IEEE P802.15 Working Group for Wireless Personal Area Networks

Interference Aware Bluetooth Scheduling Techniques

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Objectives

- Update the January scheduling proposal 01/63r0.
  - Implementation details
  - Additional traffic type results
  - Extensions to maximize channel utilization.
- Observations based on performance evaluation results for interference based environments:
  - Which HV packet type to use for BT voice? Is HV3 better than HV1?
  - What packet length to select? Does fragmentation help?
  - Is FEC useful?
- Recommendations

Recap of Interference Aware Scheduling

- Interference Estimation Phase
  - Maintain a Frequency Usage Table
  - Mark “Used” frequencies
  - Slave updates master’s Frequency Usage Table
- Master Delay Policy
  - schedule packet transmission at the master and ensure that both master to slave and slave to master packets are received in “unused” frequencies.

Step by Step Algorithm

- Slave's End.
  - For every packet received, update BER_f which is an average value of the BER per frequency.
  - Every update interval, U, refresh the Frequency Usage Table by marking the frequencies, and
  - Send a status update message to the master.
- Master's End.
  - For every packet received update BER_f
  - Every update interval, U, refresh Frequency Usage Table by marking frequencies, and
  - Delay transmission until slave and master's receiving frequencies are available.

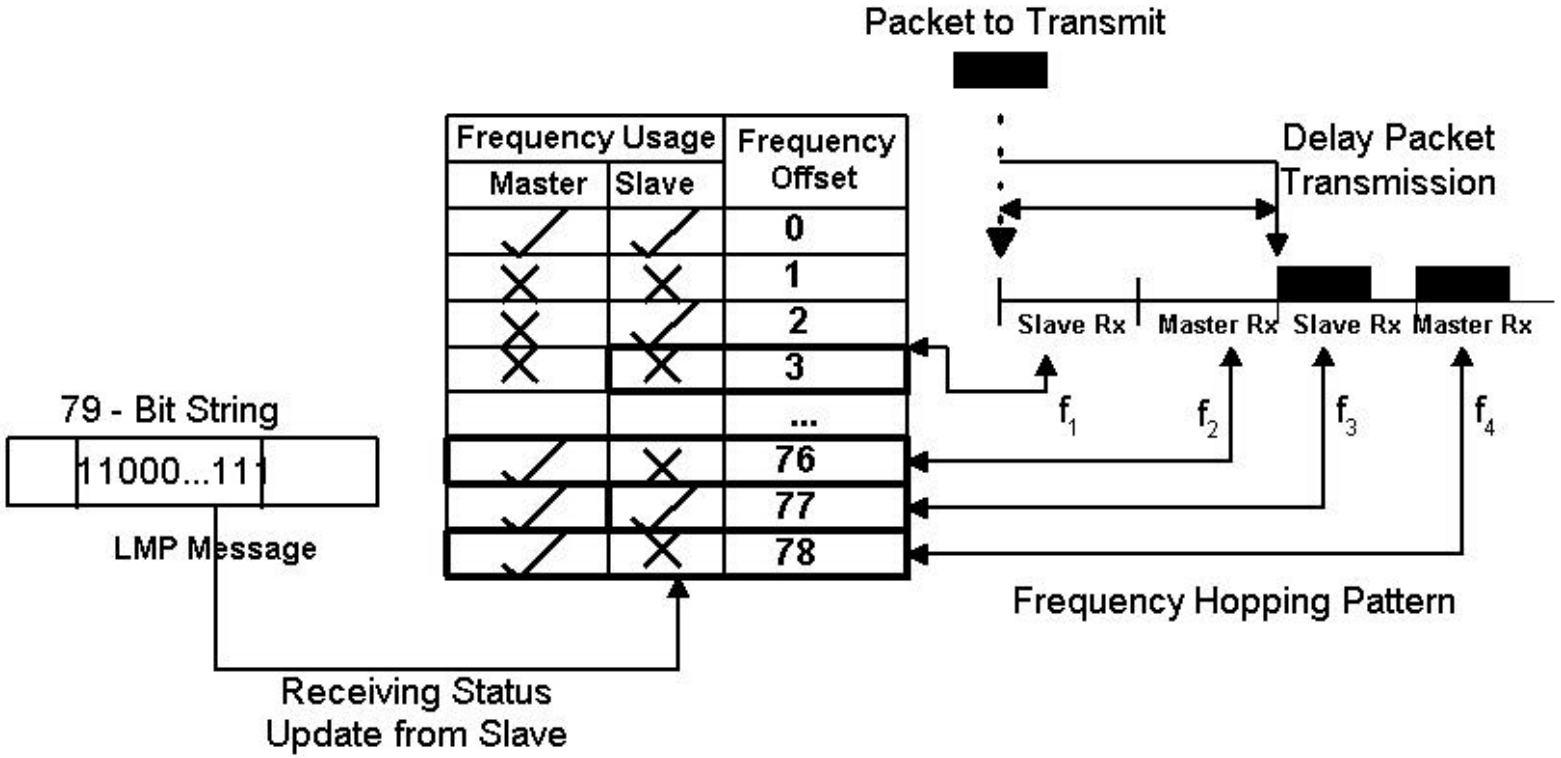
Frequency Usage Table

- Construct a table of the available frequencies based on the BER measurement at the receiver.

