EE5406 Wireless Network Protocols – Emerging Standard and Research MAC Protocols

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Academic Year 2010/2011

Outline

- Emerging standard and research MAC protocols
  - LTE Advanced Cellular Network
  - IEEE 802.22 Cognitive Radio Wireless Regional Area Network (WRAN)
  - IEEE 802.11ad Very High Throughput WLAN
  - Cooperative MAC (CoopMAC)
  - Cognitive MAC
  - Multi-channel MAC
  - Reservation MAC
  - Directional MAC

Emerging Standardized and Research MAC Protocols

Emerging Standard and Research MAC Protocols

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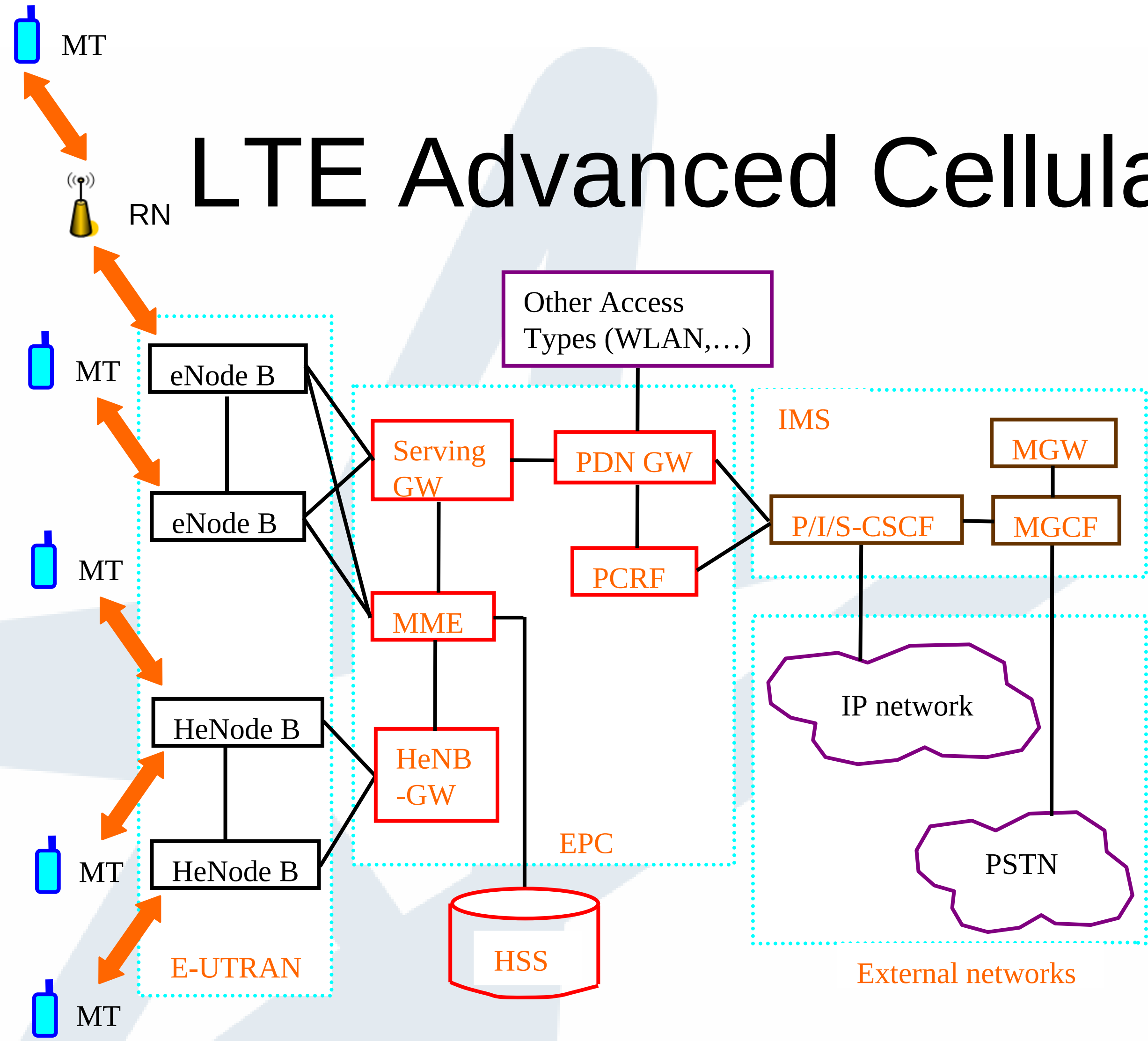
Emerging Standard MAC Protocols | **Emerging Research MAC Protocols**

LTE Advanced
IEEE 802.22
IEEE 802.11ad

CoopMAC
Cognitive MAC
Multi-Channel MAC
Reservation MAC
Directional MAC

LTE Advanced Cellular Network



MT – mobile terminal
RN – relay node
eNode B – an evolved network component that serves one cell
HeNodeB – an evolved network component that serves one femtocell
Serving GW – serving gateway
MME – mobility management entity
HSS – home subscriber server
PDN GW – packet data network gateway
PCRF – policy and charging rules functions
EPC – evolved packet core
WLAN – wireless local area network
P/I/S-CSCF – proxy/interrogating/serving –call session control function
MGCF – media gateway control function
MGW – media gateway
IMS – IP multimedia subsystem
IP – internet protocol
PSTN – public switched telephone network
E-UTRAN – Evolved UMTS Terrestrial Radio Access Network

