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Wireless LANs

Extension of Bluetooth and 802.11 Direct Sequence Interference Model

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Abstract

A basic model of the effects of interference generated by a Bluetooth piconet co-located with a high speed DSSS IEEE 802.11 wireless node was described in an earlier paper entitled “Impact of Bluetooth on 802.11 Direct Sequence” (Doc: IEEE P802.11-98/319). Basic assumptions used in the original paper are discussed and refinements are suggested. Results using the modified model are presented. The impact of 802.11 Direct Sequence on Bluetooth is not considered in this paper.

1.0 Introduction

The effects of interference between the various wireless standards and specifications now proliferating in the 2.4 GHz band is matter of growing interest. An earlier paper, “Impact of Bluetooth on 802.11 Direct Sequence” [1] has already described a basic model for estimating the interference between a Bluetooth (BT) piconet and a co-located IEEE 802.11 Direct Sequence (DS) station. The DS station (STA) is some arbitrary distance from the DS Access Point (AP). Results were presented showing the degradation in 802.11 network throughput as a function of piconet utilization and of packet fragment size.

The basic model rested on the assumption that due to the close physical proximity of the BT piconet and the DS node, that any overlap in frequency and time between BT traffic and a downstream (AP-to-STA) DS packet resulted in a DS packet error. Upstream DS traffic (STA-to-AP) is largely unaffected because the BT piconet would not be in close proximity to the AP. Interference from a co-channel BT burst would be approximately 20 dB below the DS upstream signal at the AP receiver. This assumption is retained in the modified model.

Model Feature	P802.11-98/319	Proposed Modification
Probability of co-channel interference	33%	25%
Packet s	long preamble & header (192 µsec)	short preamble & header (96 µsec)
BT Interference Profile	same as dwell period (625 µsec)	BT burst 366 µsec long, 625 µsec period
Modified Inter Frame Spacing on dropped fragment	ACKTimeout + DIFS + 7 slot times	ACKTimeout + DIFS + 15 slot times

Table 1-1 Proposed Modifications to Interference Model

The basic model also included many simplifying assumptions, as summarized in Table 1-1. While the basic model remains intact, some of the underlying assumptions can be refined. A modified set of assumptions is therefore also included in Table 1-1. These proposed modifications are described in detail in the following paragraphs and form the basis for this paper.

2.0 Mixed Bluetooth / 802.11 Topology

The relative geometry of the BT and DS networks is shown in Figure 2.1. For the situation described, dominant traffic flow is downstream (AP-to-STA). Due to the topology under consideration, only downstream traffic will be affected by BT interference. For upstream traffic (ACK packets in this case), the STA has a 20 dB advantage over the BT transmitter, assuming a 0 dBm BT Tx power. As will be described later, when the direction of dominant traffic flow is reversed, the impact of BT interference is significantly reduced.

