http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

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

Information Technology Journal 12 (11): 2207-2212, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.2207.2212

Analysis of Wireless Link Characteristics in RFID Location-network

Junhuai Li, Guomou Zhang, Wei Wei, Zhixiao Wang and Jing Zhang
School of Computer Science and Engineering, Xi'an University of Technology, Xi'an 710048, China

Abstract: RFID-based location awareness is becoming the most important issue in many fields in recent years, such as ubiquitous computing, mobile computing. However, the RF system is noise-limited, which leads to the readers can't read the information from tags timely and accurately, especially for RFID localization network. This study proposed a novel RFID indoor localization method based on Received Signal Strength Indicator (RSSI) and Packet Received Ratio (PRR). To do so, the environmental factors affecting the link quality are analyzed and the location awareness data is collected by RFID equipment using non-coherent Frequency Shift Keying (FSK) as modulation scheme and Not Return to Zero (NRZ) as encoding scheme. Then the relationship model between RSSI, PRR and distance is established based on the classic radio propagation model in localization field and theoretical analysis of the normal probability distribution of PRR is conducted. The experimental results show that our approach is valid and proper and also contributes to a novel perspective and theoretical support on the further study and application of RFID indoor localization.

Key words: RFID, link characteristics, PRR, RSSI

INTRODUCTION

Radio Frequency Identification (RFID) has been around for decades but the advantages of lower cost, automatic target recognition and other increased capabilities made businesses take a hard look at what RFID can do for them in recent ten years (Khoo, 2010). In RFID system, the received signals gradually decrease because of the impacts of fading varying with the distance between readers and tags. When reaching the certain distance, Signal-to-Noise Ratio (SNR) would not reach up to the threshold for maintaining reliable communications. Therefore, the RF system is noise-limited, which leads to the readers can't read the information from tags timely and accurately, especially for localization network based RFID. Because the reliability and accuracy of RF network rely on the physical layer, this study would be organized to analyze the stability, reliability and other characteristics of link quality in localization network based on RFID.

This study adopts the RFID equipment using non-coherent Frequency Shift Keying (FSK) as modulation scheme and Not Return to Zero (NRZ) as encoding scheme. Therefore, a hypothesis is made that the length of the transmission packet is fixed.

Three link quality metrics are identified in many empirical studies: Link Quality Indicator (LQI), Packet Reception Rate (PRR) and Received Signal Strength Indicator (RSSI) (Lai *et al*., 2003). LQI is an important metric for reflecting link quality provided by the chips with measurement function of LQI and widely used in the wireless net. LQI is implemented by sampling the error rate for the first eight symbols of each received packet. Through linear transformation, the final LQI values will be got by converting the sampling values (in the region of [50, 110]) to these values which are in the range of [0,255]. PRR refers to the ratio between RP and S in a certain time. The equation is described as:

$$PRR = RP/S$$

where, S is the quantity of total packets transmitted and RP is the quantity of actually received packets. Therefore, PRR is the most effective indicator for reflecting link quality. In addition, the packets which were not received may be due to the noise in the transmission so that the content of part of the data packets comes into some error in the sampling. Generally, the failure may be \found by CRC checking and the packets will be discarded. RSSI stands for Received Signal Strength Indicator. It is the measured power of a received radio signal. It is implemented and widely-used in 802.11 standards. Received power can be calculated by RSSI.

A large number of empirical studies show (Srinvasan and Levis, 2006) there exists higher linear correlation between PRR and RSSI when the Received Signal

Corresponding Author: Junhuai Li, School of Computer Science and Engineering, Xi'an University of Technology, Xi'an 710048, China

Strength (RSS) keeps above the threshold of equipment but when the RSS was below the threshold, noise factors would generate a serious influence which leads to the correlation varying. For the specific link, LQI fluctuates higher but a greater number of average values of LQI have correlation with PRR.

