Practical Beamforming based on RSSI Measurements using Off-the-shelf Wireless Clients

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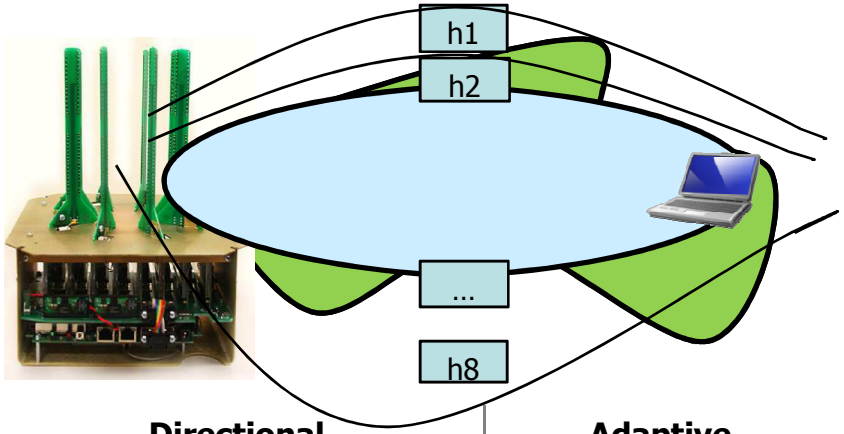
Importance of beamforming

- Indoor wireless network
  - Fading causes varying and poor link quality
  - Interference
- Link quality can be improved using antenna sophistication
  - Omni-directional: radiate equally in all directions and leaves users with low SNR
  - Beamforming: creating a beam that causes reflected signals to re-inforce at the Rx
- *Beamforming improves wireless link throughput significantly*
  - Link capacity depends on Signal to Noise Ratio as C= log(1+S/(I+N))

Current state of art

- Applying weights to signals from multiple antennas to obtain desired patterns
  - Directional - typically only phase weights
  - Adaptive - both magnitude and phase weights based on the channel
- Accomplished by sending training symbols on each antenna to estimate h1..h8
- Tx and Rx must be equipped with channel sounding and estimation hardware algorithms (symbol level processing)
- ***Beamforming requires access to baseband symbols***
  - ***Legacy clients?***
  - ***Scalability?***



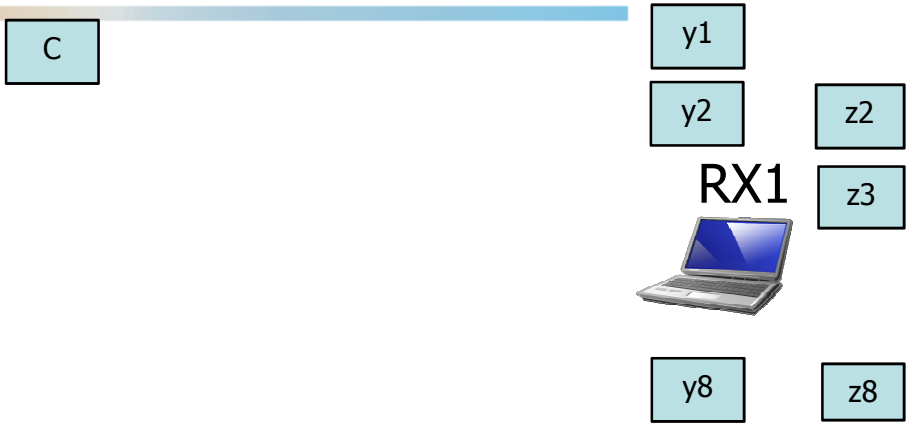
	Directional		Adaptive	
	Magnitude	**Phase (deg)**	**Magnitude**	**Phase (deg)**
a0	**35**	**-166**	**48**	**0**
a1	**35**	**-69**	**68**	**25**
a2	**35**	**69**	**22**	**142**
a3	**35**	**166**	**19**	**-120**
a4	**35**	**166**	**0**	**180**
a5	**35**	**69**	**32**	**-63**
a6	**35**	**-69**	**12**	**180**
a7	**35**	**-166**	**33**	**-27**

Key idea

- Obtain channel estimates using *just* power measurements
  - Benefits legacy clients and generic measurement methodology
- Principles
  - Use **differential phases** instead of absolute phases
  - Use **tandem activation of antennas** to obtain differential channel phases using the received power
- Details
  - With single element activation, phase information is lost when received power is computed. i.e for complex symbol $C=a\,e^{\{j\,b\}}$, Power $|c|^2 = a^2$
  - With tandem activation, $P_{ij}=P_i+P_j+2*\sqrt{P_i}*\sqrt{P_j}*\cos(\Theta_{ij})$
    - when $\Theta_{ij} = 0$ (constructive), $\Theta_{ij} = 180$ (destructive)
  - E.g , when $P_{12} = 0.8$, $P_1=1$ and $P_2=0.7$,

    $\Theta_{12} = \cos^{-1}((0.8 - 1 - 0.7)/ (2*\sqrt{1}*\sqrt{0.7})) = 122\ °$
  - But 4 possible solutions :122 °, 180-122 °, -122 °,-(180-122) °

