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SLQE: An Improved Link Quality Estimation based on Four-bit LQE

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Abstract

Link quality estimation (LQE) is an effective basic building block in wireless sensor networks (WSNs) and higher cross layer design of network protocol. Some researchers have investigated the statistical properties of the link quality estimators independently from higher-layer protocols, and their impact on the Collection Tree Routing Protocol (CTP). Then they set up a dedicated LQE, independent of the protocol interface, which has in total of four bits information: one from the physical layer, one from the link layer, and two from the network layer. Four-bit has been found to be a good estimator; however its performance heavily depends on the tuning of its parameters. But we found that Four-bit couldn't be working effectively in responding to the burst situation after repeated experiments. So we redesigned the link estimation method, called Stable Link Quality Estimation (SLQE), which combines active probing with passive snooping to make estimation more stable. We have found that the new design can cope with the emergency. Moreover it also enhances the robustness of the network, and saves the overall energy consumption of the network.

Keywords: *Link quality estimation, Collection Tree Protocol, Four-bit LQE*

1. Introduction

Due to an extreme instability with the wireless transmission in the real world, especially in the presence of transient obstacles, radio transmission has its drawbacks. Link quality estimation emerges as an important mechanism to select the most stable routes for communication[1]-[3]. Some studies focus on how to deal with network congestion or how to change the network connection status dynamically, however, few researchers are concerned about how to deal with transient network conditions deteriorating the situation and how to make full use of the dynamic link state while reducing network power consumption to a certain extent.

Out of many classic link estimation algorithms, we have selected a more robust and comprehensive, the Four-bit link estimation method, to estimate. Four-bit refers to four main pieces of information: one from the physical layer, one from the link layer and two from the network layer. These bits of information are routing independently, thereby keeping layers decoupled and avoiding unforeseen dependencies that hinder network evolution.

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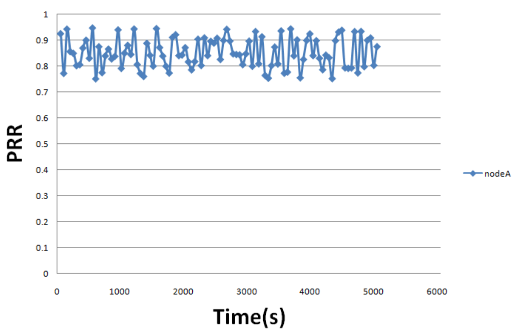
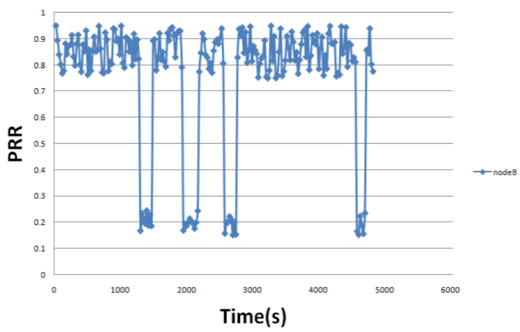
Four-bit is a link estimation method which is based on received packets, its taking lost packets into consideration, make this method reflect the link quality more accurately, but due to a number of reasons, there still exists the problem of instability: firstly, because Four-bit counts packets on network on a one minute cycle, if there had been 3 to 5 sudden deteriorations in the network status during this period, Four-bit can not perceive all packets within this one minute, which causes a lot of packets missing. Secondly, if the statistical period is too short, it will increase the energy consumption of the entire network for sure, too frequent protocol updates also could cause network problems unpredictably, such as routing loops and routing shock, etc. Furthermore, if prolonged statistics cycle, Four-bit can neither reflect the real-time network conditions, nor take advantage of such a dynamic network links to predict the occurrence of a network blocking phenomenon especially in short period of time.

In this paper, combining active and passive listeners probing mechanism, we redesigned a link estimation method, called Stable Link Quality Estimation (SLQE). In this method Node sends control packets periodically, using long-period active detection mechanisms to detect the quality of the link, while the passive node listens RSSI mean, perceives links in sudden changes effectively. When the dynamic changes are perceived in short link, it will trigger short-cycle link quality detection process. SLQE could not only perceive active link status changes respond quickly, but also smooth fluctuations in short link to maintain the stability of the estimator and avoid other overhead of frequent fluctuations in link status. In this paper, we applied SLQE in TinyOS system, and used Telosb nodes in typical indoor environment for evaluation. We also compared Four-bit link quality estimation method that exist in large number of applications in wireless sensor networks, verify and analyze the performance with SLQE.