According to the link quality, there are three different reception regions in a wireless link (Zhao and Govindan, 2003; Ganesan *et al*., 2002; Zamalloa and Krishnamachari, 2007; Goldsmith, 2005): connected, transitional and disconnected. The connected region offers a reliable link to communicate, which means this region has a high stability in reception rates. Oppositely, in the disconnected region, receivers hardly receive the signal because of the fading effect and increasing noise (Zhao and Govindan, 2003; Woo *et al*., 2003; Ganesan *et al*., 2002). The transitional region has a drastic variability in asymmetric connectivity and reception rates but plays an important role in radio communication, because the range of this region has a great effect on the links quality.

PRR is related to signal modulation and encoding, (Zuniga and Krishnamachari, 2004) etc. utilized TR1000 chip with the different modulation and signal encoding to convert RSSI value to signal-to-noise ratio in reception process, then they proposed "transitional region" in low power link and analyzed the factors in "transitional region" by studying the relationship between SNR and PRR. Son *et al*. (2004) introducing RSSI and Signal Interference Noise Ratio (SINR), found the relationship among SINR thresholds, signal power and hardware equipment and then studied the changes of SINR threshold in packets parallel transmission. In WSN, Lin *et al*. (2006) measured the impacts of spatiotemporal factors on PRR in indoor and outdoor covered environment. Similarly, through a lot of empirical studies (in corridor, playground, meadow site), Li *et al*. (2009) utilized the fitting curve to establish relationship among position distance, RSSI and PRR, then proposed the localization method by the fitting curve. But their method is only suitable for the scenes which are relatively empty, with few obstacles and slightly environment varying, for the complex indoor environment this method doesn't have enough ability to use the pre-surveyed fitting distance model for locating (Wei *et al*., 2010a; b; Gao *et al*., 2010).

ANALYSIS OF CHARACTERISTICS OF RFID LINKS

Environmental factors

Multipath Effect: Multipath effect occurs when radio waves take different paths from a signal to their final destination. The paths commonly result from a variety of factors including reflections from buildings, bodies of water and other reflecting surfaces. Because the different paths have different path loss and transmission delay under the multipath effect, the transceivers receive the signal from the tags, which is superposed by the reflected radio and shows the rise and fall of the amplitude over a period of time.

Multipath effect depends on the environment where the equipment lay out, so the radio distortion and the reception loss could hardly be solved without changing the environment.

The noise: The received signal includes not only the useful signal but also some signal without any information, which is called noise. The noise is generally regarded as additive Gaussian White Noise, which is independent to the time, because of its additivity, the different Gaussian White Noise superimposes on each other to make the new noise.

In the channel, the additive noise is comprised of man-made noise, natural noise and internal noise. The first two kinds of noise are accidental, so they can't be estimated and controlled. The third kind of noise, the internal noise, arises from the internal design of various chips, therefore, this study focuses on the internal noise. Because the SNR determines whether the signal can be received correctly or not, when the transmitted power is constant, the greater the noise power, the received SNR is lower, thus the probability of packet loss is higher.

CHARACTERISTICS OF RFID LINKS

Analyzing the model between RSSI and distance: The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line of sight path between them. As with most large scale radio wave propagation models, the free space model predicts that received power decays as a function of the T-R (Transmitter-Receiver) separation distance raised to some power . The free space received by a receiver antenna which is separated from a radiating transmitter antenna by a distance d, is given by the Friis free space (Eq. 1):

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

where, P_t is the transmitted power, $P_r(d)$ is the received power which is a function of the T-R separation, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, L is the system loss factor not related to propagation (L = 1) and λ is the wavelength in meters.

As the transmitter moves away from the receivers over much larger distance, the local average received signal will gradually decrease, the difference between the transmitter power and received power is called Path Loss and predicted by propagation models:

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10[\frac{\lambda^2}{(4\pi)^2 d^2}] \qquad (2)$$

where, PL(dB) is the path loss at the distance d between transmitter and receiver.

Both theoretical and measurement-based propagation models indicate that average received signal power decrease logarithmically with distance. Such models have been used extensively in the literature. The path loss for an arbitrary T-R distance is expressed as a function of distance by using a path loss exponent, ή:

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\eta\log(\frac{d}{d_0}) + X_\sigma \qquad (3)$$

where, d_0 is the reference distance which is determined by measurements close to the transmitter, X_6 is a zero mean Gaussian random and variable with standard deviation σ.

