Dynamic Coordination of Multi-Radio Platforms in Dense Spectrum Environments

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WIRELESS INFORMATION NETWORK LABORATORY

IAB Meeting

Outline

- Project overview
- Multi-radio co-existence problems
- CSCC etiquette protocol applied to the multi-radio scenarios
- Advanced rate-backoff algorithm for WiFi/Bluetooth
  - Identifying co-existing region from measurements
  - Cooperative service rate control for better co-existence
- Initial results for simplified rate algorithm using ORBIT multi-radio nodes
- On-going and future work

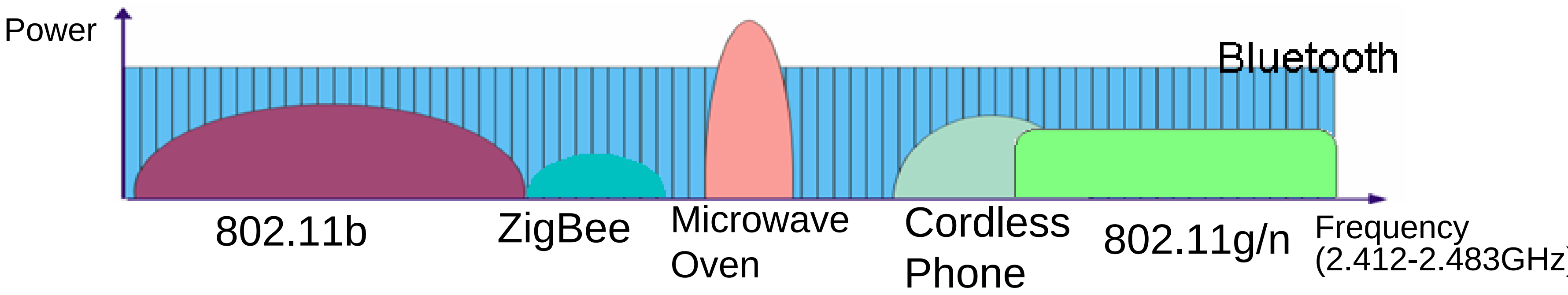
Motivations

- Spectrum resource is very scarce
  - Current spectrum utilization is inefficient
- Anecdotal evidence of WLAN spectrum congestion
  - Unlicensed systems need to scale and manage user "QoS"
- Density of wireless devices (including multi-radio devices) will continue to increase
  - ~10x with home gadgets, ~100x with sensors/pervasive computing
- Mobile device is becoming smaller and smaller
  - Limited space for multiple antennas results in in-band and adjacent-band interference
- Interoperability between proliferating radio standards

Project Goals

- High spectrum efficiency in multi-radio scenarios
  - Spectrum sensing, reactive algorithms and etiquette protocol
  - 802.11a/b/g/n, Bluetooth, Zigbee, WiMax, and UWB
- Improve end-to-end performance via multi-radio relays
  - Distributed protocols for ad hoc network formation and multi-radio forwarding
  - Algorithms for “always best connected” operation
- Experimental prototyping and validation
  - Realistic dense usage scenarios emulated on ORBIT radio grid
  - Measure spectrum efficiency at different levels of application performance