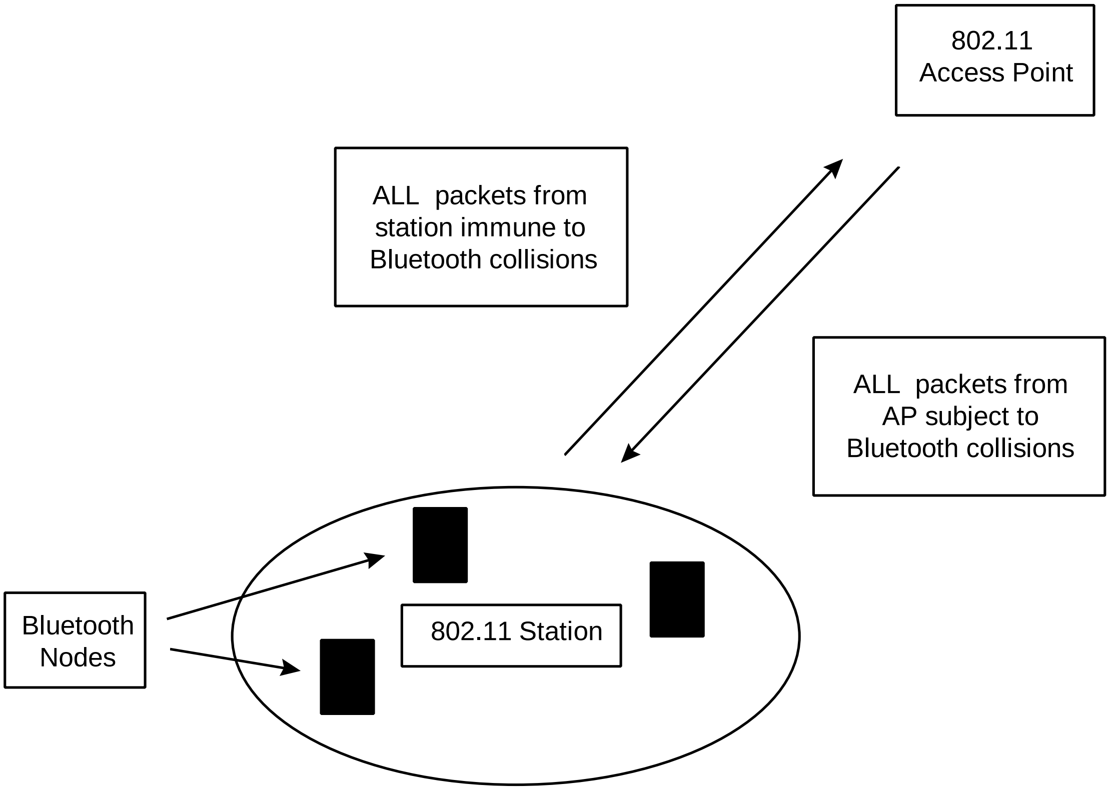

Figure 2.0-1 Relative Geometry of BT and DS Radios

3.0 Modified Assumptions

As described above, the basic model included several simplifying assumptions. The baseline assumptions can in some cases be refined. Suggestions for refinement are described in detail in the subsequent paragraphs of this section.

3.1 Probability of Co-Channel Interference

Co-channel interference will occur when a BT transmitter hops into the occupied channel of a DS network. In order to determine the probability of this situation, the effective bandwidth of the DS system must be estimated. Figure 3.1-1 shows a measured plot of CW jammer suppression for the CCK waveform as a function of frequency offset from center frequency. For this discussion, the important feature of the plot is the jammer suppression at +/- 10 MHz from band center. Note that suppression is 10 dB greater at +/- 8.5 MHz from center, relative to suppression near band center. At +/- 10 MHz suppression is about 15 dB greater than at band center. Effective DS receiver bandwidth for estimating the effect of narrowband interference, such as a 1 MHz wide BT signal, is therefore taken to be 20 MHz.

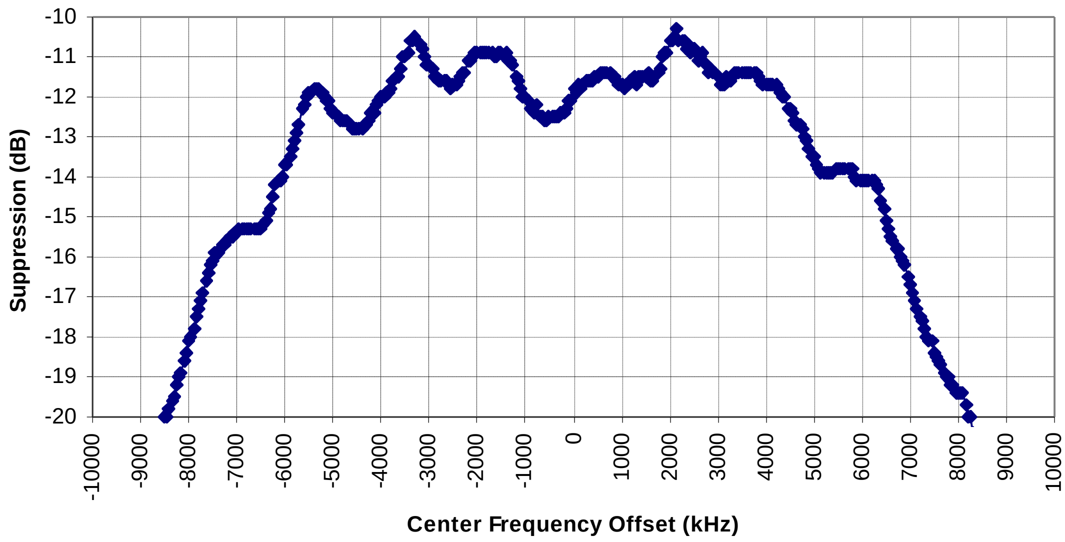

Figure 3.1-1 11 Mbps CCK CW Jammer Suppression

The probability that a co-located BT piconet will hop to a frequency in the DS passband is therefore:

$$P_{int} = 20 \text{ MHz} / 79 \text{ MHz} \sim 1/4$$

It is perhaps worthwhile to explain that the frequency response to narrowband interference shown in Figure 3.1-1 is due to the combination of the IF filter and the effects of the receiver correlation process. Consider the situation shown in Figure 3.1-2 where a jammer appears near the band edge. The IF filter has a 3 dB bandwidth of 17 MHz. For a jammer located 11 MHz from center frequency, it provides perhaps 5 to 6 dB of rejection.

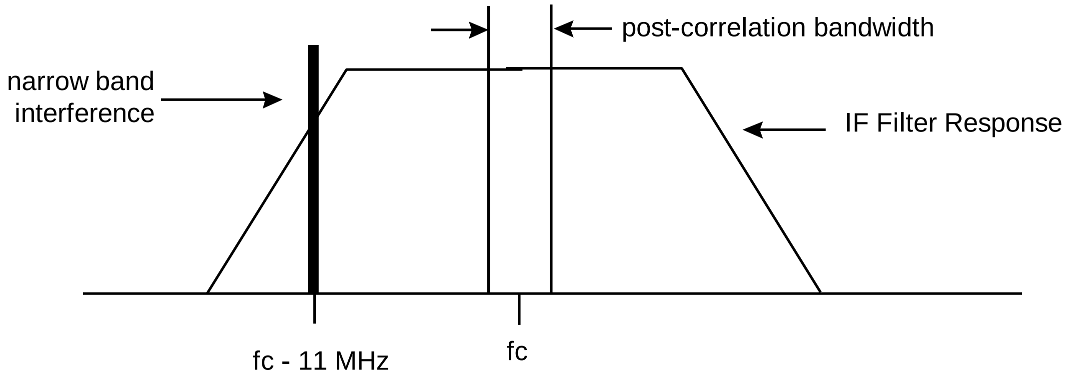

Figure 3.1-2 Narrowband Interference Located at Band Edge

The rest of the rejection comes from the fact that the receiver combines the narrowband interference with the CCK code sequences. When correlated with the CCK code sequences, CW interference takes on a sin (x) / x distribution with a null-to-null bandwidth of 22 MHz. Note that for a jammer located 11 MHz from center frequency, the null falls directly into the post correlation bandwidth of the receiver as shown in Figure 3.1-3. Beyond 11 MHz, sidelobes of the interference PSD are much lower and the IF filter effect begins to dominate, thereby suppressing narrowband interference even further.