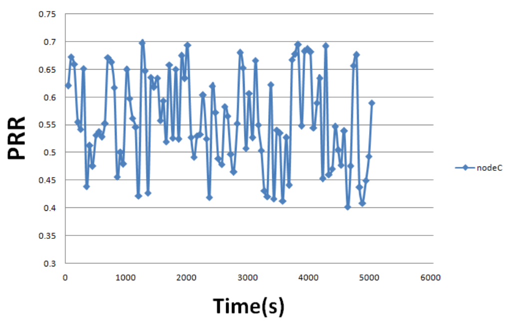
We have tested two methods in selecting the information from the network layer, counting PRR(Packet Reception Ratio) over time. In three different scenarios we can estimate the link status: a) link quality is relatively stable, b) link quality mutation occurs in a short time, c) link quality remains unstable for a long time. (showed in Figure.1)



Node A



Node B



Node C

Figure 1. Different Scenarios in Link Status

As shown in figure.1, in the case of node A and node C scenarios, we should use Four-bit routing mechanism before, where A node does not need the renew routing, and filtering process C can be filtered directly because of external causes fluctuations. However, in scenario B, mechanism is in the original blacklist (when PRR is below a threshold value in this link, discard this transmission link until the base node broadcasts next). The period of poor link status is very short, updating routing information in time is to spend a great energy (if the worst times is large). Long-period monitoring cannot detect this regulating point, causing a large number of packets missing. It isn't conducive to the network working during the long time. According to this real scenario, we design a way in link estimation combined long and short cycles. It does not affect directly routing updates only when the mutation point is detected, but it will start a short cycle higher energy detection method in detecting when time is short. Meanwhile we use such a mutation link effectively to reduce amount of data transmitted packet without routing update operation. Using this method will not add much overhead, and the algorithm logic is simple enough to implement on a limited memory nodes.

2. Related Work

Currently, there is almost little publicly reported explicitly sensor network for meteorological observation, and its relevant studies are with little breakthrough. There has been little official link quality certification for the quality of a link transmission quality standardized assessments, so routing protocols are used in reference to the latest algorithm based on the basic RNP structure. The current link quality estimation in wireless sensor network is divided into two methods: Hardware-based estimation methods and Software-based estimation methods.

2.1. Hardware-based estimation methods

Back in 2005, D.Lal, K.Srinivasan and J.Polastre and other scholars analyzed the returned data transmission module directly from: LQI (Link Quality Indicator), RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio)[4]-[6]. The reference data is only required in the return packet 8 representative data bits (and not the full data packet data), the hardware-based estimation methods are not accurate, moreover, hardware-based calculation can only be done in the receiving data terminal, without the bidirectional estimation. So some scholars combine software and hardware information in the way of the link quality estimation.

2.2. Software-based Estimation Methods

In 2006, scholars P.Jiang and Q.Huang proposed *PRR* and *ARR* methods of calculating the rate of return packets, here *PRR* is a direct assessment methods to calculate the success rate of the received packet, you can get, at the receiving end, the following specific equation: (Eq.1). This estimation method is simple, easy to use, so the time is widely used in route selection, and with its simple way, but not fully use the actual situation to represent a link quality, high error rates followed[7]:

$$PRR(w) = \frac{Number\ of\ received\ packets}{Number\ of\ sent\ packets} \quad (1)$$

In 2007, researchers M.Senel and K.Chintalapudi introduced a filtering mechanism to link quality estimation for the first time, *WMEWMA* proposed an estimation method to add a filter parameter a on the *PRR* method, and the specific formula is as follows: (Eq.2). It can reduce the energy consumption of the entire network effectively, because the information to reference is also relatively simple, we can't express the quality of a link fully[8];

$$WMEWMA(\alpha,w)=\alpha\times WMEWMA+(1-\alpha)\times PRR \quad (2)$$

The third link estimation method has proposed by the scholar A.Cerpa in 2005, which can be calculated from the transmitting side directly, and can also calculate the average number of packets transmitted and retransmitted in transmitting each data packet successfully. This is a way to calculate the link cost. With such superiority the link estimation methods are proposed in this way as a prototype[9] at this stage, using the following formula:

$$RNP(w)=\frac{Number\ of\ transmitted\ and\ retransmitted\ packets}{Number\ of\ successfully\ received\ packets}-1 \quad (3)$$

