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Evaluating The IEEE 802.15.4a UWB Physical Layer for WSN Applications

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***Abstract*—Ultra wideband radio (UWB) is a promising technology that offers exceptional data rates for short range communication. This paper presents the analysis of the IEEE 802.15.4a UWB physical layer (PHY), a novel short range wireless communication technology, for wireless sensor network (WSN) applications. We analysed and compared the performance of the UWB PHY using the MIXIM framework for a discrete event based simulator called OMNeT++. In this context, we present the simulation and implementation of line of sight (LOS) and non line of sight (NLOS) channel models with a variety of configurations such as data rates, bandwidth and forward error correction. An analysis on bit error rate (BER) over distance will be discussed in order to evaluate the channels performance. The results will serve as a base for future studies on deploying IEEE 802.15.4a based sensor networks with specific characteristics.**

***Keywords*—UWB, IEEE802.15.4a, OMNet++, MIXIM, LOS, NLOS, BER**

I. Introduction

Wireless sensor networks (WSNs), consist of tiny sensor nodes, which generally stationary and equipped with limited capacity batteries. Since the sensors act as data generators and network relays, its consume energy. The major challenge is to reduce energy consumption without disconnected from networks as long as possible. Thus, UWB with IEEE 802.15.4a standard had proven to provide powerful advantages with respect to vitality communications with variable data rate over short distances, energy efficiency and location accuracy.

Hardware testing for UWB is very expensive. Simulation is one of the methods that can save the testing cost. Simulation is the verification state by using the model that been constructed in design state. Simulation is cheaper than performing tests using real model or prototype and it is remarkably important to design a good simulation model based on specifications. In this research, network simulator tool (OMNET++) is used to perform the capabilities of UWB technologies over WSNs.

Many research has been done in recent years on IEEE 802.15.4 standard and ZigBee. Since IEEE 802.15.4a is amendment and comply with UWB PHY which is clearly better than ZigBee in LR-WPAN, this research is providing an investigation and analysis on low rate ultra wideband as the communication medium for WSNs.

A comprehensive survey of literature indicates that the UWB appears to be a promising technology for future wireless communication technology due to its significant characteristics [1]-[3]. Furthermore, a research has been done to evaluate performance of IEEE 802.15.4a models based on MATLAB. [4]. A comparison has been performed between three well known WSNs simulator – OMNet++ , NS2 and OPNet [5]. Results showed OMNet++ is better than the other simulator in terms of available protocols and models, network topology and hierarchical models, programming model and simulation library and debugging and tracking.

This paper presents the simulation and investigation of LOS and NLOS channel models with a variety configurations in term of data rates, bandwidth, and forward error correction through MIXIM-OMNet++ framework. An analysis on distance, BER and the impacts of the Reed Solomon coder for

various channel and timing parameters Ghassemzadeh [6] and IEEE 802.15.4a path loss model [7]. The result should provide an excellent stepping stone to anyone who requires UWB physical layer specified by IEEE 802.15.4a standard.

The structures of this paper are as follows. Discussion on the basic principle of UWB technology are presented in Section 2. It describes the definition of regulation, advantages and applications. Section III discusses the general research methodology and key parameters of IEEE Std 802.15.4a. Section IV presents and analyses the simulation result and conclusion is describe in Section V.

II. Principles of UWB

UWB technologies have attracted high interest in the wireless society. UWB signals are formally defined as having fractional bandwidth (BW) larger than 20% or BW larger than 500 MHz[8]. This is much wider than any existing communication system. As the trivia, fractional BW for narrow band is less than 1%. Fractional bandwidth B_f is defined as

$$B_f = 2\frac{(f_H - f_L)}{(f_H + f_L)} \quad (1)$$

where f_H is the upper frequency of the -10dB emission point and f_L is the lower frequency of the -10dB emission input. Moreover, the transmission centre frequency f_c is defined as the average of this cut-off points,

$$f_c = \frac{(f_H + f_L)}{2} \quad (2)$$

Emission between 3.1 GHz to 10.6 GHz unlicensed frequency band with total of 7500 MHz spectrum band, while specifying a set of rules to control harmful interference from UWB devices. Emission limits are given in terms of effective isotropic radiated power (EIRP). According to the FCC regulations, the maximum EIRP should not exceed -41.3 dBm.

