

## Part 4

# Modeling and Simulation

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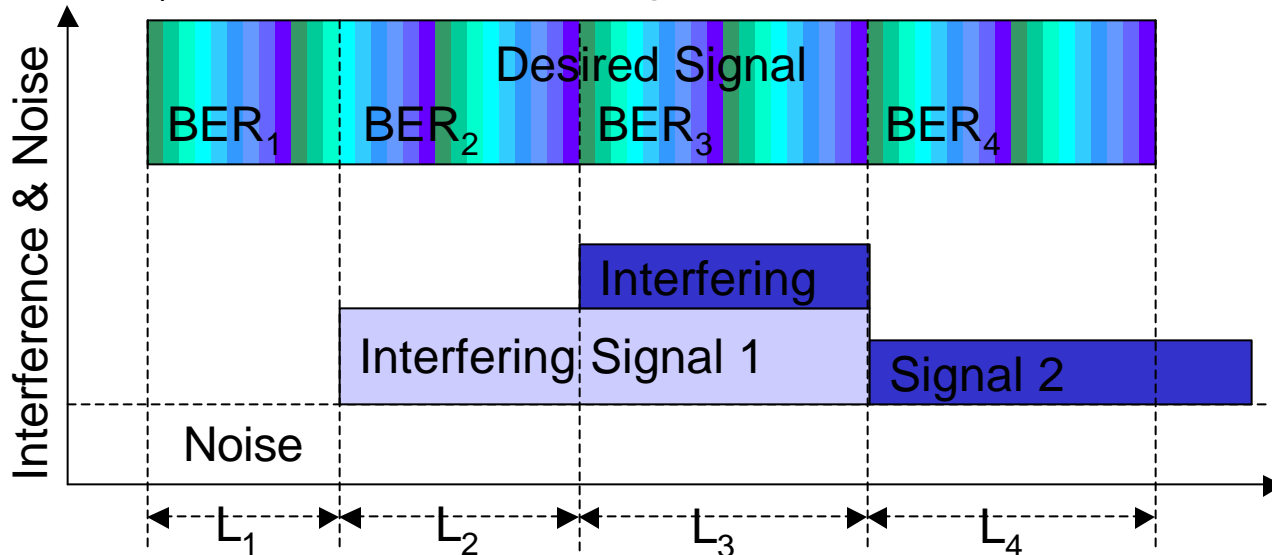
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# PHY Modeling in Network Simulation (1)

- Primary role of PHY layer models in network simulation:  
Simulate packet (frame) receptions under given conditions
- Packet error is determined by BER (Bit Error Rate)

$$PER = 1 - \prod_i^n (1 - BER_i)^{L_i}$$

- $n$ : number of segments with different interference and noise power
- $BER_i$ : instantaneous BER for the segment  $i$
- $L_i$ : number of bits in the segment  $i$