After that, D.Aguayo proposed a *ETX* method, a bidirectional link estimation method based on RNP calculation. This method is based on the estimated data sender with the receiving end of a reciprocal multiplication method to calculate the consolidated whole link quality, and the sender to the receiver on the side of the link quality estimate is expressed as $PRR_{forward}$, where the receiver to the sender of the link quality estimate is expressed as submitted $PRR_{backward}$ [10]. The specific formula of realization is as follows:

$$ETX(w)=\frac{1}{PRR_{forward}\times PRR_{backward}} \quad (4)$$

The last method, that is the way we want to improve, the most referenced information in estimating currently, is the most comprehensive representative way of link quality value, put forwarded by R.Fonseca and O.Cnawali scholars in 2007. They estimated the species named *Four-bit* LQE, taking four factors by reference into account: two from network layer, one from link layer, one from physical layer[11]. The main method is as follows:

$$fourbit(w_a,w_b,\alpha)=\alpha\times fourbit+(1-\alpha)\times estETX \quad (5)$$

In this formula, which *estETX* corresponds to $estETX_{up}$ or $estETX_{down}$. At w_a received probe packets, the sender derives the four-bit estimate according to (Eq.6) by replacing *estETX* by $estETX_{down}$. At w_p transmitted/re-transmitted data packets, the sender derives the Four-bit estimate according to (Eq.7) by replacing *estETX* by $estETX_{up}$.

$$estETX_{down}(w_a,\alpha)=\frac{1}{WMEWMA}-1 \quad (6)$$

$$estETX_{up}(w_a,\alpha)=\alpha\times estRTX_{up}+(1-\alpha)\times PNP \quad (7)$$

Given some of the problems existing Four-bit as well as its research status, we propose a research WSN routing link quality estimation method based on Four-bit, considering route updated frequently and difficult to estimate the link to design a performance improved the link quality estimate. We combine RSSI and PRR information to strengthen the link estimation; reduce routing update loss by adding filtering mechanism; and determine the uniqueness of the data packet transmission queue by adding more fields in the packet used to resolve duplicate packets problems. Then we can transmit data more accurate and more reliable in wireless sensor networks, making the networks a long-term, stable operation.

2.3. Stability Test

Stability: Figure.2 shows the average CV for each LQE from all nodes for different window sizes: w=100 (long-term estimation) and w=5 (short-term estimation), and different environments: indoor, outdoor.

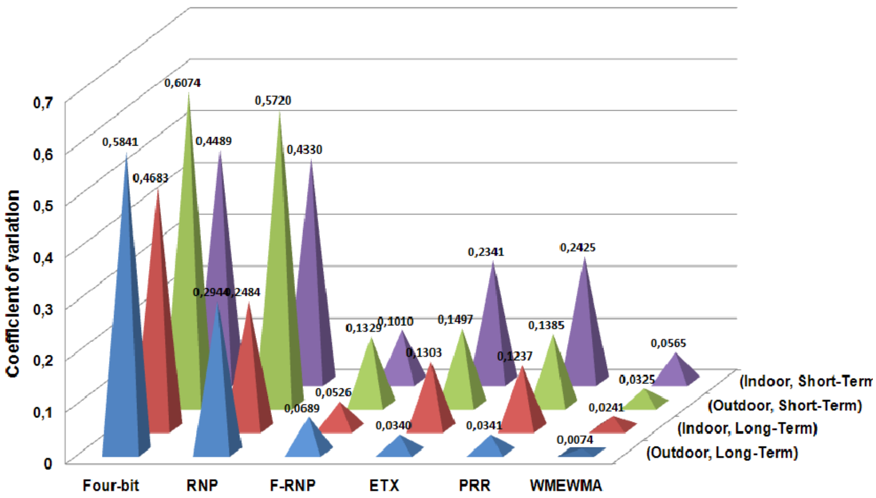


Figure 2. Mean CV for Each LQE

Firstly, according to Figure.2, we observe that WMEWMA and F-RNP are generally most stable. These estimators are based on filtering techniques, which smooth the variation of the LQE and turn them more robust to quality fluctuations than other estimators. In particular, the use of a history control factor a = 0.9 increases the stability of those filter-based estimators. In fact, the history factor has an impact on the stability of filter-based estimators. It is easily observed that the coefficient variation of the filter-based estimators linearly decreases as the history control factor α increases, leading to a more stable behavior. In practice, it is important to adequately tune the history control factor to make a balance between stability and responsiveness to link quality changes.

