Chapter 4:
Directional and Smart Antennas

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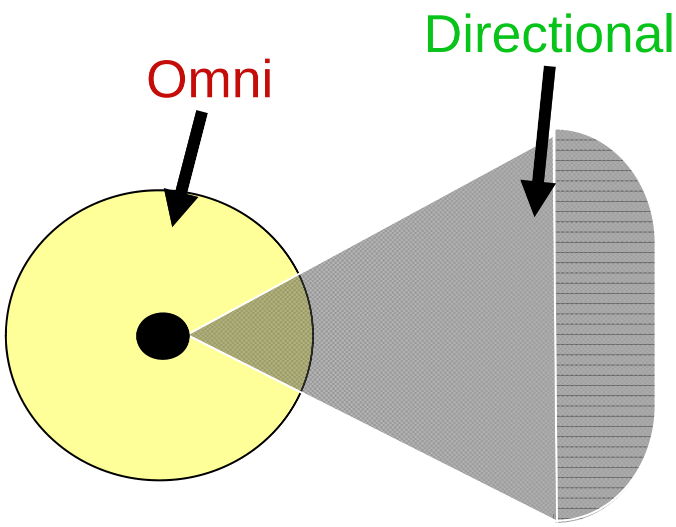
Outline

- Antennas background
- Directional antennas MAC and communication problems
- ”Using Directional Antennas for Medium Access Control in Ad Hoc Networks”, ACM MOBICOM’02
- “A Dual Access Mode MAC Protocol for Ad Hoc Networks Using Smart Antennas”, IEEE ICC’04
- “Directional NAV Indicators and Orthogonal Routing for Smart Antenna Based Ad Hoc Networks” IEEE ICDCSW’05
- “A Cross Layer MAC with Explicit Synchronization through Intelligent Feedback for Multiple Beam Antennas”, IEEE Globecom’05
- Summary

Antennas

- Antennas collect radio frequency energy from space for reception purposes and distribute energy into space for transmission



- In Omni Mode:
  - Nodes receive signals with Gain $\boldsymbol{G^o}$ **(傳送距離)**
  - While idle a node stays in Omni mode
- In Directional Mode:
  - Beamforms in any one of *N* static beams (switched)
  - Directional Gain $\boldsymbol{G^d}$ $\boldsymbol{(G^d > G^o)}$
  - Transmit and receive gains (*GT* and *GR*) are related to the transmit and receive powers (*PT* and *PR*)

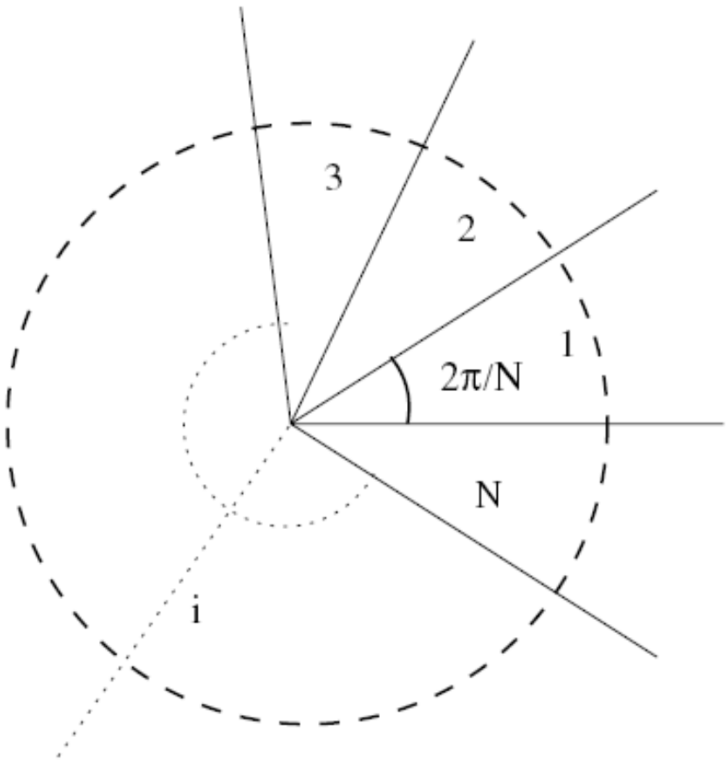
$$P_R = \frac{P_T G_T G_R}{K r^{\alpha}}$$

(*K* is a constant that accounts for atmospheric absorption)

Directional Antennas

A directional antenna can transmit a signal in any direction, using an array of antennas called array of elements

An area around the node is covered by *N* **sectors**, while all sectors are not overlapping



Directional Antennas

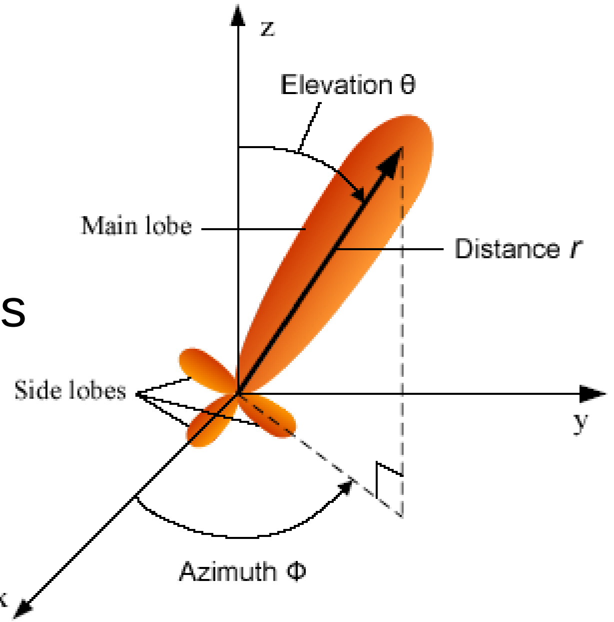
The **gain** of antennas：

$$G(\theta,\phi) = \eta \frac{U(\theta,\phi)}{U_{ave}}$$

$U(\theta,\phi)$: power density in direction (θ,ϕ)

