Reliable data delivery and energy efficient aware multi-path routing protocol in wireless sensor network

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Abstract: Wireless Sensor Networks (WSNs) are generally energy and resource constrained. To provide energy efficiency while enhancing reliable delivery the packets, we propose a reliable data delivery and energy efficient aware multi-path routing protocol. The reliable delivery of the source to sink through the creation of safe routes and send data on these routes is done. The hybrid scheme is used to acknowledge received messages at every hop that larger percentages of packets are received at the sink. To reduce the energy consumption used the load balancing on multipath routs to avoid congestion and decrease delivery delay is given below, Also decreased overhead protocols spent time less for data transfer and increased network lifetime. Our protocol uses the residual energy, node available buffer size, and Signal-to-Noise Ratio (SNR) with influence hop count metric to predict the best next hop through the paths construction phase. We implemented our protocol using simulator for evaluating its performance. Results show that our protocol has significant improvement in packet delivery ratio and energy savings.

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1. Introduction

Wireless Sensor Networks (WSNs) provide a distributed, sensing and computing platform for monitoring the environments, in which deploying conventional networks is impractical. Nodes in WSN are generally organized in a multi-hop topology and consist of one Base Stations (or sinks) and a very large number of sensor nodes scattered in physical space. Applications of sensor networks is very broad, they can be used to monitor the health, military environments[5], forest fire detection [9], habitat monitoring [10], and inaccessible areas But the very special characteristics of these networks like Limited energy, and bandwidth and topology changes cause difficulties in designing protocols for these networks. Therefore, in order to design a protocol should be considered in these networks than the networks had better performance in data delivery and Energy efficiency and increase network lifetime. One of the ways that energy efficiency is disperses traffic in multiple paths and reducing the overhead transmission of protocol.

In this paper we propose a protocol to balance load by sending data through the nodes in multiple routing and reliable data delivery to sink. Our protocol uses the residual energy, node available buffer size and Signal-to-Noise Ratio (SNR) with influence hop count metric to construction path And gives the priority to this paths and send data to sink uses these paths. The paths with highest priority have high delivery rate and high reliability so this protocol uses retransmission scheme to send data packets. To ensure delivery of packets uses NACK and ACK hybrid method. Using NACK and ACK hybrid method saves energy and reduces the transmission overhead and increases network lifetime.

The remainder of the paper is organized as follow: In Section 2, we describe our proposal. Section 3 presents the performance evaluation. Finally, we conclude the paper in Section 4.

2. Related work

Reliable data delivery and energy efficient 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 proposals are being made. Some routing proposals are surveyed in [1,8]. In this section we do not give a comprehensive summary of the related work, instead we present and discuss some proposals related to our protocol.

One of the early proposed routing protocols is the Sequential Assignment Routing (SAR) protocol [12].

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. 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.

Recently, X. Huang and Y. Fang have proposed a multiconstrained QoS multi-path routing (MCMP) protocol [7] that uses braided routes to deliver packets to the sink node according to 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.

EQSR(Energy efficient and Qos based routing Protocol) protocol has recently been proposed, to send the data real-time and non-real-time applications. EQSR uses the residual energy, node available buffer size, and signal-to-noise ratio to predict the next hop through the paths construction phase. Path with higher priority to send real time data is used. But the protocol suffers from the overhead of transmission. In some cases the paths are long which consume more energy, more delay and inappropriate use of nodes with high reliability.

3. Description of protocol

We assume N identical sensor nodes are distributed randomly in the sensing filed. All nodes have the same transmission range, and have enough battery power to carry their sensing, computing, and communication activities. The network is fully connected and dens (i.e. data can be sent from one node to another in a multihop bases). Each node in the network is assigned a unique ID and all nodes are willing to participate in communication process by forwarding data. Furthermore, we assume that the sensor nodes are stationery for their lifetime. Additionally, at any time, we assume that each sensor node is able to compute its residual energy (the remaining energy level), and its available buffer size (remaining memory space to cache the sensory data while it is waiting for servicing), as well as record the link performance between itself and its neighboring node in terms of signal-to-noise ratio (SNR).

