CMQ: Clustering based Multipath routing algorithm to improving QoS in wireless sensor networks

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Abstract

Multi-path is favorite alternative for sensor networks, as it provides an easy mechanism to distribute traffic and balance network's load, as well as considerate fault tolerance. For this purpose, a new clustering based multi path routing protocol namely CMQ is proposed in this paper, which guarantees achieve to required QoS of wireless sensor networks. Proposed protocol has better performance than the EQSR in terms of energy-efficiency, end-to-end delay and delivery ratio.

Keywords: wireless sensor network; multi-path routing; Quality of Service.

1. Introduction

In WSNs, wireless devices are usually called nodes, which spontaneously form a network without the need of any infrastructure so that a multi-hop wireless network is constructed. The applications of WSNs are quite numerous, for example, target tracking in battlefields [1], habitat monitoring [2], civil structure monitoring [3], forest fire detection [4], and factory maintenance [5] and so on.

However, with the specific consideration of the unique properties of sensor networks such limited power, stringent bandwidth, dynamic topology (due to nodes failures or even physical mobility), high network density and large scale deployments have caused many challenges in the design and management of sensor networks. These challenges have demanded energy awareness and robust protocol designs at all layers of the networking protocol stack [6].

Efficient utilization of sensor's energy resources and maximizing the network lifetime were and still are the main design considerations for the most proposed protocols and algorithms for sensor networks and have dominated most of the research in this area. The concepts of latency, throughput and packet loss have not yet gained a great focus from the research community. However, depending on the type of application, the generated sensory data normally have different attributes, where it may contain delay sensitive and reliability demanding data. For example, the data generated by a sensor network that monitors the temperature in a normal weather monitoring station are not required to be received by the sink node within certain time limits. On the other hand, for a sensor network that used for fire detection in a forest, any sensed data that carries an indication of a fire should be reported to the processing center within certain time limits. Furthermore, the introduction of multimedia sensor networks along with the increasing interest in real time applications have made strict constraints on both throughput and delay in order to report the time-critical data to the sink within certain time limits and bandwidth requirements without any loss. These performance metrics (i.e. delay, energy consumption and bandwidth) are usually referred to as Quality of Service (QoS) requirements [7]. Therefore, enabling many applications in sensor networks requires energy and QoS awareness in different layers of the protocol stack in order to have efficient utilization of the network resources and effective access to sensors readings. Thus QoS routing is an important topic in sensor networks research, and it has been under the focus of the research community of WSNs. Refer to [7] and [8] for surveys on QoS based routing protocol in WSNs.

Many routing mechanisms specifically designed for WSNs have been proposed [9][10]. In these works, the unique properties of the WSNs have been taken into account. These routing techniques can be classified according to the protocol operation into negotiation based, query based, QoS based, and multi-path based. The QoS based protocols allow sensor nodes to make a tradeoff between the energy consumption and some QoS metrics before delivering the data to the sink node [11]. Finally, multi-path routing protocols use multiple paths rather than a single path in order to improve the network performance in terms of reliability and robustness. Multi-path routing establishes multiple paths between the source-destination pair. Multi-path routing protocols have been discussed in the literature for several years now [12]. Mutli-path routing has focused on the use of multiple paths primarily for load balancing, fault tolerance, bandwidth aggregation, and reduced delay. We focus to guarantee the required quality of service through multi-path routing.

2. Related works

Some QoS oriented routing works are surveyed in [7] and [8]. In this section we do not give a comprehensive summary of the related work, instead we present and discuss some works related to proposed protocol.

One of the early proposed routing protocols that provide some QoS is the Sequential Assignment Routing (SAR) protocol [13]. SAR protocol is a multi-path routing protocol that makes routing decisions based on three factors: energy resources, QoS on each path, and packet's priority level.

K. Akkaya and M. Younis in [14] proposed a cluster based QoS aware routing protocol that employs a queuing model to handle both real-time and non real time traffic. The protocol only considers the end-to-end delay. The protocol associates a cost function with each link and uses the K-least-cost path algorithm to find a set of the best candidate routes. Each of the routes is checked against the end-to-end constraints and the route that satisfies the constraints is chosen to send the data to the sink. All nodes initially are assigned the same bandwidth ratio which makes constraints on other nodes which require higher bandwidth ratio. Furthermore, the transmission delay is not considered in the estimation of the end-to-end delay, which sometimes results in selecting routes that do not meet the required end-to-end delay. However, the problem of bandwidth assignment is solved in [15] by assigning a different bandwidth ratio for each type of traffic for each node.

