

Reliable Routing Algorithm on Wireless Sensor Network

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Abstract— This paper provides a novel routing algorithm CLQR (Cumulative Link Quality Routing Algorithm) which leverages LQI to provide a better routing scheme. Unlike other schemes providing maximum link quality, CLQR does not use probe packets to measure the link quality. Instead it uses cumulative link quality as a metric to choose better routing path. Result of simulation shows that it can hold a high throughput and improve path efficiency. Moreover, CLQR can balance network load and extend network life time.

Keywords— reliable transmission, LQI, Routing

through indoor experiment results with MicaZ motes. According to the simulation of 100 nodes by TOSSIM, CLQR achieves a better performance.

The rest of the paper is organized as follows: in section 2, we discuss related works on routing metrics in multi-hop wireless network. In section 3, we explain the motivation why we bring this new metric. In section 4, we describe the basic metric of CLQR. In section 5, we display our algorithm of CLQR. In section 6, we exhibit the experiment results and the performance evaluation. Section 7 will be the conclusion and future work of this paper.

I. INTRODUCTION

Recently, the wireless sensor network is full of our daily life. It can be used to monitor the environment, such as hospital, battlefield, forest and home. Unlike the wire network, wireless sensor network has some limitations such as low battery power and memory, narrow channel, poor link quality and high packet loss rate. How to avoid noise and provide an efficient reliable data transmission is a challenge we are facing.

Most of metrics to choose the route from a node to a sink node in recent years are tend to rely on the minimum number of hop-count [1], [2] or the excepted transmission count [3], [4], [5], [6]. The minimum number of hop-count can gain a high PRR (Packet Received Rate) depending on the high and stable symmetric link quality between every node pairs. The obvious characters of wireless sensor network, nevertheless, are asymmetrical and unstable. Therefore the minimum hop-count metric is not suitable for wireless sensor network. ETX (Excepted Transmission Count Metric) and other related metrics may reduce total number of transmission packets and provide higher throughput than the minimum hop-count schemes. However, they could not balance the network load and also cannot achieve maximum the wireless link bandwidth that will be described more detail in the following section. Furthermore, they use an ocean of probe packets to measure both sides link quality.

In this paper, we provide a new routing scheme, CLQR (Cumulative Link Quality Routing Algorithm). CLQR uses cumulative LQI from a node to a sink as a routing metric. We show the close relationship between LQI and PRR

II. RELATED WORKS

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Reliable data transmission is one of challenges in wireless sensor network. The common metric in the routing schemes is the minimum hop-count. However, it cannot hold a satisfying throughput on wireless sensor network since it ignores the link quality between node pairs. In [7], R.C. Shah et al. considered the cost of communication between the node pairs and the power remained in the node as the routing metric. The proposed algorithm may decrease the energy consumption and increase the surviving period of the whole wireless sensor network, but neglect holding a high throughput. In [3], S. J. Douglas et al. describe a new metric ETX, which combines forward delivery ratio and reverse delivery ratio to choose a route. It owns the least delivery number and highest throughput. However, ETX cannot choose a better one from two routes which have the same value of ETX but having different value of forward and reverse delivery ratio. Hence, ETX may choose a path with plenty of retransmission. In [4], L.F. Sang et al. find that reverse link quality has less effect on data transmission. Consequently, they choose a route with only forward link delivery ratio. They say ETF (expected number of transmissions over forward links) can hold a higher throughput than ETX. D.W. Cheng et al. show another metric LETX [5], which uses EWMA scheme to calculate forward delivery ratio and reverse delivery ratio more accurately. Though LETX attains a higher throughput and lower power consumption than ETX, it owns the same shortcomings as ETX. In [8], D.W. Cheng et al. improved ETX by changing the RF power to meet