Figure 1. Long Term Evolution (LTE) Advanced Network Architecture

A*STAR I2R

LTE Advanced Cellular Network

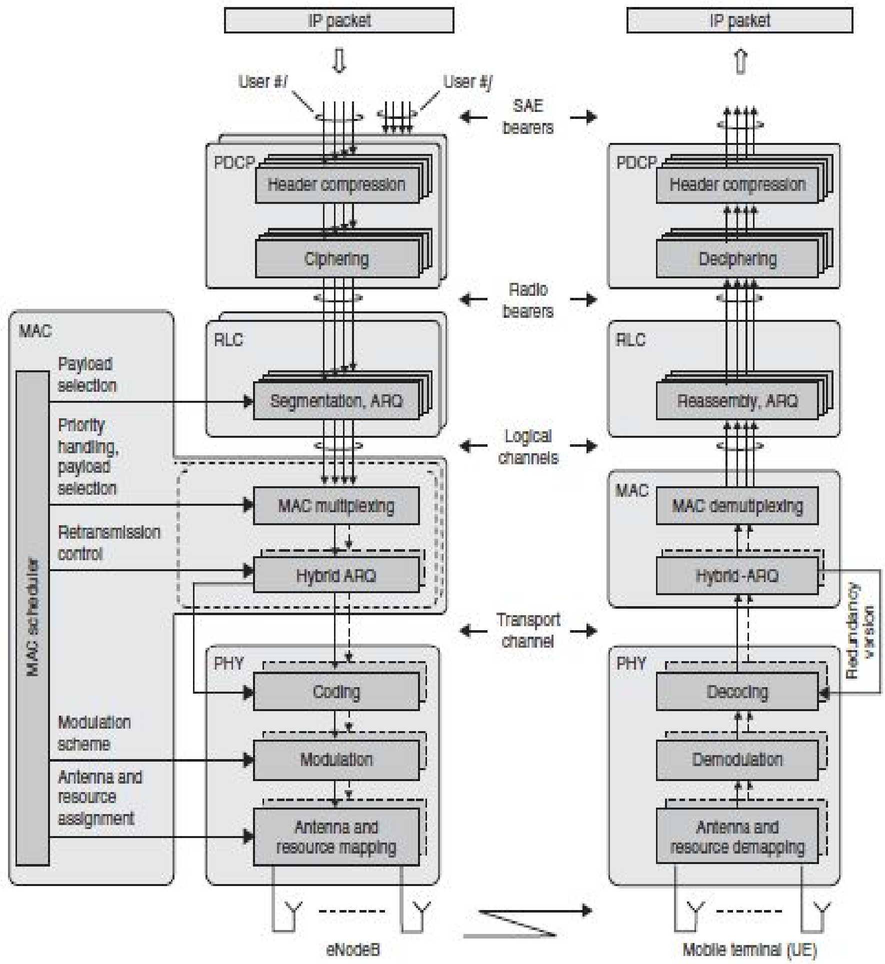


Figure 2. LTE Advanced MAC+PHY Architecture

- IP – Internet Protocol
- PDCP – Packet data convergence protocol
- RLC – Radio link control
- ARQ – Automatic Repeat Request
- MAC – Medium access control
- PHY – Physical layer
- SAE – System and architecture evolution
- UE – User equipment
- eNodeB – Enhanced Node B (base station)

LTE Advanced Cellular Network

- Components of the scheduler
  - Resource scheduling
    - Channel Quality Indication (CQI)
    - Dynamic Subcarrier Assignment (DSA)
    - Adaptive Modulation and Coding (AMC)
    - Adaptive Power Control (APC)
    - Multi-Antenna: MIMO/Beamforming
  - Packet scheduling
    - Resource Partitioning between base station (BS) and relay node (RN)
    - Quality of Service (QoS): Priorities and Sub-strategies
    - Buffer/Queue Management

IEEE 802.22 Cognitive Radio Wireless Regional Area Networks

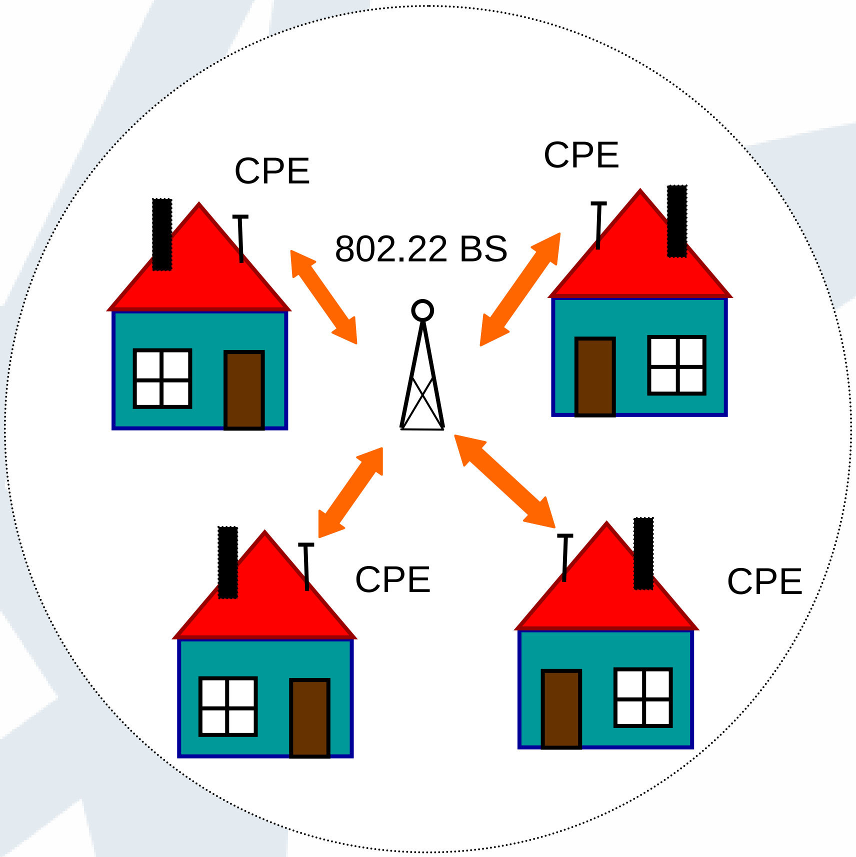


Figure 3. IEEE 802.22 Cognitive Radio WRAN PMP Network Architecture

- IEEE 802.22 wireless regional area network (WRAN) is a point-to-multipoint (PMP) network architecture, similar to PMP mode in IEEE 802.16 WMAN.
- IEEE 802.22 consists
  - Base station (BS)
  - Customer premises equipment (CPEs) with outdoor directional antennas

IEEE 802.22 Cognitive Radio Wireless Regional Area Networks

- Aimed at using cognitive radio techniques to allow sharing of geographically used spectrum allocated to TV broadcast service, on a non-interfering basis, to bring broadband access to hard-to-reach low population density areas of rural environment.
- Designed to operate in the TV broadcast bands while ensuring no harmful interference is caused to the incumbent operation (i.e., digital TV and analog TV broadcasting) and low-power licensed devices such as wireless microphones.
- Two methods used for spectral awareness
  - Geo-location/database
    - Knowledge of the location of the cognitive radio devices combined with a database of licensed transmitters can be used to determine which channels are locally available for reuse by the cognitive radio network.
  - Spectrum sensing
    - Consists of observing the spectrum and identifying which channels are occupied by licensed transmission.
    - Use quiet periods.

