Chapter 7: 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 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 G^d **(G^d > G^o)**
 - Transmit and receive gains (G_T and G_R) are related to the transmit and receive powers (P_T and P_R)
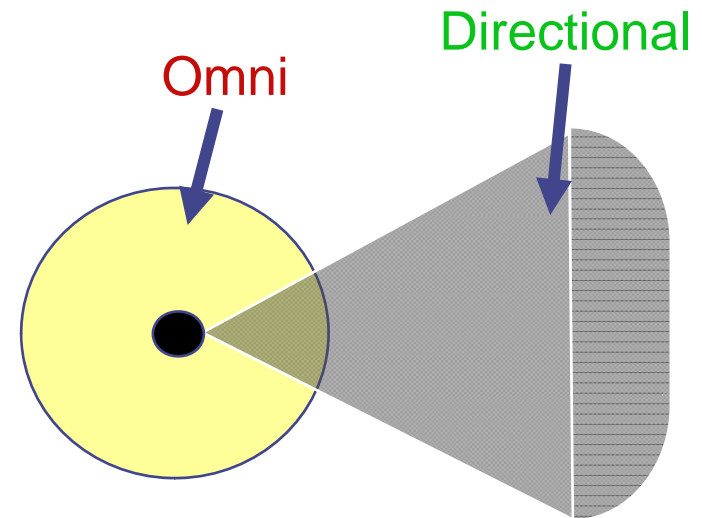
$$P_R = \frac{P_T G_T G_R}{Kr^\alpha}$$

(K is a constant that accounts for atmospheric absorption)

Omni

Directional

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
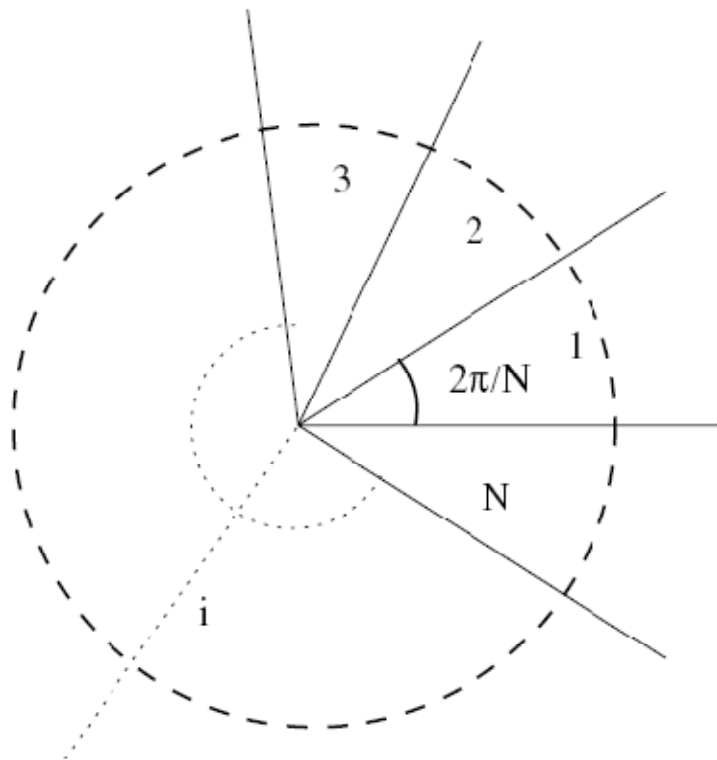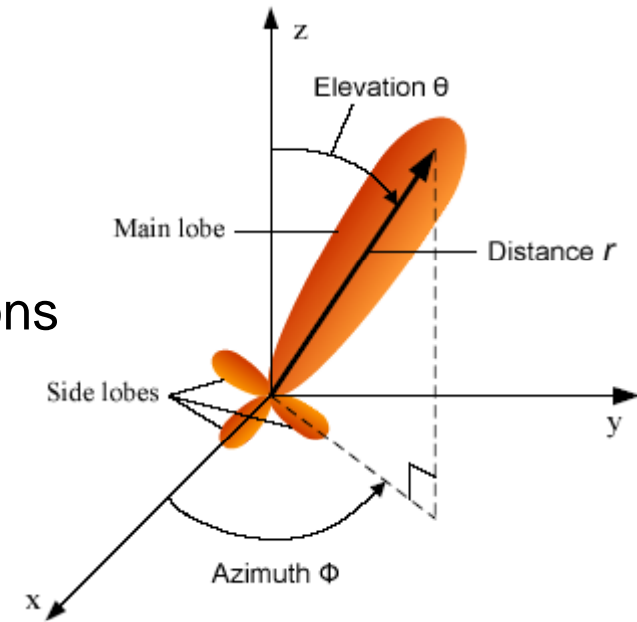
Directional Antennas