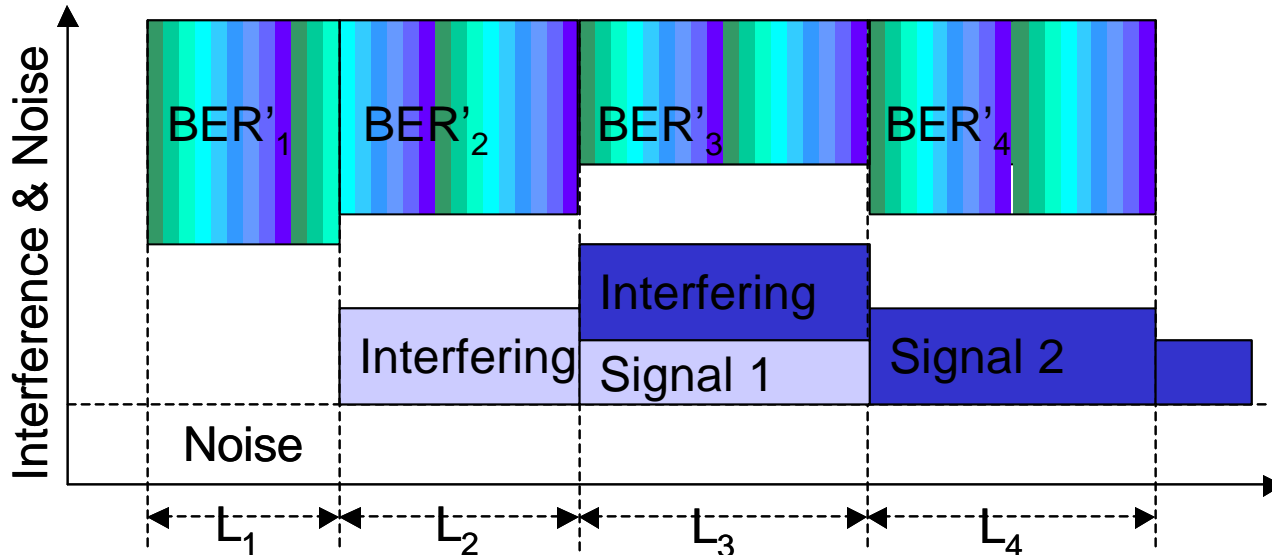
# PHY Modeling in Network Simulation (2)

- BER is determined by SINR

$$SINR = \frac{P_s}{\sum_{\text{all others}} P_{i_i} + FkTB}$$

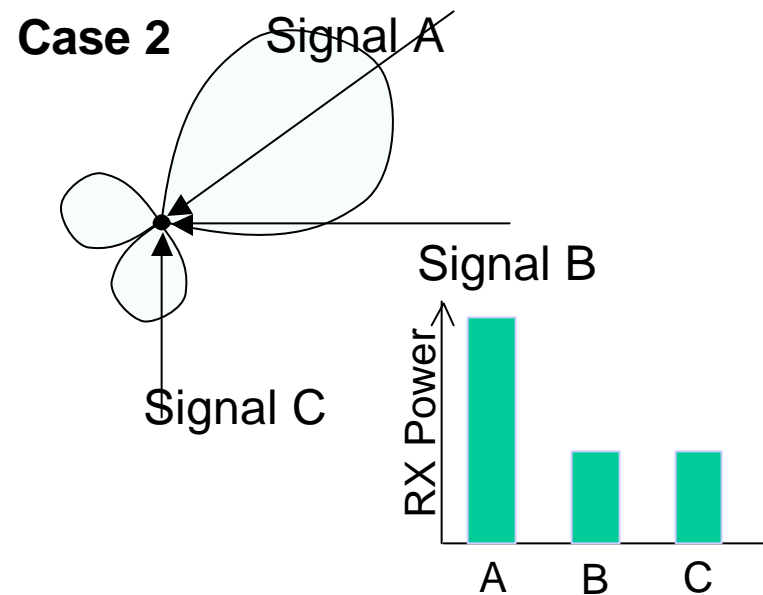
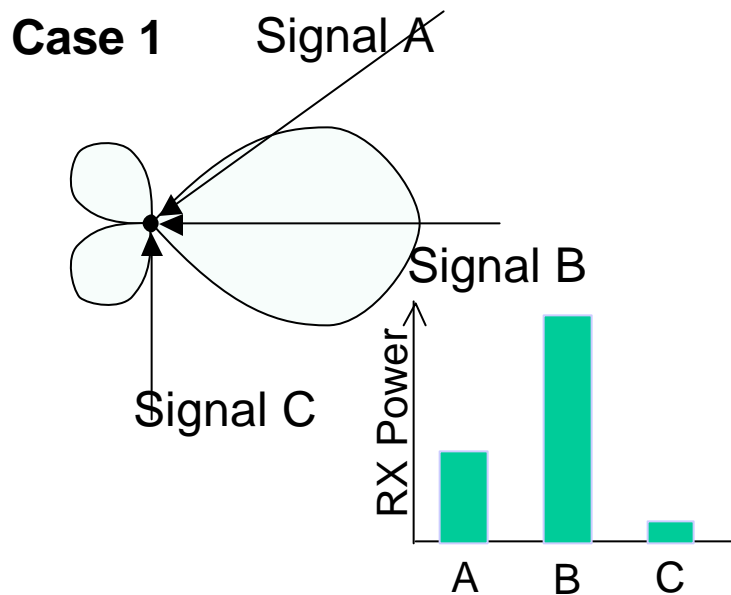
$k$ : Boltzmann's constant ( $1.379 \times 10^{-23}$  [WHz<sup>-1</sup>K<sup>-1</sup>])  
 $B$ : Effective noise bandwidth [Hz]

