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# A New Link Quality Estimation Mechanism Based on LQI in WSN

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**Abstract:** Efficient, accurate, real-time and stable link quality estimation is essential to guarantee the upper layer protocol performance in wireless sensor network. This study expounds a new LQI-based (Based on Link Quality Indicator) link quality estimation mechanism for wireless sensor networks, which takes the lost packets and error packets into account. Based on real platform, we carry out a large number of experiments. After being analyzed the collected data, a new link evaluation model between LQI and PRR (Packet Received Ratio) is established. Experiment results have validated the correctness of the LQI-PRR model and the results also show that compared with traditional assessment methods, the mechanism proposed in this study improves the accuracy of the assessment and is more useful. At last, we analyze BER (Bit Error Ratio) and draw a relationship between LQI-PER (Packet Error Ratio), LQI-BER in order to get a further understands of the link quality.

**Key words:** Wireless sensor network, link quality assessment, PRR (packet received ratio), LQI (link quality indicator), BER (bit error ratio)

## INTRODUCTION

Wireless sensor networks are distributed system. In the monitored area, all sensor nodes are deployed randomly and then constitute a network in wireless self-organization manner (Sundani *et al*., 2011). Underlying communication link is a shared channel and the electromagnetic wave has the character of wastage, multi-path and adjacent band interference in the transmission process which leads the link to be random and instable (Theodore, 2001; Zhou *et al*., 2004) pointed out that the WSN link is directional which lead the communication area irregularity. Woo *et al*. (2003) think the communication area exists a gray area in which the link quality changes continually. And the experiences have shown that the link is also non-symmetry (Kim and Shin, 2006). Due to these characteristics of the link make the data packets can not be successfully reach the sink node and this will also lead to energy loss then reducing the network lifecycle. But If the link qualities can be know from the routing table, neighbor nodes with the best link quality can be chosen as the next hop routing (Shah and Rabaey, 2002) which can improve the reliability and effectiveness of the system. Therefore, it is very important to evaluate the link quality accurately (Zhu *et al*., 2009). Up to now, various methods have proposed in order to guarantee the efficiency and stable of the network.

The existing link quality assessment methods are mainly divided into two categories (Baccour *et al*., 2009) software-based measurement and hardware-based measurement. The software-based measurement mainly used PRR (Packet Received Rate) as a metric. Xu and Lee (2006) established a relationship model between PRR and distance. If you know the distance, the link quality can be required by this model. Another model based on PRR for event monitoring is proposed and its PRR value can be easily obtain (Liu *et al*., 2009). The advantage of using PRR as a metric is that it can give an accurate estimation of link. But it is not sensitive enough for link status because it needs a period of time to count data packet reception, besides the communication overhead will be increased because the network needs to maintain a lot of probe packets to account PRR. In recent years, a hardware-based assessment method is put forward. This is the second category. It uses the value of the sample which is obtained from the radio transceiver chip directly without additional calculation, i.e., LQI (Link Quality Indicator) (Lu *et al*., 2009), RSSI (Received Signal Strength Indicator) (Benkic and Malajner, 2008). The advantage of this approach is that when the link quality changes it can quickly react. LQI represents the energy and quality of the received data frame and it is based on the signal strength and the detected SNR (Signal Noise Ratio). Each packet's LQI is defined as correlation value of the first 8 symbols of the received frame and the value is in [50,110]. RSSI represents the signal strength observed at the receiver's antenna during packet reception. The current link quality can be judged through the RSSI value (Tolle and Culler, 2005). An estimation method based on RSSI

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(Reijers *et al*., 2004) shows that RSSI is very sensitive to the environment but the accuracy is not high. A experimental result shows that the mean LQI and PRR has a strong correlation and the Pearson correlation coefficient is over 0.9. Therefore LQI can measure the link quality in WSN (Cao *et al*., 2006). And compared with RSSI, LQI have a better correlation with PRR and can better reflect the link quality (Tolle and Culler, 2005; Srinvasan and Levis, 2006). There also have many researches of link quality based on LQI. Jian and Hai (2008) proposed a link quality estimation model based on LQI with which the link quality can be inferred from the LQI (Sun *et al*., 2007) propose mean RSSI and mean LQI measurement methods based on doing analysis of the problems of traditional link measurement methods.

