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Localized quality of service routing protocol with service differentiation for wireless sensor networks

Ali Ghaffari[1a)], **Amir Masoud Rahmani**[1], **and Hanieh Rahbari Bannaeian**[2]

[1] *Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2] *Department of Computer Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran*

a) *A.ghaffari@iaut.ac.ir*

Abstract: In this paper, we propose a new localized quality of service routing (LQSR) protocol with service differentiation, for wireless sensor networks. Reliability, real time and energy efficient data forwarding are considered in proposed routing protocol. LQSR uses modular design architecture wherein different units operate in coordination to provide multiple QoS services. Data requirements are made visible to the framework using two bits in the packet header. Simulation results show that the protocol is efficient regarding QoS parameters and has significant improvements over several geographical and QoS-based routing protocols.

Keywords: wireless sensor networks, quality of service, service differentiation, localized routing

Classification: Wireless circuits and devices

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1 Introduction

Many applications of wireless sensor networks (WSNs), such as patient monitoring in a hospital and environment monitoring, have diverse data traffic ranging from reliable sensing, real time streams, mission critical support with different quality of services (QoS) requirements, depending on the monitored parameter and its value [1]. QoS-aware routing protocol provisioning in WSNs with service differentiation is a challenging task. Because WSNs are resource constraint and generate different type of data packet. Three different classes of QoS requirements are used in the proposed protocol: reliability, real time and energy efficiency. The proposed protocol is designed using a modular approach, aiming to ensure exactly the required QoS for each packet. A unit is devoted to each QoS parameters, in addition to the queuing manager and neighbor routing table. The queuing manager is responsible for implementing a priority multilevel queuing policy that gives more priority, and it consequently ensures shorter delay, to critical and delay sensitive packets.

2 Related works

Most geographical and QoS-based routing schemes have been proposed for WSNs. All the protocols proposed thus far do not make a clear differentiation in route selection between traffic with respect to QoS requirements. DARA [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 needs huge amount of sample storages. MMSPEED [4] also forwards packets toward multiple paths and multiple reliability- and delay-bound packets are considered for QoS provisioning. However, MMSPEED fails to consider energy issue. MCMP [5] uses link delay and reliability as routing decision parameters, where data packets are duplicated at source nodes by solving optimization problem. But, MCMP considers neither residual energy nor progress speed.

3 Proposed protocol

Fig. 1 (a) shows the proposed framework. A unit is devoted to each QoS

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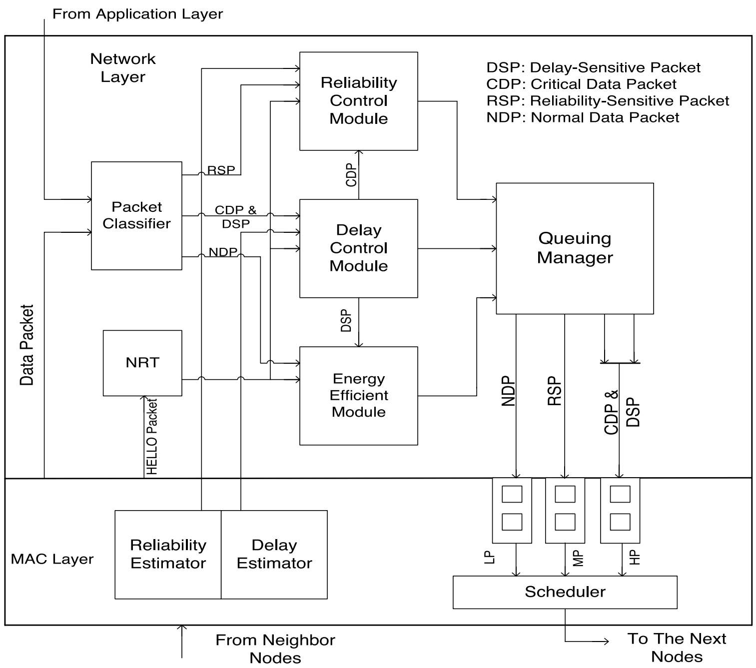
metrics, queuing and neighbor routing table. The neighbor routing table (NRT) unit runs the HELLO [2] protocol that exchanges information between neighboring nodes and updates routing table periodically. The 2 bits in the packet header, taken in combination, provide a characteristic description of an application requirement (Fig. 1 (b)).