Analyzing the model between PRR and distance: This section analyzes the probability of successfully received packets in a single transmitting process and establishes a relationship between the probability and distance. According to classic communication theory, for non-coherent detection of binary FSK, P_e as Bit Error Rate (BER), is the average probability of bit error, which is estimated by the following formula (Rappaport, 2001):

$$P_e = \frac{1}{2}\exp^{-\frac{E_b}{2N_0}} \qquad (4)$$

where, E_b presents energy per bit, N_0 is noise spectral density. However, most of the equipment manufacturers failed to provide the ratio of these two parameters. For spreading spectrum systems, the ratio of both can be converted to SNR by the following formula:

$$SNR = \frac{E_b}{N_0}\frac{R_b}{B_N} \qquad (5)$$

where, B_N is noise bandwidth, R_b is data rate in bits. For the special RF equipment, these two parameters are constant and easy to get. B_N/R_b is also known as spreading spectrum gain.

If using NRZ as the encoding model and 1 Baud = 1 bit, l (in byte) is the length of transmitting message, the probability of successfully receiving a packet is:

$$p = (1-P_e)^{8l} \qquad (6)$$

From Eq. 4-6 B_N/R_b can be calculated as follows:

$$\frac{E_b}{N_0} = -2\ln(2(1-p^{\frac{1}{8l}})) = \frac{B_N}{R_b}SNR \qquad (7)$$

$$SNR_{dB} = 10\lg(-2\frac{R_b}{B_N}\ln(2(1-p^{\frac{1}{8l}}))) \qquad (8)$$

In special RF system, RSSI dB as received signal power is presented as:

$$RSSI_{dB} = P_n + 10\lg\frac{E_b}{N_0} - 10\lg\frac{B_N}{R_b} \qquad (9)$$

where, P_n is the noise floor, including receiver noise and thermal noise. P_n is given by:

$$P_n = N_F + 10\lg(KTB_N) \qquad (10)$$

where, N_F is the noise figure, K is the Boltzmann's constant, T is the absolute indoor temperature.

In terms of log-normal shadowing path loss model, SNR can be rewritten as follows:

$$SNR_{dB} = RSSI - P_n = P_t - PL(d) - P_n \qquad (11)$$

where, P_t comprises output power of transmitter and antenna gain, PL (d) is the path loss power.

From Eq. 3, 9 and 11, the relationship between PRR and d is given by:

$$d = 10^{\frac{P_t - P_n - SNR_{dB} - PL(d_0) - \chi_\delta}{10\eta}} \times d_0 \qquad (12)$$

The previous equation shows whether successfully receiving the packets from the transmitter is correlative with the distance. This section builds the fundamental relationship between PRR and distance.

EMPIRICAL VALIDATION OF THE MODELS

In these following experiments, the distance between tags and readers is in a range of 1 m~35 m and the power of readers is between 20 and -15 dBm. For each locating point, the number of transmission processes is r≥300. After transmitting localization command from reader, tag will respond 80 packets (k = 80) in different power level and data acquisition server will record the quantity of Received Packets (RP) and the power level.

Path loss and distance: RSSI (Li *et al*., 2011a-c, 2012a, b; Wang *et al*., 2010) is an important metric for reflecting link state instantaneously because of its easy acquisition and higher linear correlation with PRR. This experiment was done in the 40 m long corridor. The distance between reader and tag is set 1m initially and could be increased by 1 m to collect data.

In Fig. 1, those points show the RSSI distribution of transmitter-receiver distance between 1 and 35 m. In the range of 1 to 10 m, the signal is more stable than other area but out of the range, the large scale and serious fading make the signal distorted, which can be shown by the fluctuation of the points (Bose and Foh 2007; Mao *et al*., 2007). In order to show the trend of the points, the curve-fitting method is used to present one curve in the figure. As expected, the curve indicates the logarithmic relationship between RSSI and distance.