SPEED [16] is another QoS based routing protocol that provides soft real-time end-to-end guarantees. Each sensor node maintains information about its neighbors and exploits geographic forwarding to find the paths. To ensure packet delivery within the required time limits, SPEED enables the application to compute the end-to-end delay by dividing the distance to the sink by the speed of packet delivery before making any admission decision. Furthermore, SPEED can provide congestion avoidance when the network is congested.

Felemban et al. [17] propose Multi-path and Multi-Speed Routing Protocol (MMSPEED) for probabilistic QoS guarantee in WSNs. Multiple QoS levels are provided in the timeliness domain by using different delivery speeds, while various requirements are supported by probabilistic multipath forwarding in the reliability domain.

Recently, X. Huang and Y. Fang have proposed multi constrained QoS multi-path routing (MCMP) protocol [18] that uses braided routes to deliver packets to the sink node according to certain QoS requirements expressed in terms of reliability and delay. The problem of the end-to-end delay is formulated as an optimization problem, and then an algorithm based on linear integer programming is applied to solve the problem. The protocol objective is to utilize the multiple paths to augment network performance with moderate energy cost. However, the protocol always routes the information over the path that includes minimum number of hops to satisfy the required QoS, which leads in some cases to more energy consumption. Authors in [19], have proposed the Energy constrained multi-path routing (ECMP) that extends the MCMP protocol by formulating the QoS routing problem as an energy optimization problem constrained by reliability, playback delay, and geo-spatial path selection constraints. The ECMP protocol trades between minimum number of hops and minimum energy by selecting the path that satisfies the QoS requirements and minimizes energy consumption. In [24], authors propose an energy efficient and QoS aware multipath routing protocol namely EQSR that maximizes the network lifetime through balancing energy consumption across multiple nodes, uses the concept of service differentiation to allow high important traffic (or delay sensitive traffic) to reach the sink node within an acceptable delay, reduces the end to end delay through spreading out the traffic across multiple paths, and increases the throughput through introducing data redundancy. EQSR uses the residual energy, node available buffer size, and Signal-to-Noise Ratio (SNR) to predict the best next hop through the paths construction phase.

Many protocols have suggested in previous papers for clustering in WSNs. In this section we explain the some celebrated clustering protocols. LEACH is one of the most famous clustering based routing protocols in WSN [20]. Cluster head selection among sensor nodes is done randomly and also data transmitting between cluster heads and base station is done directly in the LEACH. Although this specification of LEACH avoids energy hole problem but causes the energy of cluster heads that are far from the base station be discharge faster than others.

HEED [25] is another well-known clustering based routing algorithms in WSN. Cluster head selection algorithm is based on a relationship between remaining energy and reference energy in HEED.

Meeting QoS requirements in WSNs introduces certain overhead into routing protocols in terms of energy consumption, intensive computations, and significantly large storage. This overhead is unavoidable for those applications that need certain delay and bandwidth requirements. In our work, we combine different ideas from the previous protocols in order to optimally tackle the problem of QoS in sensor networks. In our proposal we try to satisfy the QoS requirements with the minimum energy. CMQ is a clustering based routing algorithm that uses a new cluster head selection algorithm and also performs path discovery using multiple criteria such as remaining energy, number of neighbors, probability of successfully packet sending and link quality.

3. Proposed protocol

In this section, we explain the assumptions and describe the various constituent parts of the proposed protocol.

A. Assumptions

We assume that all nodes are randomly distributed in desired environment and each of them is assigned a unique ID. At start, the initial energy of nodes is considered equal. All nodes in the network are aware of their location (by positioning schemes such as [23]) and also are able to control their energy consumption. Because of this assumption has been that the nodes can communicate with other nodes outside their radio range in the absence of node in their radio transmission range.

We consider that each node can calculate its probabilities of packet sending and packet receiving with regard to link quality. Predications and decisions about path stability may be made by examining recent link quality information.

B. CMQ

CMQ has three phases that are cluster head announcement, cluster formation and data transmission.

The cluster head announcement phase which is cluster head selection phase is almost like a cluster head selection algorithm in HEED but the difference is that in the beginning, all nodes calculates the probability of cluster head selection by (1) and then follows from the operations in the HEED.

$$CV_{CH} = \alpha(\frac{E_r}{E_i}) + \beta(\frac{N_{elt}}{N_n}) + \gamma(PSPS) \quad (1)$$

Where, α, β and γ are influence coefficients of energy, number of neighbor nodes which its remaining energy is less than a defined threshold and probability of successfully packet sending of sensor node, respectively. E_r is remaining energy of sensor node and E_m is initial energy of sensor. N_{elt} is the number of neighbor nodes of desired node that their remaining energy is less than a threshold. N_n is the number of nodes in the network. *PSPS* is the probability of successfully packet sending of sensor node. *PSPR* is the probability of successfully packet receiving of all neighbors of node.

