REMP: Reliable and Energy Balancing Multi-Path Routing Algorithm for Wireless Sensor Networks

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Abstract: Reliable and energy-efficient transmission of sensory data is a key problem in wireless sensor networks (WSNs). This is due to resource constraint and it is necessary to present a new routing algorithm that can provide these requirements in network layer. The main objectives of multipath routing protocols are to provide reliable communication and ensure load balancing as well as to improve quality of service (QoS) of WSNs. Satisfying Quality of Service requirements (e.g. reliability and delay constraints) for the different QoS based applications of WSNs raises significant challenges. More precisely, the networking protocols need to cope up with energy constraints, while providing precise QoS guarantee For this purpose, we propose a new reliable and energy balancing multi path routing algorithm (REMP) for wireless sensor networks. The REMP protocol guarantees the mentioned quality of service parameters in wireless sensor networks and balances the energy consumption in all sensor nodes. By means of simulations, we evaluate and compare the performance of our routing protocol with the MCMP (Multi-Constraint Multi-Path) and EQR (Energy Efficient and QoS aware multipath routing protocol) routing protocol. Simulation results have shown that our protocol achieves more energy savings and higher packet delivery ratio than the other two protocols.

Key words: Wireless sensor network · Multi-path routing · Reliability · Energy balancing

INTRODUCTION

In the recent years, the rapid advances in micro-electro-mechanical systems, low power and highly integrated digital electronics, small scale energy supplies, tiny microprocessors and low power radio technologies have created low power, low cost and multifunctional wireless sensor devices, which can observe and react to changes in physical phenomena of their environments. These sensor devices are equipped with a small battery, a tiny microprocessor, a radio transceiver and a set of transducers that used to gathering information that report the changes in the environment of the sensor node. The emergence of these low cost and small size wireless sensor devices has motivated intensive research in the last decade addressing the potential of collaboration among sensors in data gathering and processing, which led to the creation of Wireless Sensor Networks (WSNs). A typical WSN consists of a number of sensor devices that collaborate with each other to accomplish a common task (e.g. environment monitoring, target tracking, etc) and report the collected data through wireless interface to a base station or sink node. The areas of applications of WSNs vary from civil, healthcare and environmental to military. Examples of applications include target tracking in battlefields [1], habitat monitoring [2], civil structure monitoring [3], forest fire detection [4] and factory maintenance [5]. 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.

Many routing mechanisms specifically designed for
WSNs have been proposed [7-10]. 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
negotiation based protocols have the objective to
eliminate the redundant data by include high level data
descriptors in the message exchange. In query based
protocols, the sink node initiates the communication by
broadcasting a query for data over the network. 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.

The rest of the paper is organized as follows: in
section II, we explain the related works. Section III
describes the proposed algorithm with detailed. Section IV
explore the simulation parameters and result analysis.
Finally, section V concludes the paper.

Related Works: QoS-based routing in sensor networks is
a challenging problem because of the scarce resources of
the sensor node. Thus, this problem has received a
significant attention from the research community, where
many works are being made. Some QoS oriented routing
works are surveyed in [7,8]. 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 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. Multiple paths are created by building a tree rooted
at the source to the destination. During construction of
paths those nodes which have low QoS and low residual
energy are avoided. Upon the construction of the tree,
most of the nodes will belong to multiple paths. To
transmit data to sink, SAR computes a weighted QoS
metric as a product of the additive QoS metric and a
weighted coefficient associated with the priority level of
the packet to select a path. Employing multiple paths
increases fault tolerance, but SAR protocol suffers from
the overhead of maintaining routing tables and QoS
metrics at each sensor node. 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. EQGR [16] considers reliability, timeliness and energy for selecting next optimum neighbor node for data forwarding. For reliable data forwarding the authors consider multipath forwarding with optimum link quality. For timeliness domain, they use multi queue policy for data forwarding. Feldman 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. 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. Our REMP routing protocol performs path discovery using multiple criteria such as energy per distance, probability of successfully packet sending, average probability of successfully packet receiving. In many of these applications (such as multimedia applications, or real-time and mission critical applications), the network traffic is mixed of delay sensitive and delay tolerant traffic. Hence, QoS routing becomes an important issue. In [25], the authors propose an Energy Efficient and QoS aware multipath routing protocol (EQSR) that maximizes the network lifetime through balancing energy consumption across multiple nodes, uses the concept of service differentiation to allow 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. Based on the concept of service differentiation, EQSR protocol employs a queuing model to handle both real-time and non-real-time traffic.