Use	Frequency Offset	BER_f
✓	0	10^{-3}
X	1	10^{-1}
X	2	10^{-2}
X	3	10^{-1}
	...	
✓	76	10^{-4}
✓	77	10^{-3}
✓	78	10^{-3}

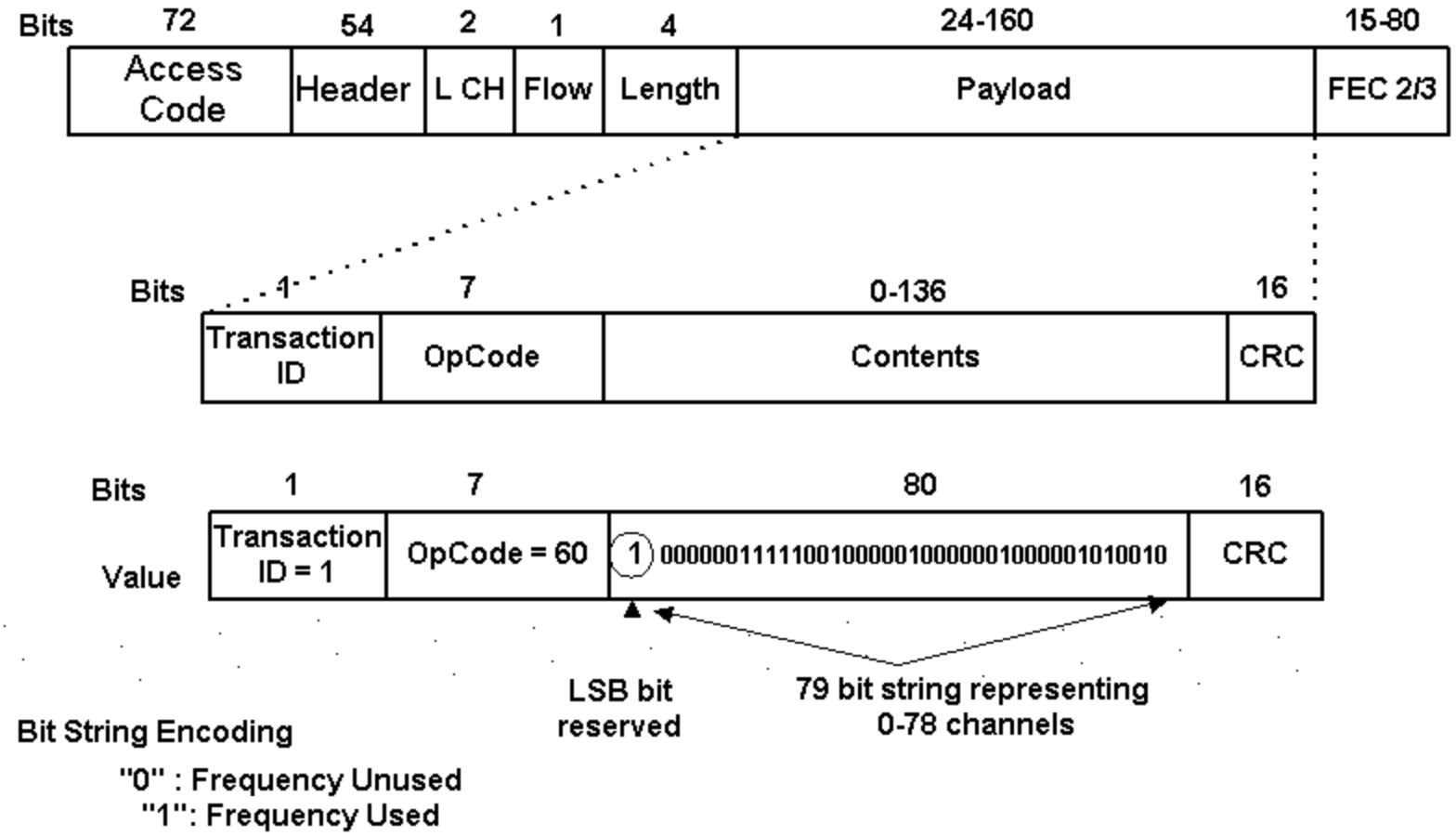
Scheduling Policy at Bluetooth Master

- Master checks both its available frequencies and the slave's available frequencies before sending a packet to the slave.

