The Third IEEE Workshop on Wireless Local Area Networks

Maximizing Performance of a Wireless LAN in the Presence of Bluetooth

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Approach:

- To develop a wireless channel model for the indoor environment.
- To use data rates, modulation and channel coding schemes specified in the IEEE 802.11b architecture for determination of the BER of the system.
- To introduce and analyze impact of Bluetooth onto the IEEE 802.11b system model, both at Physical and MAC layers.
- To maximize the performance of the 802.11b WLAN in the presence of Bluetooth by adjusting various parameter in the system model.

IEEE 802.11b System Facts:

- Operates in 2.4GHz-2.4835GHz frequency band
- Direct Sequence Spread Spectrum (DSSS)
- Three non-overlapping 22MHz channels
- Data Rates and Modulation/Coding schemes
  - 1Mbps -- DBPSK (Differential Binary Phase Shift Keying)
  - 2Mbps -- DQPSK (Differential Quadrature Phase Shift Keying)
  - 5.5Mbps -- CCK (Complementary Code Keying)
  - 11Mbps -- CCK (Complementary Code Keying)
- Nominal signal strength is 100mW (20dBm)
- Preamble and header always transmitted at 1Mbps

1Mbps Data Rate Overview:

- Modulation: DBPSK $P_e = \frac{1}{2}\exp\left(-\frac{E_b}{N_0}\right)$

- Channel Coding: DSSS -- 11 chips (Barker Sequence)

$$\frac{E_b}{N_0} = 11\left(\frac{chip}{bit}\right)\cdot\frac{E_c}{N_0} \qquad \frac{E_c}{N_0} = \frac{Signal\ Strength\ at\ the\ Receiver}{N_0 \cdot Chip\ Rate}$$

N_0 is AWGN and *Chip Rate* is 11chip/s

- Spreading Gain: $10\log 11\left(\frac{chip}{bit}\right) = 10.4dB$

2Mbps Data Rate Overview:

- Modulation: DQPSK $P_e = Q_1(a,b) - \frac{1}{2} I_0(ab) \exp\left(-\frac{1}{2}\left(a^2 + b^2\right)\right)$

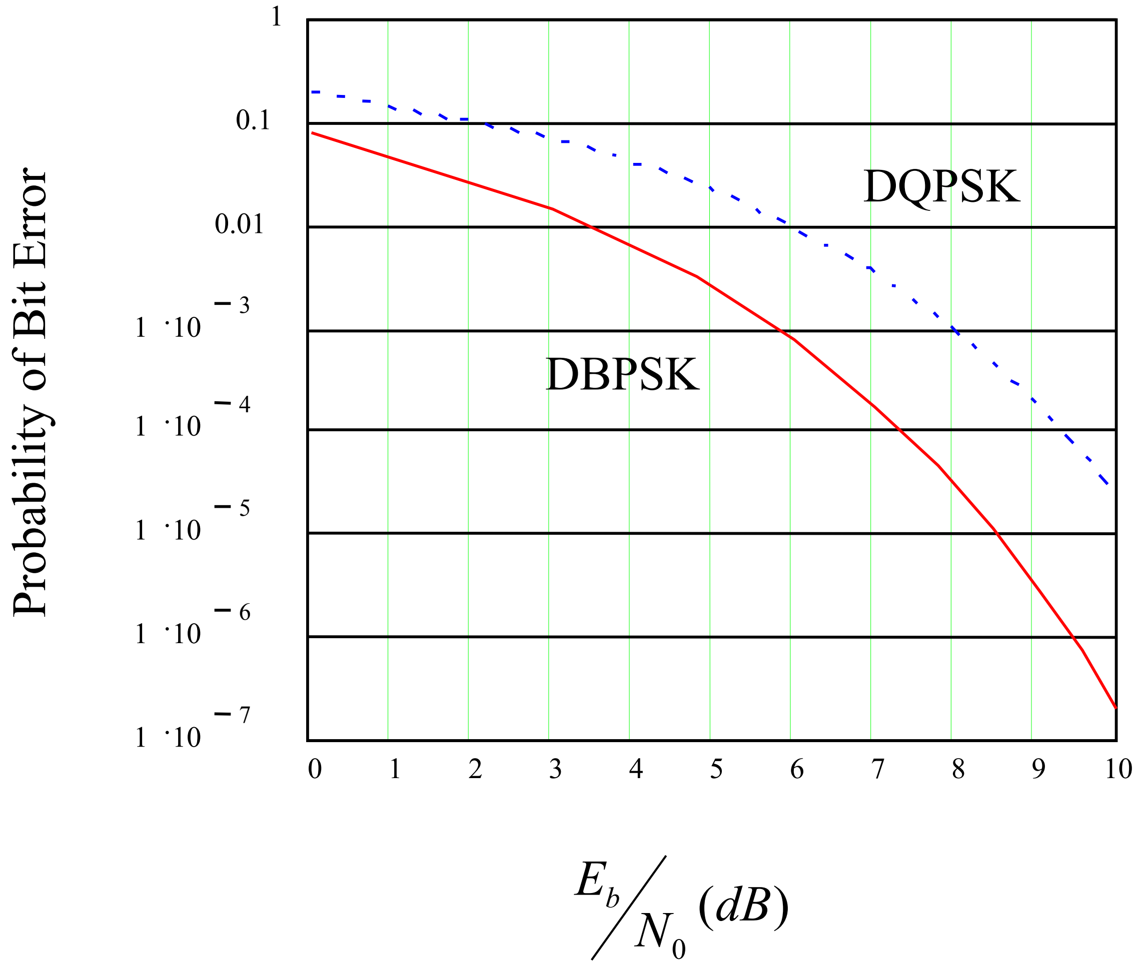
  $Q_1(a,b)$ is the Marcum Q function, $a = \sqrt{\frac{2E_b}{N_0} \cdot \left(1 - \sqrt{\frac{1}{2}}\right)}$

  $I_0(ab)$ is the modified Bessel function. $b = \sqrt{\frac{2E_b}{N_0} \cdot \left(1 + \sqrt{\frac{1}{2}}\right)}$

- Channel Coding: DSSS -- 11 chips (Barker Sequence)

- Spreading gain: $10\log\left(\frac{11 chips}{2 bit}\right) = 7.4 dB$

BER Graphs for 1Mbps & 2Mbps in AWGN:



5.5Mbps &11Mbps Data Rates Overview:

- Modulation: DQPSK
- Channel Coding: CCK -- 8 chips (Walsh Codes)

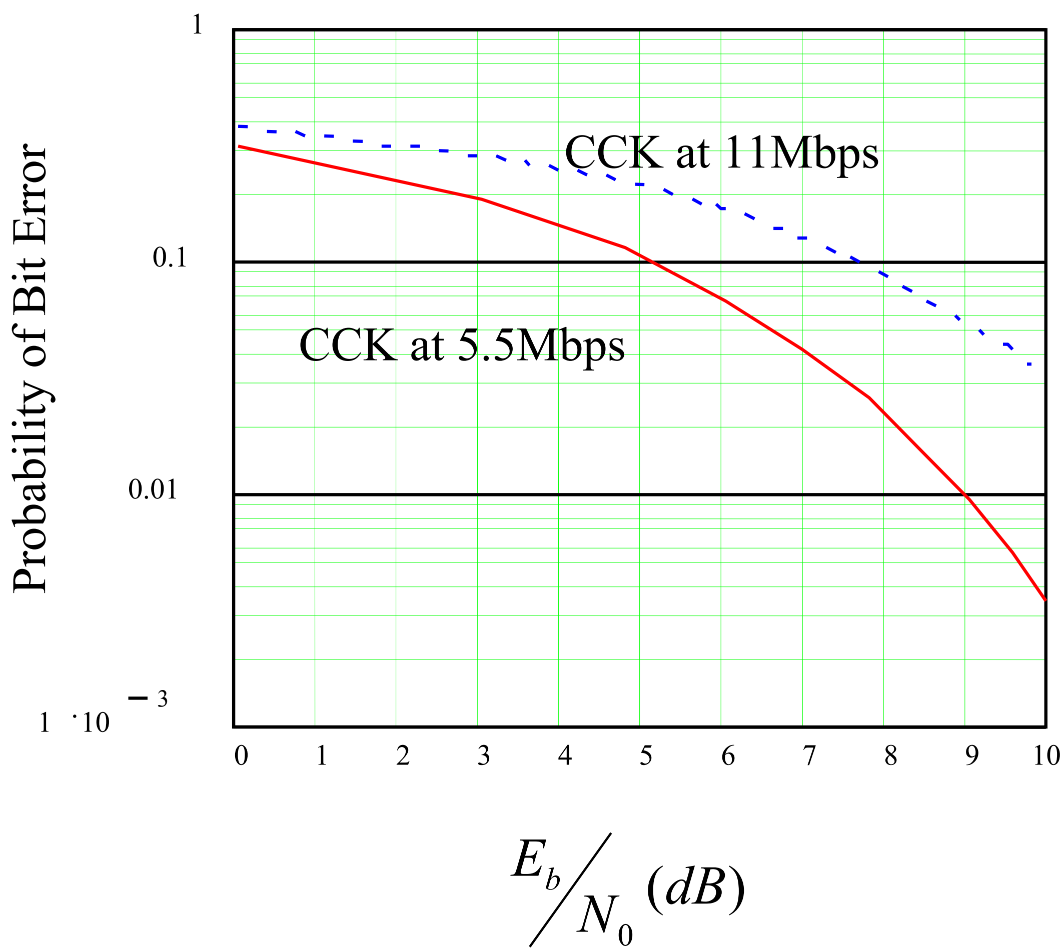
  (form of M-ary Bi-Orthogonal Keying)

$$P_e = 1 - \int_{-X}^{\infty} \left(\frac{1}{\sqrt{2\pi}} \cdot \int_{-(v+X)}^{v+X} \exp\left(-\frac{y^2}{2} \right) dy \right)^{\frac{M}{2}-1} \cdot \exp\left(-\frac{v^2}{2} \right) dv \qquad X = \sqrt{\frac{2E_b}{N_0}}$$

where M is number of bits encoded into 8 chips;