IEEE 802.22 Cognitive Radio Wireless Regional Area Networks

- Modifies its operating frequency so as to operate on channels unused by licensed transmissions.
- If the current operating channel becomes occupied by a licensed transmission, the IEEE 802.22 network must quickly identify which channels are allowed for used and move to a new unused channel.
- Application
  - Rural area of typically 17-30 km in radius up to a maximum of 100 km.
- A base station (BS) serving up to 255 fixed units of customer premises equipment (CPE) with outdoor directional antennas located nominally 10 m above ground level.

IEEE 802.22 Cognitive Radio Wireless Regional Area Networks

- The minimum peak throughput delivered to the CPE at the edge of the coverage is 1.5 Mbps in the downstream (DS) direction (BS to CPE) and 384 kbps in the upstream direction (CPE to BS), allowing for videoconferencing service.
- The frequency range used in the very high frequency/ultra high frequency (VHF/UHF) TV broadcast bands ranges from 54 to 862 MHz.
- Orthogonal frequency division multiple access (OFDMA) is used as the air interface at the physical (PHY) layer.

IEEE 802.22 Cognitive Radio WRAN MAC

- IEEE 802.22 MAC provides mechanisms for flexible and efficient data transmission.
- It also supports cognitive capabilities for reliable protection of incumbent services in the TV band and self-coexistence among IEEE 802.22 systems.
- A superframe is transmitted by a BS on its operating channel beginning with a special preamble and contains a superframe control header (SCH) and 16 MAC frames.
- Each MAC frame is 10 ms.
- Each MAC frame comprises of a DS subframe and an US subframe and an adaptive boundary in between.
- In the DS direction, data are scheduled over consecutive MAC slots.
- In the US direction, the channel capacity is shared by the CPE units based on a demand-assigned multiple access (DAMA) scheduling.

IEEE 802.11ad WLAN

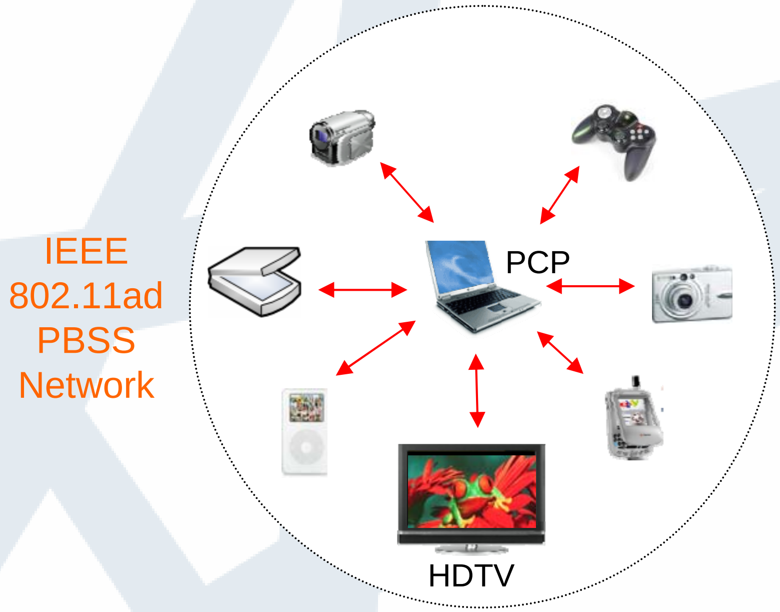


Figure 4. IEEE 802.11ad PBSS Network Architecture

PBSS – personal basic service set

PCP – PBSS central point

IEEE 802.11ad WLAN

- Applications
  - Wireless PC display for uncompressed video
  - TV for uncompressed video
  - Projector for uncompressed video
  - Sync-and-go between handheld devices or downloading movies or pictures from a camera
  - File transfer
  - Data backup