Second, Four-bit is the least stable LQE, although it relies on two filter-based estimators. Four-bit combines two different estimators that have different range of values (refer to (Eq.5)), as it is based on the inverse of WMEWMA in the upstream direction and on the inverse of F-RNP in the downstream direction. Four-bit can, however, be more stable if it only considers (Eq.7) as the actual output of the estimator and (Eq.6) as a corrective estimate when the downstream traffic is low. To solve this shortcomings, we used a combination of the length of the period to the estimated link quality, and found that such a dynamic link quality estimates can be more efficient for the transmission of data packets. Our aim is to reduce such measurements error from Four-bit, and make a more accurate representative of the quality of this link. So we made the following design.

3. SLQE Design

In the introduction each layer can measure or observe properties that help link estimation. The physical layer can quantify the state of the medium during incoming packets. The link layer can measure whether packets are delivered. The network layer can provide guidance to which is the most valuable link should be estimated. Our improvement is to estimate them in the physical layer and network layer. In the physical layer, we collect RSSI value. And we used PRR value in the link layer, which as the best link reference in estimating, choosing to listen in long period or to trigger short-cycle detection according to these values.

3.1. Process of Routing Network

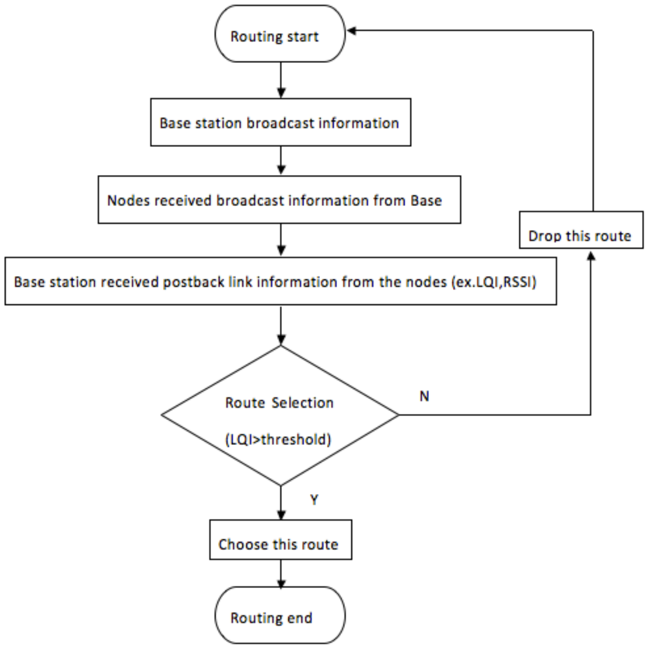


Figure 3. Formation Process of Routing

Figure.3 shows the formation process of routing, firstly, routing start, the base station broadcast information to all the nodes nearby. Secondly, when nodes receive broadcast information from the base, sending feedback link information (ex.*LQI*,*RSSI* values) to the base. In the last, base station chooses which route to send data packets base on the feedback information from the nodes nearby. We used Four-bit LQE to improve, which has presented narrow, well-defined interfaces that allow link estimation from the physical, link, and network layers. This method has shown significant improvements on the cost and delivery ratio over the state of the art, while maintaining layered networking abstractions.

3.2. Overall Architecture

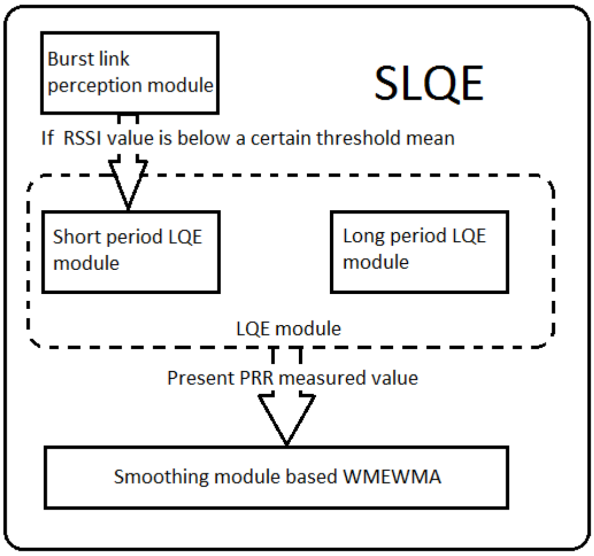


Figure 4. Frame Structure of the SLQE

SLQE combined two mechanisms in short period and long period, and estimated the link quality by the *RSSI* information which according to physical layer and link layer of the *PRR* statistical information during the period. In this paper, we use *PRR* value to measure the quality of the link by Four-bit. SLQE mainly consists of three parts (from Figure.4): Burst link perception module, LQE module and Filter module both based on WMEWMA. LQE module is divided into short period LQE module and long period LQE modules.

