responsive and	
	Routing)	power.		Critical Traffic	

fic; which has high significance and demanding both high reliability and short delay.

- 2. Link reliability is considered while choosing the next router, this selects paths which have higher probability of successful delivery.
- Routing decision is based on two-hop neighborhood information and dynamic velocity that can be modified according to the required deadline, this results in significant reduction in end-to-end PRR.
- 4. Choosing nodes with higher residual energy and minimum transmission power, balances the load among nodes and results in prolonged lifetime of the network.

We test the performance of our proposed approaches by implementing our algorithms using ns-2 simulator. Our results demonstrates the performance and benefits of TDTHR over earlier algorithms.

The rest of the paper is organized as follows: Section 2 gives a review of related works. Section 3 and Section 4 explain the network model, notations, assumptions and working of the algorithm. Section 5 is devoted to the simulation and evaluation of the algorithm. Conclusions are presented in Section 6.

2. Related Work

Stateless routing protocols which do not maintain per-route state is a favorable approach for WSNs. The idea of stateless routing is to use location information available to a node locally for routing, *i.e.*, the location of its own and that of its one-hop neighbors without the knowledge about the entire network. These protocols scale well in terms of routing overhead because the tracked routing information does not grow with the network size or the number of active sinks. Parameters like distance to sink, energy efficiency and data aggregation, need to be considered to select the next router among the one-hop neighbors.

SPEED (Stateless Protocol for End-to-End Delay)[6] is a well known stateless routing protocol for real-time communication in sensor networks. It is based on geometric routing protocols such as greedy forwarding GPSR (Greedy Perimeter State Routing) [7][8]. MMSPEED (Multi-path

and Multi-SPEED Routing Protocol) [2] is an extension of SPEED that focuses on differentiated QoS options for real-time applications with multiple different deadlines. It provides differentiated QoS options both in timeliness domain and the reliability domain. For timeliness, multiple QoS levels are supported by providing multiple data delivery speed options. For reliability, multiple reliability requirements are supported by probabilistic multi-path forwarding. The protocol provides end-to-end QoS provisioning by employing localized geographic forwarding using immediate neighbor information without end-to-end path discovery and maintenance. It utilizes dynamic compensation which compensates for inaccuracy of local decision as a packet travels towards its destination. The protocol adapts to network dynamics. MMSPEED does not include energy metric during QoS route selection.

Sharif et al., [9] presented a new transport layer protocol that prioritizes sensed information based on its nature while simultaneously supporting the data reliability and congestion control features. Rusli et al., [10] propose an analytical framework model based on Markov Chain of OR and M/D/1/K queue to measure its performance in term of end-to-end delay and reliability in WSNs.

Koulali et al., [11] propose a hybrid QoS routing protocol for WSNs based on a customized Distributed Genetic Algorithm (DGA) that accounts for delay and energy constraints. Yunbo Wang et al., [12] investigate the end-to-end delay distribution, they develop a comprehensive cross-layer analysis framework, which employs a stochastic queuing model in realistic channel environments. Ehsan et al., [13] propose energy and cross-layer aware routing schemes for multichannel access WSNs that account for radio, MAC contention, and network constraints. Geographical routing protocols have been proposed, such as GREES (Geographic Routing with Environmental Energy Supply) [14], DHGR (Dynamic Hybrid Geographical Routing) [15], and EAGFS (Energy Aware Geographical Forwarding Scheme) [16].

DARA (Distributed Aggregate Routing Algorithm) [3] considers reliability, delay, and resid-

ual energy in the routing metric, and defines two kinds of packets: critical and non-critical packets. The same weighted metric is used for both types of packets, where the only difference is that a set of candidates reached with a higher transmission power is considered to route critical packets. For delay estimation, the authors use queuing theory and suggest a method that, in practice, needs huge amount of sample storages.

All the above routing protocols are based on one-hop neighborhood information. However, it is expected that multi-hop information can lead to improved performance in many issues including message broadcasting and routing. Chen et al., [17] study the performance of 1-hop, 2-hop and 3hop neighborhood information based routing and propose that gain from 2-hop to 3-hop is relatively minimal, while that from 1-hop to 2-hop based routing is significant. Li et al.,[4] have proposed a Two-Hop Velocity Based Routing Protocol (THVR). Shiva Prakash et al., [18] propose a Link Reliability based Two-Hop Routing protocol which achieves to reduce packet deadline miss ratio while considering link reliability, two-hop delay and power efficiency.

