Reliability Based Routing in Wireless Sensor Networks

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Abstract

Sensor network deployed to recover from disaster or in military applications pose a great challenge in reliable sensed data delivery with limited power consumption. Due to the small transmission range of sensor nodes the data is forwarded using multiple hops where unexpected node failure is common at each hop. Routing techniques in sensor network gives priority to reliable transmission as the loss of important information prevents the sensor network from fulfilling its primary purpose and hence this information loss should be avoided. The commonly used routing protocols uses single path routing or multiple path routing techniques to deliver the data, without differentiating between more reliable information from less reliable and hence the overhead involved is same for all information. It leads to wastage of network resources. Thus the routing techniques evolved in sensor network should be capable of delivering the information at desired reliability at a proportionate communication cost by considering the importance of the information.

Key words:
Reliability, Metrics, Wireless Sensor networks, Delivery- Success Ratio.

1.Introduction

The sensor nodes collect the data and forward it to the base station. The base station is a special node that has more computing power. Once the data is routed back to the base station, it processes the data. In a typical sensor network there are sensor nodes collecting data and base-stations with higher computing power. Data is routed back to these base-stations possibly using a "multi-hop infrastructure-less architecture".

Sensor networks are mainly deployed to monitor and provide feedback of environmental variables in areas, which are intractable to humans. With such deployments in mission critical applications, sensor networks gained importance and provide for immense potential for research in this area. Two challenging issues identified in this realm are the reduction in consumption of power by these sensors to increase their lifetime and the design of routing strategies for communication in the network.

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Routing in sensor networks is a complex issue due to the large number of parameters. Unfortunately, there exists no single routing strategy, which is considered to be efficient in all aspects. A routing strategy may be shown to be efficient based on obtaining minimum load on a particular node in the grid. However, that same strategy might not be efficient if we consider load balance over all the nodes in the grid as the performance criterion. Therefore, it is better to decide the routing strategies based on the criteria of the application for which the sensor network is deployed. In addition, a routing strategy shown to be efficient in static network might not be an efficient strategy in dynamic networks. Hence, both the scenarios of static and dynamic networks are to be considered separately and also the criterion for efficiency in both scenarios is to be decided.

This paper is organized as follows. Section 2 discusses work related to existing routing protocols, path metrics and reliability improvement techniques. Section 3 presents an overview and the details of approach to the problem and the implementation of the system. Section 4 consists of the result obtained and performance evaluation of the system. Section 5 provides the conclusion with future areas of development in this area.

2. Related Work

Multi-hop routing for wireless networks [15] is and integrated routing and MAC protocol that increases the throughput of large unicast transfers in multi-hop wireless network. In this technique each node receives a packet must agree on their identities and choose one forwarder. It must have low overhead and forwarder should have lowest remaining cost to reach the ultimate destination.

Multi-path On-demand Routing protocol [8] uses hop-by-hop reliability layer for routing and data delivery in a wireless ad-hoc network. Every node makes local decision about forwarding of data packet. It also has a reliability layer incorporated that reroutes the packets through a different path if any failure occurs in delivering the packet. The reliability layer improves end-to-end packet delivery by transmitting packets limited number of times. If node fails to acknowledge packet a particular number of times then the route that pass through that node can be deleted.

To quickly recover from failures multiple paths from source to destination are used in diffusion routing in highly resilient, energy efficient multi-path routing [10] in wireless sensor network. But the drawback is extra overhead that occurs due to multi-path formation and maintenance. Many multi-path-routing schemes are used to recover from broken paths and they are not adaptive to channel errors and required reliability specified in the packets.

GRAdient Broadcast [9] forwards data along a band of interleaved mesh from each source to receiver and controls the width of band by the amount of credit carried in each data message, allowing sender to adjust robustness. In GRAB each receiver decides whether it should forward a packet by comparing its own cost to that of sender. Sender does not keep state information about which neighbor to forward data and this elimination of such explicit path state also removes overhead and complexity in repairing paths for failed nodes.

Directed diffusion [11] is data-centric in that all communication is for named data. All nodes in a directed diffusion-based network are application-aware. Data generated by sensor nodes is named by attribute-value pairs. A node requests data by sending interests for named data. Data matching the interest is then "drawn" down towards that node. Intermediate nodes might aggregate the data. An important feature of directed diffusion is that interest and data propagation and aggregation are determined by localized interactions.

