Experimental Investigation of Reed-Solomon Error Correction Technique for Wireless Sensor Network

Cheng-Lai Cheah, Poh-Ling Tan, and Chee-Kit Ho

***Abstract*—In this paper, we propose a Reed-Solomon (RS) error correction code with an error correction capability of 32 bytes for IEEE 802.15.4 wireless sensor network (WSN). This code is chosen based on our experimental investigation and the analysis of error pattern, which revealed that although there are as much as 82% of burst errors out of the total errors are present at WSN, the rate of occurrence of the burst errors decreases when the burst length increases. Experimental results show that the proposed error correction code is able to reduce the packet error rate (PER) significantly for distances shorter than 40 m. At the target PER of 10^{-3}, the proposed technique is able to improve either the transmission distance by about 10 m or the received signal strength indication (RSSI) by about 8 dB compared to the WSN without error correction.**

***Index Terms*—Error pattern analysis, forward error correction, Reed-Solomon, wireless sensor network.**

I. Introduction

In radio frequency (RF) communications, the transmitted data are susceptible to various types of noise, fading, interference and power related impairments. These impairments may cause data errors at the received data packets. The IEEE 802.15.4 wireless sensor network (WSN) uses frame check sequence (FCS) to detect the errored packets, and may subsequently discard the errored packets and request for re-transmission of the packets using a recovery protocol such as automatic repeat request [1], [2]. While this approach can be used to ensure the accuracy of the received packet, it however causes re-transmission delay and hence it is not suitable for time sensitive data.

Forward error correction (FEC) technique can be used to overcome this problem. The FEC can correct certain level of data errors at the received packets hence it reduces the requirement of re-transmission. An important consideration in applying FEC for RF communications is the error pattern. While the noises and power related impairments normally cause random errors, other types of impairments i.e. fading and interference produce burst errors [3], [4].

Many research works on error control techniques for IEEE 802.15.4 WSN have been reported. Few authors investigated the techniques using simulation or through analytical approaches [5]-[11]. Some studied the error control techniques for WSN using hardware experimental approaches, but their focus was more on enhancing the resource usage e.g. power consumption, computational requirement and storage space and not much attention was given to the error patterns [12]-[15].

This paper presents the experimental investigation of a Reed-Solomon (RS) error correction code for IEEE 802.15.4 WSN with an emphasis on error patterns. First, we investigate the error pattern of the WSN channel (see Section II). Then we use the knowledge of the error pattern analysis to propose an FEC technique for WSN (see Section III). The results of the proposed FEC technique are presented and discussed in Section IV before we conclude the paper in Section V.

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II. Error Pattern Analysis

Fig. 1 shows the experimental setup for investigating the error pattern of WSN. At the transmitting end, the Texas Instruments CC2520 IEEE 802.15.4 2.4 GHz RF transceiver is used to continuously send 10,000 packets of random data to the receiving end [1], [2]. The length of each packet is set at 114 bytes which is very close to the maximum packet length of IEEE 802.15.4 WSN of 122 bytes [1]. At the receiving end, another CC2520 2.4 GHz RF transceiver is used to receive the packets. A computer at the receiving end is used to identify the errored packets by comparing the received packets with the transmitted packets.

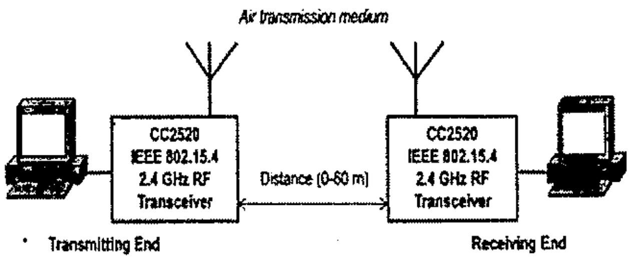

Fig. 1. The experimental setup for investigating the error pattern for WSN.

