

Evaluation of Interference Between IEEE 802.11b and Bluetooth in a Typical Office Environment

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ABSTRACT

Both 802.11b and Bluetooth operate in the 2.4GHz ISM band and both these standards are expected to become prevalent in the near future. Thus, interference poses a major problem. The IEEE 802.15 Wireless Personal Area Networks (WPAN) group has done extensive mathematical modeling and simulation on this subject, but very little work has been done with actual Bluetooth and 802.11b radios with respect to actual office usage. This paper deals with actual radio interference experiments conducted in a typical office environment.

1. INTRODUCTION

Wireless Communications is an evolving technology in today's society. In order to control the diversity of developed products, the Institute of Electrical and Electronics Engineers (IEEE) created the 802.15 Working Group for Wireless Personal Area Networks (WPAN). This group addresses wireless networking of portable and mobile computing devices, and develops standards that allow for coexistence and interoperability among the differing product brands. One such standard, the IEEE 802.11, governs the operation of products in wireless local area networks (WLANs). These products are used in WLANs to establish wireless links that cover a fairly large area instead of using long wire connections. Although the 802.11 standard has existed since 1990 and been implemented in WLANs worldwide, Ericsson has constructed a new, emerging scheme. [8]

Ericsson's new technology, known as Bluetooth, is useful for replacing short-range cables in WLANs as well as other computer equipment and communication products. Both IEEE 802.11 and Bluetooth products operate at the 2.4 GHz International Scientific and Medical (ISM) frequency band; therefore, concern over interference arises when 802.11 and Bluetooth devices operate in the same environment. However, due to their differing operational protocols, interference may not cause as many problems as it first appears. Out of the seventy-nine 1 MHz channels available in the ISM band, the operating regions of IEEE 802.11 and Bluetooth only overlap in twenty-six.(Figure 1). [11]

The IEEE 802.15 WPAN completed theoretical work on 802.11/Bluetooth interoperability. However, all conclusions were based on a mathematical premise. Also, various assumptions were made in the calculations, including superficial and rule of thumb assessments. Furthermore, the calculations do not take into account situations when both are operating in close proximity to one another. The IEEE 802.15 WPAN admits that practical tests are needed for more conclusive assessments.

The dilemma of interference requires further investigation with emphasis on practical tests. Thus, the goals of this work were to design a test bed containing both IEEE 802.11 and Bluetooth radios in order to examine the effects of interference and to develop recommendations on how the different devices can be used in the same environment. A typical office environment was the motivation behind the scenarios investigated.

This paper is based on a Major Qualifying Project (MQP) completed by 4 undergraduates at Worcester Polytechnic Institute (WPI) under the supervision of Professor Kaveh Pahlavan. [1] We will first outline the technical background required to understand the methods used. We will then present our test scenarios followed by results and conclusions.

2. TECHNICAL BACKGROUND

IEEE 802 protocols are based on a layered hierarchy. The user is at the top level from which data is broken up into packets in the Transport Protocol and Logical Link Control levels. All packets consist of a packet header that contains network address information and a payload that contains the user data. These packets are sent to the Medium Access Control layer, which makes sure packets are sent to the correct station without collision. The physical layer is the level where the packets are actually sent and received. At the physical layer, the 802.11 standard allow for implementation of two transmission schemes: Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS).

The most commonly used PHY scheme is DSSS, which uses Binary Phase Shift Keying (BPSK) to modulate the information signal with a digital signal. Alternately, FHSS transmission requires a Frequency

Shift Keying (FSK) code to shift the instantaneous frequency output of the incoming data stream from one value to another. Both of these schemes share a common Medium Access Control layer, which includes mechanisms to provide conflict free access control. The fundamental access method defined by 802.11 standard is known as Carrier Sense Multiple Access with collision avoidance (CSMA/CA). Collision avoidance is necessary because it is difficult to detect collisions in a RF transmission network. CSMA/CA works by having the radios listen to a defined channel to determine if another station is transmitting. In our testing, we used 20dBm DSSS Lucent Orinoco 802.11b 11Mbps PC cards.[9]

Bluetooth radios operate in the 2.4 GHz ISM band and use the Frequency Hopping Spread Spectrum scheme in order to make links more robust. This is accomplished by designating 79 hop frequencies, each displaced by 1 MHz