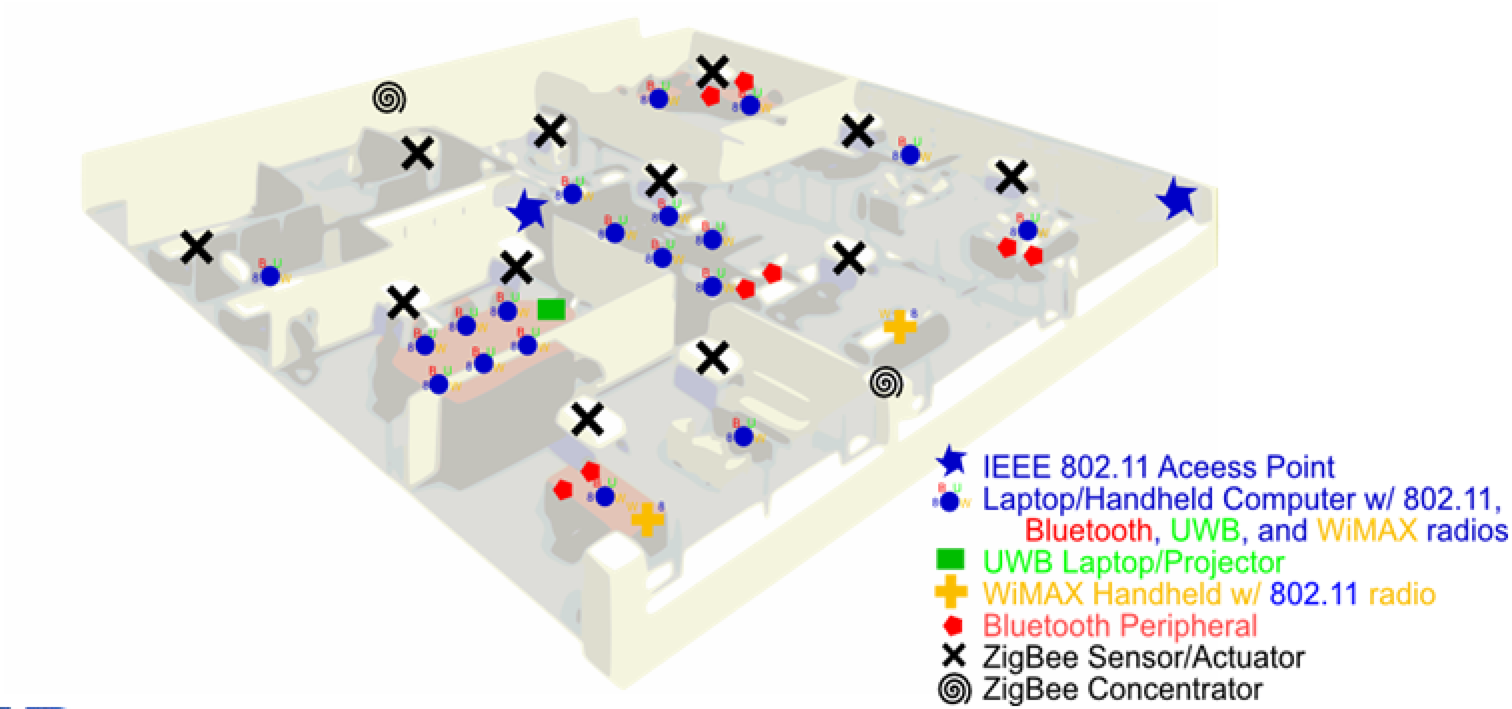
Multi-radio Platforms



Radio Technology	Typical Range	Max. Output Power	Frequency Occupied	Max. Bitrate Supported	Typical Usage
802.11a/b/g/n (WIFI)	150-300 feet	17 dBm	2.4 GHz ISM, 5 Ghz UNII	up to 248 Mbits/s	WLAN point-to-multipoint, Mixed web, file and streaming traffic.
802.16 (WiMAX)	3-5 miles (12 miles)	22 dBm (handheld), 26 dBm BS	2.300-2.400 GHz, 2.496-2.690 Ghz, 3.300-3.800 GHz	4 Mbits/s (70 Mbits/s)	WMAN broadband, Mixed web, voice traffic.
802.15.1 (Bluetooth)	150-300 feet (Class 1), 15-30 feet (Class 2), 3-4inch (Class 3)	20 dBm (Class 1), 4 dBm (Class 2), 0 dBm (Class 3)	2.4 ISM	3 Mbits/s (EDR)	WPAN, low speed peripheral communications and voice/audio.
UWB/Wireless USB	30-100 feet	-41dBm/Hz	3.1-10.6 GHz	500 Mbits/s	WPAN, high-speed peripheral communications
802.15.4 (ZIGBEE)	33-246 feet	3 dBm (current implementations)	868 MHz (EU), 915 MHz (US), 2.4GHz ISM	20-250Kbits/s	WPAN, very low rate, intermittent traffic for sensors

Typical Scenario - SOHO

- Devices: Multi-radio laptops, handheld, Bluetooth headset, sensors, etc.
- Clustered distribution in conference rooms
- Dominate traffic:
  - Periodical WiFi data (web, email, file, VoIP, etc.)
  - CBR/VBR Bluetooth voice/audio sessions



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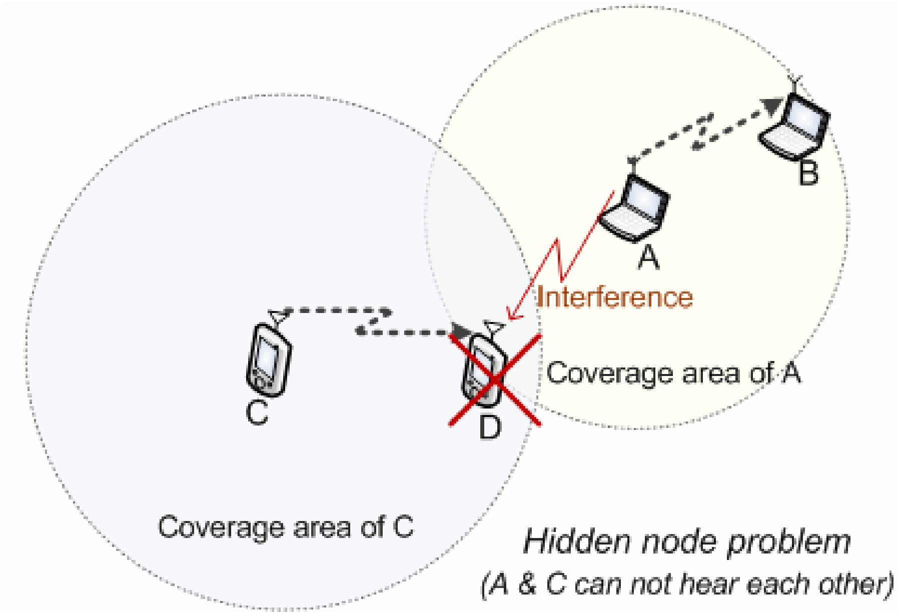
Co-existence Problems/Solutions

