A Novel Approach for Coexistence of ZigBee with WiFi

Sai Manoj P. D., Sasirekha G. V. K., and Jyotsna Bapat

***Abstract*—ZigBee co-exists with other unlicensed technologies such as Bluetooth, WiFi in the 2.4GHz spectral band. This coexistence scenario is especially unfavorable for ZigBee networks since WiFi has considerably higher transmission power. Even when the ZigBee signal is strong enough to be detected by WiFi, WiFi may perform backoff depending on position of WiFi device with respect to ZigBee device. Simultaneous activity by ZigBee and WiFi will result in errors in the header of ZigBee packet. Error in Header results in loss of ZigBee packet. To overcome such situation, multi-header approach has been suggested in literature. Multiple Headers (MH) reduce the effective throughput. In our work, we propose a scheme that determines the number of headers adaptively based on the presence of heterogeneous networks. MH scheme is effective only if interference is present, allowing for better efficiency and throughput.**

***Index Terms*—Interference, co-existence, ZigBee, WiFi.**

I. INTRODUCTION

ZigBee is a low power digital device, for which communication protocols are based on IEEE 802.15.4 standard. ZigBee basically address the unique needs of low-cost, low-power wireless networks. It operates in unlicensed bands including 2.4 GHz, 900 MHz and 868 MHz ZigBee is a low power device compared to other devices existing in same ISM band such as WiFi. These devices follow a similar format of message in order to have communication present between them. The ZigBee protocol provides an efficient wireless data transmission solution characterized by secure, reliable wireless network architectures in commercial and industrial applications.

Depending on the available network information, device may follow different methods for communication. When the network address is known, the unicast communication can be carried out. When it is not, broadcast communication is done.

WiFi devices communication protocol is defined by WiFi alliance to use 802.11 standards. WiFi also operates in the frequency band of 2.4GHZ or 5GHz bands which are license free. Since the 2.4GHz band is unlicensed, WiFi is designed to share spectrum with devices of same type as well as different type. One of the reasons for interference raises with the fact that transmit power of WiFi is nearly 10 to 100 times power compared to ZigBee’s transmit power [1].

Even though the physical layer properties of ZigBee and WiFi are different the presence of WiFi will cause the interference to ZigBee. Continuous sensing of the spectrum before transmission makes the ZigBee to consume more power. The existing CSMA mechanisms are inadequate for sensing the coexistence of ZigBee and WiFi [2]. The major problem with the coexistence is that WiFi mostly affects and corrupts the header part of the ZigBee resulting in complete loss of packet, even though payload is not corrupted. Use of Multiple Headers reduces the redundancy of transmission because even if the first header is corrupted, with the help of other headers packet can reach the destination node [1]. But it is unnecessary to use Multiple Headers in an interference free environment.

The remainder of paper is organized as follows. Section II gives overview of previous work; Section III gives reasons for collision and error distribution due to interference. Proposed solution and analytical results are given in Section IV and Section V concludes the paper.

Manuscript received May 1, 2012; revised June 12, 2012. This work was supported in part by International Institute of Information Technology, Bangalore.

The authors are with the International Institute of Information Technology, Bangalore, India. (e-mail: saimanoj.pd@ iiit.org, sasirekha@iiitb.ac.in, jbapat@iiitb.ac.in).

II. BACKGROUND

Static and Dynamic channel assignment are two most simple and basic models proposed solution for co-existence. In Static channel Assignment [1], it is assumed that fixed channels are assigned to other devices and unused channels are used by ZigBee. However, this solution may not always work due to mobility in nodes, different channel allocation in different locations for different devices may cause interference, and deployment of more devices may cause interference in reserved channels. In case of Dynamic channel Assignment [1], different nodes of same network or same nodes at different points of time will use different 802.15.4 channels to avoid interference from nearby WiFi sources. The solution requires detection of the WiFi traffic by ZigBee devices and coordination of channel among different 802.15.4 senders and receivers and complexity involved in the same. Carrier Sense Multiple Access (CSMA) is also one approach. White Space Aware Frame Adaptation (WISE) [2] is another coexistence scheme which predicts the presence of white space (available spectral band) and adapts packet size accordingly. But this also have some disadvantages such as complexity and wait time if the data length is less than header length, if length field of header is corrupted, it may result in error. In opportune transmission [3], we measure and quantify packet delivery and use the same to set the packet transmission delivery but the disadvantage is it is unable to use the white space effectively