U_{ave} : the average power density over all directions

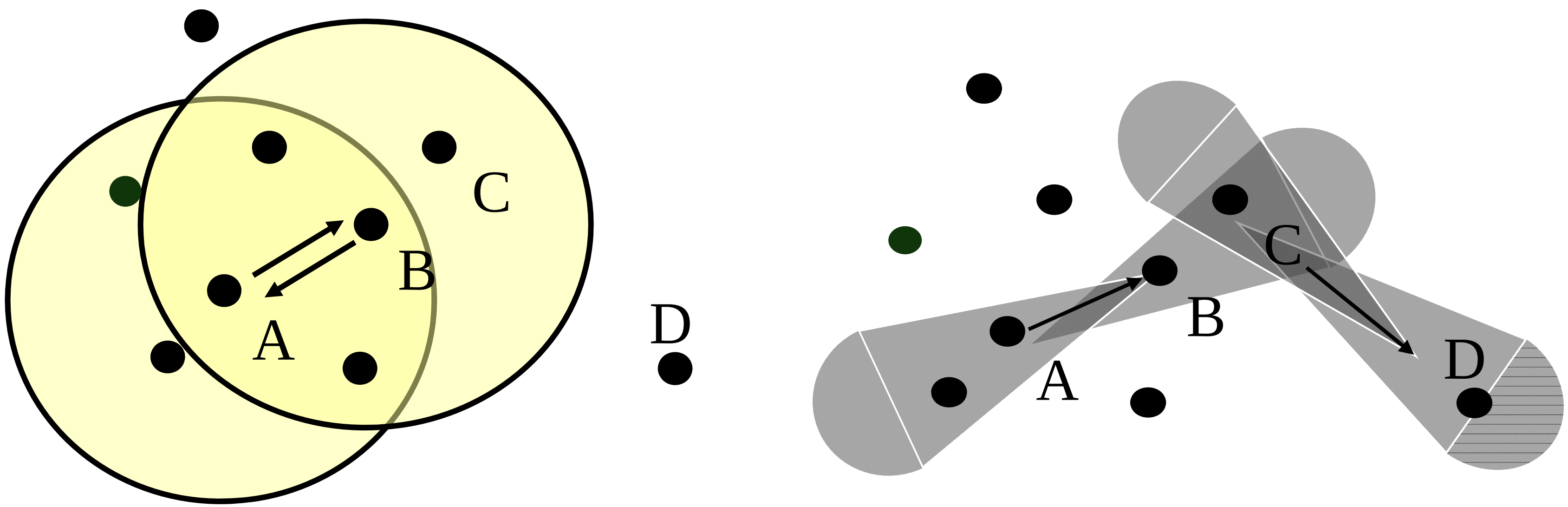
η : the efficiency of the antenna



When $U(\theta,\phi) = U_{ave}$ the antenna is called **isotropic**.

Directional Antennas

- MAC layer performance shown to be improved
  - Spatial **reuse** increases
  - Wireless **interference** reduces
  - **Range** extension possible
  - Saving **power**

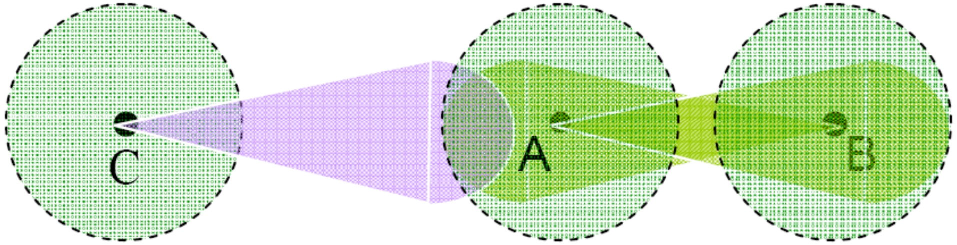


Directional Antennas

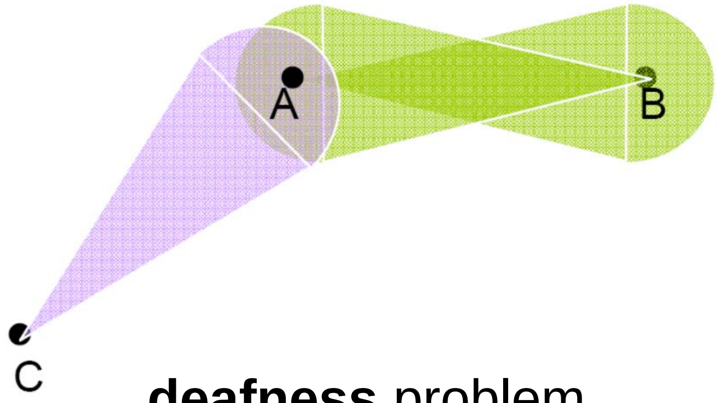
- Directional antennas increase the possibility of replacing many small hop communication links with one long, single hop link

- Directional antennas enable the receiver node to avoid interference that comes from unwanted directions, thereby increasing the *signal to interference and noise ratio* (**SINR**) to provide higher-gain transmission