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

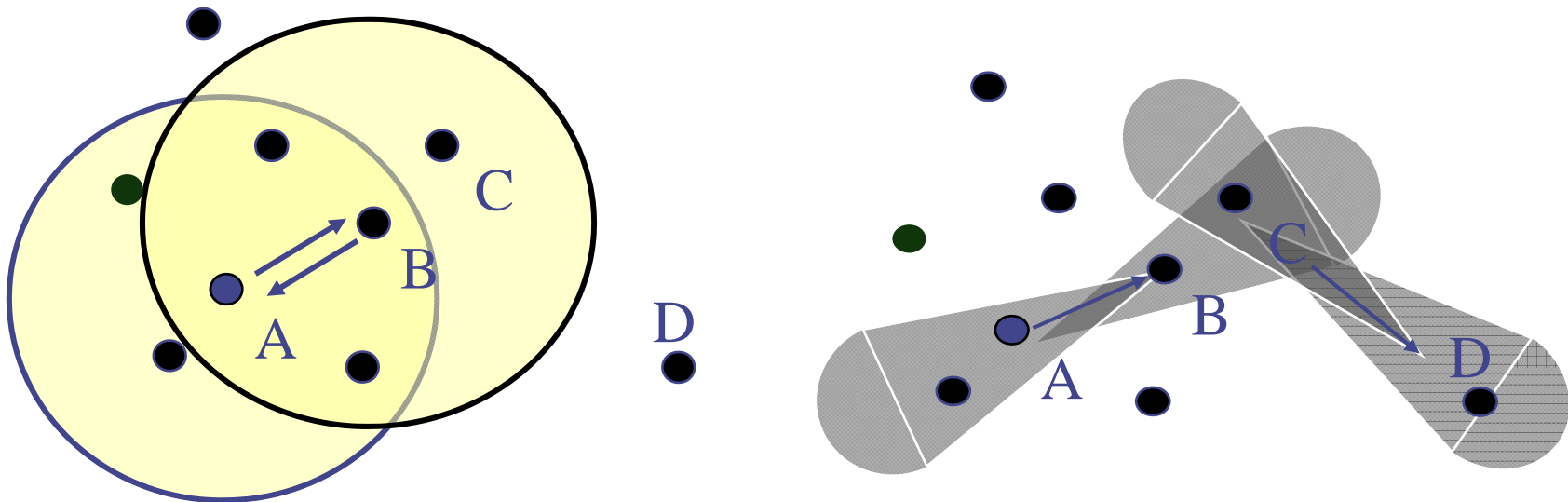η : the efficiency of the antenna

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
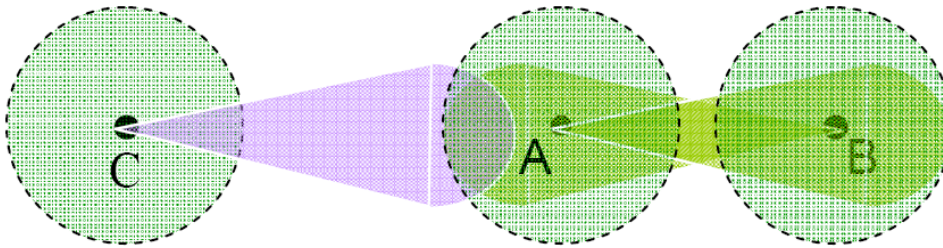
Due to **asymmetry** in gain

deafness problem
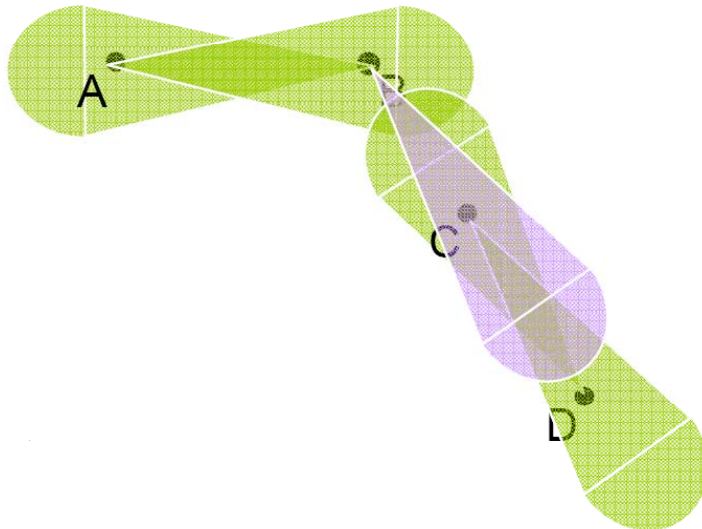
- Unfairness
- Channel waste
- Packet drop - reroute