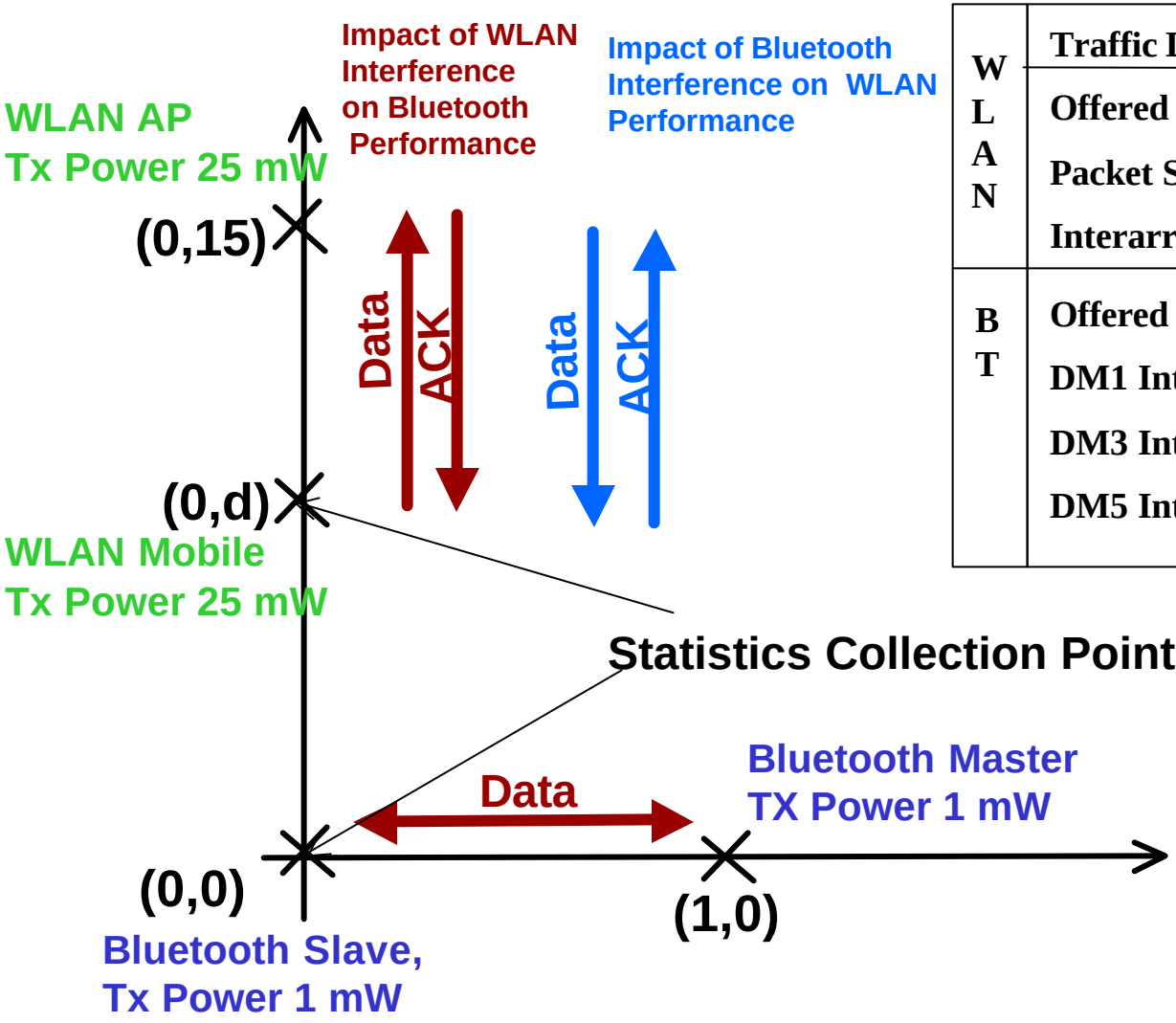


LMP Interference Status PDU

- Define LMP_Interference_Status Message



Simulation Scenario

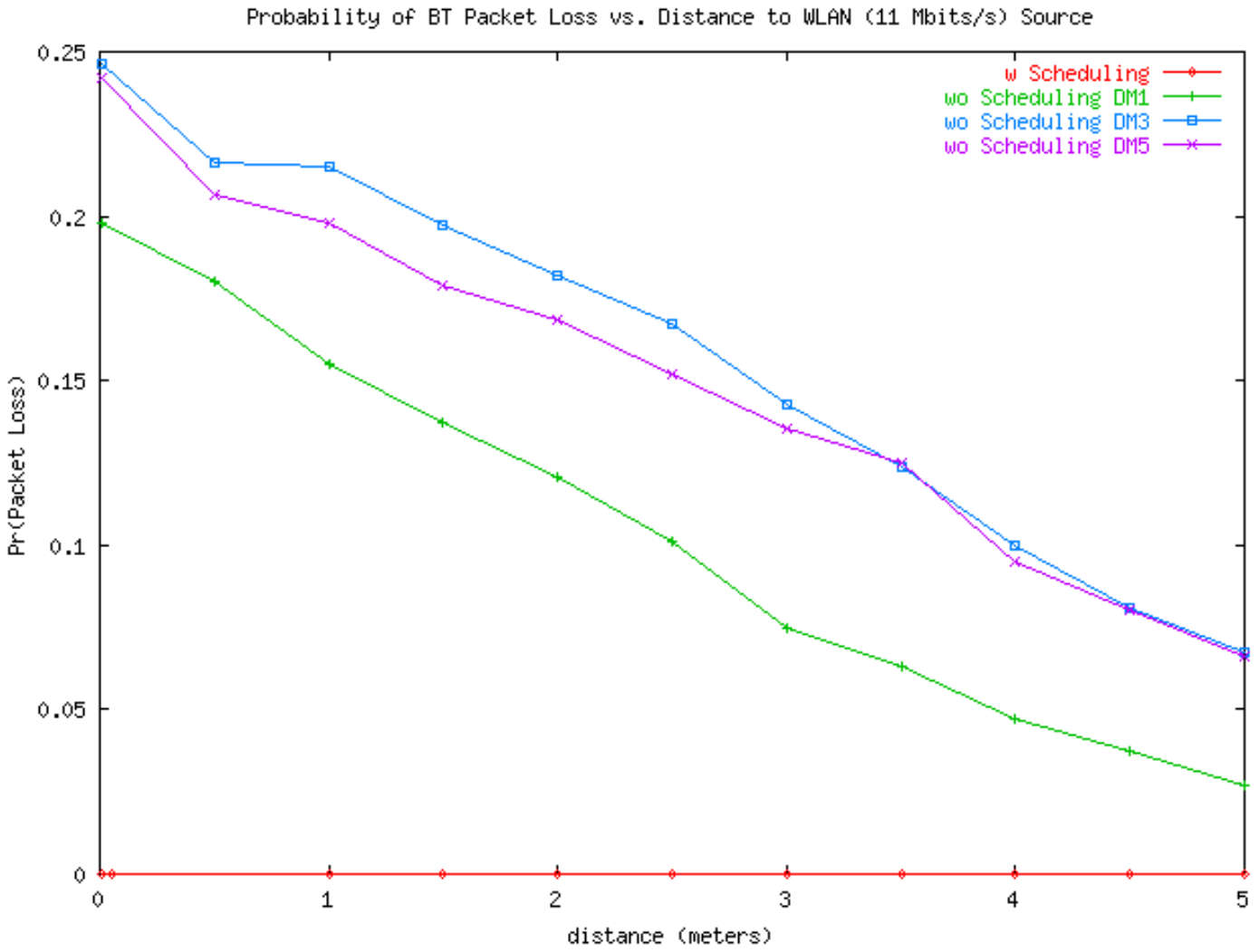


	Traffic Distribution	
WLAN	Offered Load	50 % Of Channel Capacity
	Packet Size	8000 bits
	Interarrival	1.86 ms
BT	Offered Load	30 % Of Channel Capacity
	DM1 Interarrival	2.91 ms