- Directional antennas can lower BER
  - BER' < BER (SINR' > SINR)



# Directional Antenna Modeling in Network Simulation (1)

- Omni-directional or fixed directional communications
  - Constant antenna gains at both transmitter and receiver
- Directional communications with pattern changes
  - Gain for each signal changes with a different pattern
  - SINR changes every antenna pattern (either tx or rx) change



# Directional Antenna Modeling in Network Simulation (2)

- Simulation of omni-directional communications
  - SINR recomputation for every
    - Interfering signal
    - Other propagation effects (fading)
- Additions for directional communications
  - SINR recomputation for every pattern change at
    - The node (receiver)
    - All transmitters (for directional transmissions)
  - Compute AOA (Angle of Arrival) and add appropriate gains

# Distance and Angle Calculation (Cartesian)

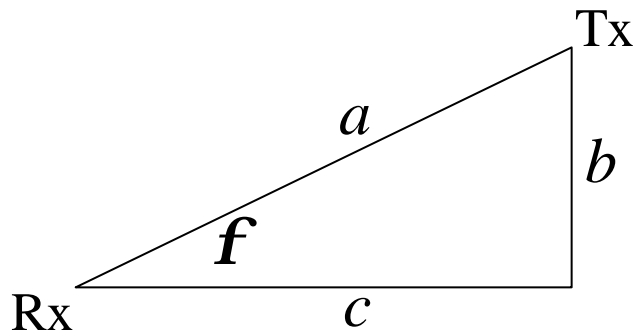
- Calculate distance and angle in plane trigonometry

Distance (including vertical) :  $d = \sqrt{a^2 + h^2}$  where  $a = \sqrt{b^2 + c^2}$

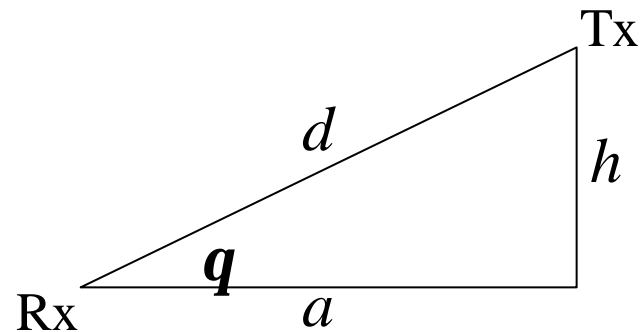
Horizontal (azimuth) angle :  $f = \sin^{-1}(b/a)$

