http://dx.doi.org/10.5392/IJoC.2016.12.1.065

Channel Coding-Aided Multi-Hop Transmission for Throughput Enhancement

Inchul Hwang
Dept. of Information and Telecommunications Engineering
Sangmyung University, Cheonan, Korea

Hanho Wang
Dept. of Information and Telecommunications Engineering
Sangmyung University, Cheonan, Korea

ABSTRACT

Wireless communication chipsets have fixed transmission rate and communication distance. Although there are many kinds of chipsets with throughput and distance purpose, they cannot support various types of wireless applications. This paper provides theoretic research results in order to support various wireless applications requiring different throughput, delayed quality-of-service (QoS), and different communication distances by using a wireless communication chipset with fixed rate and transmission power. As a performance metric, the probability for a data frame that successfully receives at a desired receiver is adopted. Based on this probability, the average number of transmission in order to make a successful frame transmission is derived. Equations are utilized to analyze the performance of a single-hop with channel coding and a dual-hop without error correction matter transmission system. Our results revealed that single-hop transmission assisted by channel coding could extend its communication distance. However, communication range extending effect of the single-hop system was limited. Accordingly, dual-hop transmission is needed to overcome the communication distance limit of a chipset.

***Key words**: Dual-hop system, Throughput Analysis.*

1. INTRODUCTION

Purposes of wireless communication chipsets are separated with respect to throughput and communication distance. However, they cannot only support various kind of wireless applications, but also provide narrow range of communication distances [1], [2]. Hence, in this paper, channel coding and dual-hop transmission are adopted for communication chipsets to overcome limited capability due to fixed throughput and transmission power [3]-[5]. Using micro processors, multi-hop transmission protocol and simple channel codec can be implemented with communication chipsets [6].

First, a channel coding is a good methodology to overcome lack of received signal strength due to its own channel gain. Channel gains can compensate the path loss through error correction effect [7]-[9]. However, channel encoding generates redundancy information bits, so data bits to be transmitted increases two times. For the comparison purpose, dual-hop transmission is also adopted in this paper. In dual-hop transmission, two transmissions occur because of relay transmission, which consumes the same amount of transmission time as the channel encoded data transmission.

In this paper, theoretic research results in order to support various wireless applications requiring different throughput, delay quality -of-servide(QoS) and communication distances by using a wireless communication chipset with fixed rate and transmission power [10], [11]. As a performance metric, probability that a data frame is successfully received at a desired receiver is adopted. From this probability, the average number of transmission in order to make a successful frame transmission is derived. Those equations are utilized to analyze the performance of a single-hop with channel coding and a dual-hop without error correction matter transmission system. In our result, single-hop transmission assisted by the channel coding can extend its communication distance. However, communication range extending effect of the single-hop system is limited. Accordingly, dual-hop transmission is needed to overcome communication distance limit of a chipset.

This paper is organized as introduction, system model, frame error rate analysis, numerical, and conclusion sections.

** Corresponding author, Email: hhwang@smu.ac.kr*

Manuscript received Feb. 29, 2016; revised Mar. 15, 2016; accepted Mar. 22, 2016

2. SYSTEM MODEL

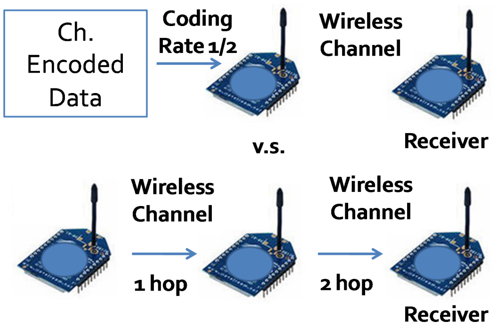

Fig. 1. DPA antenna system and rotation angle

Two wireless transmission scenarios are illustrated in Fig.1. In a single-hop transmission scenario, an encoded data stream is encoded through the convolutional encoder. After the encoding, the amount of the transmitted data bits is duald due to the redundant information for the error correction. In such case, the encoded data stream is transmitted in single-hop.

Comparing with the single hop transmission, a two-hop transmission scenario is also considered in this system model. In the two hop transmission scenario, there is no channel coding used. Hence, there might be more frame errors between a transmitter and receiver than the channel-encoded single-hop transmission scenario.