UWB communications system offer many advantages over narrowband technology. And major advantage is improved channel capacity. This is satisfy the Shannon's channel capacity formula whereby capacity increasing proportionally with BW. function of BW (bandwidth).

$$C = BW \log_2(1 + SNR) \quad (3)$$

where C is channel capacity (bits/sec), BW is channel bandwidth (Hz) and SNR is signal to noise ratio.

UWB has a huge potential in wireless platforms that support a variety applications such as [1]-[3] :

- Environmental monitoring (e.g., traffic, habitat, security)
- Industrial sensing and diagnostics (e.g., appliances, factory, supply
- Infrastructure protection (e.g., power grids, water distribution)
- Battlefield awareness (e.g., multitarget tracking)
- Context-aware computing (e.g., intelligent home, responsive environment)

III. Design Methodology

The project started with the project concept. Next step is verification on the concept of the project by doing case study and literature review. After that, the problem will be analysed on objectives, questions and hypotheses.

In designing stage, we need to consider the important parameters of UWB systems. First, we must know the global regulation and restrictions on UWB that covered on absolute bandwidth, relative bandwidth, fractional bandwidth and emission limit. Next parameter is UWB channel or propagation channels. We focused on stochastic approached in this research and two path loss models have been identified to be tested which are Ghassemzadeh path loss model and IEEE802.15.4a path loss model.

The IEEE 802.15.4a UWB specifications also need to consider in designing stage. We need to understand the PHY layer design of 802.15.4a. In line with international regulations and restrictions, a frequency band plan should be tailored Others consideration are physical service data unit (PSDU) timing parameters, bandwidth, bit rate, preamble code length and timing parameters, mean pulse repetition frequency (PRF), start of frame delimiter (SFD) and forward error correction [9].

Once the UWB system parameters has been confirm, it will be simulate with MiXiM-UWB framework under OMNeT++ simulator. Based on the simulation results, the distance, bit error rate (BER) and throughput for the various channels will be analyse. This research also requires the impact of RS coder analysis. Results will be compared between various channels and coder performance. We also analyse the bit rate and bandwidth effects.

A. IEEE802.15.4A UWB PHY

There are three different bands groups according to IEEE 802.15.4a: Sub GHz band, low-band and high-band. The groups include 16 channels with 499.2MHz. Important characteristics are taken into consideration to evaluate UWB PHY performance. The characteristics are [9]:

- Bandwidth (499.2 MHz , 1081.6 MHz, 1331.1 MHz and 1354.9 MHz)
- Frequency channel (Channel 3 , 7 , 11 and 15)
- Data rate that assigned in standard (0.11 Mbps , 0.85 Mbps, 6.8 Mbps and 27.4 Mbps)
- Mean pulse repetition frequency (3.9 MHz , 15.6 MHz and 62.4 MHz)

- Centre frequency (4492.8 MHz , 7488.0 MHz and 9984.0 MHz)
- Forward error correction (Reed Solomon coder)

Data frame structure of UWB PHY is shown in figure 1. Therefore, we need to work with timing parameters and preamble code due to various value of the above characteristics. The details of timing parameters will be provided in section C.

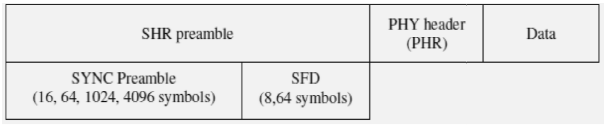

Figure 1. UWB PHY frame structure

Each PAN operating on one of the UWB PHY channels is identified by a preamble code. The preamble code is used to construct symbols that constitute the SYNC portion synchronisation header (SHR) preamble. The UWB PHY supports two lengths of preamble code: a length of 31 code and an optional length 127 code. The length 31 code sequences has been decided in this research shown in Table I.