Djenouri et al., [5] propose a new localized quality of service (QoS) routing protocol (LO-CALMOR) it is based on differentiating QoS requirements according to the data type, which enables to provide several and customized QoS metrics for each traffic category. With each packet, the protocol attempts to fulfill the required data-related QoS metrics while considering power efficiency. The protocol proposed in this paper is different from LOCALMOR it considers two-hop transmission delay and queuing delay for selecting the optimal path.

3. Problem Definition

The topology of a wireless sensor network may be described by a graph G = (N, L), where N is the set of nodes and L is the set of links. The objectives are to,

• Maximize the Packet Reception ratio (PRR).

- Reduce the end-to-end packet delay.
- Improve the energy efficiency (ECPP-Energy Consumed Per Packet) of the network.

3.1. Network Model and Assumptions

In our network model, we assume the following:

- The wireless sensor nodes consists of N sensor nodes and a sink, the sensors are distributed randomly in a field. The nodes are aware of their positions through internal global positioning system (GPS).
- The N sensor nodes are powered by a nonrenewable on board energy source. All nodes are supposed to be aware of their residual energy and have the same transmission power range.
- The sensors share the same wireless medium each packet is transmitted as a local broadcast in the neighborhood. We assume any MAC protocol, which ensures that among the neighbors in the local broadcast range, only the intended receiver keeps the packet and the other neighbors discard the packet.
- Like all localization techniques, [6][2][19] each node needs to be aware of its neighboring nodes current state (ID, position, link reliability, residual energy etc), this is done via HELLO messages.
- In addition, each node sends a second set of HELLO messages to all its neighbors informing them about its one-hop neighbors. Hence, each node is aware of its one-hop and two-hop neighbors and their current state.
- Nodes are assumed to be stationary or having low mobility. The network density is assumed to be high enough to prevent the void situation.

4. Algorithm

TDTHR has the following components: a link reliability estimator, a queuing and transmission

Table 2 Notations Used in Section 4

Symbol	Definition
N	Set of Nodes in the WSN
D	Destination Node
S	Source Node
dist(x, y)	Distance between a node pair x, y
$N_1(x)$	Set of one-hop Neighbors of node x
$N_2(x)$	Set of two-hop Neighbors of node x
$F_1^{+p}(x)$	Set of node x 's one-hop favorable
	forwarders providing positive
	progress
l m .	towards the destination D
$F_2^{+p}(x,y)$	Set of node x's two-hop
	favorable forwarders
dt_{xy}	Estimated hop delay between x and
dq_x	y Estimated queuing delay at node x
	Time deadline to reach Destination
t_{req}	D
V_{req}	Required end-to-end packet delivery
4	Velocity for deadline t_{req}
V_{xy}	Velocity offered by $y \in F_1^{+p}(x)$
$V_{xy \to z}$	Velocity offered by $y \in F_2^{+p}(x, y)$
S_{reg}	Node pairs satisfying $V_{xy\to z} \ge V_{req}$
$T_a(dist(x,y)^{\alpha})$	Transmission power cost from node x
$I_a(aisi(x,y))$	to node y
E_y	Remaining energy of node y
prr_{xy}	Packet Reception Ratio of link relay-
P··xy	ing
	node x to node y
β	Tunable weighting coefficient for prr
r-	estimation
γ	Tunable weighting coefficient for
•	queuing and
	transmission delay estimation

delay estimator, a node forwarding metric incorporated with the two-hop dynamic velocity assignment policy and a queuing controller. The proposed protocol LRTHR implements the modules for estimating queuing and transmission delay and packet delivery ratios using efficient methods. The packet delay is estimated at the node itself and the packet delivery ratio is estimated by the neighboring nodes. These parameters are updated on reception of a HELLO packet, the HELLO messages are periodically broadcast to update the estimation parameters. The overhead caused by the 1-hop and 2-hop updating are reduced by piggybacking the information in ACK, hence improving the energy efficiency. The notations used in this paper are given in Table 2. The protocol is based on the following parameters: (i) Link Reliability Estimation; (ii) Queuing and Transmission Delay Estimation; (iii) Node

