Wireless Networks
Lecture 20: Managing Wireless Networks

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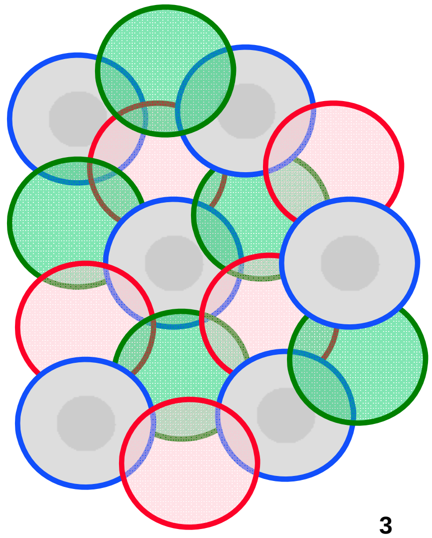
Outline

- WiFi deployments and channel selection
- Rate adaptation

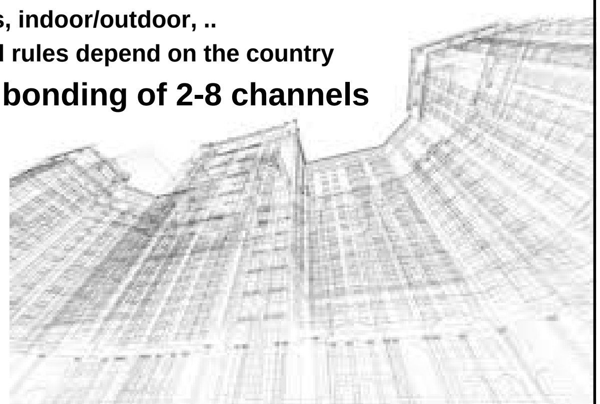
Infrastructure Deployments Frequency Reuse in Space

- Set of cooperating cells with a base stations must cover a large area
- Cells that reuse frequencies should be as distant as possible to minimize interference and maximize capacity
  - » Hidden and exposed terminals are also a concern



Frequencies are Precious

- 2.4 Ghz: 3 non-overlapping channels
  - » Plus lots of competition: microwaves and other devices
- 5 GHz: 20+ channels, but with constraints
  - » Power constraints, indoor/outdoor, ..
  - » Exact number and rules depend on the country
- 802.11n and ac: bonding of 2-8 channels
- And the world is not flat!

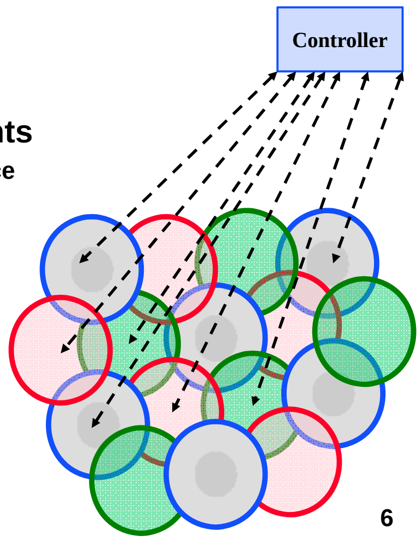


Frequency Planning

- Campus-style WiFi deployments are very carefully planned:
- A lot of measurements to determine where to place the AP
  - » What is the coverage area?
  - » What set of APs has good coverage with few “dead spots”
  - » What level of interference can we expect between cells
  - » What traffic loads can we expect, e.g., auditorium vs office
- Frequencies are very carefully assigned
  - » Can use the above measurements
- Must periodically re-evaluate infrastructure
  - » Furniture is moved, remodeling, …

Centralized Control

- Many WiFi deployments have centralized control
- APs report measurements
  - » Signal strengths, interference from other cells, load, …
- Controller makes adjustments
  - » Changes frequency bands
  - » Adjusts power
  - » Redistributes load
  - » Can switch APs on/off
  - » Very sophisticated!



Monitoring the Spectrum

- FCC (in the US) controls spectrum use
  - » Rules for unlicensed spectrum, licenses for other spectrum, what technologies can be used
- … but there is an special clause for campuses
  - » They have significant control over unlicensed spectrum use on the campus
  - » They can even use some "licensed" spectrum if it does not interfere with the license holder
- Network management carefully monitors spectrum use to make sure it is used well
  - » Shut down rogue APs – interference, security
  - » Non-approved equipment - interference
  - » Discourages outdated standards - inefficient

How about Small Networks?