TABLE I. LENGTH 31 TERNARY CODES

Code index	*Code sequence*	CH number
1	-0000+0-0+++0+-000+-+++00-+0-00	0,1,8,12
2	0+0+-0+0+000-++0-+---00+00++000	0,1,8,12
3	-+0++000-+-++00++0+00-0000-0+0-	2,5,9,13
4	0000+-00-00-++++0+-+000+0-0++0-	2,5,9,13
5	-0+-00+++-+000-+0+++0-0+0000-00	3,6,10,14
6	++00+00---+-0++-000+0+0-+0+0000	3,6,10,14
7	+0000+-0+0+00+000+0++---0-+00-+	4,7,11,15
8	0+00-0-0++0000--+00-+0++-++0+00	4,7,11,15

The path loss in dB at distance *d* is modelled as follows:

$$PL(d) = PL_o + 10\gamma \log\left(\frac{d}{d_o}\right) + S(d), d \geq 0 \qquad (4)$$

where the PL_o is the intercept point, is the path loss at the d = 1m , γ is the path loss exponent and S is log-normal shadow fading. Two types of standardized environments have been evaluated in order to analyse the UWB PHY performance. The environments are Ghassemzadeh [6] and IEEE802.15.4a channel models [7].

Ghassemzadeh statistical path loss model has been measured for residential environments and categorised as LOS and NLOS. The model is based on 300,000, 1.25 GHz wide UWB frequency responses taken at 5 GHz in 23 homes. Parameters for both environments are shown in Table II.

A channel modelling subgroup was proposed during the development of the IEEE802.15.4a standard. It defined several channel models of standardization proposals. Summary of the IEEE802.15.4a channel models shown in Table III. The details parameters of each channel models can be found in [7] and for this research we only simulate channel model CM1,CM2,CM5 and CM6. Key parameters of IEEE802.15.4a are shown in Table IV and Table V respectively.

TABLE II. GHASSEMZADEH STATISTICAL CHANNEL MODELS

Parameter	Description	LOS		NLOS	
		Mean	Std. Dev.	Mean	Std. Dev
PL_0	Path loss (dB)	47	NA	51	NA
γ	Path loss exponent	1.7	0.3	3.5	0.97
σ	Standard deviation	1.6	0.5	2.7	0.98

TABLE III. IEEE802.15.4A CHANNEL MODELS

Model	Description
CM1	Residential LOS
CM2	Residential NLOS
CM3	Indoor office LOS
CM4	Indoor office NLOS
CM5	Outdoor LOS
CM6	Outdoor NLOS
CM7	Open outdoor NLOS
CM8	Industrial LOS
CM9	Industrial NLOS

TABLE IV. KEY PARAMETERS OF IEEE802.15.4A CHANNELS

Parameter	Description	Residential		Outdoor	
		LOS CM1	NLOS CM2	LOS CM5	NLOS CM6
PL_0	Path loss (dB)	-43.9	-48.7	-43.29	-43.29
γ	Path loss exponent	1.79	4.58	1.76	2.5
σ_S	Shadowing standard deviation	2.22	3.51	0.83	2
L	Mean number of clusters	3	3.5	13.6	10.5
Λ (1/ns)	Inter-cluster arrival time	0.05	0.12	0.0048	0.0243
Γ (ns)	Inter-cluster decay constant	22.6	26.3	31.7	104.7
$\sigma_{cluster}$	Cluster shadowing variance	2.7	2.9	3	3
Validity	Range (m)	7-20	7-20	5-17	5-17

C. Simulation and Timing Parameters

A mandatory mode parameters setting of this research has been decided base on previous literature and listed in Table V.