IEEE 802.11ad MAC Architecture

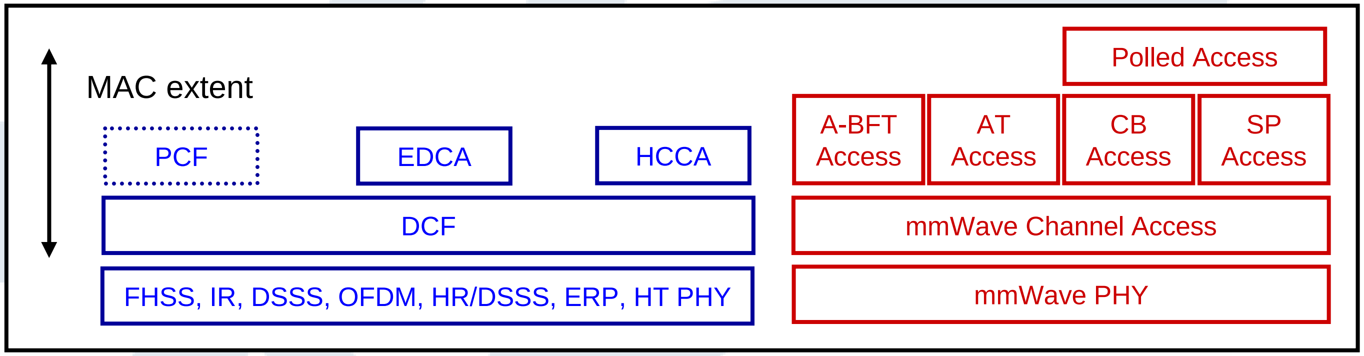


Figure 5. IEEE 802.11ad MAC Architecture

PCF – point coordination function

EDCA – enhanced distributed channel access

HCCA – hybrid coordination function controlled channel access

DCF – distributed coordination function

A-BFT – association beamforming training time

AT – announcement time

CB – contention-based

SP – service period

mmWave – millimeter wave

IEEE 802.11ad MAC

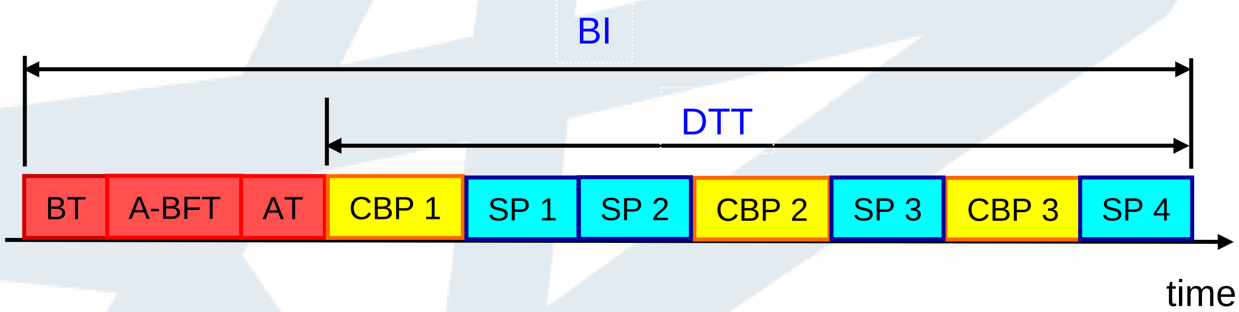


Figure 6. IEEE 802.11ad Beacon Interval (BI) Structure

BI – beacon interval

DTT – data transfer time

BT – beacon time

A-BFT – association beamforming training time

AT – announcement time

CBP – contention-based period

SP – service period

IEEE 802.11ad MAC

- The beacon interval in IEEE 802.11ad MAC is divided into mainly 4 parts
  - Beacon time (BT)
  - Association beamforming training time (A-BFT)
  - Announcement time (AT)
  - Data transfer time (DTT)
- Beacon time (BT)
  - Access point (AP)/Personal basic service set central point (PCP) transmits one or more beacons frames in different directions.
  - Beacon carries network management information.
  - Beacon frame is used to bootstrap the beamforming procedure between AP/PCP and a receiving station.
  - To join the network, a station scans for a beacon, continues with the beamforming process with the AP/PCP in the A-BFT and then associates with the AP/PCP during the AT or CBP.

IEEE 802.11ad MAC

- Association beamforming training time (A-BFT)
  - To perform the initial beamforming training between a station and the AP/PCP.
  - Follows the BT to provide continuity to the beamforming process that was bootstrap through the beacon transmission during the BT.
  - It is slotted and allows for multiple stations to do beamforming with the AP/PCP concurrently in the same A-BFT.
- Announcement time (AT)
  - To perform management request-response frame exchanges between AP/PCP and a station.
  - AP/PCP uses this time to exchange frames with stations to distribute information on contention-based period (CBP) and service period (SP) allocations in the data transfer time (DTT).
- The DTT is divided into CBPs and SPs which are used to provide transmission opportunities for stations in the network.

IEEE 802.11ad MAC

- Data transfer time (DTT)
  - Any frame can take place during a CBP and a SP, including application data frame transmission.
  - Access during CBPs is based on a modified IEEE 802.11 EDCA operation that is fine-tuned for directional communications.
  - Access during SPs is scheduled and assigned to specific stations.
  - One major problem with SP type of TDMA scheduling is robustness of transmissions during SPs.
  - A protected period is used during the SPs
    - A station that owns a SP can protect the SP by transmitting an RTS frame at the start of the SP to reserve the medium.
    - If a CTS frame is received from the destination station in the SP in response to the transmitted RTS, the SP is considered protected.

Cooperative MAC in WLAN

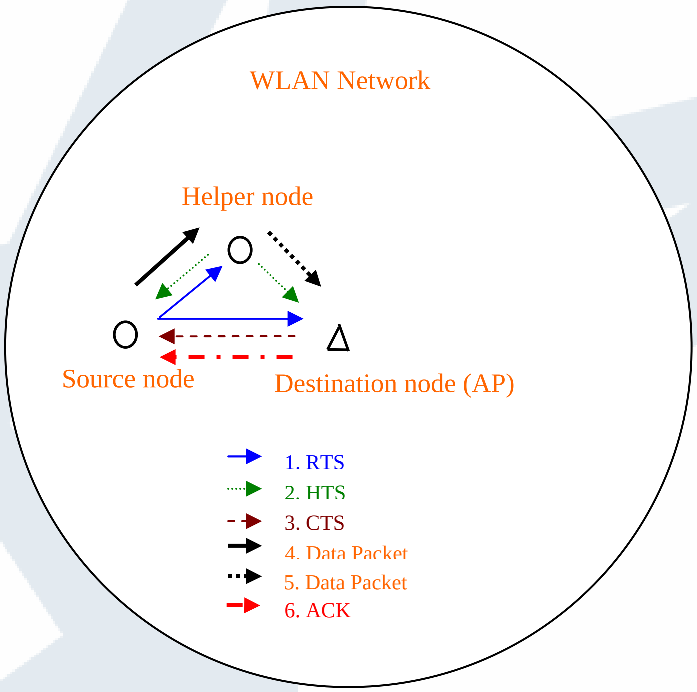


Figure 7. Cooperative MAC in WLAN

WLAN – wireless local area network

AP – access point

RTS – request-to-send

HTS – helper-to-send

CTS – clear-to-send

ACK – acknowledgement

Cooperative MAC

- The basic idea in Cooperative MAC is to transmit a packet through a faster 2-hop link rather than a slower 1-hop link.
- This MAC protocol will help in the following ways.
  – Increase throughput
  – Cut down delay

