On the Effectiveness of Switched Beam Directional Antennas in Indoor Environments

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WIRELESS INFORMATION NETWORK LABORATORY

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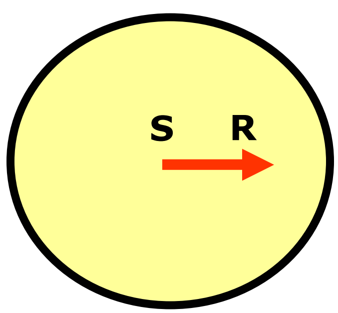
Why Directional Antennas?

- Last-mile network access predominantly 802.11
  - High bandwidth, low/no cost

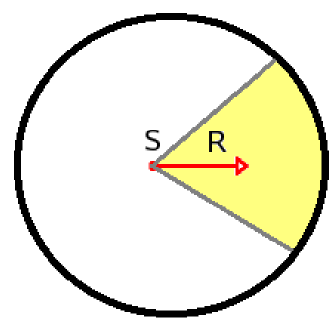
- 802.11 Success → Changing requirements
  - Spatial reuse [Navda07, Choudhury06], Localization [Sayrafian-Pour06, Niculescu04], Security [Carey04]

100 million WiFi handsets over the next 5 years. Source: *IDC, Frost & Sullivan, Infonetics*

- Directional antennas can meet several requirements
  - How? Directional antennas reduce the wireless *footprint*



OMNI



Directional antennas

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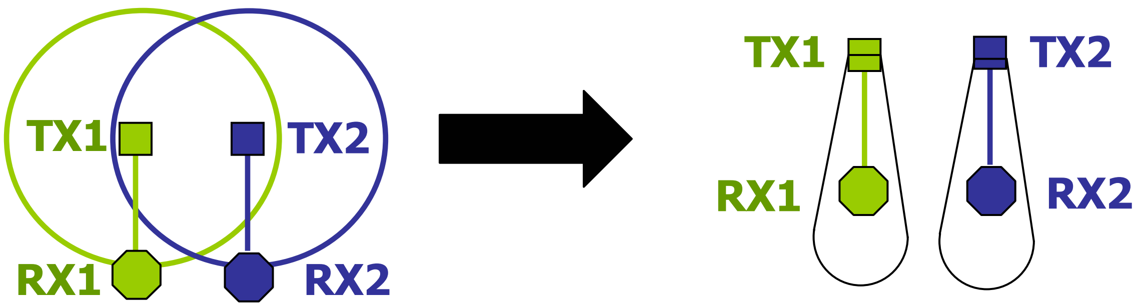
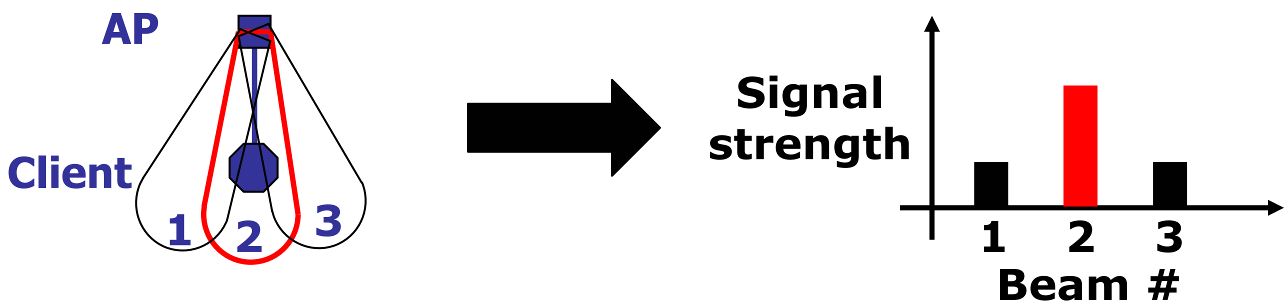
Application Scenarios

- Spatial Re-use: Increased #(simultaneous transmissions)
  - Energy focused in one direction and suppressed in others



- Node localization
  - Using increased signal strength in the direction towards a client.



Effectiveness in Indoor Environments?

Focus: Most 802.11 deployments today are indoors.

