15-744: Computer Networking

L-13 Cognitive Wireless Networks

Cognitive Wireless Network

- Optimize wireless networks based context information
- Assigned reading
  - DIRC: Optimizing Directional Antennas
  - Online Estimation of Interference (3 sections)
- Optional reading
  - Centaur: Hybrid optimization

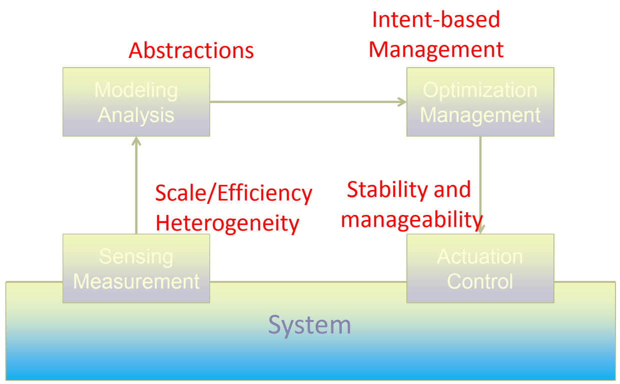
Overview

- Background on cognitive wireless
- Online estimation wireless networks
  - Slides Ameya
- DIRC: directional antennas
- Centaur: hybrid optimization
  - Slides Junchen
- White space networks

Cognitive Wireless Networks

- Performance of wireless network depends on deployment environment and use
  - Try for any complex system, but especially for wireless given interactions with physical world
  - Node density, mobility, physical infrastructure, traffic load, wireless technologies, ..
- Often not practical to hand tune the system
  - Ok on campus: fairly predictable, strong control
  - Home, hotspots, vehicular, industrial, ..

Generic Cognitive System



How about Cognitive Wireless?

- Sensing and measurement
  - Limited by capabilities of wireless NICs
  - Low resolution, lack of calibration
  - Cost of exchanging measurements
- Modeling and analysis
  - Abstraction of link, network
  - Minimizing cost in building, maintaining model
  - Basis for "CS" optimization, global management

Cognitive Wireless continued

- Optimization and management
  - Focus is often network capacity plus fairness, but can consider other factors
  - Often uses heuristics (always exponential)
- Actuation and control
  - Execute the plan devise above
  - Minimize overhead in distributing instructions, coordination in execution
  - Low resolution control, lack of calibration

Haven't We Seen This?

- Yes! Earlier papers are based on this model
  - But optimization tends to be very local, or use minimal context information
- More global optimizations, e.g. dealing directly with interference
  - Use a conflict graph as the abstraction
- Dynamic spectrum access
  - Adapt to presence of primary users

Some Examples

- Routing and opportunistic forwarding based on signal propagation conditions
- Maximizing spatial reused based on transmit power adaptation, directional antennas, carrier sense tuning, …
  - Avoid hidden/exposed terminals
- Packet scheduling as a replacement for carrier sense
  - Managing bandwidth, avoiding hidden/exposed terminals

9

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10

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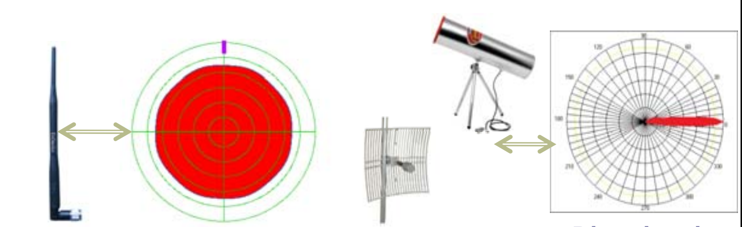
11

What Are Directional Antennas?