Hop count metric provides minimum hop-count routing. Link quality for this metric is a binary concept; either the link exists or it doesn't. The advantage of this metric is its simplicity. Once the topology is known, it is easy to compute and minimize the hop count between a source and a destination. The disadvantage of this metric is that it does not take packet loss or bandwidth into account. It has been shown that a route that minimizes the hop count does not necessarily maximize the throughput of a flow.

Per-hop RTT metric [1] is based on measuring the round trip delay seen by unicast probes between neighboring nodes. To calculate RTT, a node sends a probe packet carrying a timestamp to each of its neighbors every 500 milliseconds. Each neighbor immediately responds to the probe with a probe acknowledgment, echoing the timestamp. This enables the sending node to measure round trip time to each of its neighbors. The node keeps an exponentially weighted moving average of the RTT samples to each of its neighbors.

This metric has the following disadvantages. First, there is the overhead of measuring the round trip time. Second, the metric doesn't explicitly take link data rate into account. Finally, this measurement technique requires that every pair of neighboring nodes probe each other. Thus, the technique might not scale to dense networks.

Per-hop Packet Pair Delay [12] metric is based on measuring the delay between a pair of back-to-back probes to a neighboring node. It is designed to correct the problem of distortion of RTT measurement due to queuing delays. The packet-pair technique is well known in the world of wired networks. To calculate this metric, a node sends two probe packets back-to-back to each neighbor every 2 seconds. The first probe packet is small, and the next one is large. The neighbor calculates the delay between the receipt of the first and the second packets. It then reports this delay back to the sending node. The sender maintains a exponentially weighted moving average of these delays for each of its neighbors. The objective of the routing algorithm is to minimize the sum of these delays.

To attain reliability in senor network there are many techniques available that can be incorporated with routing algorithms. The three most commonly used techniques [13] to improve reliability are:Link-level retransmission (ARQ) ,Blacklisting and routing using a metric that reflects path reliability

Per-hop retransmission (often called ARQ at the MAC layer) is a widely used technique to improve reliability of a given link. Retransmissions are attempted one or more times up to some limit before the packet is declared lost. Using link-level ARQ, losses can be quickly detected and corrected, and even a few per-link retransmissions can greatly improve end-to-end reliability.

All routing protocols use some routing metric to select paths. If the routing metric is selected to represent end-to-end reliability, the routing protocol can identify paths with high reliability.

3 SYSTEM ARCHITECTURE

The objective of our work is to deliver the packets at desired reliability based on the information sensed using a multi-path routing technique. The information is delivered reliably using less number of transmissions of data packet. Only limited number of paths is used between the source and the destination based on the criticality of the information to be delivered instead of using all possible paths. The three main modules of the proposed system are as follows:

- Path creation between the source and the sink
- Calculation of ETX metric
- Forwarding and retransmission of the data packets

The number of multiple paths that exists between the source and the destination varies to a great extent based on the number of nodes in the network. All these paths are used when the packets are delivered at same level of reliability. When the reliability level differs based on the information there is no need to utilize all the paths for any level of reliability. If the reliability required is small then only few paths are used and as the reliability required increases the number of paths used also increases. Such creation of multiple paths between a source and the sink has been done.

In delivering the packets in wireless sensor network routing protocols fail to find high quality paths in presence of lossy wireless links. So in routing the packets for desired reliability, a link quality metric, which considers loss in wireless links, has to be identified. The metric selected should produce high throughput in data delivery through the path. Based on the metric selected optimal path for routing has to be determined and case of any failure subsequent paths should also be selected based on the criteria identified. The metric value of all paths should be calculated.

After the creation of multiple paths between the source and the sink based on the reliability required, a reliability layer mechanism must be incorporated to deal with failures. When a node in the path through which the packets are forwarded fails, it leads to packet loss and this packet loss is overcome by using this reliability layer mechanism which routes the remaining packets through the next optimal path. It also helps in routing the lost packets to the destination.

3.1 PATH CREATION

Multiple paths between a source and a sink can be created using many techniques that are used in Ad-hoc On-demand Multi-path Distance Vector, Multi-path Dynamic Source Routing. But these techniques create all possible paths between a source and a sink, which is not desirable when the number of paths to be used differs, based on the information.

