

Adaptive Throughputs Depend On Channel Quality For Zigbee Transceiver

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Abstract :

IEEE 802.15.4 (also known Zigbee) is the standard that has been developed for low cost, low data rate and low power consumption wireless network, in advance Wireless Sensor Network (WSN) need to high throughput and low power consumption. This paper proposed an improved ZigBee transceiver architecture (for 915MHz model) to maximizing throughput to enhance the network performance for high data rate application while maintain compatibility with the essential WSN requirements: low power, low cost, bandwidth, and low complexity. The idea is to design a three code length of Direct Sequence Spread Spectrum (DSSS) with three data rate: 40kbps, 75kbps and 150kbps by modification the chip coding architecture of the modulation process of IEEE 802.15.4. Here we need a channel estimation and Signal to Noise Ratio (SNR) measurement to be on the basis of which the selection of appropriate length of the code and therefore the amount of the data sent. Also in this research we present a detailed technically of such idea, it has been tested, scheduling result, and explained how the system works. The results show that it is possible to apply the idea of increasing the data transfer rate while maintaining the same hardware specifications.

Keywords: - ZigBee, Adaptive throughput and 802.15.4

الكمية المتكيفة المعتمدة على كفاءة القناة في الارسال والاستقبال لنظام ZigBee

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الخلاصة

النظام *IEEE 802.15.4* وايضا يسمى *ZigBee* وهو بروتوكول تم تطويره ليكتسب ميزات اساسية وهي قلة القدرة المستهلكة فيه وكذلك قلة كلفته بالاضافة قلة كمية البيانات المرسله فيه لاسلكيا. في التطبيقات المتقدمة ومنها شبكة المتحسسات اللاسلكية *WSN* تحتاج الى نقل كمية اكبر من البيانات. في هذا البحث تم تقديم مقترح لزيادة كمية البيانات المرسله لهذا النظام في الموديل الذي يعمل في مدى الترددات *915MHz* في تطبيقات *WSN* مع الحفاظ على مواصفاته في استهلاك القدرة الواط، والكلفة القليلة وبساطة التركيب. الفكرة تتضمن تصميم ثلاثة انواع من طول الشفرة لنوع التشفير المستخدم (*DSSS*) مع ثلاثة مديات لكمية البيانات وهي *40kbps, 75kbps, 150kbps* وذلك بتطوير مرحلة التشفير والتضمين في *IEEE 802.15.4*. هنا نحتاج الى اختبار حالة القناة، وقياس نسبة الاشارة الى الضوضاء (*SNR*) والذي على اساسه يتم اختيار طول الشفرة المناسب ومعه كمية البيانات المرسله. في هذا البحث ايضا تم تقديم التفاصيل التقنية للفكرة، وتم اختبارها وتم جدولة النتائج وتم توضيح كيفية عمل النظام. النتائج اوضحت امكانية تطبيق الفكرة لزيادة كمية البيانات مع الحفاظ على الميزات العملية.

1. Introduction

Wireless medium suffers from unstable channel conditions (e.g. Signal fades due to distance, frame collision from simultaneous transmissions, and interference from other sources). For nodes supporting multiple data rates, rate adaptation is indispensable to optimally exploit the scarce wireless resources under such instable channel conditions. Rate adaptation consists of assessing the wireless channel conditions and selecting ^[1].

The ZigBee standard is developed by the ZigBee Alliance, which has hundreds of member companies, from the semiconductor industry and software developers to Original Equipment Manufacturers (OEMs) and installers ^[2]. ZigBee provides a low cost, low power, fixed low data rate solution ideally suited for Personal Area Network (PAN) for control applications in telecommunication devices. The low cost allows the technology to be widely deployed in wireless control and monitoring applications. Low power-usage allows longer life with smaller batteries. The standard specifies that a compliant system will operate in three license-free bands: 2.45 GHz (250 kbps maximum data rate), 868 MHz (20 kbps), and 915 MHz (40 kbps). The transmission range is 10 to 100 meters based on the environment ^[3]. The PHY layer functionalities are the modulation process of IEEE802.15.4, activation and deactivation of the radio transceiver, energy detection within the current channel, link quality indication for received packets, clear channel assessment for CSMA-CA, Channel frequency selection and data transmission and reception ^[4].