The standard deviation is used to depict the change of above RSSI-distance points. In Fig. 2, the relation between standard deviation and distance is shown by the broken line, line fitting method is used to present the trend of the standard deviation of all test points. With the growth of distance between reader and tag, fading effect is so serious that the standard deviation is rising continuously.

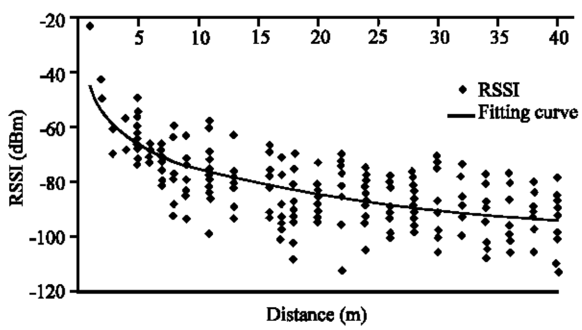

Fig. 1: Comparison between received signal strength indicator and Fitting curve for different distance

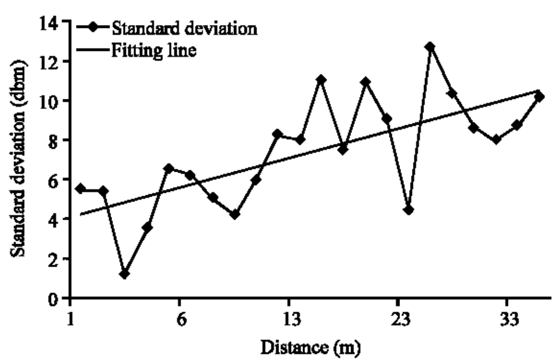

Fig. 2: Comparison between standard deviation of received signal strength indicator and fitting curve for different distances

PRR and distance: This section will give the relationship model between PRR and distance. The RFID readers and tags used in this system are all produced from XiGu Company. The parameters of these RFID devices as follow: channel bandwidth is BN = 1 MHZ and communication rate is Rb = 128 kbps, thus the spreading spectrum gain is 9dB and Eb/N_0 = 8.9 dB through the formula (7). Considering the sensitivity of the reader is-96dB, if the sensitivity is obtained during BER is 3%, the noise floor is about Pn = -94.5dB. Meanwhile, the length of localization packet responded from the RFID tag is l = 17 bytes, then from Eq. 12, the border distance of transitional region in theory is as follows:

$$d_u = 9.2 \text{ m (PRR } P_u = 95\%)$$

$$d_l = 31.9 \text{ m (PRR } P_l = 5\%)$$

In this part, the experimental environment is same as the previous section, the PRR at the above test points are collected. Figure. 3 shows the PRR for different distances in the corridor.

These results show the PRR is almost close to 100% when the tag lies within 9 m from readers; but when the tag is out of the 33 m, the packets can't be received due to the serious fading and noise, the PRR is unreliable and unstable in the range of 9 to 33 m. According to these results, it could be asserted that the transitional region is between 9 and 33 m, which is consistent with the previous value in theory.

The above analysis show the transitional region is the most significant part of links (Petrova *et al*., 2006;

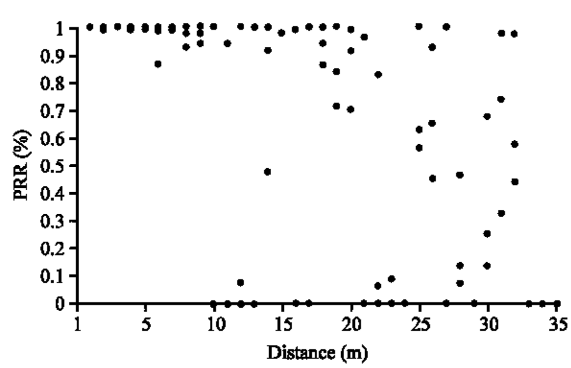

Fig. 3: Packet received ratio for different distances

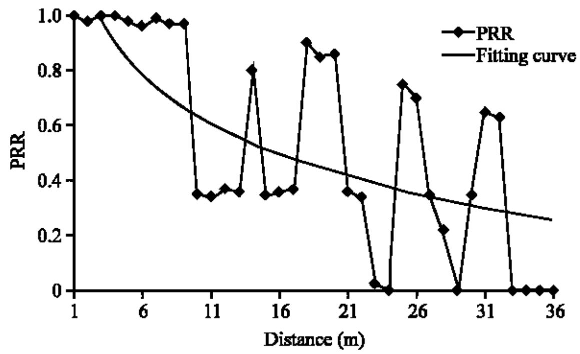

Fig. 4 : Comparison between average of packet received ratio and fitting curve for different distances