- Less power to undesired directions
- More power to desired directions
- Primarily used to form long distance point-to-point links
- Can also provide “spatial reuse”



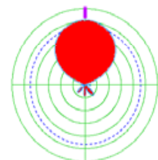
nni-directional antenna | Omni-directional pattern | Directional antennas | Directional pattern

12

Phased Array Antennas

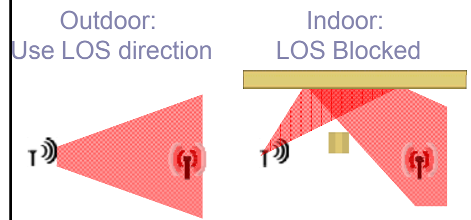
- Multiple antenna radio system provides ability to electronically steer signal
  - Fast reconfiguration: 100μs steering delay
- Assumption: only APs use them
  - Still too bulky for clients
  - Incremental deployment

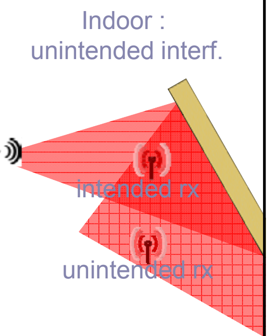
Phased-array antenna with 8



antenna pattern

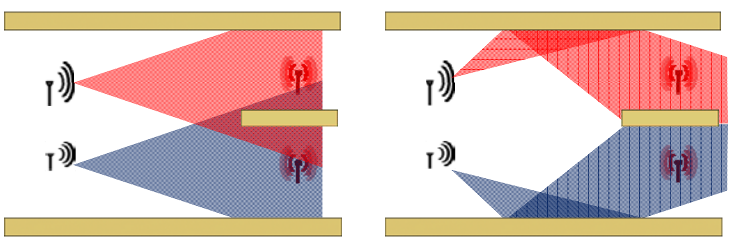
Directional Antennas Indoors





- Indoor space is rich-scattered
  - LOS may be blocked
  - May cause unintended interference
- Conventional wisdom: directional antennas are not effective in indoors environment

But There is Good News



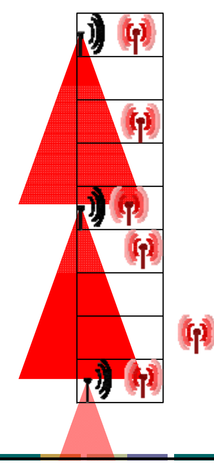
Max SNR: No Spatial Reuse

Use Alternative Path: Spatial Reuse

- Straightforward way to orient antennas: maximize signal strength at receiver (Max SNR)

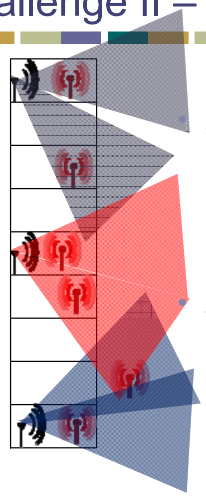
Key idea: leverage multiple paths and obstacles to improve spatial reuse

Challenge I – How to Find Orientations?



- Naive solution: Max Cap
  - Too slow in practice, e.g., 8 minutes for this setup
- Challenge I' – finding optimal antenna orientations quickly
  - Goal is to find a solution cost the same as Max SNR, i.e., each AP scans once
  - Use SINR model

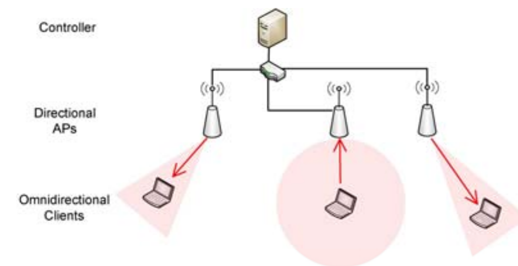
Challenge II – Coordination



- Among dirc. senders to identify non-interfering transmissions and choose orientations
  - Centralized controller
  - TDMA scheduling MAC
- Among dirc. and omni. senders
  - Two phased TDMA to separate dirc. and omni. senders