Bluetooth radios attempt to avoid interference by hopping to a new hop frequency after transmitting or receiving either a data or voice packet. Compared with other systems in the ISM band, Bluetooth typically hop faster (1600 hops/s) and use shorter packets, making them more robust. In addition, they use Forward Error Correction (FEC), which limits the impact of random noise. These radios utilize Gaussian Frequency Shift Keying (GFSK); therefore, all channels support a 1 MHz transmission rate. Under the Bluetooth protocol specifications, packet slots are defined as 625 μ s in length and use a Time Division Duplex scheme where master alternates time slots with a slave. Bluetooth networks are typically called piconets, which are devices connected via Bluetooth technology in an ad hoc fashion. A piconet is initially established by two connected devices and may grow to contain a maximum of six. In our testing, we used 20-dBm Digianswer Development Module PC cards. [4]

The interference evaluation of Bluetooth and 802.11b required the integration of software packages from both products. The Bluetooth Demo Cards need to execute their own Bluetooth Neighborhood program for connection establishment.[2] The Bluetooth data channel performance was evaluated using the Harris LanEval software while the voice channel performance was evaluated using the Bluetooth Statistics Viewer. This separation of data and voice packet testing allowed us to be much more methodical in our evaluation and analysis.

The monitoring of wireless performance of the WaveLAN network fell upon the WaveManager/Client diagnostic utility. The software displays the quality of communication between independent stations and the access points. The WaveManager tool displays the effective placement of the access points and signals the actual point of hand-off. [1]

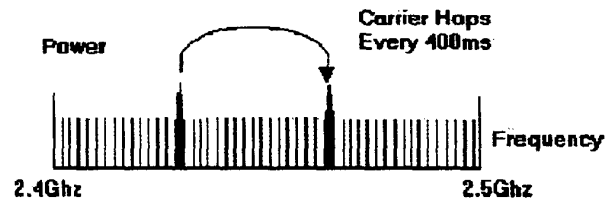


Figure 1. Interference between direct sequence (DSSS) and frequency hopping(FHSS) modulation schemes.

3. TEST SCENARIOS AND PERFORMANCE METRICS

In the course of our testing, we investigated 6 scenarios for interference in a typical office environment. However, only 2 of them yielded conclusive results. The other scenarios (concerning hand-off, wall interference etc) may shed further light on interoperability performance, but further investigation must be carried out. The diagrams illustrating the 2 relevant scenarios are shown in Figures 1,2 and 3. In all these diagrams, STA refers to the 802.11b stations whereas BT refers to the Bluetooth stations used in our testing.

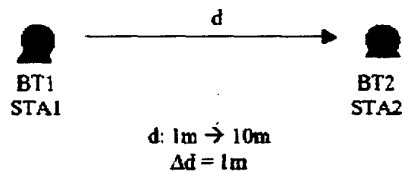


Figure 2. Schematic of simultaneous ad hoc radio application. The two units were moved 10m apart in 1m increments starting at 0m.

The first scenario, illustrated above in Figure 1 is straightforward and involves both cards operating in the same laptop or computer. We could not physically place both cards in the same computer owing to transmitter size, so we placed the cards such that both transmitters were directly adjacent to each other to simulate same computer operation.

The second scenario, illustrated below in Figures 2 and 3 shows the effect of one transmitter on a wireless link in an open office environment. Figure 2 shows the scenario that investigates the effect of

Bluetooth on 802.11b while Figure 3 shows the converse scenario i.e. the effect of 802.11b on Bluetooth. The second "interfering" unit (BT2 in Figure 2 and STA2 in Figure 3) in each scenario was present only to set up a transmitting link.

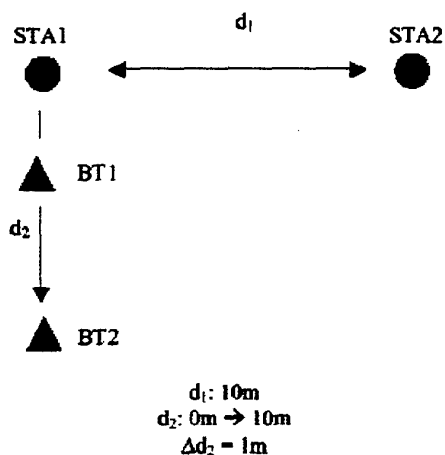


Figure 3. Effects of one interferer on IEEE 802.11b in an open office environment ad hoc network. BT2 was removed far enough that it would not interfere with the 802.11b link.

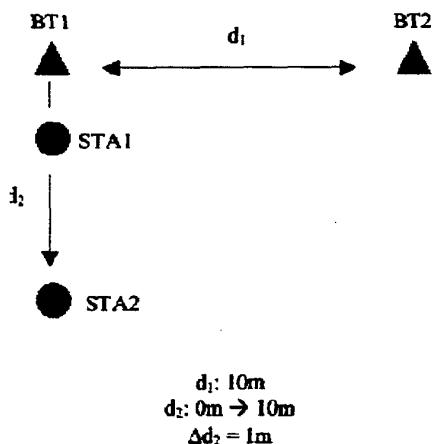


Figure 4. Effects of one interferer on Bluetooth in an open office environment ad hoc network. STA2 was removed far enough that it would not interfere with the Bluetooth link.