3.1.2 Algorithm for creating multiple paths

The steps that are followed in creating multiple paths between the source and the sink is through:

- Hop Count Calculation
- Classification of Neighbor nodes
- Path Creation using control packets

3.1.2.1 Hop Count Calculation

1. Once the topology size is given it is divided into grids using the grid size specified. The number of nodes per grid is also determined. These nodes are randomly placed in the given topology.
2. Nodes that are required to act as source are attached to the sensor agent and sink node is attached to the sink agent. The simulation is started at specific time.
3. Initially sensor nodes are made to be in sleeping state and when any node has to be made working, first the node should switch to probing state and then only it switch to working state.
4. There are timers that has been set for probing, probing reply, probing reply response hello, hello reply, hello reply response and advertisement messages. When these timers expire corresponding procedures will be called.
5. Initially a node on expiration of its wakeup time switch to probe state and probe message is broadcasted to all neighbor nodes. If any node is awake within the probing range they respond with probe reply message. Based on the reply the probing node can decide whether to sleep or to work.
6. If no probe response is obtained this node starts to work and broadcasts the hello message. The working nodes respond with hello reply message, which contains the information stored in its sink table.
7. Sink broadcasts the advertisement message with the value of hop count has 1 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 sink

table if it is lesser than the previous value.

3.1.2.2 Classification of Neighbor Nodes

1. The maximum number of neighbors for each node is limited to 1000.
2. When a node receives an advertisement packet, it stores the source of the packet as its neighbor. Thus each node maintains a list of its neighboring nodes.
3. A node classifies its neighbors by comparing its hop count value with that of its neighbors as follows:
   - 3.1.1. If the hop count value of the neighbor node is less by one, then this neighbor node is placed in a negative set.
   - 3.1.2. If the hop count value of the neighbor node is greater by one, then this neighbor node is placed in a positive set.
   - 3.1.3. If the hop count value of the neighbor node is the same, then this neighbor node is placed in a zero set.
4. The classified nodes are added to the appropriate fields (positive, negative, zero) in the sink table.
5. A Count of number of nodes in each set is also maintained in the sink table.

3.1.2.3 Path Creation using Control Packets

On generating a packet, the source node determines the importance of the information it contains and decides the desired reliability r_s for it. It also knows the local channel error e_s. The source s is at distance hs from the sink, which is computed in hop count calculation step. The neighborhood set of the source is divided into 3 subsets H_s^- , H_s^0 , H_s^+, which contain neighbors at distance hs −1,hs, hs + 1 respectively with help of previous step. Using these values, the source computes the number of paths N_s, required for delivering the packet at desired reliability to the sink.

3.2 CALCULATION OF ETX METRIC

The metric most commonly used by existing ad hoc routing protocols is minimum hop-count. These protocols typically use only links that deliver routing probe packets (query packets, as in DSR or AODV, or routing updates, as in DSDV). This approach implicitly assumes that links either work well or don't work at all.

Minimizing the hop-count maximizes the distance traveled by each hop, which is likely to minimize signal strength and maximize the loss ratio. Even if the best route is a minimum hop-count route, in a dense network there may be many routes of the same minimum length, with widely varying qualities; the arbitrary choice made by most minimum hop-count metrics is not likely to select the best.

The solution that overcomes the drawbacks of minimum hop-count metric is ETX metric. ETX finds paths with the fewest expected number of transmissions (including retransmissions) required to deliver a packet all the way to its destination. The metric predicts the number of retransmissions required using per-link measurements of packet loss ratios in both directions of each wireless link. The primary goal of the ETX design is to find paths with high throughput, despite losses. The metric's overall goal is to choose routes with high end-to-end throughput. The metric must account for the following issues:

- The wide range of link loss ratios.
- The existence of links with asymmetric loss ratios.
- The interference between successive hops of multi-hop paths.

3.2.1 ETX Metric

The ETX of a link is the predicted number of data transmissions required to send a packet over that link, including retransmissions. The ETX of a route is the sum of the ETX for each link in the route.

ETX has several important characteristics:

- ETX is based on delivery ratios, which directly affect throughput.
- ETX detects and appropriately handles asymmetry by incorporating loss ratios in each direction.
- ETX can use precise link loss ratio measurements to make fine-grained decisions between routes.
- ETX penalizes routes with more hops, which have lower throughput due to interference between different hops of the same path.

- ETX tends to minimize spectrum use, which should maximize overall system capacity.

