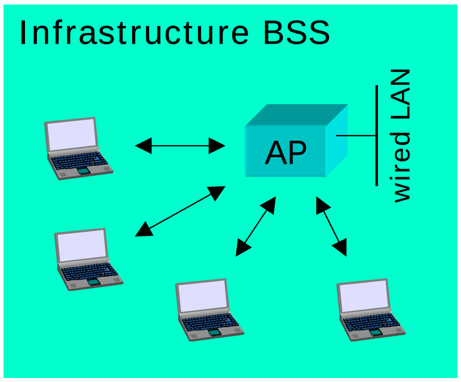
Wireless Local and Metropolitan Area Networks (WLAN, WMAN)

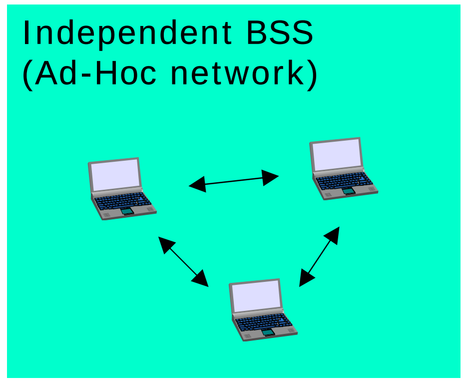
WiFi, WiMAX

Wireless Fidelity (WiFi)

IEEE 802.11 WLAN architecture

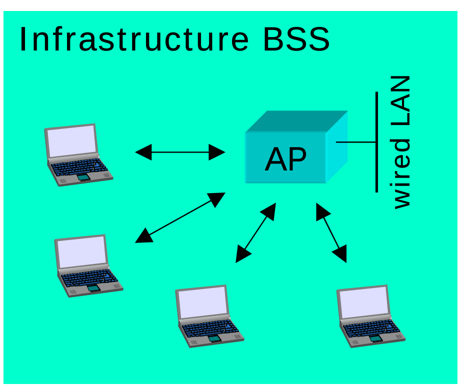
802.11 defines two BSS (Basic Service Set) options:





Infrastructure BSS

This is by far the most common way of implementing WLANs.



The base stations connected to the wired infrastructure are called access points (AP).

Wireless stations in an Infrastructure BSS must always communicate via the AP (never directly).

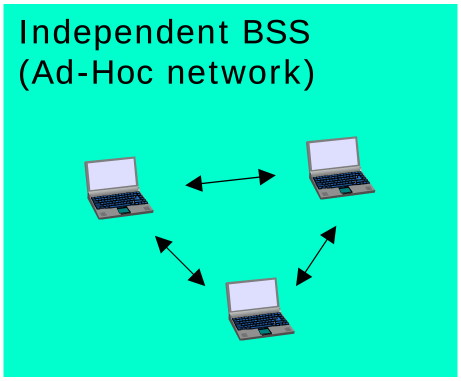
Before stations can use the BSS: Association.

Independent BSS

Mainly of interest for military applications.

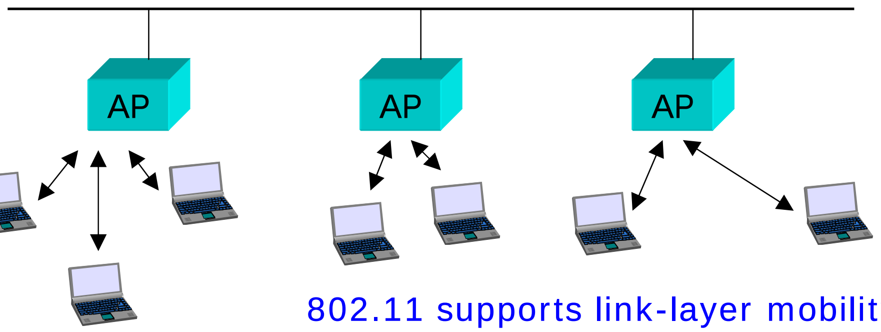
No access point is required, stations can communicate directly.

Efficient routing of packets is not a trivial problem (routing is not a task of 802.11).