For all these scenarios, the following three Medium Access (MAC) layer performance metrics were evaluated using either the Harris LanEval software, the

Digianswer Bluetooth diagnostic software or the Windows PING utility:

1. Packet Error Rate- percentage of bad packets of all received packets.
2. Throughput- effective data rate at the receiving end.
3. Ping Time-Round trip time for one 32byte poll packet.

The first two metrics deal with high traffic situations whereas the third deals with low traffic situations for the link being investigated. [5]

For Bluetooth, we had problems with objective data collection when both voice and data channels were operating at the same time. Hence, we separated the voice and data scenarios to obtain conclusive results and to maintain a methodical approach to our testing, as already stated.

4. RESULTS

a. Bluetooth and 802.11b in One Computer

The following graphs (Figures 4 and 5) summarize our results for the scenario in Figure 1.

Packet Loss Rate of Bluetooth in an open office environment ad hoc network: Bluetooth data and 802.11b DSSS used in the same computer

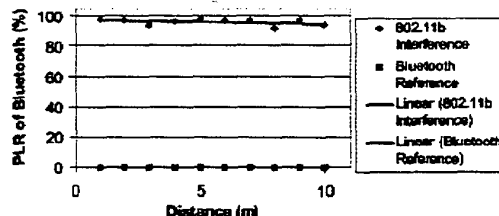


Figure 5. PLR for BT data with 802.11b interference on the same computer.

Throughput of Bluetooth in an open office environment ad hoc network: Bluetooth data and 802.11b DSSS used in the same computer

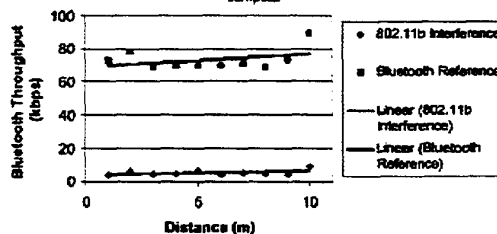


Figure 6. Throughput for BT data with 802.11b interference on the same computer.

The ping times for both wireless standards timed out. Bluetooth voice and data and 802.11b data exhibited similar behavior, with Bluetooth voice performance being slightly better owing to its lower piconet utilization. Voice quality was terrible, as one would expect.

This scenario showed that the two standards, in the form that they exist, cannot operate in the same laptop or in close proximity. The results are much worse than the theoretical predictions of about 67% [3], as we see a virtual obliteration of throughput (~0kbps) and intolerably high packet error rates (~99%).

b. Effects of One Interferer on Network Performance

In this scenario, illustrated in Figures 2 and 3, we observed very good correlation between theoretical predictions and experimental data. Furthermore, as we can see from the sample graphs below, the 3m mark proved to be a very important distance between the two interferers as beyond this distance, we observed no more interference. This shows that at very close range, some other effects beyond probabilistic collisions are occurring to reduce network performance.

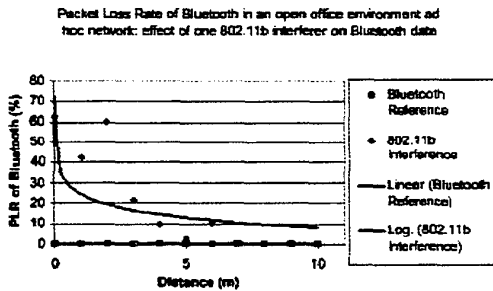


Figure 7. PER of BT data piconet with one 802.11b interferer.