Vertical (elevation) angle :  $q = \sin^{-1}(h/d)$

Azimuth plane



Elevation plane



# Distance and Angle Calculation (Spherical)

- Calculate distance and angle in spherical trigonometry

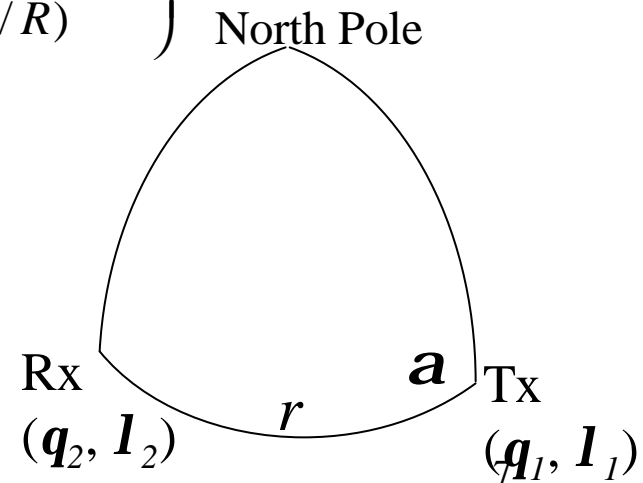
Horizontal distance :  $r = R \cos^{-1}(\cos \mathbf{q}_1 \cos \mathbf{q}_2 \cos(\mathbf{l}_1 - \mathbf{l}_2) + \sin \mathbf{q}_1 \sin \mathbf{q}_2)$

(for less rounding error :)  $r = 2R \sin^{-1} \left( \sqrt{\left( \sin \frac{\mathbf{q}_2 - \mathbf{q}_1}{2} \right)^2 + \cos \mathbf{q}_1 \cos \mathbf{q}_2 \left( \sin \frac{\mathbf{l}_2 - \mathbf{l}_1}{2} \right)^2} \right)$

Distance (including vertical) :  $d = r + h(r / R)$

Horizontal (azimuth) angle :  $\mathbf{a} = \cos^{-1} \left( \frac{\sin \mathbf{q}_2 - \sin \mathbf{q}_1 \cos(r / R)}{\cos \mathbf{q}_1 \sin(r / R)} \right)$

Vertical (elevation) angle :  $\mathbf{b} = \sin^{-1}(h / d) - d / 2R$



# Typical Antenna System Architectures

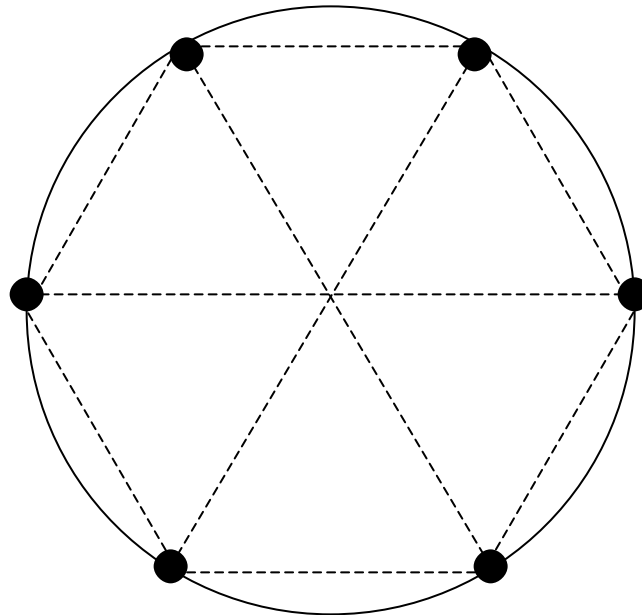
- **Switch:**  
Directional elements + switch
- **Switched or steered beam:**  
Omni-directional elements + pre-configured weight vectors
- **Adaptive:**  
Omni-directional antenna elements + adaptive beamforming

## Beamforming (2): Presented Previously

- Beamforming direction
  - Switch (directional): boresights of elements
  - Switch (omni): can be arbitrarily set
  - Adaptive: multiple beams + nulls possible
- Time for beamforming
  - Switch (directional): per frame
  - Switch (omni): instantaneous
  - Adaptive: almost instantaneous (depending on algorithm)
- Side lobes
  - Switch (directional): up to each antenna element
  - Switch (omni): large side lobes
  - Adaptive: large side lobes, but may have less effects

