Zigbee Baseband Hardware Modeling for Internet of Things IEEE 802.15.4 Compliance

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***Abstract*—This paper is modeling the hardware for baseband communication in Internet of things (IoT) Chip with processor 32 bit RISCx. Based on IEEE 802.15.4 about Wireless Personal Area Networks (WPANs), for zigbee with frequency 2450 MHz we have to used Direct Sequence Spreading Spectrum (DSSS) and for the communication modulation we have to used Offset Quadrature Phase Shift Keying (O-QPSK). In this hardware modeling we used the AWGN (Additive White Gaussian Noise) and Rayleigh fading as part of non ideal system in the channel. In receiver we used costas loop to recover the carrier. as it is a hardware modeling, we compare Bit Error Rate (BER) between 6 bit and 8 bit. There is a big BER difference between the 6 bit system and the 8 bit system. 8 bit system has a better bit error rate but the chip area that it used is bigger. Contrary for the 6 bit, the chip area used is smaller but the bit error rate is worse than the 8 bit.**

Keywords—component; DSSS, AWGN, OQPSK, Zigbee, WPANs.

I. Introduction

IoT or Internet of things is not in the future anymore. Nowadays, there are so many device connect to one another. IoT system consists of 4 main parts, End Node, Gateway, Cloud and User Interface as you can see in the figure 1. End Node device connect to cloud system via gateway. End node also connects to controlled or monitored device using baseband communication.

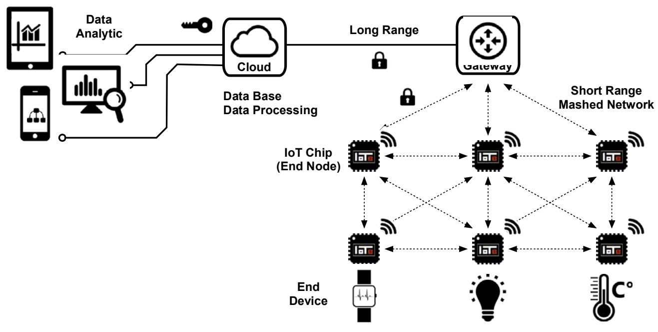

Fig. 1 Internet of things system

We are conducted the experiment about SoC (System on Chip) for IoT system that name IoTB®. This design focuses on the end node module. The main processor in IoTB® is 32 bit RISCx Processor. This IoTB® module is powered with short range communication that can connect using mesh or star topology network. Based on IEEE 802.15.4 standard, zigbee is one of the most simple and easiest compare to another WPANs like Bluetooth or wifi.

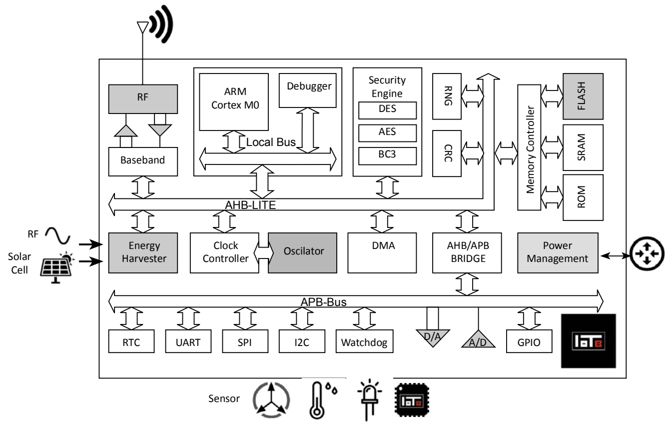

Fig. 2 SoC of IoTB®

Zigbee is a wireless communication network protocol that convey information with relatively short distance, low power and also low cost [5]. Zigbee and Wireless Personal Area Networks are used to transfer short message like command information, so the data rate is small. Nowadays zigbee has been used in many application in daily life, such as wireless switch for lamp, wireless temperature measurement and another consument device that using radio communication with low range. Because zigbee is low cost and likely easy to use, zigbee is widely used in IoT (Internet of things).

In real time environment, wireless communication can be degraded in several ways, including multipath interference, interference from other users, broadband noise, narrow-band interference and changing (fading) channel gains [4]. Because of that interference, the carrier in transmitter and receiver can be different. So in the receiver we have to add the carrier recovery.

For the transmitter, this paper follow IEEE standard 805.15.4, operated in frequency 2450 MHz. The digital information spread using direct sequence spreading spectrum (DSSS). After that the signal is converted to analog by half sine pulse shaping. To simulate the noise in the channel we add the

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additive white Gaussian noise (AWGN). In the Receiver we used modified costas loop as the carrier recovery. This paper is analyzed by calculating bit error rate (BER) values in different bit size, e.g. 16 bit, 32 bit and 64 bit.