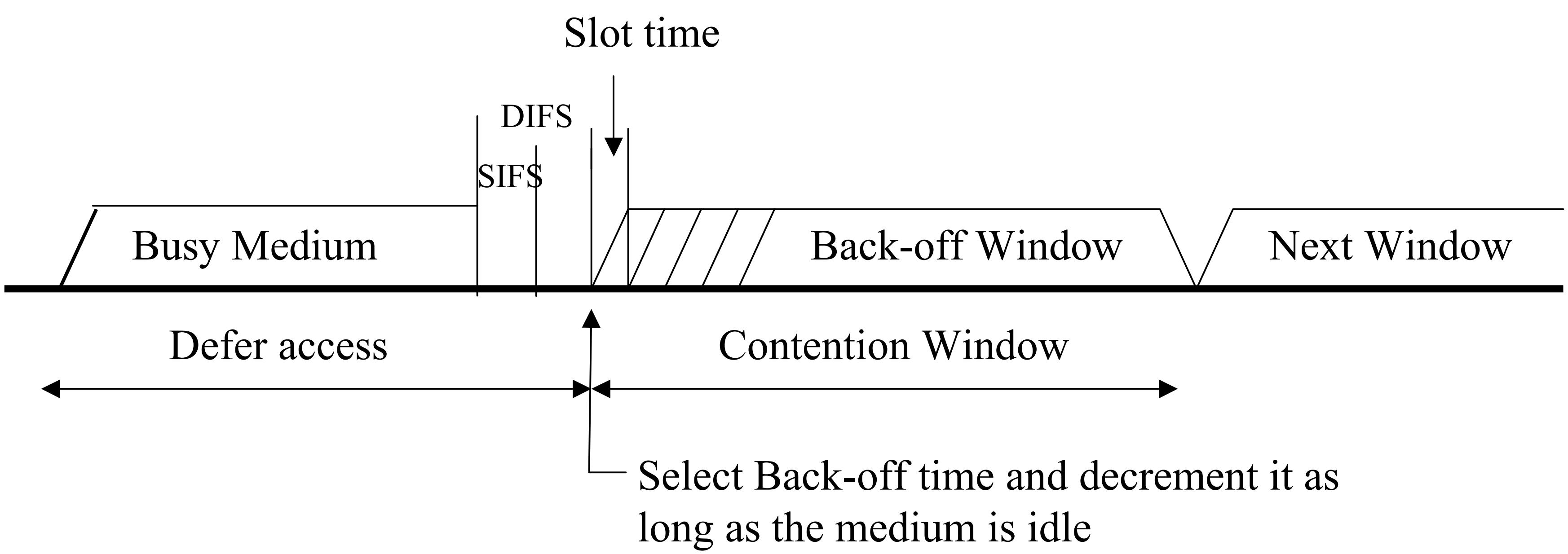
for 5.5Mbps M = 4 and for 11Mbps M = 8.

BER Graphs for 5.5Mbps & 11Mbps in AWGN:



IEEE 802.11b Medium Access:

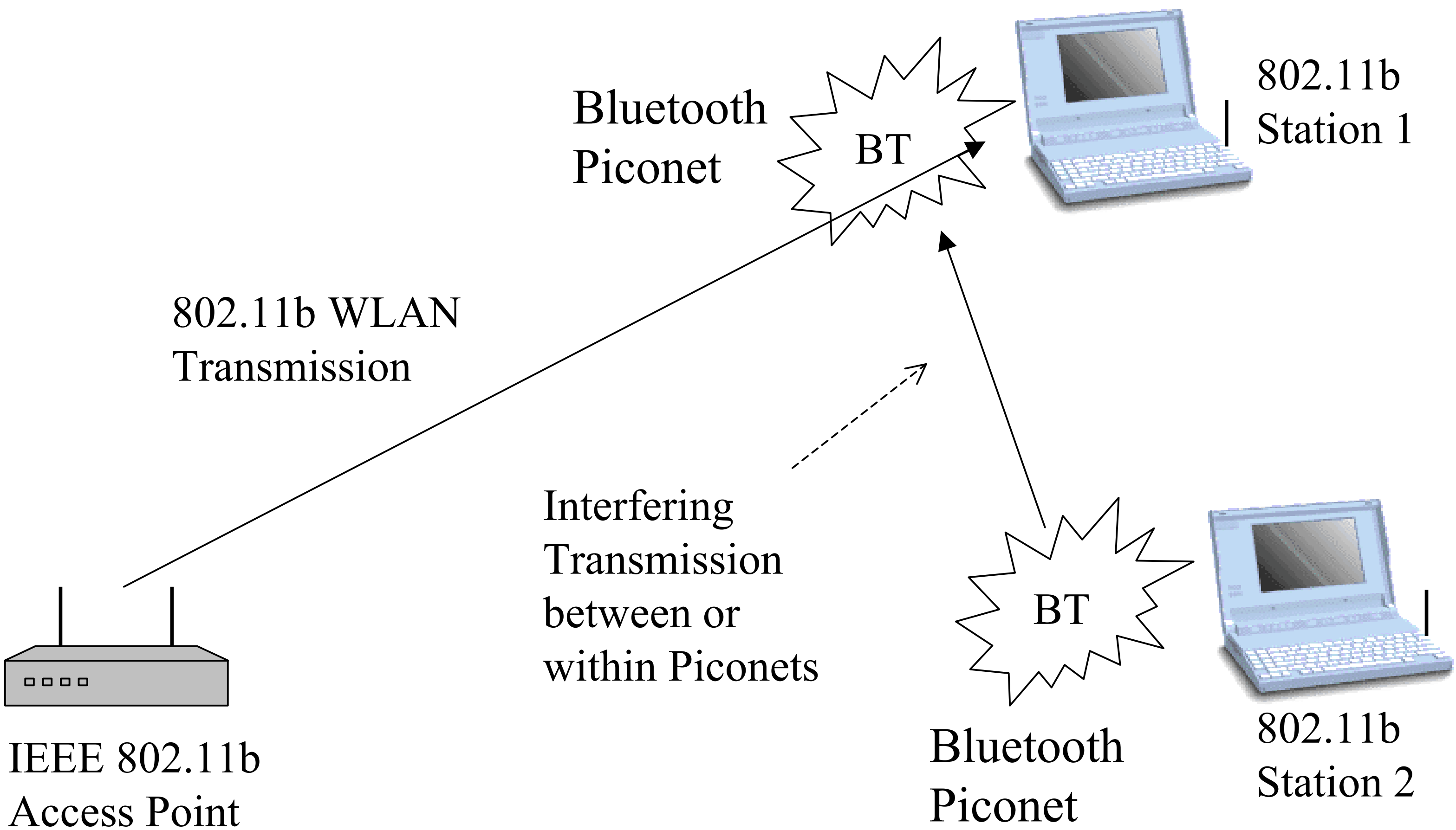
- Carrier Sense Multiple Access/Collision Avoidance with immediate acknowledgements (ACK)



Bluetooth System Facts:

- Operates in 2.4GHz -- 2.4835GHz frequency band
- Frequency Hopping Spread Spectrum (FHSS)
- 1600 hops/second or 625μs/hop
- 78 non-overlapping 1MHz channels
- Constant Data Rate of 1Mbps
- Modulation is a Gaussian Frequency Shift Keying
- Nominal signal strength is 1mW (0dBm)

Collision Scenario:



Channel Model: $Channel(dB) = PL(d) + X_{\sigma} + Y$

PL(d) and X_{σ} are large scale fading and *Y* is small-scale fading.