the transmission demand. However, in order to hold a high throughput, the chosen nodes will maintain a large RF power that will make the nodes to die quickly. In [6], U. Ashraf et al. improved ETX by adding link traffic interference factors into it. Therefore, ELP (expected link performance) has higher throughput and lower delay than ETX. ELP has the same disadvantages as ETF. T. He et al. pay their attention to use hops and traffic load to decrease the collision and reach a very high throughput [9]. Nevertheless, TADR[9] neglects the link quality influence on throughput. In [10], Q. Cao et al. provide a new method CBF (Cluster-Based Forwarding) to achieve a reliable data transmission. CBF is also based on link quality, but the difference is that it uses two types of helpers to reduce more retransmission and it gains more reliable end-to-end packet delivery. Although CBF can obtain a lower cost and delay, it is designed for low-data-rate sensor networks, where congestion is rare. Therefore, it cannot be used in the environment with dense nodes.

III. MOTIVATION

A. Relationship between PRR and LQI

Nowadays, link quality evaluation almost relies on calculating correct received probe packets. However, it is not easy to obtain the statistics with this traditional method. As well, it wastes a large number of bandwidth to propagate the probe packets. With the development of sensor nodes, Micaz can get link states directly from the value of LQI. Experiment results in [5], [13], [14] show that LQI and PRR has a strong relationship, and the work in [4], [6] reflect us that PRR can be affected by transmission payload. To prove the relationship between LQI and PRR, we use Micaz nodes to do some indoor experiments. We divided sensor nodes in two parts. One part has 4 bytes transmission payload, the other one has 114 bytes. Every time, we send 1000 packets between one pair nodes and gain the test results under different values of LQI. As shown in figure 1, we find some evidences to prove packets which have smaller payload size can easily obtain a higher and more stable PRR.

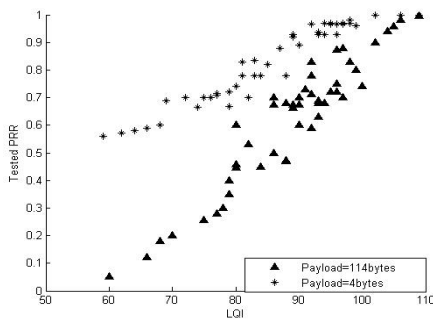


Figure 1: Relationship between LQI and PRR

According to figure 2 we conducted, we can clearly get a conclusion that tested PRR has little effect on ACK packets. ACK packets almost hold 80% successful received rate no matter what the tested link quality is good or bad.

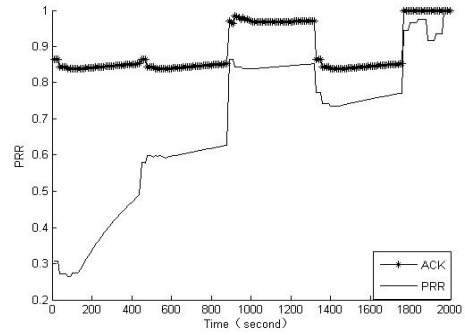


Figure 2: Relationship between PRR and ACK

Hence, evaluating link quality with LQI can accurately reflect the real link states. Meanwhile, this method without using probe packets can save unnecessary power consumption.

Most of recent metrics commonly used by wireless sensor network routing metrics are minimum hop-count, ETX metric and other advanced metrics improved from them.

Minimum hop-count metric and some metrics related with them only focus on the number of hops, where they want to use the minimum hop-count to gain the least number of packet transmission and high throughput. However, without considering link quality, it only suits symmetric and stable wire network.

B. Limitation of ETX

ETX and other development metrics from ETX such as ETF pay more attention to the expected transmission count. The definition of ETX is as follows:

$$ETX = \frac{1}{df \times dr} \quad (1)$$

where df and dr mean forward and reverse delivery ratio, respectively.

ETX cannot choose a better one from two routes if they have the same value of ETX but having different value of df or dr . If the chosen path has a high dr and a low df , it will lead many unnecessary packets retransmission. We use the following example depicted in Figure 3 to show that ETX does not provide the optimal route in terms of throughput and network efficiency. In Figure 3, a node A wants to send data to a node D.