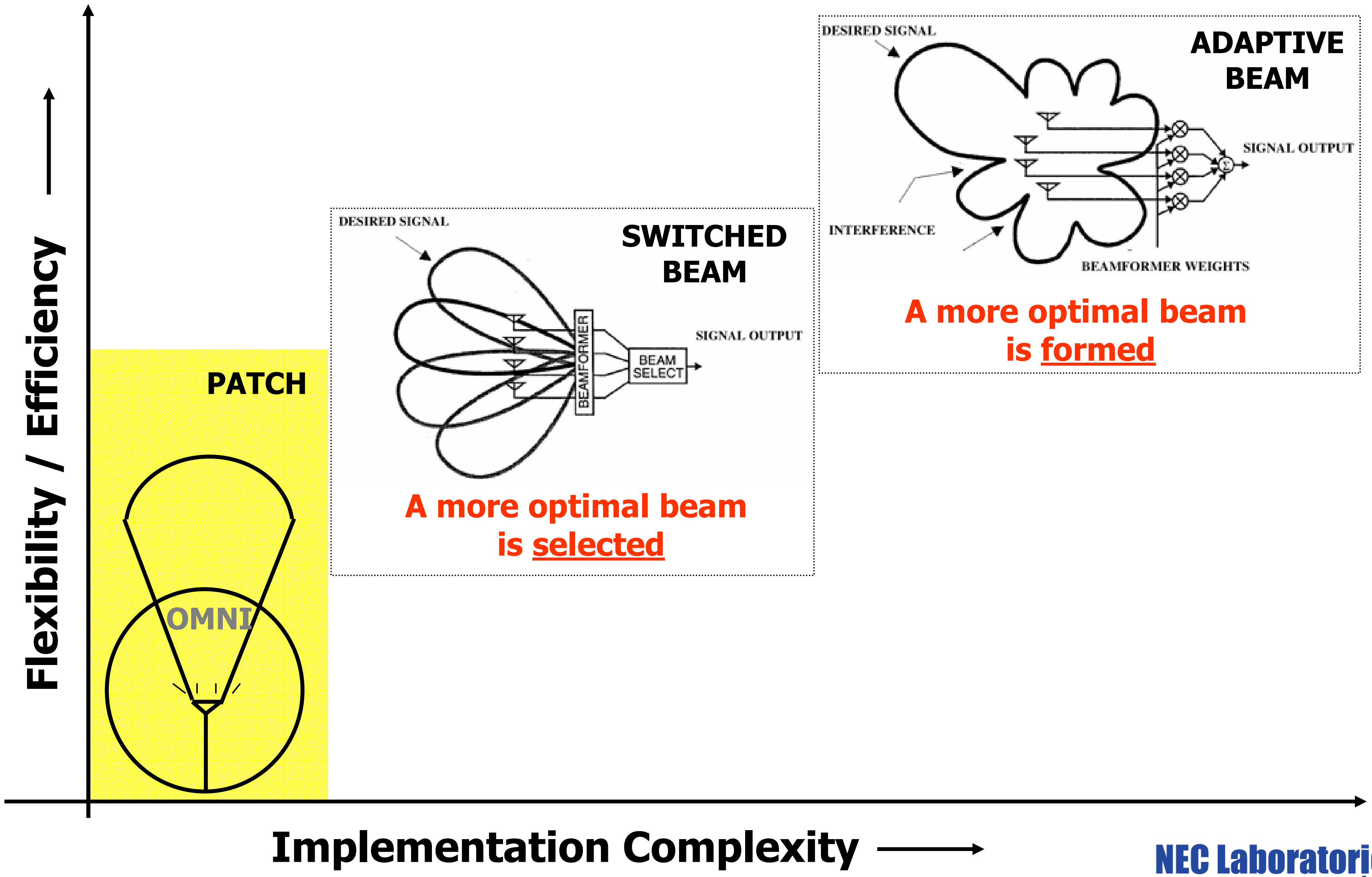
Challenge: indoor environments rich in Multipath reflections → limit the benefits of directionality

Objective: Evaluate the effect of multipath reflections on directionality in indoor environments

Related work:

- [Navda07, Raman05, Ramanathan05] – outdoor studies
  - Not applicable due to differing radio propagation characteristics

Background: Types of Directional Antennas

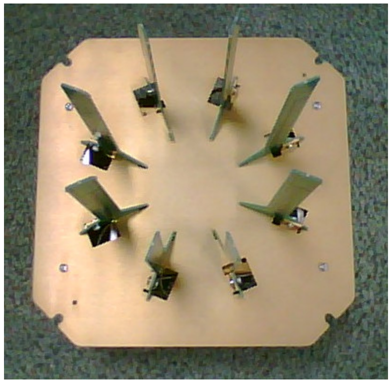


Switched Beam Antennas: Background

- Commonly realized using a *phased array*.
  - Antenna pattern formed by signals sent to elements
  - Signals weighted in magnitude and phase

$$A(k) = a_0 e^{jkd_0} + a_1 e^{jkd_1} + \ldots a_{N-1} e^{jkd_{N-1}}$$

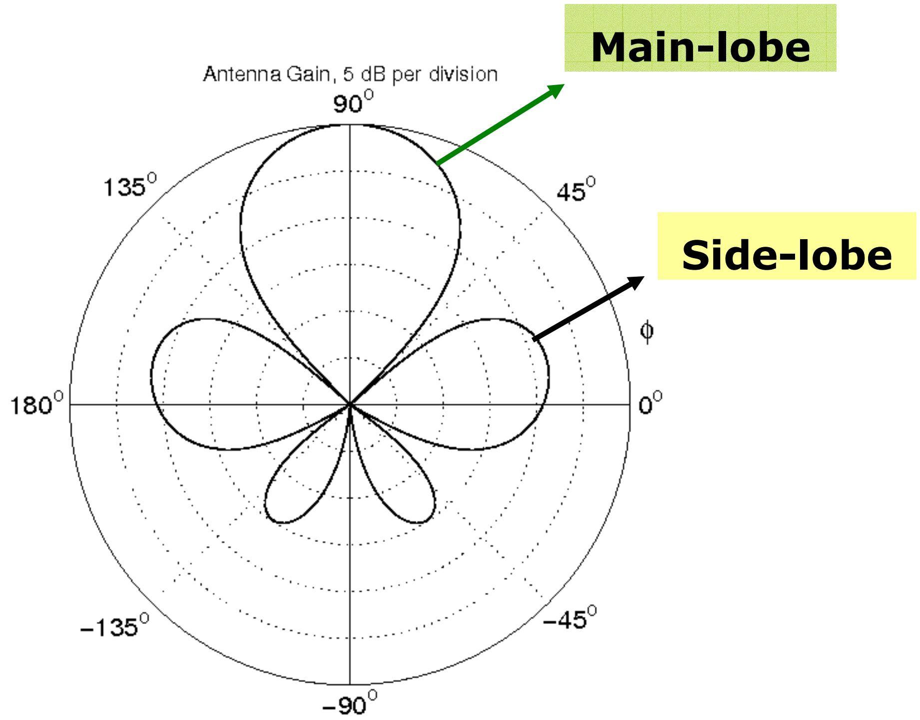
- Beams can be changed by modifying amplitude and phase of array coefficients a0, a1, ...