TABLE V. MANDATORY MODE PARAMETER SETTING

Centre Frequency (MHz)	4492.8
Bandwidth (MHz)	499.2
Total Packets Sent	150
PHY payload (bytes)	8
Transmitted Bits	36000
Data Rate (Mbps)	0.85
Mean PRF (MHz)	15.60
Pulse Duration (ns)	2
Symbol duration (ns)	1025.64
Burst duration (ns)	32.05
No. of Chips per burst	16
Preamble symbol duration (ns)	993.6
Duration of SHR preamble	71.5
Length of Ternary Code	31
SFD length (symbols)	8

IV. Result and Discussion

A. Effect of Channel Models

Figure 2 shows the BER performance between a source and receiver for Ghassemzadeh LOS and NLOS. Energy detection sensitivity at the receiver is 3 dB. For the same environment, NLOS performance degradation is worse than LOS channel. According to the figure, the system become impractical for distance larger than 5 metres while the LOS condition can be use up to 100 metres distance. The different are mainly caused by the difference of path loss exponent. Values for Ghassemzadeh residential LOS is 1.7 and 3.5 for residential NLOS. The results verify that the path loss exponent value contribute the performance of BER for the same model families. The smaller the path loss exponent value, the greater the BER performance.

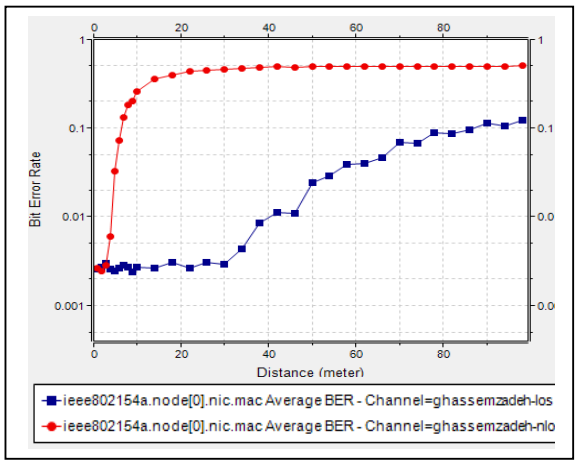

Figure 2 BER as a function of link distance with Ghassemzadeh LOS and NLOS

B. Effect of Data Rate

Figure 3 and Figure 4 show the outdoor CM5 LOS simulation results for various data rates {0.11, 0.85, 6.81, 27.24} Mbps that assigned in IEEE802.15.4a standard respectively. We noticed that the BER performance and throughput become worse proportionally with the increment of data rate. For example, BER for data rate 0.11 Mbps at 40m distance is about 0.004 while for data rate 27.24 Mbps is about 0.007 at the same distance. For the throughput, the received packets for data rate 6.81 Mbps start attenuated at 10 meters but at 60 m for data rate 0.85 Mbps. The main factor of this situation is the bandwidth size. In this case, we use the same bandwidth for all data rates. The increments of data rate will cause congestion in the traffic (bottle neck traffic) since the transmitted bits are increase per seconds but the bandwidth remains the same. Thus it also affected the BER and throughput performance due to data has been corrupted.

C. Effect of Bandwidth

The BER performance of channel {3,7,11,15} for residential CM2 NLOS are shown in Figure 5. The results depict an improvement in the BER. The results differ only for one to two metres (between 0.0004 to 0.004). To analyse the result, we need to consider the Shannon's capacity theory whereby the larger the bandwidth allows the greater capacity. The larger bandwidth also enables devices to transmit a higher power (for fixed PSD constraints), and thus they may achieve a longer communication range. The larger bandwidth pulses offer enhanced multipath resistance. Additionally, larger bandwidth leads to more accurate range estimates. forward error correction does not effective in improving the BER due to too many error to be corrected.

