FORWARD ERROR CORRECTION FOR IMAGE TRANSMISSION SYSTEM USING IEEE 802.15.4

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Abstract

Wireless Sensor Network (WSN) has been highly considered as an alternative for multimedia transmission. However, there are not so many research reports which discuss about advances in images transmission using WSN. One of important considerations in image transmission is the capability of a system to provide quality retaining as well as reliable transfer scheme. This issue arises since image data is more sensitive to erroneous wireless channel rather than scalar sensor data. To counter this problem, utilization of Error Control Coding (ECC) is highly considered. In this paper, the use of ECC in WSN is discussed and the system performances based on simulation for of uncoded and coded system are presented. The system to evaluate ECC in real time is also discussed and some important steps which based on literature review compilation are drawn at the end of this paper.

Keywords: *Error Correction Control, IEEE802.15.4, Image Transfer, Wireless Sensor Network.*

I. INTRODUCTION

Limited power resources and low computing capability have been the two most concern in recent research related to Wireless Sensor Network (WSN). Nowadays, instead of using WSN for communicating scalar sensor data, many researches have begun to improve the WSN system so that the mote—a WSN transceiver device sometimes referred as sensor that can send data wirelessly—can carry multimedia data. Specifically, the concern is how to make the mote capable of transmitting images captured by low voltage camera installed on the mote, stored into buffer and finally send it to the respective sink mote. This issue has brought up new term in WSN world such that deriving the name Wireless Multimedia Sensor Network (WMSN).

Image transmission over IEEE 802.15.4 have received much attention from researcher around the world. Several researchers have done important contribution towards image transmission system using WSN. In [1], the authors developed multimedia wireless sensor network by coupling camera device, integrated flash memory, battery power and IEEE 802.15.4 transceiver altogether controlled by microcontroller unit (MCU). The work tried to build low cost and low power Multimedia WSN node which is run by embedded operating system called *WiseOS*. The developed system has shown its capability in transmitting image and has comparable performance with commercially available *TelosB* WSN mote. Furthermore, it was also suggested that the developed mote can transmit voice data with 8 Kbps of quality.

In [2], the authors reported that JPEG and JPEG2000 image format can be transported effectively by using Zigbee WSN. In the experiment, 5 motes are functioned as the source of images and 1 mote attached on personal computer to view the received images. However important notion should be made due the failure of multihop image transmission. The author noted that the failure at the second hop transmission is due to adverse interference generated from uncontrolled 802.15.4 and WiFi radio that makes the JPEG2000 image data not decodable.

In [3], the authors reported the work on developing 802.15.4 motes namely *TEA*-15.4. The improvement mainly resides in Media Access Layer (MAC) domain. It is shown that by using their algorithm, the improvement made in two respects; increased throughput by using non-beacon feature and conserving more energy as the motes intelligently adjust its sleep/wake up period based on traffic information.

It is worth noting that while in [1], [2] and [3] the works are more concerned with improving the capability of the motes to transmit image, but there is not enough information regarding the quality of the received image itself. On the contrary, there are a lot of solutions offered from multimedia study to enhance image transmission system but it lacks on the real implementation. As stated in [4], there are rooms to improve WMSN, ranging from PHY to Application layer (OSI 7 Layer). The use of Error Control Coding in WMSN PHY not only can improve the robustness of communication but also can reduce power consumption. Thus, based on above explanation, finding an approach to evaluate image transmission with ECC in WSN is very important.

The rest of paper is organized as follows: Section II gives a brief introduction about ECC mechanism in WSN. Section III discuss about image transmission technique from multimedia study. Section IV presents simulation results for uncoded and coded 802.15.4 system. Section V proposes a method to evaluate the use of ECC in image transmission system using WSN. The conclusion is drawn in Section VI.

II. ERROR CORRECTION CODING IN WIRELESS SENSOR NETWORK

According to [5], the configuration of 802.15.4 transceiver system utilize spread spectrum techniques which can provide processing gain from 6 until about 12 dB depending on frequency operation and the technique that is being used. The gain achieved by implementing spreading techniques which utilizes either Direct Sequence Spread Spectrum (DSSS) or Parallel Sequence Spread Spectrum (PSSS). Instead of transmitting narrow band signal with high power, the system transmit noise-like signal. This technique enhance the receive signal quality.