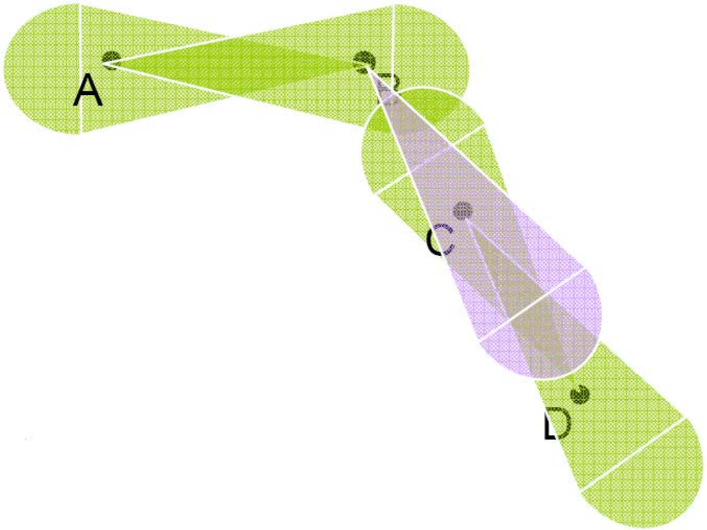
Communication problems



Due to **asymmetry** in gain



deafness problem



Due to unheard RTS/CTS

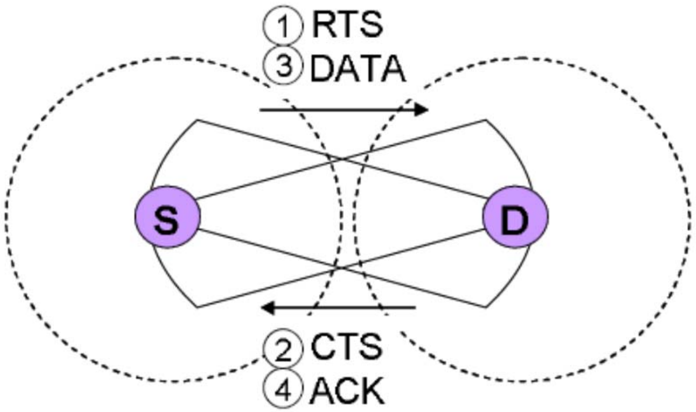
- Unfairness
- Channel waste
- Packet drop - reroute

Directional MAC, ACM MOBICOM'02

- This can increase spatial reuse of the wireless channel
- The higher gain of directional antennas allows a node to communicate with other nodes located far away, implying that messages could be delivered to the destination in fewer hops

Directional MAC

- Basic DMAC:
  - Basic DMAC is similar to IEEE 802.11, adapted for use over directional antennas
  - Transmit RTS/CTS/DATA/ACK directionally with the omnidirectional antenna coverage range – improved spatial reuse provides better throughput
  - An idle node listens to the channel omnidirectionally



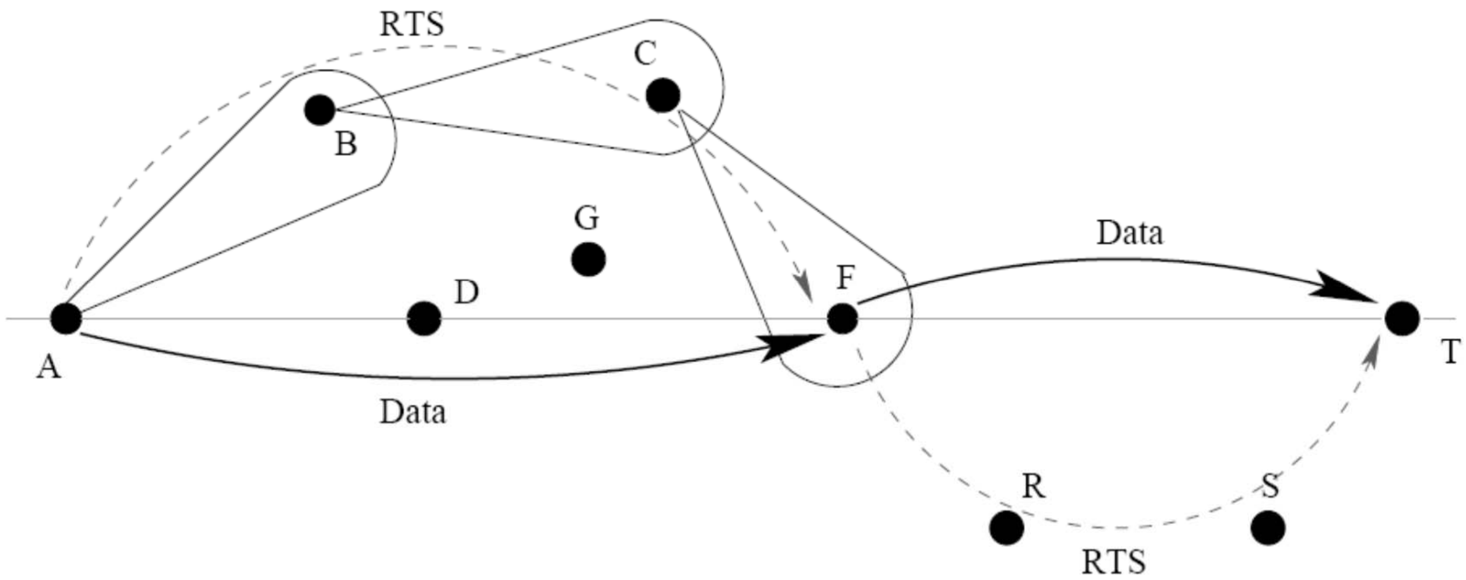
RTS/CTS/DATA/ACK

MMAC (Multi-Hop RTS MAC Protocol), ACM Mobicom’02

- The MAC layer of node transceiver receives a packet containing the DO-neighbor (Directional-Omni) route to the next DD-neighbor (Directional-Directional)
- Transceiver sends a RTS to the physical layer to be transmitted using the direction of the DD-neighbor receiver
- Other nodes set their DNAVs in the direction of transceiver and also in the opposite direction
- MMAC now constructs a special type of RTS packet that is delivered to the destination over multiple hops (*forwarding-RTS*)