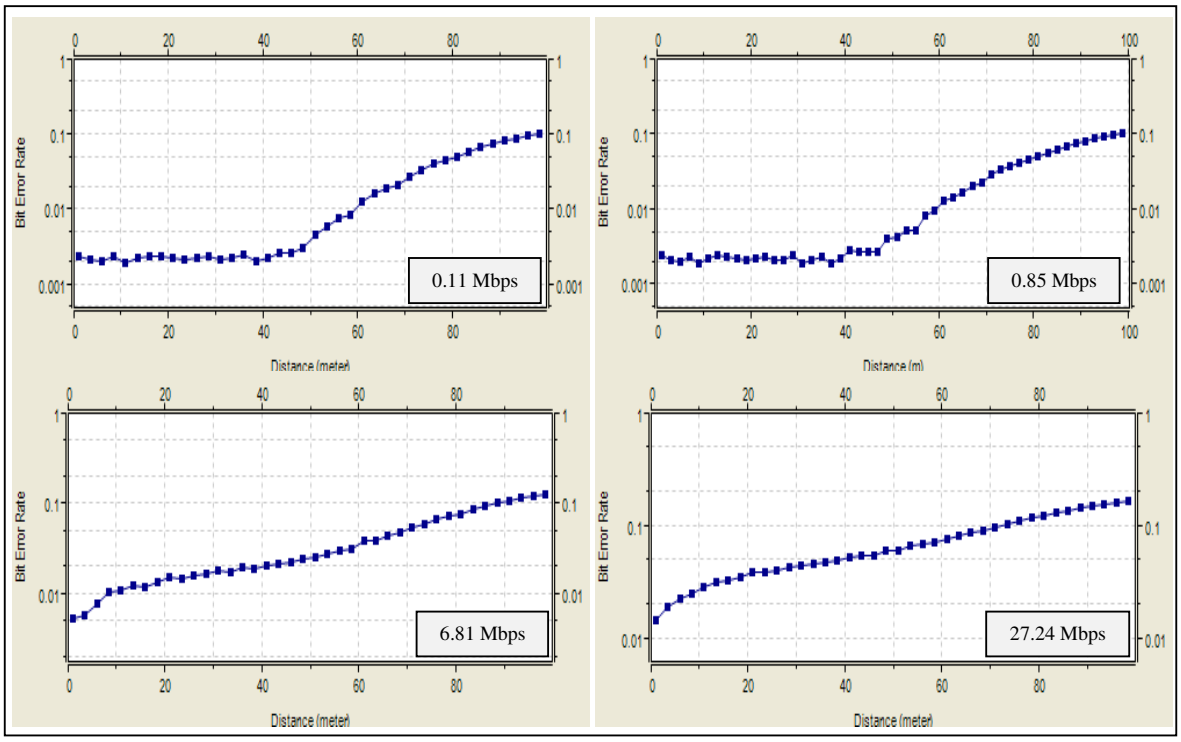

Figure 3 IEEE802.15.4a CM5 outdoor LOS bit error rate performance for different data rate