(a)

D	R	Packet Type	Example	Priority
0	0	Normal packet (NP)	"alive" Message or ACK	Low
0	1	Reliability sensitive packet (RSP)	File Transferring	Medium
1	0	Delay sensitive packet (DSP)	Video Streaming	High
1	1	Mission critical packet (MCP)	Safety alarm	High

(b)

Fig. 1. LQSR modules. (a) LQSR Architecture and interconnection and (b) Combination of the two preamble bits.

3.1 Reliability unit

This unit uses multiple paths with high link quality forwarding approach to increase reliability. If several nodes have the maximum reliability, then the most energy efficient is selected using the energy module. For link reliability estimation, we use exponential weighted moving average (EWMA [6]). Because EWMA has the advantage of being simple and resource demanding compared to other methods. We update the packet reception rate (PRR) in regular time intervals, w, instead of doing it for every packet as follows:

$$PRR(i, j) = \alpha PRR(i, j) + (1 - \alpha)\frac{s}{s + m} \tag{1}$$

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Where α Represents the tunable parameters, m, the number of missed packets, and s, the number of received packets. Appropriate values for α and w for stable EWMA are $w = 30$ and $\alpha = 0.6$ [6]. For reliable data forwarding, candidates offering the high reliability, PRR and most energy efficient are selected to satisfy R_{req}. On generating a packet the source node determines the importance of the information it contains and decides the desired reliability, R_{req} for it. It also knows the local channel error e (i, j) and its hop distance from sink, h. Using these values, the source computes the number of paths (or equivalently, the number of copies of the packet to be sent), N, required for delivering the packet at desired reliability to the sink [7]:

$$N = \frac{\log(1 - R_{req})}{\log(1 - (1 - e(i,j))^h)} \tag{2}$$

Where, h is hop count from source to destination and can be calculated as:

$$h = \frac{dist(i, \sin k)}{R_c} \tag{3}$$

Where, R_c is radio distance of sensor nodes and $dist(i, \sin k)$ is geographical distance from node i to sink.

3.2 Delay unit

At each hop, the node updates the deadline and puts it in the packet header as:

$$rd = Deadline - \left(t_d - t_a + \frac{L}{R}\right) \tag{4}$$

Where rd represents the remaining time to deadline, t_d the transmission time, t_a the reception time, R the channel bandwidth, L the packet size. In real time domain, we define two speeds: speed offered by node j, denoted by, V_j and required speed, V_{req} as follows:

$$V_{req} = \frac{dist(i, \sin k)}{rd} \tag{5}$$

$$V_j = \frac{dist(i, \sin k) - dist(j, \sin k)}{t_{queue}(i)[p.t] + t_{tr} + t_{queue}(j)[p.t]} \tag{6}$$

Upon reception of the packet, node i uses the deadline value to calculate the required speed, V_{req}, and it estimates the speed offered by neighboring nodes that provide positive advance, by taking into account queue waiting time at node i, say $t_{queue}(i)$, transmission time, t_{tr}, and next hop queue time, $t_{queue}(j)$. The queue time will be different for each packet type (p.t). We can obtain the set of nodes that have speed greater than required speed as follows:

$$N_n = (j \in N^{pos}_{i,\sin k} : V_j \geq V_{req}\} \tag{7}$$

Where, $N^{pos}_{i,\sin k}$ is defined as the set of neighboring nodes providing positive advance for node, i, toward final destination, sink. It consists of neighboring nodes that are closer to the destination than i. N_n is the set of Nodes that have speed, greater than V_{req}. After computing velocities of all candidate

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nodes, the delay sensitive unit calculates the set of nodes supposed to meet the required deadline and calls the energy unit, or reliability unit in case of critical packets. The Modules select the most appropriate forwarding node from the set N_n.

