DATE: June 14, 2007

TO: Pierre Collinet

FROM: Chinmoy Gavini

SUBJECT: A proposal for quantifying tradeoffs in the Physical Layer's modulation methods of the IEEE 802.15.4 protocol through simulation

INTRODUCTION

The objective of this proposal is to discuss the problem statement of quantifying modulation tradeoffs in the IEEE 802.15.4 protocol through MATLAB simulation. The Physical Layer (PHY) of any telecommunications protocol is an abstraction of the bits that carry information from a source to a destination. Modulation methods are techniques for encoding digital information in the form of bits onto analog media such as electronic cable or air. The scope of the project is baseband simulation of the modulation, demodulation, and wireless channel using MATLAB's Signal Processing and Communication Toolbox. The IEEE 802.15.4 protocol is a Wireless Personal Area Network (WPAN) protocol that accommodates lower power requirements, and therefore lower data rates compared to other wireless protocols. One can apply the protocol in areas such as consumer electronics, home security, personal healthcare, automotive sensing, and industrial process control [1]. Other potential applications include systems in which communication is not the dominant feature [1]. An example of such a system is a pressure sensor in a manufacturing plant. Although most sensors in a manufacturing plant communicate continuously with the central controller, some sensors only communicate with the controller for five minutes each week. Therefore, a low power requirement prolongs the sensor's battery life, and a low data rate is acceptable. Current adopters of the IEEE 802.15.4 PHY include the HART Communication Foundation [2].

My qualifications for completing the project consist of the Telecommunications courses that I have taken and my practical experience working at the HART Communication Foundation. I have taken classes in Communication Theory, Real-Time DSP, Telecommunication Networks, and Data Structures. In this proposal, I discuss the simulation and analysis of the IEEE 802.15.4 protocol using MATLAB's Signal Processing and Communication Toolbox. I will complete the project in six weeks by July 26th. There are no project expenses at this time.

PROBLEM DEFINITION

The purpose of the project is to quantify tradeoffs in the modulation methods of the IEEE 802.15.4 protocol through simulation. I propose to simulate the baseband processing of the IEEE 802.15.4 PHY layer in MATLAB with Offset-Quadrature Phase Shift Keying (O-QPSK) modulation for the 2.4 GHz PHY and Binary Phase Shift Keying (BPSK) modulation for the 868 and 915 MHz PHY. All three PHY layers use Direct Sequence Spread Spectrum (DSSS). MATLAB's Signal Processing and Communications Toolbox is directly applicable to this project. The simulations' channel model is the UltraWideBand (UWB) model, which the IEEE 802.15.4a channel modeling subgroup has recommended. Other potential candidates for a channel model are the Rayleigh fading and Rician fading models. After the simulation is complete, I will quantify the tradeoffs by plotting Bit Error Rate (BER) of each modulation method, comparing data throughput of each modulation, comparing data throughput versus implementation complexity, and verifying the simulation results against the following table [3]:

Table 1. Expected characteristics of IEEE 802.15.4 [3]

Band	Frequency Band	Bit Rate	Symbol Rate	Modulation	Chip Rate
868 MHz	868-868.6 MHz	20 kb/s	20 ksymbols/s	BPSK	300 kchips/s
916 MHz	902-928 MHz	40 kb/s	40 ksymbols/s	BPSK	600 kchips/s
2.4 GHz	2.4 – 2.4835 GHz	250 kb/s	62.5 ksymbols/s	O-QPSK	2 Mchips/s

Implementation complexity refers to memory and processor requirements. I will use additional modulation comparison methods if they are appropriate for the project.

According to Dr. Brian Evans, an appropriate channel model for this project has to include "time-varying gain for fading", "time-varying finite impulse response filter for multipath effects", and Additive White Gaussian Noise (AWGN) [4]. The UltraWideBand (UWB) channel model proposed by the IEEE 802.15.4a channel modeling subgroup meets these constraints. The

UWB model has a d^{-n} pathloss law, frequency dependent pathloss, a modified Saleh-Valenzuela model, block fading, and Nakagami distribution for small-scale fading [5]. I will add Additive White Gaussian Noise (AWGN) to the channel modeling subgroup's model. For background information on the Saleh-Valenzuela channel model, modulation, and Direct Sequence Spread Spectrum (DSSS), please refer to Appendix A.

