Experimental Results for Interference between Bluetooth and IEEE 802.11b DSSS Systems

Ratish J. Punnoose, Richard S. Tseng, Daniel D. Stancil *

Abstract

There is an increasing presence of wireless LAN devices in the ISM band. Co-located operation of these devices causes mutual interference and performance degradation. This paper presents experimental results of interference measurements between sample Bluetooth and IEEE 802.11b DSSS devices.

Keywords – *Bluetooth, IEEE 802.11, Interference.*

1 Introduction

Devices conforming to the IEEE 802.11b standard [1] are some of the most commonly used wireless LAN products in the ISM bands. Bluetooth [2, 3] and HomeRF [4] are other recent wireless LAN technologies. These incompatible technologies operate in the same frequency spectrum, the 2.4 GHz ISM band. The co-located operation of these technologies causes mutual interference which is seen as a higher rate of lost packets. The performance of these devices is adversely affected in the presence of each other.

In this paper we present experimental results for the performance degradation of Bluetooth and IEEE 802.11b DSSS (Direct Sequence Spread Spectrum) devices due to mutual interference. Experiments were conducted in a large outdoor open space and also in a lab environment. The outdoor experiments presented in Section 2 were used to observe general trends of performance degradation in the presence of interference. These experiments focussed on characterizing the performance of 802.11b devices in the presence of Bluetooth interference. Signal and interference powers were varied by varying the distances between the devices. This provided an intuitive feel for the effect of interference depending upon distance. However, exact power levels and channel effects could not be well regulated. Therefore other experiments were performed in a controlled lab environment to characterize the performance degradation of both Bluetooth and IEEE 802.11b devices in the presence of each other. These experiments are presented in Section 3.

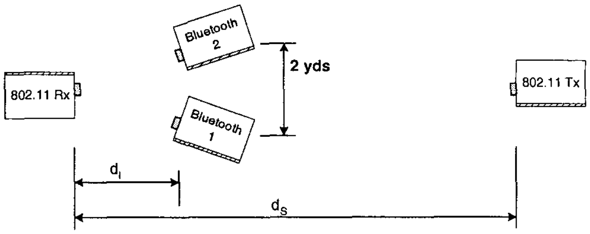

Figure 1. Experimental Setup for Measuring Interference of Bluetooth on 802.11b

2 Experimental Setup 1: Outdoor Location

2.1 Description of Experiment

The experiment setup for field measurements consisted of an 802.11b DSSS transmit-receive pair and a Bluetooth transmit-receive pair (Fig 1). Laptops with 802.11b and Bluetooth PC Cards were used as the transmitters and receivers. The Bluetooth devices used on the laptops were Digianswer Bluetooth PC cards with a power output of 20 dBm. The 802.11b cards used in the experiment were Lucent/Orinoco 802.11b High Rate (11 Mb/s) PC cards with a power output of 15 dBm.

The aim of the experiment was to vary the Signal-to-Interference (S/I) ratio in a controlled manner and then measure the packet loss rates directly.

The experiments were carried out in a flat open area (a football stadium). There were no objects nearby that could be a significant source of multi-path. All laptops were mounted on cardboard stands, 9 inches from the ground.

An HV3 audio connection was setup between the Bluetooth cards to provide a steady traffic stream. Link tests between the 802.11b laptops were performed using the Orinoco Client Manager. This software initiates packet transmissions and provides statistics on the SNR, Signal Level, and number of lost packets as observed by the 802.11b device.

The Client Manager software statistics also log the number of packets that were successfully transmitted at each

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* Department of Electrical and Computer Engineering
Carnegie Mellon University
Pittsburgh PA 15213
{punnoose,srt,stancil} @andrew.cmu.edu

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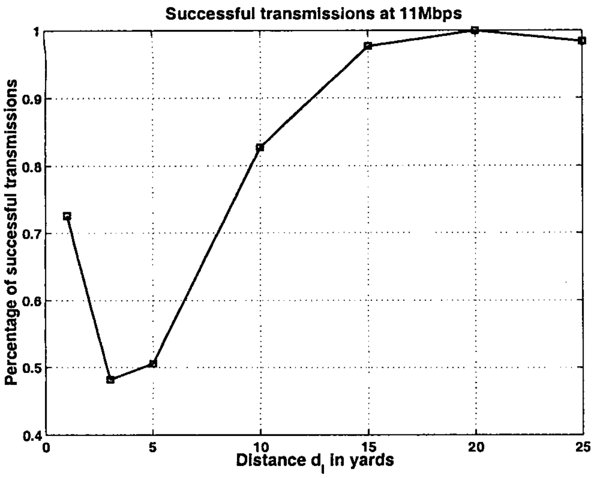