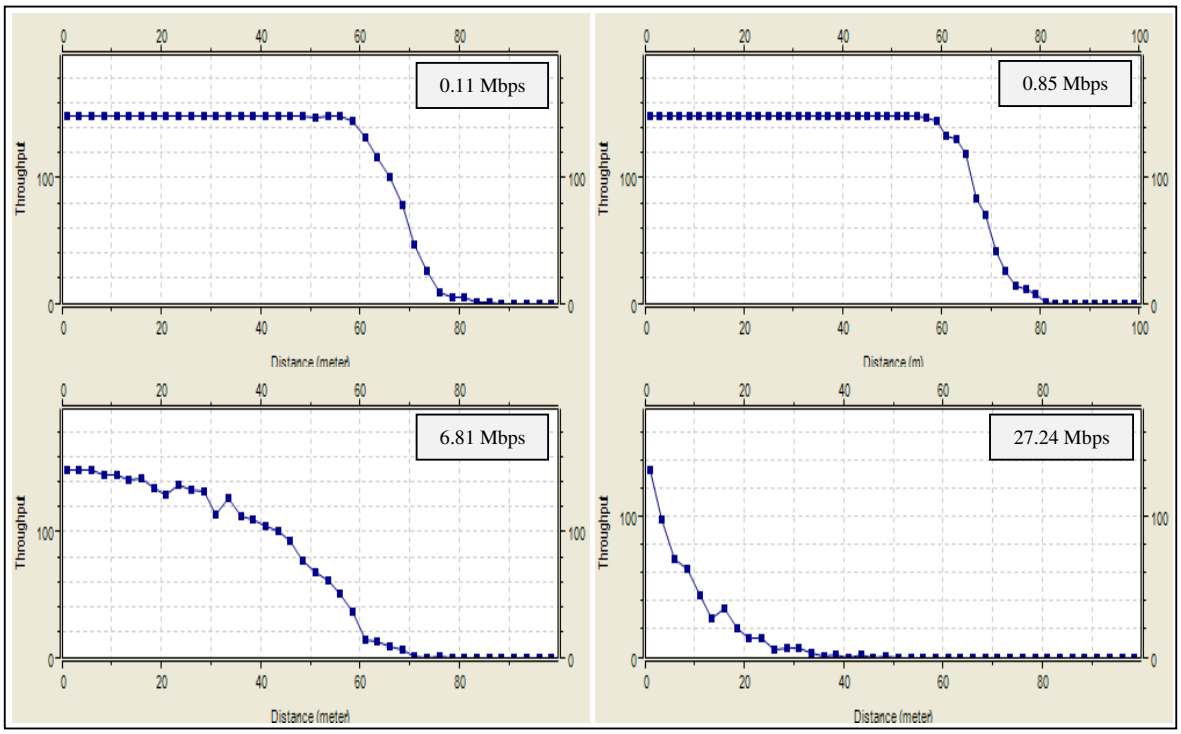

Figure 4 IEEE802.15.4a CM5 outdoor LOS throughput performance for different data rate