However, the existing measurement methods based on LQI only consider successful received packet's LQI to evaluate the link quality and do not take the influence of the lost packets and error packets into account during the transmission. Therefore, these methods cause the link assessment not detail and accurate. For example, in a statistical cycle, when five packets are sent, if the node only receives a packet with high LQI value and other four packets lost. While another neighbor node receives four packets (just one packet lost), but the LQI value slightly worse than the former. Based on the past method calculates, they will select the previous link as the routing path which reduce the accuracy of the assessment method. Referred to the method only based on successfully received packets as SR-mean (Success Received mean). In addition, the previous research takes the error packets the same handle as the lost packets. Error packet means after the recipient has received packet from the sender, the packet does not pass the CRC check and dropped by recipient, but in fact, why CRC check does not pass may be due to the instability of link quality, LQI can best reflect the link quality at this time. So these error packets should be analyzed. Here we have disabled the CRC functionality, since we want to obtain the LQI values of all packets, including those that fail the CRC check. We keep this error packets information in order to give a more accurate assessment to the link quality.

The purpose of this study is using the above information to establish a more accurate, real-time link quality evaluation model. With this model, we can use the LQI which can be obtained from the data packets to judge the link quality is good or not. Thus the routing table can choose the best link quality to translate data packets which will enhance the stability of the network. In addition, it can decrease the energy consumption caused by sending a lot of probe packets compared with the evaluate mechanism based on PRR.

The main difference between the method proposed in this study and the past methods is that: First the hardware platform is based on ATEMGA 88+CC 2420 transceiver chip; secondly it takes the lost packets and error packets into account; at last, all dates are obtained based on the actual hardware platform measurements then using MATLAB and SPSS simulators to establish the model differed from any theoretical derivation and simulation.

## EXPERIMENT DESIGN

According to all the information mentioned above, an improved method based on SR-mean is proposed in this study which is based on all packets LQI named AP-mean (All Packet mean). In the method, the receiving node does not only receive the packets transmitted successfully, but also receive the error packets. Besides the lost packets information is also integrated to the link evaluation mechanism to improve the accuracy of the link quality assessment. AP-mean method can be described as follows: Assuming that the number of transmission data packets is n, the number of successfully received packets is m (0 = m = n) and the number of error packets is q (0 = q = n), every successful reception packets LQI value is $lqi_s$, each error packets LQI value is $lqi_{error}$ and the lost packets LQI value is $lqi_{lost}$. AP-mean can be expressed as equation:

$$\overline{LQI_{ap}} = \frac{\sum_{s=1}^{m} lqi_s + \sum_{flost=1}^{q} lqi_{flost} + lqi_{lost} * (n - m - q)}{n} \quad (1)$$

where, according to CC 2420 chip information, LQI value accounts for 7 bits. And the existing experimental results also show that when the LQI value close to 50, PRR is near to zero, therefore, the definition $lqi_{lost}$ = 50.

The wireless sensor nodes are composed of ATGMEGA 88 microcontroller and CC 2420 transceiver chip in the experiments. And there are a sending node and a receiving node. The receiving node is connected to the PC with the serial port. The software on the computer can receive data through the serial port and the background connects to SQLSERVER database. The experiment environment is the corridor of laboratory. The transmitting frequency is set to 868 MHZ. The transmission power is set to-20 dbm. The node distance is set to 1m. The sending node sends 500 packets, this process is referred as a run and this procedure is repeated 10 times. The received packets are recorded to the sample library. We keep the same transmission power of the node and then increase the distance between two nodes (2 m, 3 m, 4 m, 5 m...) gradually until the receiving node can not receive any packets. Fig. 1 is the experimental environment.

Fig. 1: Experimental environment

## EXPERIMENTAL ANALYSIS

Jian and Hai (2008) proposed a link quality estimation model based on LQI with which the link quality can be inferred from the LQI. Compared with their experiment, The environment and hardware facilities in this experiment can not be exactly the same as theirs. so, we referred their method only based on successfully received packets by using our data packets information as SR-mean.

Figure 2 shows the relationship between the LQI and the PRR in a link with SR-mean method and AP-mean method. When the LQI value in [80,105], the fluctuation range of the link quality is large with SR-mean which may lead to inaccurate results. Compared with SR-mean, the relationship between the LQI and PRR in a link with AP-mean has a higher degree of correlation of the two factors. The correlation analysis between LQI and PPR is shown in Table 1, which shows that the correlation coefficient of the AP-mean is 6% higher than SR-mean. Therefore, the AP-mean assessment method can reflect the link quality more accurately.

