Spectrum Management in ISM band

- Coexistence Issue between IEEE 802.11 and Bluetooth

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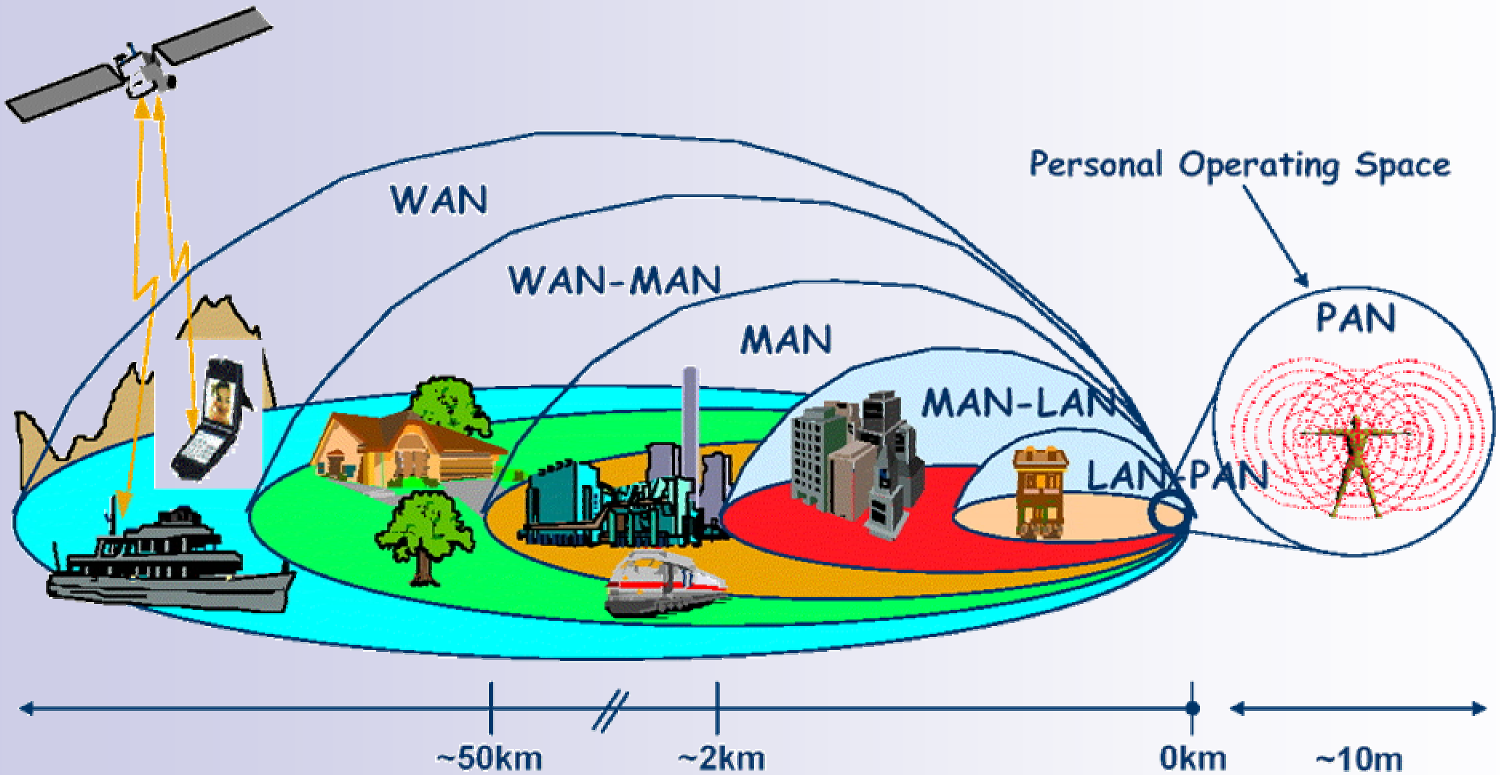
Outline

- Overview of WLAN/WPAN
- Review of IEEE 802.11 and Bluetooth
- Coexistence Issues between IEEE 802.11 and Bluetooth
- Dynamic Spectrum Management and Multi-channel coordination of 802.11
- Our future work

Network Area Definition



ISM Band Allocation:

902-928MHz

2.4-2.483GHz
(America)

5.15-5.35GHz
5.725-5.85GHz

Other ISM
24GHz, 60GHz

Overview of WLAN

ISM 2.4 GHz	UNII 5 GHz
▪ 802.11b (Wi-Fi): ~11Mbps, CCK 3 non-overlapping channel, 30m~120m @11Mbps 90m~460m @1Mbps ▪ 802.11g: ~54Mbps, OFDM	▪ 802.11a (Wi-Fi5): ~54Mbps, OFDM 8 non-overlapping channels, 12~30m @54Mbps 90~300m @6Mbps ▪ HiperLAN1 ~20Mbps, CSMA MAC ▪ HiperLAN2 ~54Mbps, OFDM TDMA, Connection-oriented adaptive frequency allocation

