MAC Layer Mitigation of Interference between IEEE 802.11a and Ultra Wideband (UWB) Systems

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Abstract– *The performance of an Ultra-Wideband (UWB) system in the presence of IEEE 802.11a interference is evaluated. Our results indicate that IEEE 802.11a interference can cause a significant increase in the bit error rate and a severe degradation of the attainable throughput of UWB systems. We propose a novel idea in the medium access control (MAC) layer in order to mitigate this interference. We demonstrate this idea by simulating an independent device capable of moderating IEEE 802.11a transmissions, thereby allowing UWB stations to communicate without interference. Our simulation results further demonstrate the feasibility of such simple and inexpensive third party devices that can be used within future homes and offices to guarantee coexistence of the two systems.*

Keywords: Ultra Wideband, UWB, Interference, IEEE 802.11a, Medium Access Control, MAC

1 Introduction

Recently, Ultra Wideband (UWB) [1] technology has attracted a lot of interest in the research community. UWB offers the potential for high data rates, low-power transmissions, low cost, robustness to multipath fading, and excellent geolocation capabilities. Given these superior capabilities, it is expected that UWB will quickly become a critical and integral part of the future home and office environments.

As specified by the FCC [1], UWB can operate in the frequency range of 3.1-10.6 GHz with an indoor emission limit of -41 dBm/MHz. IEEE 802.11a [2] wireless systems also operate in the 5 GHz U-NII bands, which overlaps the allowed UWB band, and will most likely co-exist with UWB technology in the future home and office environments. This poses an important question on weather both technologies can peacefully coexist together, how much interference they impose on each other, and how can this interference be minimized.

The rest of this paper is organized as follows: In section 2 we provide a closed form expression for the interference of an IEEE 802.11a system on an example UWB system using time-hopping pulse position modulation (TH-PPM). In section 3 We propose a technique in the MAC layer to reduce the aforementioned interference and evaluate our system using simulations, and in section 4 we conclude our paper and provide future research directions.

2 IEEE 802.11a and UWB Interference

Using logical and analytical [4] tools it can be demonstrated that the interference between IEEE 802.11a and UWB is asymmetrical; The interference from an UWB system on an IEEE 802.11a system is minimal and in most situations, harmless. However, the interference from the same IEEE 802.11a on the UWB system is a lot more significant and critical. The main reason for this is that for both cases the interference is within the same range/band of frequency (20 MHz). Within that range, IEEE 802.11a is the dominant interferer, as evident from equation (1):

$$\left(SIR_{UWB} = \frac{P_{UWB}.\ BW_{UWB}}{P_{802.11a}.\ BW_{802.11a}}\right) \ll \left(SIR_{802.11a} = \frac{P_{802.11a}.\ BW_{802.11a}}{P_{UWB}.\ BW_{802.11a}}\right) \tag{1}$$

It is because of this asymmetry that we focus mainly on the more critical issue of IEEE 802.11a interference in this paper.

2.1 Effect of IEEE 802.11a Interference on UWB Systems

We have presented a unique technique to derive closed form expressions for IEEE 802.11a interference on different UWB systems [3]. As an example, consider an UWB signal transmitted using Time Hopping Pulse Position Modulation (TH-PPM):

$$s^{(l)}(t) = \sum_{p} w\left(t - pT_f - c_p^{(l)}T_c - \delta d_{[p/N_s]}^{(l)}\right) \tag{2}$$

where $w(t)$ represents the UWB monocycle, T_f is the time duration of a frame, N_s represents the number of monocycles transmitted per symbol, and $c_p^{(l)}$ represents the pseudorandom time hopping sequence assigned to transmitter l. The quantities with the superscript (l) indicate transmitter-dependent quantities. The data sequence $d_{[p/N_s]}^{(l)}$ is a binary symbol stream, where the notation $_{[p/N_s]}$ represents the integer part of $_{p/N_s}$ to account for the oversampling in our system.