On the basis of the above analysis, varieties of models (exponential model, power model, Cubic model, the logarithmic model etc.) are used for fitting on the relationship between PRR and LQI. Through the comparison of the various models, Cubic model is significantly better than other models, the goodness of fitting is 0.969. Cubic model is constructed as follows:

$$Y = p1\times x^3+p2\times x^2+p3\times x+p4$$

where, p1, p2, p3, p4 are variable parameters, x represents the independent variable value LQI, Y represents the independent variable value PRR. The above equation can be rewritten as:

$$PRR = p1\ LQI^3+p2\ LQI^2+p3LQI+p4$$

where, the parameters calculated by matlab and the results are as follows:

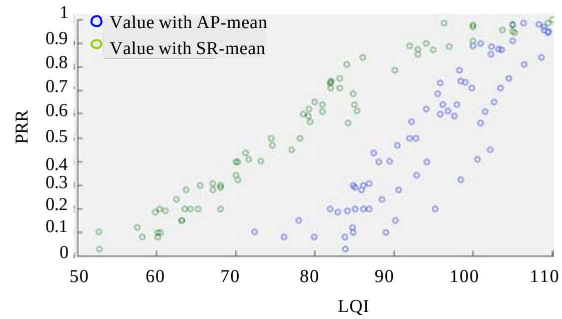


Fig. 2: The distribution between LQI and PRR with SR-mean and AP-mean, LQI: link quality indicator, PRR: packet error ratio, SR-mean: Success Received mean, AP-mean: All Packet mean

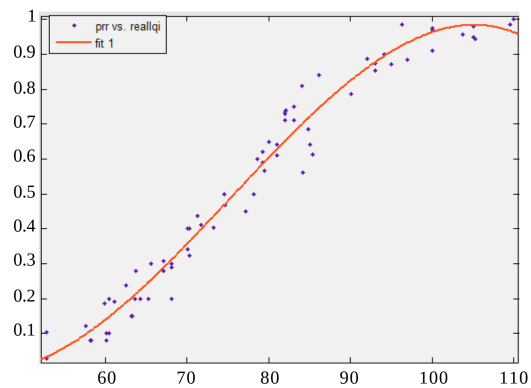


Fig. 3: The curve fitting of LQI and PRR, LQI: link quality indicator, PRR: packet error ratio

Table 1: SR-mean LQI,AP-mean LQI,PRR correlation analysis

| Correlations | | SR mean LQI | AP mean LQI | PRR |
|---|---|---|---|---|
| SR mean LQI | Pearson correlation | 1.000 | 0.910 | 0.904 |
| | N | 72.000 | 72.000 | 72.000 |
| AP mean LQI | Pearson correlation | 0.910 | 1.000 | 0.969 |
| | N | 72.000 | 72.000 | 72.000 |

p1 = -0.000009323
p2 = 0.002105
p3 = -0.1335
p4 = 2.585

Where the result of curve fitting is shown in Fig. 3.

In the fitting we can see that when the LQI is greater than 105, the PRR may be reduced as the LQI increases. But in practical applications, the PRR is generally above 98% in the same situation. In response to this problem, we take the piecewise fitting way to build the model and do some corrections (3):

$$PRR = \begin{cases} -0.000009323LQI^3 + 0.002105LQI^2 - 0.1335LQI + 2.585 & LQI < 105 \\ 0.98 & LQI < 1.05 \end{cases}$$

where, according to the above model, we can acquire the PRR by substitute the mean LQI value into the model. Network overhead and low real-time caused by sending large amounts of probe packets can be avoided with this method.

Not only the rationality of the AP-mean model is validated in this study, but also the performance of the estimation mechanism is analyzed. In our experiment, we change the distance to obtain different circumstance link quality. Comparison between experimentally measured data and the data calculated with AP-mean model is shown in Fig. 4.

In Fig. 4, real value represents the measured PRR; Model Value is calculated by AP-mean. The Fig. 4 shows that the calculated value is very close to the measured value and their variation with LQI is consistent. This turns out that the new link quality assessment model is reasonable. In order to further analyze its accuracy, the error ratio between the measured value and the model value analysis is shown in Fig. 5. It shows that the maximum error ratio is approximately 14%, the smallest error ratio is 0%. When the link is in good case, the error ratio is mostly less than 8%. It's verifying the reasonableness of AP-mean assessment method.