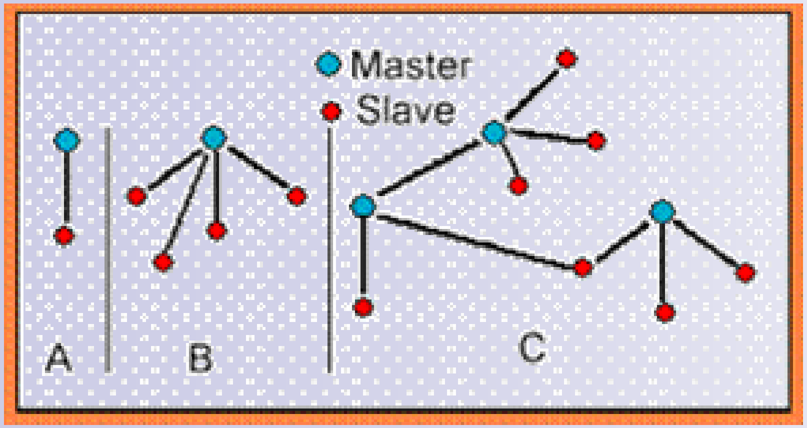
Overview of WPAN

Technologies	Date Rate	Power/Cost	Performance
Infrared	~115Kbps	Low cost Low power	Require Line-of-sight, will be replaced by Bluetooth
Bluetooth (802.15.1)	~723.2Kbps	Medium cost (goal low cost ~$5/chip), Low power	Replacement for cables and interconnecting computer and peripherals, support voice channels
UWB (802.15.3)	> 20Mbps	Currently high cost, Low power for unit spectrum	Very high date rate, no dedicated frequency needed

Review of 802.11

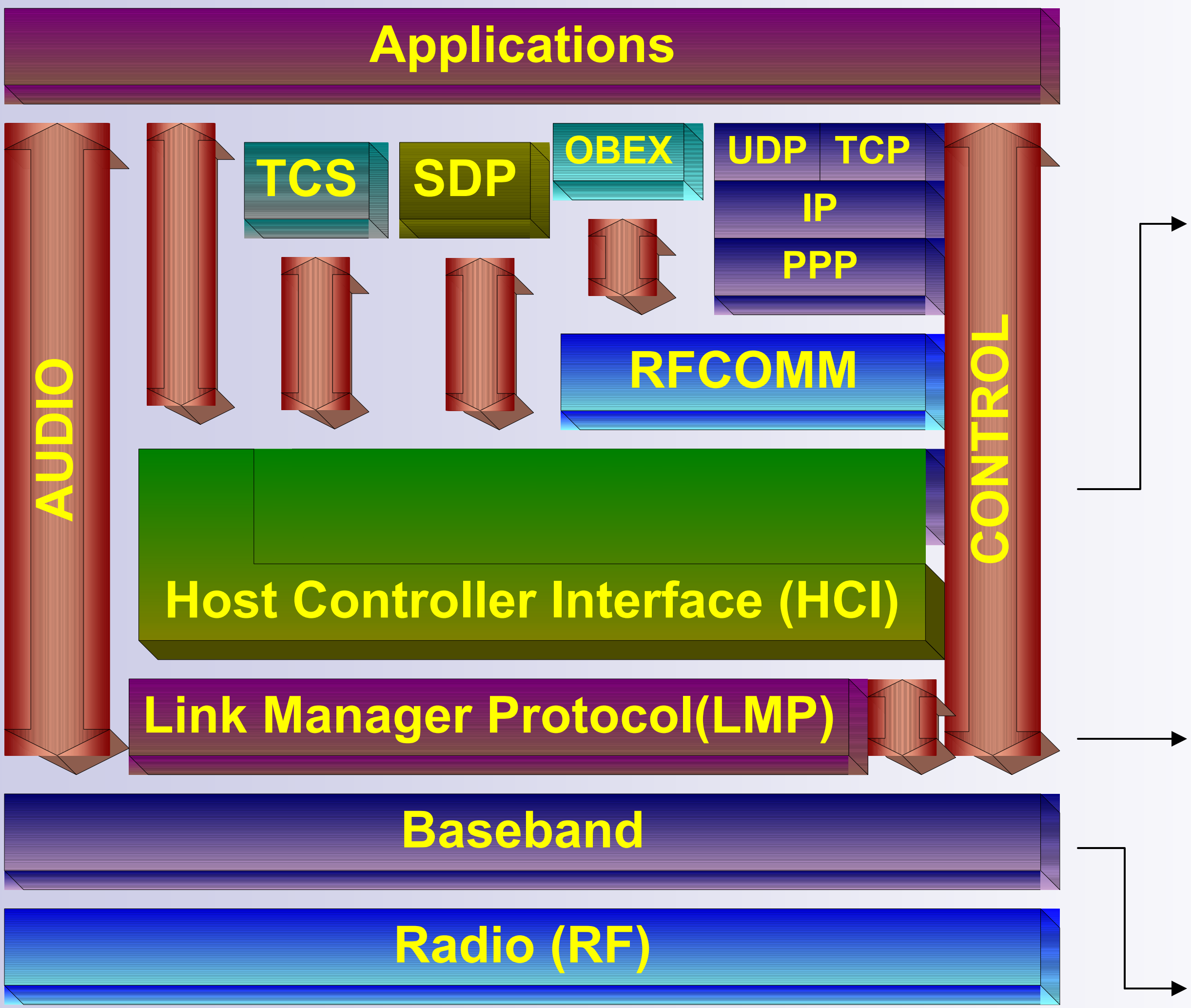
- Media Access Control:
  - CSMA/CA
  - RTS/CTS handshake to avoid hidden node problem
- Physical Layer
  - Basic 1Mbps (BPSK for DSSS, GFSK for FHSS), 2Mbps(DQPSK)
  - 802.11b extends data rate to 5.5 and 11Mbps (QPSK/CCK for HR-DSSS)
  - Totally 83.5MHz BW, defines 11 channels(CH1, 6 and 11 are interference-free), 22 MHz wide each
  - Power levels: 30mW ~ 1W