Theoretically, the error rate is depended on the received power such that the higher value of received power the received packets are less susceptible to errors and vice versa. In the free space signal propagation, the received power P_r is given by Friis' equation [16],

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

where P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, d is the distance and λ is the wavelength. During the experiment, P_t is set as 10^{-3} watts (0 dBm) and the signal frequency is 2.44 GHz. Therefore $\lambda = 0.123$ m. From the CC2520 specifications [1], [17], $G_t = G_r = 1$. Hence

$$P_r = \frac{9.58\times10^{-8}}{d^2} \tag{2}$$

Equation (2) reveals that the received power decreases with increasing distance. Hence the received packets will be more susceptible to errors when the distance increases.

The abovementioned experiment was repeated for different distances from 0 m to 60 m between the transmitting and the receiving ends. All errored packets received are further analysed to determine the burstiness of the errors. The error location analysis proposed by Foster and Waschura was useful for analysing the error pattern for a continuous data stream [3], [4]. However, for WSN, the data are transmitted by short length packets and each packet is transmitted independently. As such, we use a simpler approach by taking the burst length as the number of byte errors within a packet. Our approach is straightforward for deciding the error correction capability needed if an FEC code is to be used for error correction. For distances exceeding 60 m, excessive packet lost was observed which cannot be recovered by an error correction code. Therefore they are excluded from the analysis in this paper.

Fig. 2 shows the rate of occurrence of all errored packets received during the abovementioned experiment. According to Foster and Waschura the random errors should have the burst length of not more than one symbol error [3], [4]. For the offset quadrature phase-shift keying (OQPSK) modulation scheme of WSN, a symbol consists of only two bits, thus all errored packets with burst length of more than one byte can be classified as burst errors. From this we observe that only 18% of the error packets are caused by random errors while the remaining 82% are caused by burst errors. Besides, the graph also shows that the rate of occurrence is high for errored packets with short burst length but it gradually decreases with increasing burst length. It is important to note that the rate becomes very small and insignificant when the burst length exceeds 50 bytes.

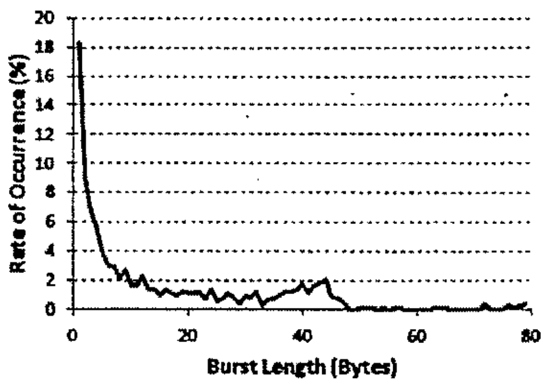

Fig. 2. The rate of occurrence of burst length of all errored packets received.

Fig. 3 shows the breakdown of the rate of occurrence of burst length for different distances. The graph shows that the rate distribution of burst length varies with distance. Most of the burst errors exceeding 40 bytes are contributed by transmission distances of 40 m and 60 m.

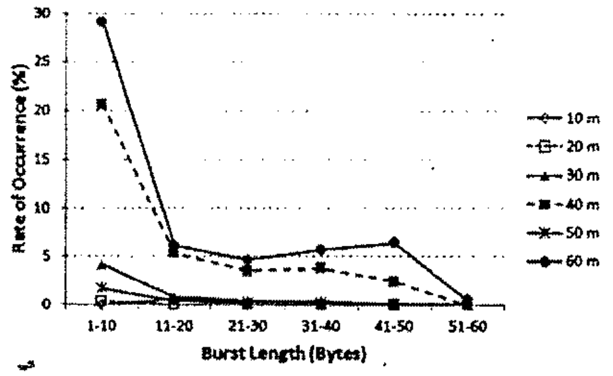

Fig. 3. The breakdown of the rate of occurrence of burst length for different distances.

Based on the above findings, it can be concluded that an FEC code with the error correction capability of 50 bytes per packet will be able to correct most errors for WSN. However, the error correction capability of less than 50 bytes, e.g. 32 bytes can be used for protecting most errors at shorter distance.