Consider the case of a second order Gaussian monocycle pulse, most commonly used in UWB studies:

$$w_0(t) = \left[1 - 4\pi\left(\frac{t}{\xi}\right)^2\right] e^{-2\pi\left(\frac{t}{\xi}\right)^2} \tag{3}$$

In here ξ represents a time normalization factor. Assuming perfect synchronization between the UWB transmitter and receiver, we derive a closed form expression for the amount of interference from IEEE 802.11a:

$$\begin{aligned} s_{int} = \frac{\xi^3\pi}{\sqrt{2}} A_2 \sum_{p=0}^{N_s-1} \sum_{k=-N_{ST}/2}^{N_{ST}/2-1} (f_c + k\Delta F)^2 e^{-\frac{\xi^2\pi}{2}(f_c+k\Delta F)^2} \\ \cdot Re\left\{c_k\ \left[1 - e^{j2\pi(k\Delta F+f_c)\delta}\right]\ e^{j2\pi[(k\Delta F+f_c)(pT_f+c_p^{(l)}T_c+\xi)-k\Delta F T_G]}\ \right\} \end{aligned} \tag{4}$$

where N_{ST} represents the total number of subcarriers, c_k is the set of coefficients (data, pilot, etc.) transmitted, T_G is the guard time and ΔF represents the subcarrier frequency spacing, for the IEEE 802.11a (OFDM) system.

Using equation (4) and parameters of Table 1, we characterize the interference in terms of bit error rate (Fig. 1). A_2 and A_1 are proportional to the square root of the received powers for OFDM and UWB, respectively.

The solid curve shows the BER and throughput without the presence of any interference. The dashed curves represent the upper limits for the probability of error due to interference and noise combined. Please note that these curves represent a worst-case scenario, assuming that both stations are transmitting at the same time. The actual error rate would fall in a region between the solid line and the interference curves shown, depending on the temporal overlap of the two systems. Given $P(\alpha) = probability\ of\ signal\ overlap$ and $P(\beta) = probability\ of\ no\ signal\ overlap$, the probability of error can be calculated as:

$$P(error) = P(error|\alpha)P(\alpha) + P(error|\beta)P(\beta) \tag{5}$$

This is the basic idea that we address in the next section, when dealing with the interference in the MAC layer.

Table 1: Simulation Parameters for IEEE 802.11a impact on UWB receiver

Parameter	Value
ξ	0.13×10^{-9}
δ	0.1×10^{-9}
T_f	8×10^{-8}
N_s	1
f_c	5.22×10^{9}
N_{ST}	52
T_G	0.8×10^{-6}
ΔF	0.3125×10^{6}

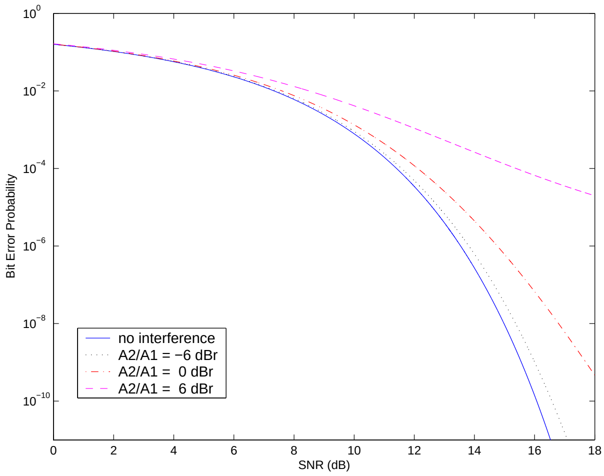


Fig. 1: UWB BER in the presence of AWGN and 802.11a interference

3 Interference Mitigation in the MAC Layer

3.1 IEEE 802.11a DCF Mechanism

IEEE 802.11a's primarily access protocol is the Distributed Coordination Function (DCF), which is based on carrier sense multiple access with collision avoidance (CSMA/CA) [2]: If a station wants to transmit, it first senses the medium for other active transmissions using virtual and physical carrier sensing. If the medium is not busy, the transmitting station will make sure that the medium remains idle for a required duration before attempting to transmit. If the medium is busy, then the station defers until the end of the current transmission, followed by a required idle period, at which time it will observe a random backoff time while the medium is idle, before attempting to transmit.

A combination of virtual and physical sensing is used to determine if the medium is busy or idle. Virtual carrier sensing uses the reservation information found in the duration field of the frames. The station's Network Allocation Vector (NAV) monitors this information. The NAV operates like a timer, starting with the value of the duration field of the last transmission, and counting down to zero. If duration field of a current frame is higher than the NAV, then the NAV stores (updates to) that value. Once the NAV reaches zero, the station proceeds to physically sense the channel. Physical carrier sensing is done by monitoring the energy level on the RF to determine if another station is transmitting or not. After the data frame is sent, if the destination correctly receives a frame, it waits for a specified short interval of time, and then sends an acknowledgment (Ack) frame back to the sender. Acknowledgment is used for all directed traffic and retransmission is scheduled by the sender if no ACK is received.