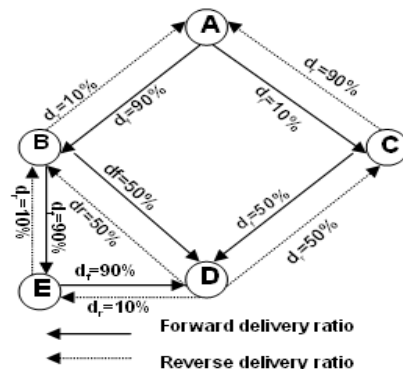


Figure 3: A random wireless sensor network

First, we introduce performance metrics to compare the performance on the different paths from the node A to the node D. For the following formulas, we define terms in Table 1 and PRR (Packet Received Rate) is defined as follows.

$$P R R = \frac{N_{dr}}{N_{sd}} \quad (2)$$

Table 1: Terms used in the formulas

N_{dr}	total number of received packet at destination node
N_{sd}	total number of transmitted packet at source node
N_d	total number of transmitted packet by whole nodes
N_{dn}	total number of transmitted packet by whole node if there is no packets loss

To compare the average number of packet transmission at each node to provide the reliable transmission from the sender to the sink, we introduce Node Transmission Pressure and it is defined as follows.

$$\text{Node Transmission Pressure} = \frac{N_d}{\text{Hops}} \quad (3)$$

A route with low *Node Transmission Pressure* indicates that the total number of packet transmission at each node in the network is low, thus this route dose not waste the network resources.

We also consider that how much of packet is transmitted on the error link comparing to the error-free link. We introduce *Path Efficiency* defined in [13]. Path efficiency is the ratio of total number of transmitted packet by whole nodes to total number of transmitted packet by whole node if there is no packet loss, and it is defined as follows:

$$\text{Path Efficiency} = \frac{N_{dn}}{N_d} \quad (4)$$

The value of path efficiency is closely related to the value of PRR and throughput. If PRR is low, the sender has to transmit more packets to the sink, thus it induces the low value of path efficiency. According to the value of figure 3, we obtain some results in table 2.

Table 2: Results of path performance comparing

Route	A->B->D	A->C->D	A->B->E->D
ETX	15.11	15.11	33.33
PRR	0.45	0.05	0.729
Path Efficiency	47%	9%	81%
Node Transmission Pressure	211	1100	123

Comparing the results, we clearly find ETX cannot attain an optimizing routing.

- If we use ETX or other related metrics to chose route, they has equal probability to chose path A->B->D and path A->C->D for the same minimum value of ETX. However, based on table 2, the best route would be a path with high forward delivery ratio and low reverse delivery ratio such as path A->B->D rather than path A->C->D. However, using ETX or other related metrics could not distinguish the right path when the two paths have the same ETX.
- From Table 2, path A->B->E->D provides us a higher PRR than the other two paths. It also attains the most efficient Path Efficiency to maximize the bandwidth. Actually, it holds a lower Node Transmission Pressure to reduce motes power consumption as well. Thus, we doubt, whether ETX or other improved metrics such as ETF are good routing metrics or not. Furthermore, we fall into a puzzling how to select a satisfying route just like path A->B->E->D.

IV. BASIC METRIC

Taking into account all these complex reasons as we mentioned above, we bring a novel metric CLQ to solve these involved problems. This new metric chooses a route using a novel parameter CLQ (Cumulative Link Quality) which is the probability that packets can be successfully received in the receiver. It only focuses on forward delivery ratio. The definition of CLQ is in formula 5.

$$CLQ_{\text{new}} = CLQ_{\text{old}} \times PRR \quad (5)$$

The routing selection depends on the value of CLQ. Actually, the node, which has the maximum value of CLQ, will become the next hop node. Maximum CLQ indicates the chosen path can maximize the throughput. Meanwhile, $1/CLQ$ means how many packets the source node will deliver for the sink to receive a packet reliably. The chosen route is a path which has the least number of packets which the source node will delivery and the intermediate node will forward. Decreasing the number of transmission packets will extend the node surviving period by cutting down the Node Transmission Pressure. Thus, for the extending life time, CLQR can avoid network breaking down unexpectedly.