Extended Service Set (ESS)

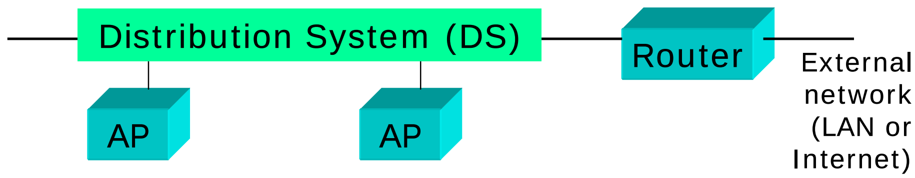
This is a larger WLAN network consisting of a number of BSS networks interconnected via a common backbone



802.11 supports link-layer mobility within an ESS (but not outside the ESS)

Distribution system

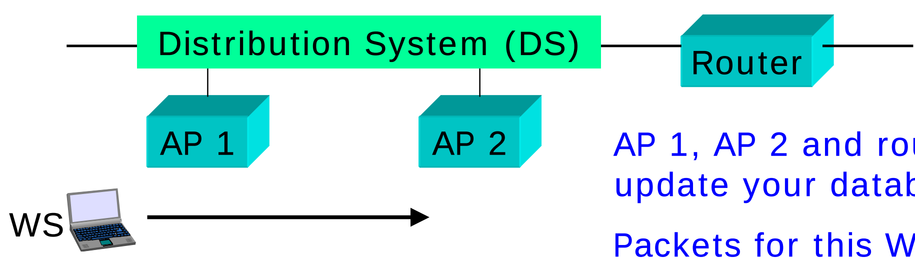
This is the mechanism by which APs and other nodes in the wired IP subnetwork communicate with each other.



This communication, using the Inter-Access Point Protocol (IAPP), is essential for link-layer mobility (=> stations can seamlessly move between different BSS networks).

Distribution system (cont.)

For instance, when a wireless station moves from one BSS to another, all nodes must update their databases, so that the DS can distribute packets via the correct AP.



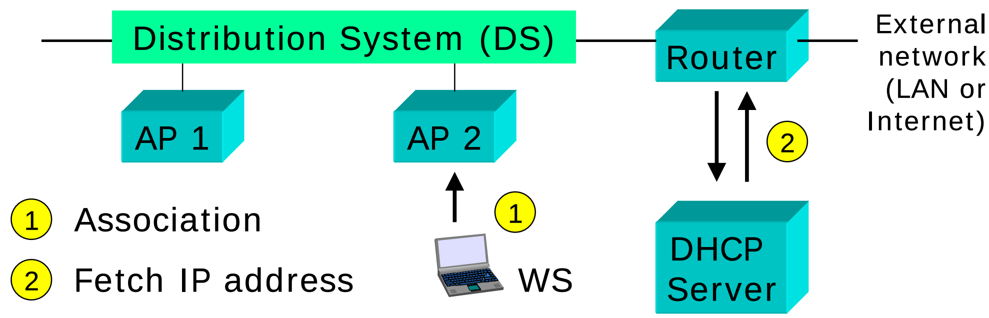
WS moves to another BSS

AP 1, AP 2 and router: update your databases!

Packets for this WS will now be routed via AP 2.

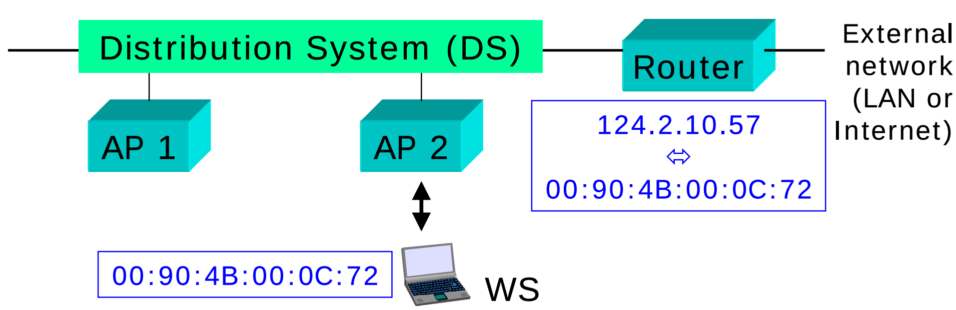
Basic routing example

When WS associates with AP 2, the router in charge of the IP subnet addressing obtains an IP address from the DHCP (Dynamic Host Configuration Protocol) server.