If compare with Bluetooth because is closed technology to ZigBee, one of the main advantage of ZigBee it has response time about 3 millisecond its more suitable for critical applications while Bluetooth required about 3 second to joined, ZigBee focused on control and automation this need high reliability by using Direct Sequence Spread Spectrum (DSSS) technology, Bluetooth is focused on connectivity between laptops, phones. ZigBee can support a large number of device and longer range between than Bluetooth ,The battery Not rechargeable (one reason batteries will last for up to 10 years) In low power standby mode, two AA batteries can be used for 6 months to 2 years. This is an outstanding advantage of ZigBee technology [5,6].

Rate adaptation for IEEE802.11 networks has been studied at length through the last decade. In [7], the authors propose an adaptive channel allocation scheme, which allows nodes experiencing significant interference to switch to new frequency channels with less congestion. To minimize the effect of Wi-Fi interference in 802.15.4 WSNs, an interference detection and avoidance mechanism is proposed which selects the radio channel that is least likely to have interference [8]. In practice wireless transceivers are always half duplex. Hence the IEEE 802.15.4 devices require a finite amount of time to switch between transmission and reception, this time is denoted by a Turnaround Time in the standard and is equal to 12 symbol times [9].

This paper attempt to deliver high data rate based on channel quality with maintain the reasonable Bit Error Rate (BER) by modifying the 802.15.4 modulation process while maintain the same capacity of RF front end.

2. ZIGBEE/IEEE 802.15.4

The ZigBee protocol stack is composed of four main layers: the Application Layer (APL), the Network (NWK) layer, the Medium Access Control (MAC) layer, and the Physical Layer (PHY). While the NWK and APL layers of the ZigBee protocol are defined by the ZigBee specification, the PHY and MAC layers are defined by the IEEE 802.15.4 standard. The functionalities of network layer include maintenance, providing and organizing routing over a multi hop network, route discovery [10]. The IEEE 802.15.4 architecture is defined in terms of a number of blocks in order to simplify the standard. These blocks are called layers. Each layer is responsible for one part of the standard and offers services to the higher layers. **Figure.(1)** shows these blocks in a graphical representation [4].

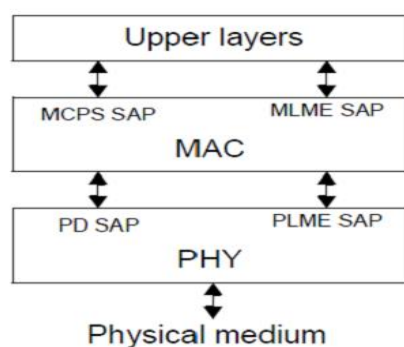


Fig.(1): The IEEE 802.15.4 architecture

The upper layers, shown in **Figure.(1)**, consist of a network layer, which provides network configuration, manipulation, and message routing, and an application layer, which provides the intended function of the device.

IEEE 802.15.4 PHY supports unlicensed Industrial, Scientific, and Medical (ISM) Radio Frequency (RF) bands including 868 MHz, 915 MHz, and 2.4 GHz [11]. ZigBee communication uses DSSS. In 915 MHz 102- MHz wide channels are available. The Binary Phase-Shift Keying (BPSK) PHY shall employ DSSS with BPSK used for chip modulation and differential encoding used for data symbol encoding. Each bit in the PHY Protocol Data Unit (PPDU) shall be processed through the differential encoding, bit-to-chip mapping, and modulation functions in octet-wise order, beginning with the Preamble field and ending with the last octet of the PHY Service Data Unit (PSDU), within each octet, the Least Significant Bit (LSB), b0, is processed first and the Most Significant Bit (MSB), b7, is processed last 4]. In the IEEE 802.15.4 Differential (DBPSK) system, the transmitter maps the symbol ‘0’ to a 15-bit long Pseudo Noise (PN) sequence and the symbol ‘1’ to a different 15-bit sequence. The PN sequence is input into the modulator before transmission [4]. The standard modulation process in IEEE 802.15.4 (DBPSK 915 MHz) is shown in **Figure.(2)**.

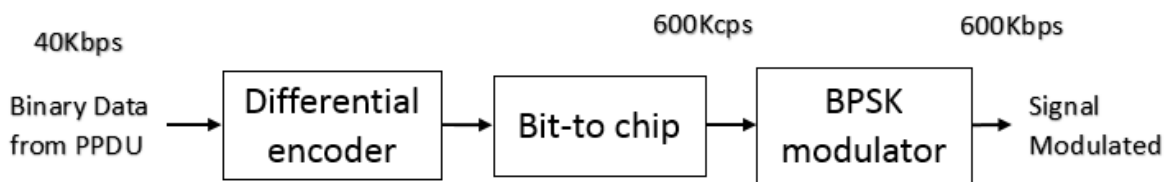


Fig.(2) : The modulation process in 802.15.4(DBPSK915 MHz) [4].

