



# Chapter 7 Directional and Smart Antennas



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# Outline

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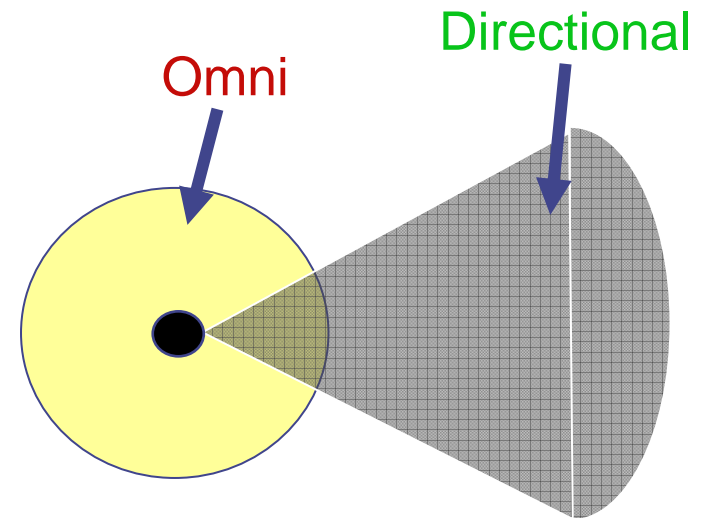


- Antennas background
- Directional antennas MAC and communication problems
- "Using Directional Antennas for Medium Access Control in Ad Hoc Networks", ACM MOBICOM'02
- "A Dual Access Mode MAC Protocol for Ad Hoc Networks Using Smart Antennas", IEEE ICC'04
- "Directional NAV Indicators and Orthogonal 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  $P_R$ )



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

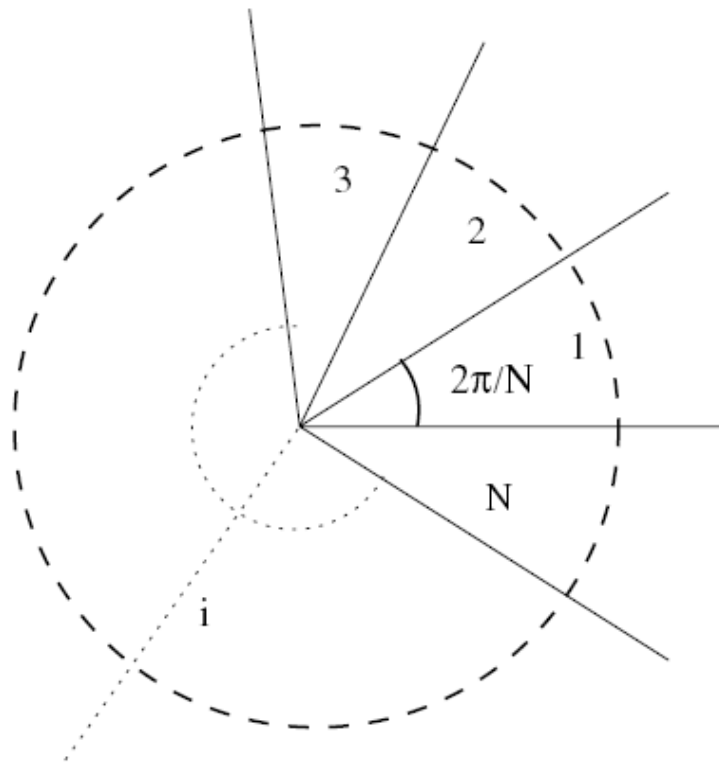
( $K$  is a constant that accounts for atmospheric absorption)

# 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



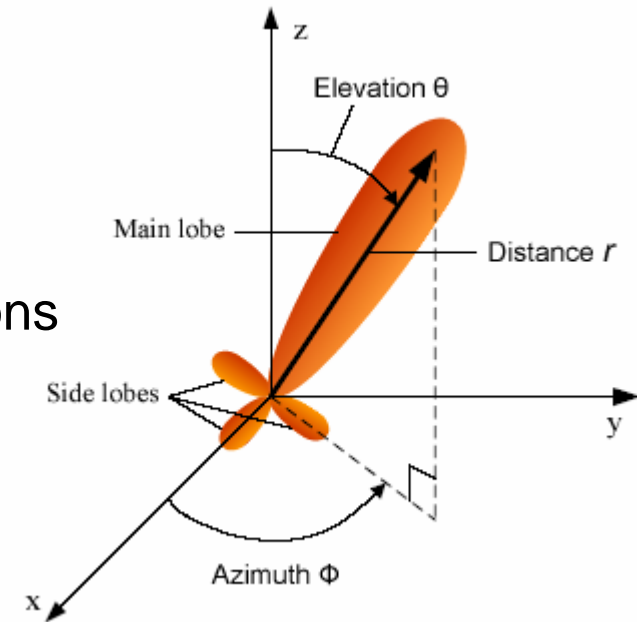
The **gain** of antennas :