Due to unheard RTS/CTS

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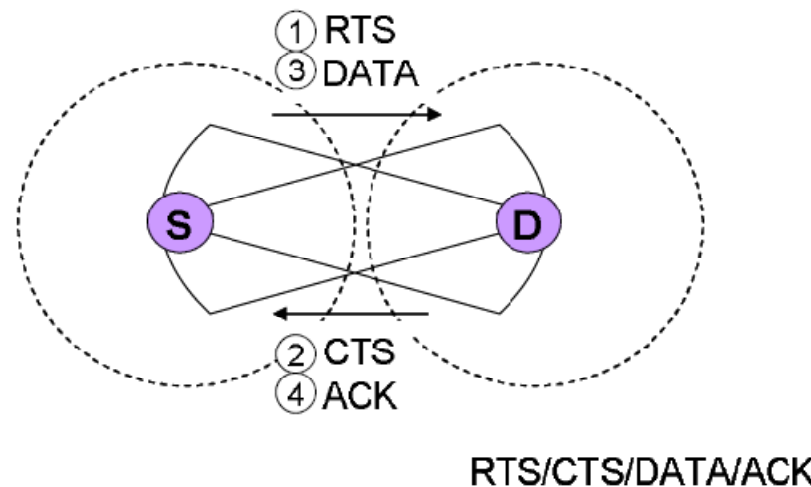
MMAC（Multi-Hop RTS MAC Protocol）, ACM Mobicom'02

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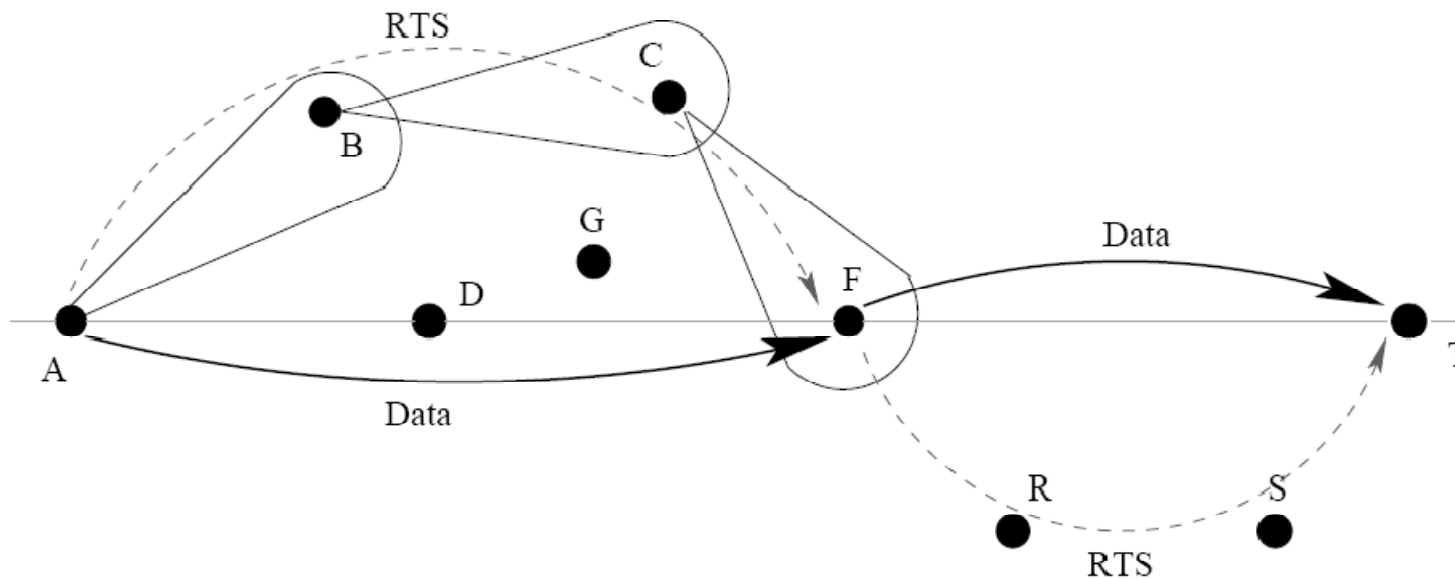
SWAMP (Smart Antennas based Wider-range Access MAC Protocol), IEEE ICC'04