Differential encoding is the modulo-2 addition (Exclusive OR) of a raw data bit with the previous encoded bit.

This is performed by the transmitter and can be described by:

$$E_n = R_n \oplus E_{n-1} \dots \dots \dots (1)$$

Where

R_n is the raw data bit being encoded

E_n is the corresponding differentially encoded bit

E_{n-1} is the previous differentially encoded bit

\oplus is Exclusive OR of a raw data bit with the previous encoded bit.

For each packet transmitted, R_1 is the first raw data bit to be encoded and E_0 is assumed to be zero. Conversely, the decoding process, as performed at the receiver, can be described by:

$$R_n = E_n \oplus E_{n-1} \dots \dots \dots (2)$$

For each packet received, E_1 is the first bit to be decoded, and E_0 is assumed to be zero ^[4].

The bit to chip shows in the table 1, the second bits sequences are inverse of the first bits sequence this inverse give the sequence orthogonally. The DSSS help improve performance of receivers in a multipath environment ^[2].

Table 1: Bit to Chip Mapping ^[4].

Input bits	Chip values (c ₀ c ₁ ... c ₁₄)
0	1 1 1 1 0 1 0 1 1 0 0 1 0 0 0
1	0 0 0 0 1 0 1 0 0 1 1 0 1 1 1

In BPSK modulation the chip sequences are modulated onto the carrier using BPSK with raised cosine pulse shaping (roll-off factor = 1) where a chip value of one corresponds to a positive pulse and a chip value of zero corresponds to a negative pulse. In the Pulse shape the raised cosine pulse shape (roll-off factor = 1) used to represent each baseband chip is described by ^[4]:

$$p(t) = \begin{pmatrix} \frac{\sin \frac{\pi t}{T_c}}{\frac{\pi t}{T_c}} & \frac{\cos \frac{\pi t}{T_c}}{1 - \frac{4t^2}{T_c^2}}, & t \neq 0 \\ 1, & t = 0 \end{pmatrix} \dots \dots (3)$$

3. The proposal system model

In advance applications large data transfer this cause the high traffic load in WSN. Rate adaptation is the determination of the optimal data transmission rate most appropriate for current wireless channel conditions. There are two different ways to the data rate, first by adapting the modulation order from 2-PSK to 8-PSK this scheme required to modify the RF font end (analog part) this will lead to more complexity to ZigBee transceiver. The second scheme by modify the Bit-to-Chip code length. In this paper, we investigate an adaptive code length depend on channel environment to increase the data transmission efficiency. So, the DSSS length is adjustable, it is possible to employ a shorter DSSS code to increase the data rate in higher SNR scenarios, while decreasing data rate in low SNR. **Figure.(3)** illustrates the scenario of the adaptive DSSS. The output of spreading stage is 600kcps, so the data rate of the RF-font end of the device is fixed to 600Kbps which the same value before adaptive, this allow

to maintain the same capability and capacity of RF-front end. The adaptive data rate calculations for ISM Band 915 MHZ are:-

First data rate (Low SNR) = 40Kbps \times 15bit PN = 600 Chip Per Second (cps)

Second data rate (Medium SNR) = 75Kbps \times 8 bit PN = 600 cps

Third data rate (High SNR) = 150Kbps \times 4 bit PN = 600 cps

So that the system will select one of code length from previous three types of bit-to chip codes depending on SNR channel states.