8/19/2009 17

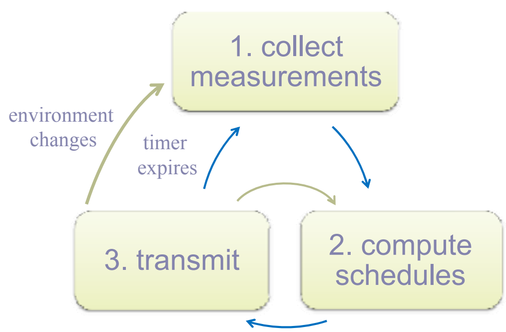
System Overview



- Directional APs
- Omni-directional users
- Centralized controller

8/19/2009 18

DIRC Operation



19

SINR Model

- SINR Model: whether a frame can be successfully received depends on whether the SINR is larger than a threshold

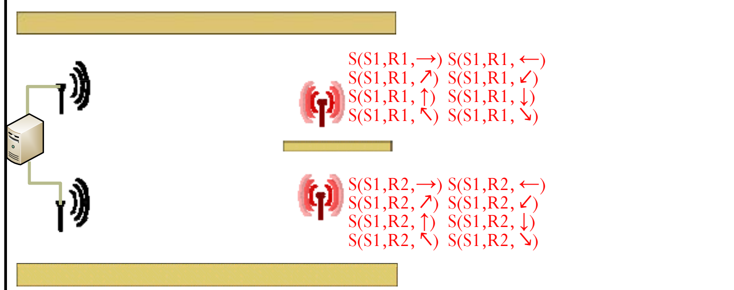
$$SINR = \frac{Signal}{Interference + Noise} > SINR_{thresh}$$

- S(i,j,k) denote signal strength from AP i to client j with direction k
- For example, to determine whether transmissions (i1,j1,k1) and (i2,j2,k2) can happen simultaneously

$$SINR_1 = S(i_1, j_1, k_1) / S(i_2, j_1, k_2)$$
$$SINR_2 = S(i_2, j_2, k_2) / S(i_1, j_2, k_1)$$

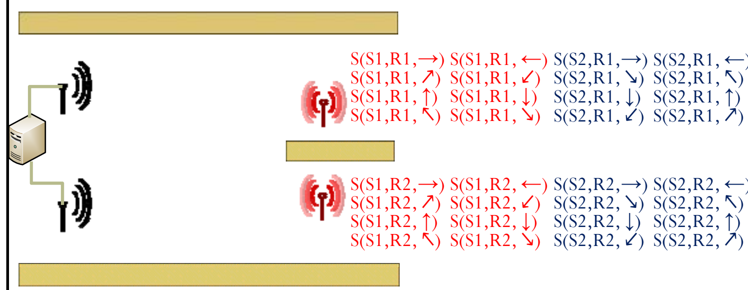
20

DIRC Operation I - Measurement



- The scheduler instructs each AP to scan once, e.g., 240ms overhead for 3 APs.

DIRC Operation I - Measurement



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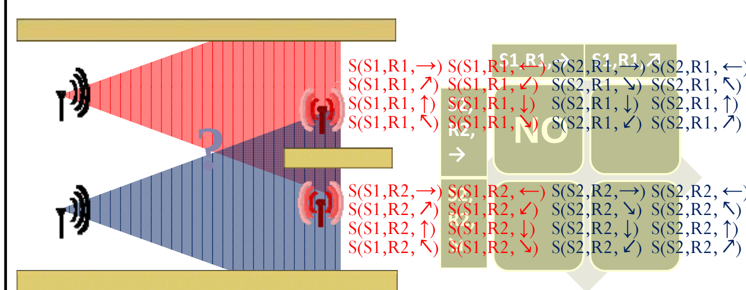
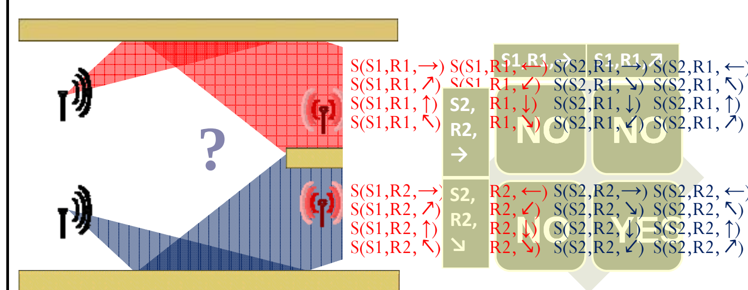
DIRC Operation II – Compute Schedules