Switched Beam Antennas: Background

- Example pattern:

	Magnitude	Phase (deg)
a0	100	-166
a1	100	-69
a2	100	69
a3	100	166
a4	100	166
a5	100	69
a6	100	-69
a7	100	-166

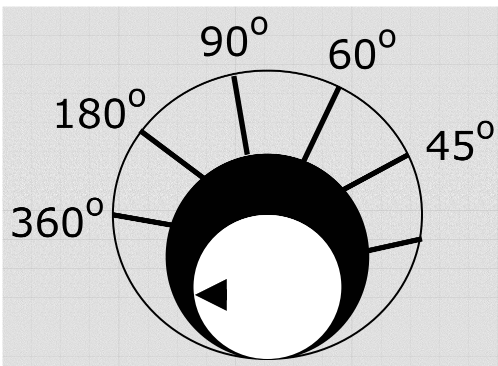


- Energy cannot be fully eliminated in undesired directions
  - Results in spill-over or side-lobes
  - As main lobe is made more focused, spill-over increases

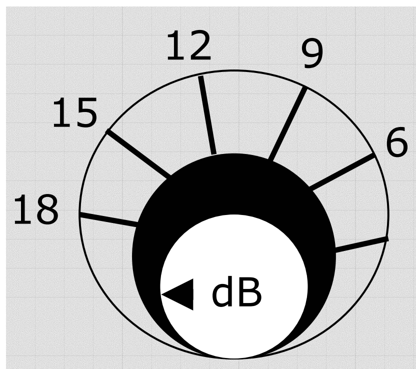
Experimental Objective

Evaluate the effect of multipath on the directionality of switched beam antennas under varying parameters such as:

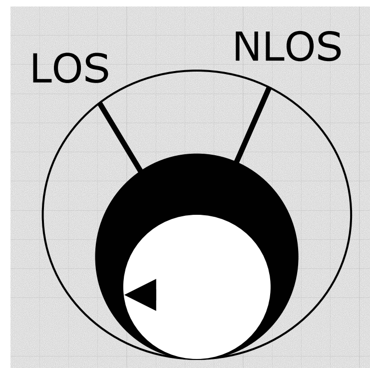
Beam width



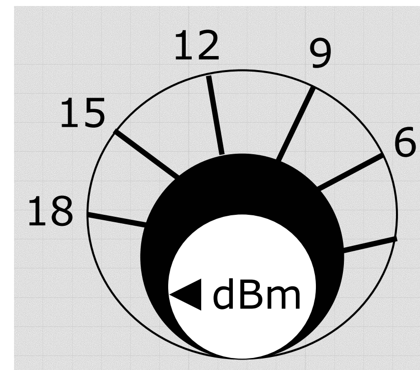
Front-to-side-lobe ratio (FSR)



Location

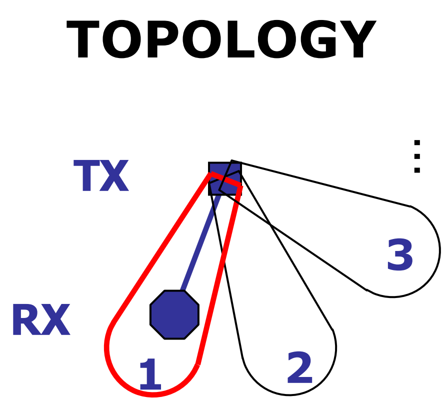


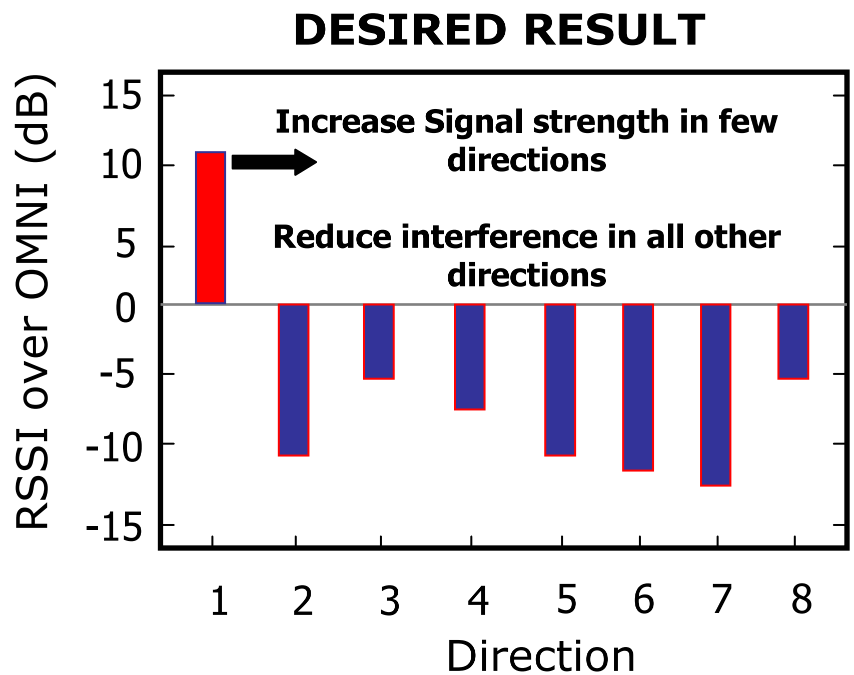
Transmit Power



- Thin beams = reduced multipath?
- Effect of side lobes
- LOS = strong directionality and NLOS = weak directionality?
- Can we combine transmit power and directionality?