3.3. Short Period and Long Period Combination

SLQE receives data packet includes control packets and data packets(Eq.8), the calculation of the average RSSI in $T_{passive}$ (long-period) $Rssi_{CureentM}$, receives packet according to the formula, when $Rssi_{CureentM}$ below a certain threshold $Rssi_{Threshold}$ triggers short period T_{active} (short-period) link quality detection process. Estimate the quality of the next link in a short time. $Rssi_{Threshold}$ values are set by the different needs of specific applications and hardware devices. When you need high accuracy, the threshold can be set to be higher. *RSSI* mean by passive listener to perceive the link mechanism of burst do not add energy cost and small computing and storage overhead. Meanwhile, the node sends control packets active probing link quality periodically, according to (Eq.1) calculate the current link $PRR_{current}$ value, and active probing cycles are generally very long periodically due to limited resources sensor network node, however, the period is too long, they cannot probe links changing continuously in a short time. Therefore when perceived burst link in the net, we can use a short period detection mechanism. When the link state is stable, using a long period link quality detection mechanisms. SLQE passive perception in long period and active detection in short period mechanism can better weigh estimated energy cost of link quality, timeliness and accuracy.

3.4. SLQE Logical Process

SLQE Logical Process

```
Input:   RssiThreshold , T_passive , T_active(short−term) , T_active(long−term) ,T,n
Output:  E (PRR)_t
Initialization
  for every node do
    timer1←T active (long−term)
    timer2←T passive
    timer3←T
    while the timer3 is fired
      Read rssi from the CC2420 and save it
        if RssiCureentμ < RssiThreshold then
          n++
          if n<5 then choose timer1 to fired
          else n>5 then choose timer2 to fired
          end if
        end if
    end while
      while the timer1 is fired
        broadcast the probing packets
        receive the probing packets and compute the PRR_current
      end while
      while the timer2 is fired
        read rssi from the CC2420 and save it
        compute the RssiCureent_μ
```

```
            if RssiCureent_µ < RssiThreshold then
              timer1←T active (short−term)
            else
              timer1←T active (long −term)
            end if
          end while
        compute the E(PRR)_t
      end for
```

4. Implementation

In this paper under experimental scene, we analyzed the behavioral characteristics of sudden link, and pointed out the presence of burst network link is a link quality estimation problems posed through a lot of statistical experiments from Four-bit LQE.

Then we used Telosb nodes based on CC2420 RF chip, IEEE802.15.4 standard, selected the college office interior scenes, and analyzed behavioral characteristics of sudden link. In a weekend period, there are less mobile staff, but the presence of other wireless networks such as 802.11, Bluetooth, WiFi and some large indoor obstacles. Figure.4 shows the schematic diagram of the node and experimental scenario are used herein.