Cooperative MAC

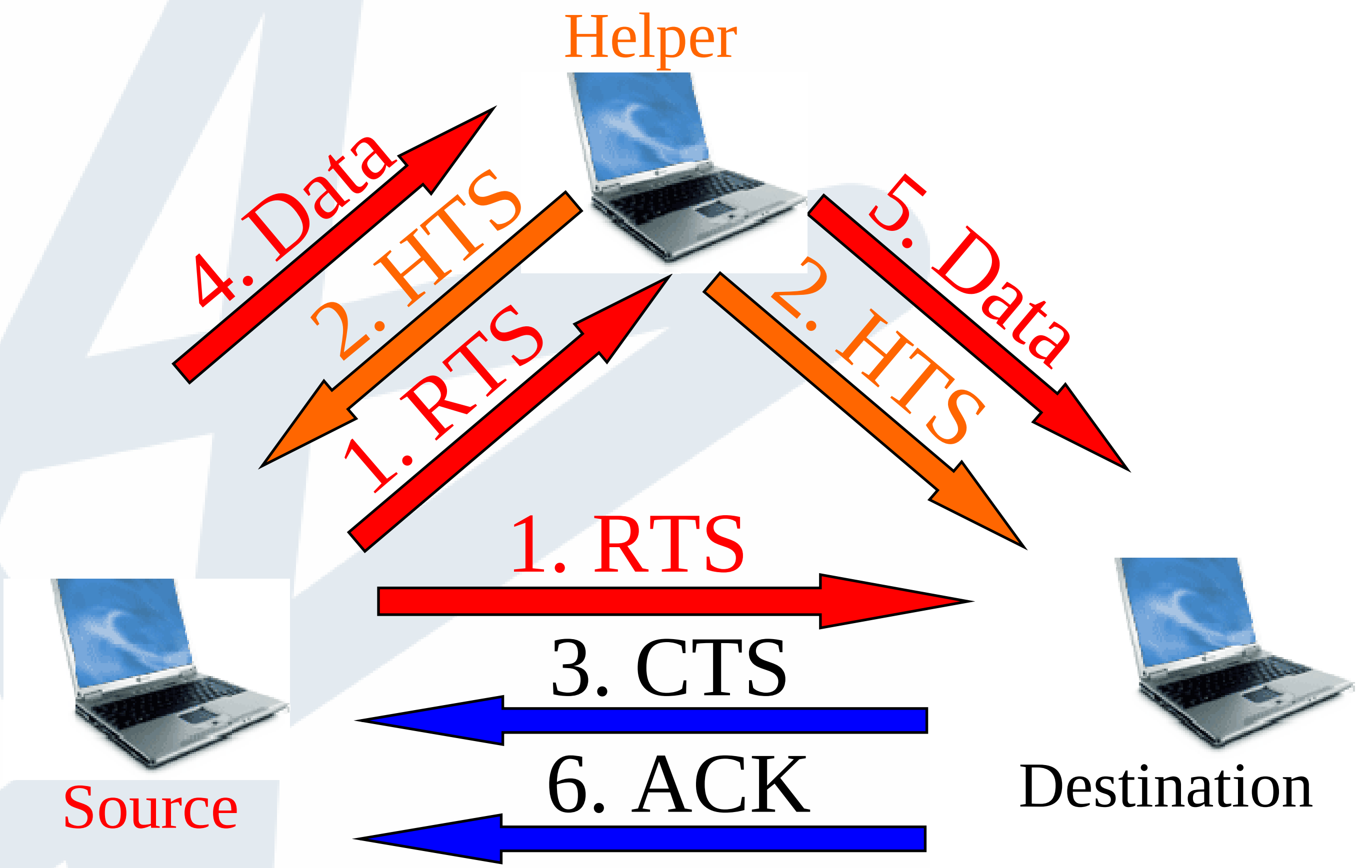


Figure 8. Cooperative MAC Protocol

Cooperative MAC

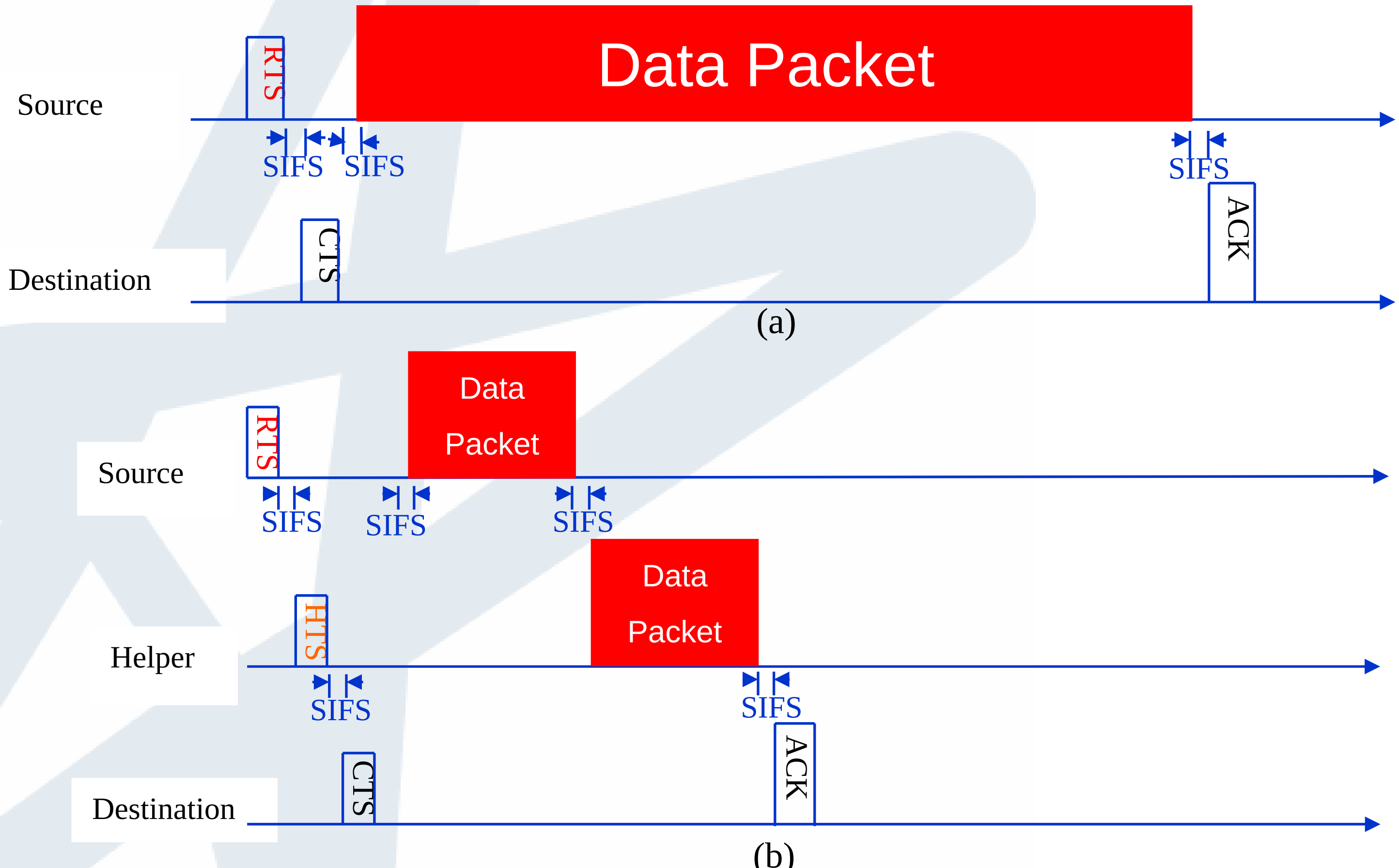
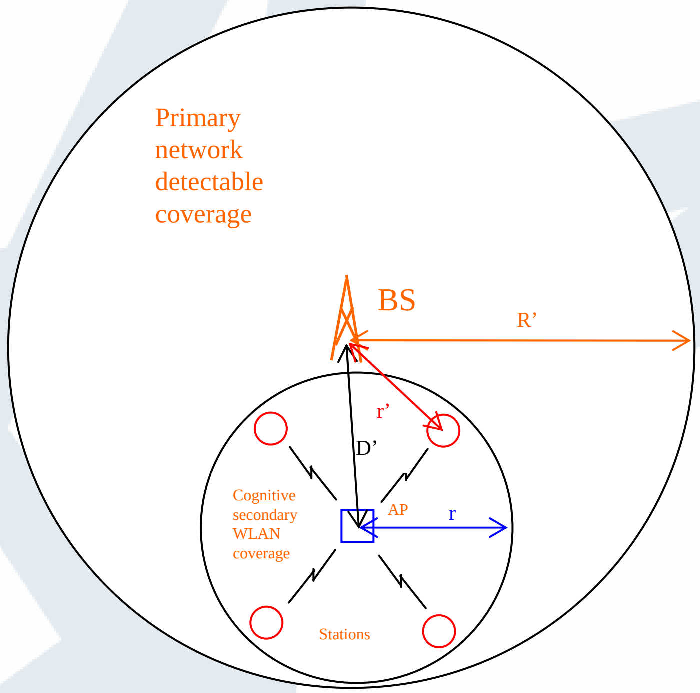


Figure 9. (a) IEEE 802.11 MAC protocol timing diagram
(b) Cooperative MAC protocol timing diagram

Cognitive Secondary Networks



BS – base station

AP – access point

r – cognitive secondary WLAN coverage

R' – primary network detectable coverage

D' – distance between BS of primary network and AP of the cognitive secondary network

r' – distance between BS of primary network and a station of the cognitive secondary network

Figure 10. Cognitive Secondary WLAN in the presence of a Primary network

Cognitive MAC

- A secondary cognitive IEEE 802.11 MAC can be used in a primary and secondary network scenario.
- The frame format is shown in Fig. 11.
- The frame format consists for three parts.
  - Beacon period
  - Data transmission period
  - Quiet period

Cognitive MAC

Beacon Period	Data Transmission Period	Quiet Period

Figure 11. Superframe Structure for a Cognitive MAC

Cognitive MAC

- The beacon period is used to inform the stations on the quiet period in secondary cognitive network.
- During the data transmission period, IEEE 802.11 MAC can be used, provided that the sensing outcomes by the access point (AP) and the station are both negative.
- That is, there is no primary network detected.
- In the quiet period, the AP and all the stations will keep quiet and sense for the presence or absence of the primary network.
- Thus, any signal detected should be from the network(s) other than the secondary cognitive IEEE 802.11 network.

Cognitive MAC

- Detecting that a signal is not present when it is there gives rise to *misdetection*.
- Detecting that a signal is present when it is not there give rise to *false alarm*.
- In a primary network and a secondary network scenario, the traditional view is to protect the primary network and the secondary network should work around the primary network.