PROBLEM ANALYSIS AND APPROACH

My preliminary approach to the problem statement consists of evaluating the merits of some channel models, researching additional modulation comparison methods, and dividing the simulation into the ideal case and the realistic case. The ideal case consists of the modulation, demodulation, DSSS and AWGN without the channel model. I will add the channel model once the modulator, demodulator, and PN generator work correctly in the ideal case.

A design solution to the problem consists of first decomposing the telecommunication system into three modules: the transmitter, receiver, and channel. The transmitter consists of the Bits to Symbols converter, PN Multiplier, and Modulator. The modulator is either an O-QPSK modulator or a BPSK modulator. The receiver consists of the O-QPSK or BPSK Demodulator, PN Multiplier, and Symbols to Bits converter. The channel consists of the signal distortion due to the channel model and AWGN. Please refer to Figure 1 below.

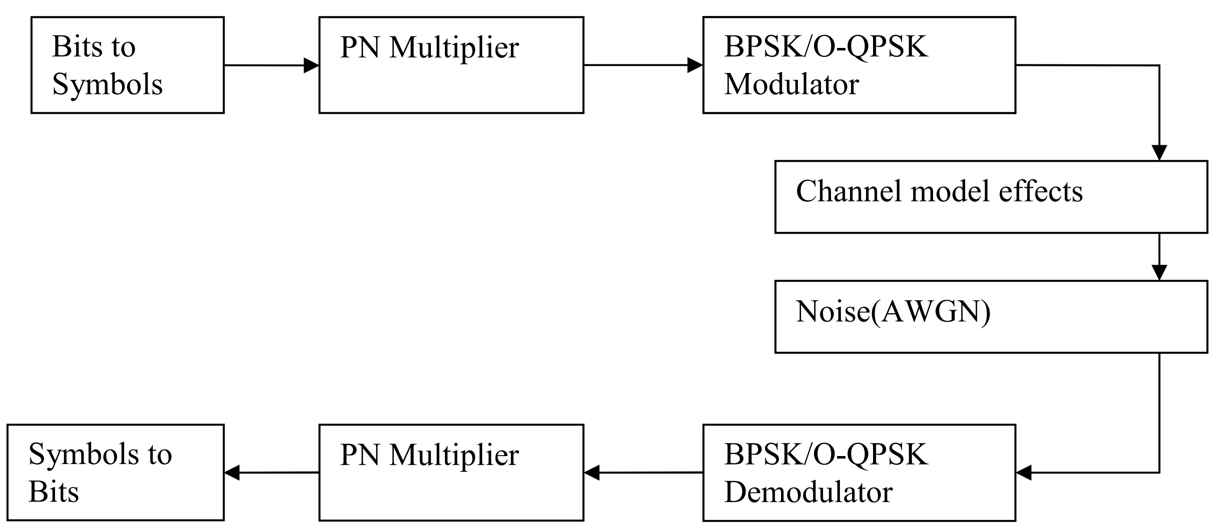

Figure 1: Simulation Block Diagram

The project activity consists of writing the MATLAB code without channel effects, adding the channel effects, and quantifying the performance using BER plots and other comparison methods. I will test the simulation in each stage. I will unit test each module and perform integrated tests on the entire simulation as I add code.

Comparing the modulation methods is a significant part of the design. One can compute the theoretical Bit Error Rate using MATLAB's BERTool. This theoretical plot would serve as a standard against which the actual Bit Error Rate would be compared. To generate the actual Bit Error Rate plot for the BPSK and O-QPSK modulation, I will create a MATLAB function that provides BERTool with the appropriate results from the simulation after generating the theoretical BER plot. I will account for the differences in DSSS chip rates when comparing data throughput and evaluate the implementation complexity from the perspective of a Digital Signal Processor (DSP) implementation.