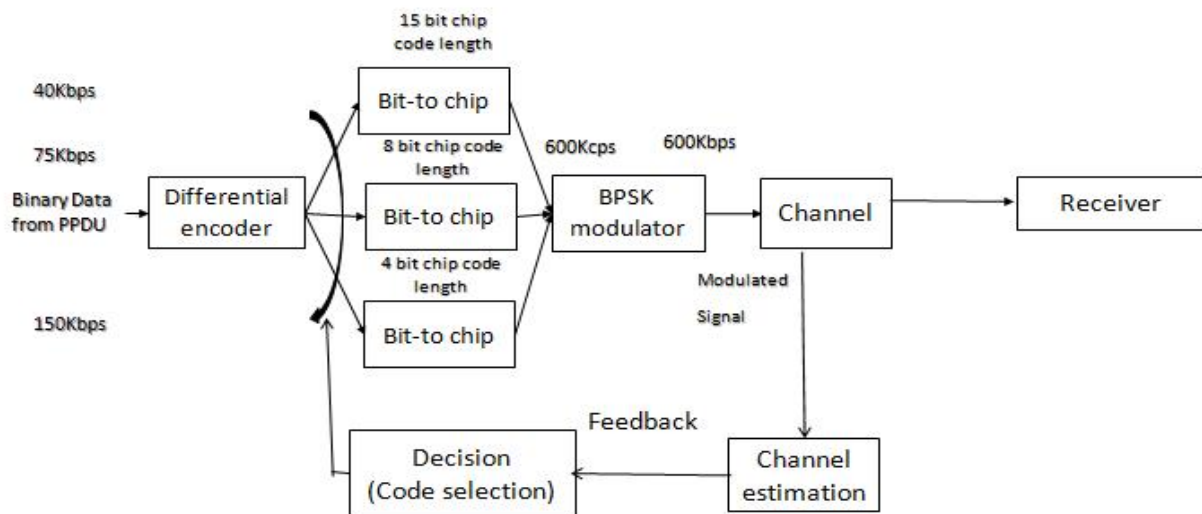


Fig. (3) : The proposal system model

Rate adaptation provides a critical mechanism for wireless systems to trade between physical layer data rate and robustness to maximize the performance ^[12]. In this work we used three types of code length 15 bits for data rate 40 Kbps, 8 bit for 75 Kbps and 8 for 150Kbps. In adaptive code length, the accuracy of estimation channel is the most important to choose mode type. The channel estimation in this work depending on SNR that needed to maintain BER below 1 for 1000 chips. And how is the process of testing if the channel is outside interest of this research, the important thing is to send an information on the status of the channel in the form of feedback to three levels (bad case, middle, and good condition), which requires to sending of two bits only about the level of SNR and therefore the decision is made for the length of the code required.

4. SIMULATION RESULTS.

The modulation process of IEEE 802.15.4 (915 MHz, DBPSK mode) has been simulated in Matlab R2012b. The channel model used in this paper is the impulse response (channel LOS Residential (CM1) [13], and Additive White Gaussian Noise (AWGN). **Figure.(4)** shows the BER for standard DBPSK system with 15 bits DSSS, the BER continually decreases with increasing SNR and the BER is close to zero for all SNR values after 23dB because the number of bits corrupted in the received signal did not affect the despreading process. This result is consistent with the expectation that a higher SNR results in a lower bit error rate.

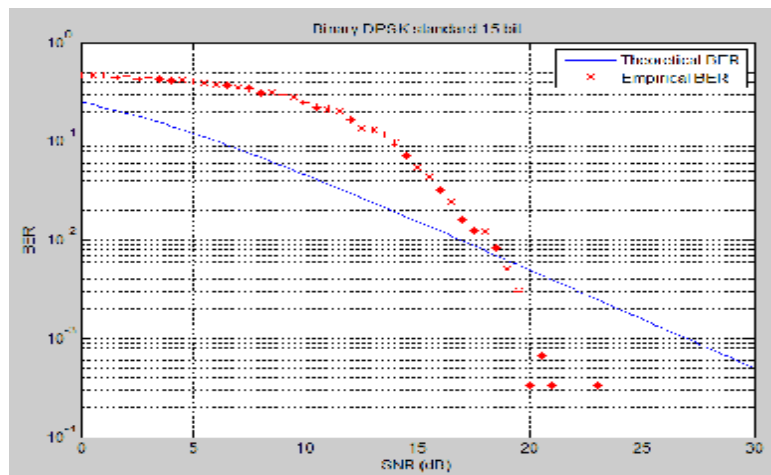


Fig. (4) : BPSK for system (AWGN and channel model)