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

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

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

$\eta$  : the efficiency of the antenna

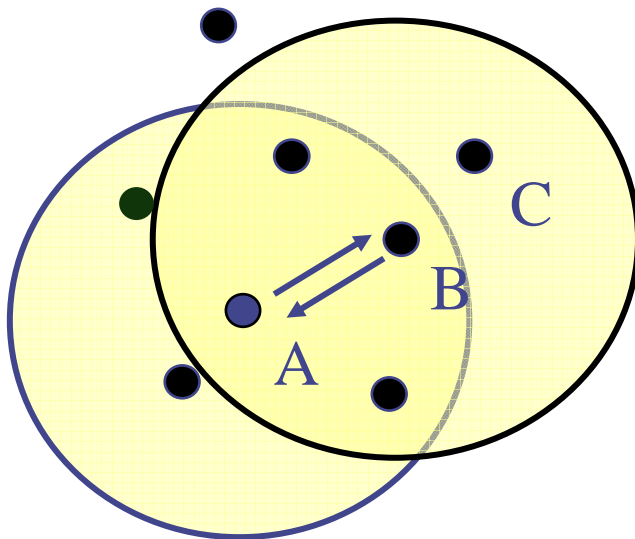


When  $U(\theta, \phi) = U_{ave}$  the antenna is called **isotropic**.

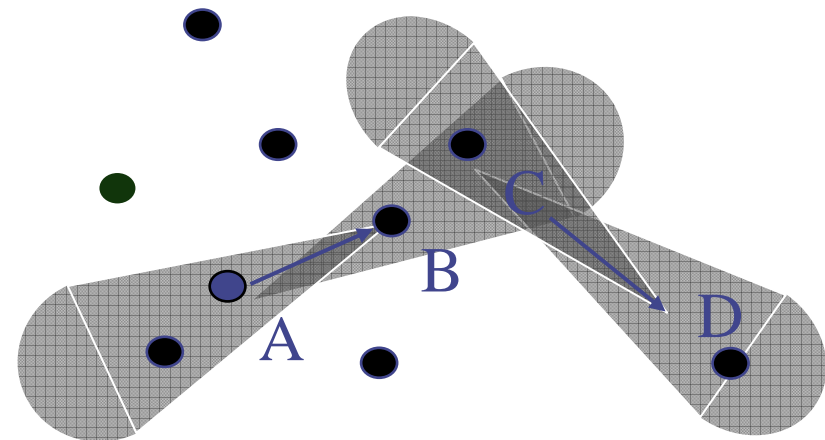
# Directional Antennas



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



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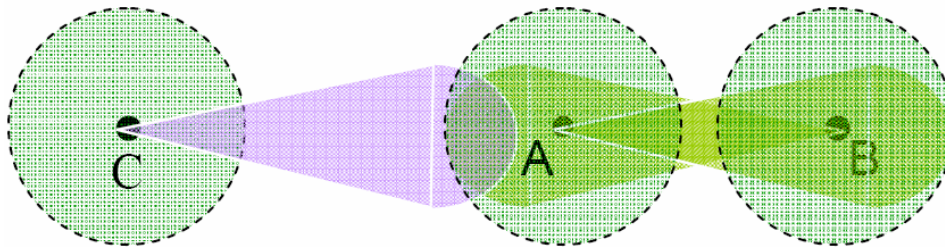


# Directional Antennas

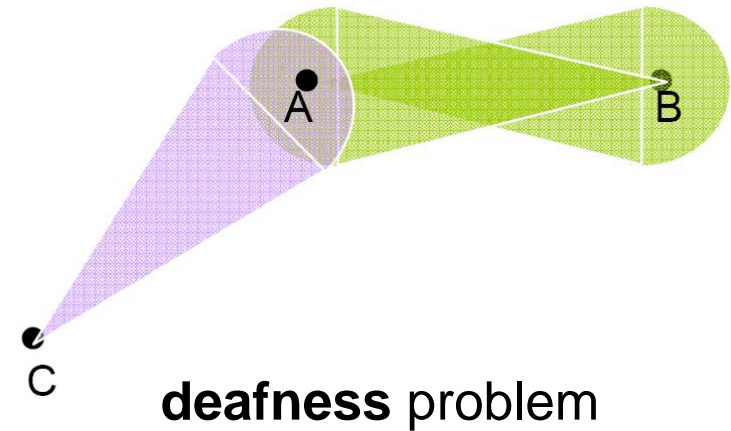


- Directional antennas increase the possibility of replacing many small hop communication links with one long, single hop link
- Directional antennas enable the receiver node to avoid interference that comes from unwanted directions, thereby increasing the *signal to interference and noise ratio* (**SINR**) to provide higher-gain transmission