- Interference of co-located radios on the same platform
  - Close proximity of heterogeneous radios will have major impact
  - Antenna placement/sharing for multi-radios
  - Other on-platform interference such as wideband LCD noise
  - → Physical separation/insulation
  - → In-platform local scheduling
- Interference due to proximity of radios
  - High radio density in typical co-existing scenarios
  - Hybrid-type traffic over the air
  - Different interference range for different radios
  - → Simple LBT or reactive frequency/rate/power control
  - → **Spectrum etiquette protocol for explicit spectrum negotiation and coordination**

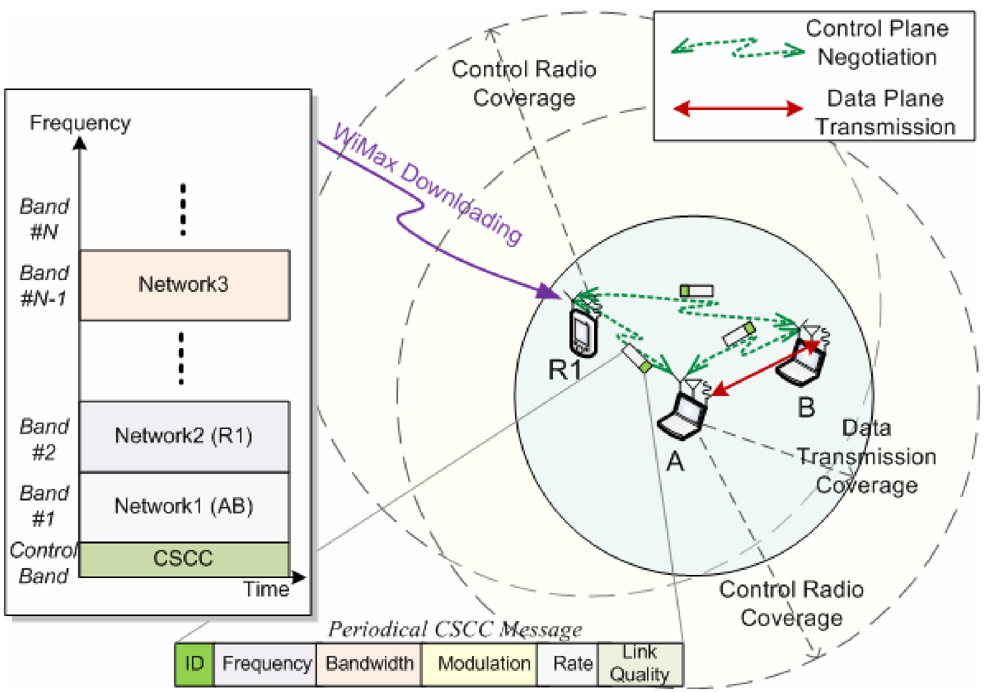
Hidden-node Problem

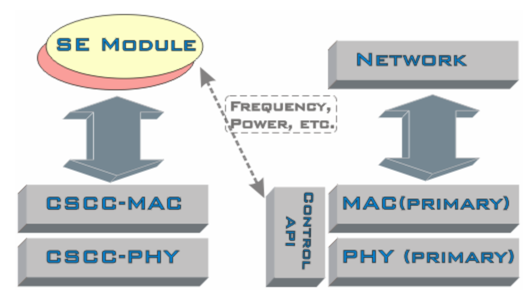
- Should care the receivers
  - Local channel scanning has limitation in detecting absence of receivers rather than transmitters
  - Interference is fundamentally a receiver property
  - Need explicit coordination protocols for mutual observations



CSCC Approach

- Explicit coordinate spectrum and operating parameters using Common Spectrum Coordination Channel for mutual observability
  - Periodical message exchange using a common signaling approach
  - Execute coordination algorithms based on the information collected
  - Implementation: extra control radio OR re-use a common data radio

