

Chapter 9: 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

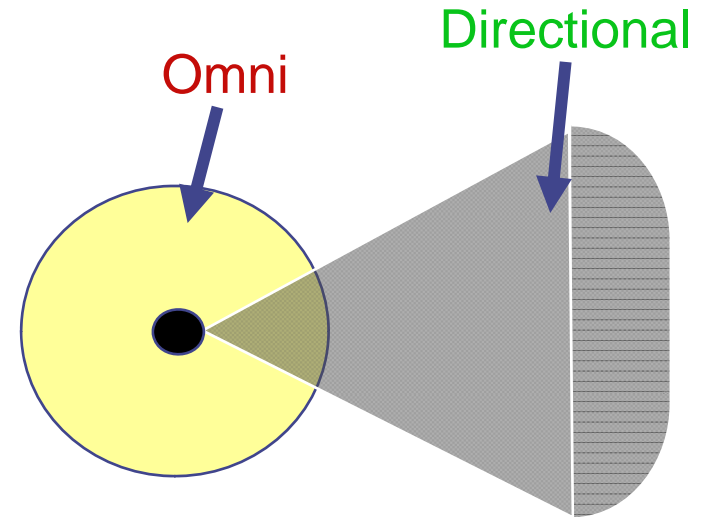
- Antennas collect radio frequency energy from space for reception purposes and distribute energy into space for transmission

- 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)



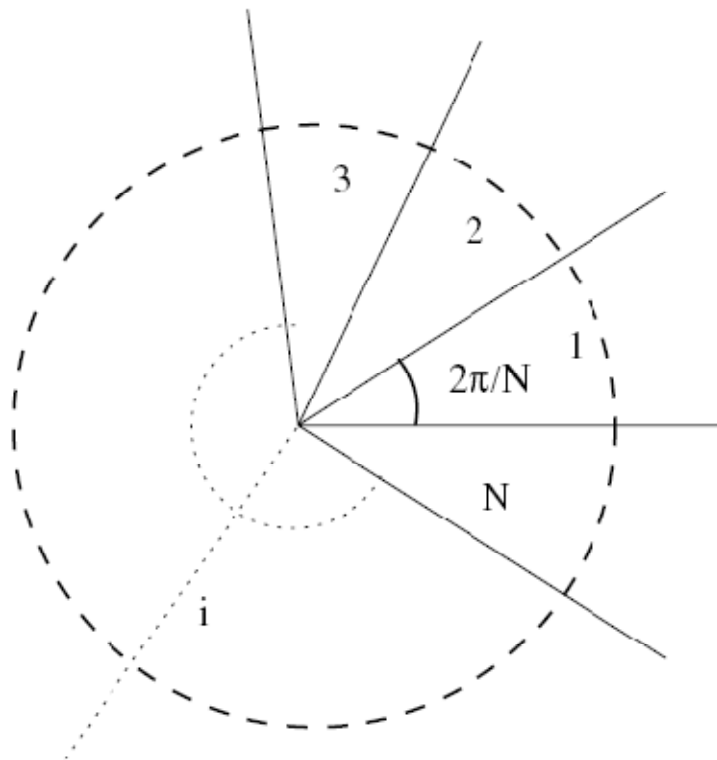
$$P_R = \frac{P_T G_T G_R}{K r^\alpha}$$

(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 :

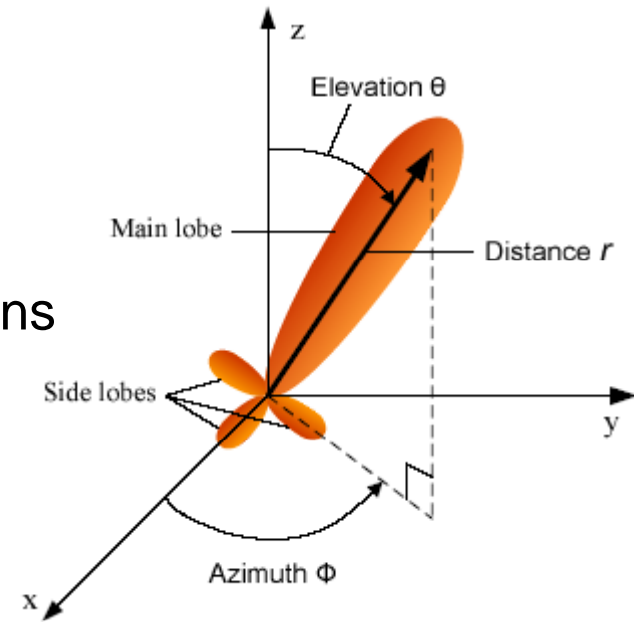
$$G(\theta, \phi) = \eta \frac{U(\theta, \phi)}{U_{ave}}$$