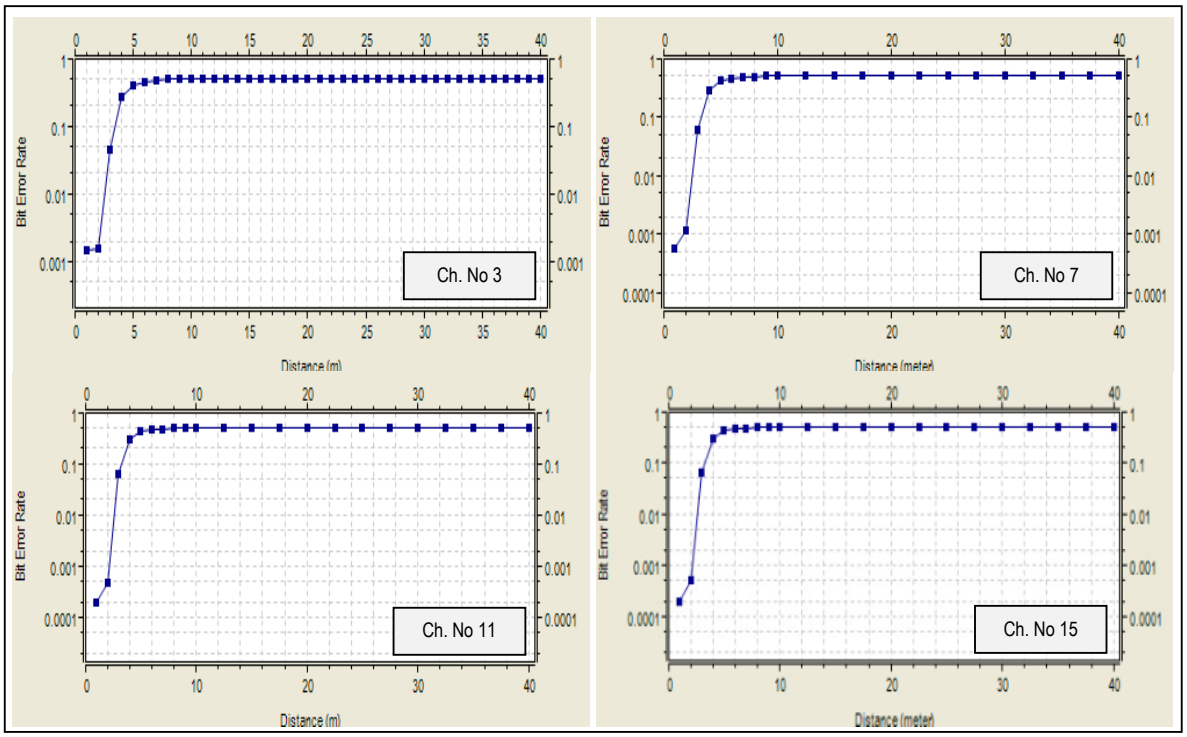

Figure 5 IEEE802.15.4a CM2 residential NLOS BER performance of different bandwidth

V. Conclusion and Future Work

Analyses on BER and throughput for channel models have been performed in this project. The timing parameters are playing the key role on the BER and throughput performance. Selection of suitable bit rate and bandwidth also contribute on BER and throughput results. Overall, we discover that the BER and throughput performance are proportionally with bit rate. A higher bit rate will results a higher BER. The BER and throughput performance are inverse proportionally with bandwidth size. A large bandwidth pulses offer enhanced multipath resistance and lead to more precise ranging. The

As future works, we suggest analysing the impact of the convolutional encoder and Viterbi decoder on the distance, throughput and BER. We also suggest using another OMNet++ framework such as INET which is provides many modules for the upper network stack that MiXiM is missing. This could potentially allow for many existing protocols to be used in ultra wideband environment.

References

[1] Chia-Chin Chong; Watanabe, F.; Inamura, H.; , "Potential of UWB Technology for the Next Generation Wireless Communications," *Spread Spectrum Techniques and Applications, 2006 IEEE Ninth International Symposium on* , vol., no., pp.422-429, 28-31 Aug. 2006.

[2] Karapistoli, E.; Pavlidou, F.-N.; Gragopoulos, I.; Tsetsinas, I.; , "An overview of the IEEE 802.15.4a Standard," *Communications Magazine, IEEE* , vol.48, no.1, pp.47-53, January 2010.

[3] Aboelaze, M.; Aloul, F.; , "Current and future trends in sensor networks: a survey," *Wireless and Optical Communications Networks, 2005. WOCN 2005. Second IFIP International Conference on* , vol., no., pp. 551- 555, 6-8 March 2005.

[4] Min-su Kim; Hojun Kim; Jong Tae Kim; , "High-Level Modeling of UWB PHY for IEEE802.15.4a," *Convergence and Hybrid Information Technology, 2008. ICHIT '08. International Conference on* , vol., no., pp.351-354, 28-30 Aug. 2008.

[5] Xiaodong Xian; Weiren Shi; He Huang; , "Comparison of OMNET++ and other simulator for WSN simulation," *Industrial Electronics and Applications, 2008. ICIEA 2008. 3rd IEEE Conference on* , vol., no., pp.1439-1443, 3-5 June 2008.

[6] Ghassemzadeh, S.S.; Jana, R.; Rice, C.W.; Turin, W.; Tarokh, V.; , "A statistical path loss model for in-home UWB channels," *Ultra Wideband Systems and Technologies, 2002. Digest of Papers. 2002 IEEE Conference on* , vol., no., pp. 59- 64, 2002.

[7] Molisch, A.F.; Cassioli, D.; Chia-Chin Chong; Emami, S.; Fort, A.; Kannan, B.; Karedal, J.; Kunisch, J.; Schantz, H.G.; Siwiak, K.; Win, M.Z.; , "A Comprehensive Standardized Model for Ultrawideband Propagation Channels," *Antennas and Propagation, IEEE Transactions on* , vol.54, no.11, pp.3151-3166, Nov. 2006.

[8] First Report and Order 02-48, FCC, 2002.

[9] IEEE Computer Society, Part 15.4a : Wireless Media Access (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area networks (LR-WPAN), IEEE Std 802.15.4a, Aug. 2007