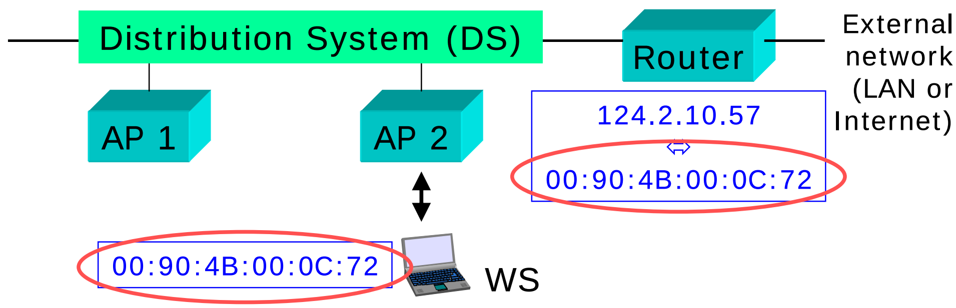
Basic routing example (cont.)

The router must maintain binding between this IP address and the MAC address of the wireless station.



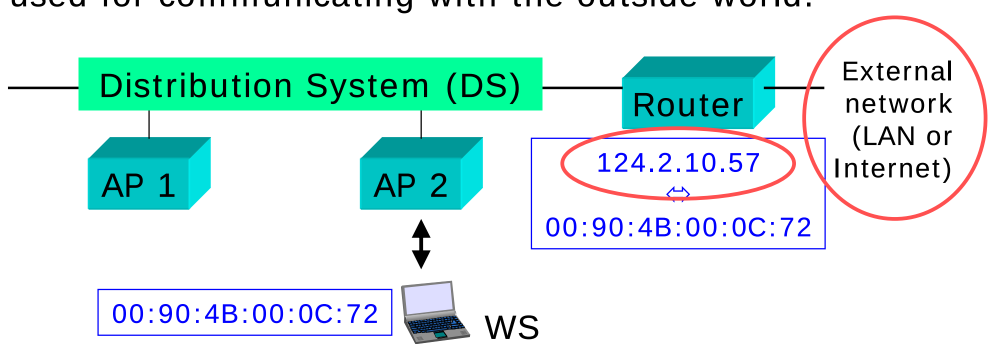
Basic routing example (cont.)

The globally unique MAC address of the wireless station is used for routing the packets within the IP subnetwork (DS + attached BSS networks).



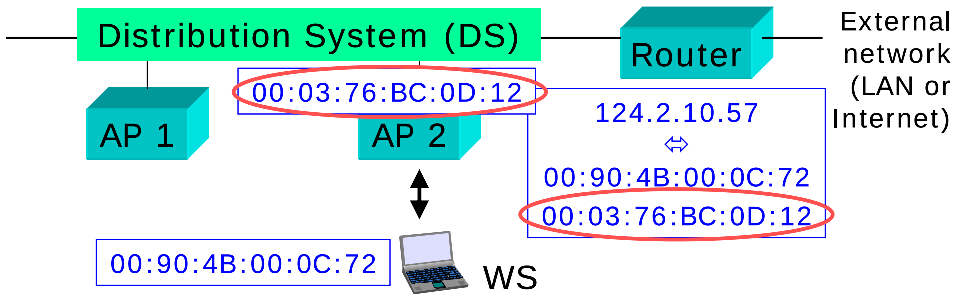
Basic routing example (cont.)

The dynamic and local IP address of the wireless station is only valid for the duration of attachment to the WLAN and is used for communicating with the outside world.



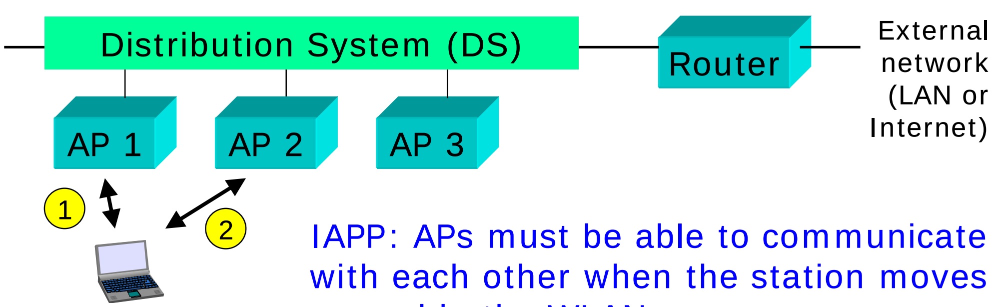
Basic routing example (cont.)