Review of Bluetooth™



- Topology: peer-to-peer (A), Piconet (B), Scatternet (C), BT-AP
- Media Access: TDD, 625us/slot, master and slave alternatively transmit at even-slot and odd-slot
- Link/Packet Type: can support 1 ACL and 3 SCO at the same time
  - SCO (64Kbps voice): HV1, HV2, HV3 , DV
  - ACL (data): DH1, AUX1, DM3, DH3, DM5, DH5
- PHY
  - FHSS, hopping rate at 1600hops/sec, GFSK modulation
  - 79 hopping channels at 1 MHz wide each
  - Power level: 100mW(~100m), 2.5mW(~10m), 1mW(~10cm)

Bluetooth Protocol Stack



Multiplexing,

Segmentation & Reassembly

Quality of Service

Link Setup, Information Exchange, Authentication, Encryption

Formation of Piconet Inquiry, Paging

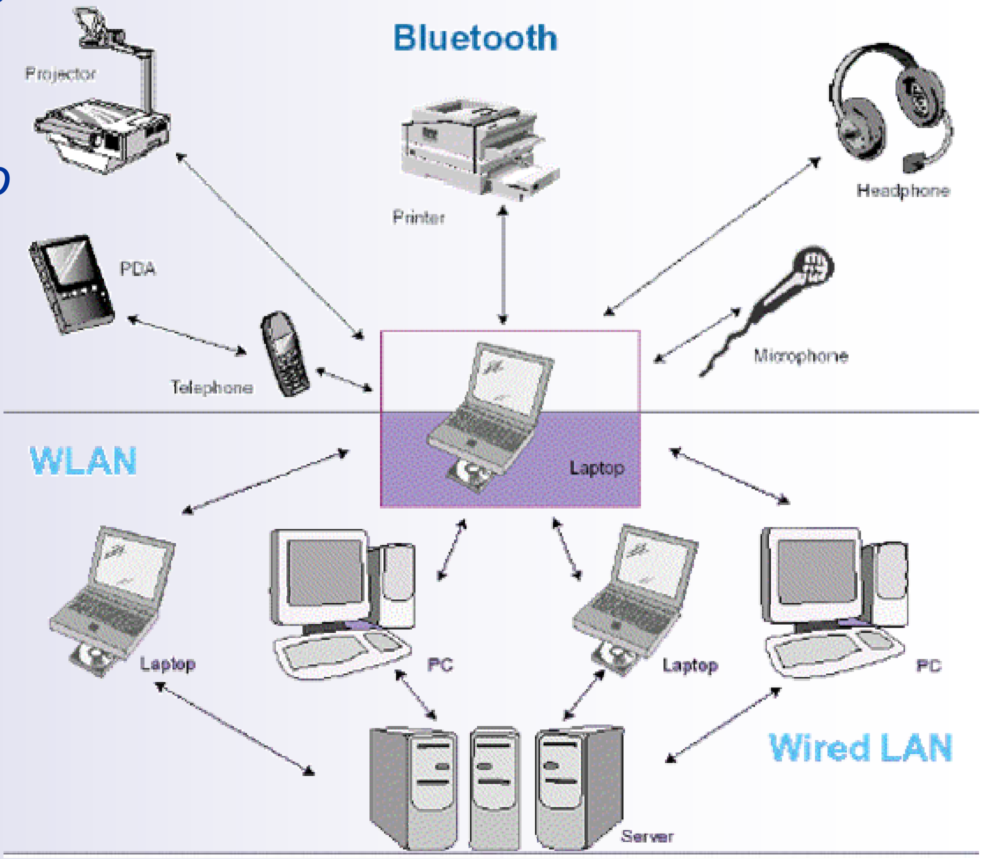
Bluetooth Connection Control

- Connection Setup
  - Inquiry/Inquiry Scan: discover which devices are in range, and determine the addresses and clocks for the devices
  - Page/Page scan: an actual connection can be established, and the slave switches to the master's timing and channel frequency hopping
- Piconet Setup: One master can have up to 7 slave nodes attached to it, by repeating connection setup
- Scatternet Setup: Edge nodes perform as both master and slave in different piconets and then piconets are connected to form a scatternet
- Connection mode: Active, Hold, Sniff and Park mode.