Application-specific Requirements





For spatial reuse:

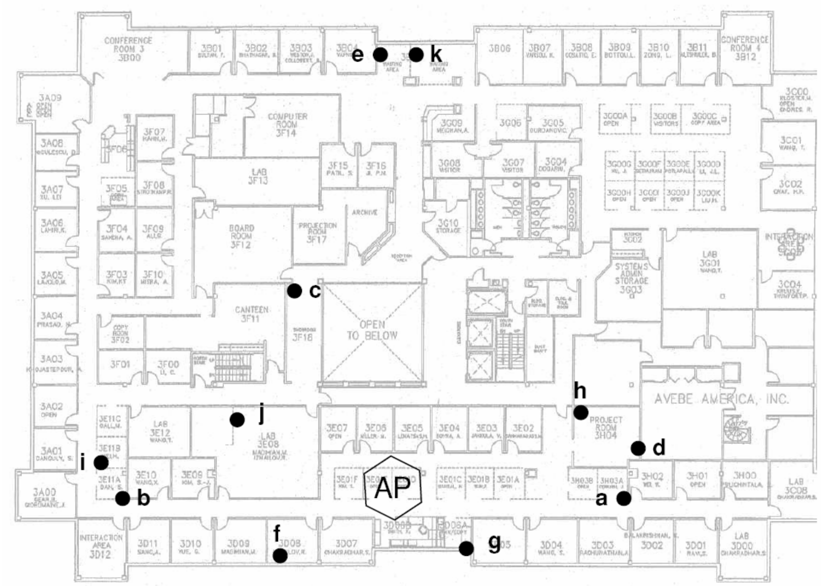
- "Very few" beams with signal stronger than OMNI
- "Large number" of beams with signal weaker than OMNI

For localization:

- Beam with largest gain = geographical beam towards RX.

Experimental Setup

- One transmitter (AP)
  - Phocus Array – cycles through directions (or beams).
  - Pseudo-IBSS + monitor mode.
  - Broadcasts 128 byte UDP packets.
- Eleven receivers
  - OMNI antenna (6dBi “rubber-duck”)
  - Monitor mode and **`tcpdump`**.



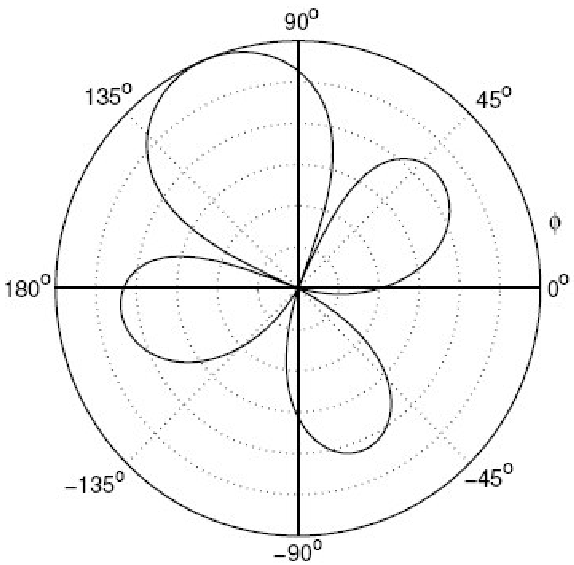
Indoor Office Testbed

Black dots = receivers

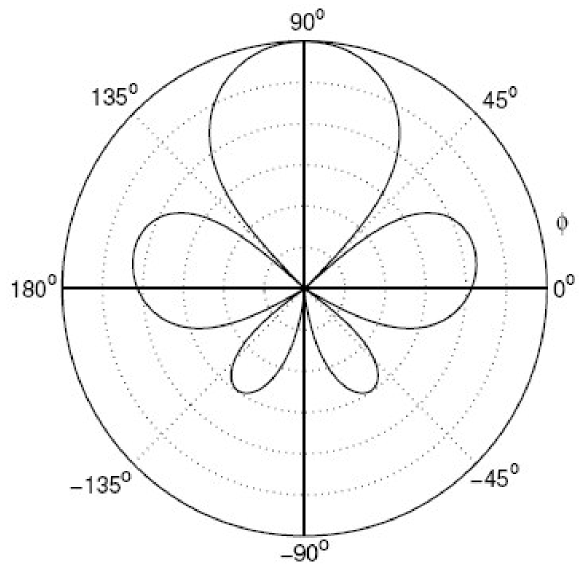
AP = transmitter

Experimental Setup (continued)

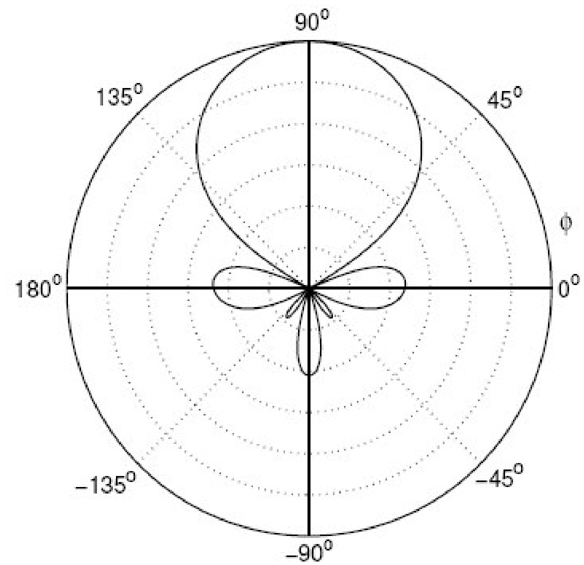
Three pattern sets (p1, p2, p3) used:



P1 (BW = 45°, FSR = 8dB)



P2 (BW = 45°, FSR = 8dB)