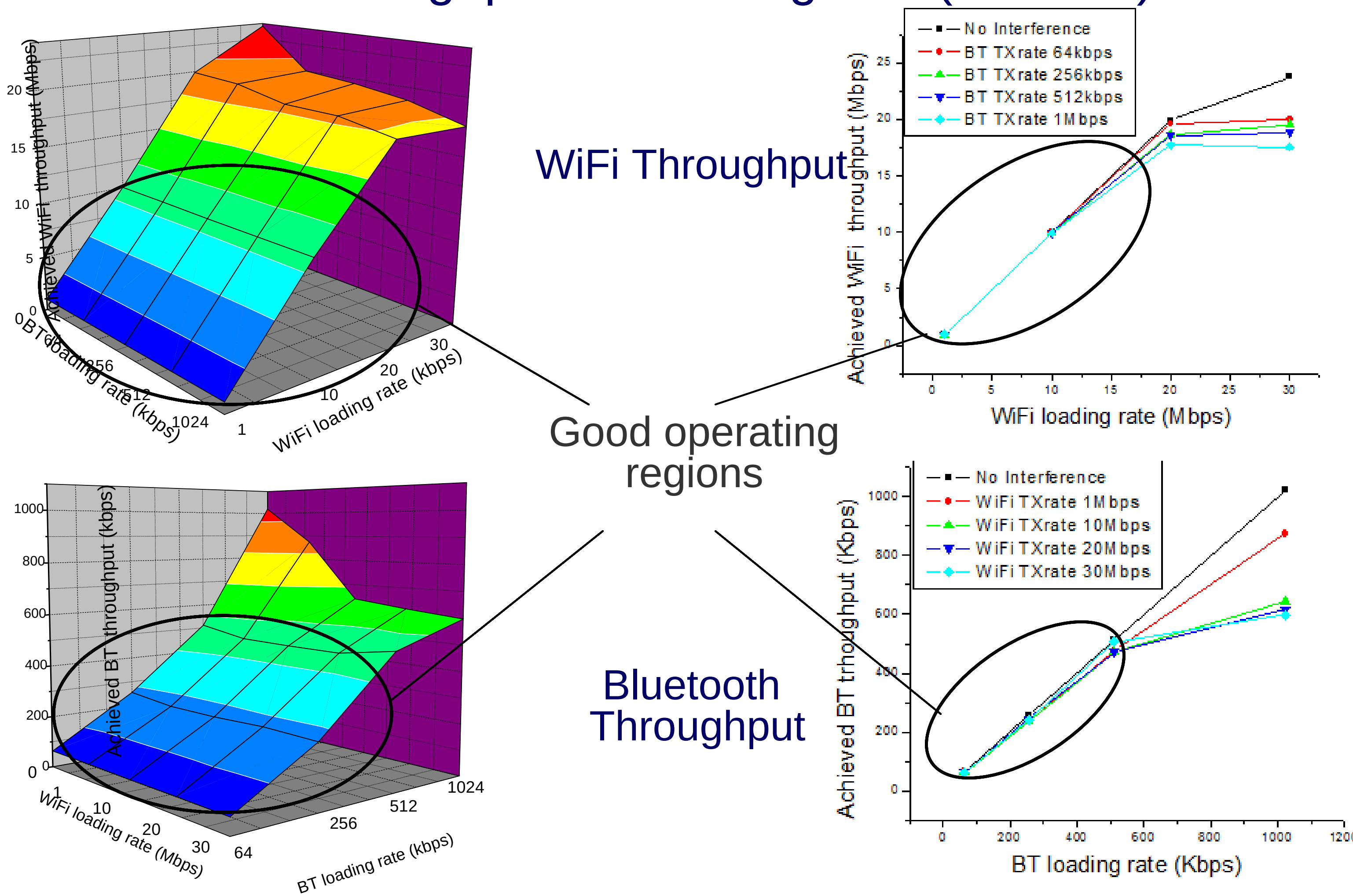




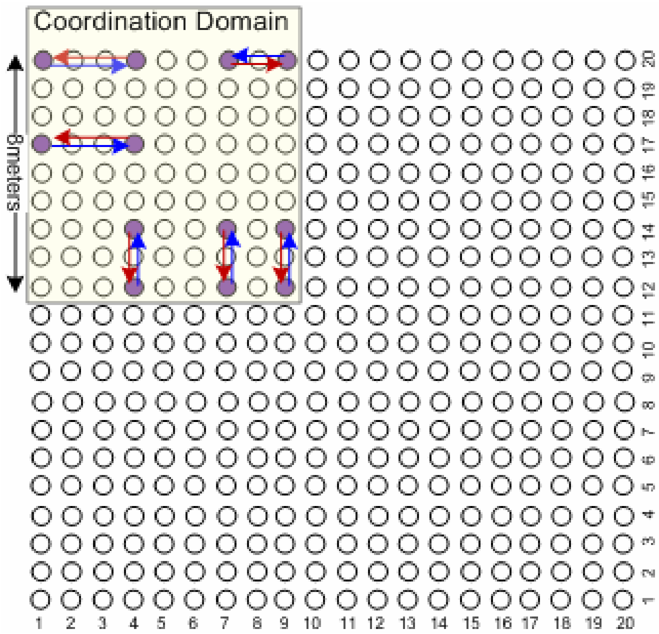
Separate control and data

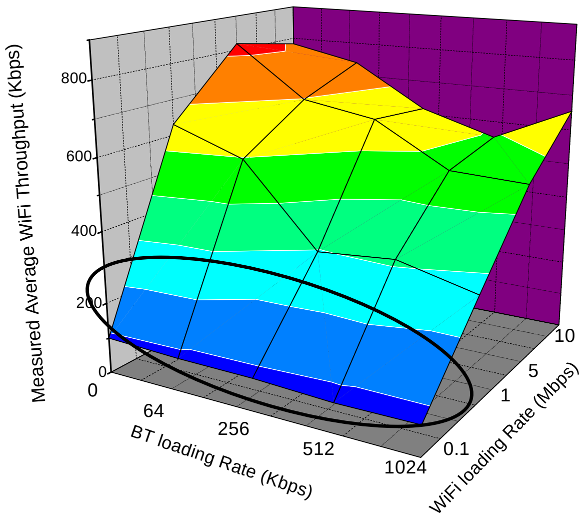
WiFi-g/Bluetooth Measurements

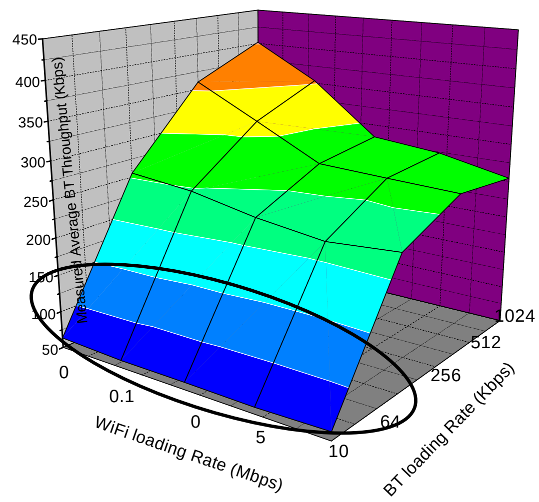
- Plot measured throughput vs. loading rate (2 nodes)



A Denser 12-node Scenario



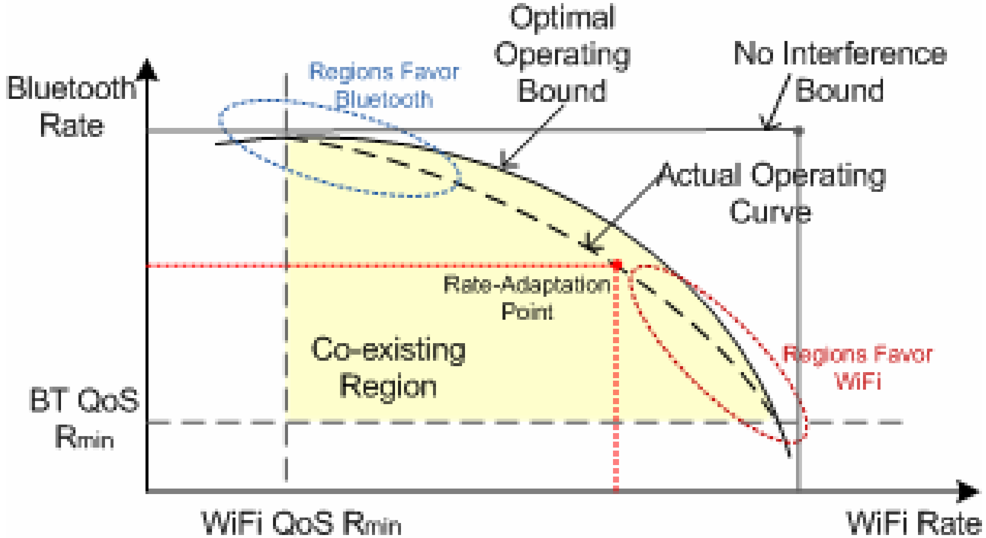




- In co-existing region both systems can achieve mostly what they expect if they control their transmit rate cooperatively