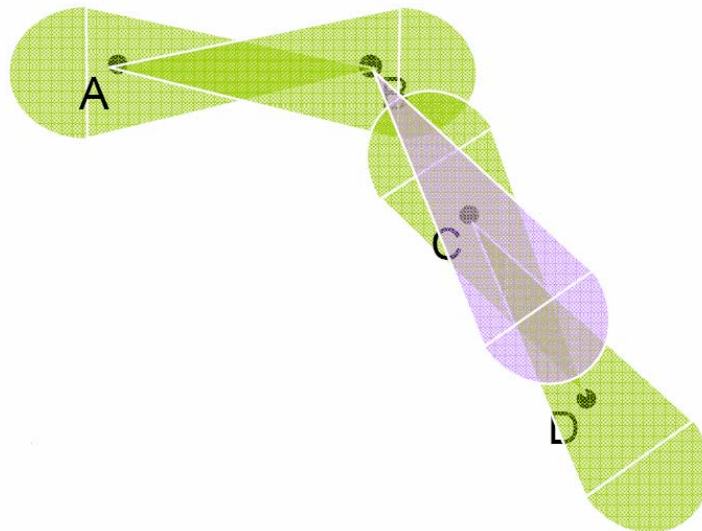
# Communication problems



Due to **asymmetry** in gain



**deafness** problem



Due to unheard RTS/CTS

- Unfairness
- Channel waste
- Packet drop - reroute

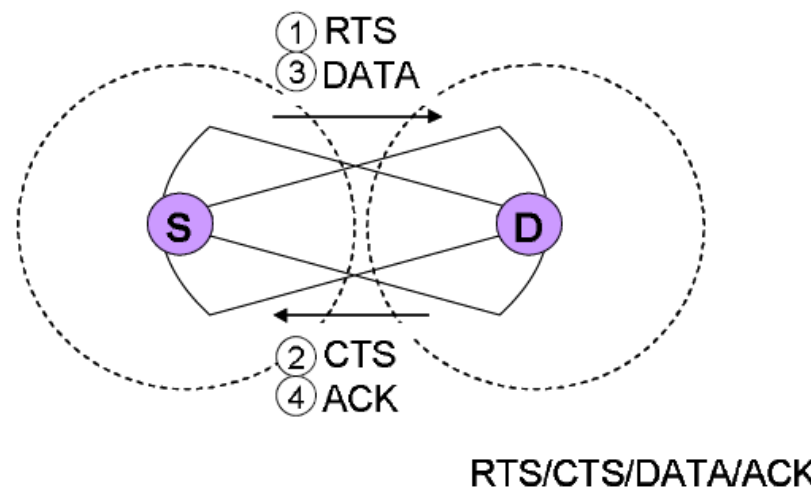


- This can increase spatial reuse of the wireless channel
- The higher gain of directional antennas allows a node to communicate with other nodes located far away, implying that messages could be delivered to the destination in fewer hops

# 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

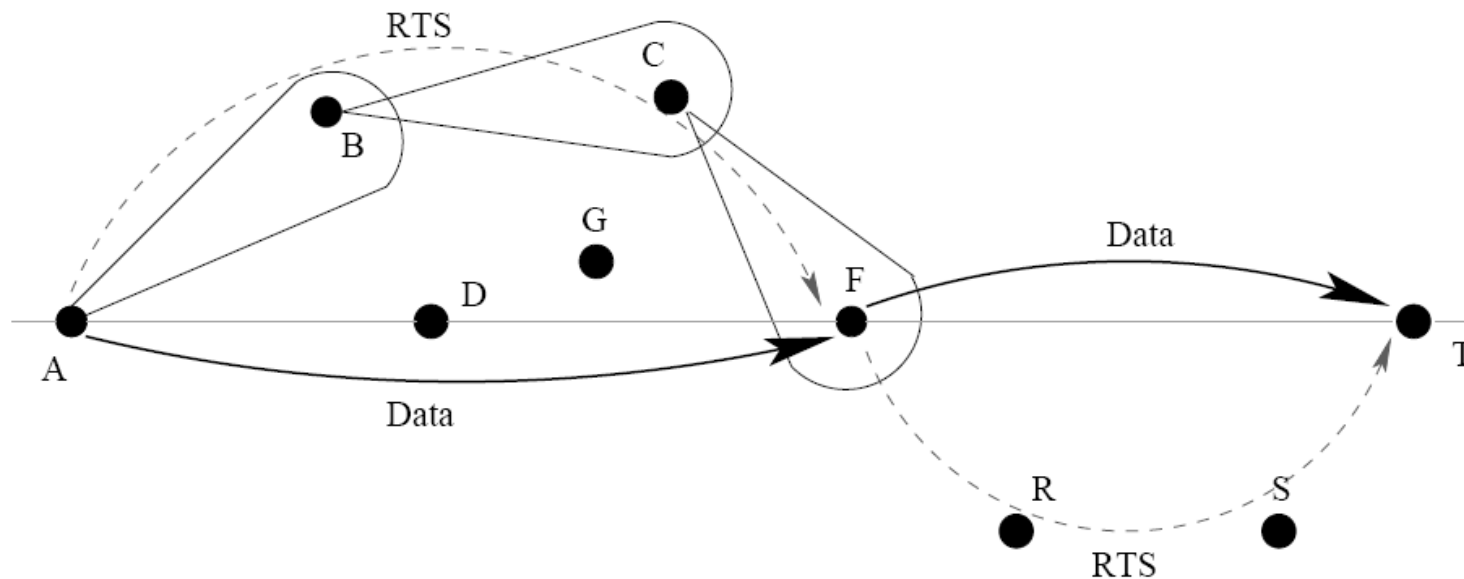
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- The MAC layer of node transceiver receives a packet containing the DO-neighbor (Directional-Omni) route to the next DD-neighbor (Directional-Directional)
- Transceiver sends a RTS to the physical layer to be transmitted using the direction of the 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