IEEE 802.11 DCF may also use a handshaking mechanism to further minimize collisions. In this method, the transmitting and the receiving stations exchange short control frames, referred to as RTS (Request to Send) and CTS (Clear to Send) after determining that the medium is idle and after any deferrals or backoffs, prior to data transmission. The details of this method are as follows: When a station wants to transmit a frame, it first sends a Request to Send (RTS) packet to the receiver. The receiver responds with a Clear to Send (CTS), giving the sender permission to send. The RTS and CTS packets contain a duration field that specifies the period of time needed to transmit the data frame and the Ack frame. All stations hearing the RTS or the CTS learn about the pending transmissions and update their NAV fields. Following a successful transmission, the receiver sends an Ack frame. This mechanism reduces the probability of collision, since the stations within the sender's and receiver's transmission range will hear the RTS and CTS messages and refrain from accessing the channel during the expected duration of transmission. Also, because RTS and CTS frames are short, any collision involving these frames will last a shorter time than the actual data frame, so the total overhead of collisions is reduced.

3.2 Proposed Mechanism

Our proposed mechanism involves cross-standard design for the ability of UWB and IEEE 802.11a to communicate with each other. The basic idea is to use handshaking control signals associated with the IEEE 802.11a standard, in order to inform IEEE 802.11a stations that the medium will be unavailable for intended periods of time. During those times, UWB stations can communicate with each other without fear of interference. Although invasive in nature, this technique can be used as a practical and very inexpensive technique by future users who find interference to be a serious problem (for example, consider a patient using his/her IEEE 802.11a Internet connection while having his vital signs monitored wirelessly using an UWB technology, or a user surfing the web using IEEE 802.11a while watching a TV program broadcast from the next room using UWB).

To illustrate this technique we introduce a proxy that is capable of sending IEEE 802.11a "Clear to Send" CTS messages at specific intervals using CSMA/CA mechanism similar to IEEE 802.11a. When the other IEEE 802.11a stations in the range hear the CTS messages, they delay (backoff) their transmissions, clearing the channel for UWB communications.

3.3 Simulation Results

We use the Georgia Tech Network Simulator, GTNets [5], which is a a full-featured network simulation environment based on C++, to model the system shown in figure 2. The figure shows an (IEEE) 802.11a transmitter which follows a 50 m trajectory (shown by dark arrow) in an indoor environment, as it communicates with the 802.11a receiver. We demonstrate the amount of interference received by a neighboring UWB receiver who is communicating with a nearby UWB transmitter. We simulate the system behavior with, and without, the presence of the "CTS Generator" device which we have proposed in the previous section. A free space propagation model was used. A transmit power spectral density (PSD) of -41 dBm/MHz was used for UWB and a a PSD of 2.5 mW/MHz was used for 802.11a. Antenna gains of 0 dBi were assumed for both systems. A constant bit rate application was used, generating traffic at 54 Mbps. System throughput from the perspective of each system is discussed and evaluated. We choose to simulate the entire trajectory over a one second period in order to reduce the density of our plots for discussion purposes. This will not affect the power and throughput results of our simulation in any way.

Figure 3(a),(b) shows the received interference power at the UWB receiver antenna without the CTS Generator present and with the CTS Generator present (on). It can be seen that the received interference is the highest in the middle of the simulation/trajectory, where the 802.11a transmitter is closest to the UWB receiver. Figure 3(b) demonstrates that during the periods when the CTS messages are sent by CTS