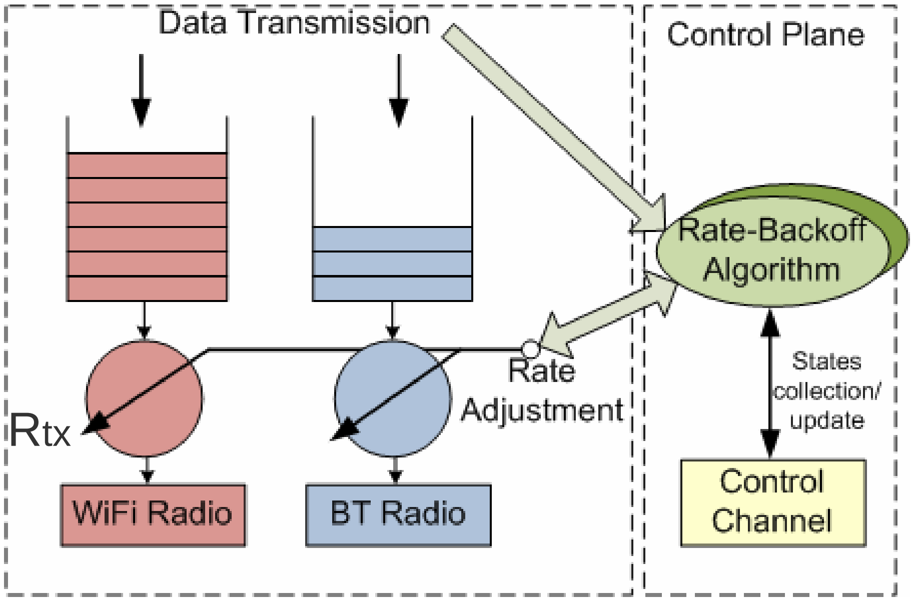
Guidance for Algorithm Design

- Study a network with reasonable load condition
- Both systems should control their loading rates
- QoS can be addressed by demanding a minimum rate
- Avoid transmit more than required/achieved
- Adapt transmit rate cooperatively to approaching the optimal operating bound
- How to identify this region? Need instant receiving throughput feedback.