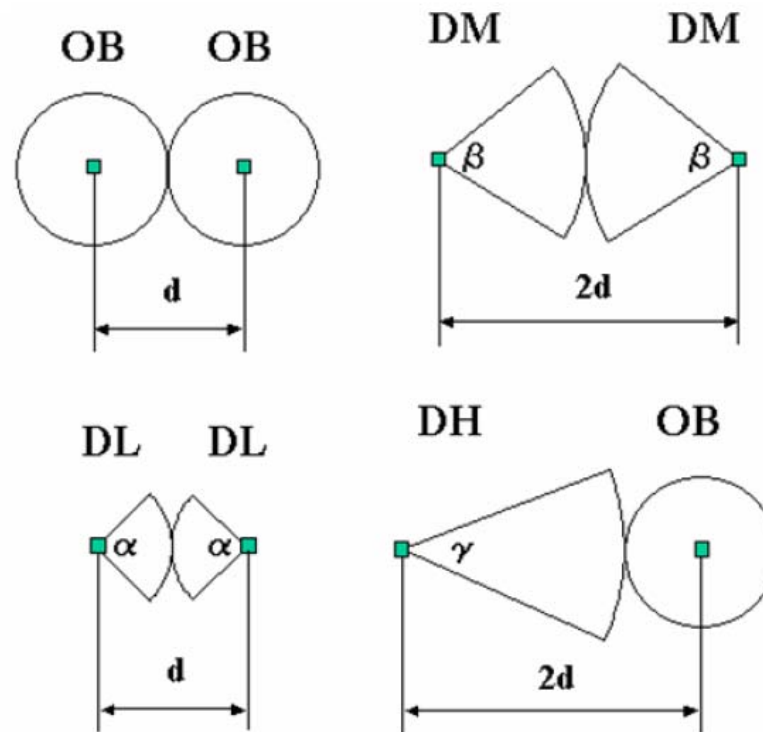


- Two access modes and uses four beamform patterns effectively
  - spatial reuse of the wireless channel
  - extension of the communication area
- **OC**-mode (Omni-directional area Communication access mode)
  - exchanges RTS/CTS/SOF (Start of Frame)
- **EC**-mode (Extend area Communication access mode)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