The project materials consist of MATLAB's Signal Processing and Communication Toolbox, library books on wireless communication, the IEEE 802.15.4 standard, and the IEEE 802.15.4a channel modeling paper. For technical assistance, I will consult EE 464 TA Pierre Collinet and Dr. Evans.

PROJECT MATERIALS AND COSTS

The project does not have any expenses at this time. The MATLAB Signal Processing and Communication Toolbox is freely available to students at all the Electrical and Computer Engineering Learning Resource Center laboratories (ECE-LRC). Although one has to purchase the IEEE 802.15.4 standard, it is freely available for University of Texas students through the library. There are no transportation costs as I walk from my apartment to the ECE-LRC facilities.

PROJECT SCHEDULE

Before August 2, 2007, I can finish the simulation and analysis. I will also try to provide a User Manual in addition to HTML documentation of the source code. Please refer to Appendix B for the Gantt chart depicting the Project Schedule. Besides the deadlines for the written and oral reports, the major project milestones are investigating various channel models and modulation analysis methods, finding the best channel model, programming the simulation without the channel model, unit testing each module, adding the channel model, comparing each modulation method, and testing the entire simulation. I refined the pre-proposal and researched the project topic from May 31st to June 4th. The research refers to learning about channel models and acquiring sources for the project. I continued the research and worked on the proposal from June 6th to June 14th. I have started to research and compare channel models and modulation analysis techniques from June 11th. I will finish this research work on June 15th.

Comparison of channel models and modulation analysis methods will be applicable to the Oral Design Review. I will finish the comparison of channel models and modulation analysis methods and prepare the Oral Design Review from June 15th to June 20th. From June 21st to June 28th, I will program the simulation without channel effects for the simulation prototype. This work will include O-QPSK modulation/demodulation, BPSK modulation/demodulation, DSSS, and AWGN. After the Pre-Demo, I will unit-test each module in the prototype from June 28th to July 4th in addition to working on the Intellectual Property Report. I will implement the channel model and unit-test each module in the updated simulation from July 6th to July 13th. Comparing each modulation method is the main design aspect of the project. From July 13th to July 25th, I will make sure the simulation is working and compare each modulation method using the criteria in the Problem Definition as well as other applicable methods. From July 26th to July 31st, I will work on final testing. From July 30th to August 7th , I will complete the Oral Final Report and the Written Final Report. I will complete the written and oral assignments by the dates on the Gantt chart in Appendix B.

CONCLUSION

In this proposal, I have defined the project topic of quantifying modulation tradeoffs in the IEEE 802.15.4 protocol and provided a three-step approach to the problem consisting of the ideal simulation, realistic simulation, and modulation evaluation. Finally, I have provided the project schedule, presented technical background information, and discussed the lack of project costs at this time. When the project is completed, I will have analyzed the modulation methods after completing and testing the entire simulation. Under the time constraints, a Radio Frequency (RF) simulation of the protocol is not feasible. If the project involved one more member, it might have been possible to actually implement the protocol with a combination of hardware and a software radio library. Comparing each modulation method is significant in that it allows an IEEE 802.15.4 system implementer to make an informed decision on the best modulation method in an actual design. Of the three frequency bands in the IEEE 802.15.4 model, the 2.4 GHz band is the only frequency band available internationally. However, engineers in the United States and Europe can choose between the 2.4 GHz frequency and the 915 MHz frequency.

REFERENCES

[1] J.A. Gutierrez, E.H. Callaway, and R.L. Barrett, *Low-Rate Wireless Personal Area Networks*, New York, N.Y., 2004 pp. 13-21.

[2] HART Communication Foundation "WirelessHART™ Technical Data Sheet" http://www.hartcomm2.org/hart_protocol/wireless_hart/wirelesshart_datasheet.pdf (current 15 May 2007).