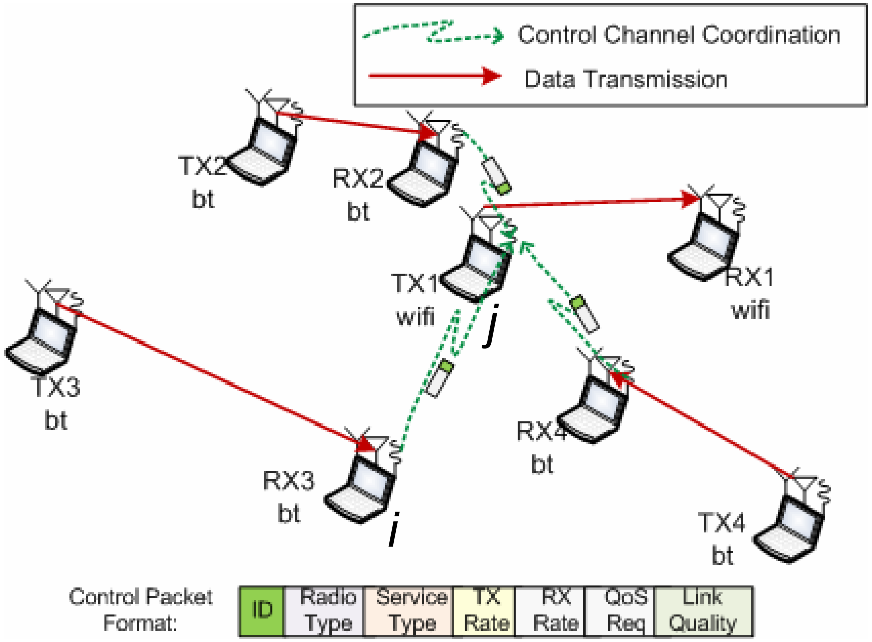
Advanced Rate-Backoff Algorithm

- Buffer data-type traffic for opportunistic transmission
- Set higher priority for satisfying QoS requirement (e.g., min rate/delay for streaming traffic)
- Try to max rate in the co-existing region (max-min)
  - Increase loading rate when channel is not saturated
  - Reduce loading rate when channel is saturated



Integrated with CSCC-based Protocol

- Each node periodically reports its self-state at control channel, and collects other's state information
- Target transmitter calculates instant operating rate based on the algorithm, considering the states of hidden heterogeneous receivers nearby