In cluster formation phase, all ordinary nodes calculate the merit value of the cluster heads that are on their radio transmission range by (2). Then they join to the cluster head that its merit value is greater than the others.

$$S_{CH} = \frac{E_{CH}}{(D_{n,CH})^2} \quad (2)$$

Here, E_{CH} is remaining energy of the cluster head. D_{n_CH} is the distance between ordinary node and the cluster head.

Data transmitting phase contains four steps that is explained in the next.

- *Link Suitability*

The link suitability is used by the node to select the node at the next hop as a forwarder during the path discovery phase.

Source node calculates the reliability of the link between itself and each of its neighbors by *Link_Suitability*.

Node *i* is a source node and node *j* is the node at the next hop. Let N_i be a set of neighbors of node *i*. *Link_Suitability* is obtained by (3).

$$Link\_Suitability_{ij} = \alpha(E_{remain})_j + \beta(LQ_{ij}),\ j \in N_i \quad (3)$$

In here, E_{remain} is the remaining energy of node *j*. LQ_{ij} is quality of the link between *i* and *j* which is calculated by (4).

$$LQ_{ij} = \left(1 - \frac{1}{2}\exp^{-\frac{\gamma(d)}{2}\frac{1}{0.64}}\right)^{8F}. \quad (4)$$

Here, *F* is frame size and $\gamma(d)$ is the signal to noise ratio.

The total suitability (TS) for a path *p* consists of a set of *m* nodes is the sum of the individual link merit along the path. Then the total merit is calculated by (5).

$$TS_p = \sum_{n=1}^{m-1} Merit\_Value_{(ij)_n}. \quad (5)$$

- *Path Discovery*

In multi-path routing, node-disjoint paths (i.e. have no common nodes except the source and the destination) are usually preferred because they utilize the most available network resources, and hence are the most fault-tolerant. If an intermediate node in a set of node-disjoint paths fails, only the path containing it node is affected, so there is a minimum impact to the diversity of the routes [21].

In first, sink broadcasts the RREQ message using the direction-angle mechanism to all the neighboring cluster heads which are in the right direction towards source. Fig. 1 shows the RREQ message structure.

Source ID	Path ID	TS_P

Figure 1. RREQ message structure

Then the cluster head at the next hop which receive RREQ message locally selects its preferred next hop cluster head which is in the right direction towards source using the link suitability function, and sends out a RREQ message to its most preferred next hop. This operation continues until source. The TS_p is updated at each hop.

To avoid having paths with shared node and to create disjoint paths, we limit each node to accept only one RREQ message with the same source ID.

- *Path Maintenance*

In order to energy saving, we reduce the overhead traffic through reducing control messages. Therefore, instead of periodically flooding a KEEP-ALIVE message to keep multiple paths alive and update merit function metrics, we append the metrics on the data message by attaching the residual energy and link quality to the data message.

- *Path Selection*

After the execution of paths discovery phase and the paths have been constructed, we need to select a set of paths from the N available paths to transfer the traffic from the source to the destination with a desired bound of data delivery given by α. To find the number of required paths, we assume that each path is associated with some rate *pi* (i=1, 2 … N) that corresponds to the probability of successfully delivering a message to the destination. Following the work done in [22], the number of required paths is calculated by (6).

In here, $PSDT_j$ is the estimated packet reception rate to the node *j*, which is one of the nodes in the desired path.

$$k = x_a \sqrt{\sum_{i=1}^{N} p_i (1 - p_i) + \sum_{i=1}^{N} p_i}. \quad (6)$$

Here, x_a is the corresponding bound from the standard normal distribution for different levels of *α*. Table I lists some values for x_α.

TABLE I. SOME VALUES FOR THE DIFFERENT BOUNDS [23].

α	95%	90%	85%	80%	50%
x_a	-1.65	-1.28	-1.03	-0.85	0

4. Simulation and Performance Evaluation

In this section, we present and discuss the simulation results for the performance study of CMQ protocol. We used GCC to implement and simulate CMQ and compare it with the EQSR. Simulation parameters are presented in Table II and obtained results are shown below. The radio model used in the simulation was a duplex transceiver. The network stack of each node consists of IEEE 802.11 MAC layer with 40 meter transmission range. Data rate is 250 kbps. Transmission power is 2 mw and RREQ message length is 15 bytes. The values of influence coefficients in each equation are equal with each other.