III. The Proposed FEC Technique

In order to cater for the bursty errors of RF communications, the shortened RS (114, 50) code is proposed for providing error correction for each WSN packet. The code is derived from the RS (255, 191) parent code. It consists of 64 bytes of FEC redundancy and 50 bytes of user data. The remaining 141 bytes of unused portion of the codeword is shortened by filling it with all zeros as shown in Fig. 4. The error correction capability of the code is 32 bytes. The total length of 114 bytes of FEC redundancy plus user data is suitable for transmission over WSN which can support up to the maximum payload of 122 bytes. This combination is a trade-off between the numbers of bytes of user data that can be transmitted and the error correction capability. The RS code is chosen because it is simple. Besides, the code treats errors based on symbol, in which case a symbol is a byte. Hence it is suitable for correcting burst errors because a byte that contains many bits in error is as easy to correct as a single bit error [18], [19].

64 bytes	50 bytes	141 bytes
Redundancy	User data	All zeros

Fig. 4. The proposed shortened RS (114, 50) code.

The same experimental setup as shown in Fig. 1 is used. The computers at the transmitting and the receiving ends functioned as RS encoder and RS decoder, respectively. The RS encoder and decoder are implemented based on the RS encoder/decoder algorithm in standard C language obtained from the error correcting coding (ECC) website (http://www.eccpage.com) owned by Morelos-Zaragoza [19]. The decoding portion of the algorithm is based on Berlekamp iterative algorithm.

IV. Results and Discussion

The experiment discussed in the previous section was performed to investigate the packet error rate (PER) before and after error correction. Here errored packets include all packets which are not received correctly at the receiving end. It includes lost packets, packets with incorrect packet length as well as the errored packets. Although the lost and the incorrect-length packets are unable be corrected by FEC, they are still included in the computation of PER so that the results are more realistic.

Fig. 5 shows the PER against distance before and after error correction. The results showed that the proposed FEC technique is able to reduce the PER significantly especially for distances shorter than 40 m. For longer distances, the errored packets have a high rate at longer burst lengths so the PER improvement is smaller. By setting the target PER of 10^{-3}, which is acceptable for most internet protocol (IP) applications [20], the proposed FEC technique is able to improve the transmission distance by about 10 m compared to the WSN without error correction.

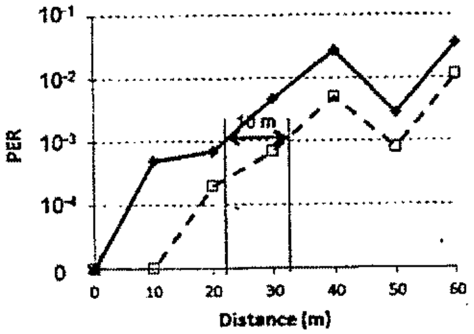

Fig. 5. The PER against distance before and after error correction.

Fig. 6 shows the PER against received signal strength indication (RSSI) before and after error correction. By setting the same target PER of 10^{-3}, the proposed FEC technique is able to improve the RSSI by about 8 dB compared to the WSN without error correction.

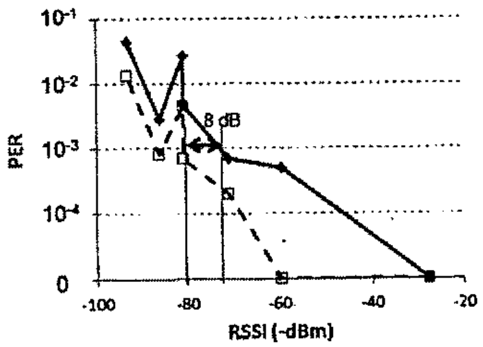

Fig. 6. The PER against RSSI before and after error correction.

V. Conclusion

In this paper, we showed that by analysing the error pattern of IEEE 802.15.4 WSN, a simple RS code can be used to improve the PER performance of the WSN.

Although more burst errors than random errors occurred at the WSN, the rate of occurrence of the burst errors decreases when the burst length increases. From the result of the error pattern analysis, an RS code with error correction capability of 32 bytes is proposed for WSN. This capability is a trade-off between the maximum length of the user data and the length of burst errors that can be supported.

Our experimental results showed that the proposed FEC technique is able to reduce the PER significantly for distances shorter than 40 m. At the target PER of 10^{-3}, the proposed FEC technique is able to improve either the transmission distance by about 10 m or the RSSI by about 8 dB compared to the WSN without error correction.

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