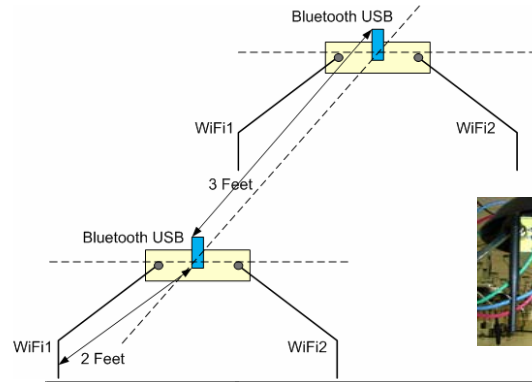


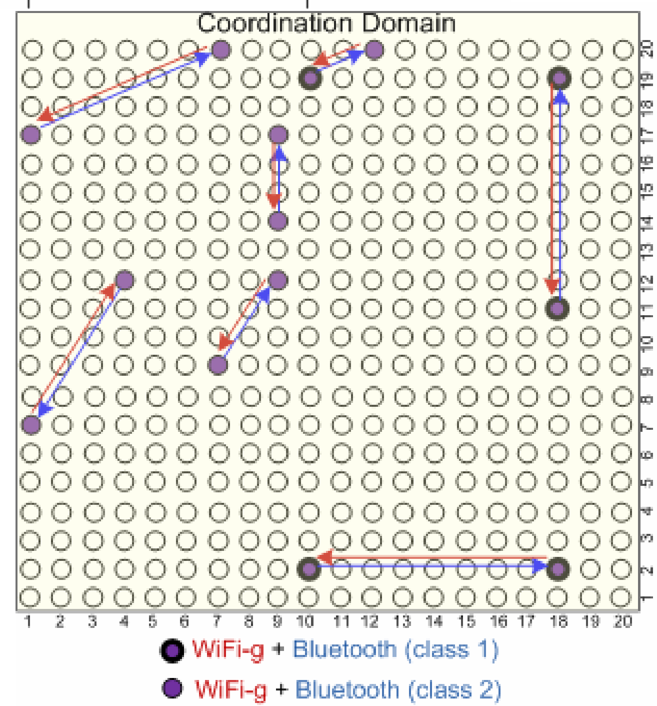
Simplified Coordination Algorithms

- For proof-of-concept by ORBIT experiments
- Low-rate BT avoids to high-rate WiFi
- (1) Simple BT-Rate Adaptation
  - Adjust BT streaming service levels when WiFi receivers detected
  - In-platform WiFi receiver active? BT reduces to lowest 64kbps
  - Nearby WiFi receiver active? BT lowers service rate by one level
  - No hidden-receivers detected? Increase to the highest rate
- (2) Simple BT-DeferTransfer
  - Any nearby WiFi receivers active? BT turns off its radio
- Experiment goal:
  - Help study different interference impact on overall network performance from different system
  - Break down the benefit by self-adaptation for the advanced algorithm design

ORBIT Experiment Parameters

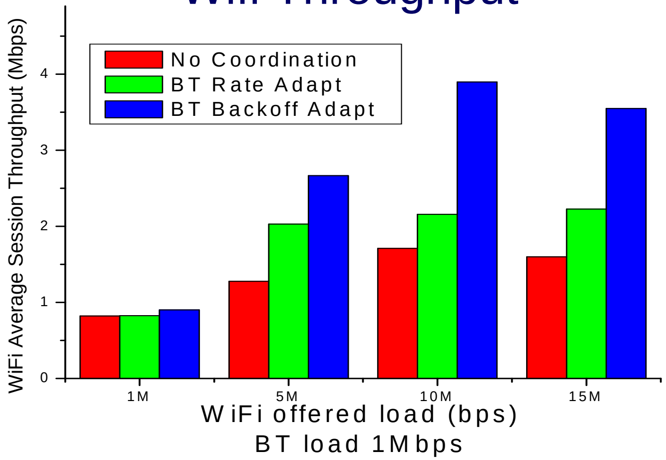
	Data Radio Service	
PHY Type	IEEE 802.11g (Atheros AR5212)	Bluetooth (Belkin and IOgear USB Dongle)
Frequency	2427-2447MHz	2402-2483.5MHz
Modulation	OFDM (256 FFT) QAM	GFSK + FHSS (DQPSK for EDR)
Transmit Power	18dBm	4dBm (~20m) (class 2) 20dBm (~100m) (class 1)
PHY Rate	Up to 54Mbps AutoRate	Upto 1Mbps Upto 2.1Mbps (w/ EDR)
Data session	Random ON/OFF CBR: 5 sec random session	Constant audio streaming (64, 128, 320, 512, 1024kbps)