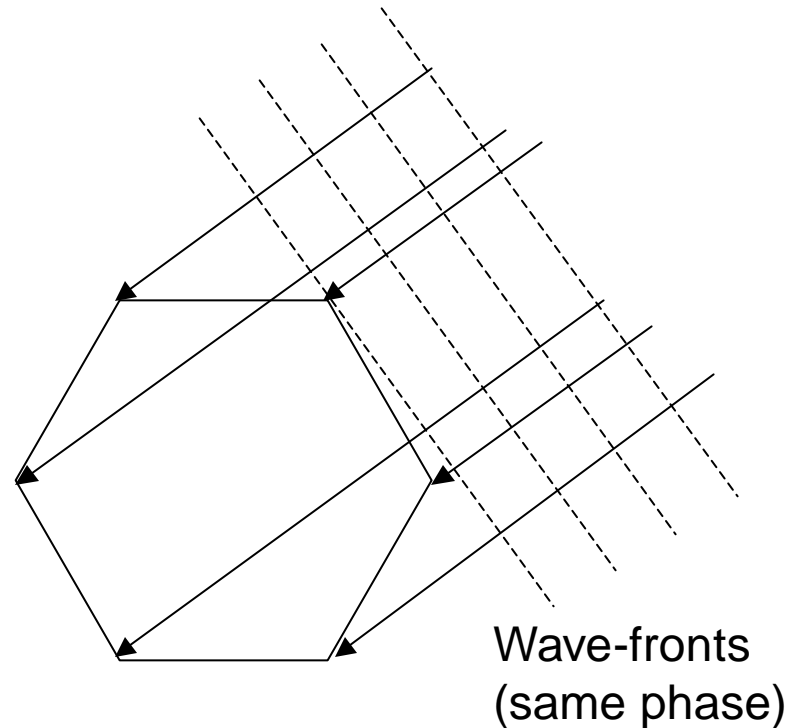
# Steerable Antenna Modeling (1)

- Antenna pattern creation:  
Electrically steerable beam antenna system
  - Circular antenna array with 6 isotropic elements each spaced 0.4 wavelengths apart
  - At 2.4Ghz it is 12 cm or about 4.7" apart (radius)