Adaptive Back off Exponential algorithm is proposed in [5]. It mainly focuses on improving the data rate in the presence of interference from same kind and different kind of devices. Each device which needs to transmit data is provided with Media Access Control (MAC) Backoff Exponent (BE) which determines the data slots available for transmission. It provides high range of Backoff so that different devices will start transmission with different BE. Only devices that are involved in a transmission are taken into consideration and devices that are not transmitting do not come under the purview of the algorithm. At regular intervals co-ordinator will decide whether to change the value of MAC Minimum BE to a transmitting node or not. Thus, the algorithm implements a variable MAC Minimum BE, and the variation factor is chosen to be related to each node's contribution to the network. The main drawback is the devices contributing high network load are kept to wait for long time. In [1], an efficient method is proposed. The interference regions are divided into two, symmetric and asymmetric. It has been proven in [1] that even WiFi transmitter backs off when ZigBee transmitter is close to it, classified as symmetric region. Asymmetric region is one in which WiFi devices are unable to detect the presence of ZigBee devices, i.e. distance between WiFi and ZigBee transmitters are large.

III. Error Distribution Because of Collision

The packet format of ZigBee using a single header is shown below.

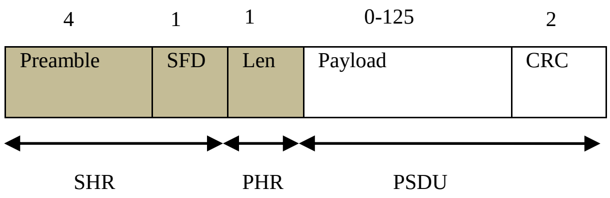

Fig. 1. Format of 802.15.4 packet.

Preamble represents the start of the packet; Start of Frame Delimiter (SFD) represents the start of delimiter. The combination of Preamble and SFD is called as Synchronization Header (SHR). The length of the frame is represented by Len field, called Physical Header (PHR). The length of payload varies from 0 to 125 bytes. The Cyclic Redundancy Check (CRC) is used for checking the errors in the packet. Physical Service Data Unit (PDSU) represents the actual data coming from MAC layer. The lengths of each field are represented above it, are in bytes.

First we will explain why and how 802.15.4 and 802.11 packets collide. The total packet time of WiFi transmitter is smaller than the slot waiting time for ZigBee transmitter. The collision will occur only when an 802.15.4 sender begins its transmission during the Discrete InterFrame Space (DIFS) + Contention Window period, otherwise devices sense the channel as busy. Furthermore, from the data presented in [1], that the 802.15.4 sender senses the medium for the slot time (= 320μs) and senses the medium for eight symbol periods (= 128μs) before declaring channel as idle [1], [4]. It is very likely that during the time the 802.15.4 sender senses the channel, the 802.11 node also senses the channel. As a result, both nodes sensing the channel idle and start transmitting at the same time resulting in collision. One solution for this is Multi Header solution for this [1]. Unnecessary use of MH may increase the overload; it is proven experimentally in [1] that the lack of bit errors near the end of the packet is partly due to the corrupted length field. The interference pattern and error distribution from [1] is shown in Fig. 2.

It can be clearly observed that the header part of the ZigBee packet is affected by interference.The error disribution shown in above figure is for symmetric region. In asymmetric region CRC or some other Forward Error Correction techniques may be used for correction, as interference effect is uniformly distributed. If the source is 802.11g, due to its high data rate.