[3] J.A. Gutierrez, E.H. Callaway, and R.L. Barrett, *Low-Rate Wireless Personal Area Networks*, New York, N.Y., 2004 p. 40.

[4] Email Communication with Dr. Brian L. Evans, May 26, 2007.

[5] A.F. Molisch, et al, "IEEE 802.15.4a channel model - final report", http://www.eecs.berkeley.edu/~slanzise/research/ channel_models/15-04-0662-00-004a-channel-model-final-report-r1.pdf

[6] Dallas Semiconductor MAXIM. "Application Note 686" http://www.maxim-ic.com/appnotes.cfm/appnote_number/686/

[7] J.A. Gutierrez, E.H. Callaway, and R.L. Barrett, *Low-Rate Wireless Personal Area Networks*, New York, N.Y., 2004 p. 44.

[8] Dallas Semiconductor MAXIM. “Application Note 1890”
http://www.maxim-ic.com/appnotes.cfm/appnote_number/1890/

APPENDIX A – TECHNICAL BACKGROUND INFORMATION

Modulation with O-QPSK and BPSK

QPSK is a type of phase shift keying in which the carrier goes through one of four changes in phase at a point in time. Therefore, QPSK can represent 2 bits per symbol [6].O-QPSK is a modification to QPSK modulation which offsets the timing of the odd and even bits by ½ of a symbol period so that the in-phase and quadrature components do not change simultaneously [7].

Direct Sequence Spread Spectrum (DSSS)

Spread Spectrum is a technique in which “the baseband signal bandwidth is intentionally spread over a larger bandwidth by injecting a higher-frequency signal.”[8]. Both the modulator and demodulator know the PseudoNoise (PN) sequence which the transmitter will use. The DSSS modulator multiplies the data to be transmitted is multiplied by a PN sequence and transmits the output signal. The demodulator multiplies the received signal by the PN sequence to recover the data. Only the intended receiver can correctly demodulate the received signal [8]. The main advantages of Spread Spectrum techniques are resistance to jamming. The advantage of DSSS is a higher number of users per frequency band.

Saleh-Valenzuela Channel Model

The probability density function (pdf) for the Saleh-Valenzuela Model is given in [5]

$$pdf(x) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1}\exp\left(\frac{-m}{\Omega}\right)x^2 \qquad (1)$$

where $m \geq 1/2$ is the Nakagami m-factor. Ω is the mean-squared value of the amplitude. $\Gamma(m)$ is the Gamma function [5]

Additive White Gaussian Noise (AWGN)

In the AWGN model, the noise is additive in that one models it as accumulated background noise at the receiver. “White” refers to the uniform power spectral density value of $N_0/2$ over all frequencies. Different sources of noise can be modeled as independent and identically distributed sources. According to the Central Limit Theorem, the Gaussian distribution approximates the sum of independent and identically distributed random variables.

Therefore, one can approximate the probability distribution of the combination of noise sources with a Gaussian distribution.

Channel Impulse Response

The impulse response for the Saleh-Valenzuela model is given in [5]:

$$h_{discr}(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k.l} \exp(j\phi_{k,l})\delta(t - T_l - \tau_{k,l}) \tag{2}$$

where $a_{k,l}$ is the weight of the k^{th} component. $\varphi_{k,t}$ is the phase which is uniformly distributed from 0 to 2π .[5]. Based on the results of a channel simulation, the channel impulse response has 2211 terms [5].

Cluster distribution

The number of clusters is Poisson distributed, and is given by [5]:

$$pdf_L(L) = \frac{\bar{L} \exp(-\bar{L})}{L!} \tag{3}$$

$\bar{L}$ represents arithmetic mean [5].

Pulse Shape

The BPSK modulation for the 868/915 MHz frequencies uses the raised-cosine shape. The 2.4 GHz O-QPSK modulation uses the half-sine pulse shape [1].