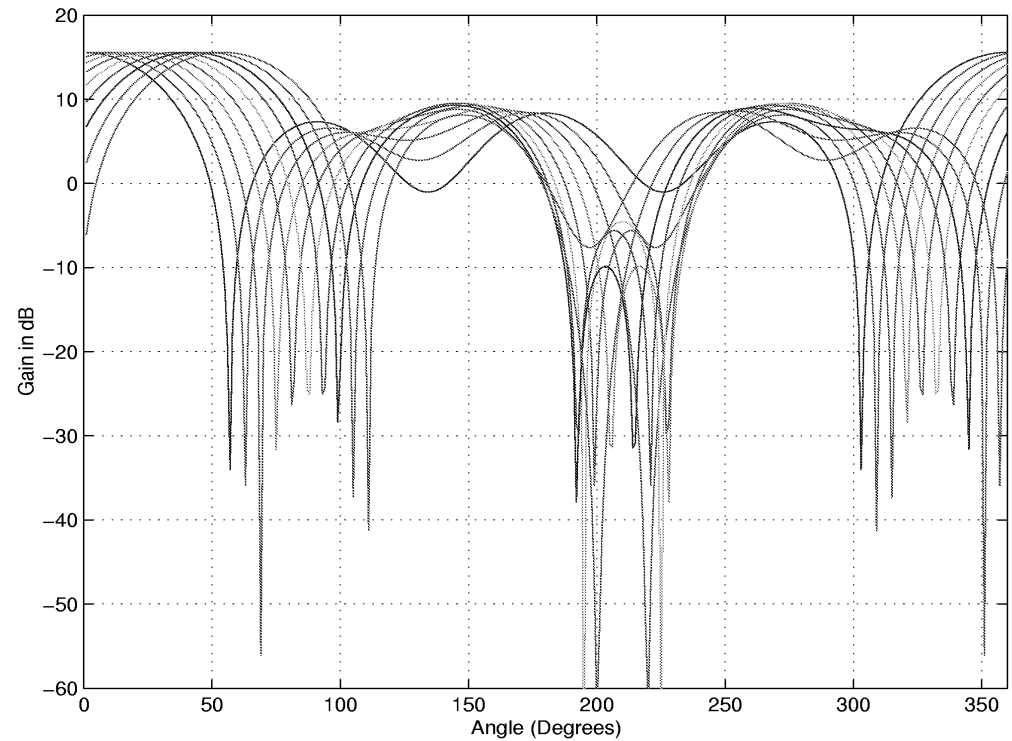
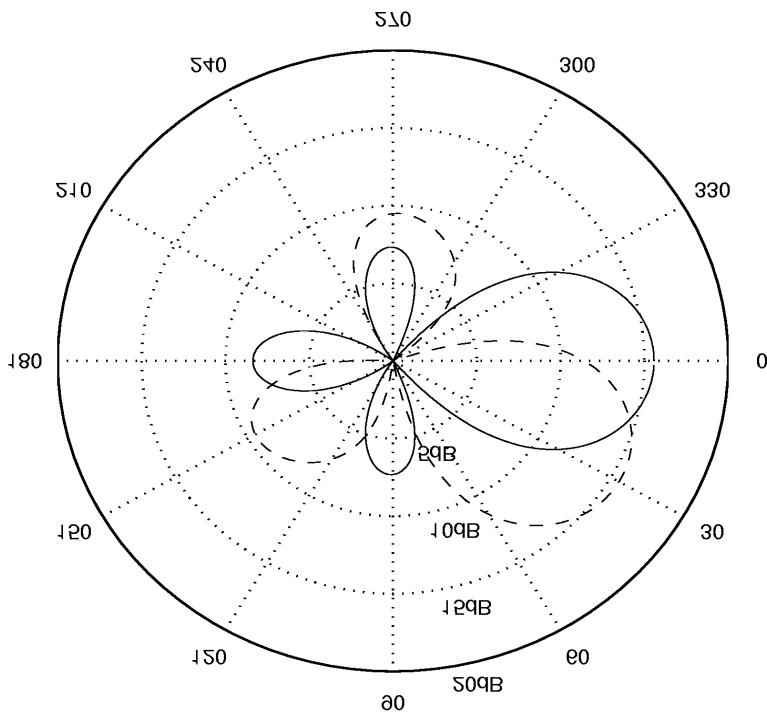


## Steerable Antenna Modeling (2)

- Pattern creation using MATLAB
  - A fixed pattern for a given AOA (Angle of Arrival): precomputation possible
  - Objective function: maximizing the gain
  - Determine the weight for each element and combine 6 outputs
  - Six times larger amplitude: 15.5 dB (36x) gain
  - Compute gains for all directions