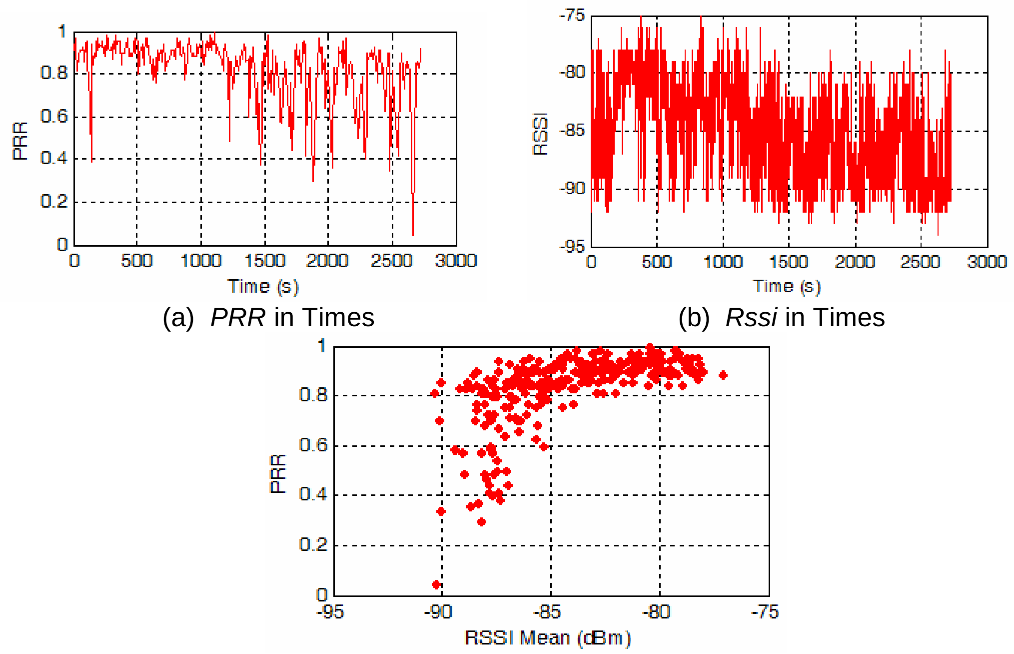
(a) The Nodes (b) Office Building

Figure 5. Nodes and Experiment Environment

In section 2, we know the individual variation in *LQI* value over time, Mean values and *PRR* multiple *LQI* values correlate well, but collecting *LQI* value will bring a large number of overhead and latency, so we analyze burst characteristic behavior of the link through statistics single *RSSI* value, *RSSI* Mean and *PRR* value. CC2420 provides *RSSI* measurements and stores in the *RSSI_VAL* register, the given *RSSI* formula (In dBm): *P=RSSI_VAL+RSSI_OFFSET*, where *RSSI_OFFSET* is -45dBm, in this paper we receive information in listening *RSSI* values in the above formula. In the experiment, CC2420 transmitter power is set to maximum, and distance between nodes is tested between 5 meters and 10 meters. Every node transmits a data packet per one second, while the receiving node receives each of the recording *RSSI* value of the group, and statistical short node receives a packet *RSSI* Mean expressed as M_{rssi},, and *PRR* values. *PRR* is in (Eq.1) and *RSSI* is calculated as the mean in next:

$$M_{rssi} = \sum_{i=1}^{n} rssi_i / n \quad (8)$$

$Rssi_i$ expressed as signal energy received by the i-th groups, n is a number of statistical period receiving packets. In this experiment, the statistical period is 10 seconds. Figure.5 shows the result in Office Building.



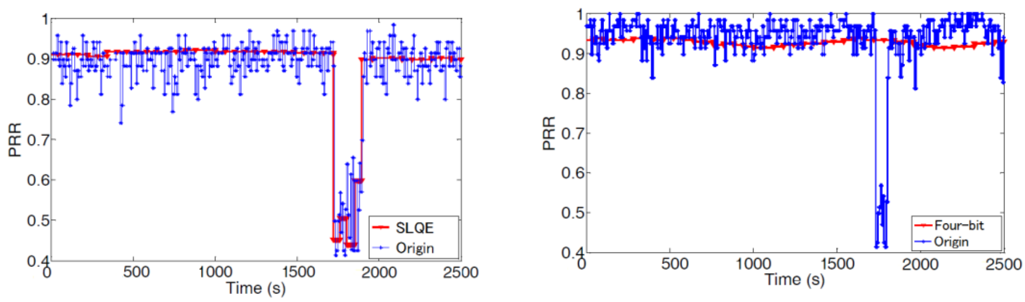
(a) *PRR* in Times (b) *Rssi* in Times

(c) *PRR* in *Rssi* Mean

Figure 6. Experimental Results in Office Buildin

Figure 6.(a) shows the *PRR* timing diagram, results large fluctuations in later time, mainly due to the influence of other wireless networks and obstructions in the office. Figure 6.(b) shows the variation of individual *RSSI* value in time, indicating that the individual *RSSI* values fluctuate greatly in time, not a very good response current link quality. Figure 6.(c) shows the relationship between the *PRR* and the mean *RSSI* is apparent from the figure, when the mean *RSSI* is less than -83dBm, *PRR* between 30% to 95% volatile forth, the link is unstable, *RSSI* is greater than the average -83dBm in the same time, link quality has changed slightly.