What we are focusing on is which transmission scenario is superior to the other transmission scenario with respect to throughput. In the channel-encoded single-hop transmission scenario, although a transmitted frame is protected from bit errors, a frame transmission time increases due to two times longer data frame. On the other hand, using the two-hop transmission, a propagation distance between a source transmitter and a destination receiver is shortened, which results in higher SNR and lower frame error rate although data transmission for the same information occur twice.

3. FRAME ERROR RATE ANAYSIS

In order to the propagation distance of a wireless link on the throughput performance, received signal strength (RSS) should be defined as a function with respect to the propagation distance, and transmission power. Generally, thermal noise power at a receiver is considered as a constant. Hence, received signal strength directly affects the bit error rate performance. RSS depending on the number of hops is defined as [12]:

$$s(h) = p_T \cdot \left(d/h\right)^{-\alpha}, \tag{1}$$

where s, h, p_T, d, and α are RSS, the number of hops, a transmission power, a propagation distance, and the path loss exponent, respectively. In 2.4 GHz where IEEE 802.15.4 or 802.11 are working, the transmission power is usually limited up to 10mW. The path loss exponent α has values between 2 and 4 in that frequency band. When microwave propagates in a free space with no obstacles, the value might be close to 2. However, if there is no line-of-sight, the path loss exponent value is almost 4.

As the value of the path loss exponent increases, gain on the RSS by using a multi-hop transmission increases. For example, if the value of the path loss exponent is 3, RSS of a two-hop transmission is 8 times larger than that of the single-hop transmission. If the value of α is 4, the RSS of the two-hop transmission is 16 times stronger than the single-hop RSS.

Subsequently, SNR should be defined. According to the Shannon capacity theorem, link capacity between a wireless transmitter and a receiver is a function of SNR. Especially, post SNR after channel decoding should be considered in the received SNR as follows [13]:

$$y = \sqrt{s(h)\cdot G_c}\cdot x + n, \tag{2}$$

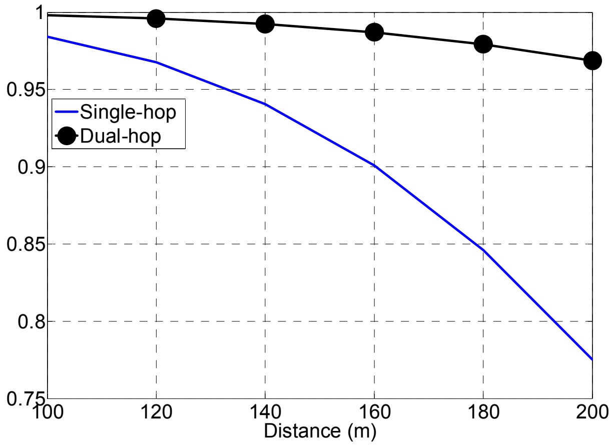

Fig. 2. Probability of successful transmission.

where y, x, G_c, n are the received signal, information signal, the coding gain, and the additive white Gaussian noise (AWGN) at the receiver, respectively.

From the received signal, we can calculate the SNR as follows:

$$SNR(h) = \frac{s(h)\cdot G_c}{N}, \tag{3}$$

where N is the power spectral density (PSD) of AWGN. In this paper, PSD of AWGN is -174dBm/Hz.

Using (3), bit error probability (BER) can be calculated. For the QPSK modulation in Rayleigh fading channel, BER is expressed as [14]:

$$BER(h) = \frac{1}{2}\cdot\left(1 - \sqrt{\frac{SNR(h)}{1+SNR(h)}}\right) \tag{4}$$

In wireless communications, a frame carries data which consists of hundreds of bits. If a received frame does not have an error bit, data in the frame is delivered to higher layers.

However, a data frame should be discarded and retransmitted if there is an error bit in the data frame. When K bits are carried in a data frame, the probability that a frame is successfully received can be calculated as:

$$P_S(1) = (1 - BER(1))^K \tag{5}$$

This probability is for a single-hop transmission. For a dual-hop transmission, the probability that a frame is successfully received can be calculated as:

$$P_S(2) = (1 - BER(2))^K \cdot (1 - BER(2))^K \tag{6}$$

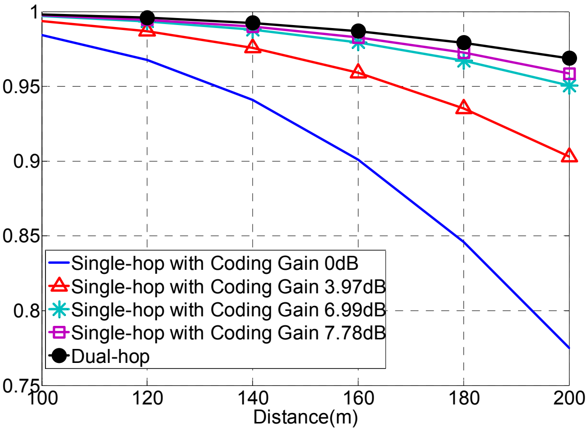

Fig. 3. Probability of successful transmission with coding gain

Equation (5) and (6) is plotted in Fig. 2. In this result, p_T and α are 10 dBm and 4, respectively. System bandwidth is 2MHz. The value of K is 800. In Fig. 2, we can see that the dual-hop transmission outperforms the single-hop transmission in terms of the probability of successful transmission. Actually, this is unfair comparison because transmission time of the dual-hop transmission is two times longer than that of the single-hop transmission. Accordingly, it is assumed that channel coding is used with coding rate 0.5. In this case, the frame length is duald due to redundancy information. It is also assumed that there is no processing delay at the intermediate nose in multi-hop transmission. Using the channel coding, probability of successful transmission considering the coding gain can be plotted in Fig. 3.

Coding gain is directly related to the constraint length C which is proportional to the shift register length. Generally, upper bound of the coding gain is calculated as:

$$G_c \le 0.5 \cdot (C + 2) \tag{7}$$

In Fig. 3, coding gains 3.97, 6.99, and 7.78 dB are used, which corresponds to the constraint length 3, 7 and 9, respectively. In this case, channel-coded transmission consumes the same time that dual-hop consumes. As we can see in Fig. 3, single-hop transmission performance is getting closer to the dual-hop transmission performance as the coding gain increases.

In (5) and (6), it is only considered that a frame transmission is succeeded for the first transmission. However, there could be transmission failures. Accordingly, we have to consider retransmission scenarios.

First, we consider a retransmission scenario of the dual-hop transmission. Two is the minimum required number of transmissions for the dual-hop transmission. If three transmissions are required for the successful frame transmission in dual-hop transmission, one successful transmission and one transmission failure should occur before the last successful transmission occurs. Accordingly, the probability that N transmissions are required for a successful frame transmission in a dual-hop transmission system can be calculated as:

$$\begin{aligned} P_{double}(N) &= \binom{N-1}{1} \cdot \sqrt{P_S(2)}^{\,2} \cdot \left(1 - \sqrt{P_S(2)}\right)^{N-2} \\ &= (N-1) \cdot P_S(2) \cdot \left(1 - \sqrt{P_S(2)}\right)^{N-2}, N \ge 2 \end{aligned} \tag{8}$$

From (8), we can calculate the expected number of transmissions for a successful frame transmission in dual-hop transmission system as follows:

$$E_{double}(N) = \sum_{N=2}^{\infty} N \cdot P_{double}(N) \tag{9}$$

For an efficient system operation, the maximum number of retransmissions $N_{\max}$ is pre-determined. The probability that a successful frame transmission cannot be made within $N_{\max}$ transmissions can be calculated as:

$$P_{F_{double}}(N_{max}) = 1 - \sum_{N=2}^{N_{\max}} P_{double}(N) \tag{10}$$

For the single-hop case, the probability that N transmissions are required for a successful frame transmission is calculated as:

$$P_{single}(N) = (1 - P_S(1))^{N-1} \cdot P_S(1) \tag{11}$$

Similar to (9), the expected number of transmissions for a successful frame transmission in single-hop transmission system can be calculated as:

$$E_{\sin gle}(N) = \sum_{N=1}^{\infty} N \cdot P_{\text{single}}(N) \tag{12}$$

If a retransmission protocol limits the number of retransmissions up to $N_{\max}$, the probability that a successful frame transmission cannot be made within $N_{\max}$ transmissions can be calculated as:

$$P_{F_{\text{single}}}(N_{\max}) = 1 - \sum_{N=2}^{N_{\max}} P_{\text{single}}(N) \qquad (13)$$

4. NUMERICAL RESULTS

In order to obtain numerical results, it is assumed that communication distance is 400 m. In this environment, bit errors occur more frequently than the case in Fig. 3.