Proposed Protocol: In this section, we explain the assumptions and energy consumption model used in REMP and describe the various constituent parts of the proposed protocol.

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 [24]) 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. Let us assume that nodes are aware of their remaining energy and also remaining energy of other nodes in their transmission radio range (via received beacon from them). 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.

Energy Consumption Model: In REMP, energy model is obtained from [20] that use both of the open space (energy dissipation $d^2$) and multi path (energy dissipation $d^2$) channels by taking amount the distance between the transmitter and receiver. So energy consumption for transmitting a packet of l bits in distance $d$ is given by (1).  

$$E_{Tx}(l,d) = \begin{cases} IE_{elec} + lE_{fs} d^2, d \leq d_o \\ IE_{elec} + lE_{mp} d^2, d > d_o \end{cases}$$  

(1)

Here $d_o$ is the distance threshold value which is obtained by (2), $E_{elec}$ is required energy for activating the electronic circuits. $E_{fs}$ and $E_{mp}$ are required energy for
amplification of transmitted signals to transmit a one bit in open space and multi-path models, respectively.

\[ d_o = \sqrt{\frac{E_{fs}}{E_{mp}}} \]  

(2)

Energy consumption to receive a packet of \( l \) bits is calculated according to (3).

\[ E_{Rs}(l) = IE_{elec} \]  

(3)

**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. Our suitability function includes two sub-functions namely \( Merit\_Value\_1 \) and \( Merit\_Value\_2 \) which are used to calculating the link reliability and energy per distance factors, respectively. Source node calculates the reliability of the link between itself and each of its neighbors by \( Merit\_Value\_1 \). Then it sorts its neighboring nodes ascending based on the value of the \( Merit\_Value\_1 \) of each of them. So that the neighboring node that has the highest value of \( Merit\_Value\_1 \) is dedicated to first. Node \( A \) is a source node and node \( B \) is the node at the next hop. Let \( N_A \) and \( N_B \) be a set of neighbors of node \( A \) and \( B \), respectively. \( Merit\_Value\_1 \) contains the \( PSPS \) (Probability of Successfully Packet Sending) and \( APSPR \) (Average Probability of Successfully Packet Receiving) and obtained by (4).

\[ Merit\_Value\_1(AB) = (PSPS_B + APSPR_{N_B}), B \in N_A \]  

(4)

In here, \( PSPS_B \) is the probability of successfully packet sending of node \( B \). Each node can calculate the value of this parameter for themselves by (5). \( APSPR_{B,a} \) is the average probability of successfully packet receiving of all neighbors of node \( B \) that is obtained by (6).

\[ PSPS = \frac{\text{Number of Successful Sending Packets}}{\text{Total Number of Sending Packets}} \]  

(5)

\[ APSPR_{N_B} = \frac{\sum_j P_{SPR_j}}{n(N_B)}, X \in N_B \]  

(6)

In here, \( P_{SPR_j} \) is probability of packet receiving of node \( j \) which is the neighbor node of node \( B \). purpose of \( n(N_B) \) is the number of neighbor nodes of node \( B \). Then source node calculates the parameter of energy per distance for each of its neighboring nodes by \( Merit\_Value\_2 \). Then again it sorts its neighboring nodes ascending based on the value of the \( Merit\_Value\_2 \) of each of them. So that the neighboring node that has the highest value of \( Merit\_Value\_2 \) is dedicated to first.

\[ Merit\_Value\_2(AB) = \frac{E_A + E_B}{D_{A,B} + D_{B,S}} \]  

(7)

This relationship is used for balancing the energy consumption which introduced in [21]. \( E_A \) and \( E_B \) are remaining energies of node \( A \) and node \( B \), respectively. \( D_{A,B} \) is distance between node \( A \) and node \( B \) and \( D_{B,S} \) is distance between node \( B \) and base station. After these calculations, as it can be seen in Fig.1, source node selects the neighboring node as a forward node that the sum of its two order numbers is the minimum. If some nodes have equal value, in this case the node is selected as a forward node that difference between its two order numbers is minimum.