Figure 2. Experimental performance of 11Mbps 802.11b Mbps in the presence of Bluetooth interference with d_S = 35 yards.

data rate. Statistics were recorded at the station marked **802.11 Rx**. Varying the distance d_S varies the received signal level at the 802.11b cards. Varying the distance d_I varies the interference received at the 802.11b receiver.

The Bluetooth laptops were placed so that the cards always pointed towards the 802.11b Receiver. The experiment was setup as shown in the figure to minimize the effect of any angular variation in antenna gain of the Bluetooth units. The antenna pattern of the 802.11b devices was measured and taken into effect (Fig 4,Fig 5).

2.2 Results and Observations

Figure 2 shows the performance of the 11 Mbps 802.11b devices in the presence of Bluetooth interference. At a smaller value of d_I, the interference is greater and there is greater packet loss. The packet losses correspond to the decrease in Signal-to-Interference ratio which was calculated using a 2-ray ground reflection model taking the antenna pattern of the 802.11b device into consideration (Fig 3).

As expected, the number of successful transmissions is lower for smaller values of d_I (the interferer is closer to the receiver). The improvement in S/I from Laptop 1 at very short distances ($d_I < 3 yards$) is caused by receiver antenna pattern nulls in the direction of the interference (Fig 5). Although the minima in Figures 2 and 3 do not precisely match, these pattern nulls appear to be the explanation for improved performance at distances less than 3 yards (Fig 2). A similar but less pronounced feature is present in the S/I behavior from Laptop 2.

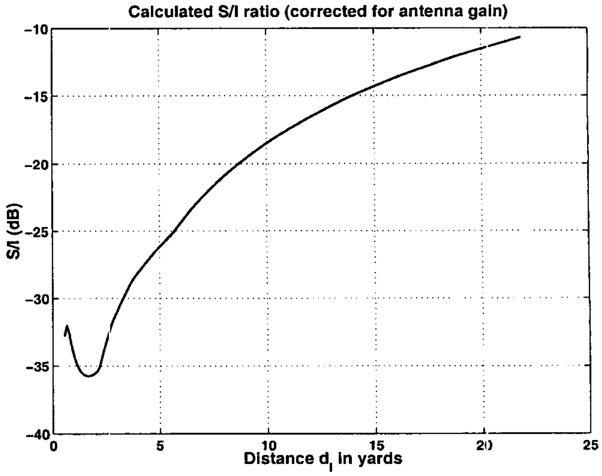

Figure 3. Computed S/I ratio due to interference from Bluetooth Laptop 1 with d_S = 35 yards.

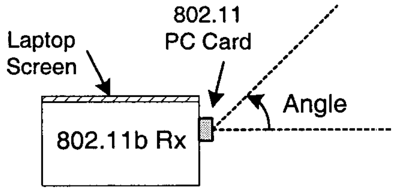

Figure 4. Laptop Orientation for Antenna Pattern measurement

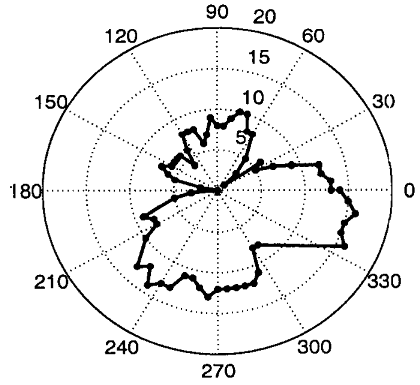

Figure 5. Measured Antenna Pattern for Lucent Orinoco card (dB) [Not Normalized]