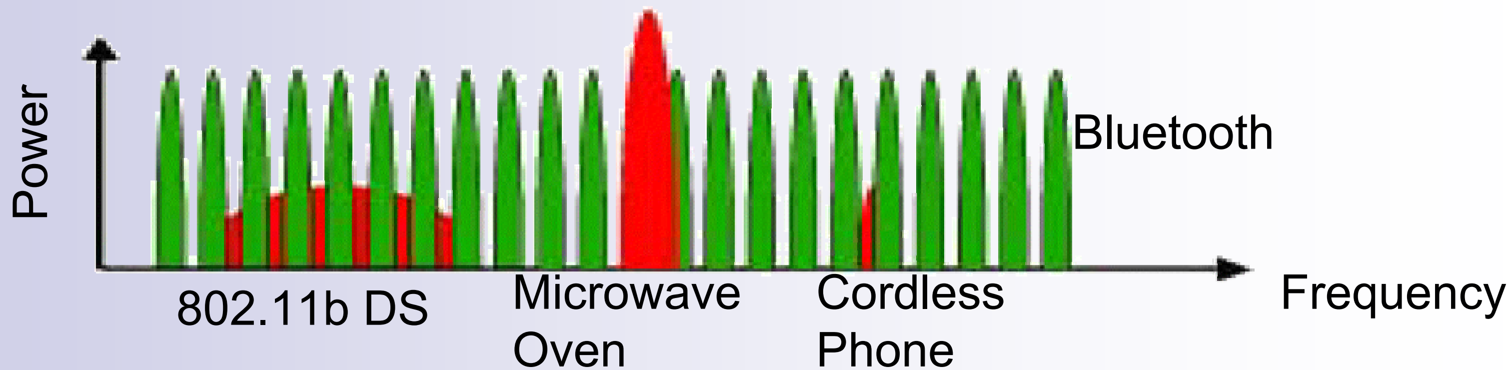
802.11 and Bluetooth Coexistence

- *"These this technologies will live side by side with 802.11b used in more established LANs, and Bluetooth when notebooks need to communicate with peripherals like printers or digital cameras." -Donald McDonald, Director Intel MPG*

- *"802.11b and Bluetooth will peacefully coexist in many applications. … There will be emerging products, such as PC Cards, notebook PCs, gateways, and access points with combined." - Joyce Putscher, Cahners In-Stat*

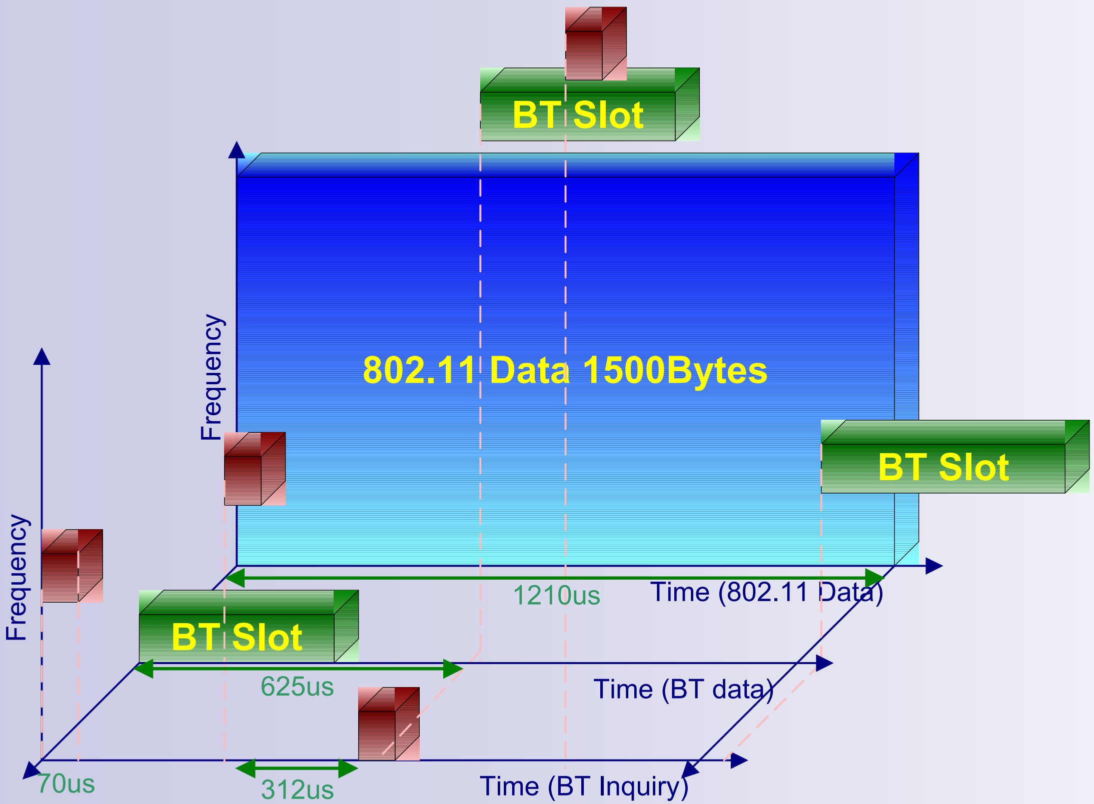


802.11 and Bluetooth Interference



		Bluetooth			
		Tx In-Band	Tx Out-of-Band	Rx In-Band	Rx Out-of-Band
802.11b	Tx	No conflict	No conflict	Strong Interference 802.11b Degrades BT performance	Moderate Interference 802.11b Degrades BT performance
	Rx	Strong Interference BT Degrades 802.11b performance	Moderate Interference BT Degrades 802.11b performance	Strong Interference*	Moderate Interference*