MMAC (Multi-Hop RTS MAC Protocol)

- MMAC uses a multi-hop RTS which relays RTS at a neighboring terminal for extension of the communication area

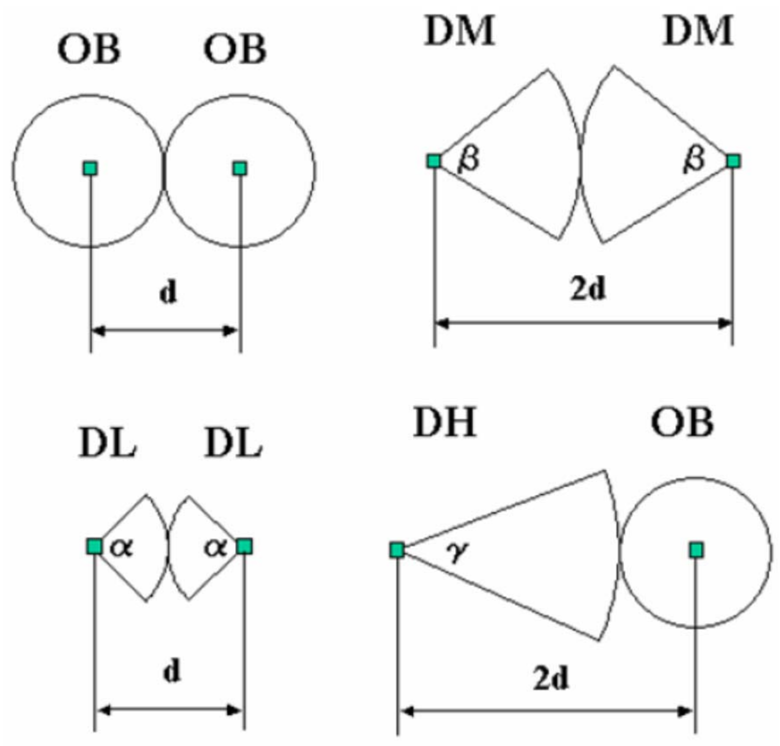


SWAMP (Smart Antennas based Wider-range Access MAC Protocol), IEEE ICC'04

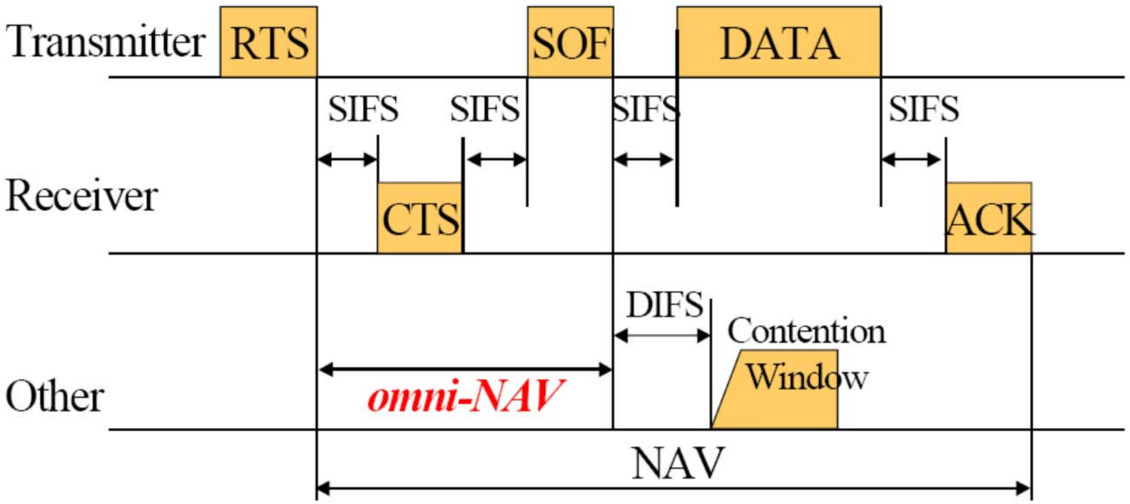
- Two access modes and uses four beamform patterns effectively
  - spatial reuse of the wireless channel
  - extension of the communication area
- **OC**-mode (Omni-directional area Communication access mode)
  - exchanges RTS/CTS/SOF (Start of Frame)
- **EC**-mode (Extend area Communication access mode)
  - exchanges DATA/ACK
- By exchange of RTS/CTS/SOF, a communication partner's position information is acquired

SWAMP

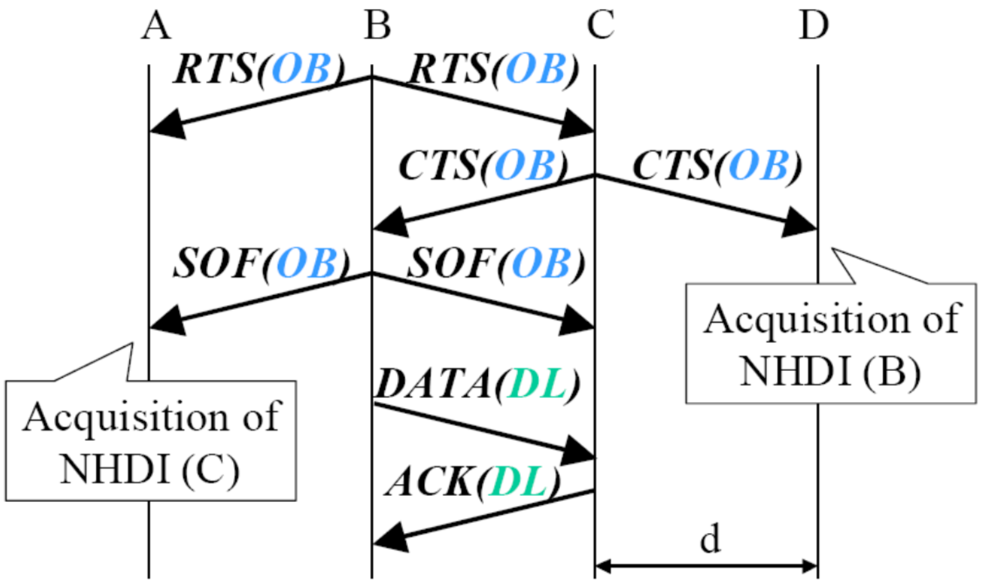
- SWAMP is composed of dual access mode that utilizes four beamform patterns effectively to combine the spatial reuse of the wireless channel and a wider transmission range