3.2.2 Steps followed in calculating ETX metric

1. A timer is scheduled to expire at an interval of 0.1 second and each node is assigned a counter with an initial value of 0.
2. On expiration of this timer probe packets are transmitted to neighboring nodes and the timer is rescheduled.
3. When a node receives the probe packet its counter value is incremented by one.
4. The above two steps are repeated for w seconds.
5. At time t, node calculates the delivery ratio by knowing the number of the probes it received during the last w seconds and the actual number of the probes that should have been received.
6. ETX metric of the link is calculated using the delivery ratio obtained in previous step.
7. The steps 1 to 6 are repeated for all links in a path and the summation of each link in the path gives the path ETX metric value.
8. When ETX values of all paths are determined, the path that has least ETX metric value is selected as an optimal path.

Each node's ETX value is the sum of the link ETX values along the lowest-ETX path to E. A link's ETX value is the inverse of the link's delivery probability in the forward direction.

3.3 FORWARDING AND RETRANSMISSION

Reliability layer mechanism that improves reliability in sensor network can be done making use of techniques like:

- Link-layer retransmission
- Blacklisting bad links
- End-to-end routing metrics

The main algorithm used is as follows:

The data packets are forwarded through the selected optimal path using data forwarding algorithm described below.

1. On path failure the remaining and the lost packets are sent through the next available optimal path using the retransmission algorithm.
2. At the end of the simulation, the success ratio, which is defined as the number of packets received successfully at the sink to the number of copies of packets actually used is calculated.

Algorithm for forwarding the data packet:

1. The data timer present in the source is scheduled for an interval. When the time interval expires a data packet is sent to the next node prevailing in the path.
2. The timer is rescheduled whenever a data packet is sent from the source.
3. The node on receiving the data packet passes it to its neighbor node which is present in the path.
4. Whenever a data packet is received by the sink, it sends an acknowledgement to the source.
5. This process continues until all the packets are delivered to the sink or the source detects the failure in the path and stops the transmission.

Algorithm used for retransmission:

1. Path failure is detected whenever acknowledgement is not received by the source for considerable amount of data packets.
2. The sent packets for which the acknowledgements are not received are categorized as lost packets and the packets, which are yet to be sent, are categorized as remaining packets.
3. When a path failure is detected the existence of optimal paths are found. If exists, the remaining data packets are sent to the sink through the next best optimal path. This process too makes use of the data timer, which is used in the forwarding.
4. A retransmission timer is scheduled for sending the lost packets. This works similar to that of the data timer.
5. Thus the remaining packets and the lost packets are sent to the sink based on the reliability level successfully.

4. PERFORMANCE EVALUATION

The performance of our system is evaluated mainly based on the following parameters.

- Delivery Ratio
- Success Ratio

4.1 Delivery Ratio

The Delivery Ratio (DR) service level parameter reports the networks effectiveness in transporting an offered packet load in one direction of a single connection. The DR is a ratio of successful packet receptions to attempted packet transmissions. Attempted packet transmissions are referred to as Sent Packets. Successfully delivered packets are referred to as Received Packets. These loads may be further differentiated as being within the committed information rate or as burst excess.

Method:

1. For each simulation run, sum up the total number of packets sent and the total number of packets received for that run.
2. Calculate the packet delivery ratio for each run as:

$$DeliveryRatio = \frac{TotalPacekts\,\mathrm{Re}\,ceived}{TotalPacketsSent}$$

4.2 Success Ratio

Success Ratio (SR) is intended to provide a metric, which summarizes the overall service provided. This metric captures the cost to send data, and includes retransmissions. This metric is computed by normalizing the total number of data transmissions by the number of messages sent to reflect the cost of packets that are sent.

$$SuccessRatio = \frac{TotalPackets\,\mathrm{Re}\,ceived}{TotalNumberofCopiesofPacketUsed}$$

4.3 RESULTS

A detailed simulation of the modified multi-path routing protocol - has been done varying the reliability, as discussed in the previous sections.

Number of Nodes	: 300
Hop Distance between Source and Sink	: 6
Error Rate	: 20%
Source	: Node 12
Sink	: Node 300
Reliability	: 70%
Number of Paths to be created	: 4

1. Paths Created

Path 1: 12->27->93->194->291->287->300
Path 2: 12->80->172->177->255->277->300
Path 3: 12->31->96->194->180->270->300
Path 4: 12->79->164->165->196->285->300

2. ETX Values

Path 1: 12->27->93->194->291->287->300 has ETX value 2.381543
Path 2: 12->80->172->177->255->277->300 has ETX value 2.251242
Path 3: 12->31->96->194->180->270->300 has ETX value 3.204246
Path 4: 12->79->164->165->196->285->300 has ETX value 2.855913

2.1.1 Optimized Paths

1. Path 2 with ETX Value 2.251242
2. Path 1 with ETX Value 2.381543
3. Path 4 with ETX Value 2.855913
4. Path 3 with ETX Value 3.204246

First best Path is Path 2

4.3.1 Delivery Ratio and Success Ratio Results

Also detailed comparisons between the two protocols are done for performance evaluation and are given as plots. Figure 4.1 and Figure 4.2 show the performance comparison of modified multi-path routing protocol and Gradient Broadcast.