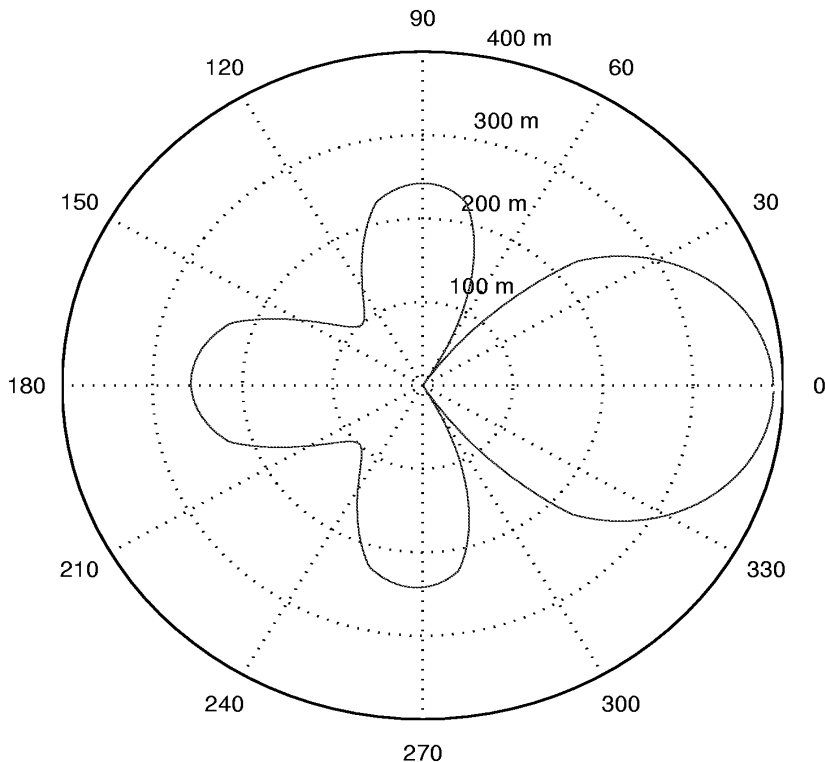


# Antenna Patterns: Gain



- Angle between two adjacent elements:  $60^\circ$
- Side/back lobe pattern repeats every  $60^\circ$

# Antenna Pattern: Range



- Gain translated into range:
  - Two-ray path loss
  - Fixed threshold (96 dB)
- Effects of power leakage out of back and side lobes:
  - Nodes located behind or to the side of the aimed direction can receive a frame as far as 250m away (range is 376m)
  - Significant source of interference

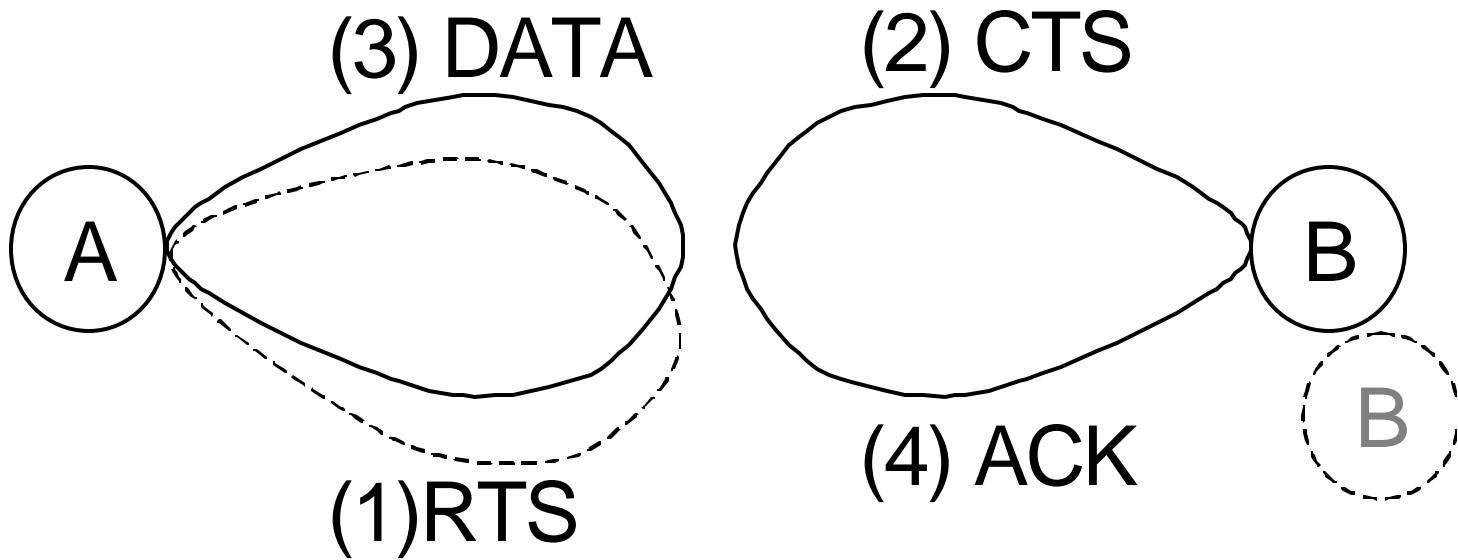
# Case Study: MANET Performance with Steerable Antennas (1)