Cognitive MAC

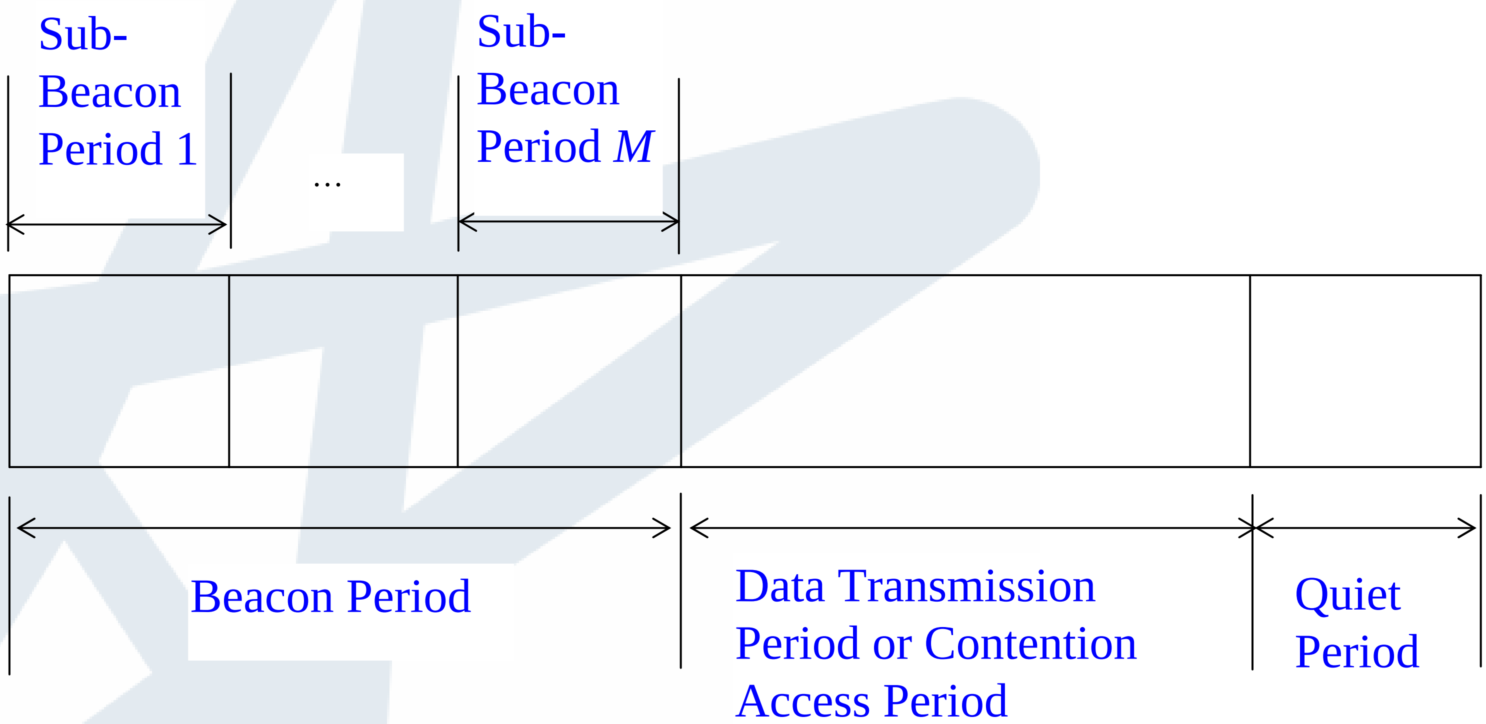


Figure 12. Superframe Structure for of Multiple Secondary Cognitive Networks

Cognitive MAC

- The superframe structure for multiple cognitive secondary networks in the presence of a primary network is shown in Fig. 12.
- Each superframe consists of three parts: a beacon period (BP) subframe, a data transmission or contention access period (CAP) subframe and a quiet period subframe.
- The beacon period subframe consists of sub-beacon periods for different secondary networks.
- If there are *M* secondary networks, there are *M* sub-beacon periods.
- We assume that there is a device that can operate in all of the *M* secondary networks.

Cognitive MAC

- This device is designated as the piconet coordinator (PNC).
- We also assume that the secondary networks can use a centralized MAC or a distributed MAC.
- For examples, a centralized MAC can be some form of Infrastructure-based IEEE 802.11 MAC, while a distributed MAC can be a modified WiMedia MAC.
- The PNC is used to transmit its beacon in its sub-beacon period for networks using centralized MACs as well as transmit a beacon period start time (BPST) as well as its own beacon for networks using distributed MACs.

Cognitive MAC

- The data transmission subframe is used for CSMA/CA access to transmit data packets for each network.
- *Each network takes turn to transmit in the data transmission period of different superframes*.
- The PNC coordinates this through the use of information elements (IEs) in its beacons in the sub-beacon periods to inform the devices in each network on the usage the data transmission period *for which particular network* in the current superframe.
- Only one network can use the CAP in each superframe.

Cognitive MAC

- The devices in each of their own network will not transmit data in the data transmission period in the current superframe if the IE of the PNC's beacon in its sub-beacon period informs them that they cannot to transmit in the current frame.
- On the other hand, if the IE of the PNC's beacon in its sub-beacon period informs the devices in their network that they can transmit in the data transmission period of the current superframe, it transmits in the current superframe only if its sensing of the primary network in the quiet period in the previous superframe is that there is no primary network transmissions.

Cognitive MAC

- The sensing in the quiet period is to decide if there is any primary network transmission.
- For a fixed detection probability of the primary network transmission, the longer the sensing time, the lower the probability of false alarm.