Time/Frequency Comparison



- A DSSS 802.11 packet can overlap a number of BT slots
- BT has a fast hopping rate *(1600hops/s for data and 3200hops/s for paging)*
- Traffic load condition is critical for the interference *(a duplex phone call by HV3 packet requires 33% of the BT time slots)*
- Lower transmission range of BT makes it suffer more
- Larger 802.11 payload suffers more for throughput degradation

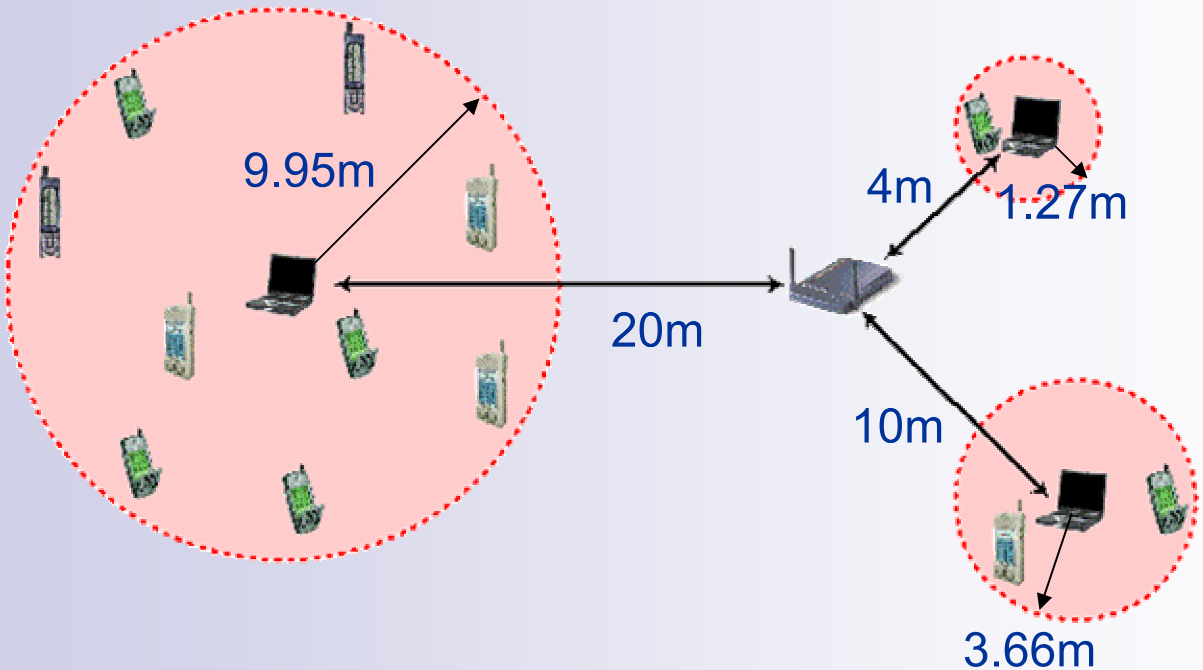
Interference Con’t

- Effect of 802.11 on Bluetooth
  - Long Ethernet packets degrades BT performance
  - ACK (<150us) affects much less
  - BT SCO is degraded until capture effect block the interference (802.11 devices far enough)

  Tips to BT: Hop to good channel and power control
- Effect of Bluetooth on 802.11
  - Bluetooth voice traffic is the worst of all cases
  - Faster hopping rate can easily destroy large 802.11 packet

  Tips to 802.11: Use fragmentation and power control

Interference Scenario (BT on 802.11)