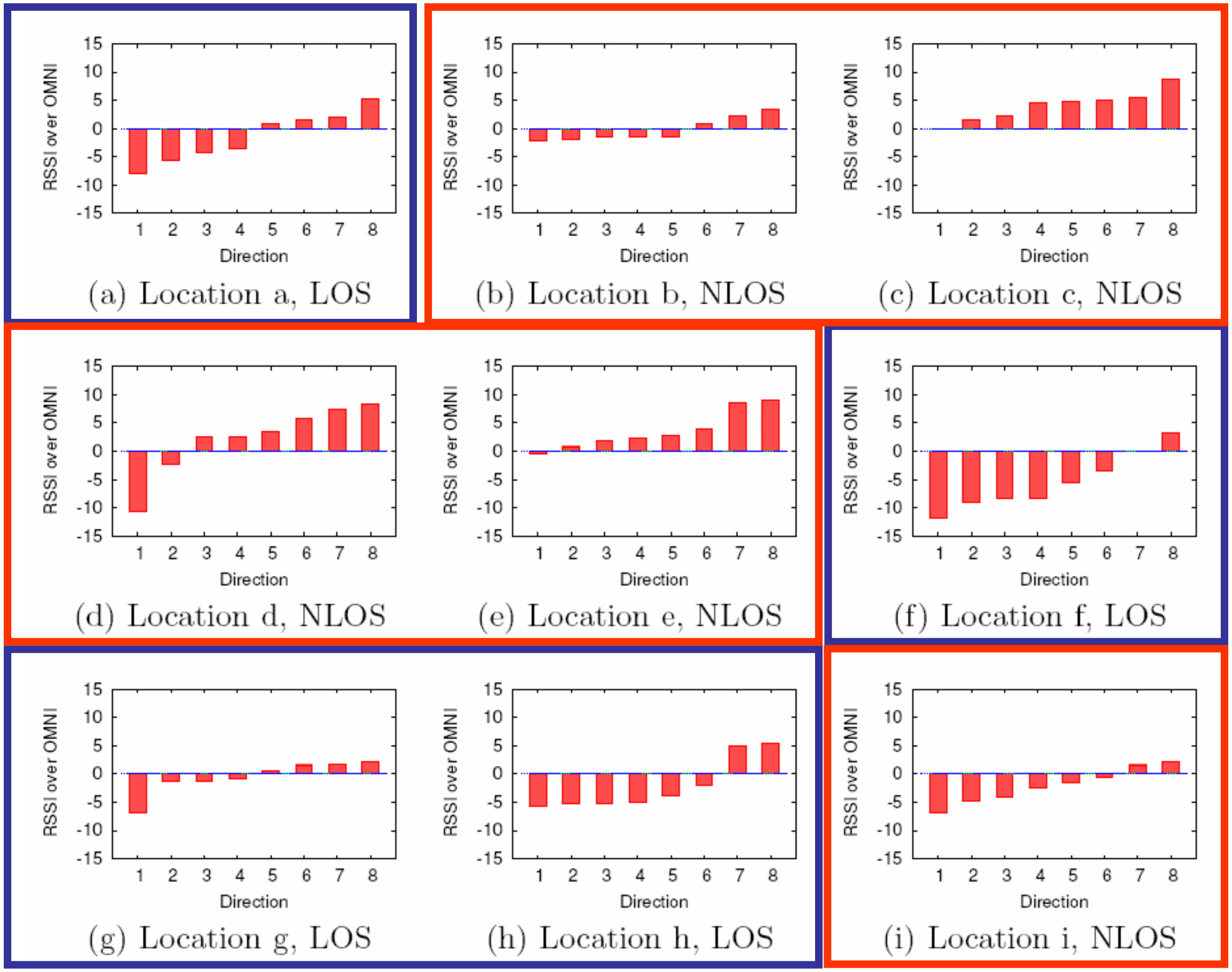
P3 (BW = 60°, FSR = 18dB)

- All nodes
  - Use Linux v2.4.26 with mini-PCI 802.11 b/g (Atheros, MadWifi)
  - Use channel 6 after office hours

Results

- Degree of directionality
- Potential for Spatial Re-use
- Accuracy of Node Localization

Degree of directionality – Results (p3)



(a) Location a, LOS
(b) Location b, NLOS
(c) Location c, NLOS
(d) Location d, NLOS
(e) Location e, NLOS
(f) Location f, LOS
(g) Location g, LOS
(h) Location h, LOS
(i) Location i, NLOS