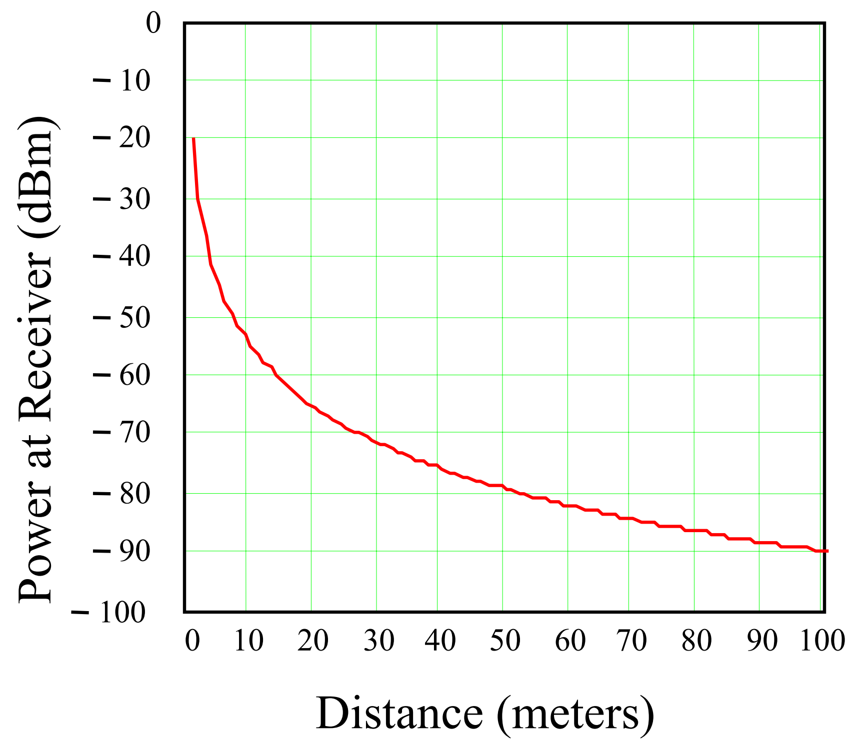
- **Large Scale Fading:**

(a) Path Loss:

$$PL(d) = PL(d_0) + 10 \cdot 3.5 \cdot \log_{10}\left(\frac{d}{d_0}\right)$$

$$PL(d_0) = 20\log\left(\frac{4\pi d_0}{\lambda}\right) = 40dB$$

d_0 is 1 meter



(b) Shadow fading: $X_\sigma = 10 \cdot \log_{10}(x_\sigma)$

Modeled by a log-normal random variable; a Gaussian with a mean (μ) of zero and variance (σ) ranging from 6 to 12dB depending on the environment.

The PDF is $g(x) = \frac{1}{\sqrt{2\pi}\sigma x} \cdot \exp\left(\frac{-\ln^2 x}{2\sigma^2}\right)$

- **<u>Small Scale Fading</u>:** Multipath Fading (Non-LOS)

  Modeled by a Rayleigh random variable.

  The PDF of the envelope amplitude is $f_p(p|\,\overline{p}\,) = \frac{1}{\overline{p}} \exp\left(-\frac{p}{\overline{p}}\right)$

- **<u>Channel Noise</u>:**

(a) The “wide band” noise from multiple sources without any coordination between them represented by Additive White Gaussian Noise (AWGN); the noise power spectral density is

$$N_0(dB) = 10\log\left(\frac{k \cdot T \cdot BandWidth(1Hz)}{1Watt}\right) = -174dB$$

(b) The “narrow band” noise from Bluetooth transmission depends on nominal signal strengths of the signals and distance between WLAN station and Bluetooth transmitter.

$$N_{total}\,(dB) = N_0\,(dB) + N_{bluetooth}\,(dB)$$

IEEE 802.11b Performance in Fading Wireless Channel:

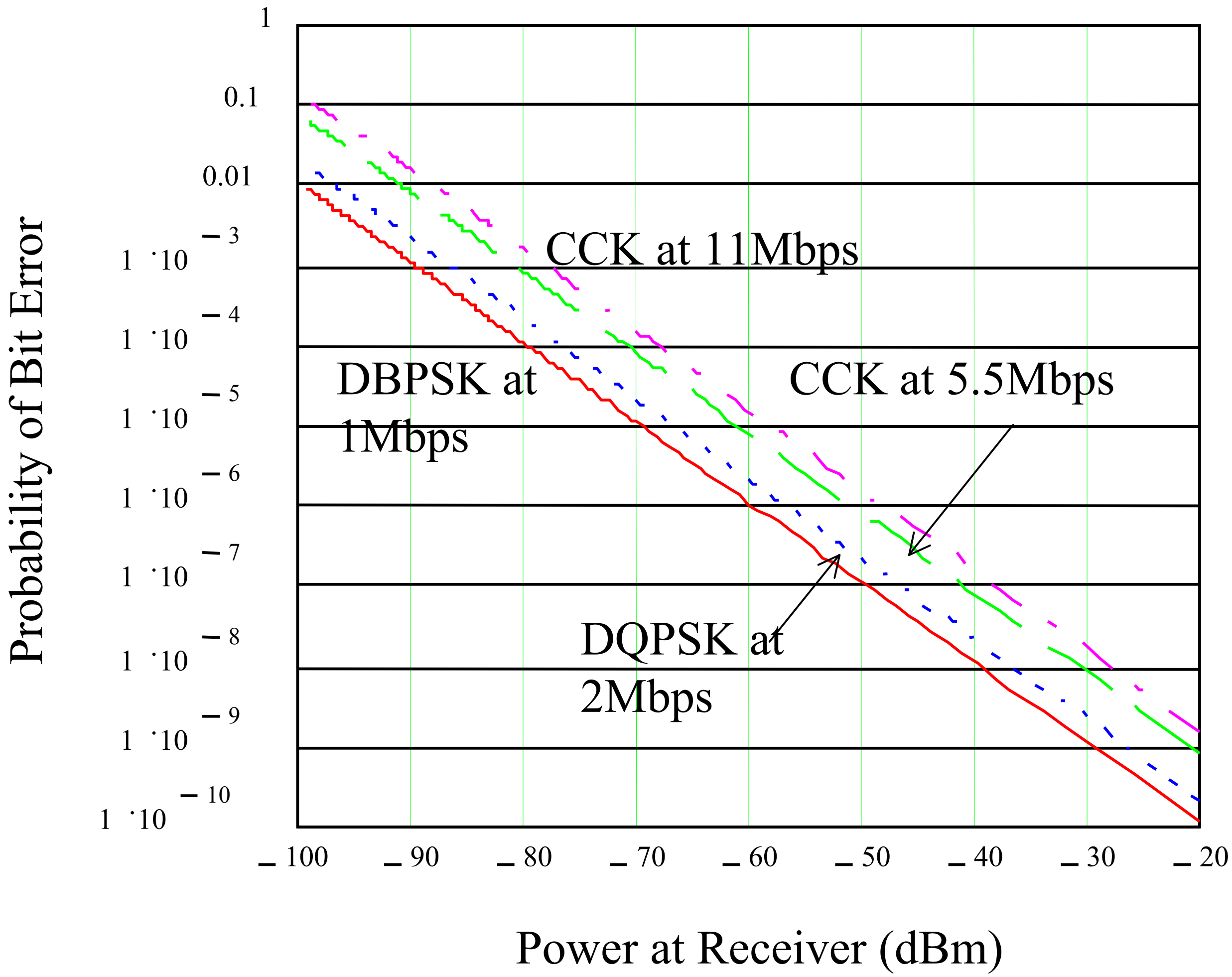
- Probability of Bit Error (BER) in fading channel:

$$P_e = \int_0^\infty P_e(x) \cdot f(x) dX$$

- BER of DBPSK in Rayleigh Multipath Channel:

$$P_e = \int_0^\infty \left(\frac{1}{2} \cdot \exp(-x) \right) \cdot \left(\frac{1}{E_b / N_0} \cdot \exp\left(-\frac{x}{E_b / N_0} \right) \right) dx = \frac{1}{2 \cdot \left(1 + E_b / N_0 \right)}$$

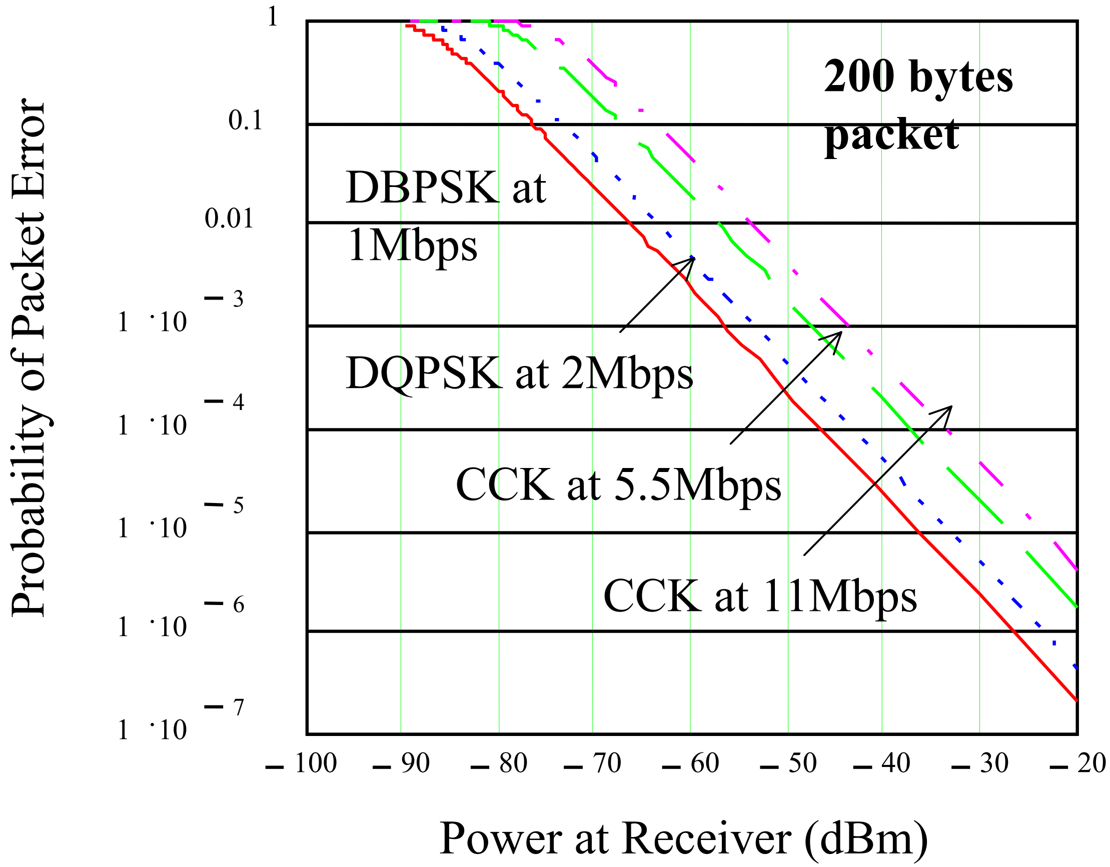
BER in Rayleigh Multipath Channel:



PER in Rayleigh Multipath Channel:

Assuming P_e independent for every bit

$PER = 1\text{-}(1\text{-}P_e)^{\textit{number of bits in packet}}$



The IEEE 802.11b Throughput Calculation:

- Time to transmit a packet

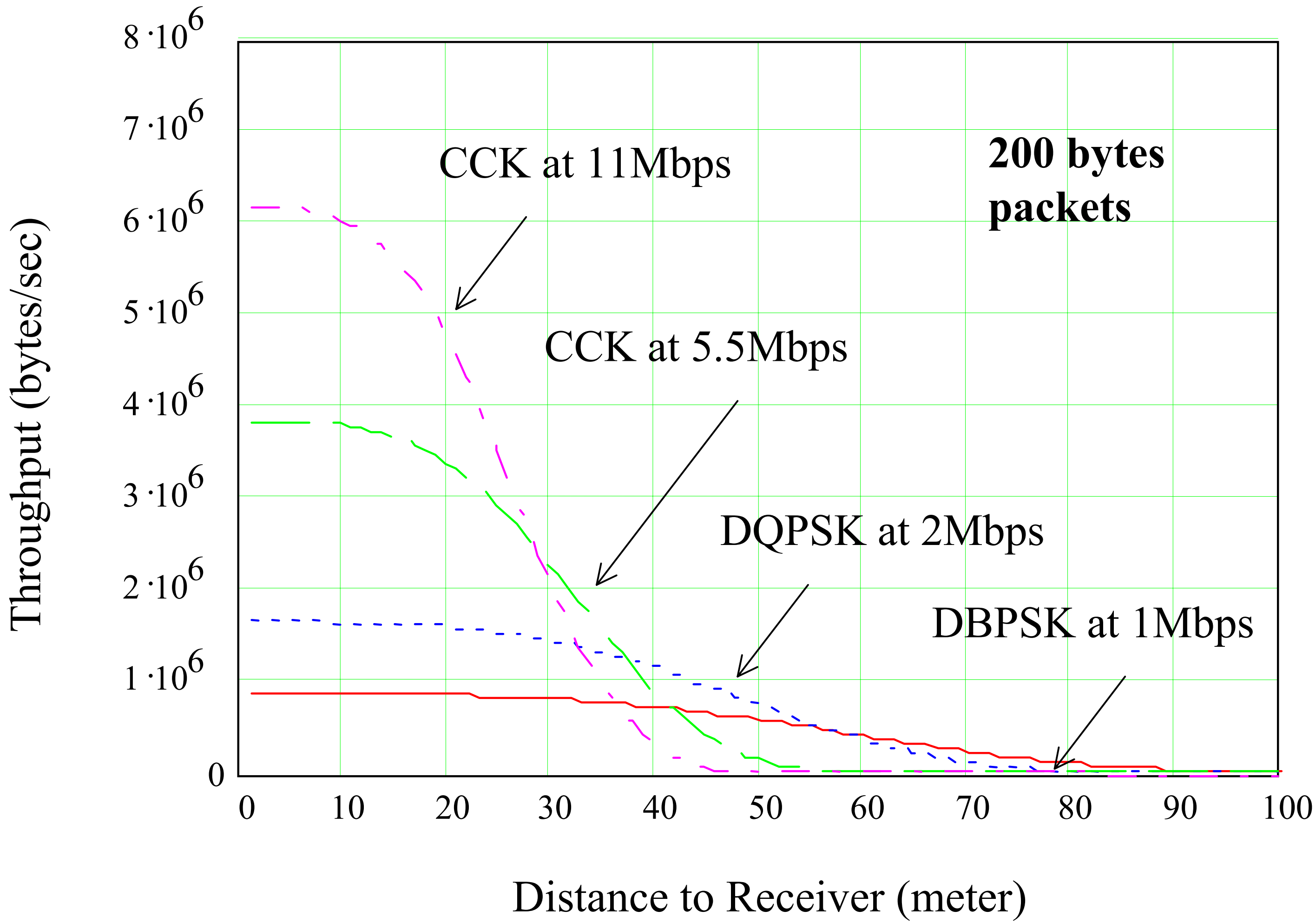
$$t_T = DIFS + Overhead + \frac{Data(bits)}{Rate(bits/\sec)} + SIFS + ACK$$

For example, for 1000 bytes long packet:

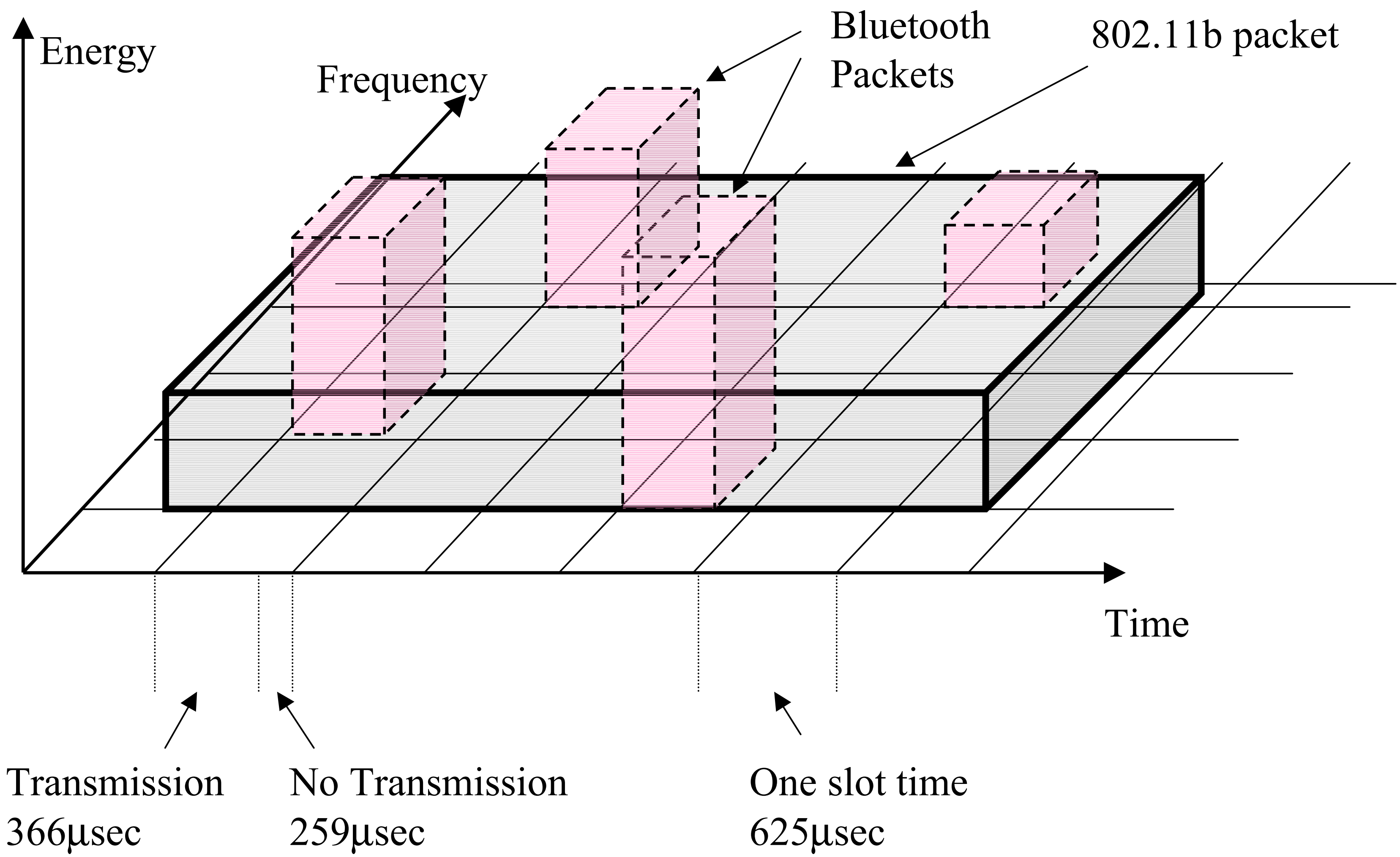
Rate	1Mbps	2Mbps	5.5Mbps	11Mbps
t_T	8.4msec	4.2msec	1.6msec	0.9msec