APPENDIX B – GANTT CHART

ID	Task Name	Start	Finish	Duration
1	Refining Pre-Proposal, Research	5/31/2007	6/4/2007	3d
2	Show Pre-Proposal to TA	6/5/2007	6/5/2007	1d
3	Work on proposal and start design review	6/6/2007	6/14/2007	1w 2d
4	Proposal Due	6/14/2007	6/14/2007	1d
5	Finish Design Review,Prepare for Oral Report	6/15/2007	6/20/2007	4d
6	Oral Design Review due	6/21/2007	6/21/2007	1d
7	Submit Notebook	6/21/2007	6/21/2007	1d
8	Finish Simulation without Channel Effects(for Pre-Demo)	6/21/2007	6/28/2007	1w 1d
9	Pre-Demo due	6/28/2007	6/28/2007	1d
10	Unit Testing of the simulation, work on IP Report	6/28/2007	7/4/2007	1w
11	Intellectual Property Report Due	7/5/2007	7/5/2007	1d
12	Channel Model Implementation, Unit Testing(of updated sim)	7/6/2007	7/13/2007	1w 1d
13	Submit Notebook	7/10/2007	7/10/2007	1d
14	Comparison of modulation methods, debugging	7/13/2007	7/25/2007	1w 4d
15	Written Progress Report Due	7/17/2007	7/17/2007	1d
16	Project Demo Due	7/26/2007	7/26/2007	1d
17	Submit Notebook to TA	7/26/2007	7/26/2007	1d
18	Final Testing	7/26/2007	7/30/2007	3d
19	Work on Oral and Written Final Report	7/30/2007	8/7/2007	1w 2d
20	Demo Project for Open House	8/2/2007	8/2/2007	1d
21	Present oral Final Report	8/7/2007	8/7/2007	1d
22	Proofread Written Final Report	8/8/2007	8/8/2007	1d
23	Submit written final Project Report	8/9/2007	8/9/2007	1d
24	Submit Notebook	8/9/2007	8/9/2007	1d

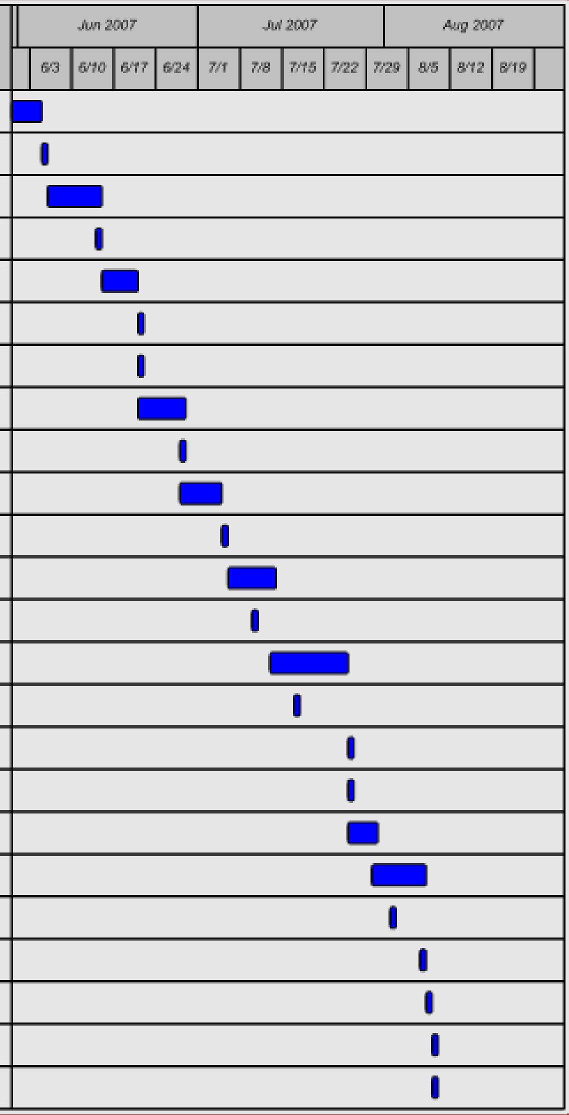

Figure 2: Gantt chart