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

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

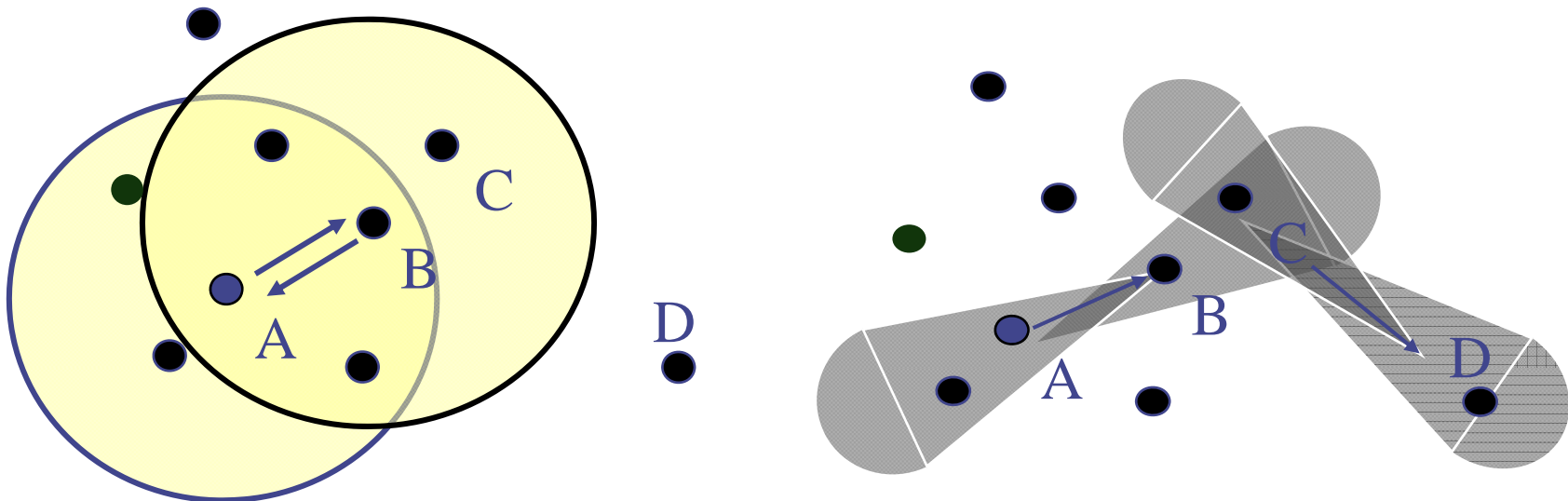
η : the efficiency of the antenna

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



Directional Antennas

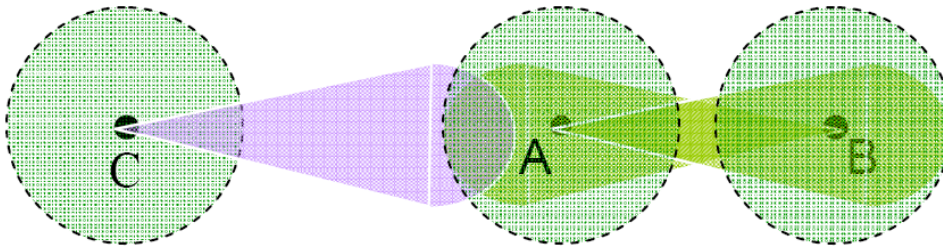
- MAC layer performance shown to be improved
 - Spatial **reuse** increases
 - Wireless **interference** reduces
 - **Range** extension possible
 - Saving **power**