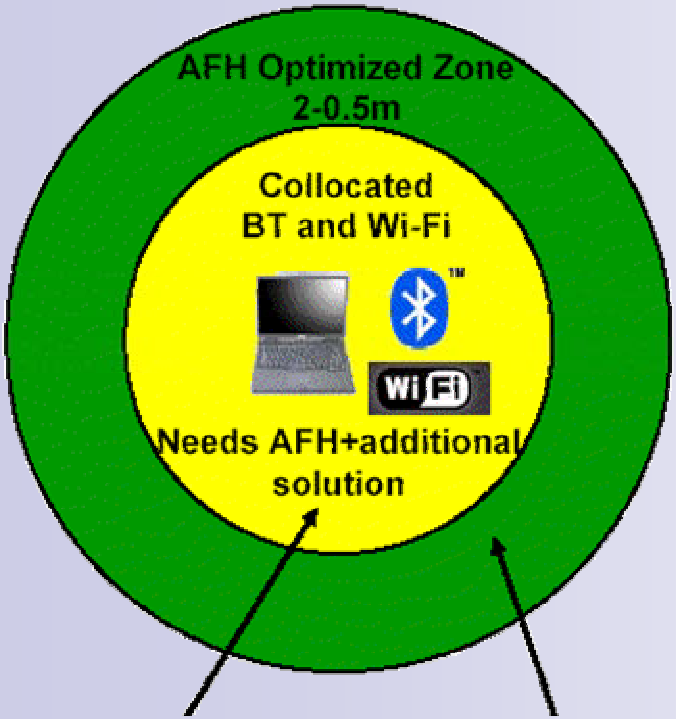


DSSS signal must be 10 dB greater than BT signal to overcome the interference

Propagation Model: $L_{path} = 20\log(\frac{4\pi r}{\lambda})$ r<8m

$L_{path} = 58.3 + 33\log(\frac{r}{8})$ r>8m

Severe Interference Zones



Mobilian Sim-op solution

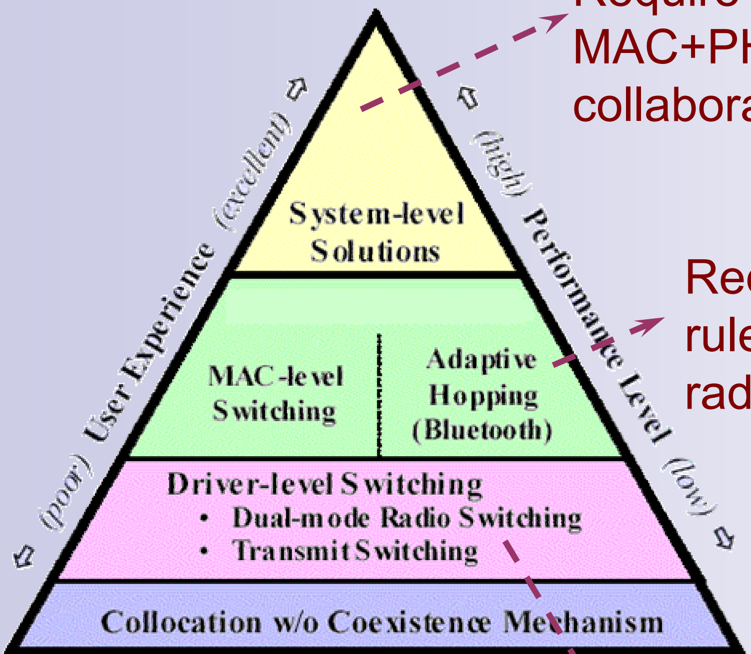
Graceful Degradation of BT and Wi-Fi,

- Separation > 0.5m:
  - Theoughput increases to almost 100% until > 2m
  - Voice quality suffers without AFH inside 2m
- Separation < 0.5m:
  - Significantly reduced throughput
  - Voice quality can be poor

Current Solutions

- Collaborative: *Extra control radio, or centralized coordination server is needed*
  - TDMA: time domain switching, No SCO links
  - MEHTA: Scheduling based on interference parameters, priority is given to BT voice and WLAN data
  - Spectrum Coordination with power control: Spectrum Server Pool?
- Non-Collaborative: *Detecting the presence of other devices by measuring the bit/frame error rate, the signal strength or the SNR (by RSSI)*
  - Adaptive Frequency Hopping: BT solution, alters hopping sequence to avoid interference channels
  - Packet MAC Scheduling: BT MAC keeps a frequency usage table to schedule packets