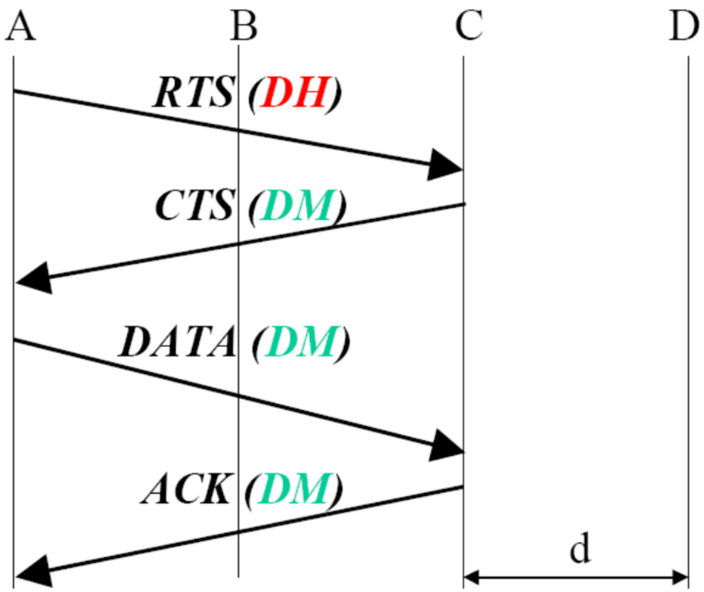
SWAMP



Transmitter
RTS
SOF
DATA
SIFS
SIFS
SIFS
SIFS
Receiver
CTS
ACK
DIFS
Contention Window
Other
omni-NAV
NAV



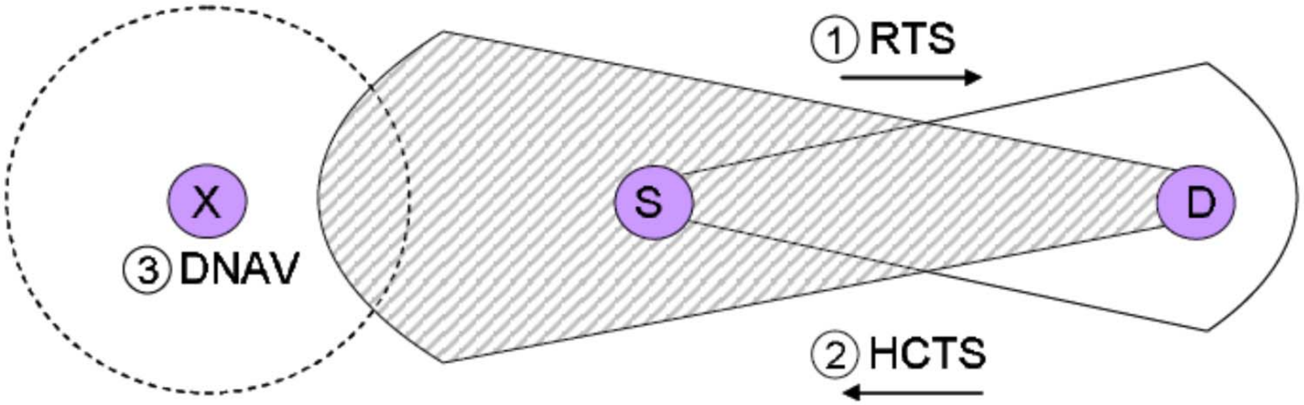
A
B
C
D
RTS(OB)
RTS(OB)
CTS(OB)
CTS(OB)
SOF(OB)
SOF(OB)
DATA(DL)
ACK(DL)
Acquisition of NHDI (C)
Acquisition of NHDI (B)
d



A
B
C
D
RTS (DH)
CTS (DM)
DATA (DM)
ACK (DM)
d

HCTS (HIGH GAIN CTS), IEEE ICDCSW'05

- CTS needs to cover all the area in which a directional hidden terminal may exist
- Antenna gain must be enlarged. However, HCTS does not need to introduce a new flame

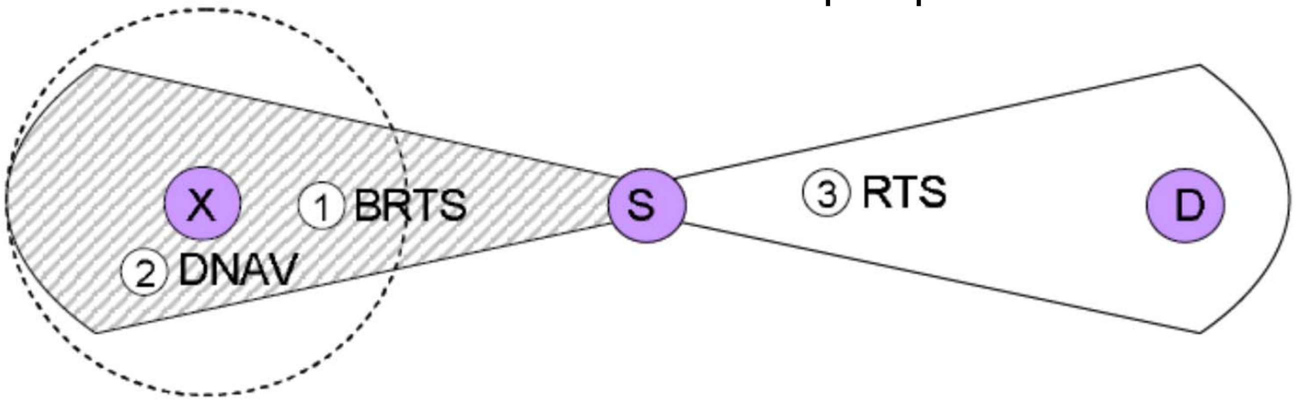


BRTS (Backward RTS)