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

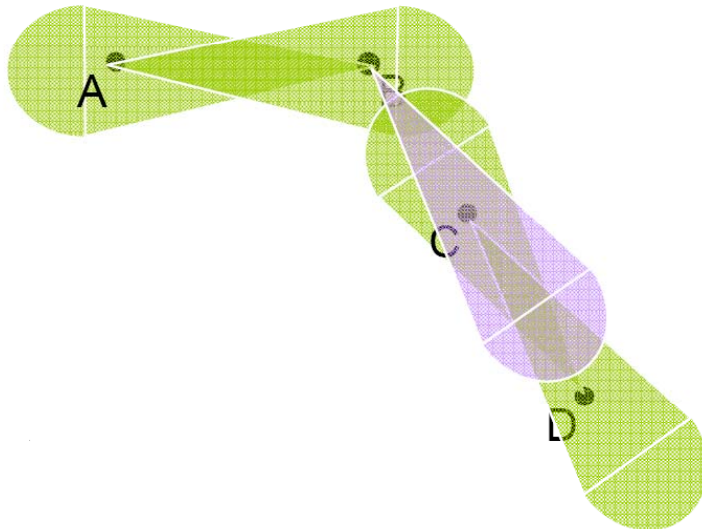
Communication problems



Due to **asymmetry** in gain



deafness problem



Due to unheard RTS/CTS

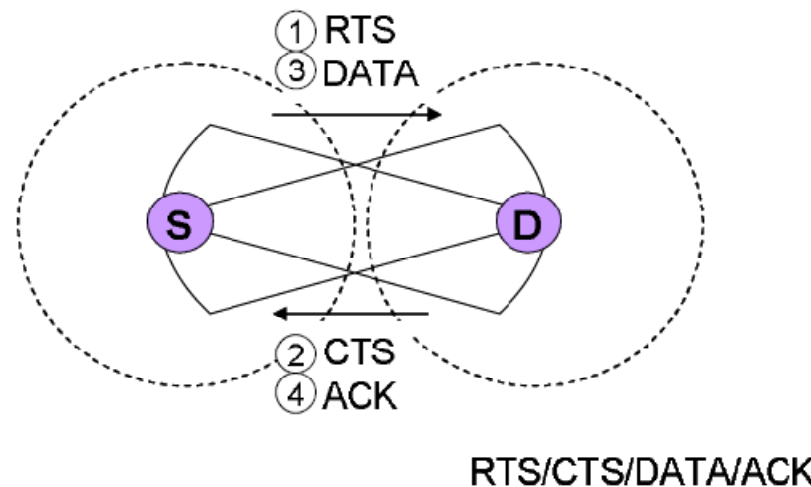
- Unfairness
- Channel waste
- Packet drop - reroute

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

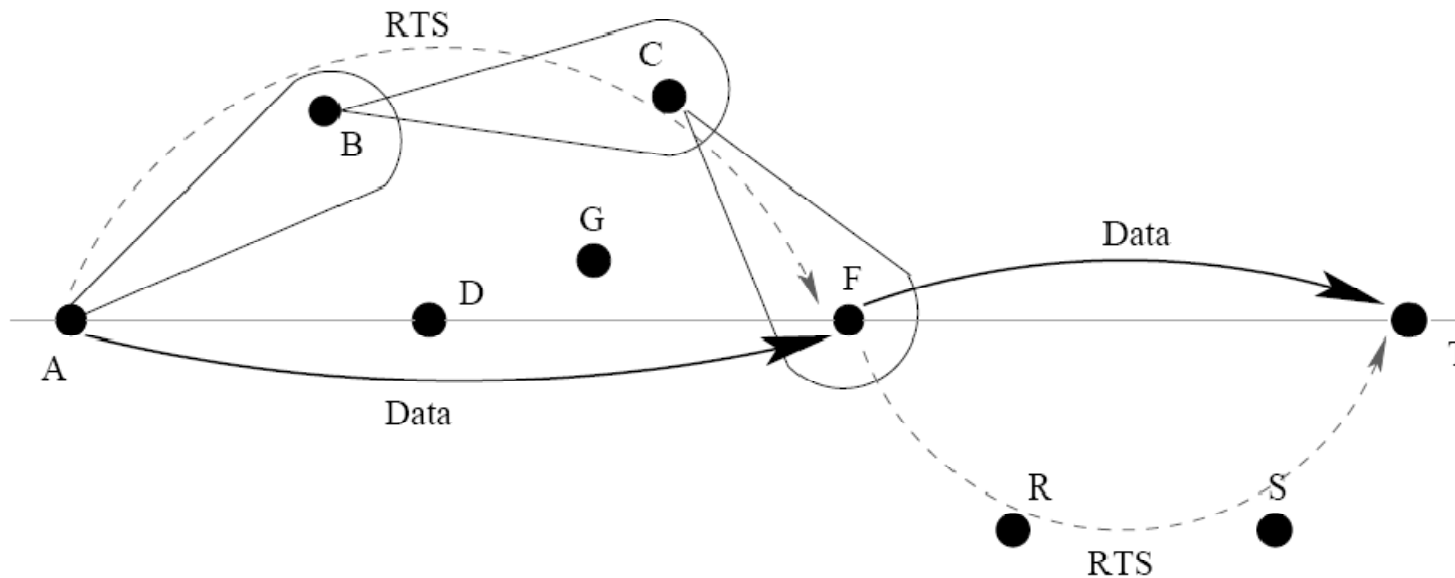


MMAC (Multi-Hop RTS MAC Protocol), ACM Mobicom'02

- 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 DNAV's 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