In order to further understand the link conditions and link quality, we research the BER (Bit Error Ratio) of error packets. BER represents the ratio of bits with errors to the total number of bits that have been received over a given time period. In order to research the BER in practice, the CRC functionality has to be disabled first so as to have access to erroneously received packets. We use the information from these error packets to compute the BER. Figure 6 shows the LQI and BER scatter diagram:

$$BER = \frac{\sum_{i=1}^{q} l}{(m+q) \times k \times 8}$$

where, k is the number of bytes in each packet, l is the number of erroneous bits in the error packet. Figure 7 shows the relationship between the PER (Packets Error Ratio) and LQI:

$$PER = \frac{q}{n}$$

where, seen from Fig. 6, when the LQI value is in [50, 70], the fluctuation range of the BER is large, so in this area, the link quality is very unstable. This case may be due to the bit errors which result from environmental interference, multi-path effects etc. it impedes the CRC check progress, eventually results in the loss of the package and reduces the link quality and network throughput and also increase the energy consumption in the network. Thus, the BER can also be an evaluation index as a measure of the link quality and it's more accurate to estimate the current link quality and link burst than the PRR. As can be seen from Fig. 7, LQI and PER have a significant association. PER will decrease as the LQI increases, When LQI is in [100,110], PER basically tends to 0. It means that the link quality is very good and the error ratio is relatively low.

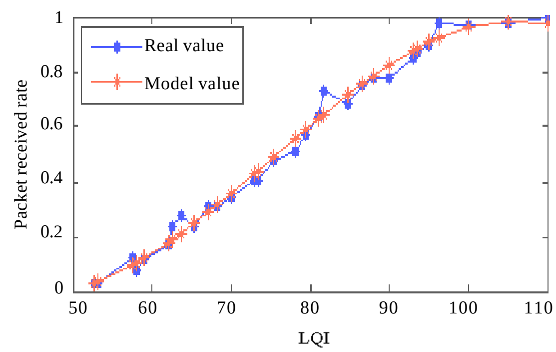


Fig. 4: True value and the model value

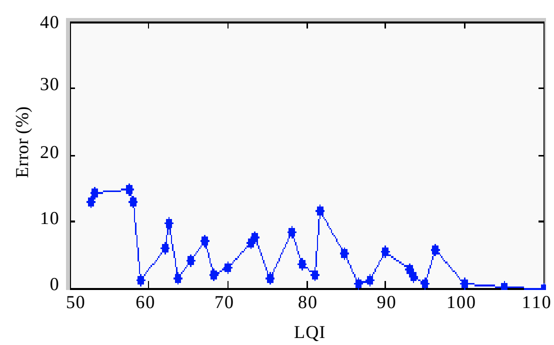


Fig. 5: Error between the measured values and model values

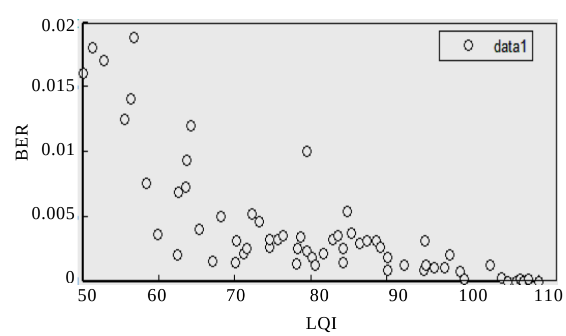


Fig. 6: LQI and BER scatter distribution, LQI: link quality indicator, BER: bit error ratio

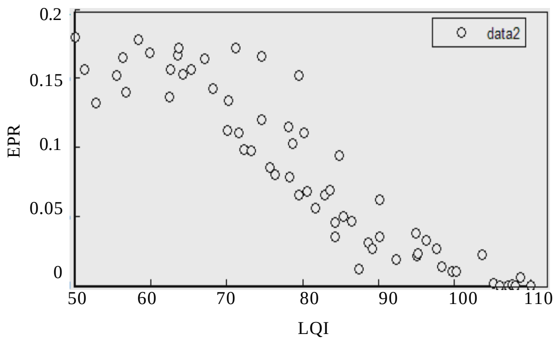


Fig. 7: LQI and PER scatter distribution, LQI: Link Quality Indicator, PER: Packet Error Ratio

## CONCLUSION

In wireless sensor networks, an accurate assessment of the link quality has important implications on the design and optimization of the upper-layer protocols. This study gives a conclusion of current link quality estimation method in wireless sensor networks. Considering the inadequate of the former researches, this study proposes a new link quality assessment model based on LQI. Experimental results show that the PRR calculated by AP-mean and the actual measurement value is very close and the error decreases with the LQI value increasing. Besides, the accuracy of the assessment improved 6% with the model proposed in this study compared with the original method. Finally we also obtained the relevance of LQI, BER and PER, which will provide a valuable reference. It's also providing a valuable reference for the upper protocol designer.

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