- Before terminal S transmits RTS to destination, it turns the direction of a transmitting antenna to 180-degree back toward destination, and transmits RTS

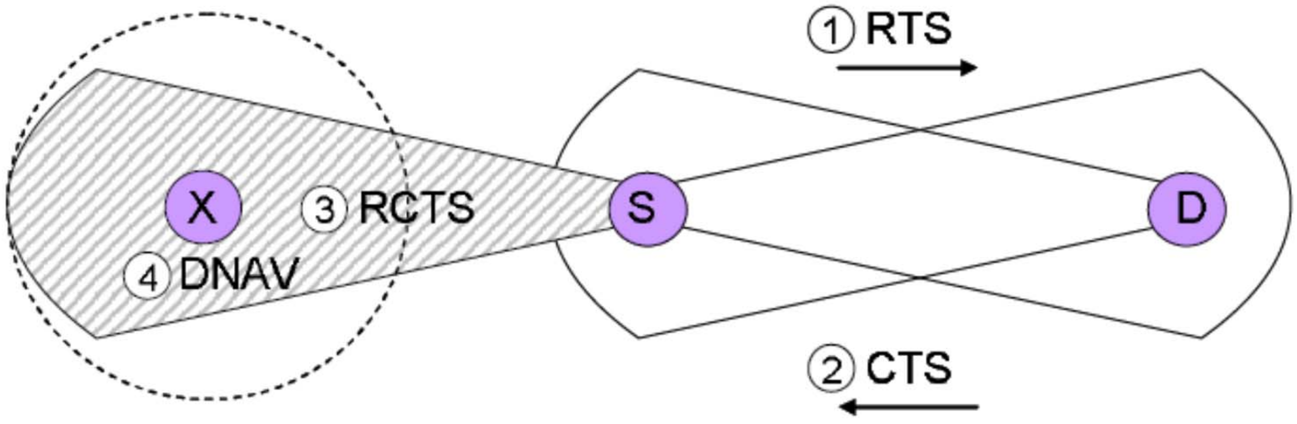
- Hidden terminal X sets DNAV by BRTS

- However, in order to transmit RTS repeatedly, changing the direction of an antenna, an overhead arises：
  - When a sender did not receive CTS from a destination terminal, terminal which received the BRTS sets DNAV and postpones own communication



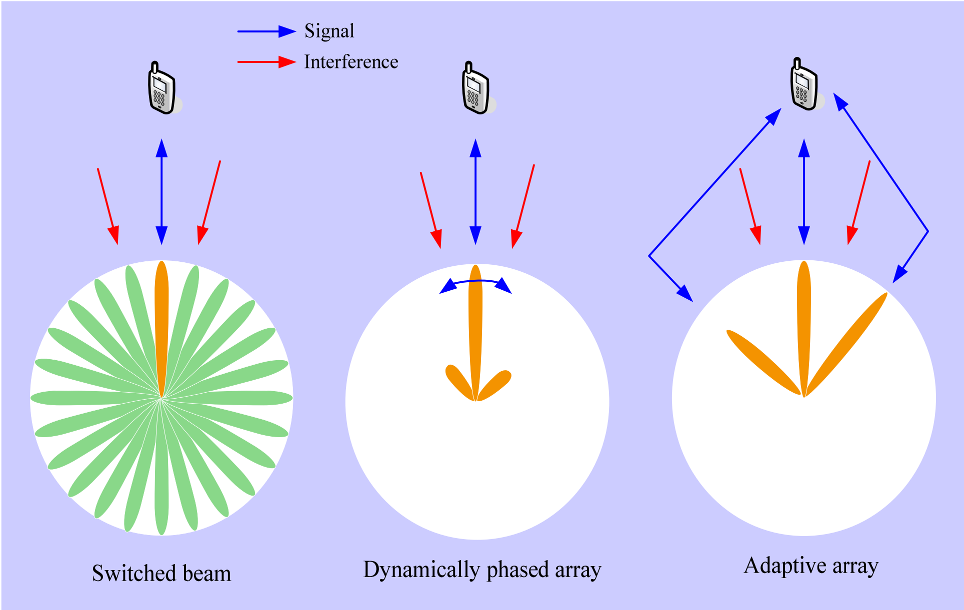
RCTS (Relayed CTS)

- S transmits RTS to the terminal D with a directional beam, and after receiving CTS from D, S transmits RCTS to 180-degree back
- The timing is not immediately after transmitting RTS. Therefore RCTS is more effective than BRTS
- RCTS is the same as SOF of SWAMP (OC-mode) with high gain and directionally