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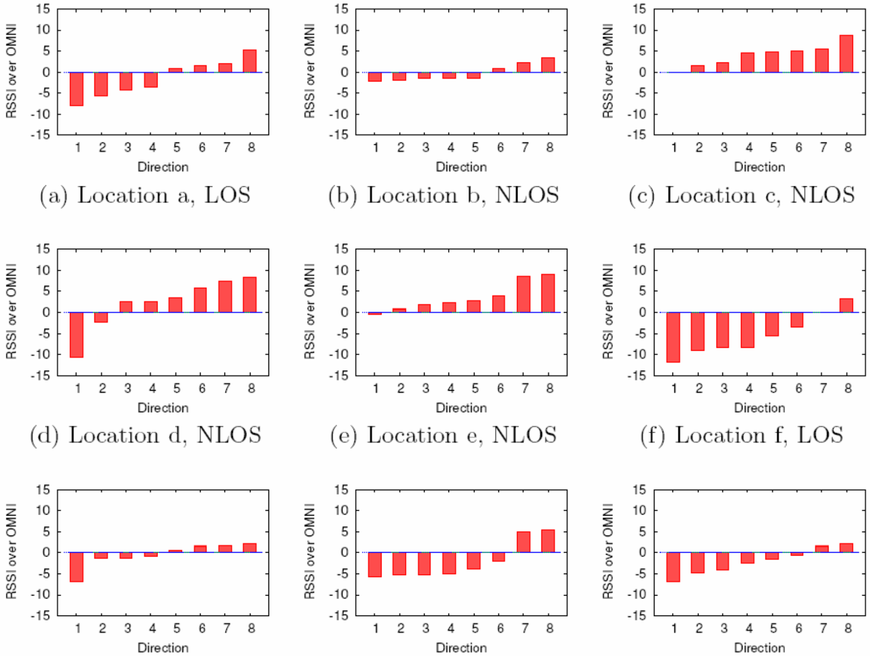
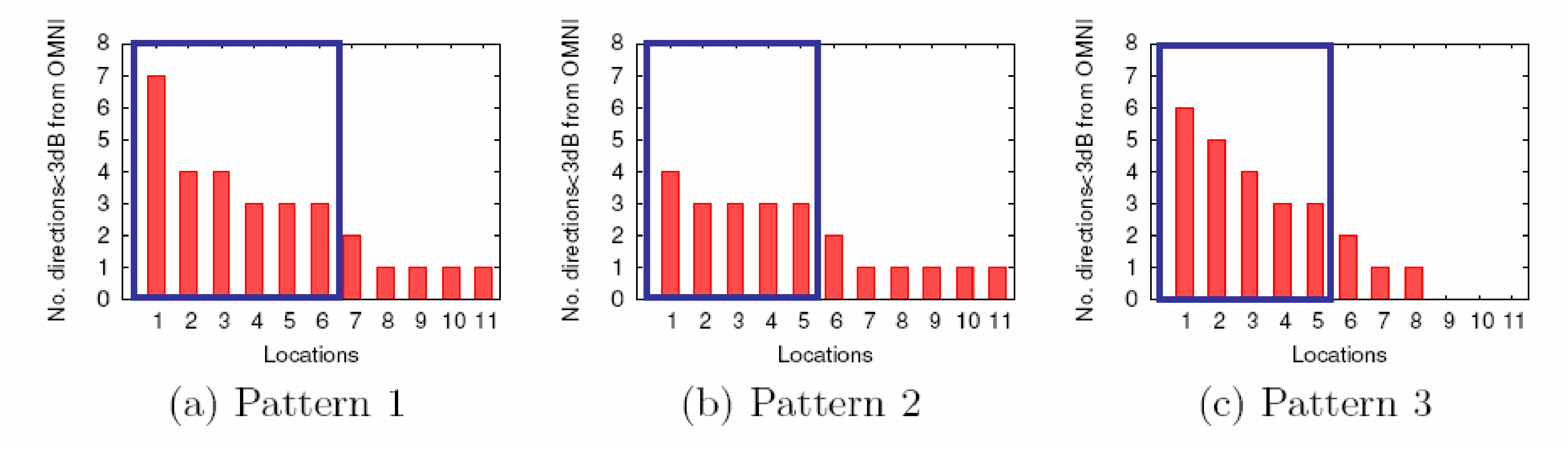
Degree of directionality – Results (p3) (continued)

- Strong signal in few directions and weak in rest
  - In many locations (LOS and NLOS)
  - For all three patterns
- Propagation characteristics based on location (LOS or NLOS) alone – hard to predict



(a) Location a, LOS (b) Location b, NLOS (c) Location c, NLOS
(d) Location d, NLOS (e) Location e, NLOS (f) Location f, LOS
(g) Location g, LOS (h) Location h, LOS (i) Location i, NLOS

Spatial reuse – Results and Observations



- For spatial reuse, RSSI should be lower than OMNI by a considerable amount
  - We choose 3dB threshold (half the received power).

- More than 5 locations have >= 3 directions showing reduced interference relative to OMNI
  - Over 45% of locations indicate chances of spatial reuse

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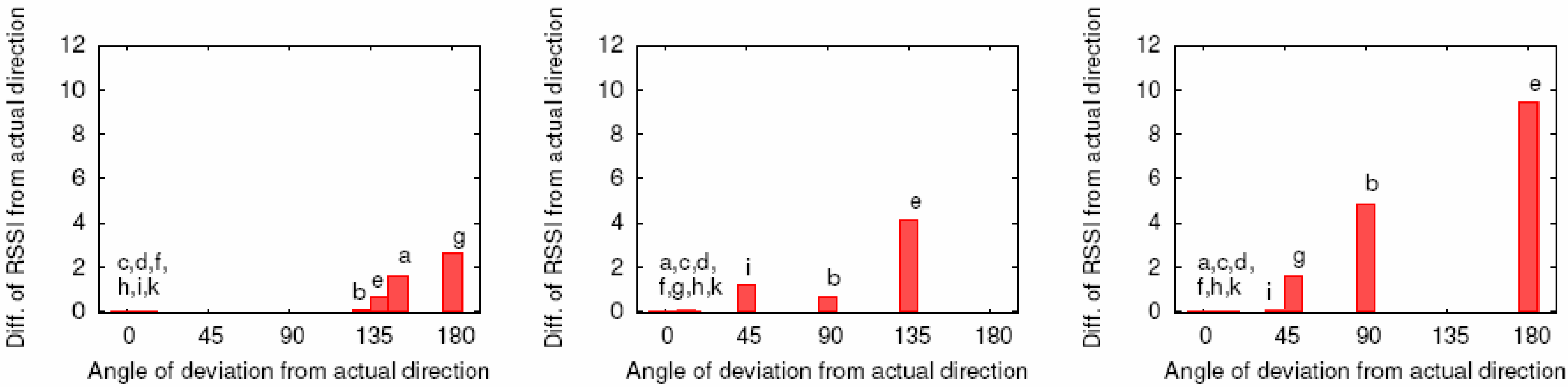
Node localization