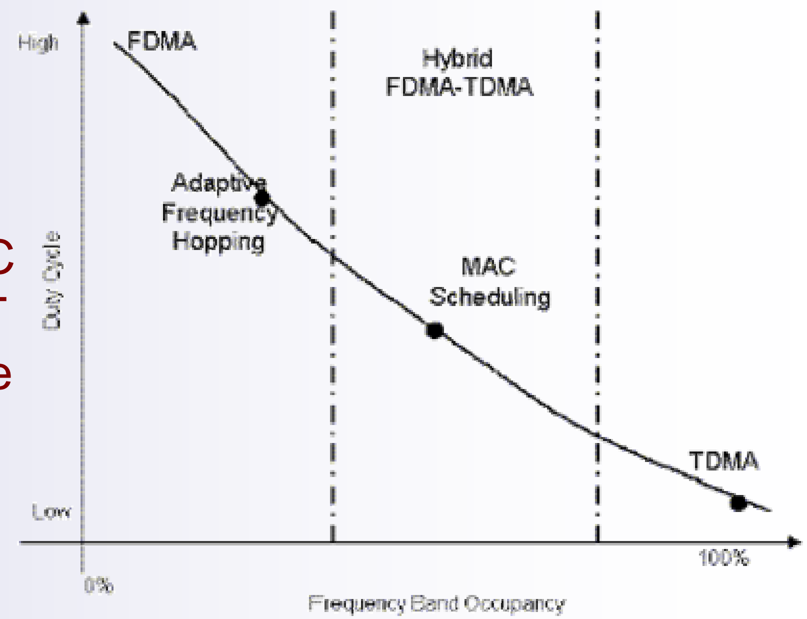
Coexistence Solution Space



Require MAC+PHY collaboration

Require FCC rules and BT radio change

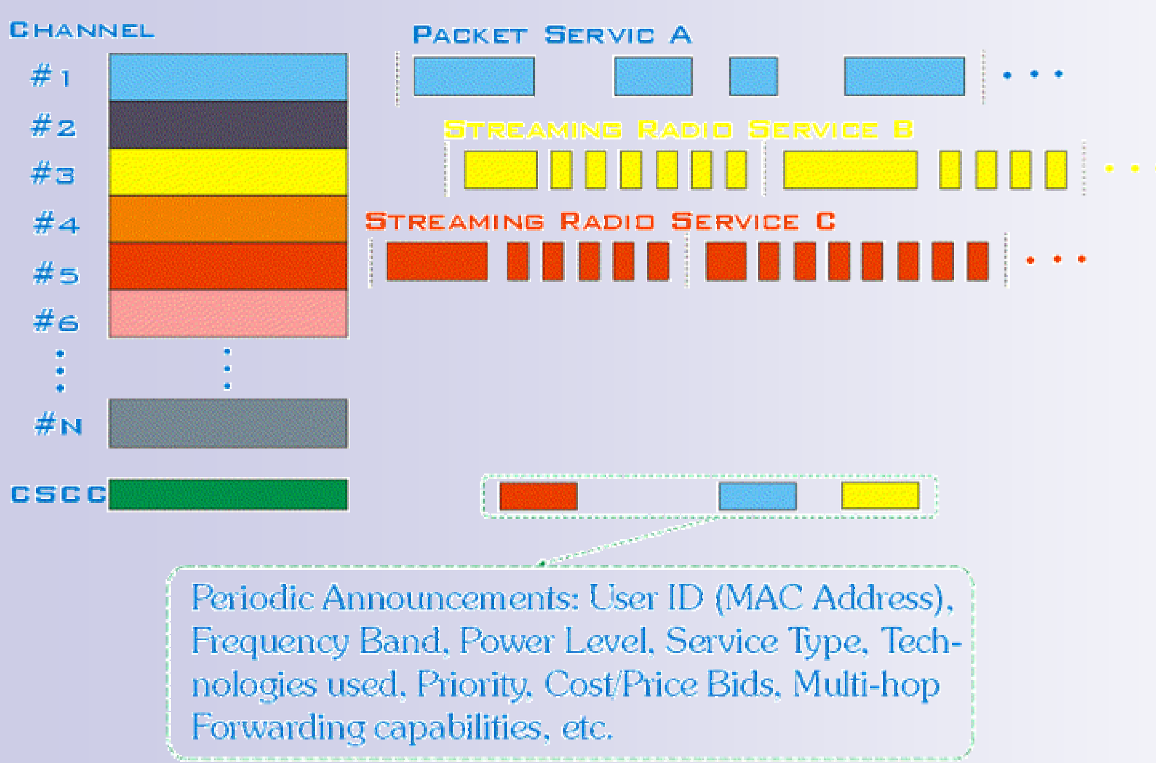
Simple, but no SCO and low throughput



As the band occupancy increases, each system is forced to transmit less often in order to avoid collisions.

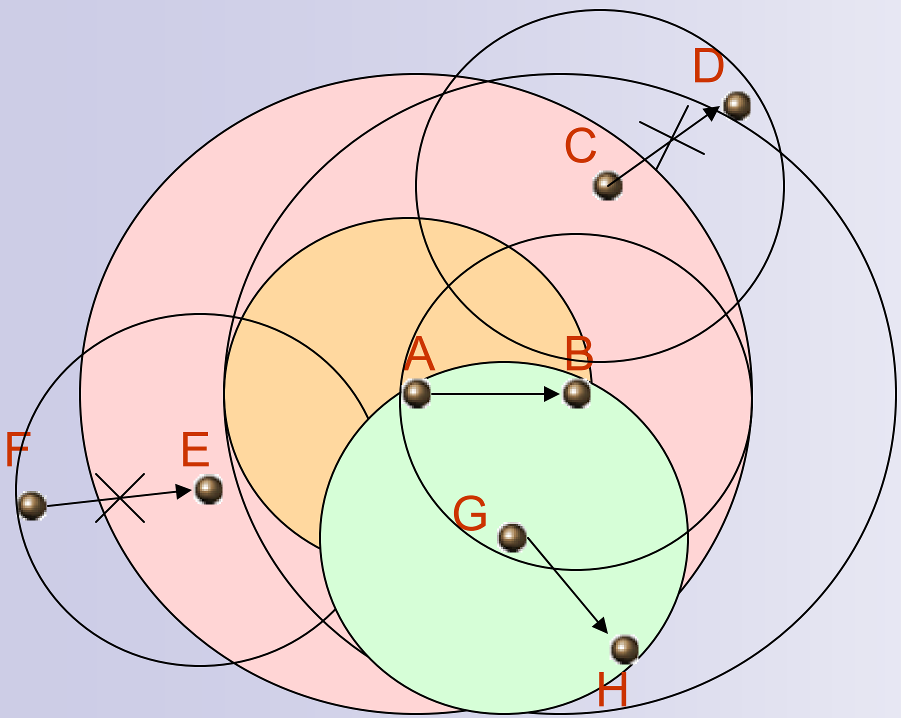
Dynamic Spectrum Management

- CSCC(Common Spectrum Coordination Channel) can enable mutual observation between neighbor radio devices by periodically broadcasting spectrum usage information



- Coordinate among 802.11 devices in dense networks
- Coordinate among different kinds of devices by CSCC (control radio with 802.11 1Mbps prototype)
- Spectrum taken up condition may be obtained from a server pool with real-time measurement capability