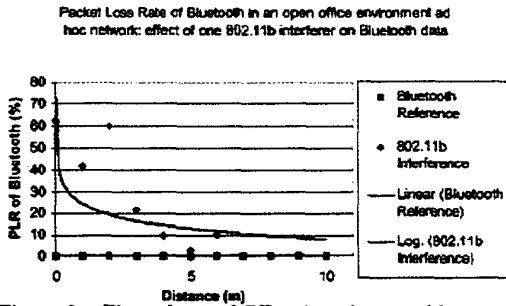


Figure 8. Throughput of BT voice piconet with one 802.11b interferer

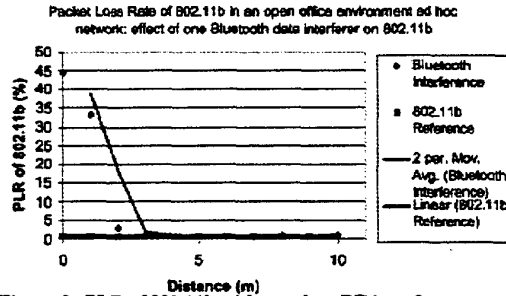


Figure 9. PLR of 802.11b with one data BT interferer

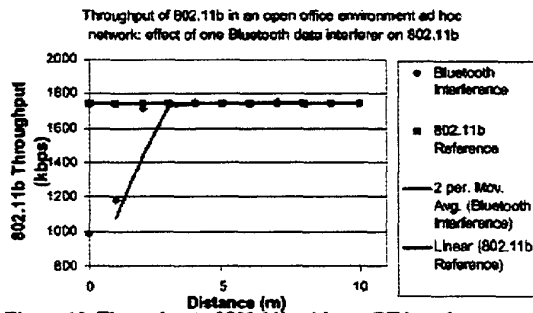


Figure 10. Throughput of 802.11b with one BT interferer

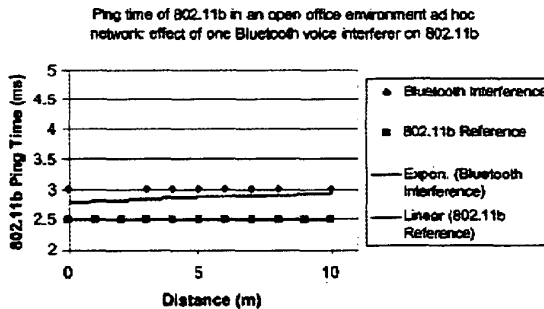


Figure 11. Ping time of 802.11b with one BT voice interferer

The 2 standards both showed very good performance after 3m, and could be used in low traffic situations at smaller distances (~1m), as seen from the ping results, which did not yield much insight. The ping results were all very similar, with similar ping times for all distances.

We can make two observations from our measurements for this scenario. First, throughput and PER for 802.11b, in general, follow the 67% collision rule discussed in the Ennis paper [3] as soon as the two cards are moved slightly apart (0.2m), which was done for the 0m readings. The BT voice shows the 33% degradation as expected from its lower piconet

utilization. The BT data exhibits a higher degradation, but this could again be because of the strange results seen in the first scenario.

The second major observation is that the 3m mark seemed to have a special significance for performance (as already noted), which was due to the interferer's power being inadequate to cause packet loss for the communicating network. Also, the variation of performance approaching the 3m mark was different for both standards. This can be explained by the different modulation techniques used by the two standards.

The first observation reinforces the conclusion drawn in the Ennis paper regarding the throughput elimination at 0m. There must be other effects influencing network performance. The second observation shows the power sensitivity of the two standards with each other.

c. Other Scenarios

The other scenarios did not yield conclusive results but did hint at Bluetooth being a fairly robust standard at larger distances from 802.11b.

802.11 FHSS seemed to be very vulnerable to Bluetooth interference whereas Bluetooth was very robust due to its high hopping rate.

2.4GHz phones did not have a substantial effect on Bluetooth performance according to our preliminary investigations, probably due to high hopping rates.

5. CONCLUSIONS

We can clearly see that it is unfeasible at this time for the IEEE 802.11b DSSS and Bluetooth radios to reliably operate simultaneously in the same computer. More specifically they will completely cancel or "kill" each other. For both data and voice transmission the packet error rate was 99% and the throughput was reduced virtually to zero once the radios were turned on. The Ping time did not even register. This indicates the complete elimination of reliability for the 802.11b DSSS as well as Bluetooth when operating in the same computer. It is important that more research be conducted to study this phenomenon, as it cannot be completely explained by stochastic analyses.

For the most reliable data transfer rates, it is necessary to keep IEEE 802.11b DSSS and Bluetooth radios at least three meters apart. Throughout our testing we noticed a drastic improvement in packet error rate, throughput, and ping time upon reaching the three meter mark. Upon reaching and passing this mark the packet error rate, throughput, and ping would almost return to their reference levels. As already stated, this was due to the interferer's power being inadequate to cause packet

loss for the communicating network. This also showed that at larger distances between the 2 standards, traditional probabilistic analyses can be used to explain performance.

Recommendations for Future Work

Our work is not exhaustive by any means. More comprehensive office scenarios must be investigated to get an understanding of how Bluetooth and 802.11b DSSS interfere.

Furthermore, we used 20dBm radios for Bluetooth instead of the projected 0dBm typical power usage in the market. Thus, more work needs to be done on lower power Bluetooth radios.[6]

More work on Bluetooth reliability with 802.11 FHSS standards could be done to improve interoperability.

6. ACKNOWLEDGEMENTS

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