3.3 Energy unit

For energy efficient forwarding, we use cost function as follows:

$$EnergyCost = Max_{j \in N_{i,\sin k}^{pos}} \left\{ \lambda_1 \left(\frac{E_{res}(j)}{E_{init}} \right) + \lambda_2 \left(\frac{dist(i,\sin k) - dist(j,\sin k)}{dist(i,\sin k)} \right) \right\} \quad (8)$$

Where, $\lambda_1 = 0.4$ and $\lambda_2 = 0.6$ are weighting parameters. We obtain the one that produces the most geographic progress and has highest residual energy that maximizes the energy cost function subject to conditions as follows:

$$dist(i,\sin k) > dist(j,\sin k), \qquad \forall j \in N_{i,\sin k}^{pos} \quad (9)$$

$$dist(i,\sin k) \geq \overline{dist(i,j)}, \qquad \forall j \in N_{i,\sin k}^{pos} \quad (10)$$

$$E_{res}(j) \geq \overline{E_{res}(j)}, \qquad \forall j \in N_{i,\sin k}^{pos} \quad (11)$$

Where, $\overline{dist(i,j)}$ is the average distance from node i to all neighbor nodes $j \in N_{i,\sin k}^{pos}$ and $\overline{E_{res}(j)}$ is the average residual energy level of the neighbor nodes j of i.

4 Performance evaluation

The performance of LQSR was evaluated by C++. Simulation parameters are set as shown in Table I. We evaluate end-to-end delay and data delivery ratio for different packet traffic in LQSR. Finally, lifetime of LQSR compared with MMSPEED and DARA protocols. In order to analyzing the end-to-end delay and data delivery ratio (DDR), each QoS traffic varies from 0.1 to 1 and the remaining rate is set to normal packets. The difference regarding the end-to-end delay between the traffic sensitive to this parameter (MCP and DSP) and the traffic unsensitive to it (NP and RSP) is clear and become more important as the QoS traffic rate increase (Fig. 2 (a)). The difference increases linearly until the end-to-end delay of DSP and MCP almost becomes halved compared to reliability-sensitive traffic.

Table I. Simulation Parameters.

Parameter	Value
Sensor Nodes	400
Bandwidth	200 KB/s
Radio Range	70 m
Simulation Area	200 m*200 m
Deadline of Critical packets	0.4 Sec
Initial Battery Life	40 joule
Hello Packet Period	6 Sec
QoS packet rate	0.1 to 1
Normal packet rate	1-QoS packet rate