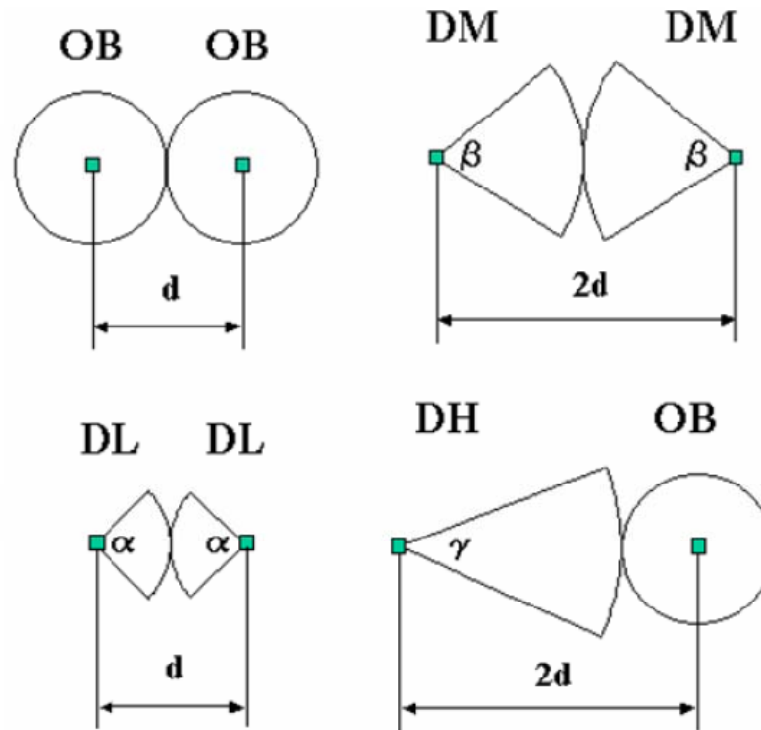


SWAMP (Smart Antennas based Wider-range Access MAC Protocol), IEEE ICC'04

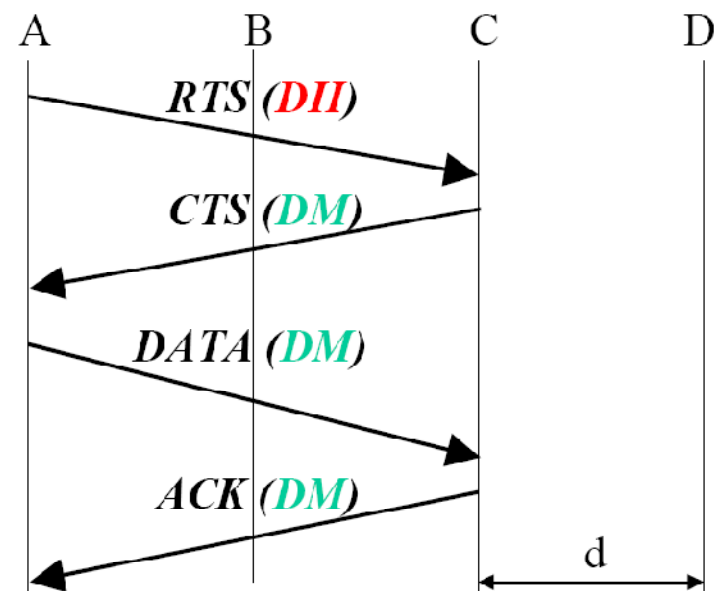
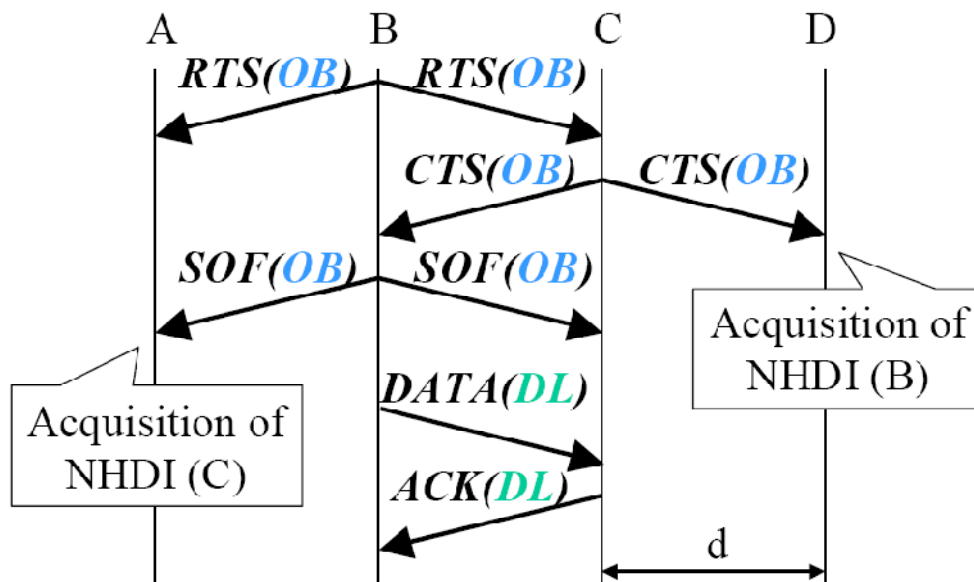
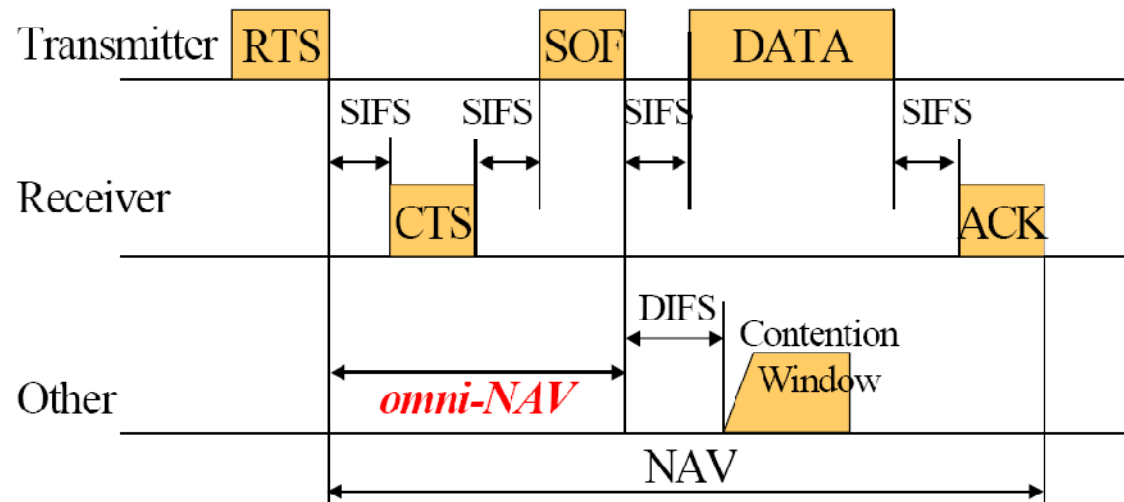
- Two access modes and uses four beamform patterns effectively
 - spatial reuse of the wireless channel
 - extension of the communication area
- **OC**-mode (Omni-directional area Communication access mode)
 - exchanges RTS/CTS/SOF (Start of Frame)
- **EC**-mode (Extend area Communication access mode)
 - 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

