Impact of Bluetooth on 802.11 Direct Sequence Wireless LANs

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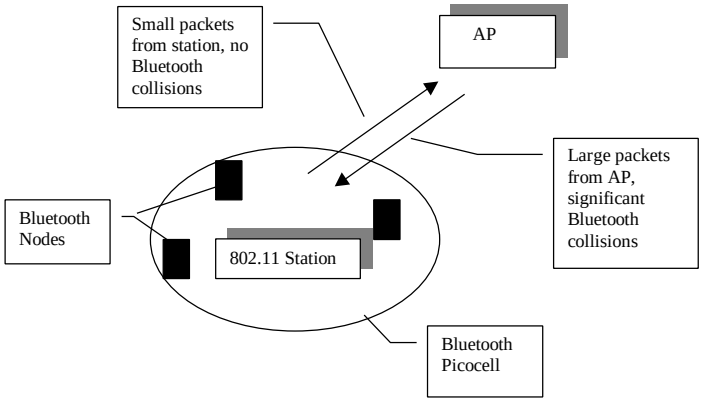
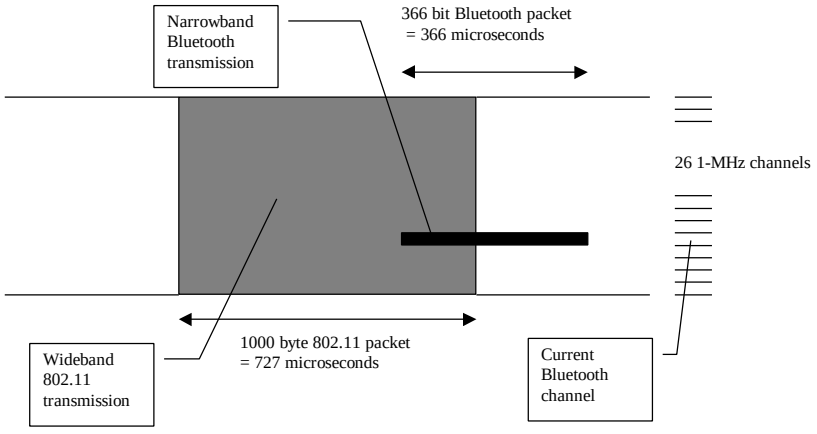
Fast Frequency Hopping

- 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



Bluetooth-induced collisions



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

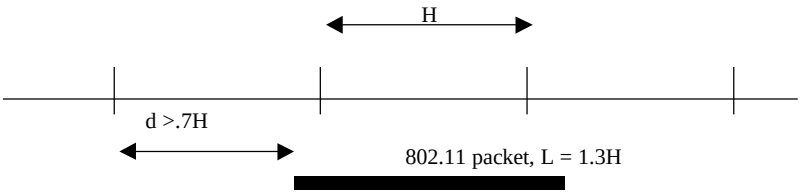
Time Overlap

- Let L = 802.11 packet duration,
  H = Bluetooth dwell duration
- Packet will partially overlap either $\lceil L/H \rceil$ or $\lceil L/H \rceil + 1$ dwell periods, depending on relative timing
- Here $\lceil x \rceil$ = 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 > .7H

Then the packet will overlap 3 Bluetooth dwell periods



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

$$(2/3)^{\lceil L/H \rceil} (\lceil L/H \rceil - L/H) + (2/3)^{(\lceil L/H \rceil + 1)} (1 - \lceil L/H \rceil + L/H)$$