	DM3 Interarrival	8.75 ms
	DM5 Interarrival	14.58 ms

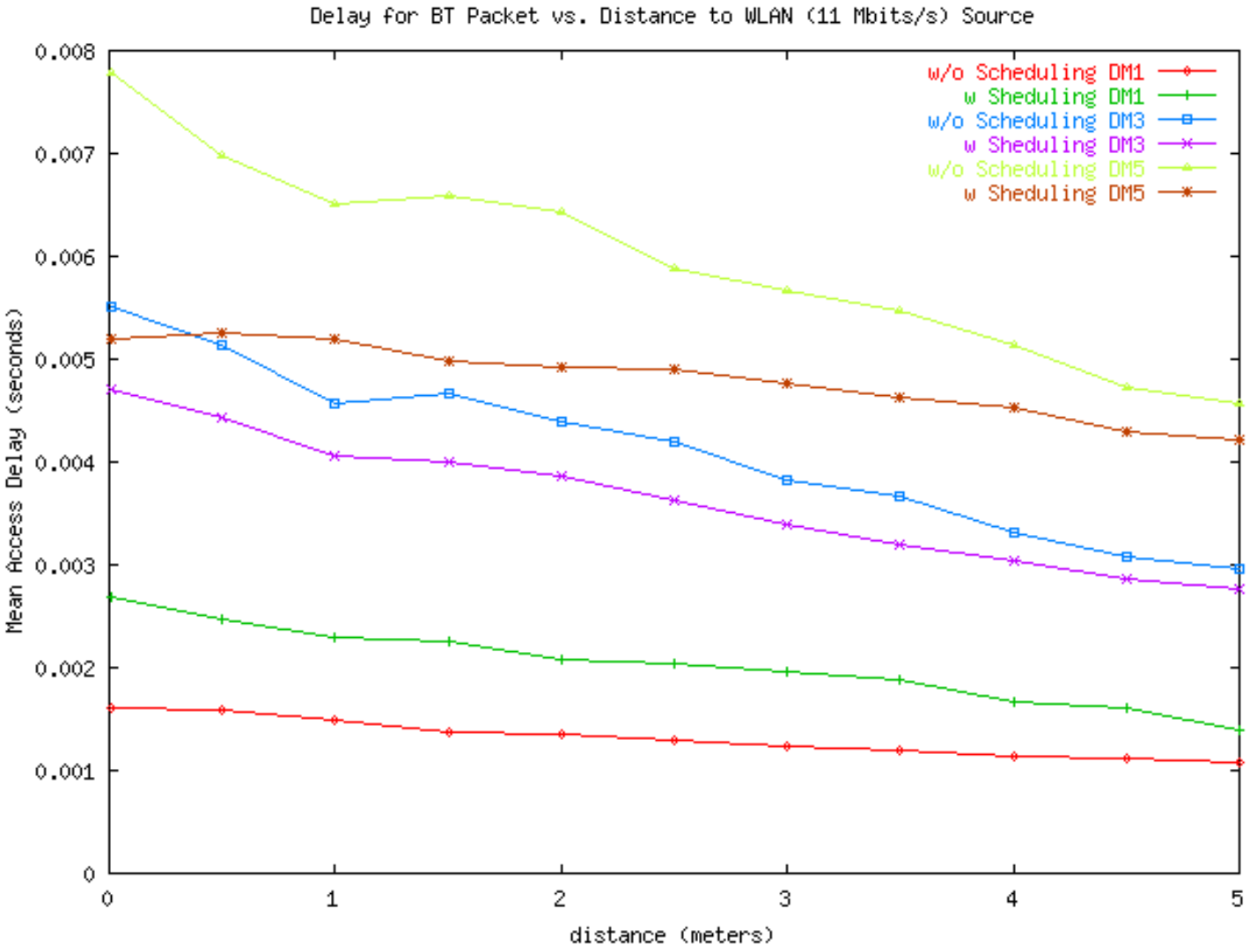
Performance Measurements

- Measurements are performed at BT Slave Device:
  - Probability of packet loss (Baseband)
  - Mean access delay (L2CAP)
- Measurements performed at the WLAN (mobile) device:
  - Probability of Packet (ACK) Loss.

