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# Empirical Study of 802.11b Wireless Networks in the Presence of Bluetooth Interference

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*Abstract: Two complementary wireless networking standards, Bluetooth and 802.11b, operate in the 2.4 GHz Industrial, Scientific, and Medical (ISM) band. Although they use different methods to modulate and transmit data, significant interference can occur. Under certain conditions, a Bluetooth-enabled device can render an 802.11b connection almost useless. This paper presents measurement results from a study on the throughput of an 802.11b link when one end of the link is subjected to interference from Bluetooth devices.*



## I. Introduction

Wireless networks are rapidly becoming commonplace in businesses, homes, and schools. These networks have made Internet access more available than it has ever been in the past — a user can roam up to 100 m away from an access point and still remain online. One of the most popular medium-range wireless networking standards is 802.11b, which operates in the 2.4 GHz band.

Another fast-growing wireless technology is Bluetooth, which comes standard with many new cellular phones and handheld computers. It is intended for short-range (generally 10 m or less) cable replacement. Although its goals differ from those of 802.11b, it shares the same 2.4 GHz Industrial, Scientific, and Medical (ISM) band with 802.11b devices. This unlicensed band extends from 2400 to 2483.5 MHz in the United States.

Although Bluetooth and 802.11b use the same frequency range, their signals are distributed over this range in completely different ways. Bluetooth is a Frequency-Hopping Spread Spectrum (FHSS) standard, where data is transmitted over a 1-MHz-wide band. Bluetooth normally 'hops' to a different frequency 1600 times per second. The scheme used by 802.11b is Direct Sequence Spread Spectrum (DSSS), where a network will occupy a fixed 22-MHz-wide frequency band. The power in this band is not constant — it is weighted so that the frequencies near the center of the band carry more information.

The performance of 802.11b, though tolerant of some fixed narrowband interference, can be devastated by an FHSS scheme such as Bluetooth's. If the Bluetooth transmitter hops into the frequency band occupied by an 802.11b network, it is likely that the current 802.11b packet will be corrupted, requiring a retransmission. Because of the fast hop rate, there is ample opportunity for these collisions to occur.

Several excellent coexistence mechanisms have been developed — either by using traffic-shaping or other means — but none are in widespread use [1, 2].

Although many papers have been published about the interference between Bluetooth and 802.11b systems, few have presented any empirical data. Much of the available data was gathered in idealized environments [3], where Bluetooth and 802.11b devices were connected via coaxial cable and not permitted to radiate RF energy. The aim of this paper is not to endorse or refute any proposed interference models, but simply to present the results of our real-world study in the hopes that it may be useful to other researchers.

## II. Test Setup

The focus of our tests was to gather sufficient data to draw basic conclusions about the robustness of 802.11b links. We did not attempt an exhaustive analysis of the mechanics of the interference between the two protocols, as this type of work has already been carried out several times before [4, 5]. Rather, we examined one specific real-world setup.

We configured a simple wireless network — one 802.11b-equipped laptop associated with one access point. The access point was connected to a 100 Mbps ethernet switch. Also connected to the switch was a desktop computer running an FTP server. (This is similar to the setup used in [6].)

In order to characterize the performance of the 802.11b link, we tested its speed at nine evenly-spaced Signal-to-Noise Ratios (SNRs) between 10 and 50 dB. At each signal level, we ran speed tests without Bluetooth interference and with one nearby Bluetooth unit transmitting. At SNRs of 50, 30, and 10 dB, we also measured the speed with two and three Bluetooth interferers.

To measure the SNR of the 802.11b network, we used a piece of software that displayed the current received signal and noise levels reported by the 802.11b card. (All SNR measurements were conducted before Bluetooth interference was introduced, as Bluetooth activity raises the noise floor and greatly affects the SNR.)

Our equipment was set up in a relatively complex environment, electromagnetically speaking. There were many metal surfaces present in the test area, so multipathing was inevitable and signal paths were difficult to predict. We feel that this is typical of the situations in which 802.11b and Bluetooth are used.

To test the speed of the link, the laptop computer would download five large files from the FTP server, and the transmission time would be recorded for each file. The files were either 50 MB or 20 MB, depending on the predicted speed of the link.

For our interferers, we acquired six Bluetooth transceivers and installed them in computers. A file transfer was set up between one pair of transceivers to simulate Bluetooth activity and to create a constant source of interference. The transmitting radio was placed 1 m away from the laptop's 802.11b radio. Up to three interferers could be created in this manner.

The power output of the 802.11b radios in the access point and the laptop was 15 dBm, and the Bluetooth interferers transmitted at 10 dBm. All power-saving and encryption features were disabled to allow the radios to perform at their full capacity.

## III. Measurements and Results

Without any Bluetooth interference, the throughput of the 802.11b network stayed relatively constant for SNRs above 10 dB (Fig. 1). At 10 dB, the network speed dropped by approximately 50%. This is consistent with how 802.11b functions — for strong signals,

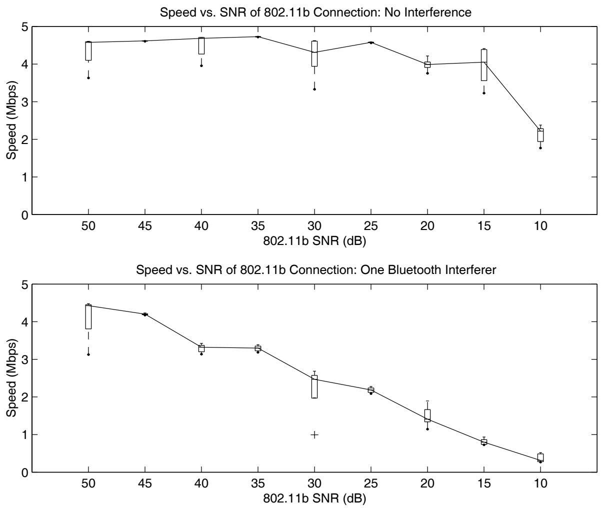


*Fig. 1: Speed vs. SNR of 802.11b*

the network sends data at 11 Mbps. However, when the signal level drops below a certain threshold (-82 dBm for our particular wireless card), the rate is rolled back to 5.5 Mbps. The signal level was -86 dBm when the SNR was 10 dB, so we believe that this feature was the cause of the large discontinuity in our results.