This Paper is organized as follow, section II explain about transmitter of this model, section III explain the channel and all of the interference such as AWGN and Rayleigh fading. Section IV explain the Receiver Model, section V describe about the performance and the analysis of the design, and section VI is the conclusion of this modeling hardware for baseband communication for IoTB®.

II. TRANSMITTER

IEEE standard 805.15.4 is describing about physical layer (PHY) for low rate wireless personal area networks (LR-WPANs). Zigbee is operated at frequency 868MHz in Europe, 916 MHz in USA and 2450 MHz in another country such as Indonesia.

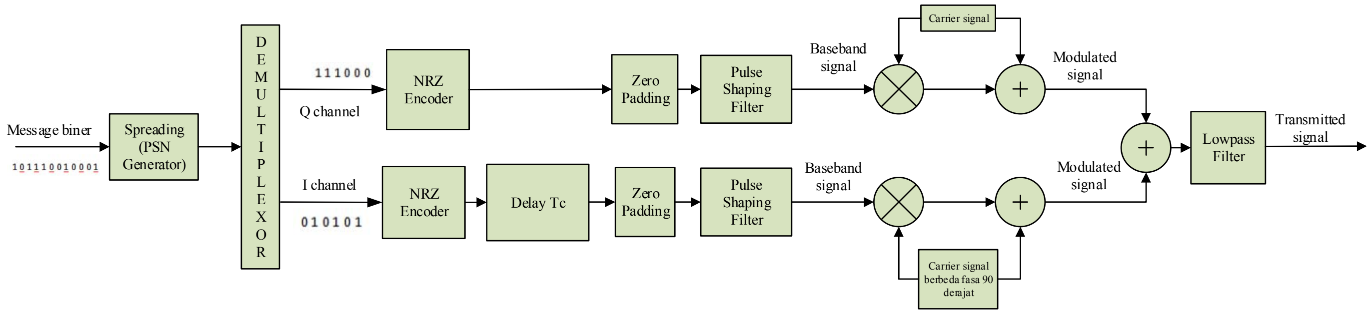


Fig 3 Transmission Diagram

So based on IEEE Standard 805.15.4 we will build zigbee at frequency 2450MHz. the transmitter for zigbee in 2450 MHz is explained in that standard and have to follow this rule.

A. *Data Rate*

Data rate for frequency 2450 MHz is fixed in 250 Kbps.

B. *Spreading*

Spreading technique uses DSSS (Direct Sequence Spectrum Spreading). O-QPSK is using 16-ary-orthogonal, each symbol is 4 bits information. Those 4 bits are used to select 16 orthogonal pseudo random noise (PN) sequence that contain 32 random number.

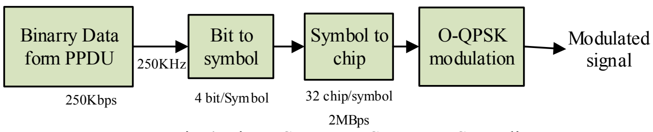


Fig 4 Direct Sequence Spectrum Spreading

After the symbol is mapped, the chip rate changes. At first, the bit rate is 250 Kbps and after mapping to chip value the chip rate is 2 Mbps.

Chip rate equation,

$$Chip\ rate = 250.10^3 \frac{bit}{s}\ x\ 4 \frac{bit}{sym} x\ 32 \frac{ChipValue}{sym}$$
$$= 2.10^6 \frac{bit}{s}$$

The pseudo random number is defined in the standard. So it is not a random number but a fix number to map the symbol into 32 bit chip value. In the chip transmission, the least significant chip, c_0 is transmitted first.

TABLE I. SYMBOL TO CHIP MAPPING FOR FREQUENCY 2450 MHZ

Data Symbol	**Chip Values (c_0, c_1,..........c_{30},c_{31})**
0000	11011001110000110101001000101110
0001	11101101100111000011010100100010
0010	00101110110110011100001101010010
0011	00100010111011011001110000110101
0100	01010010001011101101100111000011
0101	00110101001000101110110110011100
0110	11000011010100100010111011011001
0111	10011100001101010010001011101101
1000	10001100100101100000011101111011
1001	10111000110010010110000001110111
1010	01111011100011001001011000000111
1011	01110111101110001100100101100000
1100	00000111011110111000110010010110
1101	01100000011101111011100011001001
1110	10010110000001110111101110001100
1111	11001001011000000111011110111000

C. *Modulation*

The modulation for frequency 2450 MHz is must be O-QPSK (Offset Quadrature Phase Shift Keying).