- 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
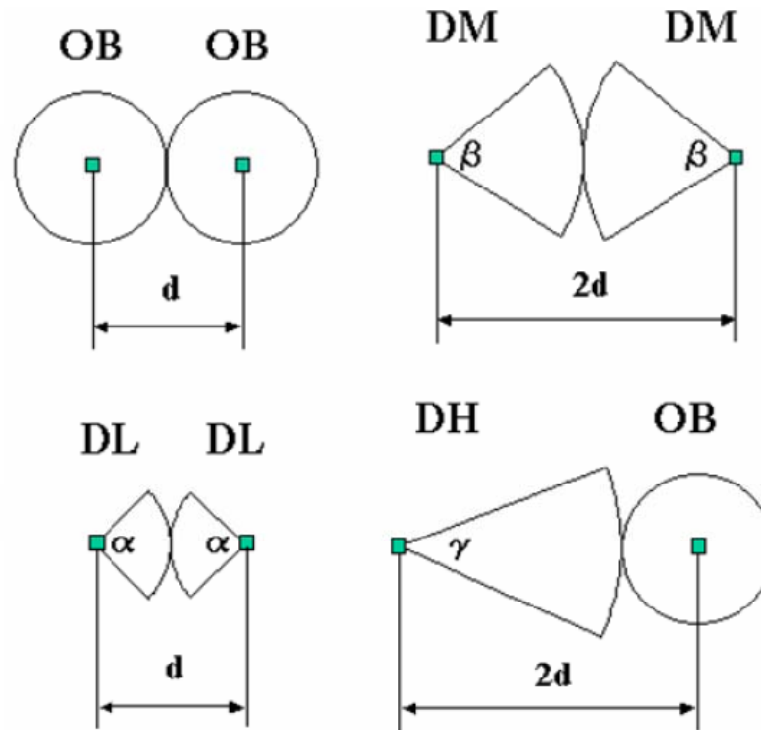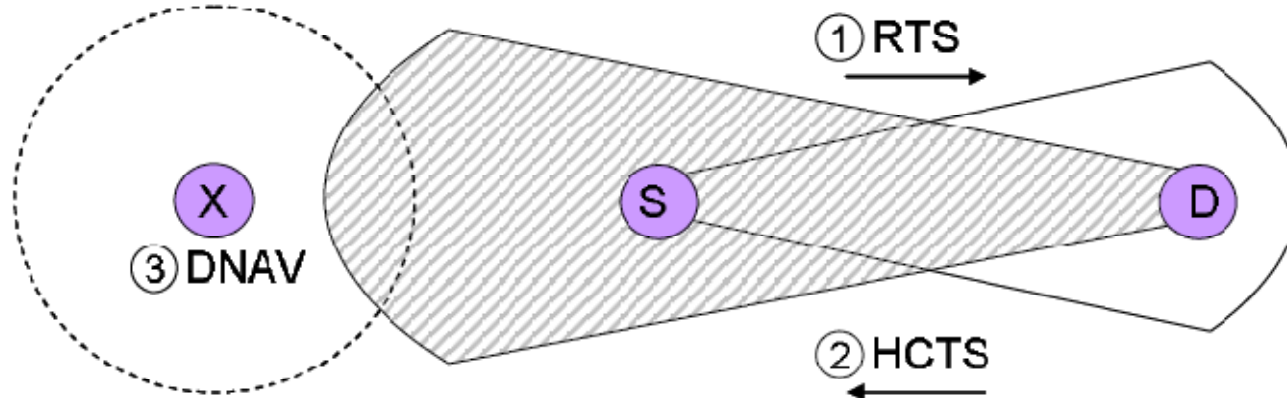
SWAMP
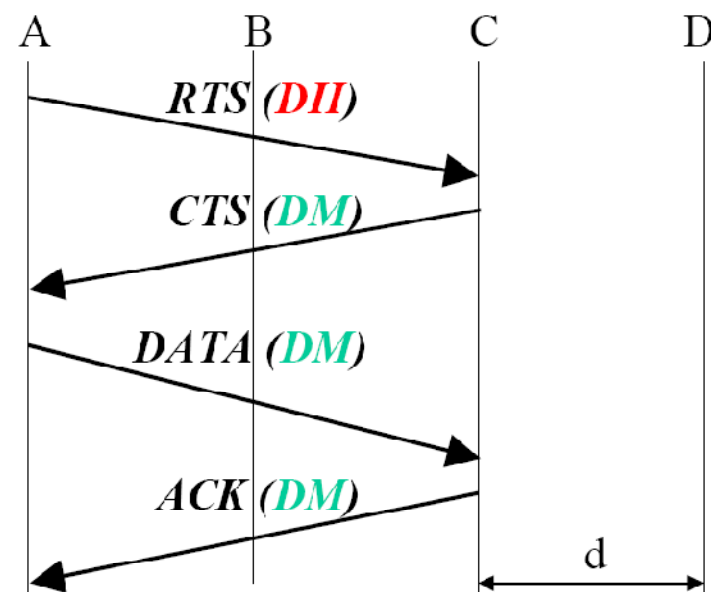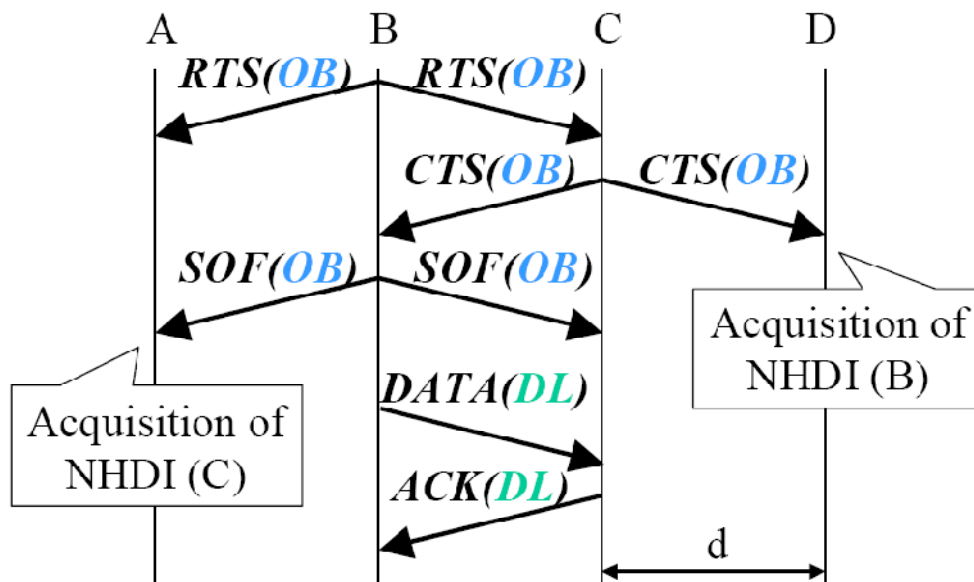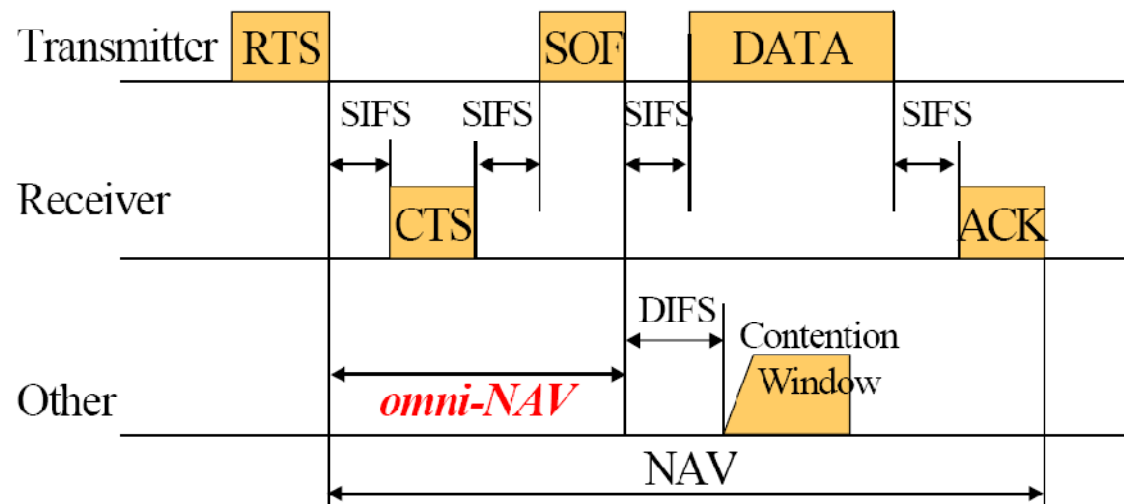
HCTS (HIGH GAIN CTS), IEEE ICDCSW'05