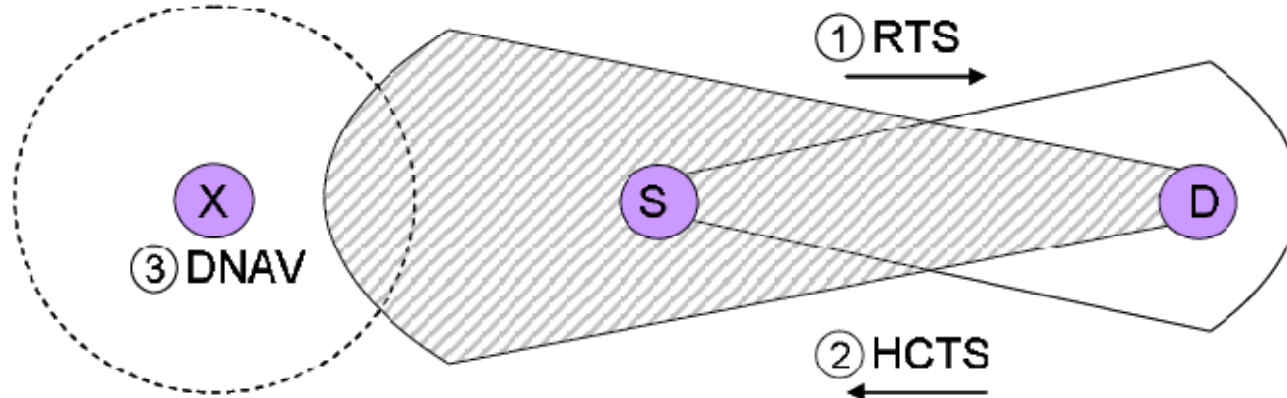


SWAMP



HCTS (HIGH GAIN CTS), IEEE ICDCSW'05

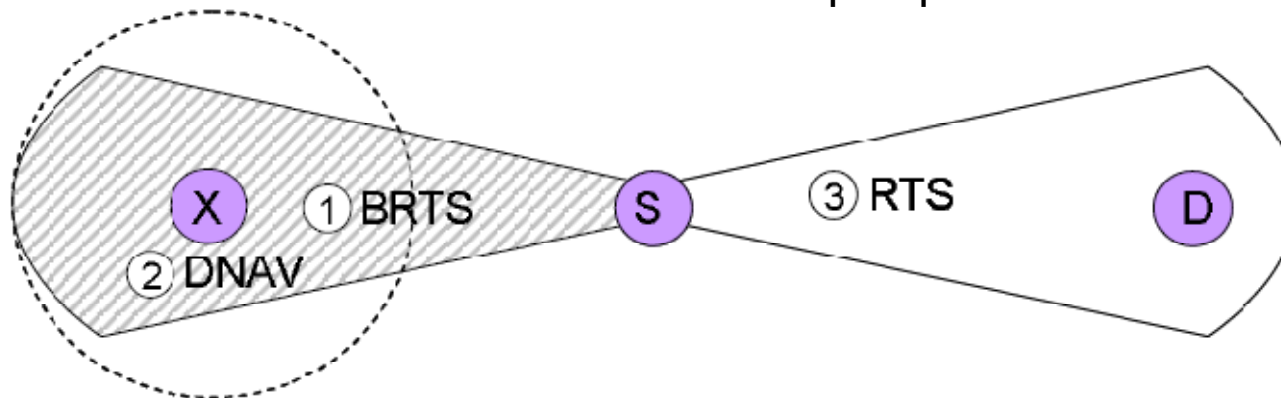
- CTS needs to cover all the area in which a directional hidden terminal may exist
- Antenna gain must be enlarged. However, HCTS does not need to introduce a new frame