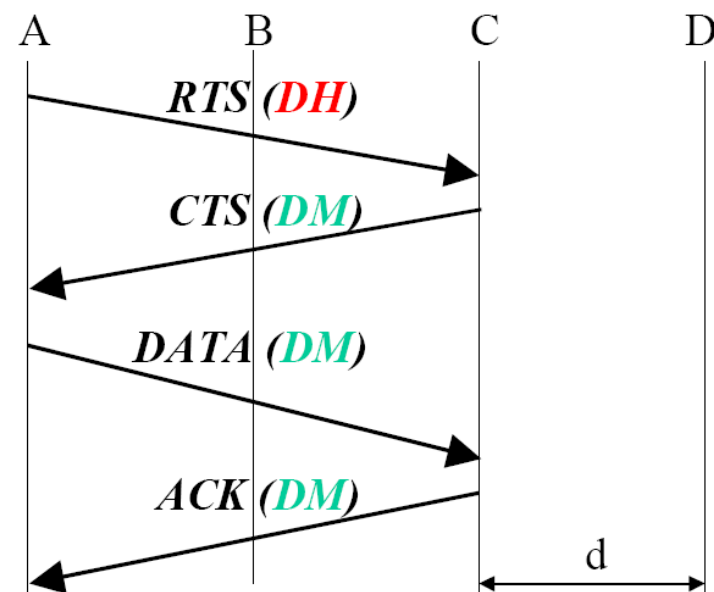
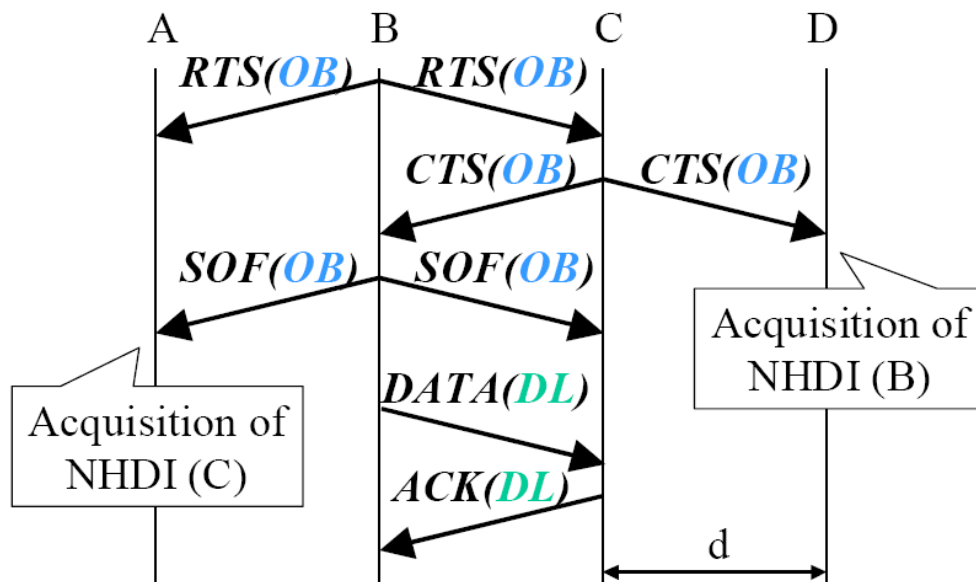
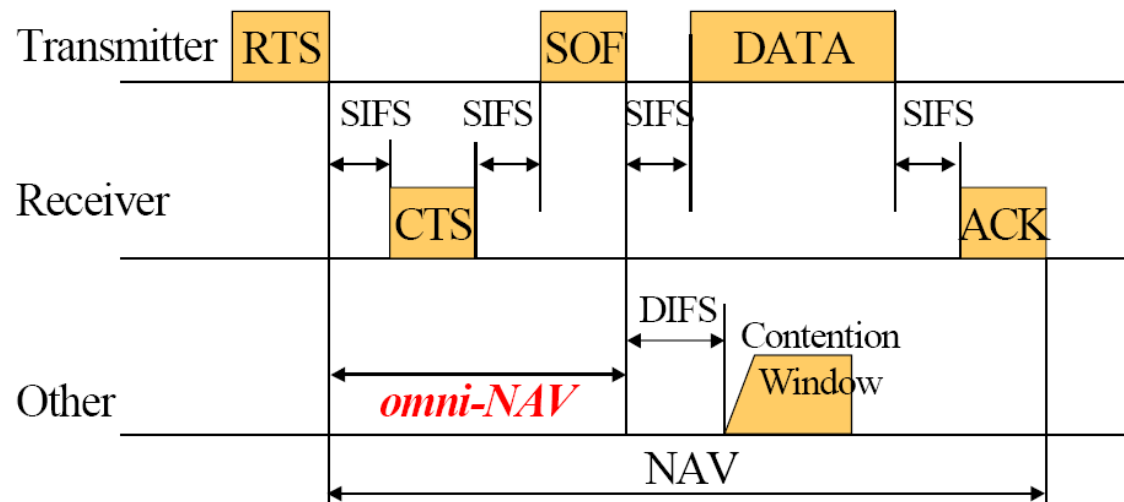
# SWAMP



