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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (4): 720-724, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.720.724

A Link Quality Evaluation Model Based on the Three-dimensional Space in Wireless Sensor Network

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Abstract: Stable, real-time and accurate link quality estimation in wireless sensor network is critical for guarantee the upper layer protocol performance, load balancing and power control. This study proposes a link quality evaluation model which describes the relationship among PRR (Packet Received Rate), transmission distance and transmission power. Based on real platform, a large number of experiments are done. After analyzing the collected data, a new link evaluation model based on three-dimensional space is established. Experiment results indicate that the model only need to know the transmission distance and transmission power, then the PRR can be obtained conveniently. It decreases energy consumption compared with sending probe packets to count PRR.

Key words: Wireless sensor network, link quality evaluation, three-dimensional space, PRR

INTRODUCTION

Wireless sensor networks are distributed system. A plenty of sensor nodes are scattered in a monitored area randomly and then make up a network in wireless self-organization manner. Communication between nodes use low power wireless RF signal such as electromagnetic wave. The electromagnetic wave has the character of wave diffraction, wave reflection, multi-path and adjacent band interference in the transmission process which make the link unreliable and random (Rappaport, 2004). The unstable link quality cannot guarantee the data transmission successfully which lead to the waste of energy (Akyildiz *et al*., 2007). If the quality of the link can be known from the routing table, then the neighbor nodes which have the best link quality can be chosen as the next hop routing (Shah and Rabaey, 2002). It can improve the reliability and accurately of the system. Therefore, it is very important to establish a link quality evaluation model to assess the link quality effectiveness and real-time.

The existing link quality assessment methods are mainly based on the software and hardware. Based on the software mainly uses PRR (Baccour *et al*., 2009) as a metric. Based on the hardware uses the value of the sample which is obtained from the radio transceiver chip, 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.

PRR is the ratio of the correctly received packets at the receiver to the total number of packets sent by the sender. Literature, Xu and Lee (2006) establish a relationship model between PRR and transmission distance. If the transmission distance is given, the link quality can be required by this model. Another model based on PRR is proposed in the literature, Liu *et al*. (2009) and it expounds that PRR value can be easily obtained by this model. The advantage of using PRR as a metric is that it can give an accurate estimation of link. But it reacts slowly to the change of link.

LQI represents the quality of the received data frame and energy and the value of LQI is based on signal strength and the detected SNR (Signal Noise Ratio). Take the CC1100 transceiver chip for example, if PKTCTRL1 APPEND_STATUS is enabled, LQI will be automatically appended at the end of the received data packet. Each packet's LQI is defined as correlation value of the first eight symbols of the received packet and its score ranges from 50 to 110 (higher values are better).

Most radio transceivers (e.g., the CC1100) provide an RSSI register. RSSI represents the signal strength which is observed at the receiver's antenna during packet reception. This value is based on the current set gain in the RX chain and the measured signal level in channel. In RX mode, RSSI values can read sequentially from the RSSI status register until the modem detects a sync word. With the RSSI values between nodes, it can determine the current link quality.

In general, three factors can be used as a link quality metrics. But researchers point out that RSSI is not a good link quality measurement because its assessment accuracy is not high (Reijers *et al*., 2004). It is shown that with the increase of transmission distance, the change of packet reception rate is higher than the RSSI and the LQI.

It is more obvious when the signal strength is weak. PRR is the most sensitive link quality indicators in the three standards. Therefore, it is more accurate and effective to use the PRR as the link quality evaluation parameters.

EXPERIMENT DESIGN AND ANALYSIS

Materials and methodology: This study is on the basis of real sensor node platform, a large number of experiments are taken to establish a link quality evaluate model. At first, a relationship between the transmission power and PRR at the same distance is analyzed. At the same time, a relationship between the transmission distance and packet reception rate relationship under a certain power is also analyzed too. Then the relationship among the transmission distance, the transmission power and PRR is further analyzed. At last, a three-dimensional spatial relationship model is established. With this model, if the distance and transmission power is sure, then the PRR can be acquired. Compared with the methods which directly account PRR, this model can avoid the overhead caused by sending a lot of probe packets.

Experiment 1

Model between the distance and PRR: The wireless sensor nodes are composed of ATGMEGA88 microcontroller and CC1100 transceiver chip in the experiments. 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 7 dBm. The node distance is set to 5 m. 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, after that keep the same transmission power of the node, increase the distance between two nodes gradually until the receiving node cannot receive any packets. Then the transmission powers are set to -20 and -10 dBm and repeat the above experiment.