- 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
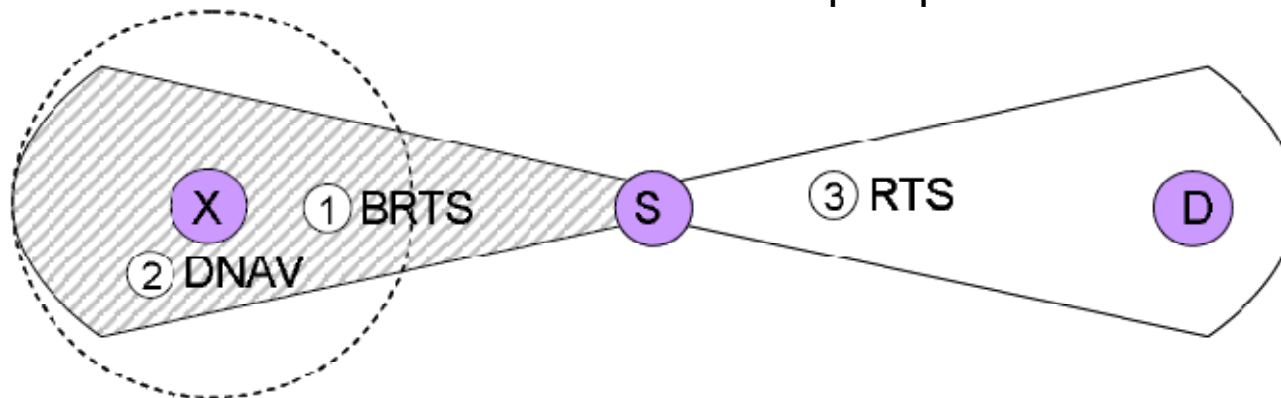
RCTS（Relayed CTS）