- 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

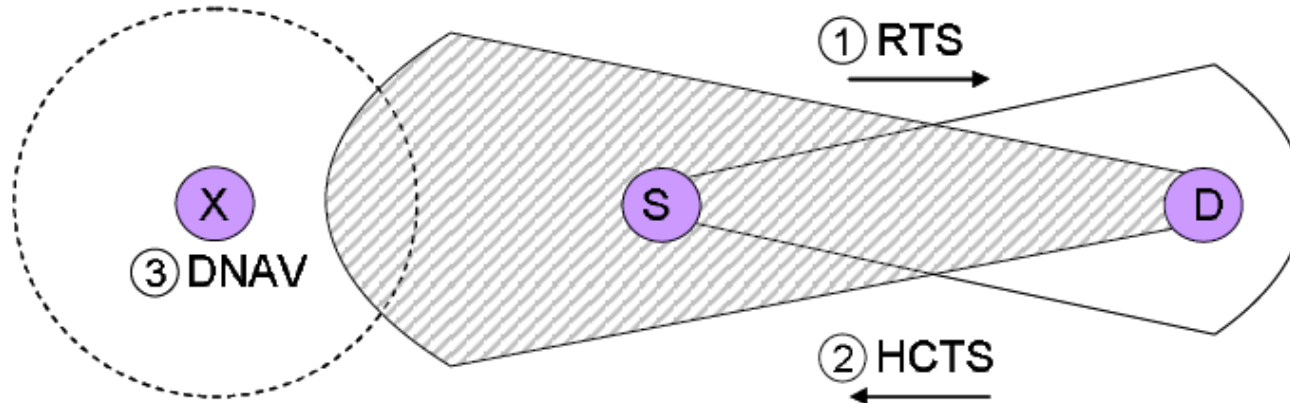


# SWAMP





- 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

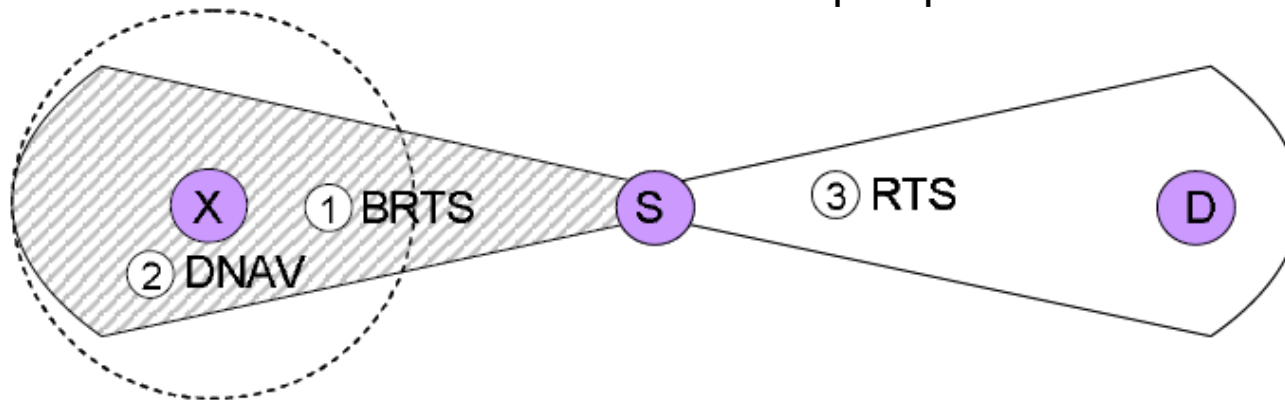


## BRTS ( Backward RTS )



- 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 :

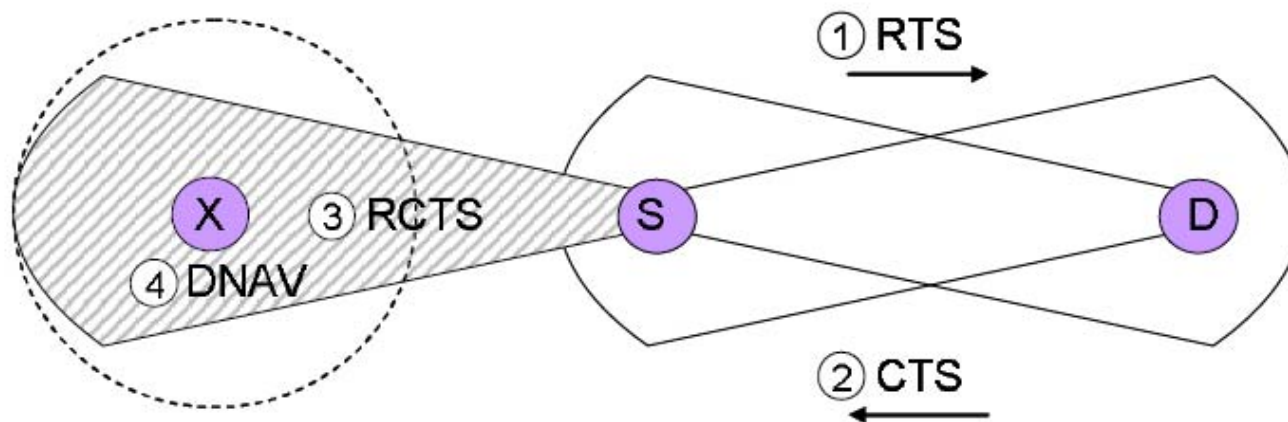
When a sender did not receive CTS from a destination terminal, terminal which received the BRTS sets DNAV and postpones own communication



## RCTS ( Relayed CTS )

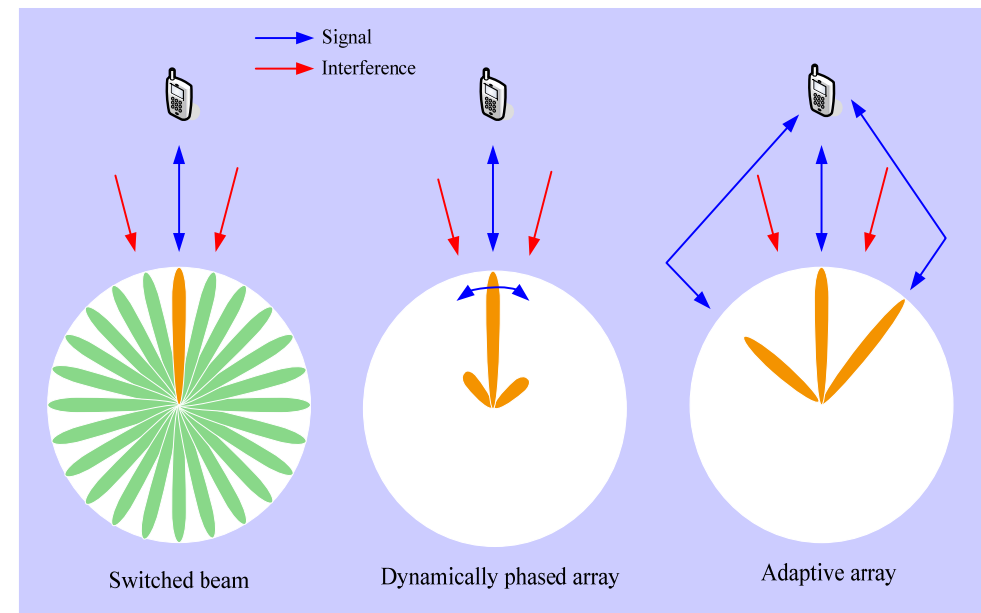


- S transmits RTS to the terminal D with a directional beam, and after receiving CTS from D, S transmits RCTS to 180-degree back
- The timing is not immediately after transmitting RTS. Therefore RCTS is more effective than BRTS
- RCTS is the same as SOF of SWAMP (OC-mode) with high gain and directionally