- Most WiFi networks are small and (largely) unmanaged
  - » Home networks, hotspots, …
- Traditional solution: user-chosen frequency of their AP or a factory set default
  - » How well does that work?
- Today, APs pick a channel automatically in a smart way
  - » Monitors how busy channels are or how strong the signals are and then picks the best channel
  - » Can periodically check for better channels

Outline

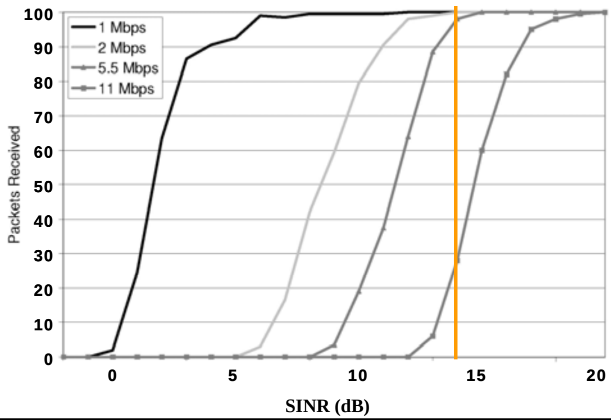
- WiFi deployments and channel selection
- Rate adaptation
  - » Background
  - » RRAA
  - » Charm

Bit Rate Adaptation

- All modern WiFi standards are multi bit rate
  - » 802.11b has 4 rates, more recent standards have 10s
  - » Vendors can have custom rates!
- Many factors influence packet delivery:
  - » Fast and slow fading: nature depends strongly on the environment, e.g., vehicular versus walking
  - » Interference versus WiFi contention: response to collisions is different
  - » Random packet losses: can confuse “smart” algorithms
  - » Hidden terminals: decreasing the rate increases the chance of collisions
- Transmit rate adaptation: how does the sender pick?

Transmit Rate Selection

- Goal: pick rate that provides best throughput
  - » E.g. SINR 14 dB → 5.5 Mbps
  - » Needs to be adaptive



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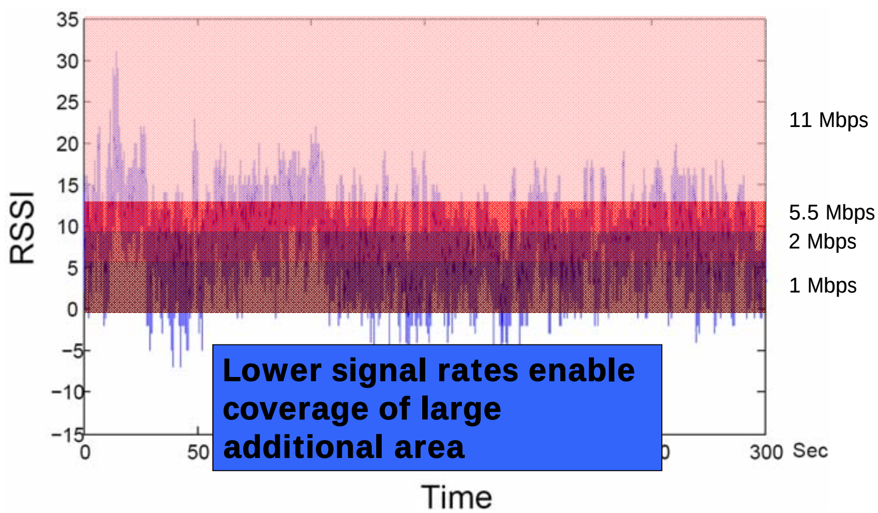
11