- 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
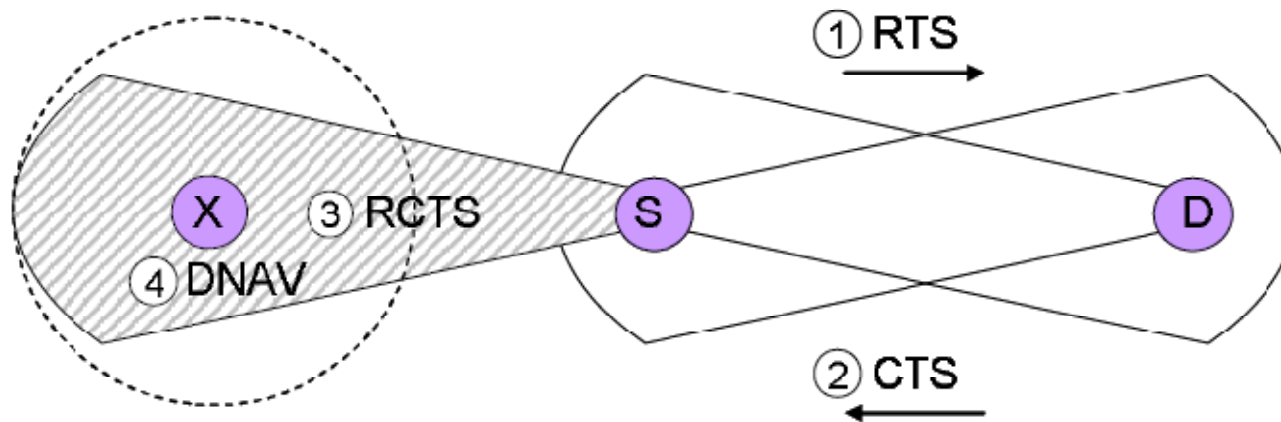
Smart Antennas ", IEEE Globecom'05

