Impact of Bluetooth on 802.11 Direct Sequence Wireless LANs

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Fast Frequency Hopping

- Bluetooth is a fast frequency hopping system focused on PAN applications
  - basic hopping period 625 microseconds
- Supports voice and data
- Low power with higher power option
- No carrier sense, no deferral
- Operates within 2.4 GHz band
Bluetooth/802.11 Environment

- Small packets from station, no Bluetooth collisions
- Large packets from AP, significant Bluetooth collisions

802.11 Station

Bluetooth Nodes

AP

Bluetooth Picocell

Bluetooth-induced collisions

- 1000 byte 802.11 packet = 727 microseconds
- 366 bit Bluetooth packet = 366 microseconds

- Current Bluetooth channel
- 26 1-MHz channels

Wideband 802.11 transmission

Narrowband Bluetooth transmission
Overlap Probability

- What is the probability that an 802.11 packet and a Bluetooth transmission will overlap in both time and frequency?
- Time overlap: depends on duration of packet and relative timing of BT hopping
- Frequency overlap: depends upon number of channels - geographic dependence

Time Overlap

- Let $L = 802.11$ packet duration, $H = Bluetooth$ dwell duration
- Packet will partially overlap either $\left\lceil \frac{L}{H} \right\rceil$ or $\left\lceil \frac{L}{H} \right\rceil + 1$ dwell periods, depending on relative timing
- Here $\left\lceil x \right\rceil = ceiling(x) = least integer greater than or equal to x
Example Time Overlap

Suppose \( d \) = the "delta" between the last Bluetooth hop and the start of the packet, where \( L = 1.3H \) and \( d > 0.7H \).

Then the packet will overlap 3 Bluetooth dwell periods.

\[
H \\
\text{d > 0.7H} \\
802.11 \text{ packet, } L = 1.3H
\]

Time Overlap Probability

The probability that an 802.11 packet of duration \( L \) will overlap with \( \lceil L/H \rceil \) Bluetooth dwell periods of duration \( H \) is

\[
\lceil L/H \rceil - L/H
\]

The probability that it overlaps with \( \lceil L/H \rceil + 1 \) dwell periods is

\[
1 - \lceil L/H \rceil + L/H
\]
Frequency Overlap

- In North America, the probability that at any given time a Bluetooth transmitter is on a narrowband channel outside of a given wideband 802.11 DS channel is 2/3.
- If an 802.11 packet overlaps with N Bluetooth dwell periods, the probability of no frequency overlap is $(2/3)^N$.

Combining Time and Frequency Overlap Probabilities

For North American operation, the probability that an 802.11 packet of duration $L$ experiences no Bluetooth collisions is:

$\frac{2}{3} \left\lceil \frac{L}{H} \right\rceil \left( \left\lceil \frac{L}{H} \right\rceil - \frac{L}{H} \right) + \frac{2}{3} \left( \left\lceil \frac{L}{H} \right\rceil + 1 \right) \left( 1 - \left\lceil \frac{L}{H} \right\rceil + \frac{L}{H} \right)$
What 802.11 Mechanisms to use?

- Fall back rates
  - increases packet size, hence likelihood of error
- RTS/CTS
  - Bluetooth won’t obey. RTS/CTS may succeed yet DATA transfer fails
- Reassociation to a new AP
  - Same interference will be present
- Fragmentation

Fragmentation

- 802.11 MAC allows for fragmentation
- Chain of frames DATA-ACK-DATA-ACK, separated by SIFS
- In case of error, transmitter backs off, continues starting with errored fragment
- Overhead: PHY and MAC headers
- Beneficial under high error conditions
Model of Bluetooth/802.11 DS

- Model developed incorporating calculation on overlap probability
- Inputs: 802 Data rate + packet size, Bluetooth hop rate + picocell utilization
- Output: “Degradation Factor” versus fragment size
  - Degradation Factor is ratio of nonfragmented unimpaired transmission time to impaired time

Example at 5.5 Mb/s

![Graph showing Degradation Factor versus Fragment Size](image)
Various BT picocell utilizations

11 Mb/s Situation
2 Mb/s, 500 byte packet

![Diagram showing degradation factor vs fragment size for various picocell utilizations]

Limited Bandwidth Situations

- France, Japan, etc.
- Impact is even more significant
- Example: if only two 802.11 channels available, expression for non-collision becomes
  
  \[ (1/2)^{\left\lfloor \frac{L}{H} \right\rfloor} \left( \left\lfloor \frac{L}{H} \right\rfloor - \frac{L}{H} \right) \]
  
  \[ + \ (1/2)^{\left\lfloor \frac{L}{H} \right\rfloor + 1} \left( 1 - \left\lfloor \frac{L}{H} \right\rfloor \right) + \frac{L}{H} \]
2 Versus 3 Channels

![Graph showing 2 Channels and 3 Channels, 5.5 Mb/s, 1500 bytes, 90% picocell utilization]

Conclusions

- Bluetooth can impact 802.11 DS significantly, particularly on large packets
- Most 802.11 mechanisms for responding to poor channel quality either have no impact or make things worse
- Fragmentation can help, mainly at lower data rates and high picocell utilizations
- Fallback to low-rate FH may be useful