SINR1 = S(S1,R1,→) / S(S2,R1,→) < $SINR_{thresh}$ X

SINR2 = S(S2,R2,→) / S(S1,R2,→) < $SINR_{thresh}$ X

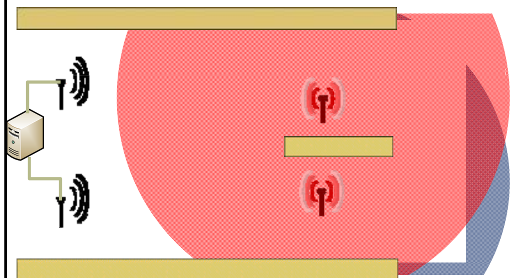
DIRC Operation II – Compute Schedules



SINR1 = S(S1,R1,↗) / S(S2,R1,↘) > $SINR_{thresh}$

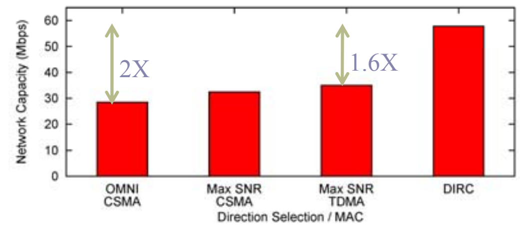
SINR2 = S(S2,R2,↘) / S(S1,R2,↗) > $SINR_{thresh}$

DIRC Operation III - Transmit



- dirc-tx and omni-tx phases for data transfer
- APs inform controller that they have frames to send
- Scheduler compute schedules

DIRC Performance



UDP Performance

- Office scenario, iperf UDP (including protocol overhead)
- DIRC significantly improves network capacity in this office environment