We use response message to establish a Direct Routing Table and beacon message to make a Reverse Routing Table. These two types of routing table are described as Table 3 and 4. "Destination Node ID" and "Sequence number" of two tables have the same meaning. Other elements in the table, however, own different meanings.

In the Reverse Routing Table, *Previous hop node ID* means the parent of current node. In the Direct Routing Table, *Next hop node ID* indicates the child of current node. Moreover, the CLQ and PRR, coming from the response message, can be used to help erasure channel code encoding more accurately.

Table 3: The format of Reverse Routing Table

Destination Node ID	Previous hop node ID	Sequence number	PRR (P->C)	CLQ (S->C)
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P: Parent node, S: Source node, C: Current node

Table 4: The format of Direct Routing Table

Destination Node ID	Next hop node ID	Sequence number	PRR (C->N)	CLQ (S->D)
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S: Source node, C: Current node, D: Destination node

Recently, with the development of sensor motes, some motes like Micaz can easily read a signal LQI from their own chip CC2420 [12]. Meanwhile, in [13], they provide a model, shown in formula 6, which can directly obtain PRR across the value of E LQI (the average value of received LQI) instead of using an ocean of probe packets to calculate.

$$E_PR(E_LQI) = \begin{cases} -1 \times 10^{-6} (E_LQI)^3 + 0.0056 (E_LQI) - 4.1948, & 70 < E_LQI \leq 110 \\ 0, & 54 \leq E_LQI \leq 70 \end{cases} \quad (6)$$

V. ALGORITHM DESIGN

In this section, we provide a routing algorithm, CLQR, which uses CLQ as a metric to choose the next hop. The algorithm of CLQR consists of 4 parts and we describe each part more detail.

A. Reverse Routing Table Establishing

The source node broadcasts beacon message periodically, almost every STTI (Source-Time-to- Interval), to help other nodes establish their Reverse Routing Table. Every time the source node broadcasts a new cycle beacon message, the sequence number will increase by one. Beacon message contains the first entry routing information of Reverse Routing Table.

After receiving the beacon message, node builds its own Reverse Routing Table based on the same Destination Node ID. Every entry is arranged by descending order of the CLQ value. At the same time, the node will broadcast the first entry information with beacon message after the Reverse Routing Table has been established or updated.

When the Destination Node receives the beacon messages, it will establish its own Reverse Routing Table. Then it will forward the first entry information of Reverse Routing Table to the node, which included in the first entry of the Reverse Routing Table, with response messages every TTI (Time-to-Interval). Destination Node stops sending response message when the data packets transmission is finished.

B. Direct Routing Table Establishing

After receiving the response messages, every node establishes its Direct Routing Table.

Every node forwards response message in every TTI to

make sure the connection is continuous between node pairs. As long as a node receives a response message, it will start a timer which time out in every $2 \times TTI$ and restart when every response message is received. During the time, if it cannot receive a response message, it will delete the first entry of Direct Routing Table and use the back entries instead of the front ones.

C. Routing Table Update

If the current sequence number is smaller than that of the received packets, the Routing Table will be updated.

If the current sequence number is the same with one of the received packets, the node will check the value of CLQ. Routing Table will be updated only after getting a larger CLQ.

D. Data Packets Transmission

When the Source Node receives the response message, it will establish its own Direct Routing Table and begin sending data messages according to the Direct Routing Table.

VI. PERFORMANCE EVALUATION

We use TOSSIM [15] [16] a simulation platform, which provided by TinyOS, to implement CLQR routing algorithm simulation. According to CC2420 Datasheet, the valid value of LQI is between [50,110]. Every time, we send 25 data packets from the source node to the destination node to measure throughput, path efficiency and node transmission Pressure. The setting details of our experiment are as follows shown in Table 5.