"Static" Channel



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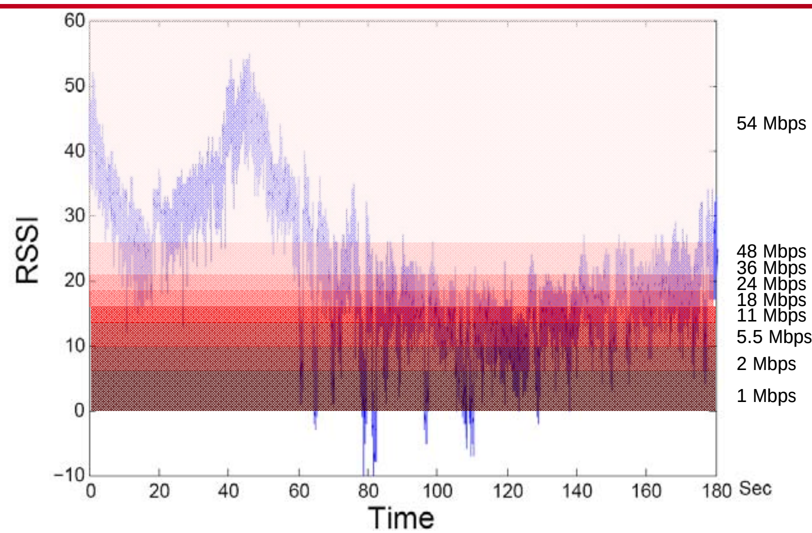
12

Mobile Channel – Pedestrian



High Level Designs

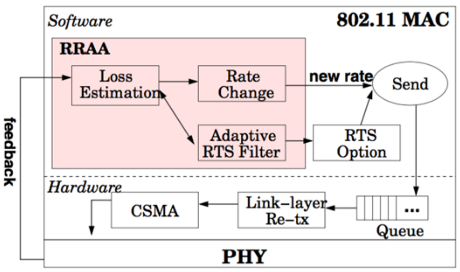
- "Trial and Error": senders use past packet success or failures to adjust transmit rate
  - » Sequence of x successes: increase rate
  - » Sequence of y failures: reduce rate
  - » Hard to get x and y right
  - » Random losses can confuse the algorithm
  - » Many variants – RRAA
- Signal strength: stations use channel state information to pick transmit rate
  - » Use path loss information to calculate "best" rate
  - » Assumes a relationship between PDR and SNR
    - – Need to recover if this fails, e.g., hidden terminals
  - » Tends to be a bit harder to manage – Charm

Robust Rate Adaptation Algorithm

- RRAA goals
  - » Maintain a stable rate in the presence of random loss
  - » Responsive to drastic channel changes, e.g., caused by mobility or interference
- Adapt rate based on short term PDR

$$R_{new} = \begin{cases} R^{+} & P > P_{MTL} \\ R_{-} & P < P_{ORT} \end{cases}$$

  - » Thresholds and averaging windows depend on rate
- Selectively enable RTS-CTS



CHARM

- Channel-aware rate selection algorithm
- Transmitter passively determines SINR at receiver by leveraging channel reciprocity
  - » Determines SINR without the overhead of active probing (RTS/CTS)
- Select best transmission rate using rate table
  - » Table is updated (slowly) based on history
  - » Needed to accommodate diversity in hardware and special conditions, e.g., hidden terminals
- Jointly considers problem of transmit antenna selection

SINR: Noise and Interference

$$SINR = \frac{RSS}{Noise + \sum \text{Interference}}$$

- **Noise**
  - » **Thermal background radiation**
  - » **Device inherent**
    - – **Dominated by low noise amplifier noise figure**
  - » **~Constant**
- **Interference**
  - » **Mitigated by CSMA/CA**
  - » **Reported as "noise" by NIC**