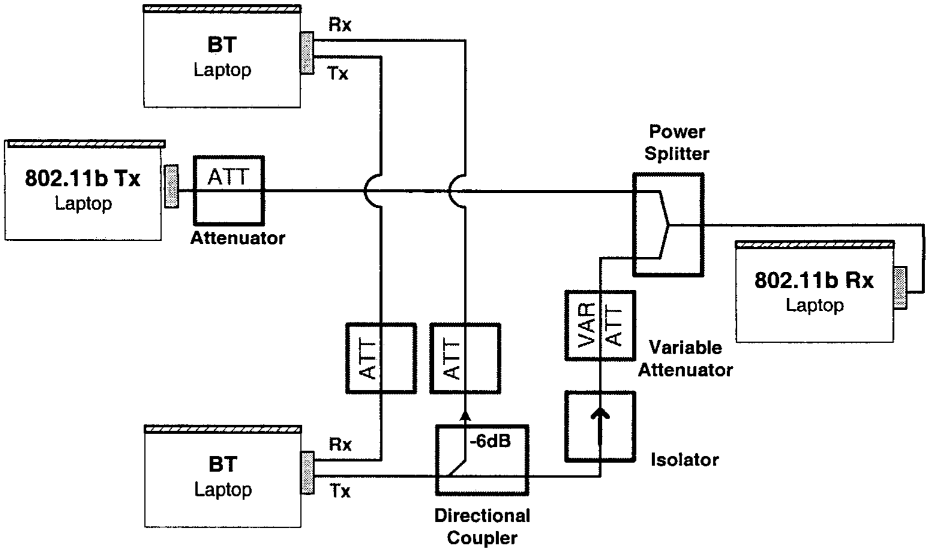

Figure 6. Lab Setup for measuring the effect of Bluetooth Interference on 802.11b

3 Experiment Setup 2: Lab Measurements

3.1 Description of Experiment

The experiment setup consisted of a pair of IEEE 802.11b DSSS laptops and a pair of Bluetooth laptops. The 802.11b cards used were Lucent/Orinoco High Rate (11Mb/s) PC cards. The Bluetooth devices used on the laptops were IBM Bluetooth PC cards (0 dBm power output). The internal antenna on all the PC cards were disabled and an external RF cable was connected to each of them. This was done so that the channel could be controlled using RF components. To ensure that all transmission and reception occurred using the attached cable, the cards were wrapped with metal foil that was lined with RF absorber. Each IBM Bluetooth card has two built-in antennas. An antenna cable was attached to each of them. It was found experimentally that only one of them was used for transmission.

The setup shown in Figure 6 was used to characterize the effect of Bluetooth interference on 802.11b devices. The signal from the 802.11b Transmitter is fed into an attenuator to control the signal level and is then combined with the interference signal using an RF Power Splitter. The resulting signal is then fed to the 802.11b Receiver. The interference is the signal transmitted by one of the Bluetooth laptops. The signal from the Bluetooth laptop is passed through a 6 dB directional coupler. The main output port of the directional coupler is connected to an RF isolator which passes the signal in one direction but not in the other. The signal is then passed through a variable RF attenuator. This allows for adjustment of the interference power. The resulting signal is then combined with the 802.11b signal and fed to the 802.11b Receiving laptop. The coupled port of the directional coupler (6 dB loss) is fed through an attenuator to the other Bluetooth laptop, so that the two Bluetooth laptops can be in constant communication. For accurate characterization, it is essential that the Bluetooth interference signal be invariant of the characteristics of the 802.11b signal. The isolator ensures that the signal transmitted by the 802.11b device is not fed back into the Bluetooth causing any complex behavior.

This setup allowed fine control over the signal and interference powers. The power output of each wireless device was measured using a diode detector. The Signal-to-Interference computation was performed using this measured power and taking into effect the measured attenuation through each RF component.

A similar setup was used to characterize the interference of 802.11b transmission on the Bluetooth devices (Fig 7).

3.2 Effect of Bluetooth upon 802.11b

A piconet was formed between the two Bluetooth laptops and an HV1 audio connection was setup between them. The HV1 packets are sent once every two time slots . This is a fairly active Bluetooth link. This constituted the interfering traffic source. The 802.11b laptops were configured to use the 11Mbps data rate without using Auto Fallback[1]. Data was transmitted from the 802.11b Transmitter to the 802.11b Receiver using UDP (User Datagram Protocol). The data was transmitted at a rate of 5 Mbit/s user data rate (excluding UDP, IP and 802.11b MAC layer overhead). Each transmitted packet contained 1470 bytes of user data. For each measurement, 100 MBytes of data was sent from the 802.11b Transmitting laptop to the 802.11b Receiving

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[1] Auto Fallback allows the card to switch to a lower data rate when transmission conditions become difficult.