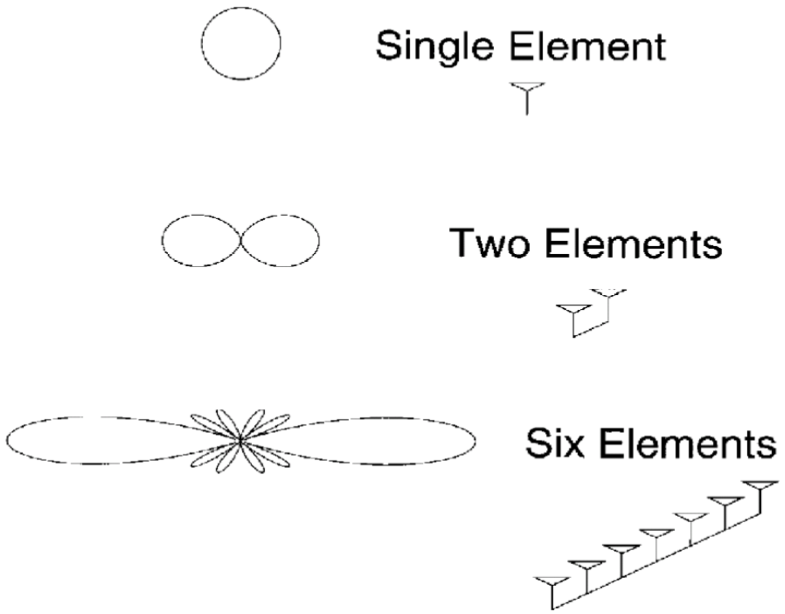
Smart Antennas ", IEEE Globecom'05

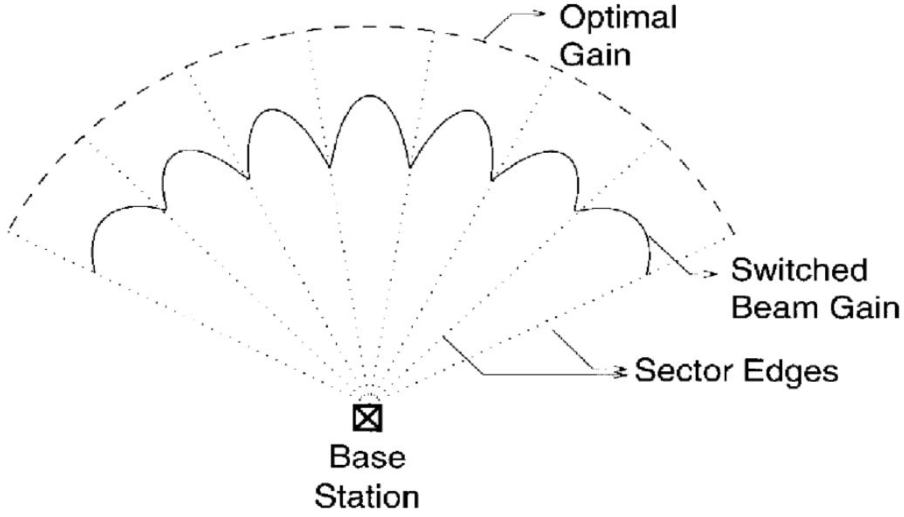
- Switched beam
  - Antenna beam patterns are predetermined by shifting every element's signal phase
- Dynamically phased array
  - Direction of arrival (DoA) algorithm is applied for signal transmission/reception and continuous tracking
- Adaptive array antenna
  - DoA for determining direction
  - Null capability
  - Radiation pattern can be adapted to receive multipath signals



Smart Antennas

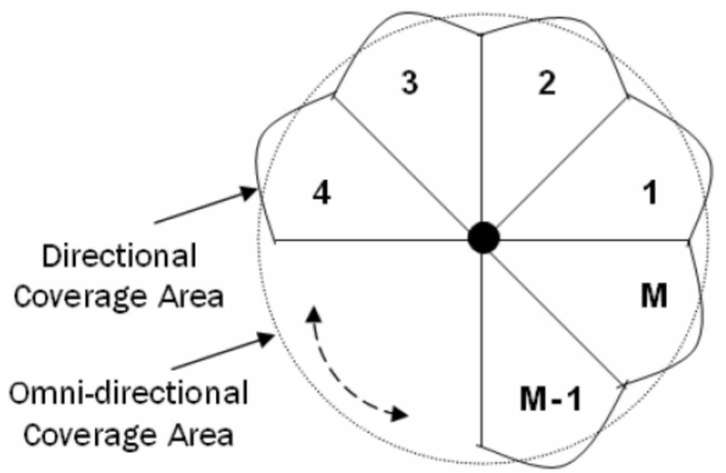
- The gain or strength of the signal at the output of the array
- There are certain directions in which the effective antenna has reduced sensitivity, or nulls

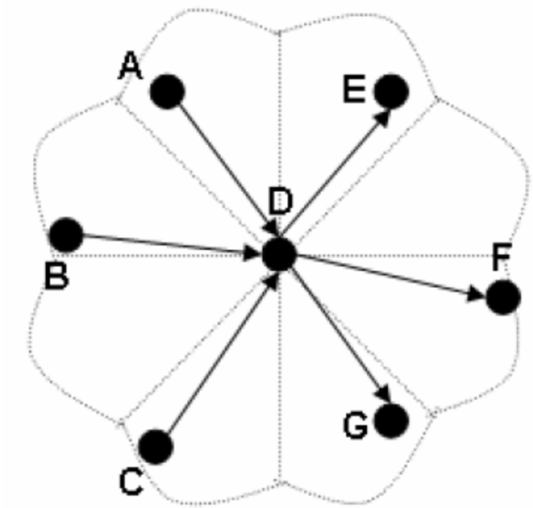




Smart Antennas

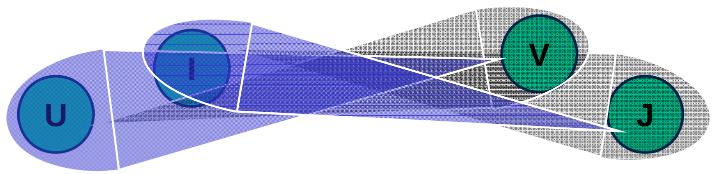
- Using complex digital signal processing techniques an antenna array can support *either* multiple transmissions *or* multiple receptions simultaneously thereby considerably enhancing the system capacity