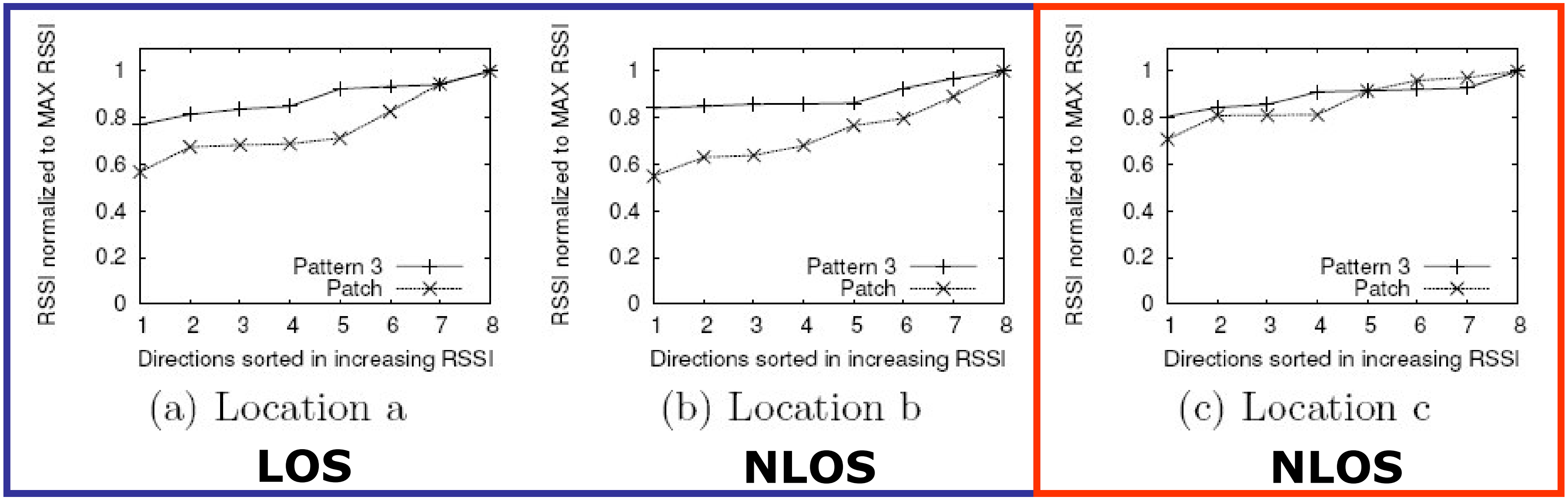
(a) Pattern 1 (b) Pattern 2 (c) Pattern 3

- Assumption: Beam with highest RSSI = geographical beam towards client – results in loss of accuracy

- Across patterns, very few clients get wrongly positioned
  - Note that RSSI difference is minor in most cases

- Techniques should choose across best beams and patterns for improved accuracy

Degree of directionality – Effect of thinner beams



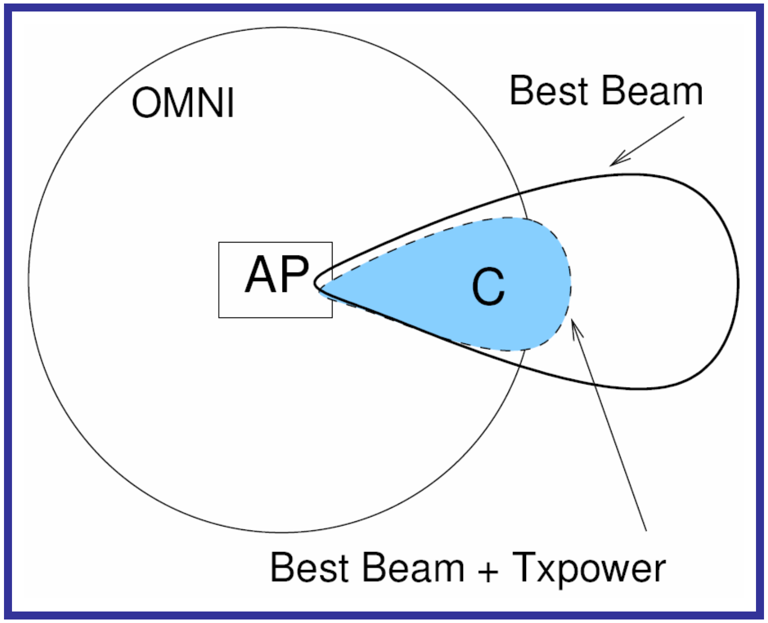
Do thinner beams change observations drastically?

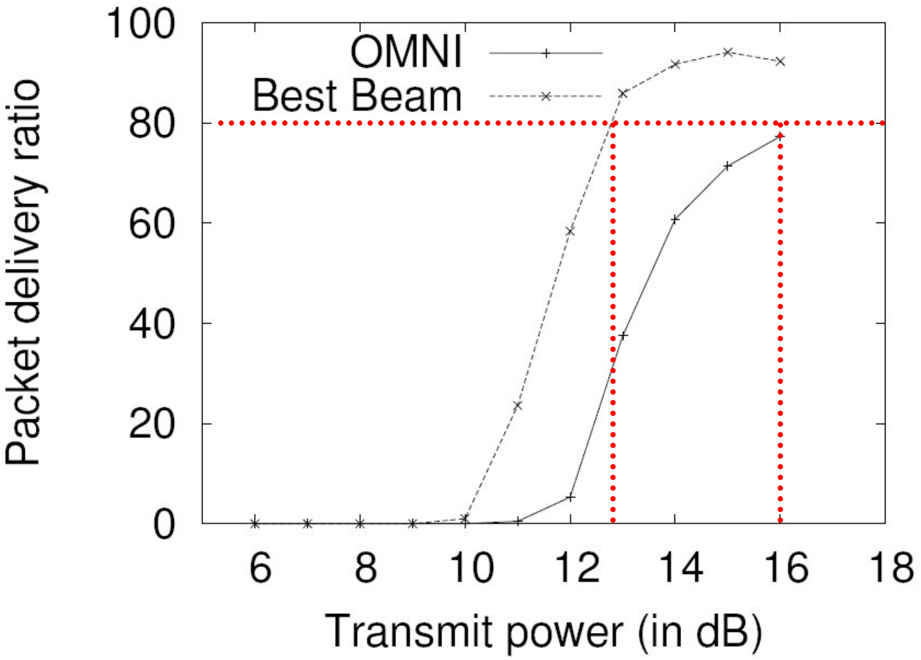
- Use a 17º patch antenna and repeat experiment

Observations:

- Thinner beam widths yield better directionality
- Multipath effects not fully eliminated