The processing gain can be interpreted in two ways; in transmitter, the processing gain is used to reduce the overall transmission power by running the system using lower Sinal to Noise Ratio (SNR) to achieve better BER level while in the receiver, the gain is used to lower the receiver sensitivity so the transmission range can be increased. As reported in [2], this basic configuration is not enough to support image transmission for more than one node due to possibly adverse environment and interference from other system. Thus, in [4] it is suggested to introduce ECC so that the system can be improved in terms of resiliency. The relationship between range and SNR is given by the following equation [5]:

$$R = 10^{\left(\frac{p_0 - F_M - P_r - 10\times n\times\log_{10}(f) + 30\times n - 32.44}{10\times n}\right)} \quad (1)$$

Where P_0 represents transmission power, Pr represent receiver sensitivity, F_M represents fading margin, f represents the signal frequency operation and n is the pathloss exponent.

The SNR itself contained inside the receiver sensitivity, P_r, which formula is given as follows:

$$P_r = N_{BW} + SNR + NF \quad (2)$$

Where N_{BW} represents receiver's additive white gaussian noise usually -174 dBm, NF represents noise figure of receiver and SNR represent minimum power signal required for correctly demodulate the signal.

There are 2 types of ECC i.e. Forward Error Correction (FEC) and Automatic Repeat ReQuest (ARQ). The proposed ECC schemes in WSN are categorized as follows [6]:

1. Automatic Repeat ReQuest (ARQ) which is an error recovery mechanism that required retransmission upon receiving broken / undecodable packet. This technique introduces significant cost in terms of delay and energy processing due to limit resources of the sensor nodes.
2. Forward Error Correction (FEC) introduces bit redundancy in the transmitted data. FEC has error detection and capability that depends on the code configuration. The long, complex and sophisticated channel code should provide robust error recovery mechanism, but in WSN, the implementation of FEC should account of the limitation in terms of complexity and energy resources scarcity.
3. Hybrid ARQ is the scheme that exploits advantages of both FEC and ARQ techniques. H-ARQ type I send the uncoded packet or a packet with low FEC then upon failure, the packet is retransmitted with higher FEC. In H-ARQ type II, the packet is sent without adding redundancy. Upon failure, only the redundancy bit, the codeword, is sent for the respective error packet.

Theoretically, H-ARQ should perform better than both FEC and ARQ. However, the performance of ECC schemes should be measured not only from the error correction capability but also from the introduced latency and energy required to process respective techniques. As stated in [6], the efficiency of ECC is derived with the following equation:

$$\tau = \frac{l_D}{E_{flow} T_{flow}} \left(1 - PER_{c2c}\right) \quad (3)$$

Where l_D is the payload length, E_{flow}, T_{flow} and PER_{c2c} are end to end energy consumption, latency and packet error rate respectively.

It is often assumed that limited resource mote is used in transmitter while the receiver has enough processing power and has more energy required per operation. Hence, it can be said that for certain FEC technique, energy wise encoding can be considered at transmitter while more complex decoding techniques can be applied at the receiver. If the system can accept certain value of delay, H-ARQ type II with low complexity FEC might be considered since it gives the lowest energy consumption at higher correction capability. In the case of high density network, FEC scheme provide better efficiency [6].

The equation given in (1) is rather conventional prediction for range estimation. For more complex and advanced WSN system, the conventional method might give misleading information. Therefore, cross layer analysis provided in [6] might be the currently best method to evaluate the ECC in WSN, especially for image transmission system.

III. IMAGE TRANSMISSION TECHNIQUE

This section will discuss applicability of ECC in WSN system. Consider a WSN packet structure as shown in figure below.