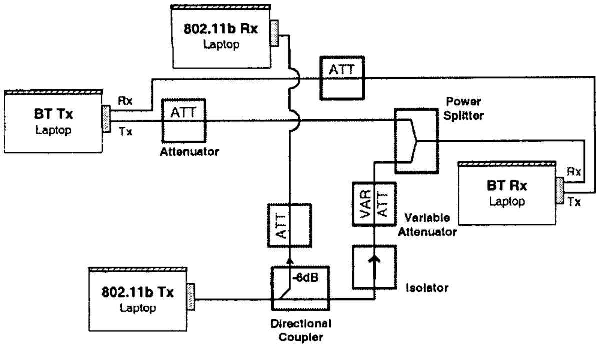

Figure 7. Lab Setup for measuring the effect of 802.11b Interference on Bluetooth

laptop. The traffic was sent using the *iperf* [5] network performance measurement program. Statistics about lost packets and effective bandwidth were collected at the 802.11b Receiving laptop.

The signal level was adjusted to a few different levels and for each level, the interference power was varied to change the S/I (Signal to Interference) ratio.

3.3 Effect of 802.11b on Bluetooth

A piconet was setup between the two Bluetooth laptops and an IP based network connection was established. UDP data was transferred from the Bluetooth transmitting laptop to the receiving laptop using the *iperf* program. Each transmitted packet contained 289 bytes of user data. The packets were chosen to be able to efficiently use the largest available Bluetooth frames, the DH5 frames. The packets were generated at a rate equivalent to a 250 Kbit/sec stream (user data). For each measurement, 10 MBytes of data were sent by the transmitting node. Statistics were collected at the receiving Bluetooth laptop. Interference was provided by an 802.11b laptop sending UDP traffic at a bit rate of 5 Mb/sec.

3.4 Results and Observations

Figure 8 illustrates the effect of the Bluetooth devices on the 802.11b system. Packet loss is high when the S/I (Signal to Interference) ratio is low. As this ratio is increased, packet loss decreases. Similarly the effective bandwidth [2] goes up as the relative power of the interference decreases.

A comparison of Figure 8 with Figures 2 and 3 shows that the outdoor experiment exhibited more severe performance degradation than the laboratory measurement for similar S/I ratios. In making this comparison it should be pointed out that the signal levels were less precisely known

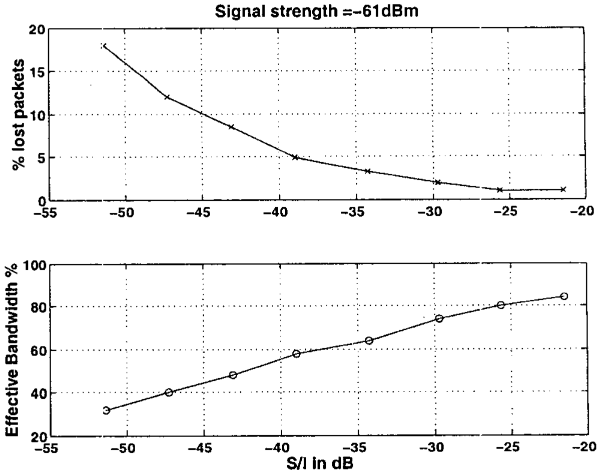

Figure 8. Performance of 11Mbps 802.11b devices in the presence of Bluetooth interference.

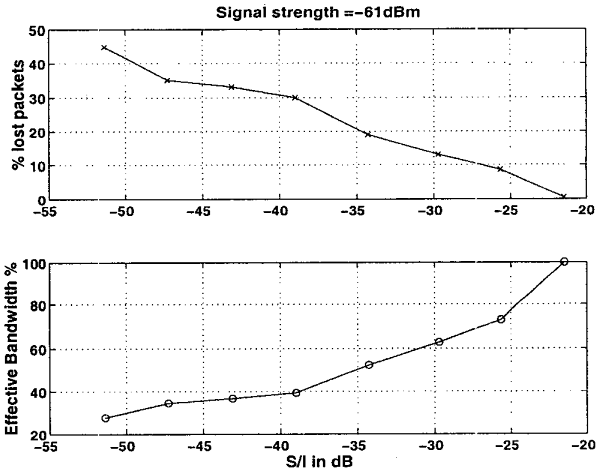

Figure 9. Performance of 2 Mbps 802.11b devices in the presence of Bluetooth interference.