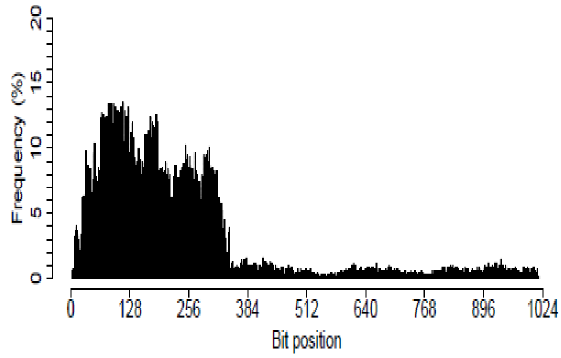

Fig. 2. Bit error distribution for 802.11b and ZigBee [1].

The ZigBee packet with Multi Header (MH) is shown in Fig. 3.

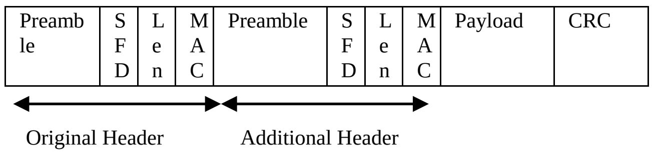

Fig. 3. ZigBee packet with additional header.

IV. Proposed Solution

The proposed approach is given below, the ZigBee will initially sends request to send (RTS) and uses CSMA to detect the channel. If the channel is free then the sender will directly transmit the packet, if it does not receive any acknowledgement, it will resends one more time and even then if it didn't get acknowledgement it transmits using MH. Even after using MH if it didn't get acknowledgement then it backs off exponentially and will start again after the backoff time. If we didn't get clear to send (CTS) it implies either the CTS acknowledgement (ACK) packet is lost or the presence of other devices. In this case the sender will start its transmission with MH and waits for acknowledgement. If it does not receive acknowledgement it implies either the acknowledgement is lost or the packet is lost. In this case, the sender will try again and wait for acknowledgement. If it didn't get acknowledgment then it tries for third time and waits for acknowledgement and if it does not receive, it backs off exponentially and will start sensing the channel after the backoff time.

After considering the different drawbacks and advantages form different approaches in reducing congestion, we now try to propose a solution which will improve coexistence along with improving successful transmission of data.

Analytical Analysis:

It is assumed that the errors in payload can be corrected effectively using the CRC and the region of errors in the analysis is considered to be symmetric. The model is developed by considering only the header part. The Buzz-Buzz protocol and proposed method are analysed mathematically. If the probability of bit error in header part is P_e with channel collision probability P_c, let the number of header bits be *n* and the threshold up to which CRC added for correcting header can correct up to T bits. The probability of successful transmission in the worst case scenario is P_{sw}.

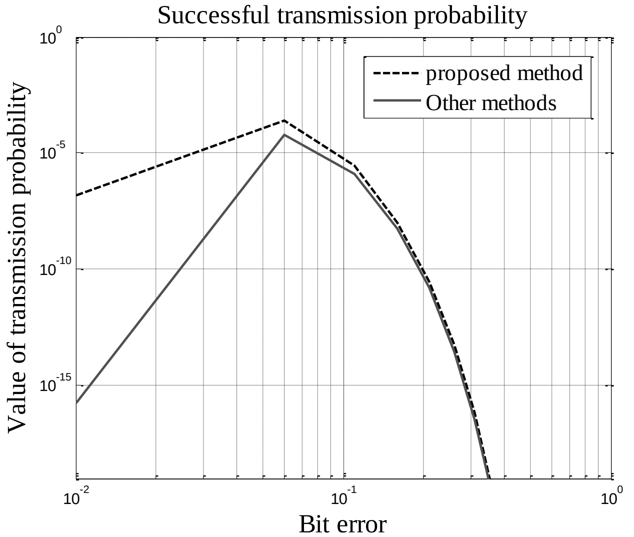

Fig. 4. Comparison between buzz-buzz and proposed method.