Preamble	SFD	Length	Frame Control	Seq. Number	Dest PAN	Dest. Address	Source Address	MAC Payload	FCS
4	1	1	2	1	2	2	2	2	2

Figure 1. A Tx/Rx Packet structure of IEEE 802.15.4

The general packet structure may consist of header, payload and trailer. The header consists of preamble, start frame delimiter, packet length, frame control, packet sequence number, destination PAN, destination address and source address which sizes are as indicated by the number on the second row. While MAC payload can contain packet with size up to 103 Byte and Frame Check Sequence (FCS) as the trailer with size of 2 Byte.

The limitation in payload size leads to data segmentation before transmission. FEC itself can be performed after data segmentation has been conducted. This implies that the size of segmented data should account for the redundant bits added after channel coding process. In this technique however, header and trailer will not be coded, because header and trailer will be created after FEC process just before the packet is passed on to transceiver module.

In the next section, results from the simulation work will be discussed. The simulation considers encoding and decoding process of the packet to over all the bytes, such that preamble and frame check will be included. Thus, the effect of preamble misdetection/preamble failure cannot be examined.

IV. LINK LEVEL PERFORMANCE OF 2.4 GHz IEEE 802.15.4

A simple simulation work is conveyed to gather information regarding the performance of FEC code in 802.15.4 system under Additive White Gaussian Noise (AWGN) and Rayleigh multipath fading channel. As pointed out in [9], the use of Reed Solomon code as FEC can significantly reduce energy consumption compared to other block code and convolutional code. This is also due to low complexity of the reed Solomon code itself. The power consumption of Reed Solomon can be seen in Table I below. As pointed out in [9], the use of Reed Solomon code as FEC can significantly reduce energy consumption compared to other block code and convolutional code. The power consumption of Reed Solomon can be seen in Table I below.

TABLE I
Power Consumption in RS Codes [9]

RS Code	Power Consumption (nW)
RS(15,11)	200
RS(31,26)	125
RS(31,21)	150
RS(31,16)	275
RS(31,11)	450

From Table I, it is shown that for RS code with total number of codewords 31 and total number of data 26 has lowest power consumption while RS(31,21) has the highest power consumption. Between RS(31,26) and RS(31,21), there is a tight energy consumption difference around 25 nW. According to [9], the simulation was conducted for point to point link between two 802.15.4 motes.

The 2.4 GHz 802.15.4 system has maximum bit rate of 250 Kbps and employs DSSS to spread 4 bit data into 32 chips and then modulated by OQPSK. By using this system, the maximum transmitted symbol rate is 62.5 Ksps. The comparison between RS(31,26) and RS(31,21) is shown in figure below.

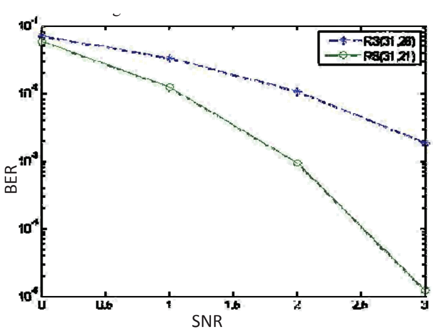

Figure 2. BER Performance of coded 2.4 GHz 802.15.4 in AWGN channel.

From Figure 2, it is shown that the performance of RS(31,21) is better than RS(31,26) for the same SNR value of 3 dB. The reason is that RS(31,21) can detect n – k erroneous symbol which is 10 symbols and can correct up to (n – k) /2 or 5 symbols while RS(31,26) can detect 5 symbol and correct 2 symbols. To make the system more realistic, simulation in Rayleigh fading channel is done. The result is shown in figure below.

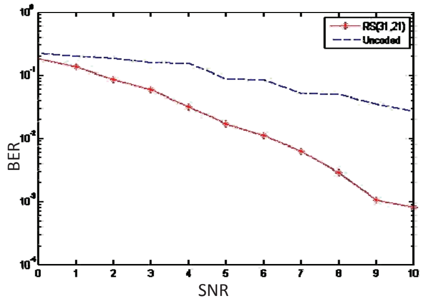

Figure 3. BER performance of 2.4 GHz IEEE 802.15.4 under Rayleigh fading channel.