- ● **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

Signal
Interference

Switched beam

Dynamically phased array

Adaptive array
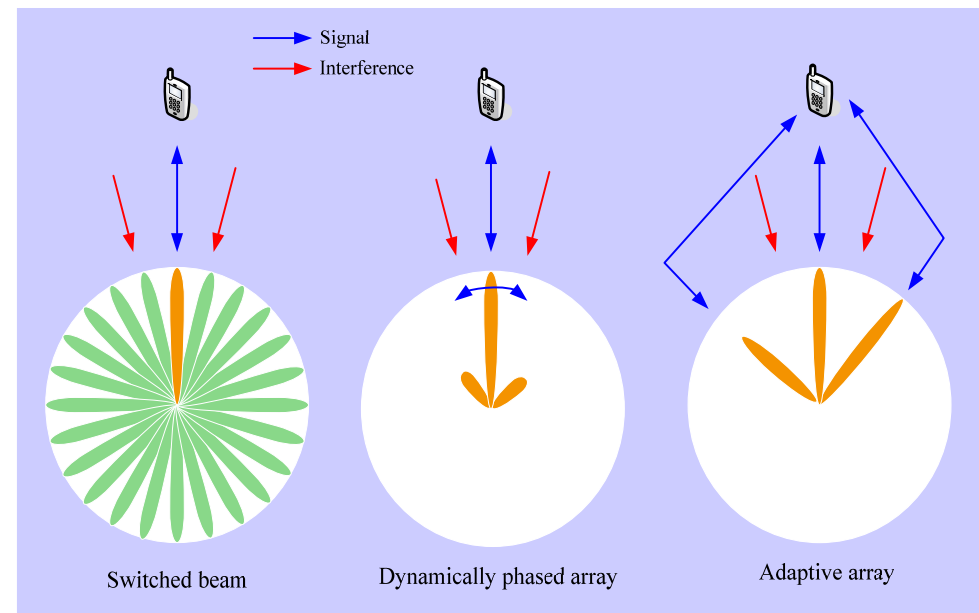
Smart Antennas

- 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
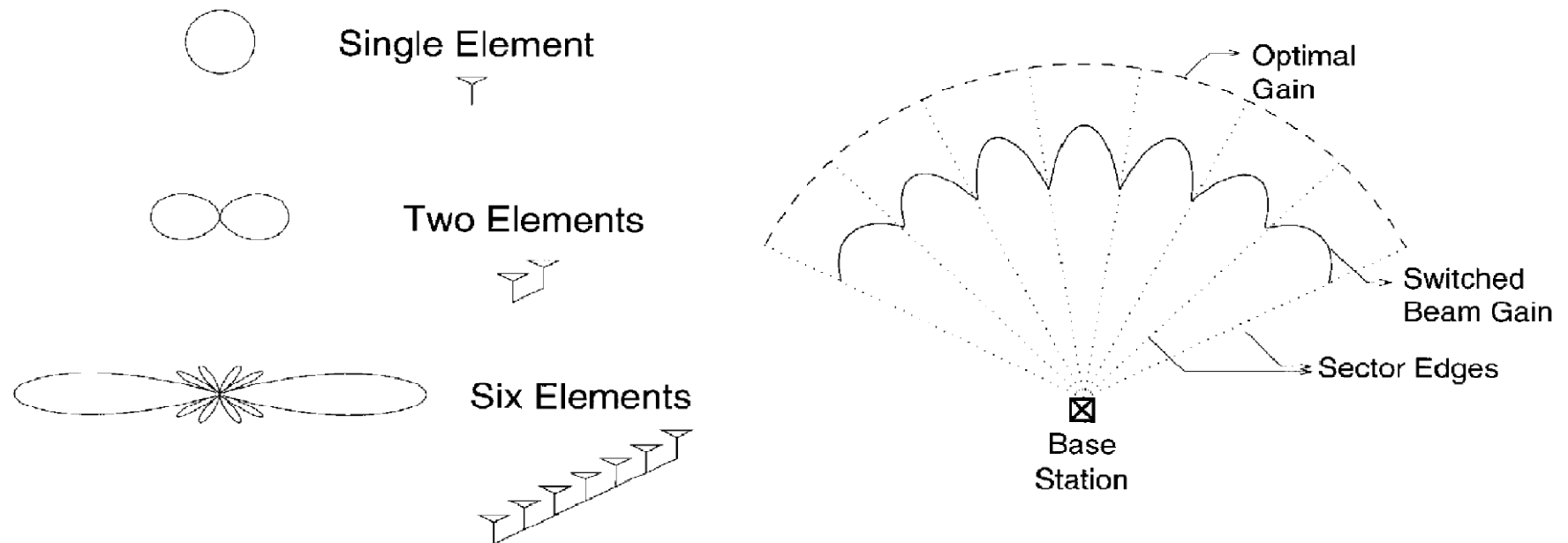
Smart Antennas

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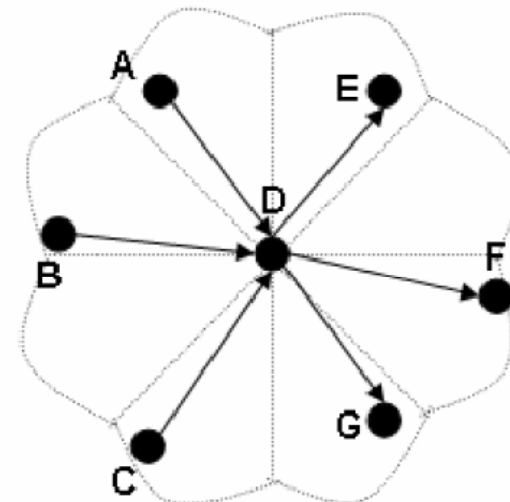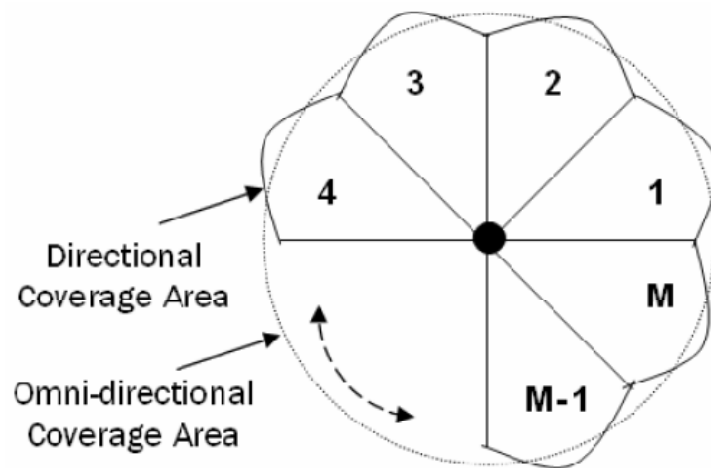
Smart Antennas