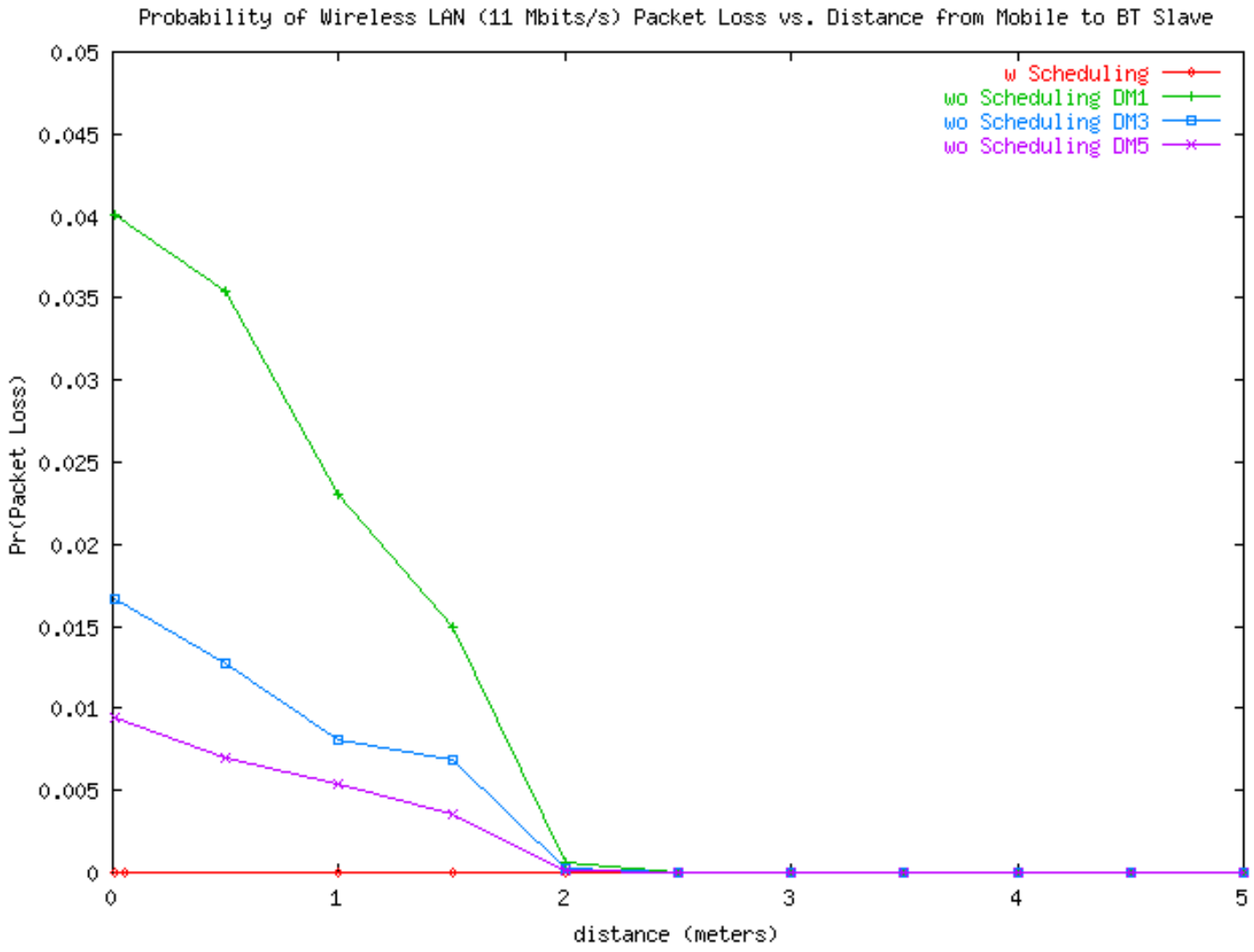
Effect of Scheduling on BT



Effect of Scheduling on BT



Effect of BT Scheduling onWLAN



Summary of Scheduling Advantages

- Scheduling technique is effective in reducing packet loss for all packet types.
- Mostly effective for reducing delays of multi-slot packets.
- It is neighbor-friendly and eliminates interference on other systems.
- It saves power since no transmission is wasted in bad channels.
- How about FCC rules?

What are the relevant FCC rules?

- FCC,"Title 47, Code for Federal Regulations," Part 15, October 1998 state
  1) "Frequency hopping systems operating in the 2400-2483 MHz (..) shall use 75 hopping frequencies. (..) The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period."
  2) "The incorporation of intelligence within a frequency hopping spread spectrum system that permits the system to recognize other users within the spectrum band so that it individually and independently chooses and adapts its hopsets to avoid hopping on occupied channels is permitted. The coordination of frequency hopping systems in any other manner for the express purpose of avoiding simultaneous occupancy of individual hopping frequencies by multiple transmitters is not permitted."
- Bluetooth uses 79 hopping frequencies; therefore the average time of occupancy on any one frequency is equal to:

  30/79 = 0.37 seconds.
- Since we are not changing the hopping pattern the average time of occupancy on any single frequency is still less than 0.4 seconds.
- In case the rules, specify that 75 channels need to be used within 30 seconds, then during a 30 second period, bad frequencies are probed at least once by a POLL/NULL message exchange between the master/slave.

Scheduling Extensions to Maximize Channel Utilization

- One of the drawbacks in avoiding “bad” frequencies is that channel utilization is limited to 57/79 = 72%.
- For single slot packets, the utilization is limited to 72%.
- However, since multi-slot packets use one frequency, the idea is to find good frequencies and use them to transmit DM3 or DM5 packets.