Forwarding Metric; and (iv) Queuing Controller

4.1. Link Reliability Estimation

The Packet Reception Ratio (PRR) of the link relaying node x to y is denoted by prr_{xy} . It denotes the probability of successful delivery over the link. Window Mean Exponential Weighted Moving Average (WMEWMA) based link quality estimation is used for the proposed protocol. The window mean exponential weighted moving average estimation applies filtering on PRR, thus providing a metric that resists transient fluctuations of PRR, yet is responsive to major link quality changes. This parameter is updated by node y at each window and inserted into the HELLO message packet for usage by node x in the next window. Eqn. 1 shows the window mean exponential weighted moving average estimation of the link reliability, r is the number of packets received, m is the number of packets missed and $\beta \in [0,1]$ is the history control factor, which controls the effect of the previously estimated value on the new one, $\frac{r}{r+m}$ is the newly measured PRR value.

$$prr_{xy} = \beta \times prr_{xy} + (1 - \beta) \times \frac{r}{r + m}$$
 (1)

The PRR estimator is updated at the receiver side for each w (window size) received packets, the computation complexity of this estimator is O(1). The appropriate values for β and w for a stable window mean exponential weighted moving average are w = 30 and $\beta = 0.6[20]$.

4.2. Queuing and Transmission Delay Estimation

The nodal delay indicates the time spent to send a packet from node x to its neighbor y, it is comprised of the queuing delay (delay_Q), contention delay (delay_C) and the transmission delay (delay_T).

$$delay_{node} = delay_Q + delay_C + delay_T$$
 (2)

The queuing delay constitutes the time the packet is assigned to a queue for transmission and the time it starts being transmitted. During this time, the packet waits while other packets in the transmission queue are transmitted. Every node evaluates its queuing delay dq_x for the various classes of queues used, i.e., Critical-Queue, Delay-Responsive-Queue, Reliability-Responsive-Queue and Regular-Queue, each packet class has a different estimation of dq_x for the queuing delay, i.e., $dq_x < packet.class >$. Eqn. 3 shows the EWMA (Exponential Weighted Moving Average) update for queuing delay estimation, dq is the current precise queue waiting time of the respective packet and $\gamma \in [0,1]$ is the tunable weighting coefficient.

$$dq_x < packet.class >= \gamma \times$$

$$dq_x < packet.class > (3)$$

$$+ (1 - \gamma) \times dq$$

The transmission delay represents the time that the first and last bits of the packet are transmitted. If t_s is the time the packet is ready for transmission and becomes head of transmission queue, t_{ack} the time of the reception of acknowledgment, BW the network bandwidth and size of the acknowledgment then, $t_{ack} - sizeof(ACK)/BW - t_s$ is the recently estimated delay. Eqn. 4 shows the EWMA (Exponential Weighted Moving Average) update for transmission delay estimation, which has the advantage of being simple and less resource demanding.

$$dt_{xy} = \gamma \times dt_{xy} + (1 - \gamma) \times (t_{ack} - sizeof(ACK)/BW - t_s)$$
 (4)

 dt_{xy} includes estimation of the time interval from the packet that becomes head of line of x's transmission queue until its reception at node y. This takes into account all delays due to contention, channel sensing, channel reservation (RTS/CTS) if any, depending on the medium access control (MAC) protocol, propagation, time slots etc. The computation complexity of the estimators are O(1). The delay information is further exchanged among two-hop neighbors.

4.3. Node Forwarding Metric

In the wireless sensor network, described by a graph G = (N, L). If node x can transmit a message directly to node y, the ordered pair is an element of L. We define for each node x the set

Algorithm 1: Traffic-Differentiated Two-Hop Routing (TDTHR)

```
Input: x, D, F_1^{+p}(x), F_2^{+p}(x), lt
Output: Node y providing positive progress towards
V_{req} = \frac{dist(x,D)}{lt};

for each y \in F_2^{+p}(x) do

V_{xy \to z} = V_{xy \to z}
   \frac{v_{xy \to z} - }{dq_x < packet.class > + dt_{xy} + dq_y < packet.class > + dt_{yz}} ; 
else
     if packet.class == delay.responsive then
           for each y \in S_{req} do
                Return y with max E_y min
               T_a(dist(x,y)^{\alpha});
           if packet.class == critical then
                for each y \in S_{req} do
                 S_c = \text{Return } y \text{ with } max \ prr_{xy};
                if (|S_c|) = 1 then
                 Return y \in S_c;
                else
                     for each y \in S_c do
                           Return y with max E_y min
                           T_a(dist(x,y)^{\alpha});
```

 $N_1(x)$, which contains the nodes in the network G that are one-hop *i.e.*, direct neighbors of x.

$$N_1(x) = \{y : (x; y) \in E \text{ and } y \neq x\}$$
 (5)