Chen and Terzis, 2010). Its size has a great influence on the link quality. Especially with its range increasing, the quality of the link would deteriorate but for the locating system based on RF, range increasing would expand the area where the prediction model can be used to predict the distance between transmitters and receivers (Li *et al*., 2009) (Fig. 3).

Figure 4 shows the comparison between average of PRR and fitting curve for different distances. In order to describe the trend of the PRR with the increasing distance, the average of PRR is used to fit a curve. This curve can be divided into three parts by the boundary of 9 m and 33 m and this experimental results are consistent with Son *et al.* (2004) and Lin *et al.* (2006) the because of the serious fading effect and interference, the middle part shows a strong bias to either high or low PRRs, with a small probability of being 5 and 95% but from a global view, the PRR presents the downward trend as the curve depicts.

CONCLUSION

This study analyzes the relationship between PRR, RSSI and distance from mathematical models and concrete experiments, which are carried out by testing the PRR and RSSI between the RF readers and tags. On the strength of these hard works, this study has proved the distribution of PRR and RSSI with distance and the existence of the three distinct regions, predicted the boundary of transitional region and confirmed these results by a lot of real experiments. So in the further studies, the relationship model among PRR, RSSI and distance provides an effective method for locating in the indoor complicated environment and next study will focus on combining multi-sense information for RFID indoor localization in the future work.

ACKNOWLEDGMENTS

This work was supported by the grant from the Natural Science Foundation of China (No. 61172018), the Science and Research Plan Project of Shaanxi Province (No. 2011NXC01-12) and Science and Research Plan Project of Shaanxi Province Department of Education (No.2010JC15). The work is also supported by Scientific Research Program Funded by Shaanaxi Provincial Education Department (Program No. 2013JK1139). The authors are grateful for the anonymous reviewers who made constructive comments.

REFERENCES

Bose, A. and C.H. Foh, 2007. A practical path loss model for indoor WiFi positioning enhancement. Proceedings of the 6th International Conference on Information, Communications and Signal Processing, December 10-13, 2007, Singapore, pp: 1-5.

Chen, Y. and A. Terzis, 2010. On the mechanisms and effects of calibrating rssi measurements for 802.15. 4 radios. Proceedings of the 7th European Conference on Wireless Sensor Networks, EWSN 2010, Coimbra, Portugal, February 17-19, 2010, Springerm, Berlin Heidelberg, pp: 256-271.

Ganesan, D., B. Krishnamachari, A. Woo, D. Culler, D. Estrin and S. Wicker, 2002. Complex behavior at scale: An experimental study of low-power wireless sensor networks. Technical Report CS TR 02-0013. http://lecs.cs.ucla.edu/~deepak/PAPERS/empirical.pdf.

Gao, A., W. Wei and X. Xiao, 2010. Multiple hash Sub-chains: Authentication for the hierarchical sensor networks. Inform. Technol. J., 9: 740-748.

Goldsmith, A., 2005. Wireless Communications. Cambridge University Press, Cambridge, MA., USA., ISBN-13: 9780521837163, Pages: 672.

Khoo, B., 2010. RFID-from tracking to the internet of things: A review of developments. Proceedings of the IEEE/ACM International Conference on Green Computing and Communications and International Conference on Cyber, Physical and Social Computing, December 18-20, 2010, Hangzhou, China, pp: 533-538.

Lai, D., A. Manjeshwar, F. Herrmann, E. Uysal-Biyikoglu and A. Keshavarzian, 2003. Measurement and characterization of link quality metrics in energy constrained wireless sensor networks. Proceedings of the IEEE Global Telecommunications Conference, Volume 1, December 1-5, 2003, USA., pp: 446-452.