Table 5: Details of experiment design

Simulated Motes Number	100 nodes
LQI	[50,110]
Transmission rate	25Kbps
STTI	5 seconds
TTI	50 milliseconds
Data message Payload	128 Bytes
Test Time	2000 Seconds
Compared Metrics	CLQR, ETX, ETF

Comparing CLQR with ETX and ETF, we achieve some evidence to prove that our metric show better performance than the other two metrics. As shown in figure 4,5, 6 and table 6, the results show that CLQR can has 1.48 and 1.19 times higher PRR, 1.30 and 1.14 times higher Path Efficiency than ETX and ETF. The higher PRR and Path Efficiency are, the more efficient we utilize the wireless link bandwidth. At the same time, it only holds 76.7% and 87.4% Node Transmission Pressure of ETX and ETF. Actually, the lower Node Transmission Pressure is, the longer of life time expend.

Table 6: Experiment results

	CLQR	ETX	ETF
Average of Throughput	0.72	0.48	0.60
Average of Path Efficiency	0.85	0.65	0.74
Average of Node Transmission Pressure from 100 packets delivery	118.55	154.45	135.66

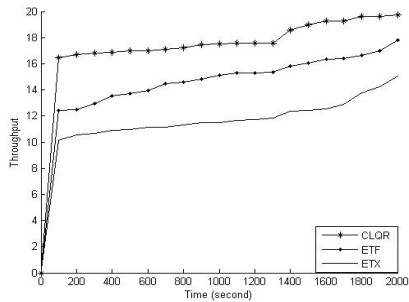


Figure 4: Compared results of Throughput with three metrics

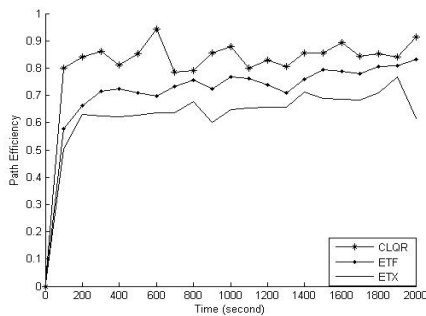


Figure 5: Compared results of Path Efficiency with three metrics

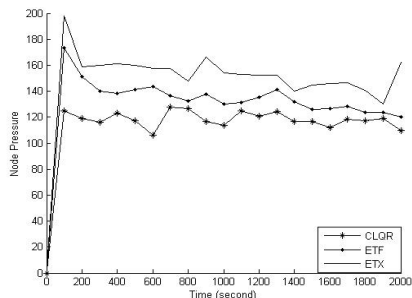


Figure 6: Compared results of Node Transmission Pressure with three metrics

Taking into account all experiments result we mentioned above, a reliable and efficient routing algorithm CLQR can not only successfully decrease Node Transmission Pressure, but also increase the Throughput and Path Efficiency.

VII. CONCLUSION AND FUTURE WORK

In this paper, we provide a novel method to make the data transmission become more reliable and efficient. We compare other related metrics, ETX and ETF.

Avoiding probe packets using, CLQR can save a large number of unnecessary power consumption and wasted bandwidth. Meanwhile it also decreases the node

transmission pressure to extend the motes life time longer than other metrics. CLQR can hold a high throughput and provide an accurate erasure channel code encoding overhead. As well, it can improve the path efficiency to maximize the wireless link bandwidth.

CLQR is an efficient and reliable dynamic routing algorithm and will become extremely useful in wireless sensor networks in the future. It, however, has a lot of space can be improved. The most important thing is how to cut down the HOT-POINT nodes. HOT-POINT nodes mean some nodes with high PRR continuous transmit plenty of data packets. Actually, the more data packets they transmit the more power they will consume and the faster they will die. How to avoid the HOT-POINT nodes occurrence is an emergency work we are facing. If we solve this involved problem in our future work, CLQR will surely be used in more expending field.

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