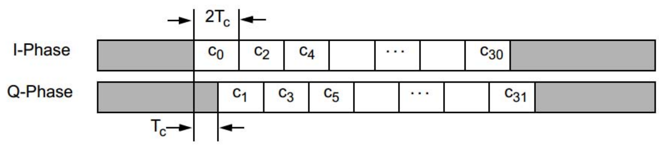


Fig 5 Offset Quadrature Phase Shift Keying

Tc = Chip value Periode

O-QPSK is a variant of phase shift keying modulation using 4 different values of the phase to transmit. 4 different values achieve by 2 bits of binary input.

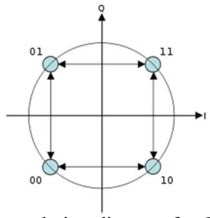


Fig 6 constelation diagram for O-QPSK

D. Pulse Shapping

Each chip value is reconstructed to analog signal shape using half sine pulse. For frequency 2450 MHz pulse shapping must be half sine pulse using this equation bellow.

$$p(t) = \begin{cases} \sin\left(\pi \dfrac{t}{T_c}\right), & 0 < t < T_c \\ 0, & else \end{cases}$$

In this paper we use the zero padding 5, which means every 5 zero there is 1 chip value bit. This padding is useful to prepare the signal before the pulse shaping process.

III. Channel

In the real world, the communication between transmitter and receiver is not fully ideal. The path in between can be degraded in several ways.

A. Noise

The signal can be interfered by a noise. One of the basic noise model is AWGN (Additive White Gaussian Noise). This noise can mimic the effect of many random processes that occur in the nature. AWGN is white noise following the normal distribution, Gaussian distribution. White noise itself means that this noise has uniform power accros the frequency band. White noise can be reduced using filter.

B. Rayleigh Fading

Fading is where the signal frequency response changes slowly over time. This may be caused by the change of transmission path, like a reflection from a cloud might be disappear when the cloud is move, additional reflection can appear when a truck moves into a narrow city street and etc. Rayleigh fading models assume that the magnitude of the signal will vary randomly, according to a Rayleigh distribution.

C. Hardware Modeling

In this research, we use matlab to modeling the hardware. In matlab the calculation is all in floating point. But in the hardware, the bit is limited. So the model has to quantize into a fixed point. In this model we used 8 bits fixed point and 6 bits fixed point.

IV. Receiver Design

IEEE 802.15.4 standard mostly explained about the transmitter. In this design we used costas loop as a carrier recovery. Costas loop is a phase-locked loop (PLL) which is used for frequency recovery from suppressed carrier modulation signals. Costas loop is using this equation

$$\theta[k+1] = \theta[k] - \mu\, LPF\{r(kT_s)\cos(2\pi f_0 kT_s + \theta[k])\} LPF\{r(kT_s)\sin(2\pi f_0 kT_s + \theta[k])\}$$

We have to prepare the received signal before it is proceed in costas loop. A common scheme uses a squaring nonlinearity follower by a bandpass filter. When the received signal r(t) square

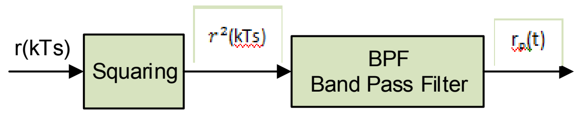


Fig 7 Preparation before the costas loop

$$r^2(t) = s^2(t)cos^2(2\pi f_0 t + \emptyset)$$

This can be rewritten using the identity

$$2cos^2(x) = 1 + \cos(2x)$$

So,

$$r^2(t) = \left(\frac{1}{2}\right) s^2(t)[1 + cos(4\pi f_0 t + 2\emptyset)]$$

$s^2(t)$ is the sum of its (positive) average value and the variation about the average.

$$s^2(t) = s_{avg}^2 + v(t)$$

$$r^2(t) = \left(\frac{1}{2}\right)[s_{avg}^2 + v(t) + s_{avg}^2 cos(4\pi f_0 t + 2\emptyset) + v(t)cos(4\pi f_0 t + 2\emptyset)]$$

The output of the band pass filter is approximately,

$$r_p(t) = BPF\{r^2(t)\} \approx \frac{1}{2} s_{avg}^2 cos\left(4\pi f_0 t + 2\emptyset + \varphi\right)$$