BRTS (Backward RTS)

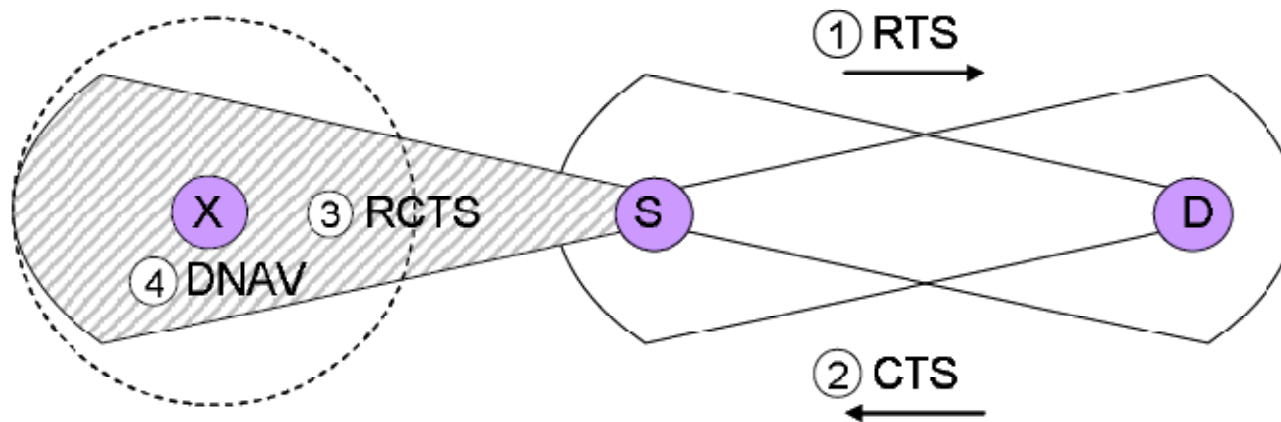
- Before terminal S transmits RTS to destination, it turns the direction of a transmitting antenna to 180-degree back toward destination, and transmits RTS
- Hidden terminal X sets DNAV by BRTS
- However, in order to transmit RTS repeatedly, changing the direction of an antenna, an overhead arises :

When a sender did not receive CTS from a destination terminal, terminal which received the BRTS sets DNAV and postpones own communication



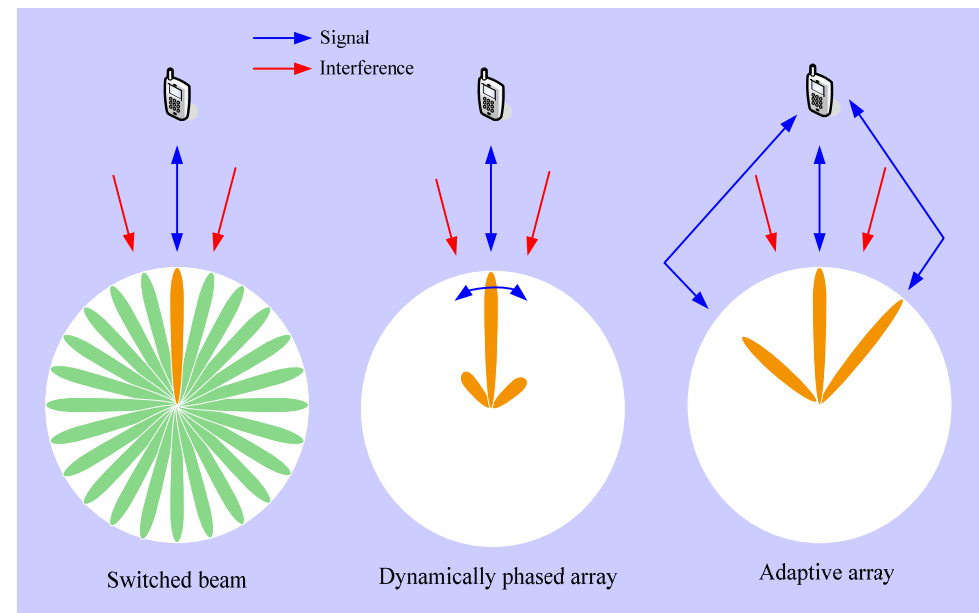
RCTS (Relayed CTS)