2.1 Link cost function

The link cost function is used by the node to select the next hop during the path discovery phase. We use a cost function such as presented in [8,2] with some changes. Let Nx be the set of neighbors of node x. Then our cost function includes an energy factor, available buffer factor, and interference factor with appropriate weights (γ, β, α):

$$\text{Next hop} = \max \{\alpha \text{Eresd,y} + \beta \text{Bbuffer,y} + \gamma \text{Iinterference,xy} \} \quad (1)$$

Where, Eresd,y is the current residual energy of node y, where y ϵ Nx, Bbuffer,y is the available buffer size of node y, and Iinterference,xy is the SNR for the link between x and y. In this cost function, we only consider the residual energy of node y but not x. Because node y consumes energy for data reception and transmission if it is selected as a next hop for node x. We do not consider node x, because whatever node y is, node x still needs to spend the same amount of energy on data transmission [8, 2].

2.2 paths discovery phase

The path discovery procedure is executed according to the following phases:

2.2.1 Hop count calculation and classification of neighbor nodes phase

Source broadcasts the advertisement message with the value of hop count has 0 to all neighbor nodes. On receiving this advertisement message, each node increments the hop count value that is specified in the message and store it in its neighbors table if it is lesser than the previous value. Then every node send advertisement message to all the neighbor nodes. When a node receives an advertisement message, it stores the sender of the packet with hop count as its neighbor. Thus each node maintains a list of its neighboring Nodes and hop count has added a number and if it is lesser than the previous value it is store as new hop count therefore a new advertisement sends to its neighbors. A node classifies its neighbors by comparing its hop count value with that of its neighbors as Follows:

A) If the hop count value of the neighbor node is less the current node, then this neighbor node is placed in a negative set. (Hs^-)

B) If the hop count value of the neighbor node is greater he current node, then this neighbor node is placed in a positive set. (Hs^+)
C) If the hop count value of the neighbor node is the same, and then this neighbor node is placed in a zero set. (Hs^0)

2.2.2 Collect information of neighbor phase

Each sensor node broadcast a HELLO message to its neighboring nodes in order to have enough information about which of its neighbors can provide it with the highest quality data. Each sensor node maintains and updates its neighboring table during this phase. The neighboring table contains information about the list of neighboring nodes of the sensor node. The link quality field is expressed in terms of signal-to-noise ratio (SNR) for the link between any node and its neighbor. Fig. 1 illustrates the structure of the HELLO message.

Source ID	Residual Energy	Free Buffer	Link Quality

Fig. 1: Hello message structure.

Source ID	Dest . ID	Route ID	Route Cost	Hop Count

Fig. 2:PREQ message structure.

2.2.1 Primary Path discovery phase

After pervious phases each sensor node has enough information to compute the cost function for its neighbouring nodes. The sink node starts the route discovery phase. Sink node locally computes Preferred next hop between nodes that are in Hs^- or Hs^0 using the cost function and sends out a RREQ message to its most preferred next hop. Similarly, the preferred next hop node of the sink computes locally its most preferred next hop between nodes that are in Hs^- or Hs^0 in the direction of the source node, and sends out a RREQ message to its next hop, the operation continues until source node. Fig. 1 illustrates the structure of the RREQ message.

Route Cost field is calculated of sum the output cost function of each node. The Hop Count field specifies the sum of hop in any paths and each node that receives a PREQ, adds it's a unit. When PREQ message for every path received to the source by divided the Route Cost field value on the Hop-Count field value can be achieved a measure of priority for each path. This measure is an average measure of each route.