Figure 1a shows the relationship between distance and PRR at different power. From Fig. 1a, it can be seen that the distance and PRR have a good correlation. The correlation analysis between distance and PPR is shown in Table 1.

From Table 1, it shows the high correlation between distance and PRR at different power. So, a model between distance and PRR in a certain power can be obtained use MATLAB and SPSS. Figure 1b shows the relationship between distance and PRR when the transmission power is set to 0 dBm. The spots are the measured value from the experiments. Varieties of models are used for fitting on the relationship between PRR and distance. Through the comparison of the various models, conic model is significantly better than other models, the goodness of fitting is 0.971.

Table 1: Pearson correlation coefficient analysis between distance and PRR at different power

Variables	PRR	Distance
PRR Pearson correlation coefficient	1.000	-0.989
N	9.000	9.000
Distance Pearson correlation coefficient	-0.989	1.000
N	9.000	9.000

PRR: Packet received rate, N: No. of samples, Pearson correlation coefficient: A coefficient used to measure the linear correlation of two variables

Table 2: Pearson correlation coefficient analysis between transmission power and PRR at different distance

Variables	PRR	Transmission power
PRR Pearson correction coefficient	1.000	0.976
N	9.000	9.000
Transmission power (dBm)	0.976	1.000
Pearson correction coefficient	9.000	9.000
N		

PRR: Packet received rate, N: number of samples, Pearson correlation coefficient: A coefficient used to measure the linear correlation of two variables

Conic model is constructed as follows:

$$prr = -0.1074d^2+0.4874d+95.57 \quad (1)$$

where, d represents the transmission distance.

Experiment 2

Model between the PRR and power: In order to get a relationship between PRR and power, another experiment is designed. Similar with the above experiment, first 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. After that keep the same distance this time, change the sending power. Then set the different distance and repeat the above experiment.

Figure 1c shows the relationship between transmission power and PRR at different distance. From Fig. 1c, it can be seen that the transmission power and PRR have a good correlation. The correlation analysis between transmission power and PPR at different distance is shown in Table 2.

According to the sample library, a relationship between PRR and sending power can be got as Fig. 1d.

Similarly, the conic model is constructed as follows:

$$prr = -0.031p_2+1.11p+88.38 \quad (2)$$

where, p represents the sending power.