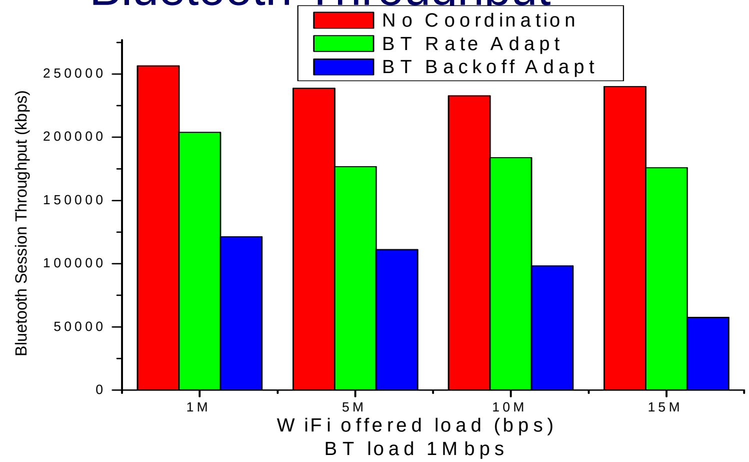


Preliminary Results – 14 Nodes

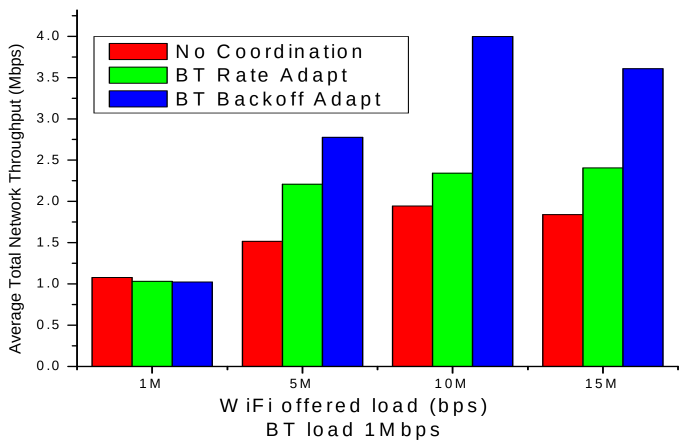
Wifi Throughput



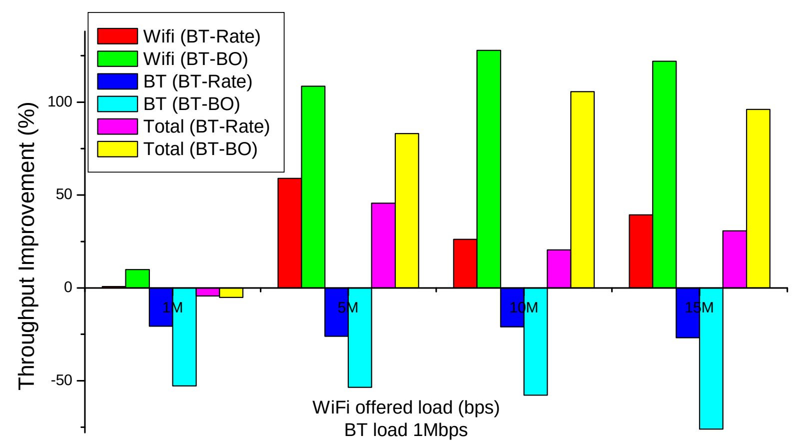
Bluetooth Throughput



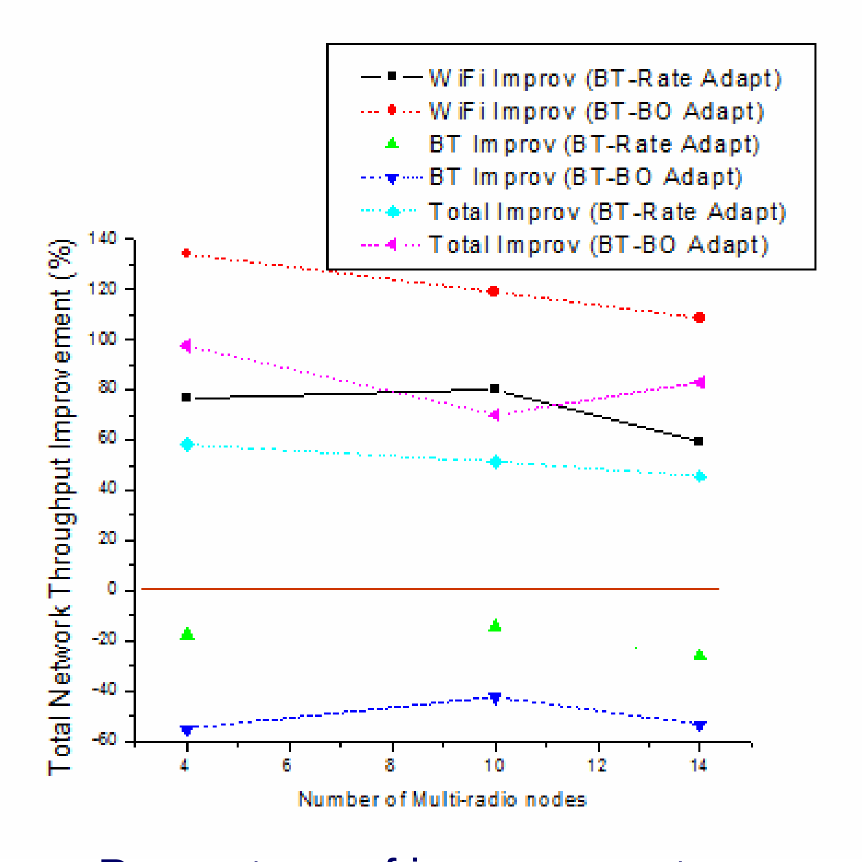
Average Network Throughput



Percentage of improvement:



Preliminary Results – Comparison



Percentage of improvement
offered load: Wifi 5Mbps BT 1Mbps

- Simple rate algorithms favour WiFi and sacrifice BT due to WiFi's intermittent traffic type
- Trade-off between how much WiFi can gain but how much BT degrade
- With 20% BT service degradation, WiFi can gain 80%
- The next version – advanced rate-backoff algorithm can balance both systems with QoS

Conclusion

- Proliferating of multi-radio devices will cause both in-platform and close-proximity radio interference severe
- CSCC protocol allows explicit spectrum coordination between multi-radio platforms
- Coordination algorithms in WiFi/Bluetooth case
  - Advanced rate-backoff algorithm helps both systems to approach optimal operating regions by cooperatively controlling their rates
  - Simplified rate algorithm favours WiFi over Bluetooth
- Proof-of-concept experiments using ORBIT multi-radio nodes
  - Simplified algorithm can significantly improve WiFi performance by lowering Bluetooth service quality

On-going and Future Work

- Improve the design and evaluate advanced rate-backoff algorithm
- Introduce ZigBee and WiMax ESG to the multi-radio platform
  - Emulate WiMax DL signal with varying duty-cycles
- Collaborative multi-radio relay network
  - Design “best-path-selection” algorithm
  - Achieve always best connected to improve end-to-end experience

Thank you!