Figure 4.1 show the Reliability Vs. Number of Paths with maximum reliability of 90%. It is evident from the graph that as the reliability level increases the number of paths required also gets increased.

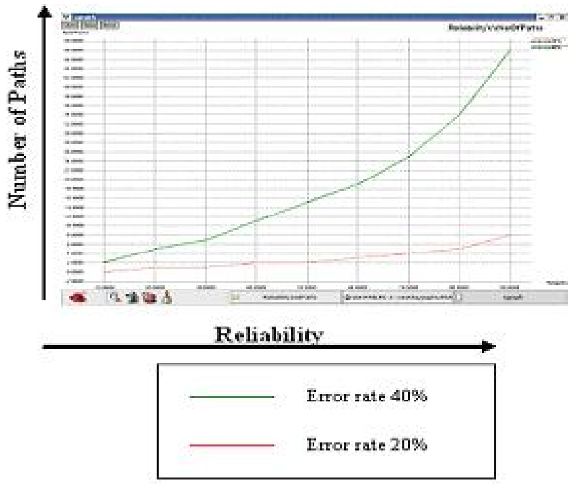

Figure 4.1 Reliability Vs. Number of Paths

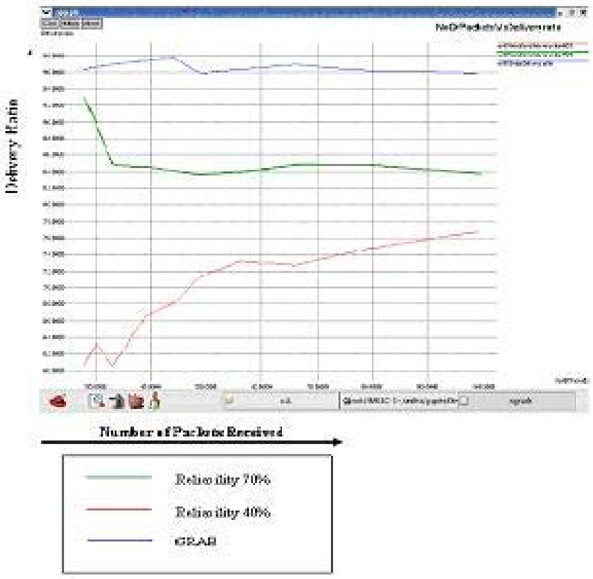

Figure 4.2 Number of Packets Sent Vs. Delivery Ratio

Figure 4.2 depicts the Number of Packets Sent Vs. Delivery Ratio with a maximum of 99 packets sent. It is obvious from the graph that existing routing protocol provide a standard delivery ratio irrespective of level of importance of the information but modified multi-path routing protocol shows a varying delivery ratios based on the reliability level specified. Modified multi-path routing protocol shows higher delivery ratio for 70% reliability compared to that of 40% reliability.

2.2 Figure 4.3 Number of Packets Sent Vs. Success Ratio

The Figure 4.3 depicts the Number of Packets Sent Vs. Success Ratio with a maximum of 99 packets sent. It is clear from the graph that total number of copies of packets used to achieve a specific delivery rate is very less in modified multi-path routing protocol than that of existing protocol.

5. CONCLUSION

At present, the existing routing protocols are lacking in the fact of indiscriminating the information based on the contents they sense. This leads to unnecessary consumption of resources when the information is of less importance. The paper focuses on the importance of mechanisms to support information awareness and service guarantees for information dissemination, essential for sensor networks. A methodology has been proposed here, which discriminates the information depending on its criticality. The proposed forwarding and retransmission mechanisms reduce the number of packet transmissions leading to greater energy efficiency and positive throughput. Discarding a packet requires discarding all the energy that has been used so far to transmit that packet and hence reasonable steps are suggested to avoid discarding packets. The work done has concentrated on single source to single sink transmission. This work can be enhanced by making it work in multiple sources and multiple sinks. In that case each node has to store hop distance for each sink. The efficiency of the work will improvise if the noise characteristic of the network is also pondered. Sink mobility is not addressed in the design and this may be considered in the further researches.

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