Likewise, the two-hop neighbors of x is the set $N_2(x)$ i.e.,

$$N_2(x) = \{z : (y; z) \in E \text{ and } y \in N_1(x), z \neq x\}$$
(6)

The euclidean distance between a pair of nodes x and y is defined by dist(x,y). We define $F_1^{+p}(x)$ as the set of x's one-hop favorable forwarders providing positive progress towards the destination D. It consists of nodes that are closer to the destination than x, i.e.,

$$F_1^{+p}(x) = \{ y \in N_1(x) : dist(x, D) - dist(y, D) > 0 \}$$
(7)

 $F_2^{+p}(x)$ is defined as the set of two-hop favorable forwarders *i.e.*.

$$F_2^{+p}(x) = \{ y \in F_1^{+p}(x), z \in N_1(y) : \\ dist(y, D) - dist(z, D) > 0 \}$$
 (8)

We define two velocities; the required velocity V_{req} and the velocity offered by the two-hop favorable forwarding pairs. In SPEED[6], the velocity provided by each of the forwarding nodes in $(F_1^{+p}(x))$ is.

$$V_{xy} = \frac{dist(x, D) - dist(y, D)}{dt_{xy}}$$
(9)

As in THVR[4], by two-hop knowledge, node x can calculate the velocity offered by each of the two-hop favorable forwarding pairs $(F_1^{+p}(x), F_2^{+p}(x))$ as shown in Eqn. 10. Furthermore, we include queuing delay at both the current (dq_x) and the next hop (dq_y) nodes, with the two-hop transmission delay (dt_{xy}) and dt_{yz} , this distinguishes the proposed protocol from LO-CALMOR[5].

$$V_{xy\to z} = \frac{dist(x, D) - dist(z, D)}{dq_x < pak.class > + dt_{xy} + dq_y < pak.class > + dt_{yz}}$$
(10)

Where, $y \in F_1^{+p}(x)$ and $z \in F_2^{+p}(x)$. The required velocity is relative to the progress made towards the destination [21] and the time remaining to the deadline, lt (lag time). The lag time is the time remaining until the packet deadline expires. At each hop, the transmitter renews this parameter in the packet header i.e.,

$$lt = lt_p - (t_{tx} - t_{rx} + sizeof(packet)/BW)$$
 (11)

Where lt is the time remaining to the deadline (t_{req}) , lt_p is the previous value of lt, $(t_{tx} - t_{rx} + sizeof(packet)/BW)$ accounts for the delay from reception of the packet until transmission. On reception of the packet the node x, uses lt to calculate the required velocity V_{req} for all nodes in $(F_1^{+p}(x), F_2^{+p}(x))$ as shown in Eqn. 12.

$$V_{req} = \frac{dist(x, D)}{lt} \tag{12}$$

The node pairs satisfying $V_{xy\to z} \geq V_{req}$ form the set of nodes S_{req} , if the packet class is delay.responsive then the node with the maximum residual energy and minimum transmission power cost is chosen from the set S_{req} . However, if the packet class is critical then the node with the highest packet reception ratio (PRR) is selected from S_{req} , but if more than one node has the same maximum PRR, a node with maximum power efficiency is picked.

The Traffic-Differentiated Two-Hop Routing is shown in Algorithm 1, the computation complexity of this algorithm is $O(F_2^{+p}(x))$. Our proposed protocol is different from LOCALMOR, as it considers two-hop neighborhood information that will provide enhanced foresight to the sender in identifying the node that can offer the required QoS and route the packets in real-time.

4.4. Queuing Controller

The queuing controller helps accomplish low delay when routing critical and delay-responsive packets, higher precedence should be given to these packets in channel contention than the normal packets (regular and reliability-responsive packets). Additionally, critical packets need higher priority than delay-responsive packets. This can be accomplished by implemented the

```
Input: Packet, Queues

for each Packet in node do

if packet.class == critical then

Place Packet in Critical-Queue;

else

if packet.class == delay.responsive then

Place Packet in

Delay-Responsive-Queue;

else

Place Packet in

Reliability-Responsive-Queue;
```

for each Timer Expire do

☐ Shift packet to Critical Queue;
for each Packet Transmission do
☐ Stop Timer;

Start Timer;

Algorithm 2: Queuing Controller

queuing controller module as detailed in Algorithm 2 [5]. Three queues are used to send packets from the highest priority queue to the lowest one. The highest priority queue, Critical-Queue, is used by critical packets, the second highest priority queue, Delay-Responsive-Queue, is used by delay-responsive packets, and the least priority queue, Reliability-Responsive-Queue, is used by regular and reliability-responsive packets. The number of critical and delay-responsive packets is usually small, and there would be instances where their corresponding queues are vacant, else higher priority traffic may hinder lower priority traffic. Hence, a timer for each packet is employed to move it to the highest priority queue.