Throughput:

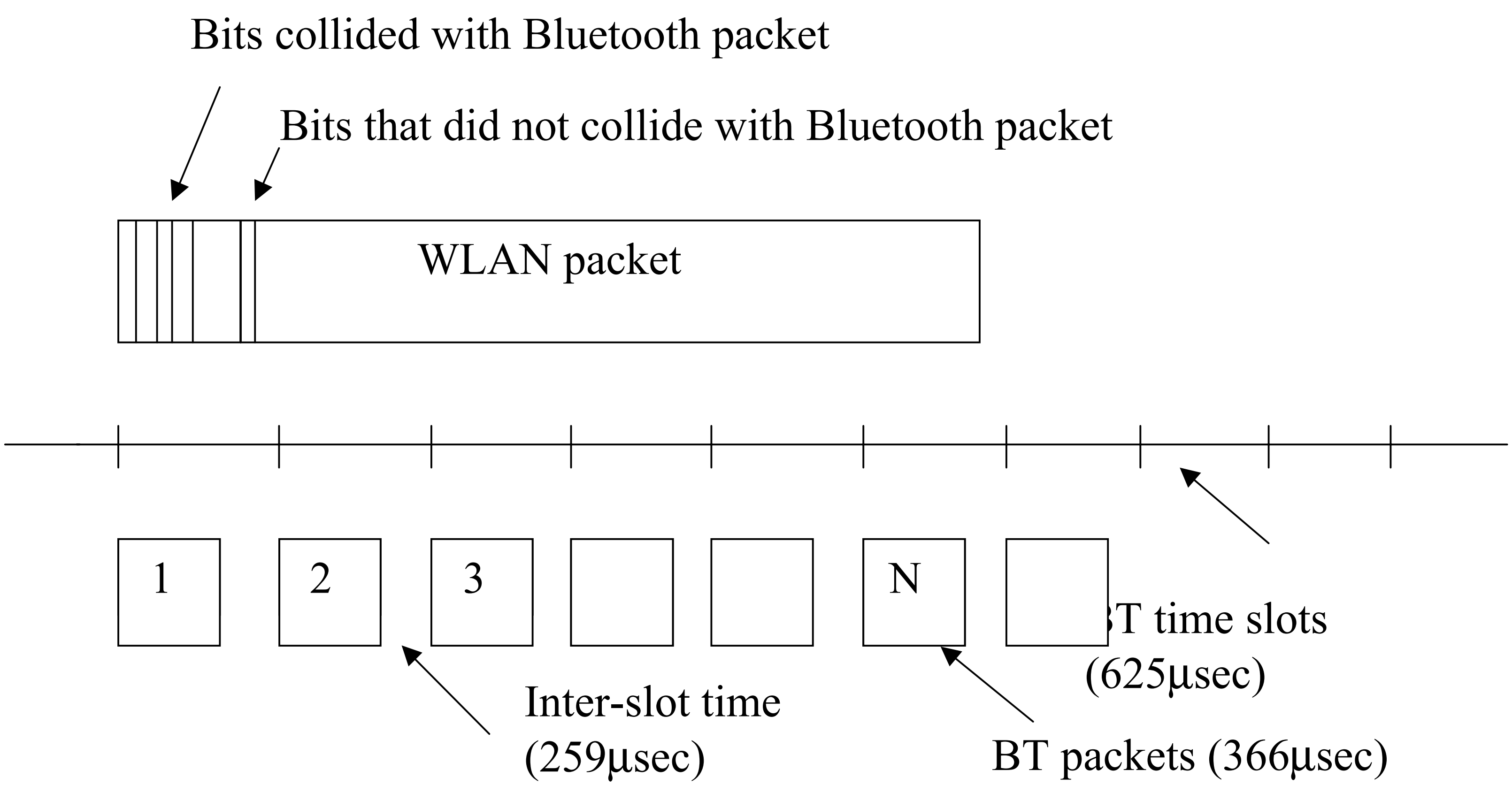
$$T(bits/\sec) = \frac{Data}{T_w} = \frac{Data}{t_T} \cdot (1 - PER)$$



Impact of Bluetooth on 802.11b:



Impact of Bluetooth on 802.11b (Details):



PER Derivation:

$$SER = P\{Bad\_Slot\} = 1 - P\{Good\_Slot\}$$

$$P\{Good\_Slot\} = P\{Good / Collision\} \cdot P_c +$$

$$+ P\{Good / NoCollision\} \cdot (1 - P_c)$$

$$P\{Good / NoCollision\} = \left(1 - P_e\{\text{No BT interference}\}\right)^{\text{bits in } 625\mu s}$$

$$P\{Good / Collision\} = \left(1 - P_e\{\text{BT inerference}\}\right)^{\text{bits in } 366\mu\text{s}} \cdot (1 \quad P \{N$$

$$\cdot \left(1 - P_e\{\text{No BT interference}\}\right)$$

$P_c = \mu \cdot \frac{1}{3}$ is probability of collision at MAC layer,

μ is utilization of Bluetooth piconet (or interference in time)

$\mathbf{\frac{1}{3}}$ is probability that 802.11b and Bluetooth interfere in frequency

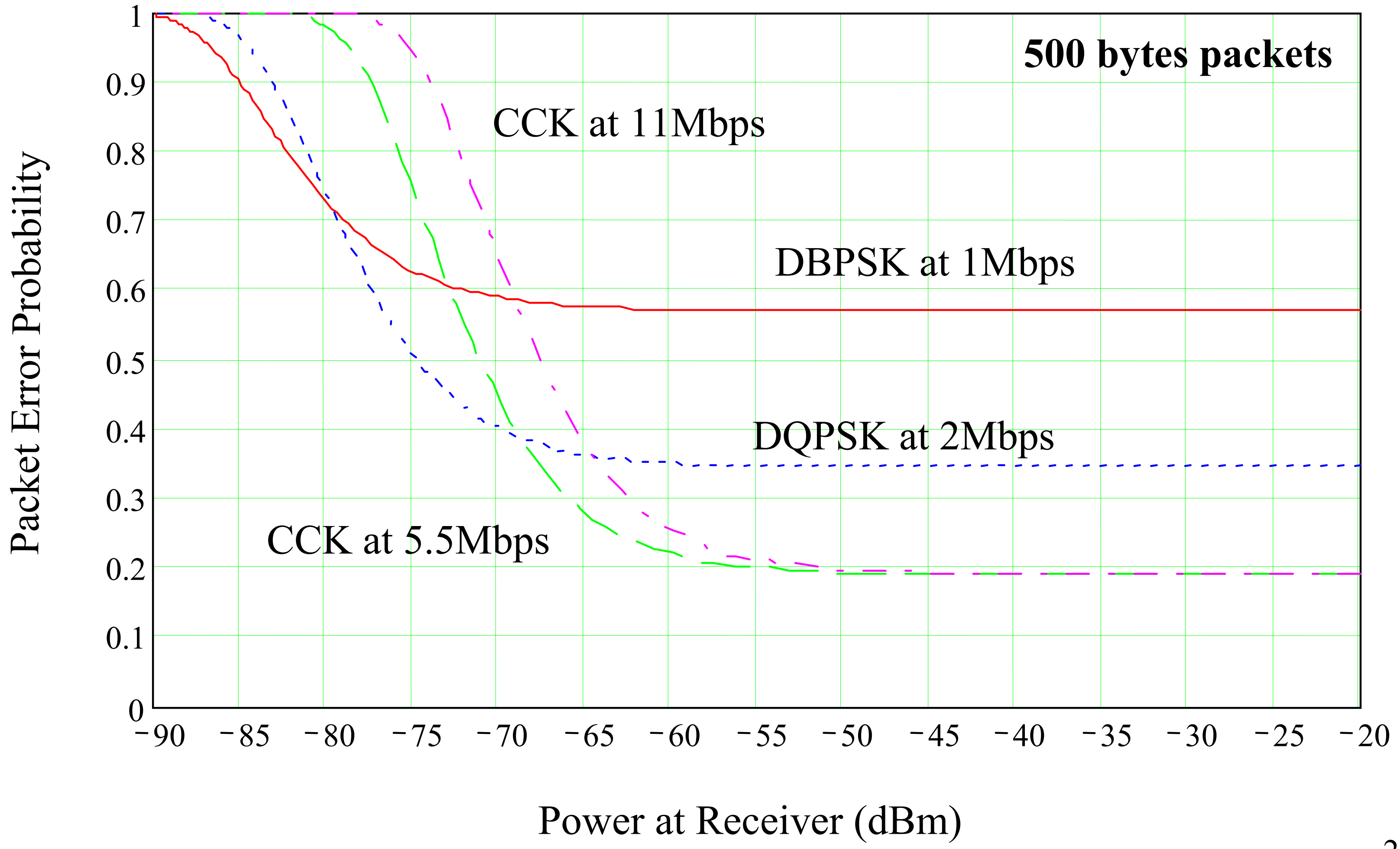
$$P\{Good\ 802.11b\ Packet\ \} = P\{Good\ Slot\}^N$$