For example, in Fig.3 after sink send the PREQ message to node 2 as the highest priority, Node 2 between the nodes are in the set Hs^- or Hs^0 as{3,4,5}, selected the Node with higher priority and selected the node 4 And the PREQ message sends for it. Among the node 4 neighbours as {3,5,6,7}, Node 3 sees a higher priority But because it is node in set Hs^+. The node 4 has avoided send the PREQ message and the message send to another node with higher priority, which is located in the Hs^- or Hs^0 that is node 7. With this method the paths will not be long and reduced the delayed and energy consumption further did not prevent the construction of more paths.

2.2.2 Alternative Paths discovery phase

For the second alternate path, similar the Primary Path discovery, sink send out the PREQ message to the next preferred neighbour node which is located in the Hs^- or Hs^0, but to avoid the path of the shared nodes, each node is limited to accepting only one PREQ message. For those nodes that receive more than one RREQ message, only accept the first RREQ message and reject the remaining messages and INUSE message is sent in response.

For example, in Figure 3 the node 6 find the node 7 with higher priorities of sets Hs^- or Hs^0 and Node 6 sends the message PREQ to node 7, But node 7 in the first path is selected then node 7 responds to node 6 with an INUSE message and node 6 sends the PREQ message the next priority node as node 9. Node 9 accepts the message and continues the procedure in the direction of the source node.

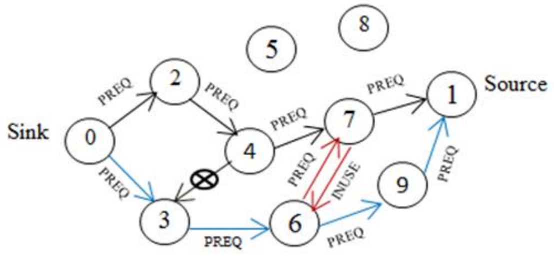

Fig. 3:Example of path discovery.

—— Primary Path
—— Alternative Path

ID	MS	Off	SA	DA	Residual Energy	Free Buffer	Link Quality

Fig. 4:ACK message structure.

2.3 Path refreshment

In order to save energy, we reduce the overhead traffic through reducing control messages. Therefore, instead of periodically flooding a KEEPALIVE message to keep multiple paths alive and update cost function metrics, we append the metrics on the ACK message by attaching the residual energy, remaining buffer size, and link quality to the ACK message. Fig. 4 illustrates the structure of the ACK message.

2.4 Paths selection

Because all paths did not have high reliable delivery and some paths are made in the retransmission probability is very high. 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.

From the N paths didn't use the paths with the lowest priority that the packet retransmission probability is very high. 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 [6], the number of required paths is calculated as:

$$K = X_\alpha \sqrt{\sum_{i=1}^{n} pi(1-pi)} + \sum_{i=1}^{n} pi \qquad (2)$$

Where x_α is the corresponding bound from the standard normal distribution for different levels of α. Table 1 lists some values for x_α. The best k paths that have higher priority are used to send packets, because the high priority routes are more reliable delivery of data.

TABLE 1. Some values for the bound α [6].

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

2.5 Data transfer across multiple paths

Data transfer is done through three steps: distributed packets; data transmission; confirmation packet. The details are given below:

2.5.1 distributed packets

The packets distributed among the k paths as the equal number of packets to be assigned to all paths and Additional packets is given to the paths with higher priority. For example, for 78 arrival packets and k = 10 paths, in each paths $\lfloor 78 / k \rfloor = 7$ packets are given and 8 paths ((78 mod k) = 8) of the k = 10 paths have an additional packet. Packets with Sequential ID are assigned to routes. Fig 5 shows the format of the packet.

Off and MS fields of packets have different usage. The Off field in the packets with a value 0 shows the first packet is assigned to each the paths. The MS field shows the last packet assigned to each the paths which In this case is 0. These values together with the ID field in the packet NACK or ACK, confirm or not confirm of each packet shows.