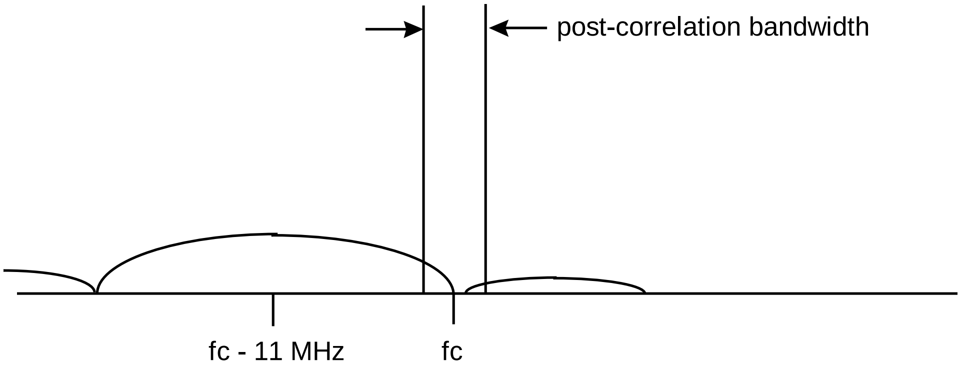

Figure 3.1-3 First Null of Spread Interferor Falls in Post Correlation Bandwidth

3.1.1 Influence of Usage Scenario

The validity of the above discussion is somewhat dependent on the BT usage scenario. More specifically, it depends on the actual range between the BT nodes and the desktop unit. For the scenario under consideration, the desktop is not associated with the BT piconet. It is therefore very unlikely that all nodes in the BT piconet would be located within 1 meter of the desktop. If the desktop were BT capable (to provide for local synchronization with a palm top computer for example), presumably it would assume the role of master in the piconet. In this instance, some positive means could be taken to prevent interference, such as preventing simultaneous use of both the DS and BT systems.

If the BT nodes are, in fact, within 1 meter, it is more accurate to assume a 1/3 chance that the BT piconet will hop into the DS passband. With such limited range loss, interferors will have to be further away from center frequency before the receiver can provide adequate rejection. Use of a 1/3 probability of interference from the BT piconet on any given hop will marginally reduce DS throughput. Under conditions of heavy BT piconet utilization, use of a 1/3 probability of co-channel interference results in a reduction in throughput of about 16% relative to the results stated below.

3.2 Packet Headers

Long packet headers were included in the basic model. However, high speed systems will be able to employ short preambles. For the purposes of this analysis, short preambles are assumed. The short preamble includes a 56 bit preamble and a 16 bit Start-of_Frame delimiter transmitted at 1 Mbps. In addition, the 48-bit PHY header is transmitted at 2 Mbps (for both 5.5 Mbps and 11 Mbps packets). Header duration is:

$$t_{header} = [72 \text{ bits @ } 1 \text{ Mbps}] + [48 \text{ bits @ } 2 \text{ Mbps}] = 96\ \mu\text{sec}$$

Packet header time is added to the time required to transmit the payload to determine total transmission time. Total transmission time is then used to determine the probability of collision. For a 1500 byte packet at 11 Mbps, the transmission time is therefore 1187 µsec.

3.3 BT interference Profile

In the basic model, the probability of collision with a BT transmission was based on the number of BT dwell periods the DS packet overlapped in time, as shown in Figure 3.3-1. In the specific example described, a DS packet which is 3.2 BT dwell periods in duration will have 20% probability of overlapping five BT transmission bursts, and an 80% probability of overlapping four transmission bursts.

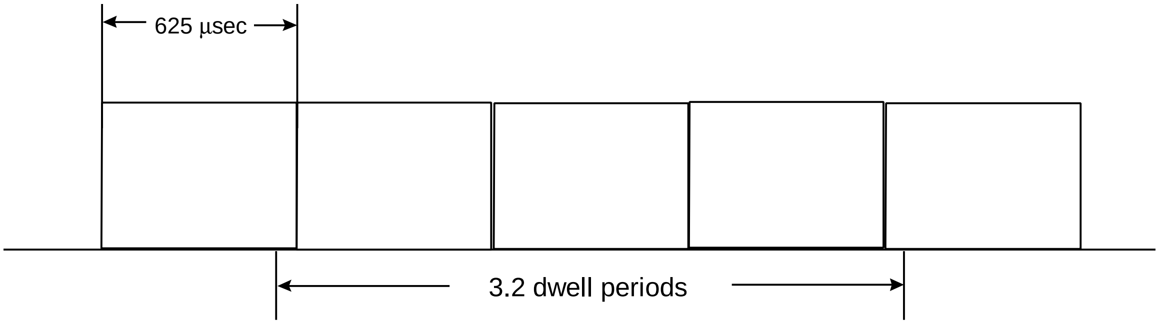

Figure 3.3-1 BT Interference Profile in Baseline Model

For single time slot packets, the BT transmission burst is 366 µsec out of the 625 µsec dwell period. If multi-slot packets are assumed, the effective hop rate is reduced. Given that the interference level is assumed to be high enough to cause a DS packet error, the single time slot packet represents the "worst case" situation. Therefore, the BT transmission profile shown in Figure 3.3-2 is used for the modified model. Based on the modified profile, a DS packet having a 3.2 BT dwell time duration will overlap 3 bursts with a 21% probability and 4 bursts with a 79% probability. Overall probability of collision is determined by a weighted average of these conditions and the fact that any given hop has a 25% probability of falling in band.