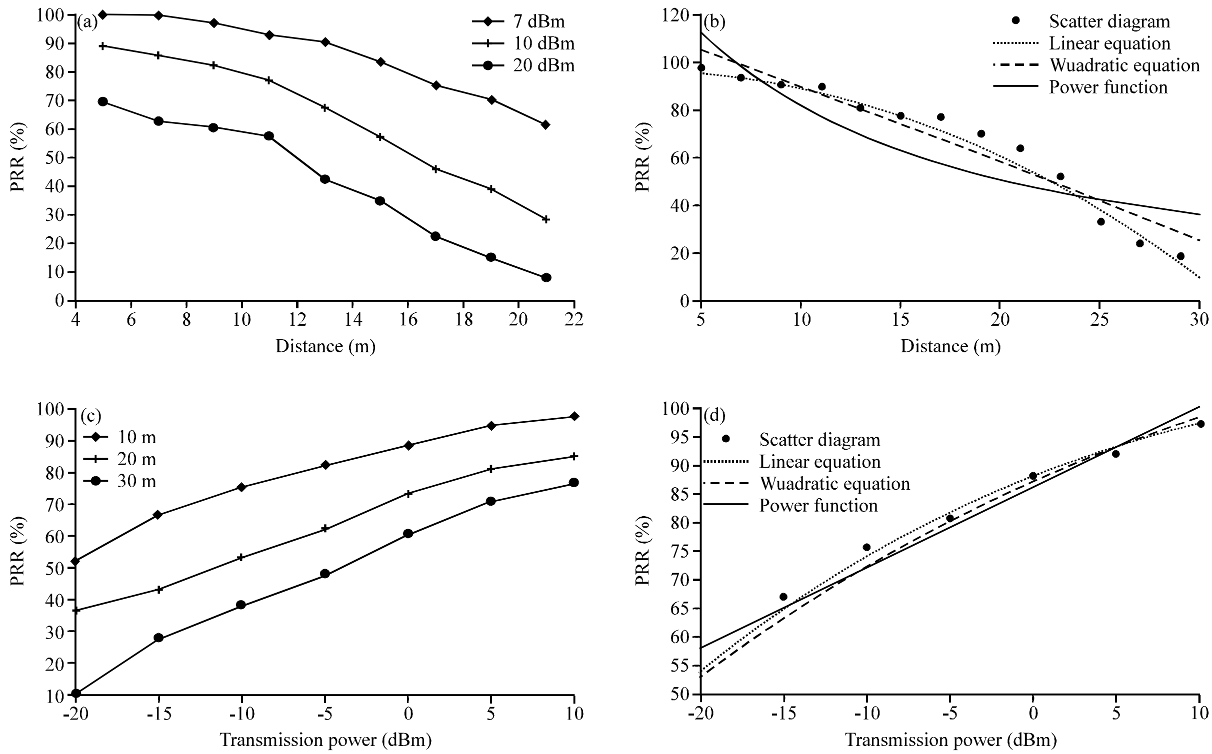

Fig. 1(a-d): High correlation coefficient between PRR and distance, as well as PRR and transmission power. (a) Relationship between distance and PRR at different power. PRR: Packet received rate, (b) Varieties of fittings on the relationship between PRR and distance in a certain power, (c) Relationship between transmission power and PRR at different distance and (d) Varieties of fittings on the relationship between PRR and transmission power in a certain distance

Experiment 3

Model among packet reception rate, transmission power and transmission distance: According to the results of experiment 1 and experiment 2, the model between PRR and transmission power in a certain distance and the model between PRR and distance in a certain transmission power can be got. It can be seen to determine the relationship between two other parameters; the third one must be a specific value. Therefore, Eq. 1 and 2 have significant limitations. If the link quality evaluation model among PRR, distance and transmission power can be got. It can evaluate the link quality more accurate and convenient.

RESULTS

In view of the above, the measured data of Experiments 1 and 2 are analyzed. And the relationship between the packet reception rate, the transmission power of nodes and transmission distance are shown in Fig. 2a. From Fig. 2a can be seen, three parameters are composed of three-dimensional graphics similar to a parabolic. Combined with the above curve fitting results of Fig. 1b and d, both are quadratic polynomial fitting. So, assume that the final model is a quadratic model. The quadratic model is constructed as follows:

$$prr = \alpha p^2+\beta d^2+\chi p+\delta d+\varepsilon pd+m \quad (3)$$

where, PRR is packet reception rate, p is the transmission power and d is the transmission distance. The correlation coefficient β, β, χ, δ and ε are parameters need to be acquired.

As Eq. 3 is the multiple nonlinear regression model, it is very hard for fitting. So, the model needs be converted to a multiple linear model. Then use SPSS tools can fit multiple linear regression models as follows. Higher order terms in the model can be calculated as the new variables and then will be included as the independent variables in the equation. Set $P = p\times p$, $D = d\times d$, $W = d\times p$, the new model comes to the following equation:

$$prr = \times P+\beta D+\chi p+\delta d+\varepsilon W+m \quad (4)$$

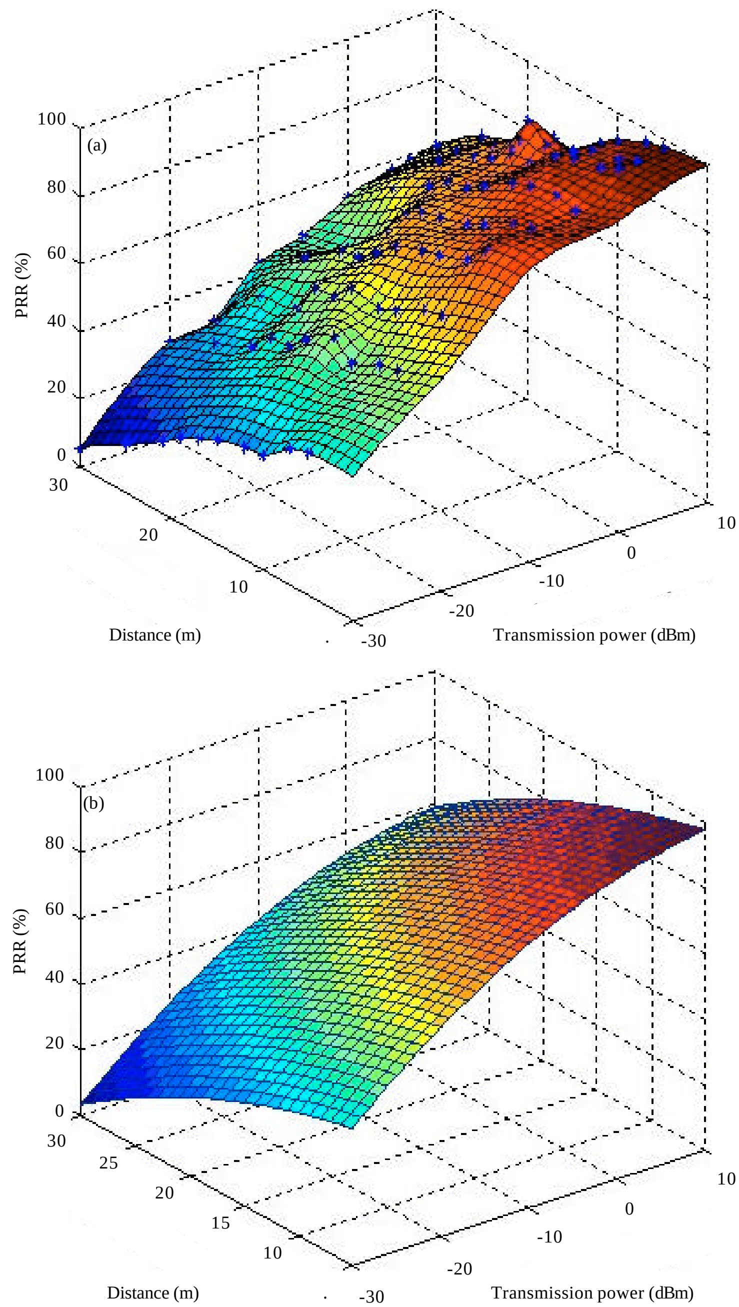

Fig. 2(a-b): Link evaluation model in the three-dimensional space. (a) Relationship among PRR, transmission power and distance in the three-dimensional space. PRR: Packet received rate and (b) Link evaluation model among PRR, distance and transmission power

The correlation coefficient β, β, χ, δ and ε can be calculated by fitting the model. According to the test results of the coefficients and the fit of the model in the software SPSS, it is decided whether to add the new high-order items or to remove them. Finally, the simplified equation can be obtained.

By repeatedly adding and removing unused high-order, then analyzing the results and the correlation coefficients of the model, a simple model can be obtained as shown in Eq. 5. The goodness of fitting is more than 90%:

$$prr = -0.24P-0.032D+0.85p-0.42d+94.736 \quad (5)$$

Then the new variables are replaced with the original variables, so, the final link evaluation model can be got:

$$prr = -0.027p^2-0.032d^2+0.85p-0.42d+94.736 \quad (6)$$

Since the experimental curve fitting and surface fitting are approximate results, in practical applications there may be result the following phenomenon. When the parameter distance value is very large or very small, PRR may be less than 0 or greater than 100% which is obviously not practical. So the model is amended as follows. In fact, the reception can not be larger than 1 and less than 0. So, if the packet reception rate Z is larger than 100%. Z is set to100%. When the value of Z is less than 0, Z is set to 0.

The above expression is shown in Fig. 2a and b is the three-dimensional surface graph posed by the actual measured values. Figure 2b is the three-dimensional surface graph measured by assessment model. Compared with Fig. 2a and b, the trend of PRR change is coincident. It validated the correctness of this model.

A relationship between distance and PRR with different transmission power is researched in Lee *et al.* (2010). But it can not get the PRR when the distance and transmission power is both variable directly. The model established in this study only need to know the distance between two nodes and the transmission power. Take the parameters into the model, it can approximately get the network's PRR and can be very good to evaluate the current link. It decreases energy consumption compared with sending probe packets to count PRR.

CONCLUSION

In wireless sensor networks, an accurate assessment of the link quality is important to design and optimization of the upper-layer protocols. This study proposes a three-dimensional space model to evaluate link quality. This model describe the relationship among the transmission distance, transmission power and packet reception rate. If you know the translation distance and the transmission power, then the PRR can be acquired with this model. Compared with the methods which directly account PRR, this model can avoid the overhead caused by sending a lot of probe packets. And the model proposed in this study can provide a better assessment to evaluate the link quality.

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