The above experimental results show that link performance shows a sudden high degree when affected link interference or moving obstacle for other wireless networks in a short time, cyclical conventional detection method can neither perceive effectively such burst link road, nor reflect changes in the current link quality accurately. When probing cycle is too long, we cannot perceive a short time span links effectively, and when the period is too short, we cannot rational use the limited resources of wireless sensor networks, especially with the increase of network size, frequent periodic probe will cost a lot of energy. SLQE method proposed in this paper can better address the issue.



(a) SLQE vs Origin (b) Four-bit vs Origin

Figure 7. The PRR Value Over Time in Office Building

Figure 7. shows the *PRR* timing diagram from diffident types of link quality estimator in Office Building, wherein Origin *PRR* value is the actual real-time statistical link the link. The results show that, SLQE can be well aware of the continuing short link fluctuations in Figure 7.(a) with the period in 1700-1800s, when the obstacle blocking, it leading to a significant decrease in link quality. SLQE uses *RSSI* changes by passive sensing means, when the *RSSI* is less than the mean -83dBm, it can active trigger short cycle active link quality detection process. It is possible to promptly response to the change in link quality, and Four-bit cannot react from dynamic changes in link quality due to intervals 60 seconds statistics period. Figure.7 (b) shows in the above-mentioned period, Four-bit is not able to perceive changes 1700-1800s period last link quality.

5. Evaluation

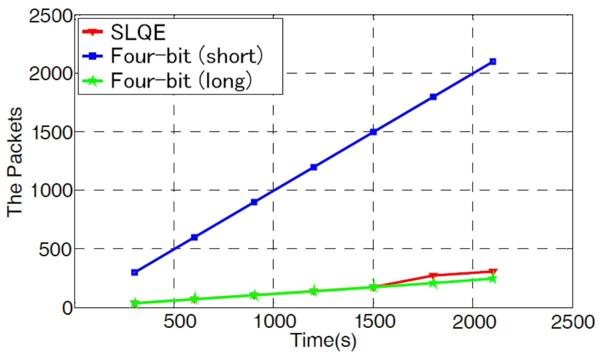


Figure 8. Energy Cost Over Time in Office Building

Figure.8 shows the total number of packets and controls SLQE, Four-bit transmission and reception in office building. *WMEWMA* is smoothing mechanism in Four-bit link quality estimation, where Four-bit(short), Four-bit(long) denote Four-bit statistical period is 1 second and 60 seconds. If Four-bit uses Four-bit(short) cycle, though the link quality estimation is possible to improve the accuracy and timeliness, it will bring large energy cost, as shown in Figure.8. Four-bit needs to send and receive 2100 control packets in the period of 0 seconds to 2100 seconds, and the total energy cost is 4200 packets, but compared in SLQE, the total cost number of packets sent and received is 490, passive detection mechanism SLQE can active triggering during a short-period after the link quality estimation, detection period time to 1 second, thereby increase the extra packet 126, the total energy cost is 616 packets in SLQE which has reduced 85.3% with respect Four-bit. If Four-bit uses long period, which is the same with SLQE probing period, due to the impact in the period 1730s-1790s by burst link, SLQE total energy cost increases by 25.7% relative to Four-bit, but has lower Four-bit cost accuracy and timeliness for the price.

From the experimental results above we can analyze that SLQE can perceive of the continued link to change in a short time timely and accurately, while the next link state changes quickly, but modest, short time environment, short-term changes smoothly link, maintaining network stability. The Four-bit do not take the stability and accuracy into account. Meanwhile Four-bit periodic detection mechanisms need to set the appropriate probing period, the period is too long to detect the ongoing changes link within a short time effectively, the period is too short to cost expensive, SLQE can be better in accuracy tradeoff, real-time and energy costs.

6. Conclusions and Future Work

In this paper we have presented narrow, well-defined interfaces that allow a link estimator SLQE, in a complex network environment, especially in the presence of a large number of unexpected link network and have achieved good results. It can effectively avoid the traditional link quality estimation lag and inaccuracy issues, and resolve Four-bit link quality estimator not taking stability and accuracy into account and problems of the estimated cost of the big dilemmas. This article will help further study in complex outdoor environments, such as link quality forest protection, water quality monitoring scenarios and their impact on the estimation method of routing protocol performance.

Acknowledgement

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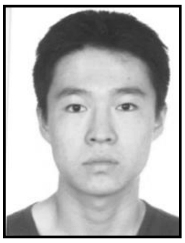

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