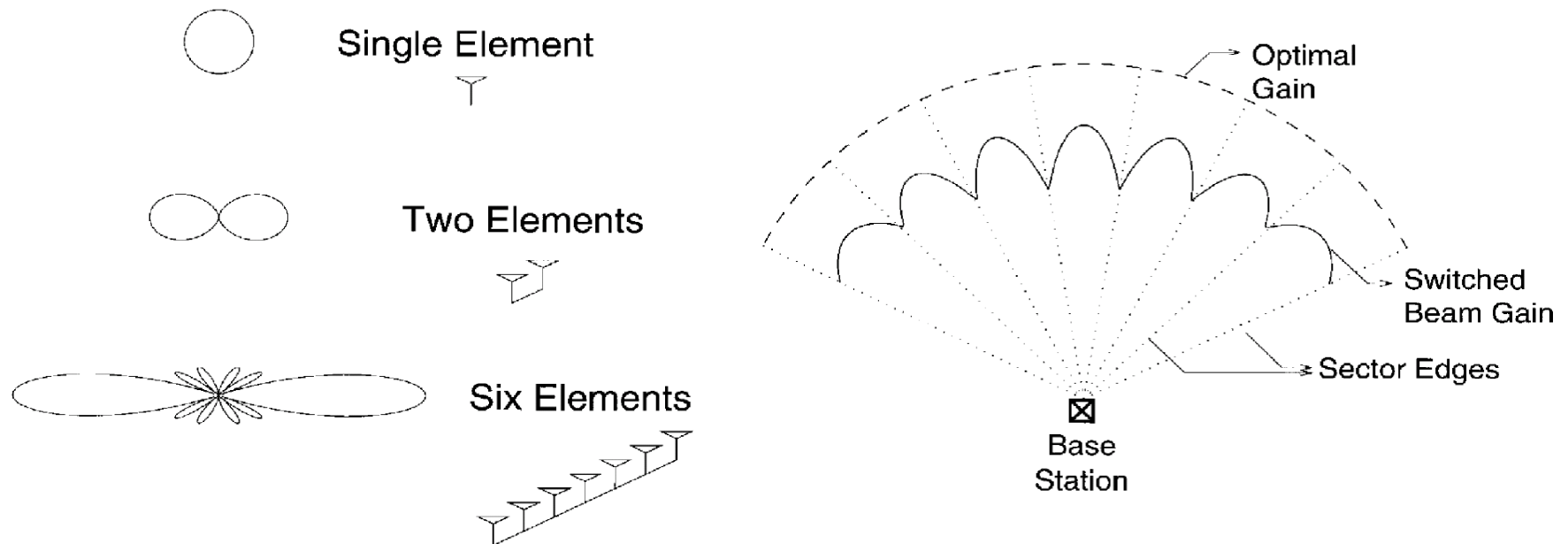
- Switched beam
  - Antenna beam patterns are predetermined by shifting every element's signal phase
- Dynamically phased array
  - Direction of arrival (DoA) algorithm is applied for signal transmission/reception and continuous tracking
- Adaptive array antenna
  - DoA for determining direction
  -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



# Smart Antennas



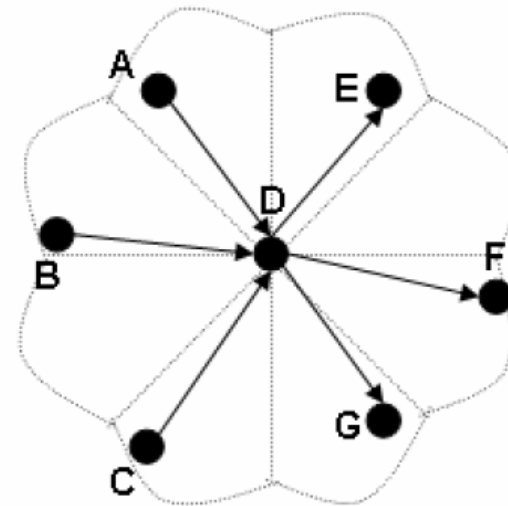
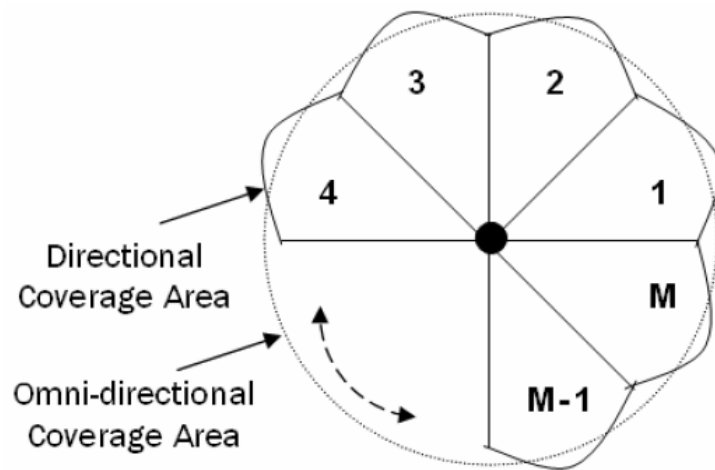
- The gain or strength of the signal at the output of the array
- There are certain directions in which the effective antenna has reduced sensitivity, or nulls