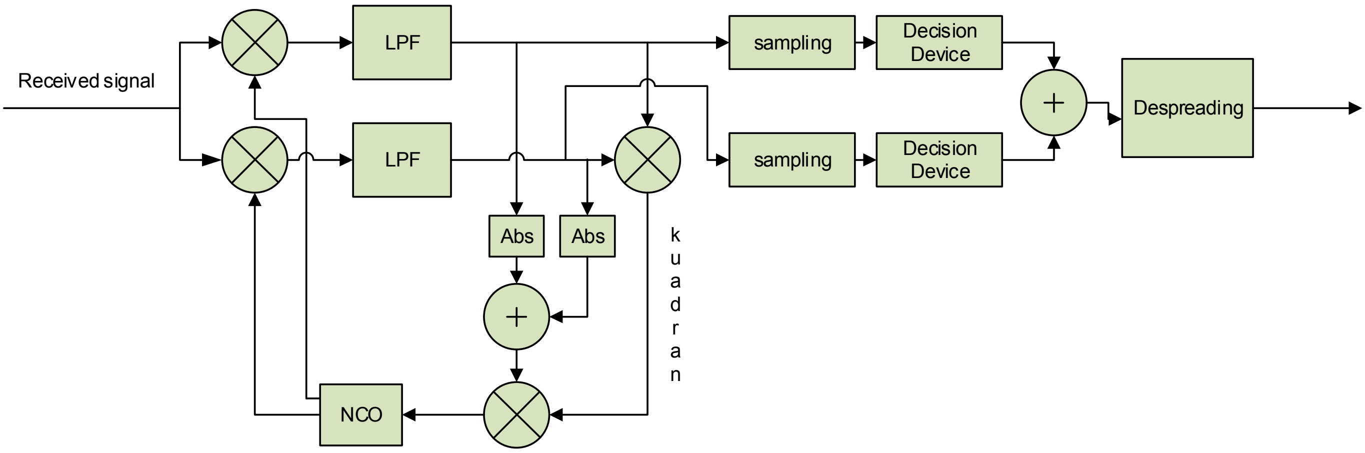


Fig. 8 Receiver with costas loop

After the carrier is recovered then the analog signal is sampling to digital. In this sampling we choose frequency sampling 5 times of the sampling frequency. We used hard decision encoder to decided the final receive bit stream. hard decision encoding use hamming method. In the hamming method, we search the nearest values that represent the symbol. Since in this experiment the symbol is spreading by PSN DSSS, so the hamming will follow the PSN DSSS.

V. Measuring The Performance

At first we are generating the symbol that will be sent, we use some random number digital between 0 and 1 as you can see in the figure 9. Then the message is spreading so the data rate become 2 MBps (figure 10).

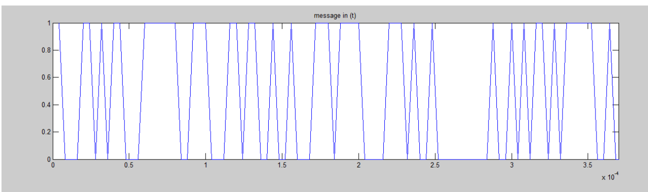


Fig. 9 Message bit stream

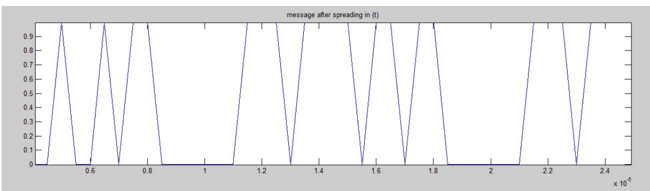


Fig. 10 Message After spreading

This message divide into 2 bit symbol, the odd symbol become the MSB (Most Significant Bit) and the even symbol become the LSB (Least Significant Bit). In the model we have to multiplex this 2 bits symbol. The MSB is become the real part or In-Phase and the LSB become the imaginer Part or Quadrature-phase. Then that message is converted using NRZ (non return zero) so the message will not contain 0 message, this is to prevent the confusion whether there is no message or the message just simply 0. The 0 message will become -1. And then we apply half pulse shaping filter to it. After the signal is going trough pulse shaping the signal called baseband signal.