Power Control for Multi-channel 802.11



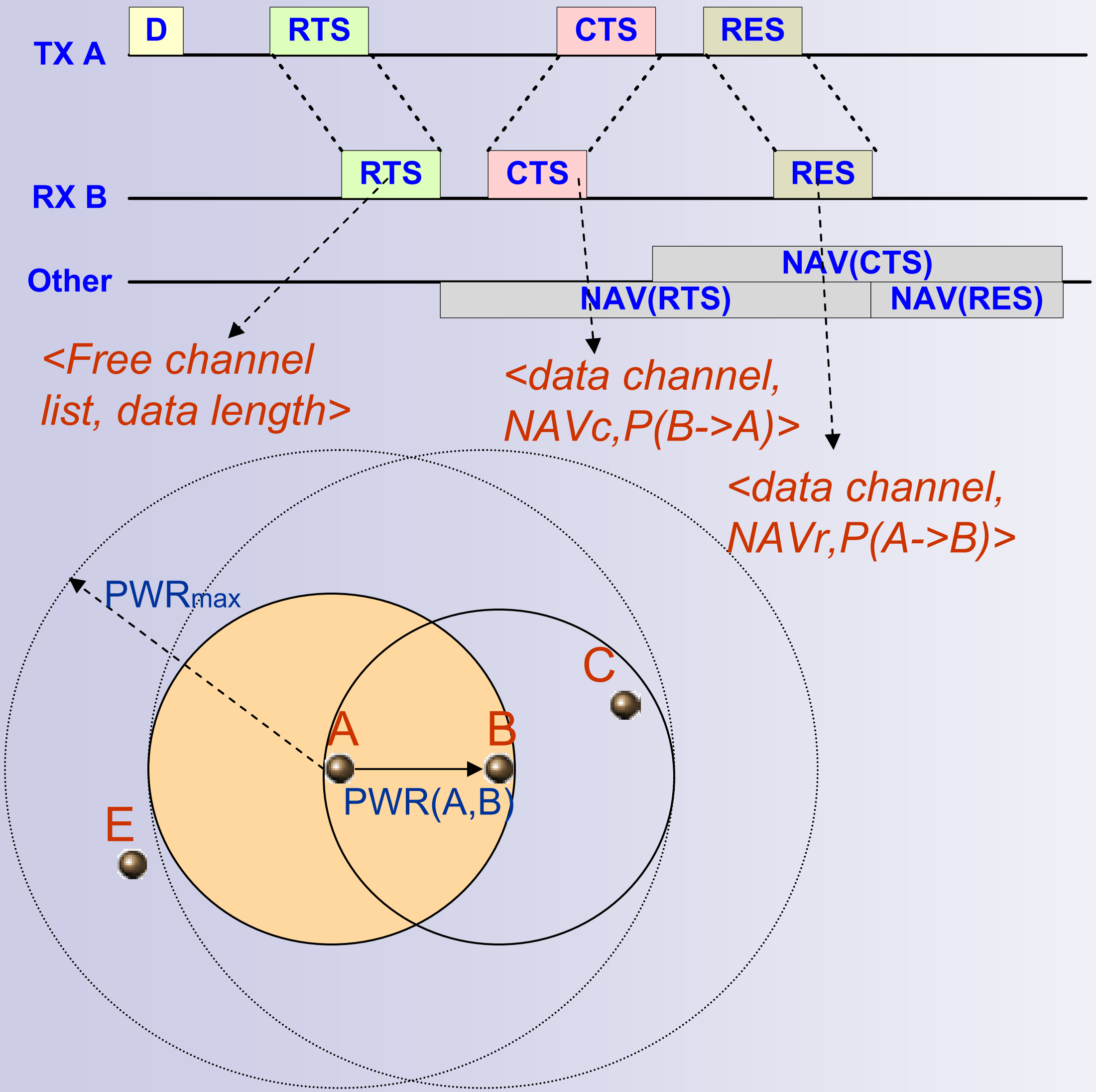
Hidden Node C is avoided by RTS/CTS

Exposed Node E is avoided by power control

G can communicate with H in a difference channel

- Power control and multi-channel schemes can increase spectrum reuse, and reduce hidden and exposed node problems
- Control packets will always use maximum power
- Power table and Spectrum table is maintained among neighbor nodes
- A modified RCS/CTS/RES 3-way handshake is used to setup connection

Control Channel Scheme



- A checks B is not busy and data channel c(i) is clear (A not interferenced). Broadcasts RTS<FCL,L>.
- B checks if c(i) clears, and broadcasts CTS<c(i), NAVc,PWR(A)>
- A checks c(i) cleared, then claims channel c(i), and broadcasts RES<c(i), NAVr,PWR(B)>, and then sends data to B
- B acks A
- Others back off by NAV, and update their FCL by comparing PWR(x) with their own power table

Our Future work

- Implement the CSCC structure in 802.11 nodes and Bluetooth nodes with control radio
- Research topics on packets scheduling between 802.11 and Bluetooth
- CSCC Protocol with power control for devices other than 802.11
- Utilization of spectrum measurement capability to construct possible spectrum server pool