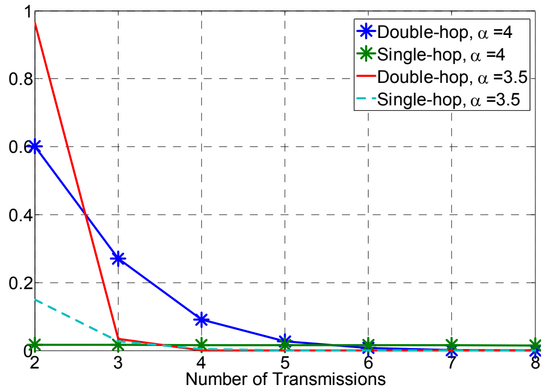

Fig. 4. Retransmission probability

First, results from (8) and (11) are plotted in Fig. 4. When the value of the path loss exponent is 4, dual-hop system can mostly make a successful frame transmission within 5 additional retransmissions. Interestingly, single-hop system does not work in this case. 400 m communication distance is too far for the single-hop system to make a successful wireless link. At every number of transmissions, there is a value of transmission probability. If the path loss exponent value decreases to 3.5, the single-hop system works better than the dual-hop system. Due to less path loss, received signal strength is enough to make a safe wireless link for the single-hop transmission. However, the dual-hop system should transmit signal two times at least, hence, the single-hop system is recommended if the path loss is not severe.

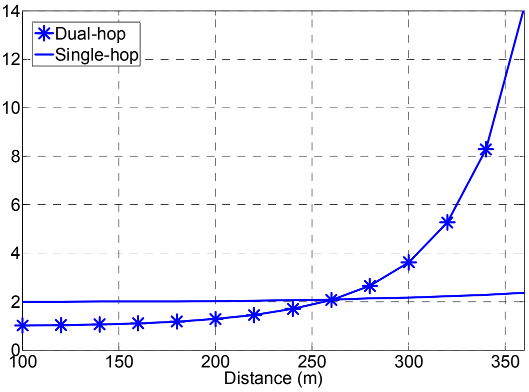

Fig. 5. Average number of transmissions

In Fig. 5, there is a performance comparison result between single-hop and dual-hop transmissions. As we can see, the dual-hop transmission outperforms the single-hop transmission after the distance 260 m. On the other hand, the average number of transmissions of the dual-hop transmission remains at 2 or a little bit more. This performance metric means both throughput and delay. For example, average throughputs of single-hop and dual-hop systems are almost same when the communication distance is 260 m because two transmissions are required to make a successful frame transmission in average. However, after that, effective throughput of the single-hop system is getting worse than that of the dual-hop system as the communication distance increases, which also means increasing latency.

In Fig. 6, effect of channel gains on the average number of transmissions is plotted. Observation range of communication distance is between 100 m and 500 m. As the coding gain increase, communication distance that the single-hop system outperforms gets longer. Using constraint length 7 and 0.5 rate code, communication range of the single-hop system is extended to 450 m. After the distance, throughput of the dual-hop communication permanently outperforms the single-hop system even if the channel coding is adopted. From this result, it is shown that there is a insurmountable communication distance by using only the channel coding. In such case, dual-hop can be adaptively utilized.

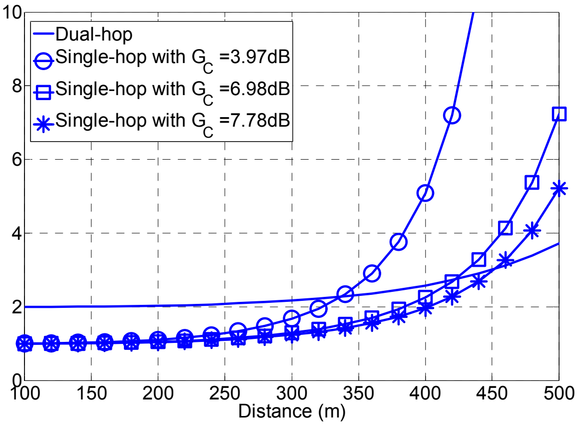

Fig. 6. Average number of transmissions with coding gain

4. CONCLUSION

Although there are many kinds of chipsets corresponding to the throughput and distance purpose, they cannot support various types of wireless applications. This paper provides theoretic research results in order to support various wireless applications requiring different throughput, delay quality -of-service (QoS) and communication distances by using a wireless communication chipset with fixed rate and transmission power. As a performance metric, probability that a data frame is successfully received at a desired receiver is adopted. From this probability, the average number of transmission in order to make a successful frame transmission is derived. Those equations are utilized to analyze the performance of a single-hop with channel coding and a dual-hop without error correction matter transmission system. In our result, single-hop transmission assisted by the channel coding can extend its communication distance. However, communication range extending effect of the single-hop system is limited. Accordingly, dual-hop transmission is needed to overcome communication distance limit of a chipset.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (NRF-2014R1A1A2058985)