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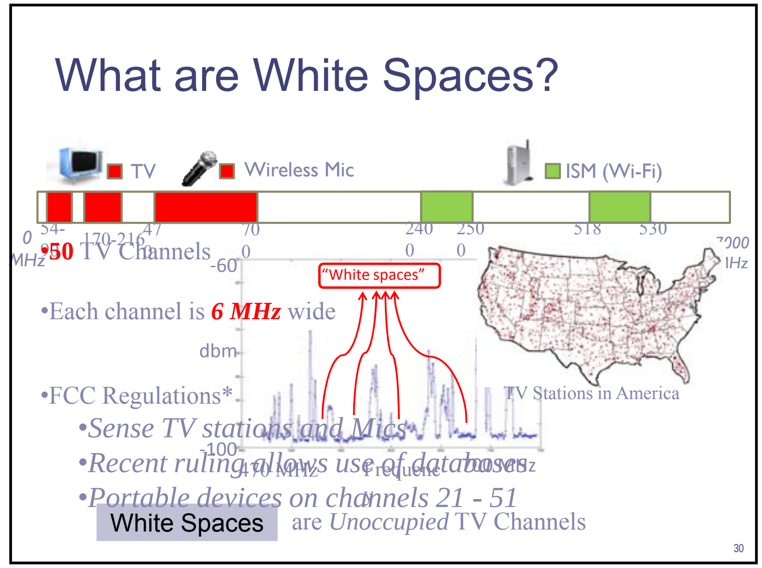
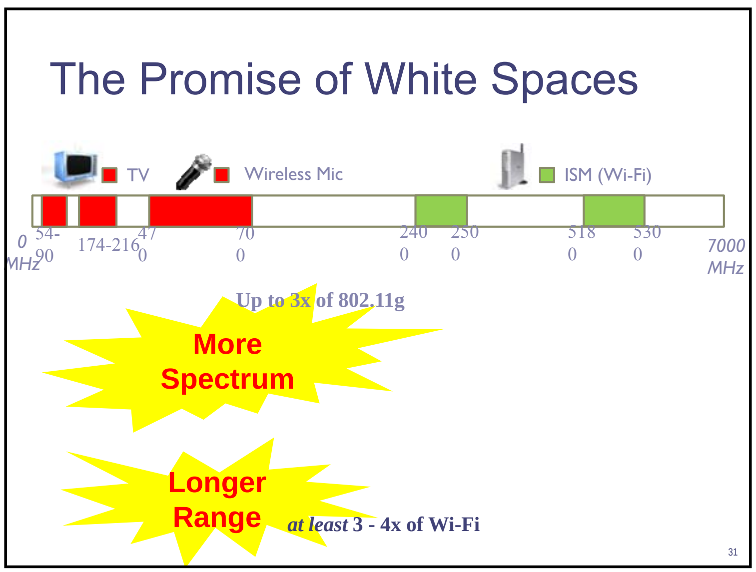
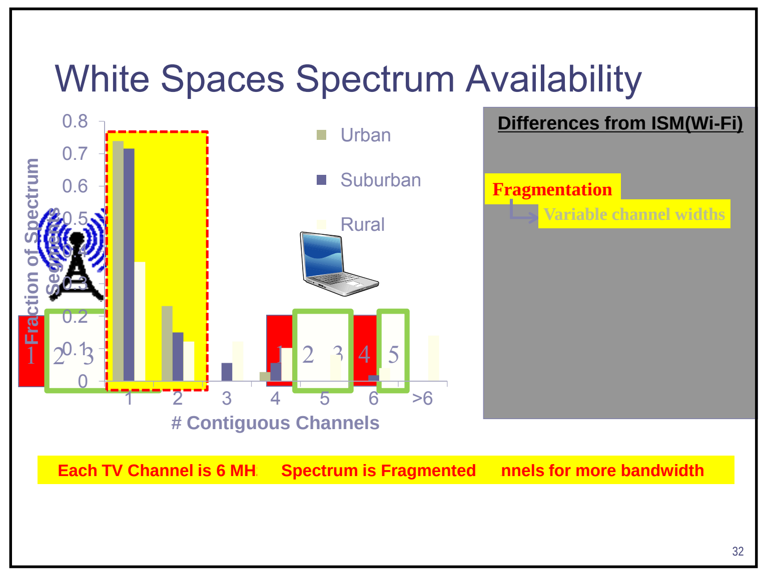
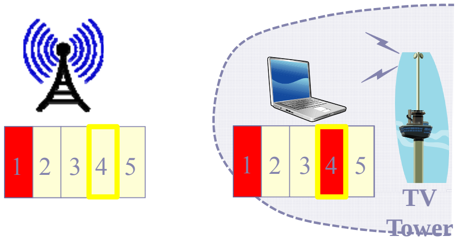
Higher Frequency
Broadcast TV
Wi-Fi (ISM)
29


What are White Spaces?
TV
Wireless Mic
ISM (Wi-Fi)
"White spaces"
•50 TV Channels
•Each channel is 6 MHz wide
•FCC Regulations*
•Sense TV stations and Mics
•Recent ruling allows use of databases
•Portable devices on channels 21 - 51
dbm
-60
-100
470 MHz
Frequency
TV Stations in America
White Spaces
are Unoccupied TV Channels
30


The Promise of White Spaces
TV
Wireless Mic
ISM (Wi-Fi)
0 MHz
7000 MHz
Up to 3x of 802.11g
More Spectrum
Longer Range
at least 3 - 4x of Wi-Fi
31