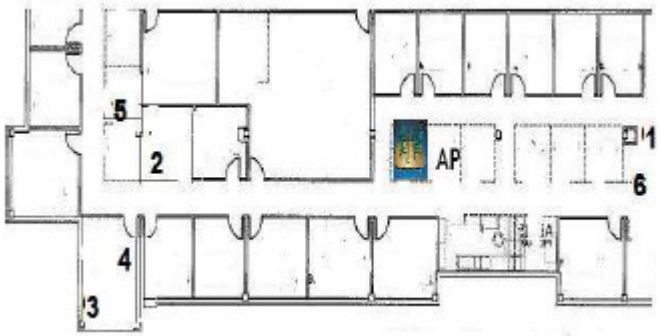
Measurement Procedure



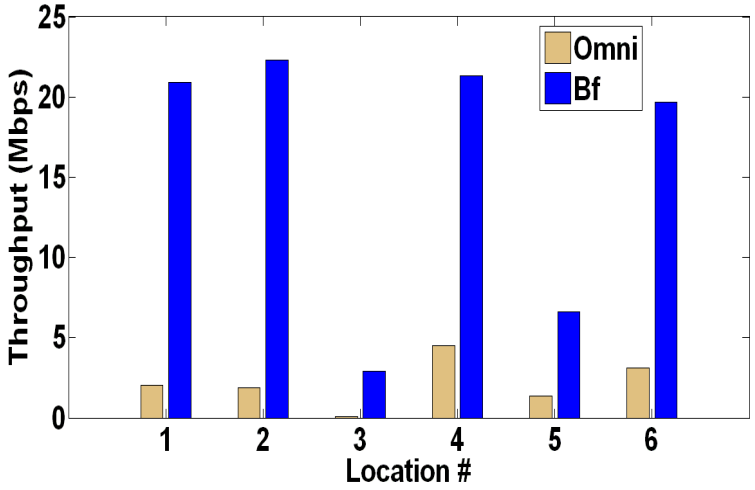
1. Activation
   - Single antenna followed by antenna pairs
2. Feedback of average powers (y1..y8,z2..z8)
3. Ambiguity resolution
   - Compute pairwise weights using ambiguous phases and activate antenna pairs sequentially
   - Choose the phase which yields highest RSSI

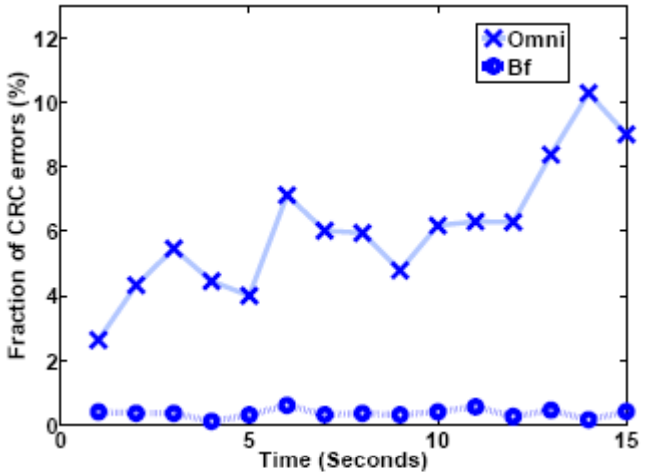
Performance Evaluation

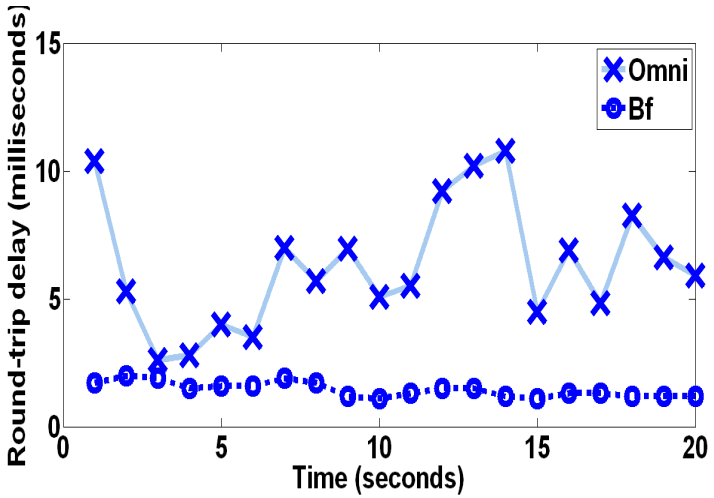
- Hardware
  - Access point – 802.11g with eight element circular array
  - Client s – Dell laptops with D-Link 802.11g card
- Software
  - Shell scripts for writing new antenna patterns
  - Octave to compute complex weights
  - Madwifi `athstats' utility to measure losses, CRC errors, RSSI
- Experimentation
  - Urban office environment with no extraneous interference
  - Iperf traffic using UDP datagrams
  - Adaptive Beamforming (Bf) compared with Omni



Experimental Results



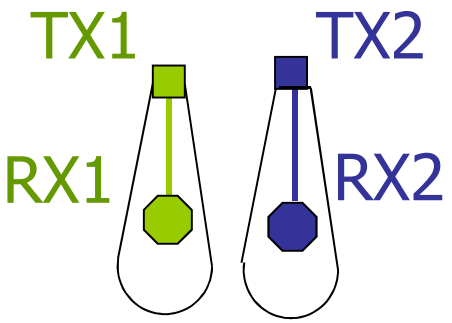




- Throughput improvements
  - 4x-5x compared to Omni
- Packet Errors are reduced from around 10% to 0.5%
- Delay is also reduced

Conclusions and Future Work

- Conclusions
  - Significant beamforming benefits can be obtained using `just' received power measurements
  - Quantization and noise have minimal impact for typical operating conditions
  - Link throughput improves up to 5x compared to Omni and 2.2x compared to directional
- Future extension
  - Implementing interference suppression to improve spatial reuse for multiple clients



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Thank You

Questions and Comments?

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