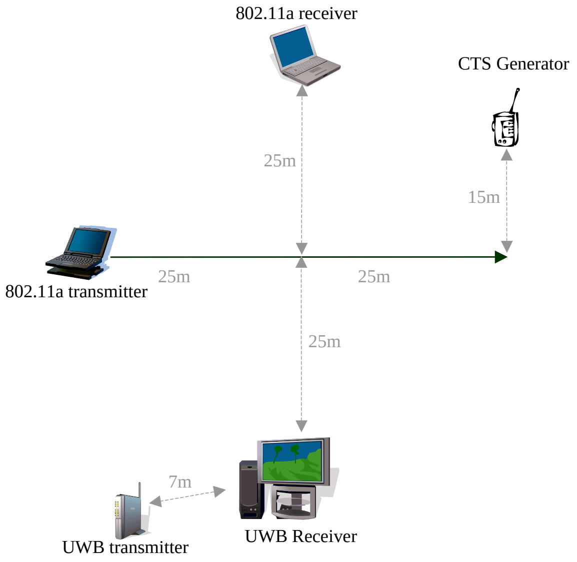
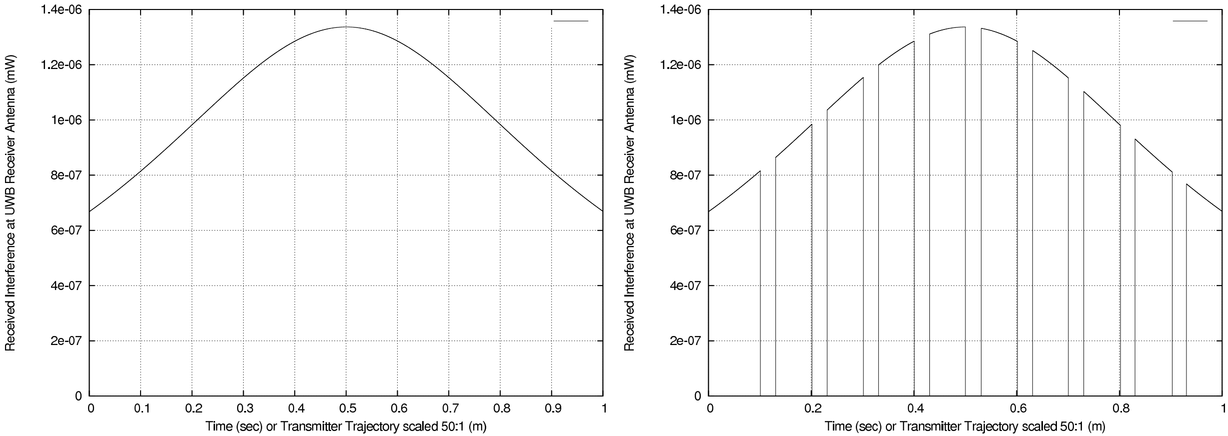


Fig. 2: Simulation Model

Generator, the 802.11a transmitter refrains from transmitting, leaving these periods available for UWB use. Within the simulation model we built, we can specify the CTS intervals and the duration field for CTS messages (limited by the maximum allowable duration), as well as the number of consecutive CTS messages. In the figure specified, we are shutting off about %30 of the 802.11a transmission at 0.1ms intervals and allocating it for UWB use.

Figure 4 shows the normalized throughput of the IEEE 802.11a system (maximum 54 Mbps). It can be observed that within our simulation ranges, the 802.11a pair demonstrate a good throughput regardless of location, due to the strength of the power received at the IEEE 802.11a receiver. Figure 4(b) shows the throughput as a result of our CTS Generator device. Again, it can be seen that the throughput drops to zero during the periods requested by CTS, and that the total 802.11a throughput is cut by about %30 in order to accompany the UWB station.

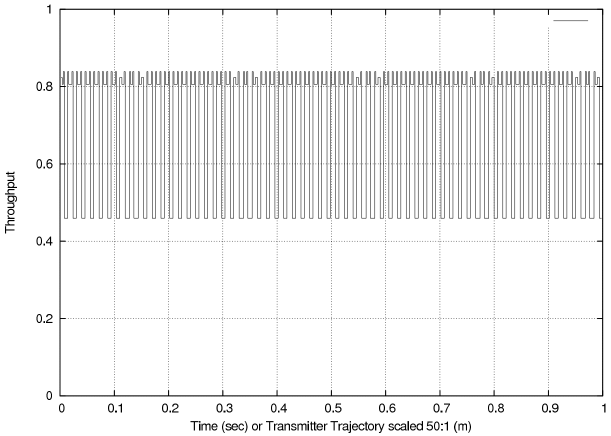


(a) without CTS Generator

(b) with CTS Generator ON

Fig. 3: Received Interference Power at UWB Receiver Antenna

Due to lack of a widely accepted UWB standard, we chose to evaluate the theoretical maximum through-