2.5.2 Data transmission

After the selection of a set of multiple paths, the source node can begin sending data to the destination along the paths. The traffic allocation mechanism used deal with how the data is distributed amongst the available paths. After the send data in the path if a node fails and it was not possible to send through that path, the most preferred next hop used for send data and continue through the most preferred next hop when the route updated at the earliest opportunity.

ID	MS	Off	SA	DA	DATA

Fig. 5: Packet format

2.5.3 Confirmation packet

For confirmation the packets, we used a NACK and ACK hybrid scheme. In this scheme, the node transmits the packet to the next node, after a certain time if the NACK message with the ID packet received, sender try again to send the same packet, otherwise, it sends the next packet. In this scheme, the packet sent in the between sequence packets that should be send, if it is missing, The receiver nodes with sequence checking of packets received, will inform sender, with a NACK and the ID of lost packets if there was no sequence ID.

For the latest packet or single packets is used an ACK message, because after sending out the packets, there are no another packets that was sent and the packet sequence is compared. Also used to create the more reliability of the ACK message.

Only on the ACK message of hybrid scheme, the amount of energy remaining, the SNR and available buffer nodes give prior nodes. The advantage of this hybrid scheme is that has little overhead, and don't need to send response message for each packet and less energy is consumed. It should be noted that the messages NACK, ACK packets to determine and inform the sender to confirm or not confirm, all the fields ID, MS, Off is used. Fig. 6 illustrates the structure of the NACK message.

ID	MS	Off	SA	DA

Fig. 6: NACK message structure.

3. PERFORMANCE EVALUATION OF PROTOCOL

We evaluate the performance and validate the effectiveness of our protocol through simulation. In this section, we describe the performance metrics, simulation environment and simulation results. We used NS-2 to implement and conduct a set of simulation experiments for our protocol and do a comparative study with the MCMP protocol [7].

Our simulation environment consists of 200 sensor nodes randomly deployed in a field of 500 m * 500 m. All nodes are identical with a radio transmission range set to 25 m. The sink node is situated at the upper right corner of the simulation field, and the source node is situated on the left bottom corner. Table 2 shows the simulation parameters [2].

We investigate the performance of our protocol in a multichip network topology. The metrics used in the evaluation are the energy consumption, delivery ratio and average delay. The average energy consumption is the average of the energy consumed by the nodes participating in message transfer from source node to the sink node. The delivery ratio is the number of packets generated by the source node to the number of packets received by the sink node. The average delay is the average time required to transfer a data packet from source node to the sink node. We study the impact of packets generation rate on these performance metrics. Simulation results are averaged over several simulation runs.

TABLE 2. Simulation Parameters [2]

Network field	500m*500m
Number of sensors	200
Number of sinks/number of source	1/1
Transmission range	25m
Packet size	1024Bytes
Sub-packet size	256Bytes
Transmit power	15mv
Receive power	13mw
Idle power	12mw
Sleep mode Power	0.015mw
Initial battery power	100J
MAC layer	IEEE 802.11
Max buffer size	256 K-bytes
Buffer threshold	1024byte
Weights(γ, β, α) respectively	3/2/3
Simulation time	1000s

3.1 Impact of packets generation rate

In this experiment, we change the packets arrival rate at the source node from 10 to 100 packets/s. We compare our protocol with the MCMP protocol.

3.2 Packet delivery ratio

Another important metric in evaluating routing protocols is the average delivery ratio. Fig. 7 shows the average delivery ratio of our protocol and MCMP protocol. Obviously, our protocol outperforms the MCMP protocol.

Our protocol for use the ACK, NACK hybrid scheme and assurance of packet delivery in every hop, packets with high delivery rates to destinations delivers. Creating paths with high reliability and distribution packets on the routes to avoid congestion and packet loss is very effective in enhancing the delivery rate.