Li, F.M., P. Han and T. Luo, 2009. Adaptive area location algorithm combining with packet lost rate and RSSI in wireless sensor networks. J. Commun., 30: 15-23.

Li, J., J. Wang, L. Yu and J. Zhang, 2011a. A novel frequent trajectory mining method based on GSP. Proceedings International Conference on Web Information Systems and Mining Part I, September 24-25, 2011, Taiyuan, China, pp: 134-140.

Li, J., R. Qi, Y. Wang and F. Wang, 2011b. An RFID location model based on virtual reference tag space. J. Comput. Inform. Syst., 7: 2104-2111.

Li, J., Z. Sun, Y. Wang and F. Wang, 2011c. RFID positioning system construction method based on virtual reference tags. Comput. Sci., 4: 107-110.

Li, J., G. Zhang, L. Yu and J. Zhang, 2012a. Analysis and simulation of RFID location method oriented to indoor environment. Comput. Eng., 38: 276-279.

Li, J., G. Zhang, L. Yu and Z. Sun, 2012b. Efficient RFID location method based on virtual signal strength. Comput. Sci., 39: 67-70.

Lin, S., J. Zhang, G. Zhou, L. Gu, J.A. Stankovic and T. He, 2006. ATPC: Adaptive transmission power control for wireless sensor networks. Proceedings of the 4th International Conference on Embedded Networked Sensor Systems, November 1-3, 2006, Boulder, CO., USA., pp: 223-236.

Mao, G., B.D.O. Anderson and B. Fidan, 2007. Path loss exponent estimation for wireless sensor network localization. Comput. Networks, 51: 2467-2483.

Petrova, M., J. Riihijarvi, P. Mahonen and S. Labella, 2006. Performance study of IEEE 802.15. 4 using measurements and simulations. IEEE Wireless Commun. Network. Conf., 1: 487-492.

Rappaport, T.S., 2001. Wireless Communications: Principles and Practice. 2nd Edn. Pearson Education, Prentice Hall, Singapore, ISBN: 81-7808-648-4. pp:62-68.

Son, D., B. Krishnamachari and J. Heidemann, 2004. Experimental study of the effects of transmission power control and blacklisting in wireless sensor networks. Proceedings of the 1st Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, October 4-7, 2004, Santa Clara, CA., USA., pp: 289-298.

Srinvasan, K. and P. Levis, 2006. RSSI is under appreciated. Proceedings of the 3rd Workshop on Embedded Networked Sensors, May 30-31, 2006, Harvard University, Cambridge, MA., USA., pp: 1-5.

Wang, Y., J. Li, J. Zhang and L. Yu, 2010. An indoor tracking algorithm with the virtual reference based positioning. Proceedings of the ACM Symposium on Applied Computing, March 22-26, 2010, Sierre, Switzerland, pp: 568-574.

Wei, W., A. Gao, B. Zhou and Y. Mei, 2010a. Scheduling adjustment of mac protocols on cross layer for sensornets. Inform. Technol. J., 9: 1196-1201.

Wei, W., B. Zhou, A. Gao and Y. Mei, 2010b. A new approximation to information fields in sensor nets. Inform. Technol. J., 9: 1415-1420.

Woo, A., T. Tong and D. Culler, 2003. Taming the underlying challenges of reliable multihop routing in sensor networks. Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, November 5-7, 2003, Los Angeles, CA., USA., pp: 14-27.

Zamalloa, M.Z. and B. Krishnamachari, 2007. An analysis of unreliability and asymmetry in low-power wireless links. ACM Trans. Sensor Network, Vol. 3, No. 2. 10.1145/1240226.1240227

Zhao, J. and R. Govindan, 2003. Understanding packet delivery performance in dense wireless sensor networks. Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, November 5-7, 2003, Los Angeles, CA., USA., pp: 1-13.

Zuniga, M. and B. Krishnamachari, 2004. Analyzing the transitional region in low power wireless links. Proceedings of the 1st Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, October 4-7, 2004, Santa Clara, California, pp: 517-526.