5. Performance Evaluation

To evaluate the proposed protocol, we carried out a simulation study using ns-2 [22]. In this study the proposed protocol (LRDTHR) is compared with LOCALMOR, DARA and MM-SPEED. The simulation configuration consists of 900 nodes located in a 1800 m^2 area. Nodes are distributed following Poisson point process with a node density of $0.00027 \text{ node}/m^2$. The primary and secondary sink nodes are located in the region (0,0) and (1800, 1800) while the source node is located in the center of the simulation area, equidistant from both the sinks. The source generated a

CBR flow of 1 kB/second with a packet size of 150 bytes. Critical and regular packets are used in the simulation for comparing our protocol with LO-CALMOR, DARA and MMSPEED, while delay-sensitive and reliability-sensitive packets are used for comparing with LOCALMOR only. The dead-line requirement was fixed in this simulation to 300ms for all class of packets.

The MAC layer, link quality and energy consumption parameters are set as per TelosB³ (TPR2420) mote [23] with CC2420 radio as per LOCALMOR. Table 3 summarizes the simulation parameters. LOCALMOR, DARA and MM-SPEED are QoS protocols and a comparison of PRR (Packet Reception Ratio), ECPP (Energy Consumed Per Packet *i.e.*, the total energy expended divided by the number of packets effectively transmitted), packet average end-to-end delay (mean of packet delay) and the network lifetime are obtained.

Table 3
Simulation Parameters.

Simulation Parameters	Value
Number of nodes	900
Simulation Topology	1800m x 1800m
Traffic	CBR
Critical Packet Rate	From 0 to 1
Regular Packet Rate	1 - CPR
Payload Size	150 Bytes
Transmission Power Range	100m
Initial Battery Energy	2.0 Joules
Energy Consumed during Transmit	0.0522 Joule
Energy Consumed during Receive	0.0591 Joule
Energy Consumed during Sleep	0.00006 Joule
Energy Consumed during Idle	0.000003 Joule
Propagation Model	Free Space
Hello Period	5 seconds
PRR - WMEWMA Window	30
PRR - WMEWMA Weight Factor (β)	0.6
Queuing/Delay - EWMA Weight Factor (γ)	0.5

In the first set of simulations the critical packet rate was varied from 0.1 to 1 and the remaining rate to 1 represents regular packet rate. Figure 1 and Figure 2 illustrates the efficiency of the TDTHR algorithm in increasing the PRR with respect to regular and critical packets. TDTHR, LOCALMOR and DARA linearly increase their performance as a function of critical packet rate, while performance of MMSPEED is relatively constant. The high reliability of TDTHR, LOCALMOR and DARA is due to the use of efficient

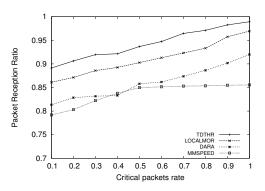


Figure 1. Packet Reception Ratio - Regular Packets

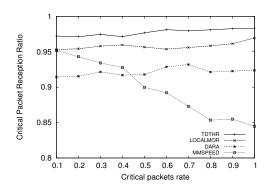
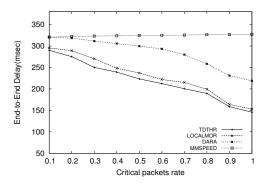


Figure 2. Packet Reception Ratio - Critical Packets

re-duplication towards different sinks, compared to MMSPEED that uses a multi-path single-sink approach, this results in packet congestion either at the final sink or intermediate nodes.