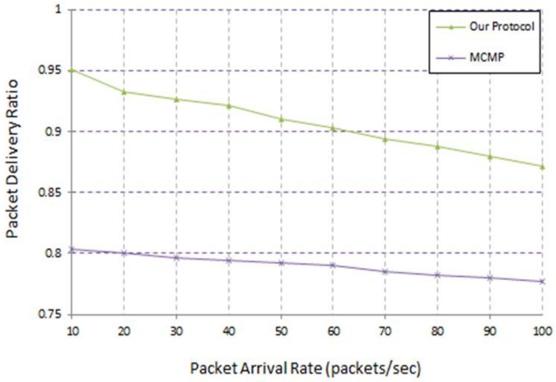

Fig. 7: Packets delivery ratio.

3.3 Average energy consumption

Fig. 8 shows the results of energy consumption. In the figure we see that our protocol has better performance than the other protocol. This is because the overhead of our protocol is lower than the MCMP protocol and also due to the use of load balancing on multi routing and reduce congestion on a route. In also this protocol to send the packet loss from the previous node is performed and energy consumed to reach the node, not wasted.

Using a combination of ACK, NACK is effective in reducing energy consumption. In this hybrid scheme, for each packet is not required to send a response packet. In the protocol because routes have been created with effect the number of hops and shorter routes have been created, packet transmission, consumes less energy.

3.4 Average end-to-end delay

The average packet delay of our protocol and MCMP protocol as the packet arrival rate increases is illustrated in Fig. 9. In this experiment, we change the packet arrival rate at the source node, and measure the delay packets. Due to the construction of paths with effect the hop count, and using a combination of NACK Our protocol delay is less than MCMP protocol.

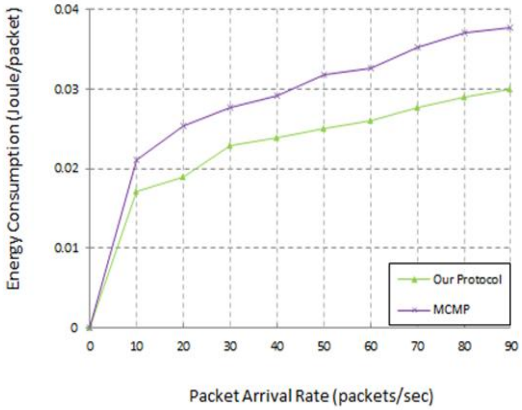

Fig. 8: Average energy consumption

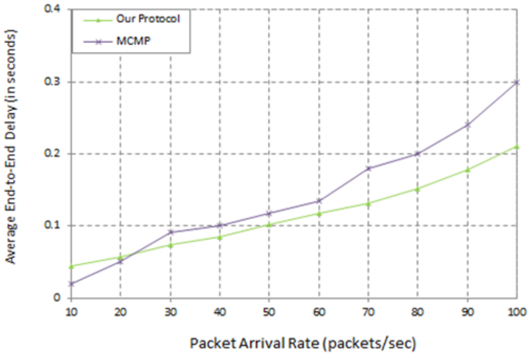

Fig. 9: Average end-to-end delay.

4. Conclusion

In this paper, we have presented our protocol; a reliable data delivery and energy efficient aware multi-path routing protocol designed specifically for wireless sensor networks to provide reliability data delivery and energy efficient. we used a NACK and ACK hybrid scheme. This method is very effective in energy efficiency. Our protocol uses the residual energy, node available buffer size, and signal-to-noise ratio with influence hop count metric to predict the next hop through the paths construction phase. Our protocol distributed packets over multiple paths to reduce overhead transmission.

Through computer simulation, we have evaluated and studied the performance of our routing protocol under different network conditions and compared it with the MCMP protocol. Simulation results have shown that our protocol achieves more energy savings, lower average delay and higher delivery ratio than the MCMP protocol.

As a future work, we are intended to deeply analyses the performance of our protocol and study the impact of the network size, path length, and buffer size on the performance metrics.

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