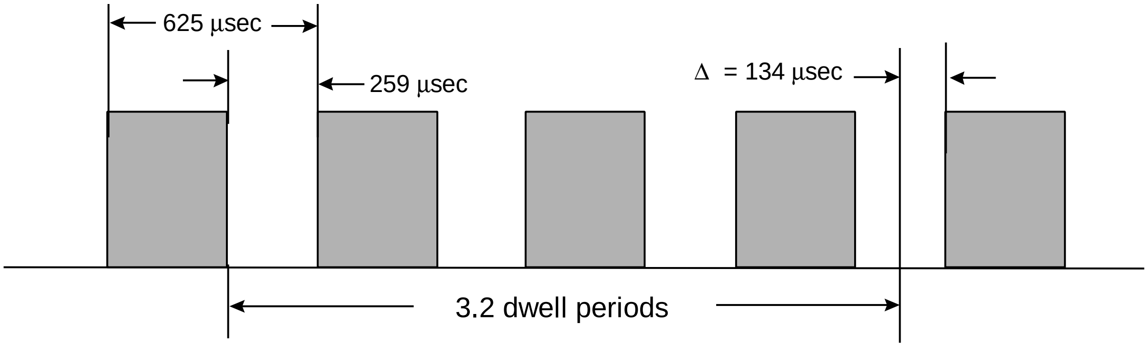

Figure 3.3-2 Modified Model of BT Interference Profile

3.4 Interframe Spacing on Dropped DS Packet

In the event a fragment is lost during transmission, the DS network must re-contend for the channel. It will enter a random back-off algorithm after determining that it has not received an ACK from the receiving STA. Therefore, in addition to the loss of the packet, a collision results in an overhead penalty. The baseline model assumes that retransmission of the dropped fragment will occur one DIFS and 7 slot times after ACKTimeout.

ACKTimeout is defined such that it represents the amount of time which would have been required to complete the ACK, thereby preventing the node transmitting the dropped packet from entering its random backoff algorithm before other stations contenting for the medium. The DS-PHY MIB indicates that the maximum number of slot times used on the first retransmission attempt (CWmin) is 31. The number of slot times used is a uniform random variable of interval (0, CWmin). The average number of slot times is 15. Therefore, in the modified model, it is assumed that retransmission of the dropped fragment will occur one DIFS and 15 slot times after ACKTimeout.

4.0 Results

Results of analysis using the modified assumptions suggested in the previous section are shown below. Figure 4.01 shows Degradation Factor as a function of Fragment Size (bytes) for various levels of BT piconet utilization. Degradation Factor measures network throughput under stated conditions of BT utilization and fragment size relative to error free transmission of 1500 byte packets on a continuous basis. The reference throughput (R) is computed as follows:

Error free throughput @ 5.5 Mbps:

$$R_{5.5} = \text{payload} / (\text{DIFS} + 15 \text{ slot times} + \text{header} + \text{payload} + \text{SIFS} + \text{header} + \text{ACK})$$

$$= 12000 \text{ bits} / 2754\ \mu\text{sec}$$

$$= 4.35 \text{ Mbps}$$

Error free throughput @ 11 Mbps:

$$R_{11} = 12000 \text{ bits} / 1653\ \mu\text{sec}$$

$$= 7.25 \text{ Mbps}$$

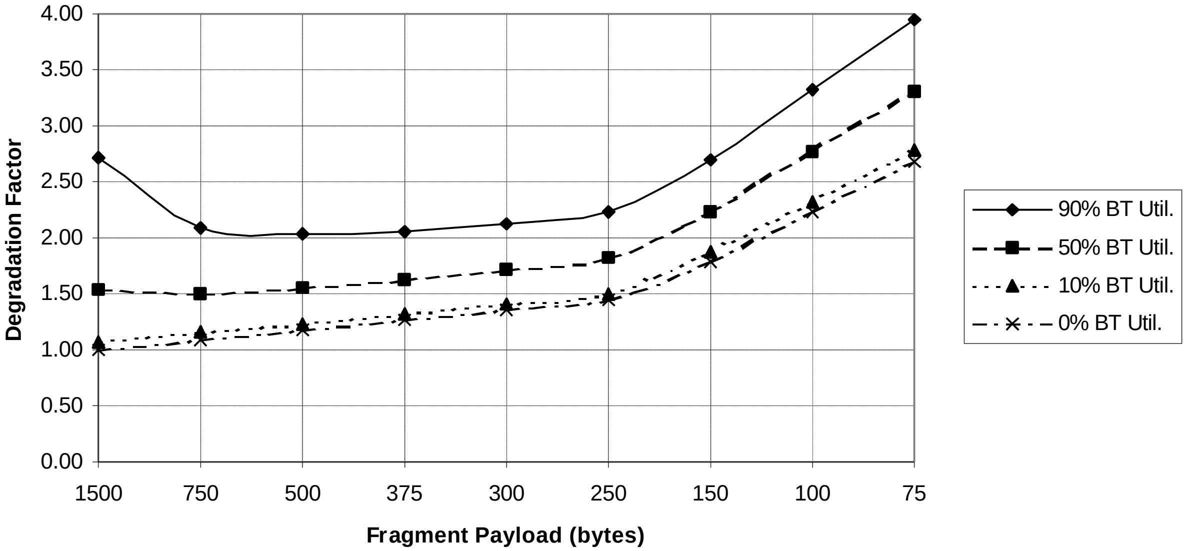

Figure 4.0-1 Degradation Factor for Transmission of 1500 Byte Packets @ 5.5 Mbps

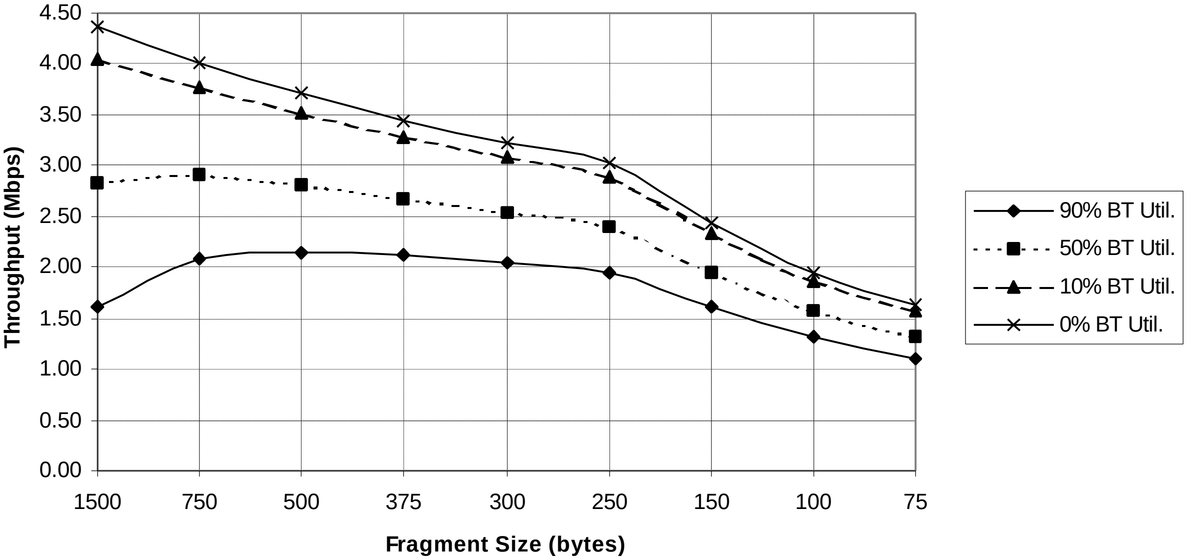

Figure 4.0-2 Network Throughput (Mbps) for 1500 Byte Packets @ 5.5 Mbps

The topology considered in this analysis is severe by any measure. Placing non-compatible radios in close proximity without taking positive measures to avoid interference is not generally advisable. However, by setting a fragmentation size of 750 bytes, DS system throughput can be maintained above 2 Mbps even when co-located with a heavily loaded BT piconet. A fragment size of 750 bytes also provides good system throughput when interference is not present (0% BT utilization)