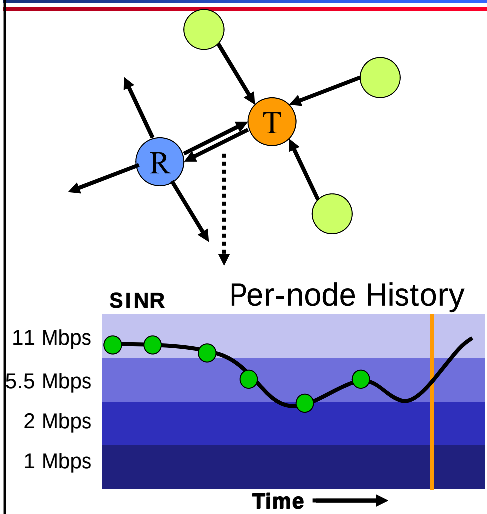
SINR: RSS

$$RSS = P_{tx} + G_{tx} - PL + G_{rx} \qquad (1)$$

$$PL = P_{tx} + G_{tx} + G_{rx} - RSS \qquad (2)$$

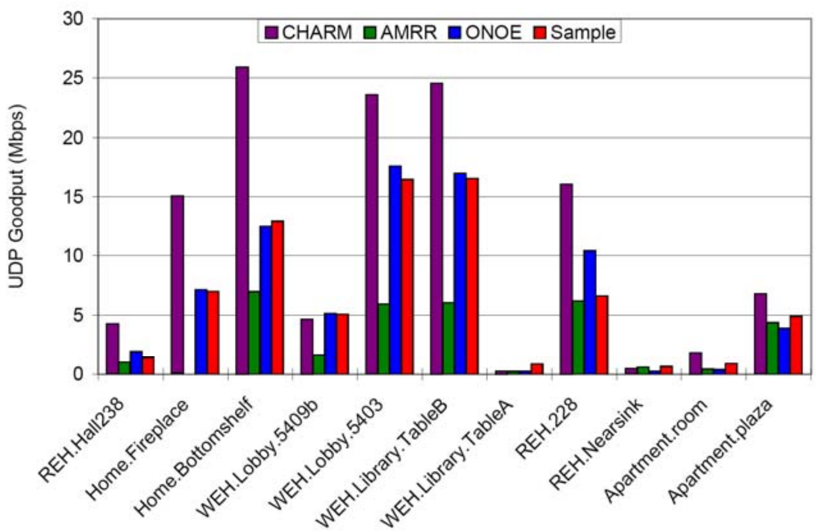
- **By the reciprocity theorem, at a given instant of time**
  - » **$PL_{A \rightarrow B} = PL_{B \rightarrow A}$**
- **A overhears packets from B and records RSS (1)**
- **Node B records P_{tx} and card-reported noise level in beacons and probes, so A has access to them**
- **A can then calculate path-loss (2) and estimate RSS and SINR at B**

CHARM: Channel-aware Rate Selection



- **Leverage reciprocity to obtain path loss**
  - » **Compute path loss for each host: P_{tx} - RSSI**
- **On transmit:**
  - » **Predict path loss based on history**
  - » **Select rate & antenna**
  - » **Update rate thresholds**

Static Performance



Conducted in uncontrolled environments with interference present.

Conclusion

- New testbed methodology: channel emulation
  - » Realism of wireless testbeds with control of simulation
  - » Enables insights that are difficult to gain with previous techniques
- Use estimate of RSS at receiver to achieving good performance in dense, chaotic networks
  - » Estimates are useful for diverse optimizations
  - » Optimizations require different levels of coordination and operate on different time scales
  - » Need to account for inaccurate RSS estimates

References

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- "DIRC: Increasing Indoor Wireless Capacity Using Directional Antennas", Xi Liu, Anmol Sheth, Michael Kaminsky, Konstantina Papagiannaki, Srini Seshan, and Peter Steenkiste, ACM SIGCOMM 2009, September 2009, Barcelona, Spain.
- "Interference-Aware Transmission Power Control for Dense Wireless Networks", Xi Liu, Srini Seshan, and Peter Steenkiste, The First Annual Conference of the International Technology Alliance in Network and Information Science, Maryland, September 2007.
- "Design, Implementation, and Evaluation of an Efficient Opportunistic Retransmission Protocol", Mei-Hsuan Lu, Peter Steenkiste, Tsuhan Chen, The Fifteen International Conference on Mobile Computing and Networking (MobiCom'09), ACM, Beijing, China, September 2009.

Collaborators

- The wireless network emulator
  - » Glenn Judd, Kevin Borries, Xiaohui Wang, Nancy Miller, Swathi Koundinya, Alex Lince, Scott Stork, Matt Bonakdarpour, Joe Damatto, Richard Want, Pat Gunn, Dan Stancil, and many others
- Self-managing chaotic networks
  - » Rate adaptation: Glenn Judd, Xiaohui Wang
  - » PRO: Amy Lu, Tsuhan Chen
  - » Xmit power ctl: Xi Liu, Srini Seshan
  - » Dir. antennas: Xi Liu, Srini Seshan, Dina Papagiannaki, Michael Kaminski, Anmol Sheth

Extra slides