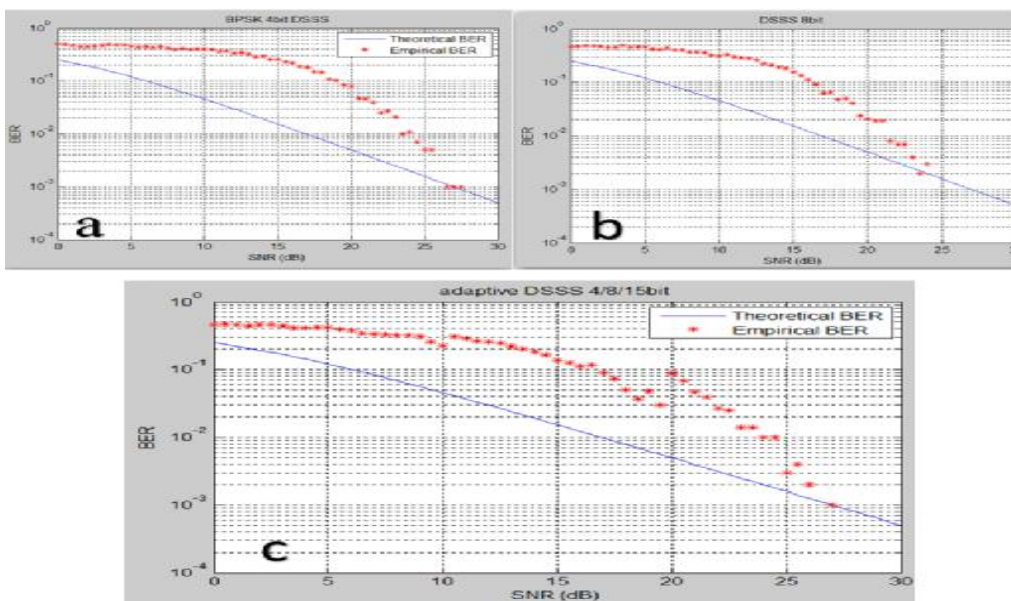


Fig. (5) : (a) using 4 bits DSSS (b) 8 bits DSSS (c) adaptive throughput using three chip code length

Figure.(5) (a) and (b) shows the BER for standard DBPSK system with 4 and 8 bits DSSS are close to zero for all SNR values after 28dB and 25dB they are allowed to increase the data rate to 150Kbps and 75Kbps Respectively.

Figure.(5) (c) shows the result of using a system model (adaptive data rate according to three thresholds using three chip code length depending on SNR, the SNR divided into three range first one below 10 SNR scale (Lowest SNR lowest data rate) using chip code length 15 bits and the second between 10 and 20 scales (Medium SNR and medium data rate) using chip code length 8 bits and the third above 30 SNR (Highest SNR and highest data rate) using a 4 chip code length. This adaptive allow to minimize the chip code and maximize the data (throughput) while maintaining the BER for three range nearly equal and below the allowable BER for IEEE 802.15.4.

Table 2: summary

DSSS length (bits)	Data rate(Kbps)	SNR(dB)	BER
4	150	5	0.4568
8	75	5	0.4293
15	40	5	0.4015
So the selected code length is 15	40	5	0.4031
4	150	10	0.3802
8	75	10	0.3283
15	40	10	0.02457
So the selected code length is 15	40	10	0.2376
4	150	15	0.2589
8	75	15	0.1428
15	40	15	0.05435
So the selected code length is 8	75	15	0.15
4	150	20	0.07923
8	75	20	0.0208
15	40	20	0.000333
So the selected code length is 8	75	20	0.07843
4	150	25	0.003601
8	75	25	0.0006001
15	40	25	0
So the selected code length is 4	150	25	0.006602

From the previous results it can describe the situation in numbers as shown in table 2 we can investigate that the system and adaptive data rate for BER below 0.4031 the switching between modes is based on SNR.

5. CONCLUSION

We have investigated the performances of IEEE 802.15.4 and its two high rate with data rates of 75 kbps and 150Kbps, using the IEEE 802.15.6 CM1 channel model “real channel” and AWGN. In many deployments the wireless link may provide far higher SNR than required and therefore it is unnecessary spreading and it decreases the data rate. Higher throughput performance can be achieved with a high SNR while low data rate with low SNR. The low data rate will prolong the transmission period of packets, which reduces the throughput and wastes energy. The advantage of this system is good for High traffic load in advance control application that need high data rate, flexibilities, and robust. The power consumption is independent of spreading mode, in theoretical the packet can be transmitted faster which leads to the less power consumption due to the duration of packet transfer that make a device on less than on double duration this will prolong the transmission period of packets, which reduces wastes energy and the throughput.

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