TABLE II. SIMULATION PARAMETERS

Parameters	Value
Network area	300 meters × 300 meters
Base station location	(0, 0) m
Number of sensors	150
Initial energy	3J
Beacon packet size	30 bytes
Data packet size	512 bytes

C. Average End-to-End Delay

The average end-to-end delay is the time required to transfer data successfully from source node to the destination node.

Fig. 2 shows the average end to end delay for CMQ and EQSR. As it can be seen, proposed protocol has performance better than EQSR in average end to end delay.

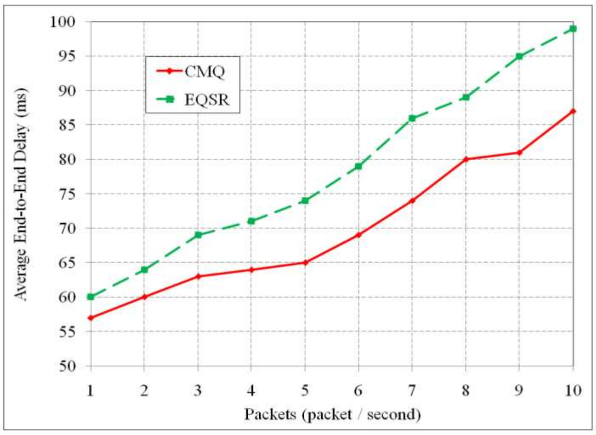

Figure 2. Average end to end delay

D. Average Energy Consumption

The average energy consumption is the average of the energy consumed by the nodes participating in message transfer from source node to the destination node.

Fig. 3 shows the results for energy consumption in CMQ and EQSR. As it can be seen, in our protocol, energy consumption for packet sending is optimizing in comparison to the EQSR.

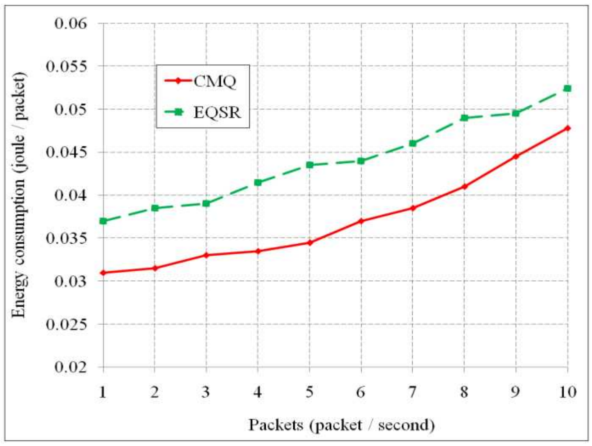

Figure 3. Average energy consumption

E. Average Packet Delivery Ratio

The average delivery ratio is the number of packets generated by the source to the number of packets received by the destination node. Fig. 4 shows the average delivery ratio. Obviously, CMQ outperforms the EQSR.

5. Conclusion

In this paper, we propose the new multi path routing algorithm for wireless sensor networks namely CMQ which is QoS aware and can increase the network lifetime. Our protocol uses some main metrics of QoS with special relation in cluster head selection and path discovery mechanism. Simulation Result shows that the performance of CMQ in end to end delay, energy consumption and packet delivery ratio is optimized compared to the EQSR.

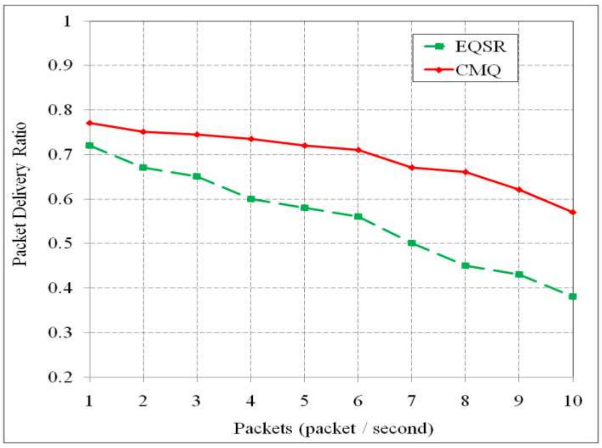

Figure 4. Packets Delivery Ratio

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