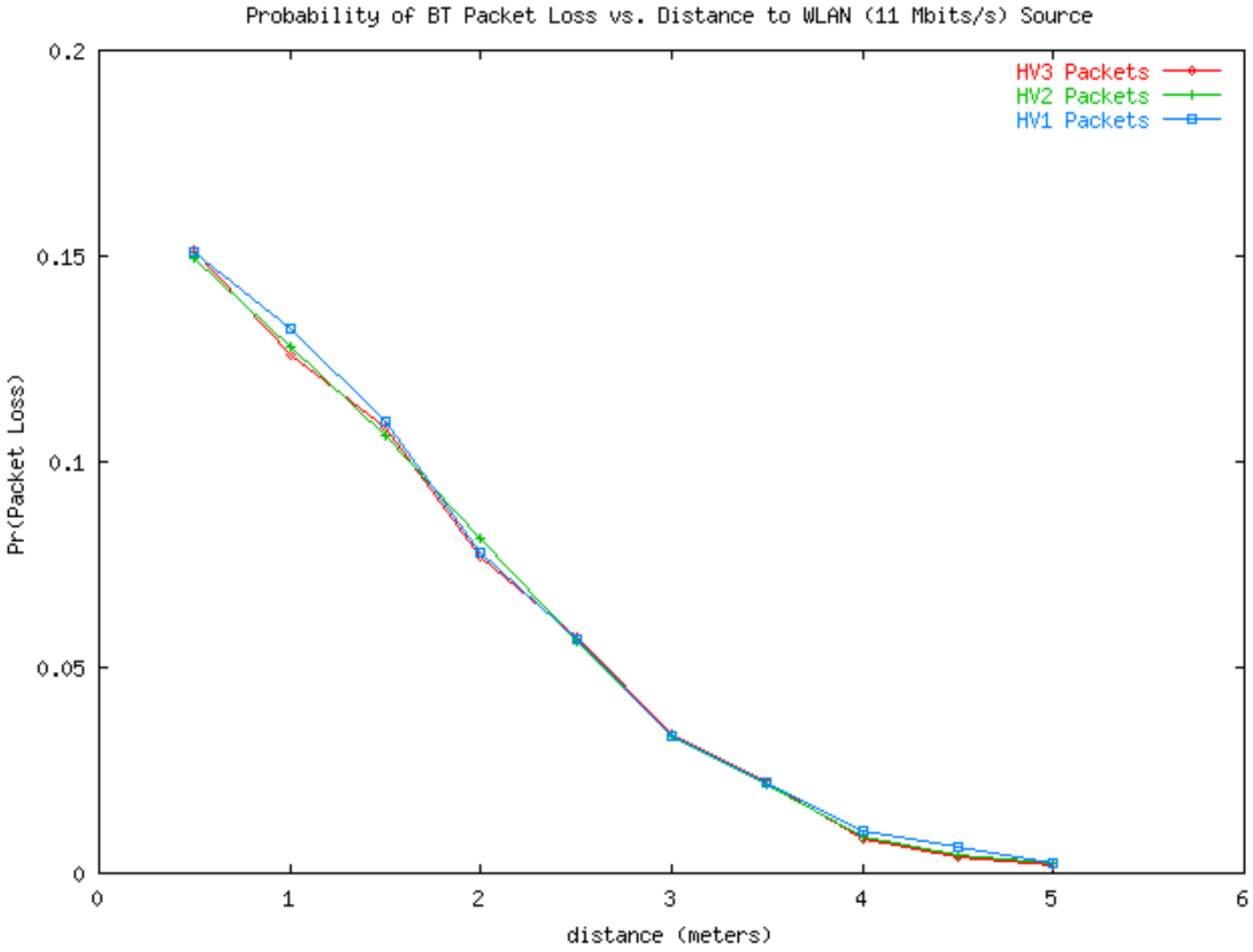
Packet Encapsulation Rules

- Master and Slave devices implement the following packet encapsulation rules in addition to the delay scheduling policy implemented by the master;
- Let f_x denote the receiving frequency associated with slot x and $S(f_x)$ and $D(f_x)$ denote the source and destination receiving frequencies respectively.
- Packet encapsulation rules:

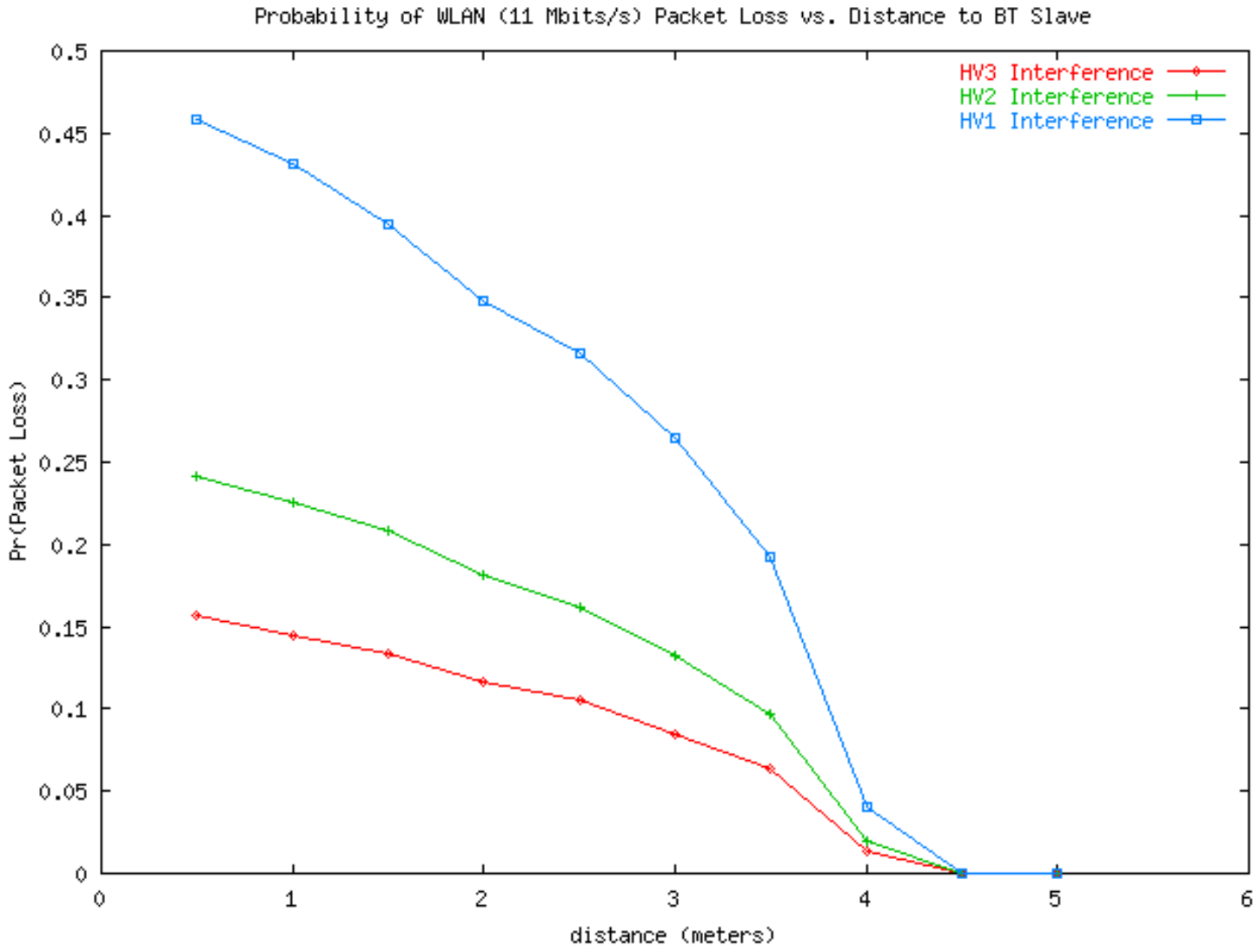
if $S(f_1)$ and $D(f_5)$
  select DM5
else if $S(f_1)$ and $D(f_3)$
  select DM3
else if $S(f_1)$ and $D(f_1)$
  select DM1