From Figure 3, the performance of uncoded system and RS(31,21). The uncoded system means the WSN system without using FEC. It is interesting to know that typical multipath fading channel model such Rayleigh channel can degrade the performance considerably. For SNR of 10 dB, the coded system can only reach as low as 10^{-3} of BER. This indicates that, in the Non Line Of Sight (NLOS) environment, the range of system is shorter than in LOS. If the requirement of the system is 10^{-3} then SNR of 10 dB is required to detect the the signal correctly.

V. PROPOSED SYSTEM TO EVALUATE FEC FOR IMAGE TRANSMISSION IN WIRELESS SENSOR NETWORK

Throughout the discussion, it is suggested that testing image transmission under real environment is that of important to verify the analysis made in [6][7] and also as means to improve the performance of the work in [2] and study the performance of image transmission in multihop transmission scheme. In this last section, the system to evaluate image transmission with ECC in WSN is proposed.

The system to realize the evaluation of image transmission in WSN consists of several elements which are; Digital Signal Processing Board, IEEE 802.15.4 compliant wireless daughtercard and antenna. The Texas Instrument Evaluation Module EVM5515 which using TMS320C5515 chip is low power fixed point DSP which is suitable for wireless modem application. EVM5515 supports System on Chip (SoC) wireless daughtercard CC2420 which is 802.15.4 compliant. The P1 and P2 connector can be used to connect CC board to DSP board. Furthermore, the DSP board can be programmed to channel the data to CC board through P1 and P2 pins.

The idea behind the device configuration is to use the DSP board as a signal processor where the preparation for image transmission is conducted. For example, the DSP is used for slicing/ joining the image data and applying channel encoding/decoding. With the programmable DSP, various ECC scheme can be evaluated. Furthermore, the CC board can run independently by using battery. The CC board which is attached to DSP board forming one wireless modem or WSN mote which referred to as a Full Function Device (FFD), a device that can perform complex task compared to Reduced Function Device (RFD). The RFD is the mote which run without board, or in this case, the CC board which is not attached to DSP board and the only task is to forward the packet data. This is one of many ways to perform and evaluate the performance of ECC in WSN without using simulation.

Lastly, implementation of ECC and Source Code in WSN system has to consider some significant issues as outlined below:

1. Defining the types of application i.e. real time or non-real time as this will affect the focus of which network parameter will be optimized (latency versus quality).
2. Since image file is larger than sensor data, segmentation of the

file is that of important issue as WSN packet structure reserve limited space for its payload.

3. The WSN system is usually deployed with numbers of motes. Thus, it implies that there is a strict resource constraint in terms of channel access. Image transmission is likely take considerable amount of time and thus good coordination among devices in the network should account for the transmission time of the image packets from one mote to another mote.
4. A separate processor might be needed because source code implementation as well as more advance form of FEC cannot be efficiently computed by using microprocessor. Hence, implementing these tasks might require a clear reference of system architecture of the mote.

VI. CONCLUSSIONS

Section I has explained the background of multimedia transmission over WSN especially for images data. Section II has briefly discussed the importance of employing ECC in WSN to support reliable transmission of images. In Section III, the discussion about image transmission study from multimedia community and suggestion regarding the possibility of realizing the system in WSN is drawn. Section IV discussed the use of efficient Reed Solomon channel code in WSN system and the performance of Reed Solomon code in AWGN and fading channel. Section VI has discussed a proposed system to evaluate ECC and also to realize image transmission in WSN.

It is also shown that the performance of coded WSN is way better than uncoded WSN. Although in conventional way, the SNR is interpreted more into the how far the transmission can be established, coupling the issue with image transmission, it is wise to acknowledge that the good SNR does not necessarily improved the image quality. It is also denoted that the system performance under Rayleigh fading is for point to point analysis. Image transmission in multihop may have different parameter than single hop.

ACKNOWLEDGMENT

This work is supported by the Ministry of Science and Technology (MOSTI) Science Fund under project 01-01-14-SF0025/ L0012.

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