$$PER = 1-P\{Good\ 802.11b\ Packet\}$$

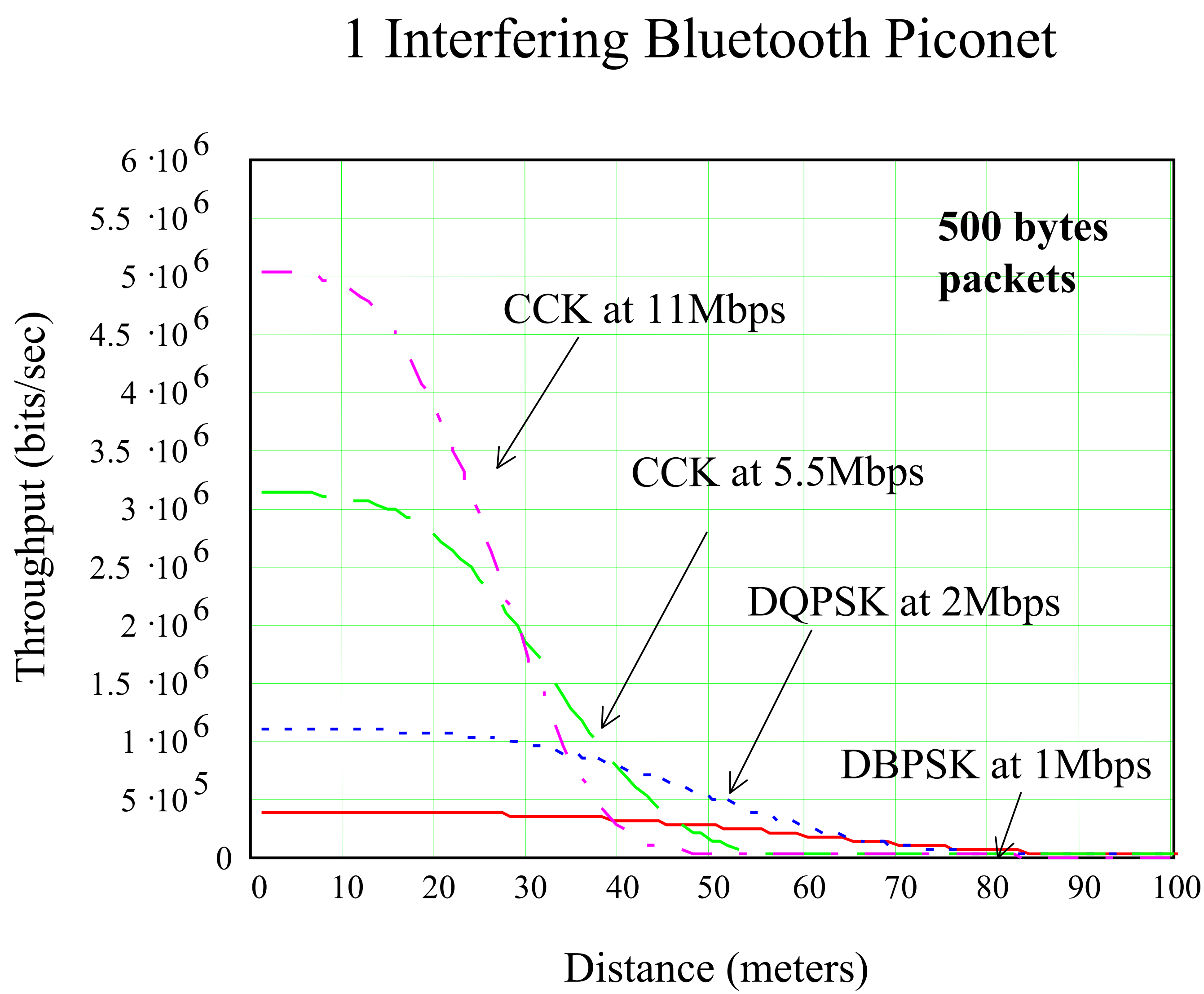
$$PER_{multiple\ piconets} = 1-\ (1-PER)^n$$

n is number of piconets

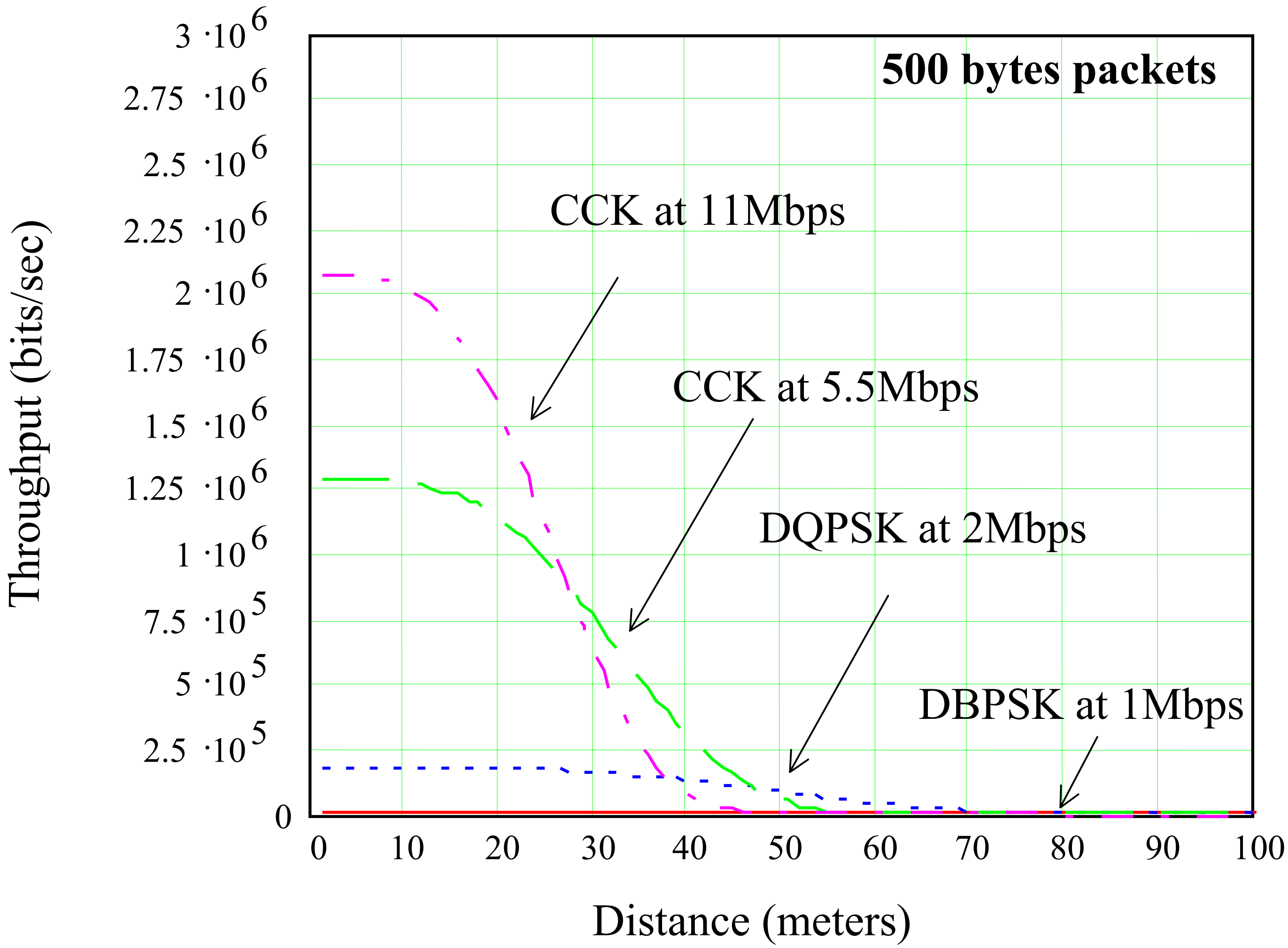
PER in Presence of Bluetooth:



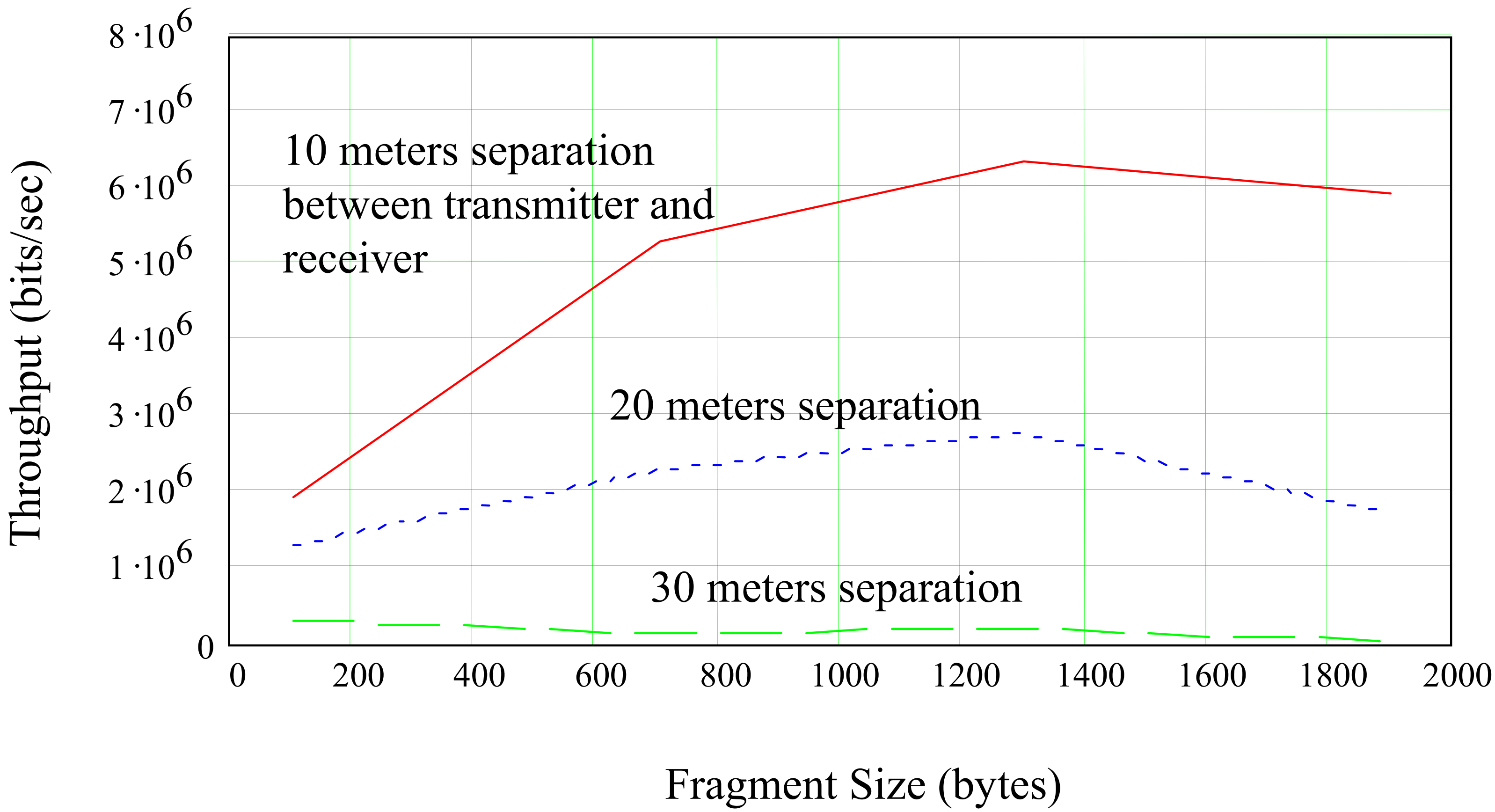
Throughput in Presence of Bluetooth:



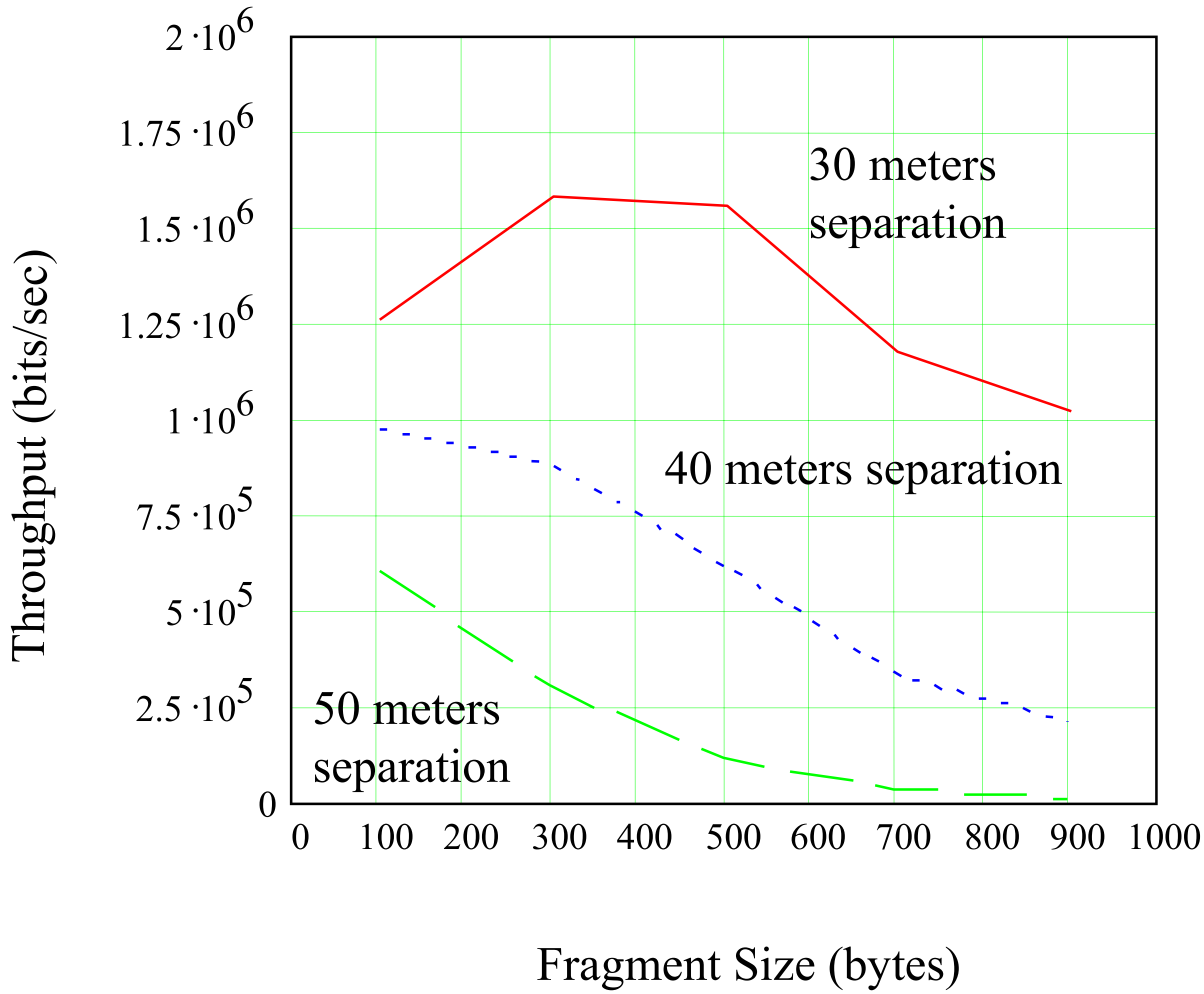
3 Interfering Bluetooth Piconets



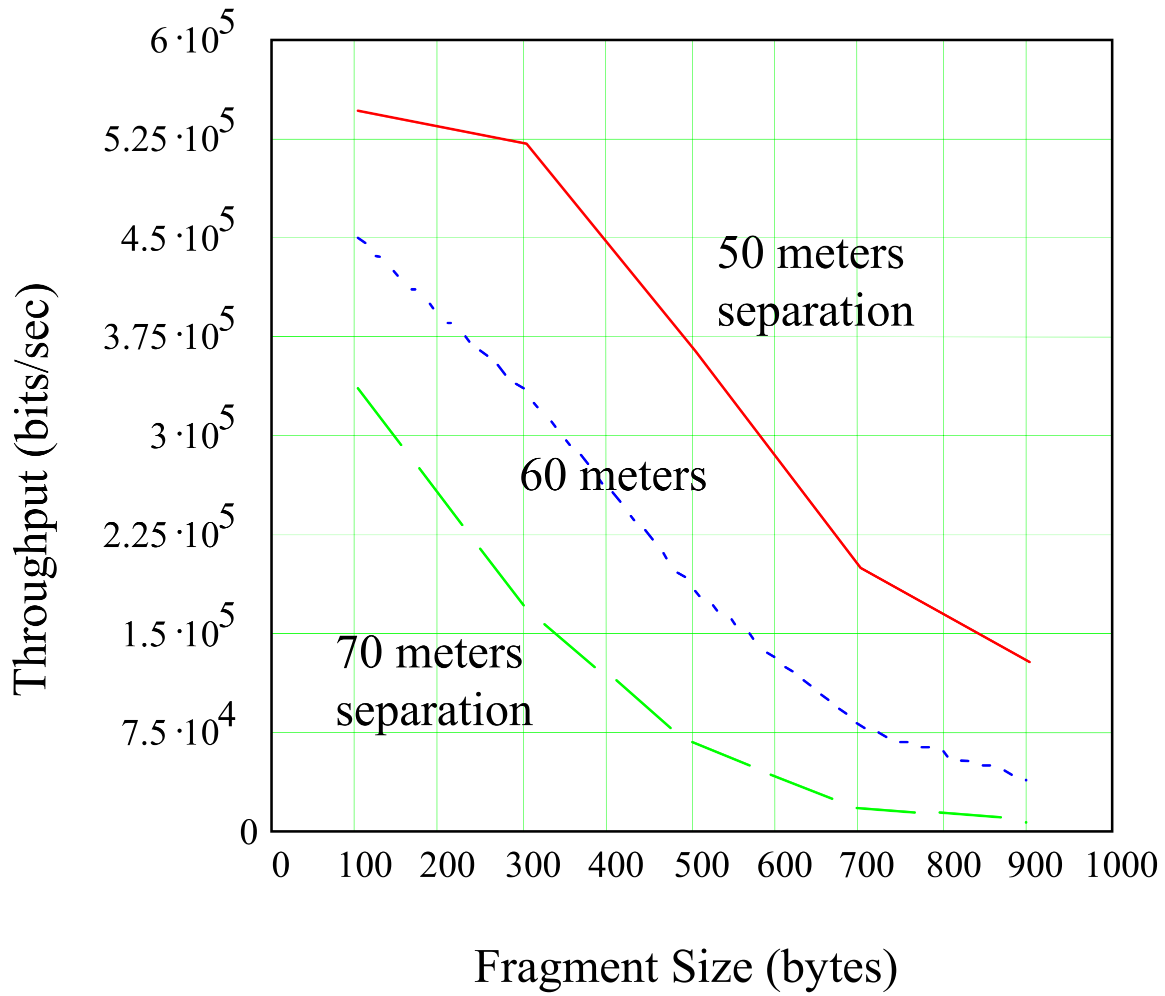
Throughput Optimization: 11Mbps



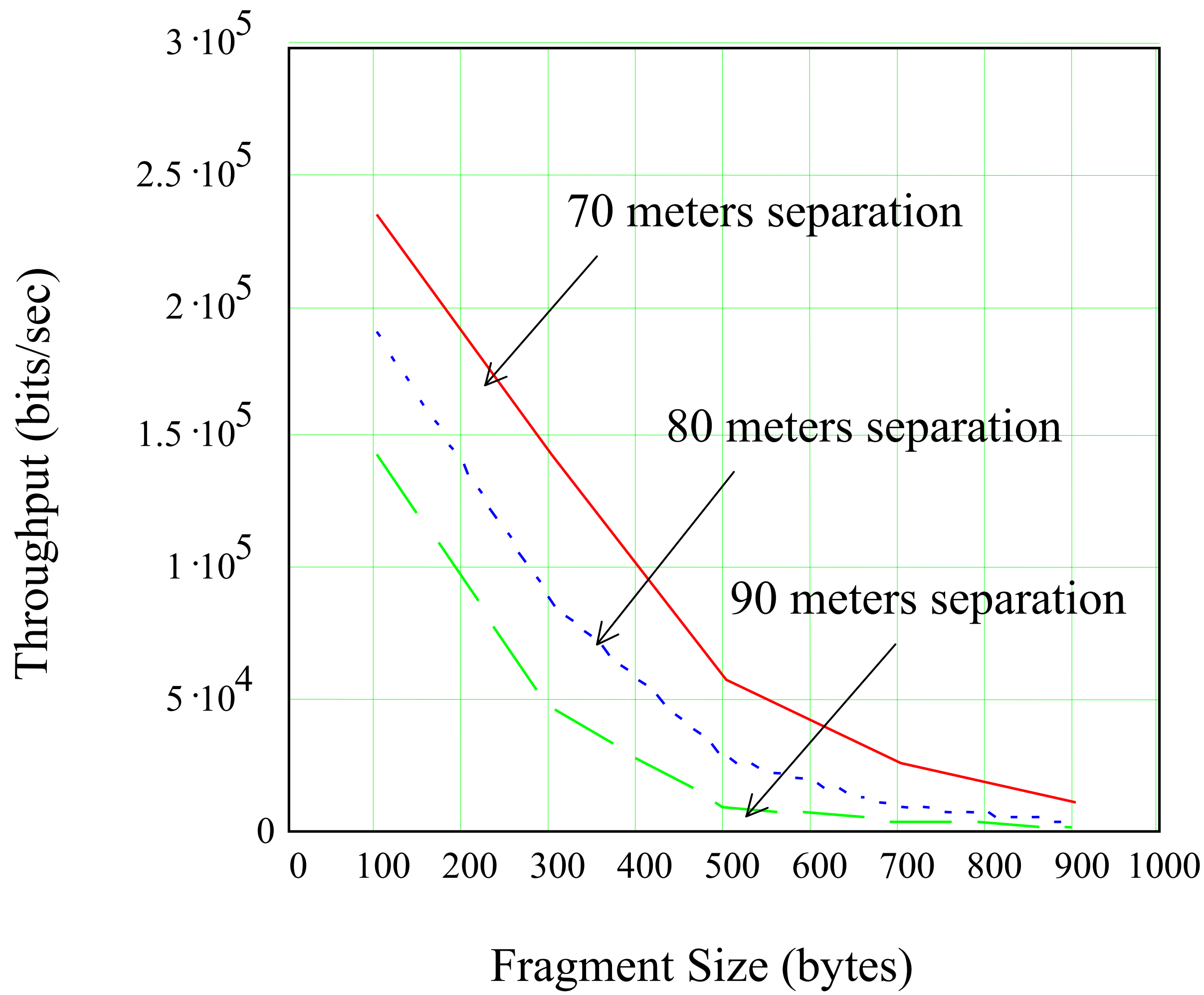
Throughput Optimization: 5.5Mbps



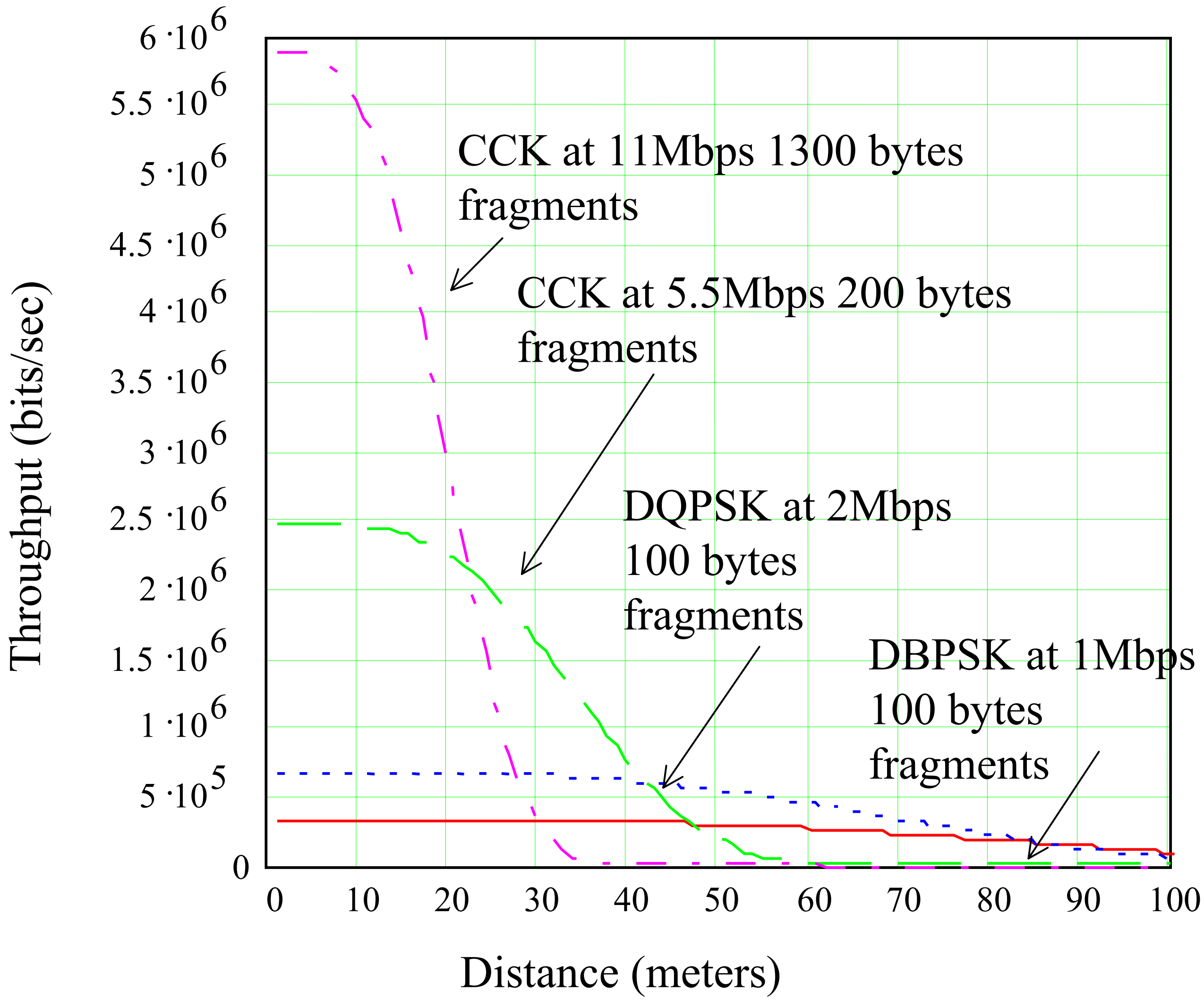
Throughput Optimization: 2Mbps



<u>Throughput Optimization</u>: 1Mbps



Total Optimized Throughput:



Conclusion:

- Collocated Bluetooth piconets have a significant effect on the performance of the IEEE 802.11b WLAN, especially, when number of piconet or their utilization increases.
- IEEE 802.11b packet fragmentation allows to optimize throughput of available data rate, thus increasing efficiency and operating range of the WLAN.

Best range of operation	1-25 meters	25-45 meters	45-80 meters	80 -∞ meters
Data Rate/ Fragment Size	11Mbps 1300bytes	5.5Mbps 200bytes	2Mbps 100bytes	1Mbps 100bytes
Throughput max/min	6Mbps/ 2.5Mbps	2.5Mbps/ 750kbps	750kbps/ 250kbps	250Kbps/ 50Kbps