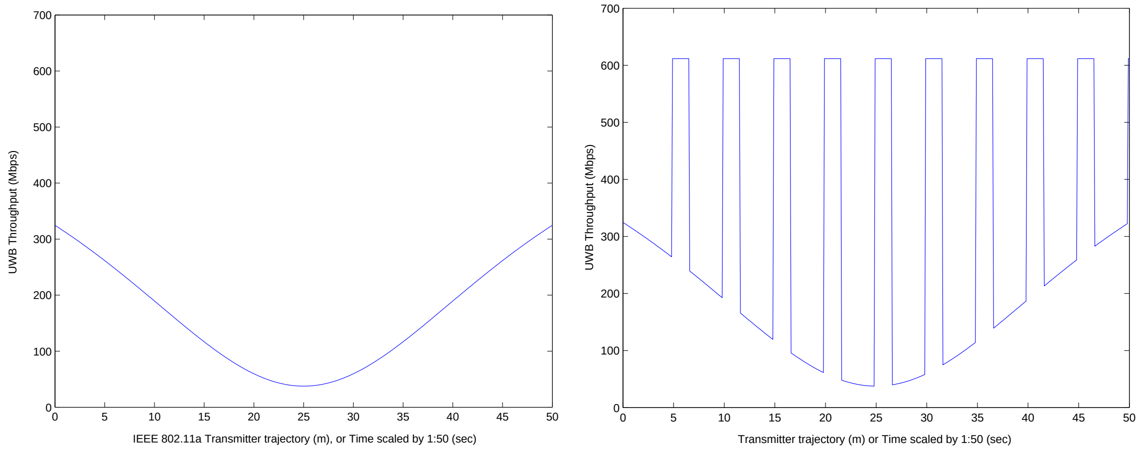


(a) without CTS Generator

(b) with CTS Generator ON

Fig. 4: Throughput of the IEEE 802.11a System

put (bit rate) at the UWB receiver, using the received UWB and IEEE 802.11a powers and the UWB effective bit energy. This was done using MATLAB [6]. Again, a free space propagation model was used. Channel noise was assumed to be additive white Gaussian noise. Transmit power spectral densities of -41 dBm/MHz and 2.5 mW/MHz were used for UWB and 802.11a, respectively. Antenna gains of 0 dBi, a noise figure of 6 dB, a target BER of 10^{-3}, and an implementation margin of 2 dB were assumed. The results are shown in Figure 5. Even though the UWB transmitter is only 7 meters away from the UWB receiver, the dramatic effect of an IEEE 802.11a interferer 35-25 meters away can be seen. Again, we demonstrate the throughput with and without the presence of our CTS generator. Observe that with the presence of the CTS Generator the instantaneous maximum throughput can increase by as much as 574 Mbps during the reserved UWB time slots. Because of UWB's potentially high data rates, this means that a temporary sacrifice of IEEE 802.11a throughput can lead to a much higher gain in the UWB throughput, thereby providing an overall gain for the entire system.



(a) without CTS Generator

(b) with CTS Generator ON

Fig. 5: Throughput of the UWB System

4 Conclusion

This paper investigated the effect of IEEE 802.11a interference on UWB radio systems. We demonstrated this using analytical expressions as well as simulation results through bit error rate and throughput curves. We demonstrated a novel idea in the MAC layer that would enable the two systems to peacefully coexist with each other. The variety of applications used (e.g., telehealth, multimedia, data, etc.), the overall system improvement due to UWB's potential for very high data rates, and the simplicity and low implementation cost of our proposed technique make it an interesting and feasible solution. The idea is still at its infancy and many additional studies will be built on this basic idea. For example, in our future CTS Generators, we may take into account the ratio of the number UWB stations to the number of IEEE 802.11a stations in the basic service set, as well as priority of traffic (e.g., telehealth applications having higher priority) and other factors in determining the generator's probability of transmission or backoff time.

References

[1] FCC Press Release, Feb 14, 2002, `http://www.fcc.gov/Bureaus/Engineering_Technology/News_Releases/2002/nret0203.html.`

[2] Institute of Electrical and Electronics Engineers, "Part11: Wirelss LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," IEEE Std 802.11a-1999, Sept 1999.

[3] B. Firoozbakhsh, T. Pratt and N. Jayant, "Analysis of IEEE 802.11a Interference on UWB Systems," in *Proc. IEEE Conf. on Ultra Wideband Systems and Technology (UWBST2003),* Nov. 2003.

[4] B. Firoozbakhsh and T. Pratt, "Ultra Wideband Communications; Coexistence with IEEE 802.11a," Georgia Institute of Technology, Atlanta, GA, GTBI Advisory Board Report, Jun. 2003.

[5] GTNetS - Georgia Tech Network Simulator, `http://www.ece.gatech.edu/research/labs/MANIACS/GTNetS/,` Dec, 2005.

[6] Mathworks Corp. MATLAB Technical Computing Environment, `http://www.mathworks.com`