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

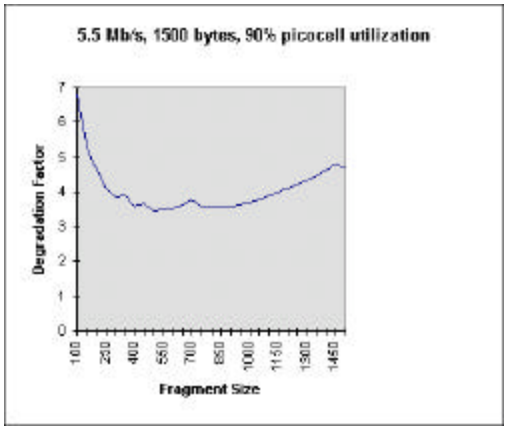
Fragmentation

- 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

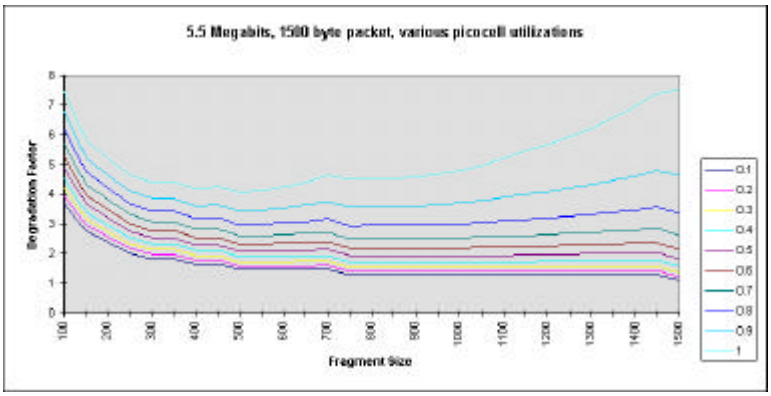
Model of Bluetooth/802.11 DS

- 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

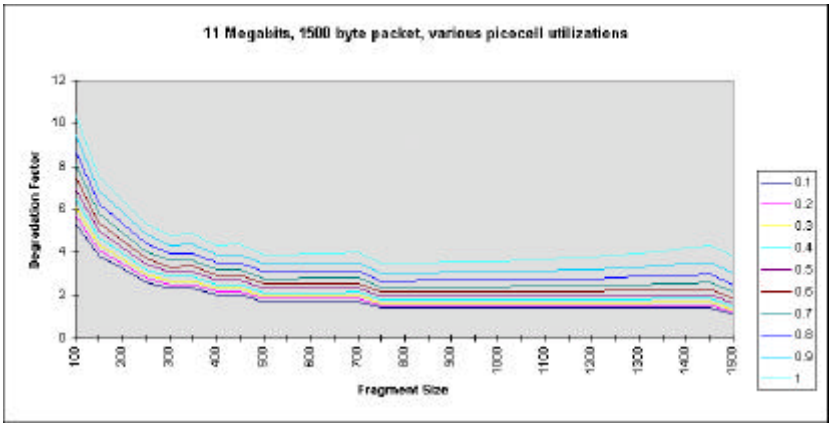
Example at 5.5. Mb/s



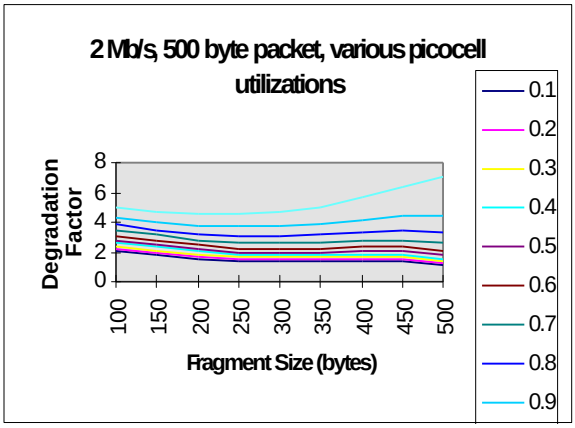
Various BT picocell utilizations



11 Mb/s Situation



2 Mb/s, 500 byte packet



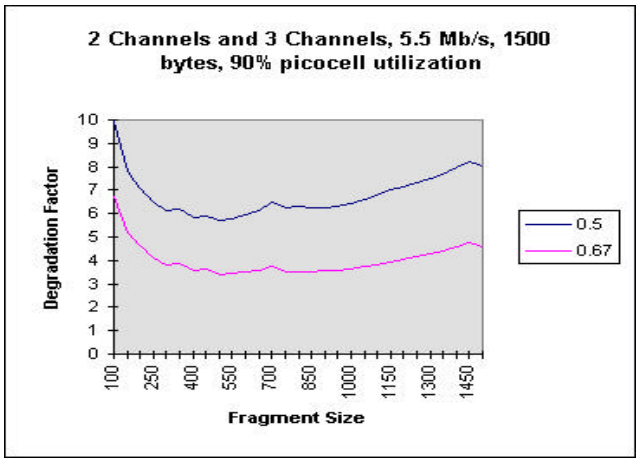
Limited Bandwidth Situations

- France, Japan, etc.
- Impact is even more significant
- Example: if only two 802.11 channels available, expression for non-collision becomes

$$(1/2)^{\lceil L/H \rceil} (\lceil L/H \rceil - L/H)$$

$$+ \ (1/2)^{(\lceil L/H \rceil + 1)} (1 - \lceil L/H \rceil + L/H)$$

2 Versus 3 Channels



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