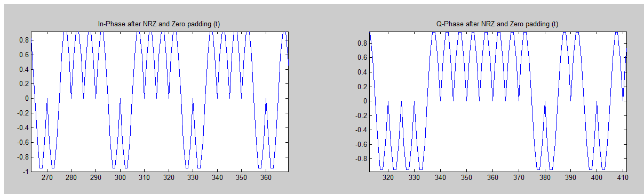
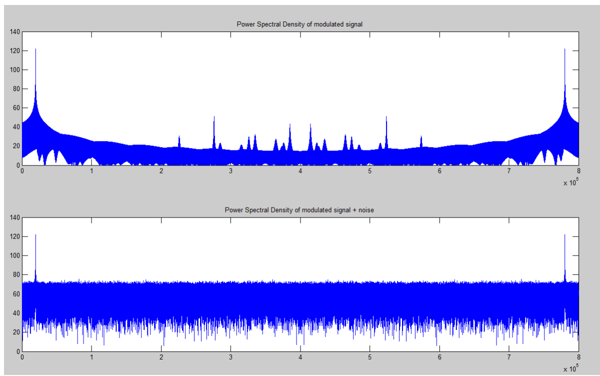


Fig. 11 baseband signal

That message is modulated using sin and cos signal with carrier frequency 2450 MHz.



Normalize frequency (f-fc)Tc Hz

Fig. 12 Power Spectral Density
(a) Modulated Signal
(b) modulated signal + AWGN

After the signal is modulated (fig 12 (a)), the message is added with AWGN (Additive White Gaussian Noise). And fading the channel so the gain change and there is some delay to it. Rayleigh fading provide in matlab function following the Rayleigh distribution. The constellation diagram is not precise in the symbol.

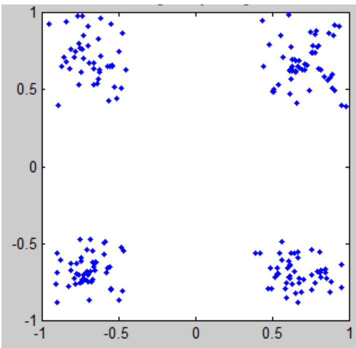


Fig 13 constelation diagram after add rayleigh fading in the channel

In the receiver, we used the costas loop so you can see the phase is changing and approaching the desire phase π/4, 3π/4, 5π/4, 7π/4. The result can be seen in the picture bellow.

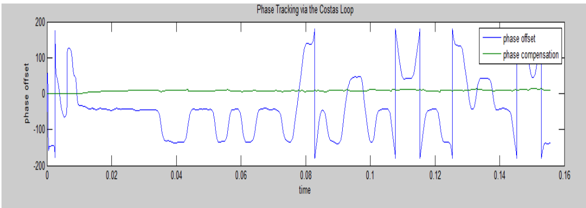


Fig 14 Phase Tracking Via Costas Loop

After the received message proceed in the receiver. The received message is translated into this symbol as you can see in the constellation diagram.

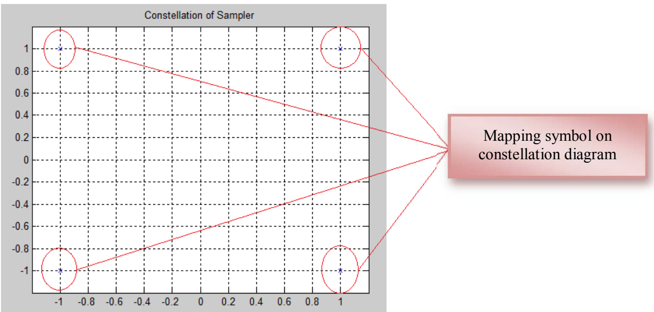


Fig 15 Constellation Diagram in after costas loop

In this research we are modeling the 8 bit and 6 bit and compare the bit error rate between the 2 quantization.

The result is very obvious that the 8 bit quantization have a better BER compare to 6 bit.

VI. Conclusion and Future Work

We have successfully modeling Zigbee baseband based on IEEE standard on WPANs 802.15.4 which is using DSSS spreading, half sine pulse shaping, O-QPSK modulation. In receiver, we have successfully recovered the carrier frequency using the costas loop. In the phase tracking plot, it can be seen that the phase is approaching to π/4, 3π/4, 5π/4, 7π/4. We have successfully modeling the channel with noise interference with AWGN and modeling the fading channel using Rayleigh fading. Comparing the result of 6 bit BER and 8 bit BER, There is a trade off for the 2 systems, it is a big BER difference between the 6 bit system and the 8 bit system. 8 bit system has a better bit error rate but the chip area that it used is bigger. Contrary for the 6 bit, the chip area used is smaller but the bit error rate is worse than the 8 bit.

For now we just model the hardware, in the next we will implement this 6 bit zigbee baseband hardware on the IoTB® Chip.

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