- 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



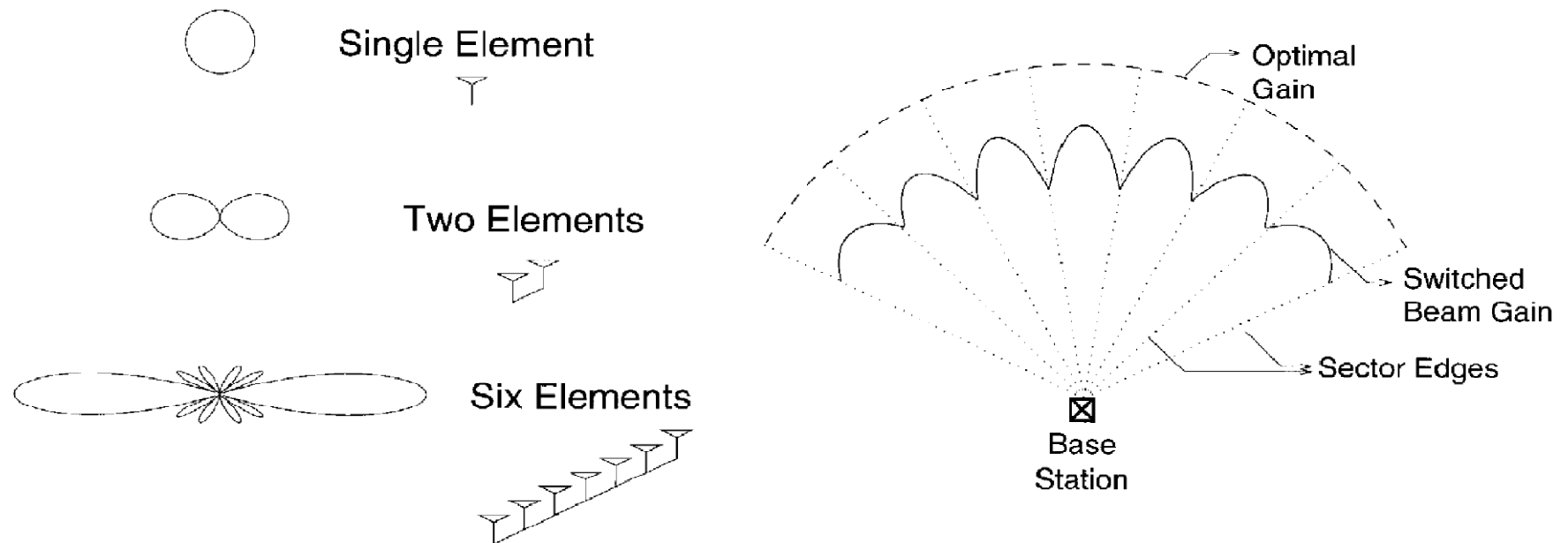
Smart Antennas ", IEEE Globecom'05

- 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



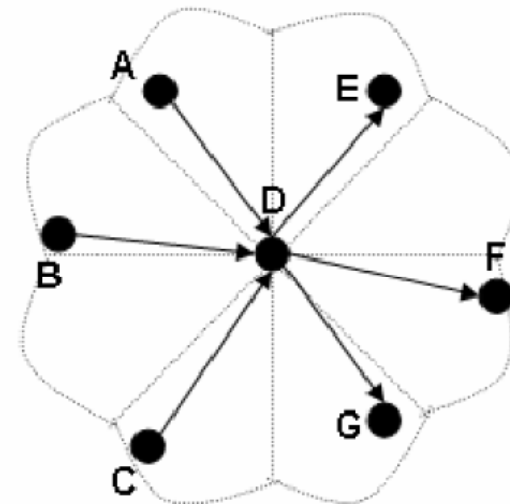
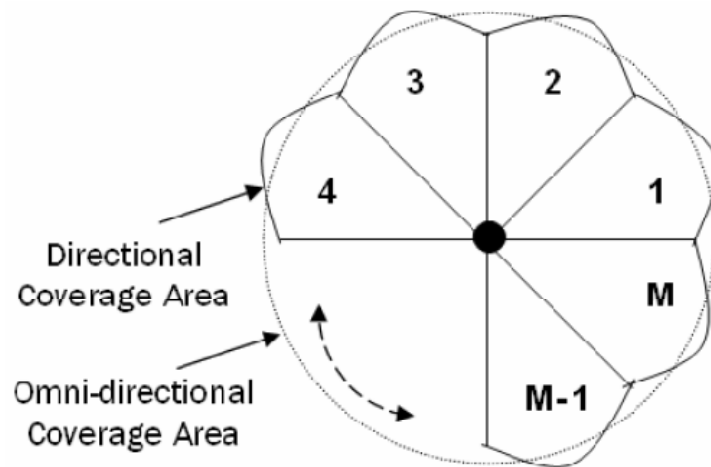
Smart Antennas