The router must also know (and use) the MAC address of the access point via which the packets must be routed. For this purpose, a special protocol (IAPP) is needed!



IAPP (Inter-Access Point Protocol)

IAPP (defined in IEEE 802.11f) offers mobility in the Data link layer (within an ESS = Extended Service Set).



IAPP: APs must be able to communicate with each other when the station moves around in the WLAN

In addition to IAPP ...

IAPP alone is not sufficient to enable seamless handovers in a WLAN. The stations must be able to measure the signal strengths from surrounding APs and decide when and to which AP a handover should be performed (no 802.11 standardised solutions are available for this operation).

In 802.11 networks, a handover means reassociating with the new AP.

Mobility Management (MM)

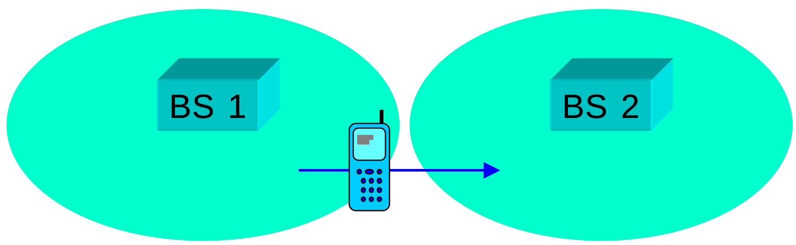
There are basically two objectives of Mobility Management:

1. MM offers seamless handovers when moving from one network/subnetwork/BSS to another

2. MM makes sure that users or terminals can be reached when they move to another network/subnetwork/BSS

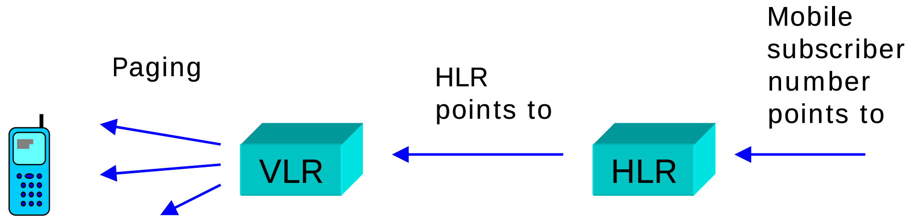
MM in cellular wireless networks (1)

1. Handover: In a cellular wireless network (e.g. GSM), the call is not dropped when a user moves to another cell. Handovers are based on measurements performed by the mobile terminal and base stations.



MM in cellular wireless networks (2)

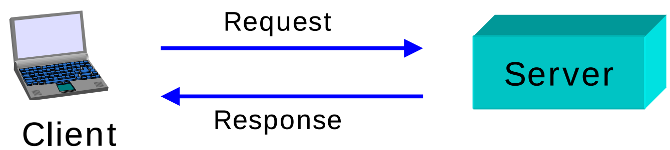
2. Reachability: In a cellular wireless network, the HLR (Home Location Register) knows in which VLR (Visitor Location Register) area the mobile terminal is located. The VLR then uses paging to find the terminal.



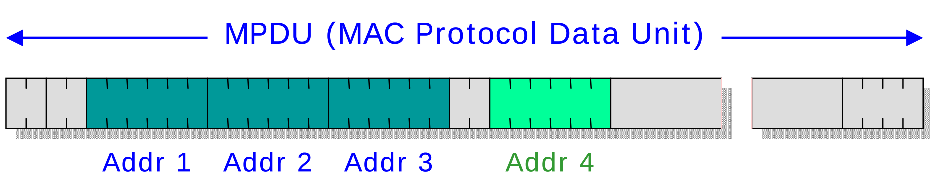
MM in cellular wireless networks (3)

3. IP services (e.g. based on GPRS): Reachability in this case is kind of a problem. Conventional IP services use the client – server concept where reachability is not an important issue.