- Simulation Scenario
  - 100 Nodes randomly placed in 1500m by 1500m flat terrain
  - Two-ray pathloss model
  - 40 random CBR sessions sending 512 byte packets
  - AODV routing protocol
  - IEEE 802.11 MAC DCF (plus DVCS)
- MANET performance with directional antennas
  - Omni: Omni-directional antenna
  - Rx-Only: Directional RX (no mods to MAC; no directional TX)
  - DVCS: Directional Virtual Carrier Sensing  
(presented in MobiHoc 2002: directional TX and RX)
  - DVCS-Ideal: DVCS plus a pattern with no back/side lobes

# Directional Virtual Carrier Sensing (DVCS) with the IEEE 802.11 MAC DCF

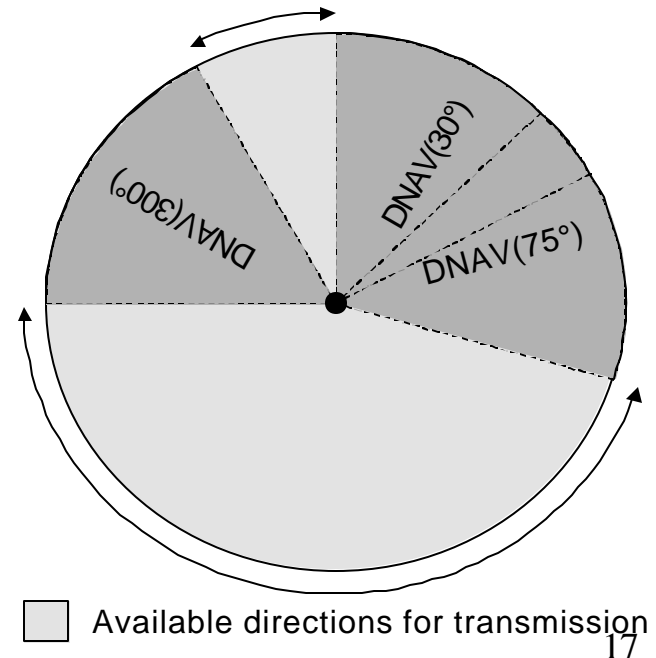
- DVCS (Directional Virtual Carrier Sensing) for contention based MAC protocols
  - Angle of Arrival (AOA) Caching
    - Remember directions of signal arrivals from neighbors
    - Send 4 RTS's directionally (if AOA is cached), and send 3 more RTS's omni-directionally if directional transmissions fail
  - Antenna Beam Pattern Locking
    - Direction of antenna kept the same during the RTS/CTS/DATA/ACK frame sequence
  - Directional Carrier Sensing
    - Check the channel with a specific antenna pattern when locked
  - DNAV: Directional NAV (Network Allocation Vector)
    - RTS/CTS based medium reservation

# Directional Transmission of Frames Using DVCS



# Directional Network Allocation Vector (DNAV)

- IEEE 802.11 NAV (Network Allocation Vector)
  - Reserve medium for an RTS/CTS/DATA/ACK sequence when overhearing RTS, CTS or Data frames transmitted for other communicating nodes
  - Spatial reuse not increased
- DNAV (Directional NAV)
  - Reserve medium only in the direction of the AOA of a received packet (plus a pad)
  - Can send frames in other directions, thus allow for more concurrent transmissions



# Case Study: MANET Performance with Steerable Antennas (2)

- Capacity increase by the use of directional antennas:
  - Rx-Only  $(1.8 \times \text{Omni})$
  - DVCS  $(1.8 \times \text{Rx-Only})$
  - DVCS-Ideal  $(1.6 \times \text{DVCS})$
- Predicted performance difference by no back/side lobes comparable to the use of directional antenna at each side
- Antenna patterns have as high impact as techniques being evaluated
- Realistic antenna patterns crucial to avoid misleading results