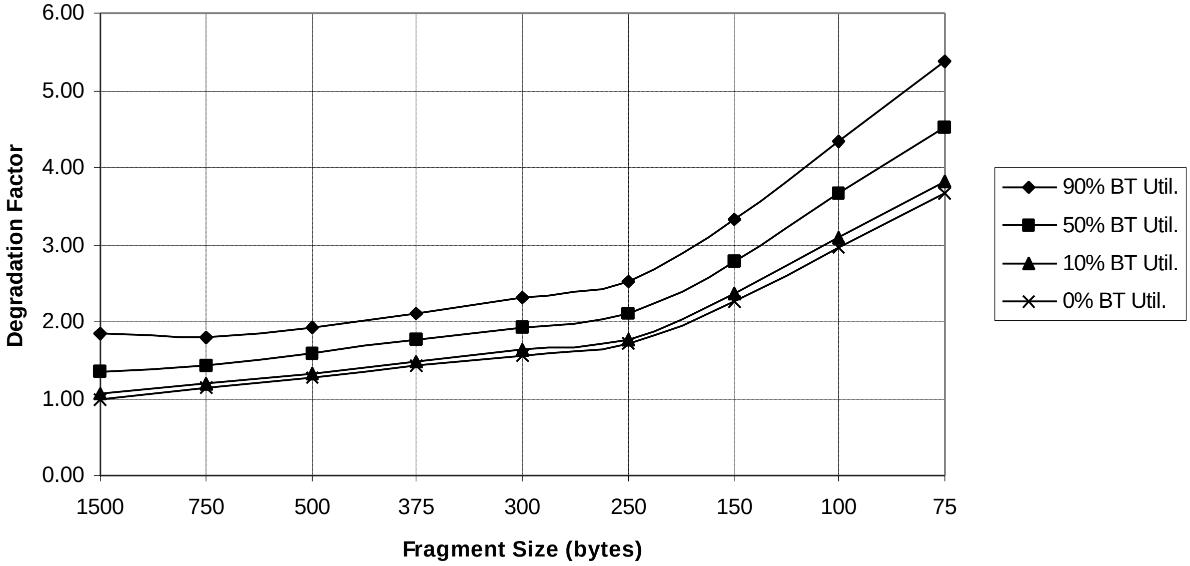

Figure 4.0-3 Degradation Factor for 1500 Byte Packets @ 11 Mbps

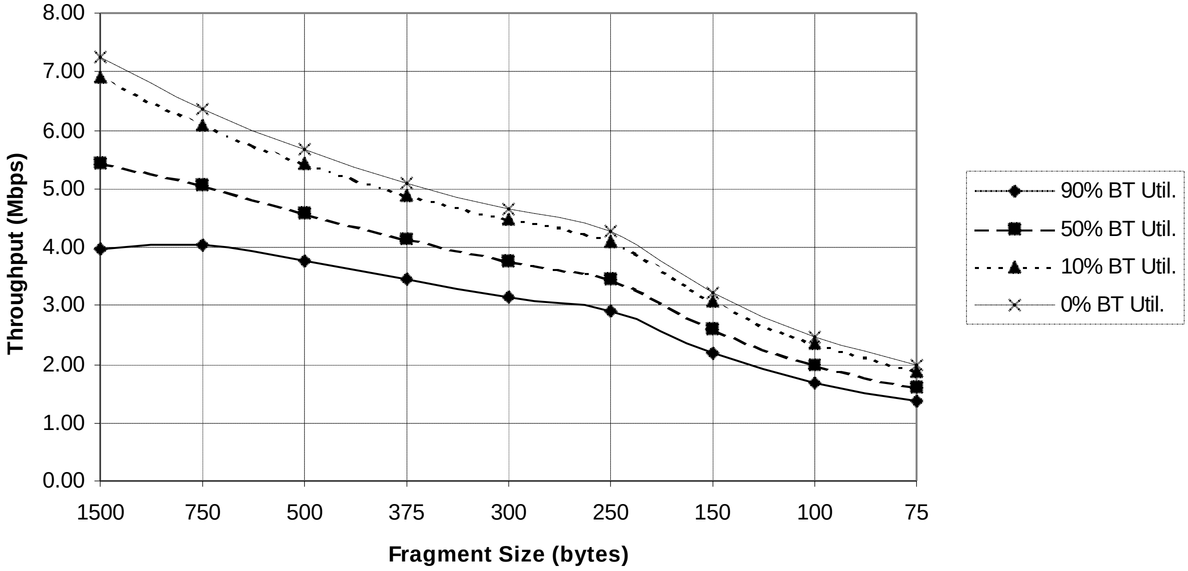

Figure 4.0-4 Network Throughput for 1500 Byte Packets @ 11 Mbps

Based on the results shown in Figures 4.0-3 and 4.0-4, fragmentation does not deliver much benefit at 11 Mbps in the presence of a highly loaded BT piconet. However, even without the use of fragmentation, a throughput of 4 Mbps can be maintained.

4.1 Upstream Traffic

It should be pointed out that the event that large files are to be uploaded, system throughput is virtually unaffected. The only packets subject to interference in this case are downstream ACK packets which are very short, and therefore have a very low probability of being jammed. System throughput for upstream traffic in the presence of varying BT utilization levels is summarized in Table 4.1-1

BT Utilization	Throughput @ 5.5 Mbps	Throughput @ 11 Mbps
90%	3.6 Mbps	6.0 Mbps
50%	3.9 Mbps	6.6 Mbps
10%	4.3 Mbps	7.1 Mbps
0%	4.4 Mbps	7.2 Mbps

Table 4.1-1 Network Throughput for Upstream Traffic

The conclusion is that interference from a BT piconet is a localized effect. The range at which interference from a BT piconet begins to seriously affect the performance of a DS node depends on several factors:

a. range of DS STA from AP
b. prevailing direction of data flow (upstream / downstream)
c. local propagation conditions
d. DS data rate
e. BT piconet utilization

5.0 Conclusions

1. These results are in general agreement with results generated in the original model. A Co-located BT piconet will have an adverse effect on the throughput of a DS receiver. However, in spite of including the effects of a longer interframe spacing on dropped fragments, network throughput is about 50% to 70% better than originally estimated.

2. Even when co-located with a heavily loaded BT piconet, the shorter packet sizes allowed by the 5.5 Mbps and 11 Mbps data rates will be able to more easily avoid BT jamming and maintain connectivity. Further, worst case throughput will still be greater than that of currently available 1 and 2 Mbps systems operating under error-free conditions.