The total merit of reliability and energy (TM) for a path \( p \) consists of a set of \( K \) nodes is the sum of the individual link merit along the path. The total merits can be calculated as follows:

\[ TM_{1,p} = \sum_{i=1}^{K-1} Merit\_Value\_1(AB)_i \]  

(8)

\[ TM_{2,p} = \sum_{i=1}^{K-1} Merit\_Value\_2(AB)_i \]  

(9)

**Paths Discovery Mechanism in REMP:** 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 [22]. In first phase of path discovery procedure, each node collects the needed information about its neighbors by beacon exchange between them and then updates its neighboring table. After this phase, each sensor node has enough information to compute the link suitability for its neighboring nodes. For faster execution of multi-path discovery, this mechanism is done in parallel.
Fig. 1: Forwarding node selection

Fig. 2: RREQ message structure

Fig. 3: RREQ and BUSY messages transmission

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.

**Paths 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 $\alpha$. To find the number of required paths, we assume that each path is associated with some rate $p_i$ ($i=1, 2 \ldots N$) that corresponds to the probability of successfully delivering a message to the destination which is calculated by (10). Following the work done in [23], the number of required paths is calculated as follows:

$$P_i = 1 - \Pi \left(1 - PSDT_j \right)$$

(10)

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

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

(11)

In here, $x_a$ is the corresponding bound from the standard normal distribution for different levels of $\alpha$.

Table I lists some values for $x_a$.

**Table 1:** Some values for the different bounds [23].

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>95%</th>
<th>90%</th>
<th>85%</th>
<th>80%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_a$</td>
<td>-1.65</td>
<td>-1.28</td>
<td>-1.03</td>
<td>-0.85</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network area</td>
<td>400 meters $\times$ 400 meters</td>
</tr>
<tr>
<td>Base station location</td>
<td>(0, 0)m</td>
</tr>
<tr>
<td>Number of sensors</td>
<td>100</td>
</tr>
<tr>
<td>Initial energy</td>
<td>2J</td>
</tr>
<tr>
<td>$E_{elec}$</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>$E_a$</td>
<td>10 pJ/bit/m2</td>
</tr>
<tr>
<td>$E_{esp}$</td>
<td>0.0013 pJ/bit/m4</td>
</tr>
<tr>
<td>$d_0$</td>
<td>87 m</td>
</tr>
<tr>
<td>$E_{OA}$</td>
<td>5 nJ/bit/signal</td>
</tr>
<tr>
<td>Data packet size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Beacon packet size</td>
<td>50 bytes</td>
</tr>
</tbody>
</table>
Simulation Results and Performance Evaluation: In this section, we present and discuss the simulation results for the performance study of REMP protocol. We used GCC to implement and simulate REMP and compare it with the MCMP protocol. 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 50 meter transmission range. We assume that location of source node in the network is (250, 250) meters. We investigate the performance of the REMP protocol in a multi-hop network topology. We study the impact of changing the packet arrival rate on end-to-end delay and energy consumption. We change the packet arrival rate at the source node from 10 to 55 packets/sec.

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. 4 shows the average end to end delay for REMP, MCMP and EQSR. In this evaluation, we change the packet arrival rate at the source node and measure the delay. This is because REMP considers the probability of successfully packet receiving in addition to considering the probability of successfully packet sending in calculating the quality of links.

As it can be seen, proposed protocol has performance better than MCMP in average end to end delay.

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. 5 shows the results for energy consumption in REMP, MCMP and EQSR protocols. As it can be seen, in our protocol, energy consumption for packet sending is some deal optimize in comparison to the MCMP. This reduction in energy consumption is due to the use of a specific function in order to balance the traffic load in REMP.

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. In this evaluation, we set the failure ratio of some path to 10% to test the protocols behavior under the presence of path failures. Fig. 6 shows the average delivery ratio. Obviously, REMP outperforms the other protocols. This optimization is because REMP combines the link quality and the remaining amount of energy parameters with each other to selecting the forward node.

CONCLUSION

The WSNs have been a subject of quite a number of investigations in recent years. Most of these investigations have been motivated by the need to design an efficient routing protocol for wireless sensor networks. A good routing protocol needs to provide reliability and energy efficiency with low control overhead. To ensure reliability and load balancing and QoS, multipath routing protocols have been proposed for WSNs. In this paper, we propose the new multi path routing algorithm for
wireless sensor networks namely REMP which is QoS aware and can increase the network lifetime. Our protocol uses some main metrics of QoS with special relation in path discovery mechanism. Simulation Result shows that the performance of REMP in end to end delay and energy consumption is optimized compared to the MCMP protocol.

REFERENCES