In Figure 2 the linear increase of the packet reception ratio for TDTHR, LOCALMOR and DARA with the increasing critical packet rate can be explained by the subsequent increase of re-duplications (addressed only to critical packets). Hence, the larger the number of critical packets we have, the more the packets are duplicated, which eventually increases their recep-



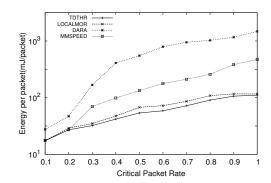
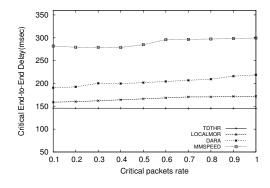


Figure 3. End-to-End Delay - Regular Packets

Figure 5. ECPP vs Packet Rate



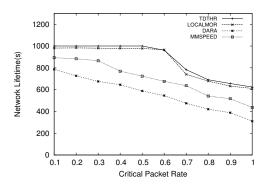


Figure 4. End-to-End Delay - Critical Packets

Figure 6. Network Lifetime vs Packet Rate

tion ratio. In TDTHR the two-hop based routing and dynamic velocity of the TDTHR algorithm is able to aggressively route more packets to the sink node, hence it is observed that TDTHR has higher PRR than the others in general.

Figure 3 and Figure 4 illustrate the packet endto-end delay of regular packets and critical packets respectively, performance of LRTHR is better that the other protocols. LOCALMOR and DARA consider one-hop transmission delay and queuing waiting time, while TDTHR considers dynamic velocity, two-hop transmission delay and queuing waiting time hence the selected paths from source to sink will be shorter and aid in reducing the end-to-end delay. MMSPEED also considers queuing and transmission delays, but on the other hand, the use of multi-path single-sink transmissions causes congestion and thus results in several retransmission of packets before successful reception, which explains the relatively higher delay. In Figure 4 we notice a stable end-to-end delay for all protocols, which indicates the strength of the routes selected for critical packets that are clearly not affected by the rise in rate of critical packets.

As depicted in Figure 5 the energy consump-

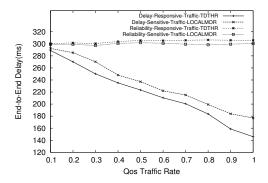


Figure 7. TDTHR vs LOCALMOR - End-to-End delay

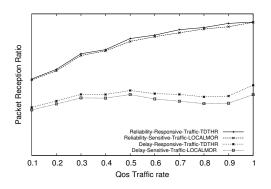


Figure 8. TDTHR vs LOCALMOR - Packet Reception Ratio

tion per packet (ECPP) successfully transmitted, ascend as the critical packet rate increases. The energy consumption has similar tendency in both TDTHR and LOCALMOR but DARA has a higher energy utilization. In LOCALMOR the energy consumption per packet smoothly increases as packet rates become higher. LOCALMOR balances the load among nodes that ensure delivery within the deadline and have high reliability. DARA performs inadequately in terms of energy, as it does neither use any traffic balancing approach nor any probabilistic allocation.

In TDTHR the two-hop based routing will ensure shorter paths between source and sink, by selecting links providing higher PRR on the route to the sink, the energy consumption of the forwarding nodes can be minimized, due to lower number of collisions and re-transmissions and help in traffic balancing. Furthermore, in the proposed protocol the link delay and packet delivery ratios are updated by piggybacking the information in ACK, this will help in reducing the number of feedback packets and hence reduce the total energy consumed. The impact of efficient energy utilization and traffic balancing on network lifetime is depicted in Figure 6, TDTHR and LO-CALMOR show good performance compared to DARA and MMSPEED.

Last, we study the performance of TDTHR and LOCALMOR with respect to delay-responsive and reliability-responsive traffic. The QoS traffic is varied in the same way as critical packets were varied in the earlier simulations, i.e., each QoS traffic varies from 0.1 to 1. Figure 7 and Figure 8 examines the results. This comparison is important because we need to ascertain the positive effect of two-hop delay incorporated in TDTHR over the one-hop delay used in the LOCALMOR. The delay-responsive traffic are routed through more delay efficient links, while reliability-responsive traffic, considers only reliable links. From Figure 7 and Figure 8 it is clear that the performance of TDTHR is better than LOCALMOR for delay-responsive traffic due to two-hop information and has similar performance for reliability-responsive traffic.

6. Conclusions

In this paper, we propose a Traffic-Differentiated Two-Hop Routing protocol for quality of service (QoS) in WSNs, it provides a differentiation routing using different quality of service metrics. Data traffic has been sequenced into different classes according to the required QoS, where different routing metrics and techniques are used for each class. The protocol is able to augment real-time delivery by an able integration of multi-queue priority policy, link reliability, two-hop information and dynamic ve-

locity. The protocol is able to increase the PRR, end-to-end delay and improve the energy efficiency throughout the network. This makes the protocol suitable for WSNs with varied traffic, such as medical and vehicular applications.

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