Typical client - server transaction:



Usage of MAC address fields

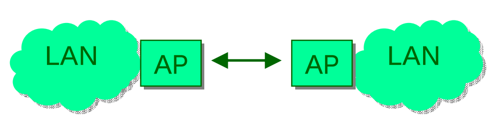


Address 1: Receiver (wireless station or AP)

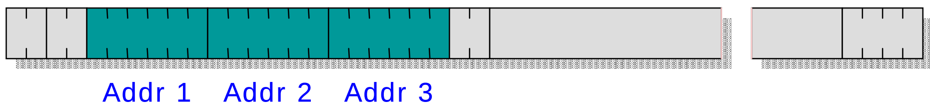
Address 2: Sender (wireless station or AP)

Address 3: Ultimate source/destination (router in DS)

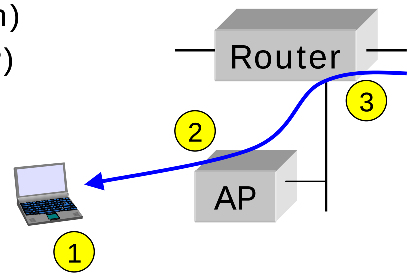
Address 4: Only used in Wireless Bridge solutions:



Direction: AP => wireless station



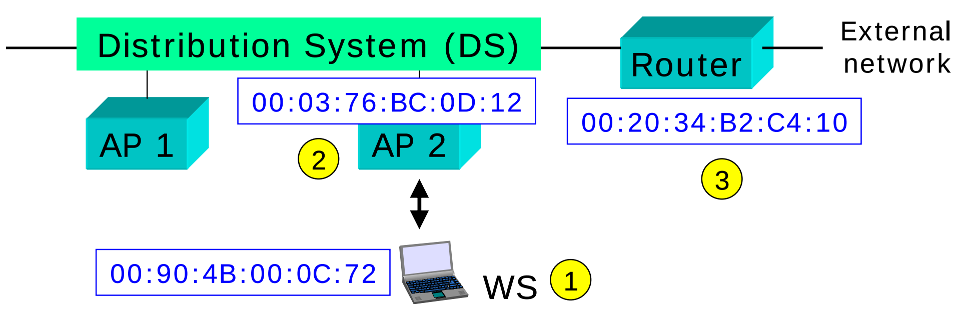
Addr 1: Receiver (wireless station)
Addr 2: Transmitter = BSSID (AP)
Addr 3: Ultimate source (router)



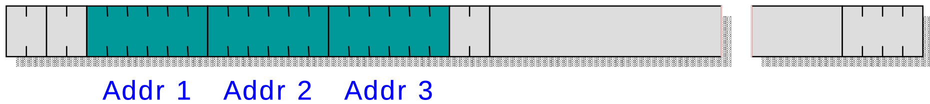
BSSID: MAC address of AP
SSID: Alphanumeric name of AP (or BSS)

MAC addressing example

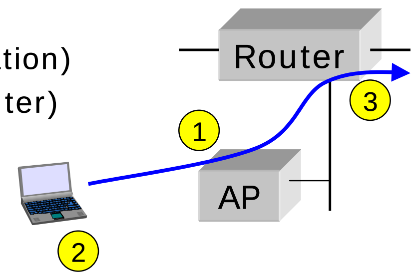
Frames to the WS must also include the MAC address of the ”ultimate source” to which return frames should be routed (then ”ultimate destination”).



Direction: Wireless station => AP



Addr 1: Receiver = BSSID (AP)
Addr 2: Transmitter (wireless station)
Addr 3: Ultimate destination (router)



Management frames

In addition to the data frames (containing the user data to be transported over the 802.11 network) and control frames (e.g. acknowledgements), there are a number of management frames.

Note that these management frames compete for access to the medium in equal terms (using CSMA/CA) with the data and control frames.

Some of these management frames are presented on the following slides.