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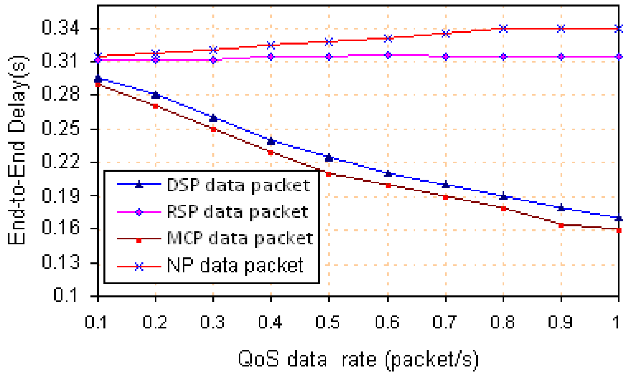
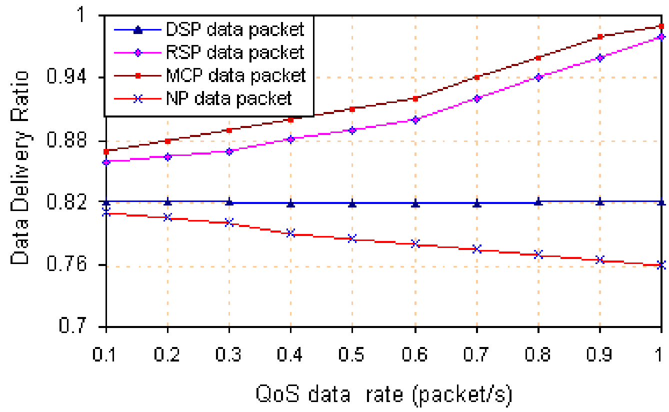
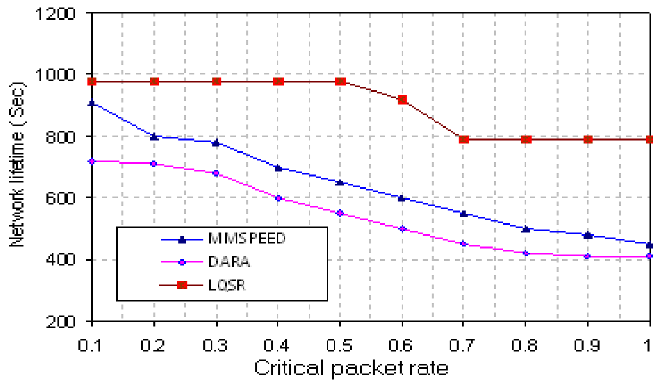


(a)



(b)



(c)

Fig. 2. Simulation results. (a) End-to-end delay. (b) Data delivery ratio. (c) Network lifetime (time to first node dies).

This increase was expected due to large delay-sensitive and critical traffic, where packets are routed through more delay-efficient links, while with reliability-sensitive traffic, the protocol considers only link reliability. This explains the constant and relatively high end-to-end delay for the reliability-sensitive traffic. For NP traffic rate LQSR do not consider link delay and reliability. For this reason, the end-to-end delay of NP packet increases due to large QoS packet rate. Because NP packets have lower priority. As shown

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in Fig. 2 (b), since link reliability is not considered for delay-sensitive traffic. DDR of the traffic sensitive to the reliability increases linearly with its rate, whereas it is stable for delay-sensitive packets at. Because more critical and reliability-sensitive traffic results in giving more consideration to link reliability and multi-path forwarding scheme, which is not considered for DSP and NP traffic. Critical traffic is sensitive to both metrics, which explains the obtained high performance for this class. The difference of DDR between critical and reliability-sensitive traffic is low because there is no priority between the two classes. As Fig. 2 (c) shows, LQSR has the highest lifetime according the other two protocols (MMSPEED and DARA).

The energy unit is responsible for routing normal packets as well as the other packets, when more than one candidate satisfy the required QoS parameters. Critical and normal packets were used in the simulation. These two traffics allow testing all the units since both DSP and RSP units are employed to rout MCP. Critical packet rate was varied from 0.1 to 1 and for each setting, the remaining rate to 1 represents NP packet rate. Only critical and normal packets are used for analyzing lifetime of LQSR, as none of the compared protocols considers the DSP and RSP packets. Both power consumption cost and residual energy of nodes should be considered to achieve power efficiency. LQSR ensures a trade-off between traffic related QoS metrics and energy. LQSR balances the load only among nodes estimated to ensure delivery within the deadline and having the highest reliability. This traffic balancing intuitively affects the network lifetime. The decrease of LQSR lifetime is due to the number of nodes used to balance the traffic, which decreases with critical packet rate.

5 Conclusion

The proposed protocol takes into account the traffic diversity, and it provides a differentiation routing using different quality of service parameters. For each packet, it tends to ensure exactly the required QoS metrics in power efficiency way. Simulation results show that LQSR provides low end-to-end delay, high data delivery ratio and prolongs the network lifetime.

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