White Spaces Spectrum Availability
0.8
0.7
0.6
0.5
0.2
0.1
0
Urban
Suburban
Rural
Fraction of Spectrum
1
2
3
4
5
6
>6
Contiguous Channels
Differences from ISM(Wi-Fi)
Fragmentation
Variable channel widths
Each TV Channel is 6 MH
Spectrum is Fragmented
nnels for more bandwidth
32

White Spaces Spectrum Availability



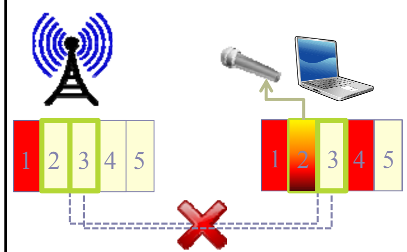
Differences from ISM(Wi-Fi)

Fragmentation
→ Variable channel widths

Spatial Variation
→ Cannot assume same channel free everywhere

Location impacts spectrum availability ⇒ Spectrum exhibits spatial variation

White Spaces Spectrum Availability



Differences from ISM(Wi-Fi)

Fragmentation
→ Variable channel widths

Spatial Variation
→ Cannot assume same channel free everywhere

Temporal Variation
→ Same Channel will not always be free
→ *Any* connection can be disrupted *any* time

Incumbents appear/disappear over time ⇒ Must reconfigure after disconnection

Channel Assignment in Wi-Fi

Fixed Width Channels ⇒ Optimize *which* channel to use

Spectrum Assignment in WhiteFi

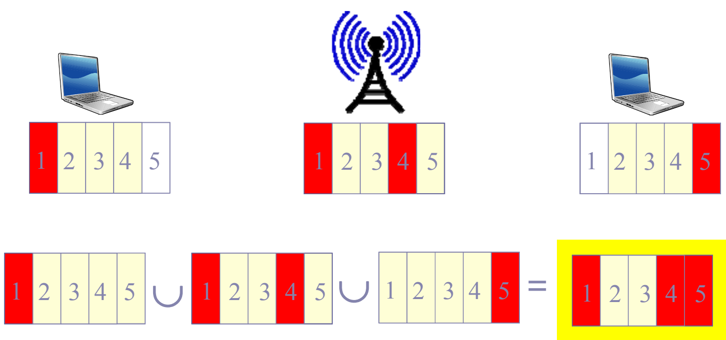
Spectrum Assignment Problem

Goal	Maximize Throughput
Include	Spectrum at clients
Assign	Center Channel & Width

Fragmentation ⇒ Optimize for *both*, **center channel** and **width**

Spatial Variation ⇒ BS must use channel *iff* free at client

Accounting for Spatial Variation



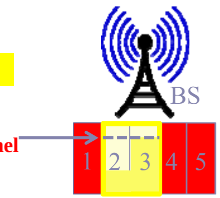
Intuition

Intuition

Use widest possible channel

But

Limited by *most* busy channel



- Carrier Sense Across **All** Channels
- **All** channels must be free
  - ρ_{BS}*(2 and 3 are free) =* ρ_{BS}*(2 is free) x* ρ_{BS}*(3 is free)*

Tradeoff between wider channel widths and opportunity to transmit on each channel

Discovering a Base Station

Discovery Time = *O(B x W)*

Fragmentation ⇒ Try different center channel and widths

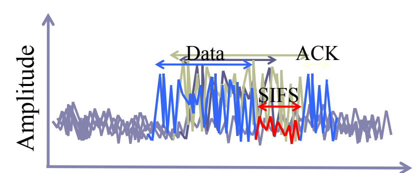
channels used by the BS?

SIFT, by example

SIFT

Does not decode packets

Pattern match in time domain



What is Next?

- Midterm on Monday
  - Closed book, material through Wednesday's lecture
- Wednesday: Topology
- Then Friday and Monday off

41