- 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



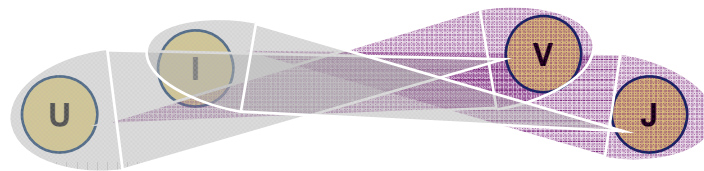
Smart Antennas

- 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

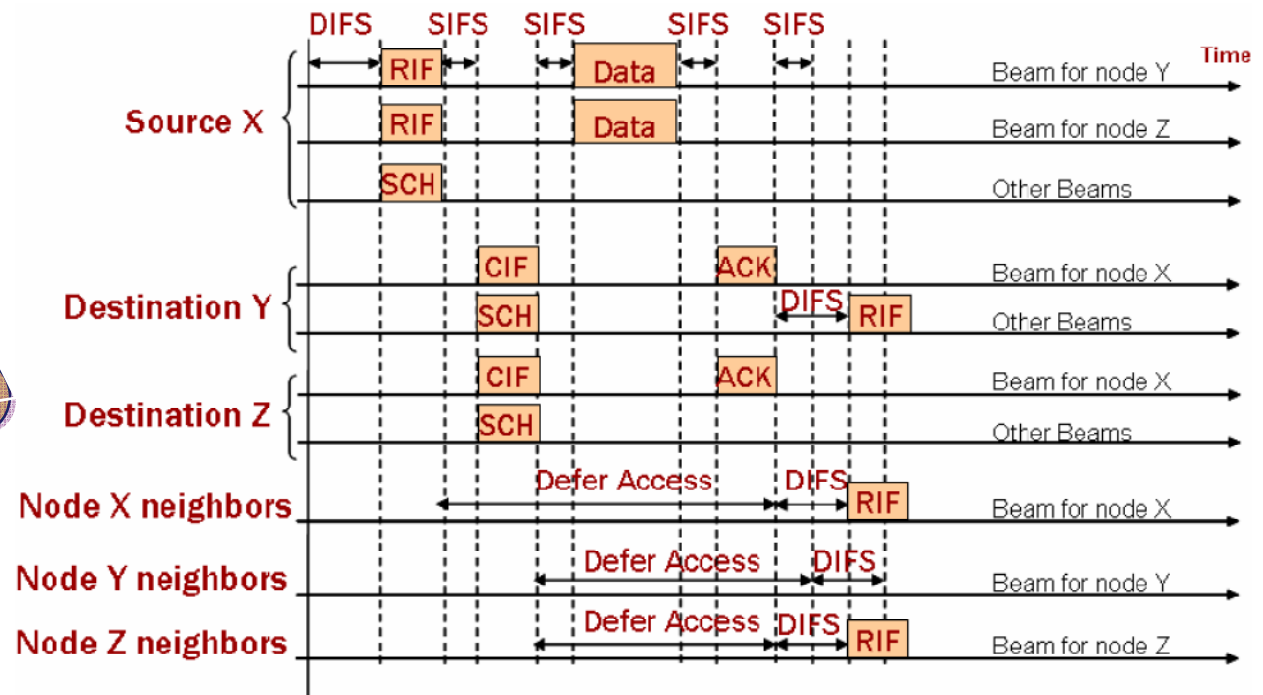
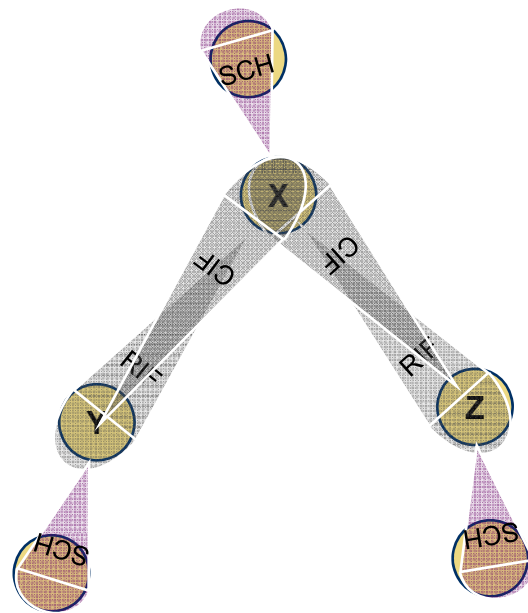


ESIF protocol (Explicit Synchronization via Intelligent Feedback)

- 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 #9:

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 ?