Smart Antennas

- Concurrent Packet Transmissions/Receptions
  - Synchronization of transmitting and receiving nodes
  - Packet receptions in different beams of the node to commence at the same time, which necessitates synchronization of transmitting nodes
  - Packet transmissions by a node in multiple beams to begin simultaneously, which requires synchronization of receiving nodes
- Hidden Terminal and Deafness
  - No information about the ongoing transmission(s) in its neighborhood
  - Transmission of control packets in all beams



ESIF protocol (Explicit Synchronization via Intelligent Feedback)

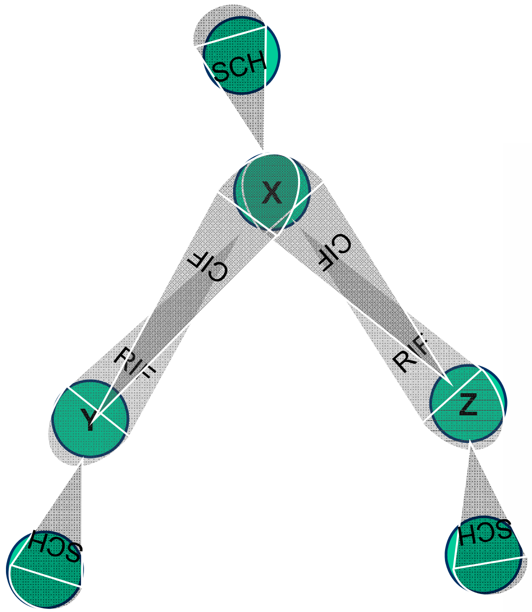
- A node ready to transmit data in multiple beams checks the expiration of *directional network allocation vector* (*DNAV*) settings, senses the channel for DIFS duration, and immediately begins data transmission in those beams concurrently

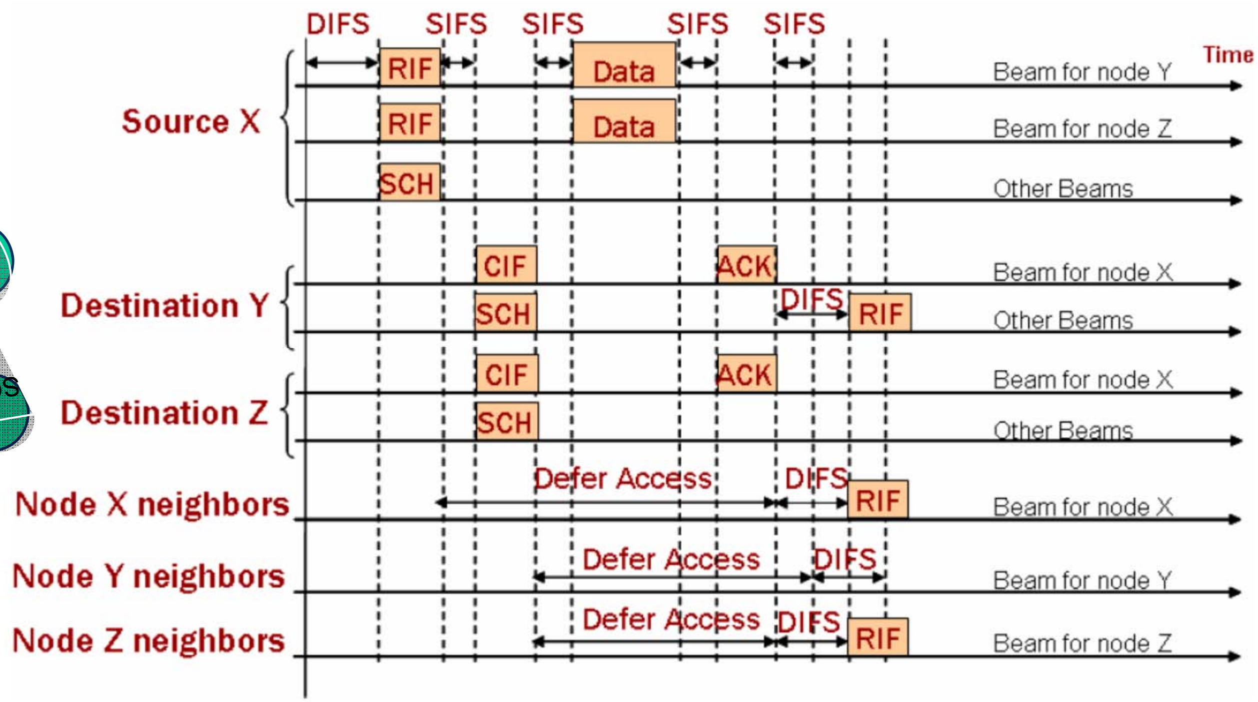
- Eradicate the random backoff period after DIFS wait
  - Transmitters are synchronized with the receivers
  - All the beams of a transmitter are synchronized

- Every node maintains the following dynamic information：
  - The beam the neighbor falls within
  - Neighbor's schedule - the duration until this neighbor is engaged in communication elsewhere
  - Whether the neighbor's schedule requires maintaining silence in the entire beam
  - Number of data packets outbound for the neighbor
  - The p-persistent probability to use when talking to this neighbor

ESIF protocol

- RIF: RTS Intelligent Feedback
- CIF: CTS Intelligent Feedback
- SCH: Schedule





Summary

- Benefits of smart antenna:
  - Better range/coverage
  - Increased capacity
  - Multipath rejection
  - Reduced costs

- The performance improvement when using directional antennas
  - End-to-end delay
  - Throughput

Homework #4:

1. What is the directional antennas ?
2. What is the deafness problem in wireless network using directional antennas ?
3. What is the differences of switched beam, dynamically phased array, and adaptive array antenna in smart antennas ?
4. What is the detailed operations of ESIF protocol ?