Multi-Channel MAC

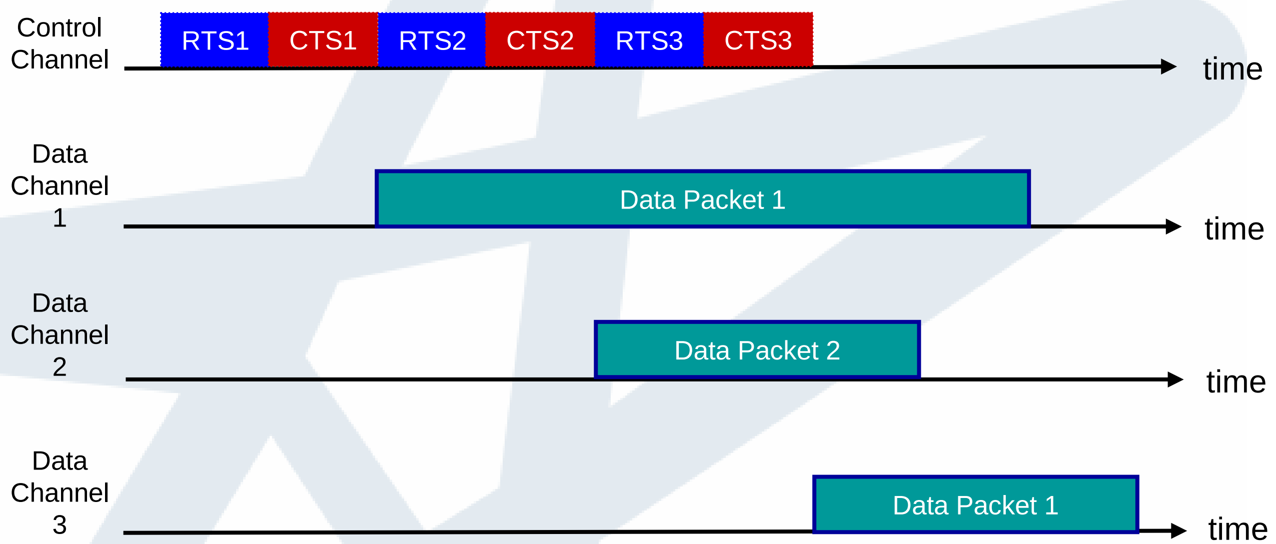


Figure 13. Multi-Channel MAC Protocol

RTS – request-to-send

CTS – clear-to-send

Multi-Channel MAC

- A multi-channel MAC protocol transmits in a number of channels at the same time, resulting in increase in throughput.
- Figure 13 shows a multi-channel MAC using a dedicated control channel.
- The devices constantly monitor the control channel and keep track of idle devices and data channels.
- When a device has packets to send to an idle device, it sends an RTS message for that idle device on the control channel.
- If the idle device hears the RTS message, it replies with a CTS message.
- Then both sender and the receiver tune to the agreed channel to start transmission.

Multi-Channel MAC

- The following simplifications are made for the multi-channel protocol.
  - Time is divided into small time slots with perfect synchronization at the slot boundaries.
  - For each channel agreement, the devices can transmit only one packet.
  - The packet length is geometrically distributed with parameter q and the mean packet length is $1/q$.
  - Every device always has packets to send to all other devices and an idle device attempts to transmit with probability p in each time slot.

Reservation MAC

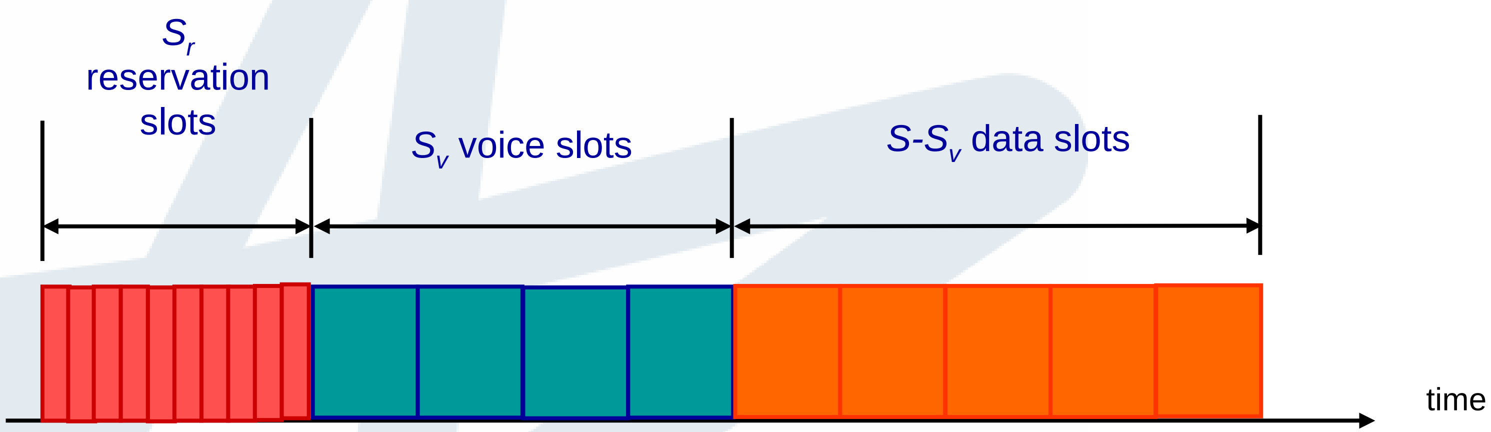


Figure 14. Reservation MAC Frame Structure

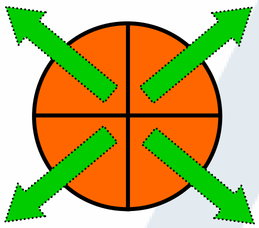
Reservation MAC

- A form of reservation MAC, known as dynamic time division multiple access (D-TDMA) is considered.
- Figure 14 shows the D-TDMA frame format, where the frame is partitioned into S_r reservation slots and S payload slots, consisting of S_v voice slots and (S-S_v) data slots.
- When a user generates a new voice talkspurt or new data packet, an appropriate reservation packet is transmitted in a reserved slot in the next frame with probability p_t or p_r for voice or data, respectively.
- If there is more than one reservation packet transmitted in the same reservation slot, a collision occurs.

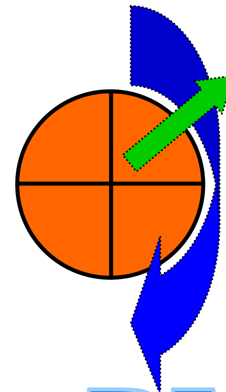
Reservation MAC

- The collided user can retry in the next reservation slot with the respective probability for voice and data.
- If the voice user is successful at the reservation phase, it will be assigned a voice slot to use until the end of the talkspurt.
- If there is no available voice slot, the voice user will re-contend in the next frame.
- If the data user is successful at the reservation phase, it can use the remaining slots excluding the voice slots.
- If there is no available data slot, the data user will re-contend in the next frame.

Contention-Based Directional MAC Protocols



Directional MAC



Non-Circular DMAC | **Circular DMAC**

ORTS/OCTS
DRTS/OCTS
DRTS/DCTS

CRTS/DCTS
CRTS/CCTS

- CSMA/CA based protocols
- Data/ACKS are transmitted directionally

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