When one interferer was introduced, the throughput graph of the network changed drastically. The highest SNRs were nearly unaffected, but the speed of the network decreased almost linearly with the SNR — even after the network rate change that happened between 15 dB and 10 dB.

(Note that the single-interferer measurements performed with an SNR of 40 dB are anomalous, in that they are almost identical to the measurements taken at 35 dB. It is possible that the tester inadvertently changed the SNR during the test by moving too close to the 802.11b laptop's radio, or simply by changing his position slightly and attenuating a reflected signal. Also, an intermittent source of 2.4 GHz interference, such as a leaky microwave oven, may have been active near the lab during that particular test.)

By computing the median percentage drop in link speed caused by one Bluetooth interferer, one can see that the plot is almost perfectly linear between 15 dB and 45 dB, except for the 40 dB point discussed previously (Fig. 2). This result suggests an important notion. It appears that there is no 'magic SNR' at which a Bluetooth device will suddenly start crippling the throughput of 802.11b networks — an increase of the SNR by a few decibels will not significantly change a device's susceptibility to Bluetooth interference.

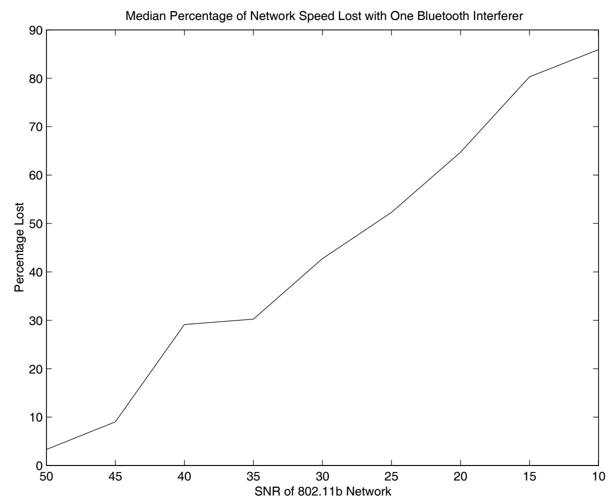


*Fig. 2: Percentage of Speed Lost vs. SNR of 802.11b*

The effects of additional Bluetooth interferers were heavily dependent on the SNR of the 802.11b connection (Fig. 3). At 50 dB, the network operated at a median speed of 3.8 Mbps, compared to 4.6 Mbps without interference. At 30 dB, the speed transfer test only successfully completed with one or two interferers (the FTP connection could not be sustained with three Bluetooth transmitters present). When subjected to two interferers, the network speed dropped to less than 1 Mbps. With an SNR of 10 dB, the speed test would fail if more than one Bluetooth device was active. The median data rate with one interferer was 0.312 Mbps.

Although the degradation of the network speed appears linearly correlated with the number of interferers, more testing is needed to confirm this relationship. The slope of the speed-versus-interferers graph is heavily dependent on the SNR of the 802.11b network, and further data is required in order to determine how the slope changes with the SNR.

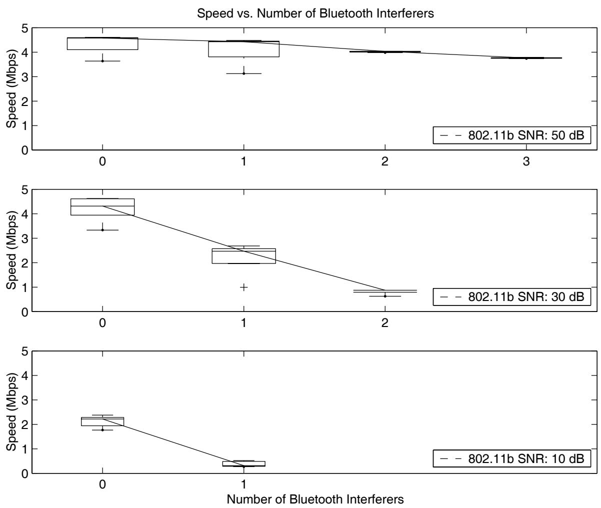


*Fig. 3: 802.11b Speed vs. Number of Interferers*

## IV. Conclusions

Although Bluetooth and 802.11b devices can coexist under many circumstances, some Bluetooth setups can cripple an 802.11b link. At SNRs below 20 dB, over two thirds of the network speed can be lost by introducing one nearby Bluetooth interferer. Two or more interferers at an SNR of 30 dB or less can also severely impact performance.

The most surprising result is the linear correlation between the SNR of the 802.11b network and the speed loss caused by one Bluetooth interferer. We see that the 802.11b link is predictably affected by Bluetooth interference, and that there is no point at which Bluetooth devices suddenly start affecting performance — they always have some effect, even at high SNRs. Although the effects of two or more Bluetooth interferers seemed to follow a linear trend as well, this relationship requires more research.

With more empirical study, it may be possible to evaluate the existing interference models, and find one which can be used to reliably predict the effects of Bluetooth-802.11b interference under a variety of conditions.

## V. References

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