Combining directionality and transmit power





- Can we exploit directional gain to reduce transmit power (for increased battery life and reduced interference)?
- TX can reduce transmit power to achieve same performance as OMNI and meet client requirements
  - Transmit power control reduces side lobes as well

Conclusion

- Multipath in indoor environments does not completely negate the benefits of directionality

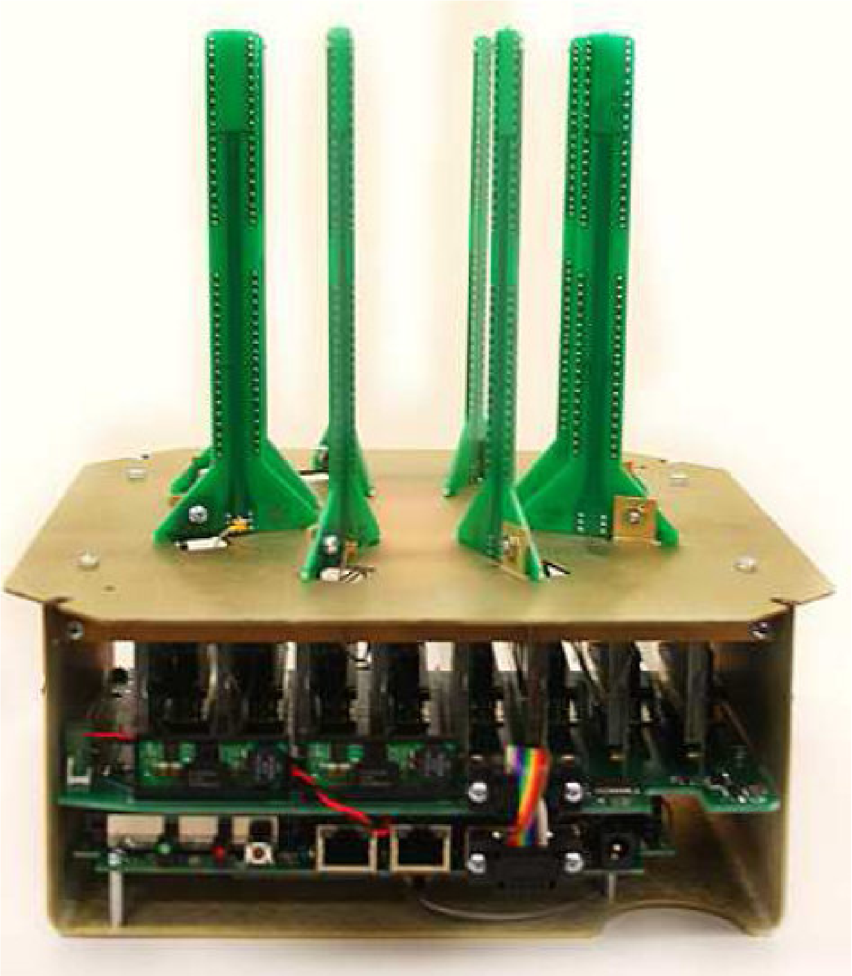
- Definition of directionality is dependent on application requirements
  - For spatial reuse, the potential exists at many locations (LOS and NLOS)
  - For localization, most clients get correctly positioned

- Thinner beam widths yield greater directionality but fail to completely eliminate impact of reflections

Future Work

- Effectiveness of beams formed in signal space in indoor environments

Questions?



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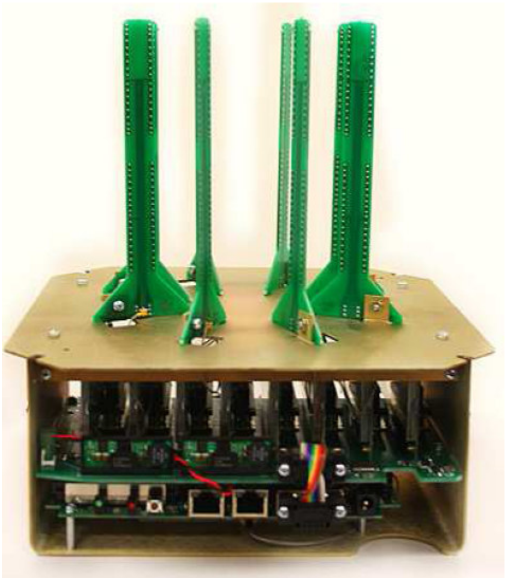
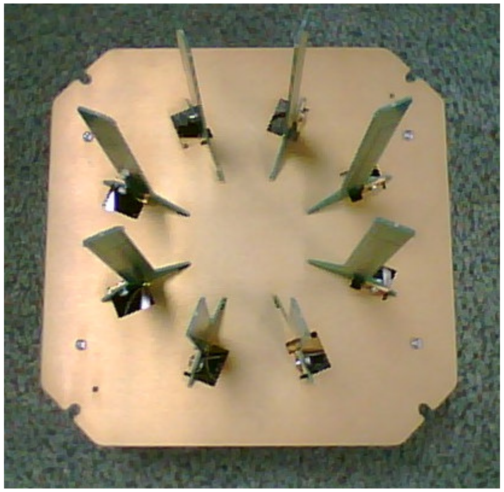
Comparison with MIMO

- Multiple-input, multiple-output (MIMO) – can exploit multipath indoors
- However, for spatial reuse and node localization, MIMO may not work as,
  - In open-loop mode, it can only improve single link performance
  - In closed-loop mode, it requires significant channel feedback and receiver modifications to enable adaptive beamforming
- Interesting avenue for future work
  - When hardware and software become friendly for experimentation

Fidelity Comtech's Phased Array (Phocus)





- Single board computer (SBC) connected to eight-element circular phased array
  - At most 360° / 8 = 45° beam width, 15dBi gain
  - Atheros 802.11 b/g radio
- Electronically steerable
  - Switch between beams at 250μs intervals