3. The effects of interference generated from a BT piconet will be localized, extending up to a range of several meters, depending primarily on the range of the DS STA from its associated AP. If the DS STA is fairly close to the AP, the BT "bubble of interference" will only be two or three meters in radius. If the DS-STA is at the edge of the BSA, the radius of BT interference may be up to 10 meters. However, affected nodes will still be able to maintain reasonable throughput.

4. A fragmentation threshold of 750 bytes provides good throughput under heavily loaded conditions without incurring a severe throughput penalty when no interference is present.

5. The results stated in this paper assume that the BT nodes in question all have a maximum Tx power of 0 dBm. The interference presented by the BT devices is essentially the result of a "near/far" problem, in that all of the BT devices are much closer to the DS receiver than the AP. In the event that +20 dBm BT nodes are used for longer ranges, the BT piconet topology would be radically different. Specifically, the nodes BT nodes would not be clustered around the DS node as depicted in Figure 2.0-1. A +20 dBm BT node operating in close proximity to a DS receiver obviously presents a more significant interference problem. However, this is countered by the fact that the other active BT devices would be much further away. In order to analyze this scenario, some distributed BT topology must be postulated. Such an exercise is beyond the scope of this paper.

6. The effect of an active DS transmitter on a nearby BT piconet was not described in this paper. Such an analysis would require a detailed discussion of BT packet structures and forward error correction measures. This topic will not be suitable for open discussion until Version 1.0 of the BT Specification is publicly released.

References

1. Greg Ennis, "Impact of Bluetooth on 802.11 Direct Sequence", *Doc: IEEE P802.11-98/319*

2. H. Hashemi, "The Indoor Radio Propagation Channel", *Proceedings of the IEEE*, pp. 943-968, Vol. 81, No. 7, July 1993