The probability up to which T bit errors can be tolerated be P_t and is given by

$$P_t = \sum_{k=0}^{T} \binom{n}{k} (1 - P_e)^{n-k} {P_e}^k \quad (1)$$

The probability of successful transmission in worst case of Buzz-Buzz protocol is given by

$$P_{Sw} = (1 - P_t)^8 P_t P_c \quad (2)$$

The probability of successful transmission in worst case scenario using the proposed solution is given by

$$P_{sw} = ((1 - P_t)^3 P_t + (1 - P_t)^5 P_t) P_c \quad (3)$$

The probability for proposed solution is considering the single and multi header cases as independent with respect to each other. The comparison is shown in Fig. 4.

It could be observed from the above result, at the time of high probability of bit error, the proposed algorithm converges to Buzz-Buzz protocol. This also shows that adapting number of headers dynamically improves the number of successful transmissions.

The advantages of this approach are it reduces latency because we the estimate channel information based on the CTS packet transmitter receives, complexity is less because it adapts the header based on the CTS received and its RSSI value and unwanted packet loss and unnecessary retransmissions are avoided by use of MH directly when there is interference and no need to transmit with MH when there is no interference. The receiver does not need to decode MH packet in interference free region. As always said, there's no free lunch, the CTS has to be correctly analysed else it again may result to transmission of packet with MH in interference free region or transmission with Single Header in interference region, resulting in need for retransmission, approaching the Buzz-Buzz protocol. This approach can be practically implemented on TinyOS using ZigBee Motes.

V. Conclusion

ZigBee devices are used in applications where low power is one of the main requirements. As it operates in ISM band, it has to coexist with other devices operating in same band, so proper interference avoidance scheme has to be used, else results in unnecessary retransmissions leading to unnecessary wastage of power. The paper focuses on adapting the number headers, thus reducing wastage of power.

References

[1] C. Liang, N. Priyantha, J. Liu, and A. Terzis "Surviving Wi-Fi Interference in Low Power ZigBee Networks," In *SenSys* 2010 November 2010

[2] J. Huang, G. Xing, G. Zhous, and R. Zhou "Beyond Co-existence: Exploiting WiFi White Space for ZigBee Performance Assurance," In *IEEE International Conference on Network Protocols* 2010

[3] K. Srinivasan, M. A. Kazandjieva, S. Agarwal, and P. Levis "The B-factor: Measuring Wireless Link Burstiness," In *SenSys* 2008

[4] IEEE Std 802.15.4™-2003, [Online]. Available: http://www.cs.jhu.edu/~cliang4/public/datasheets/802.15.4-2003.pdf

[5] V. P. Rao, D. Marandin, and V. B. Iversen, "Adaptive Channel Access Mechanism for Zigbee (IEEE 802.15.4)," in NEW2AN 2006, LNCS 4003, pp. 501 – 516, 2006.

Sai Manoj P D received the Bachelors degree in Electronics and Communication Engineering from Jawaharlal Nehru Technological University, Anantapur, India in 2010, and currently doing his Master's degree in International Institute of Information Technology, Bangalore. He has done his master's thesis in University of Kaiserslautern, Germany on Improved Algorithms for LDPC Codes. His research interests include communication theory, wireless communications, channel decoding and VLSI design.

Sasirekha GVK is currently doing her research (PhD) under the guidance of Prof. Jyotsna Bapat, IIITB in the area of Cognitive Radios. She was a Scientist at Centre for Artificial Intelligence and Robotics, DRDO, India. She has received her MS (Software Systems) degree from BITS, Pilani, India and BE (ECE) from Osmania University, Hyderabad, India.

Professor Bapat received her PhD from Penn State University. Her thesis was in the area of semi-blind equalization applied to communication systems. After graduation, she worked on design and implementation of voice-band (V.34) and DSL (G.lite) modems at Ariel Corp and Lucent Technologies respectively. Her area of interest is Digital Signal Processing as applied to communication systems. In particular, she is interested in semi-blind identification as applied to OFDM systems.