# Smart Antennas

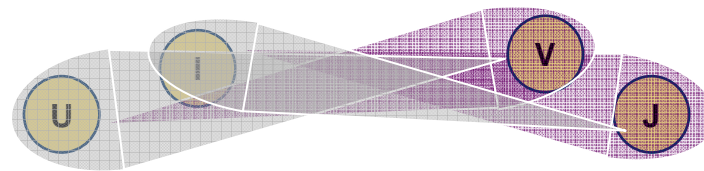


- Using complex digital signal processing techniques an antenna array can support *either* multiple transmissions *or* multiple receptions simultaneously thereby considerably enhancing the system capacity





- 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

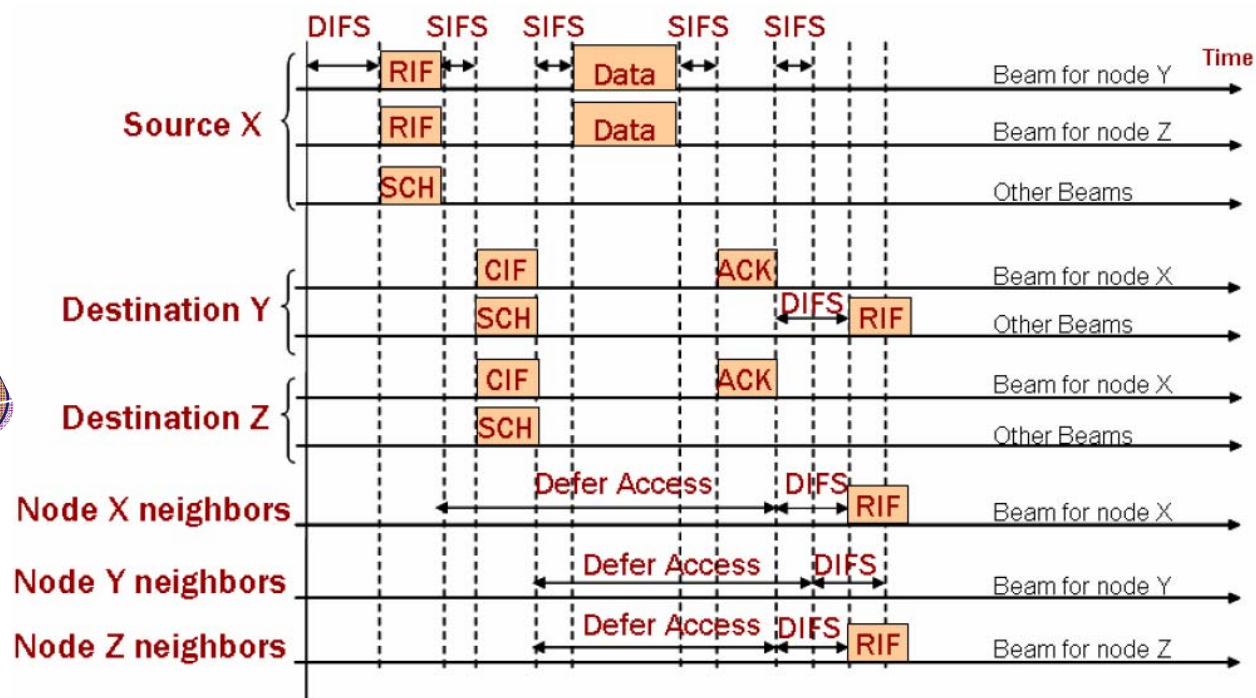
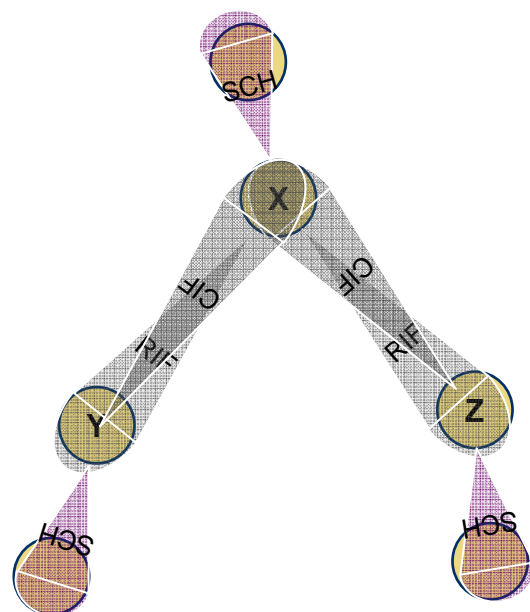


## ESIF protocol ( Explicit Synchronization via Intelligent Feedback )

- 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





- 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