REFERENCES

[1] Jaewoo Kim, Jaiyong Lee, Jaeho Kim, and Jaeseok Yun, “M2M Service Platforms: Survey, Issues, and Enabling Technologies,” IEEE Communications Surveys & Tutorials, vol. 16, no. 1, 2014, pp. 61-76.

[2] M. Hasan, E. Hossain, and D. Niyato, “Random access for machine-to-machine communication in LTE-advanced networks: issues and approaches,” IEEE Communications Magazine, vol. 51, no. 6, 2013, pp. 86-93.

[3] Z. Fan, R. Haines, and P. Kulkarni, M2M communications for E-health and smart grid: an industry and standard perspective,” IEEE Wireless Communications, vol. 21, no. 1, 2014, pp. 62-69.

[4] Y. Zhang, R. Yu, M. Nekovee, L. Yi, S. Xie, and S. Gjessing, “Cognitive Maching-to-Machine Communications: Vision and Potential for the Smart Grid,” IEEE Network, vol. 26, no. 3, 2012, pp. 6-13.

[5] H. Chang and K. Chen, “Cognitive Spectrum Sharing Economy for Heterogeneous Wireless Networks,” Proceedings of IEEE GLOBECOM, 2011, pp. 1-5.

[6] C. Yu, C. Ho, and C Huang, “Energy-Efficient Algorithms and Evaluations for Massive Access Management in Cellular Based Machine to Machine Communications,” Proceedings of IEEE VTC Fall, 2011, pp. 1-5.

[7] H. Chao, Y. Chen, and J. Wu, “Power Saving for Machine to Machine Communications in Cellular Networks,” Proceedings of IEEE GLOBECOM, 2011, pp. 1-5.

[8] J. Matamoros and C. Anton-Haro, “Opportunistic Sampling for Random Field Estimation with M2M Capillary Networks,” European Wireless Conference, Vienna, Austria, Apr. 27-29, 2001.

[9] R. Harikrishnan, “An Integrated Xbee Arduino and Differential Evolution Approach for Localization in Wireless Sensor Networks,” Procedia Computer Science, vol. 48, 2015, pp. 447-453.

[10] C. Pham, “Low cost Wireless Image Sensor Networks for visual surveillance and intrusion detection applications,” IEEE on Networking, Sensing and Control, 2015, pp. 376-381.

[11] I. Hwang and H.Wang, “Throughput enhancement of multipurpose wireless chip modules by suing channel coding,” Proceedings of Advanced Science and Technology Letters, 2015.

[12] A. Giordano and A. Levesque, *Digital Communications BER Performance in AWGN and Fading*, Wiley, 2015.

[13] B. Sklar, 2nd edition, *Digital Communications Fundamentals and Applications*, Prentice Hall, New Jersey, 2001.

[14] H. S. Nalwa, Editor, *Magnetic Nanostructures*, American Scientific Publishers, Los Angeles, 2003.

Inchul Hwang

He received He is currently a senior student in Information and Telecommunications Engineering of Sangmyung University. He has been studied microprocessor board designs and computer programming. Recently, he is interested in wireless communications. Since 2013, he has participated technical projects which are dual-polarization antenna capacity analysis supported by ETRI and multi-rate and multi-hop wireless communication platform development supported by national research foundation of Korea (NRF). He is also co-working as a main programmer to build the 5th-generation cellular system level simulator with Yonsei University and SK Telecom.

Hanho Wang

He received the B.S. and Ph.D. degrees from the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2004 and 2010, respectively. He worked in Korea Intellectual Property Office (KIPO), Daejeon, Korea from 2010 to 2011. He is an assistant professor in Information and Telecommunications Engineering of Sangmyung University, Cheonan, Korea. His current research interests are in physical layer in wireless communication, cooperative communications and cognitive radio networks.