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 \((\theta, \phi)\)
- \( U_{ave} \): 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
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

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

![Diagram of RTS/CTS/DATA/ACK process]
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.
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 #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?