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[2] Effective bandwidth is used here to refer to the ratio of the bandwidth attained under interference conditions to that attained without interference, at the same transmission rate.

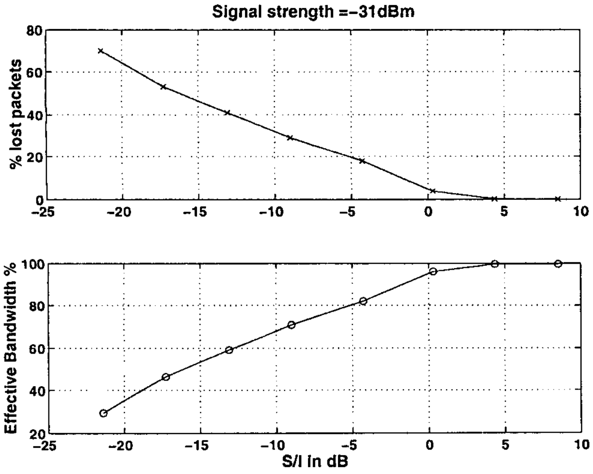

Figure 10. Performance of Bluetooth in the presence of interference.

in the outdoor experiment, and interference was offered by both Bluetooth nodes rather than one.

Figure 9 shows the effect of Bluetooth interference upon a 2 Mbps 802.11b system, all other parameters being the same. A similar traffic pattern was used in this case. The total amount of data transferred was the same but it was sent at a rate of 1 Mb/sec. The packet sizes were the same.

It is interesting to note that the 2 Mbps connection does worse than the 11 Mbps transmission, contrary to intuition. The time taken to transmit a single packet using a 2 Mbps 802.11b system is 5.5 times that taken to transmit it using a 11 Mbps system. For example, a UDP packet with a payload of 1470 bytes will take about 6 ms to transmit on the air at a data rate of 2 Mbps. This covers the duration of about ten Bluetooth hops. The increased transmit duration increases the vulnerable period for a Bluetooth collision. Since the loss of any part of the packet causes the loss of the entire packet, the packet loss rate is actually higher with the 2 Mbps system. This has been predicted by theoretical models [6].

As interference increases (S/I decreases), the decrease in the effective bandwidth of the 802.11b systems is disproportionately greater than the increase in the packet loss rate (Fig 8, Fig 9). For example, a packet loss rate of about five percent corresponds to an effective bandwidth of about sixty percent of maximum (Fig 8). Packet losses are not the only form of performance degradation. The MAC (Media Access Control) protocol of the 802.11b devices defers transmission if the channel appears busy. High levels of interference can cause the 802.11b device to defer transmission until a later time. This causes significant degradation in performance even when the packet loss rate is relatively low.

Figure 10 shows the Bluetooth performance under a range of interference levels. As opposed to the 802.11b devices, since the Bluetooth does not perform carrier sensing before transmission, the attained bandwidth is directly related to the percentage of lost packets. A packet loss rate of 20% results in a bandwidth of 80% of the maximum attainable.

Since each UDP packet that was transmitted by the Bluetooth was contained in a single DH5 frame, one would expect the Bluetooth to overlap in frequency and time with the 802.11b at most 1/3 of the time, and therefore the packet loss rate would not exceed this. However, our laboratory measurements with fixed-frequency CW interference signals suggest the much larger packet loss rates result from limited frequency selectivity of the Bluetooth receivers.

4 Summary

Our measurements show that 802.11b gives reasonable performance (Pr[Packet Loss] ≤ 0.1) even when the Bluetooth interference is 10dB or more stronger than the desired signal. However, effective data bandwidth degrades more rapidly than the packet loss rate owing to deferred transmissions caused by the CSMA/CA protocol in the presence of interference. Effective antenna patterns also strongly affect the susceptibility to the interference.

In contrast, Bluetooth performance starts to degrade rapidly when the interfering 802.11b signal is comparable to the desired signal, and reduction in data bandwidth tracks the packet loss rate since the Bluetooth protocol does not attempt carrier sensing.

5 Acknowledgements

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