- ## 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
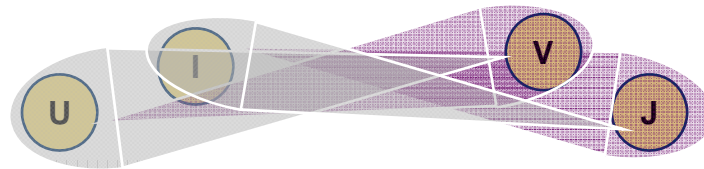
ESIF protocol（Explicit Synchronization via Intelligent Feedback）

- 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
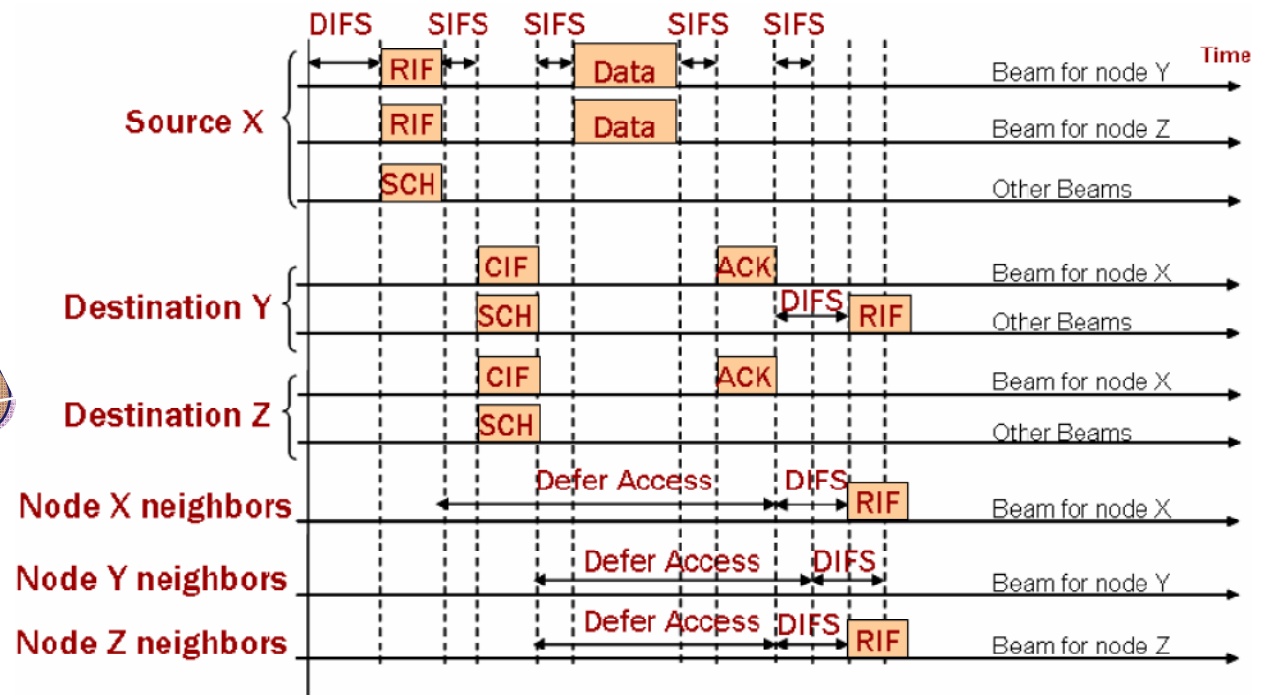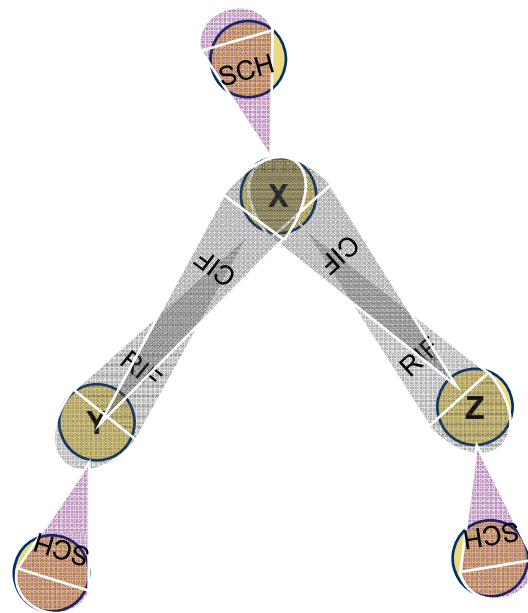
Summary

- 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