Miscellaneous coexistence observations … based on simulation performance results

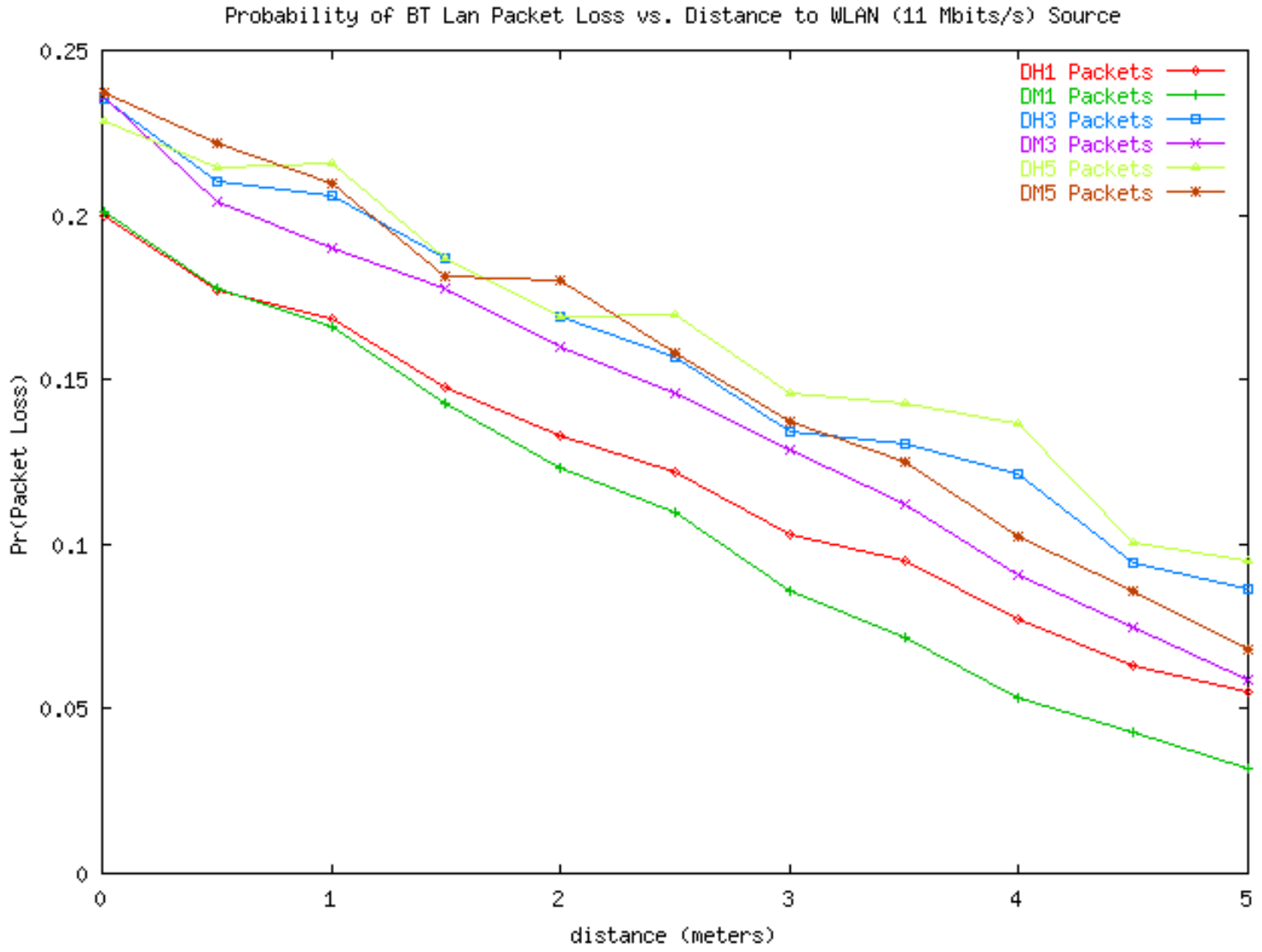
Choice of HV Packet does not affect BT



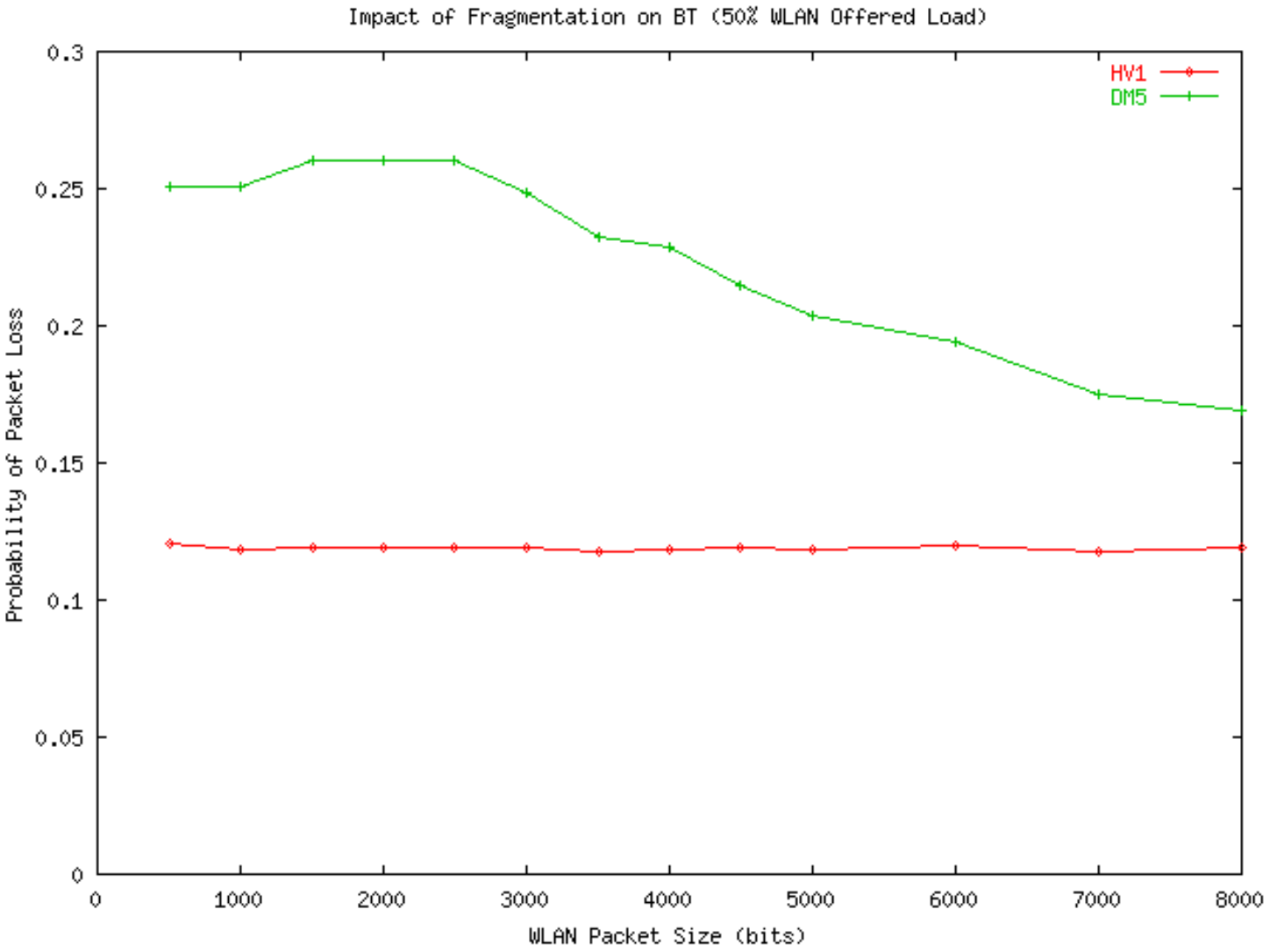
HV3 is"Friendlier" to WLAN



DM vs. DH Packets: Is FEC Useful?



Effect of Fragmentation on "Other" System



Summary of Observations

- HV3 is friendlier than HV2 and HV1 to WLAN.
- Longer packets have a higher probability of collision than shorter packets.
- Fragmentation may degrade the performance of the interfering system.
- FEC has limited performance benefits; mainly it improves the packet loss probability for low interference scenarios.

Recommendations

- Use interference aware scheduling for BT
- It can only improve the performance of BT in an interference environment:
  - reduces packet loss for all types of packets
  - reduces delay for multi-slot packets.
  - eliminates interference on other system.