Beacon frames

Beacon frames are broadcast (meaning that all stations shall receive them and read the information) at regular intervals from the Access Point. These frames contain (among others) the following information:

- Timestamp (8 bytes) is necessary, so that stations can synchronise to the network
- Beacon interval (2 bytes) in milliseconds
- Capability info (2 bytes) advertises network capabilities
- SSID (0 … 32 bytes), alphanumeric “network name”
- The channel number used by the network (optional).

Probe request & response frames

A probe request frame is transmitted from a wireless station during active scanning. Access points within reach respond by sending probe response frames.

Probe request frames contain the following information:

- SSID (0 … 32 bytes), alphanumeric “network name”
- Bit rates supported by the station. This is used by APs to see if the station can be permitted to join the network.

Probe response frames actually contain the same kind of “network information” as beacon frames.

Association request & response frames

Before a station can join an 802.11 network, it must send an association request frame. The AP responds with an association response frame.

Association request frames contain (among others):

- SSID, capability info, bit rates supported.

Association response frames contain (among others):

- Capability info, bit rates supported
- Status code (success or failure with failure cause)
- Association ID (used for various purposes)

Passive and active scanning

Wireless stations can find out about 802.11 networks by using passive or active scanning.

During passive scanning, the station searches beacon frames, moving from channel to channel through the complete channel set (802.11b => 13 channels).

During active scanning, the station selects Channel 1 and sends a probe request frame. If no probe response frame is received within a certain time, the station moves to Channel 2 and sends a probe request frame, and so on.

Case study 1: Station connecting to a WLAN

When a station moves into the coverage area of a WLAN, the following procedures take place:

1) Scanning: the station searches for a suitable channel over which subsequent communication takes place
2) Association: the station associates with an AP
3) IP address allocation: the station gets an IP address, for instance from a DHCP server
4) Authentication: only if this security option is required.

Case study 2: Handover to another AP

When a station has noticed that the radio connection to another AP is a better than the existing connection:

1) Reassociation: the station associates with another AP
2) No new IP address is needed; however, the WLAN must be able to route downlink traffic via the new AP
3) Authentication: this security option, if required, will result in a substantially increased handover delay (complete procedure sequence: deauthentication, disassociation, reassociation, authentication).

CSMA/CD vs. CSMA/CA (2)

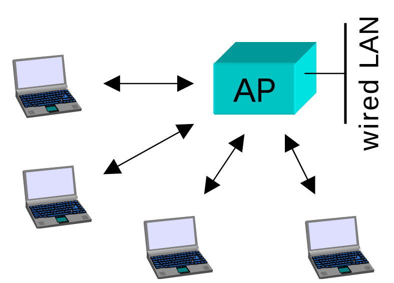
CSMA/CA (Collision Avoidance) is the MAC method used in a wireless LAN. Wireless stations cannot detect collisions (i.e. the whole packets will be transmitted anyway).

Basic CSMA/CA operation:

CSMA/CA rule:
Backoff before collision

1) Wait for free medium
2) Wait a random time (backoff)
3) Transmit frame
4) If collision, the stations do not notice it
5) Collision => erroneous frame => no ACK returned

Basic wireless medium access



CSMA:
One packet at a time

We shall next investigate Infrastructure BSS only.

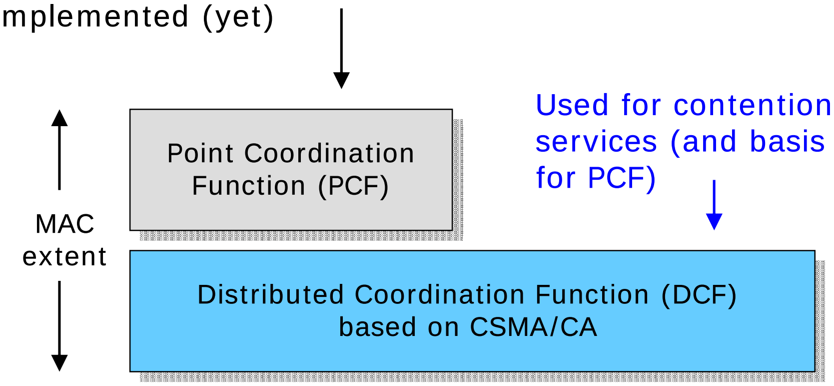
As far as medium access is concerned, all stations and AP have equal priority

⇔

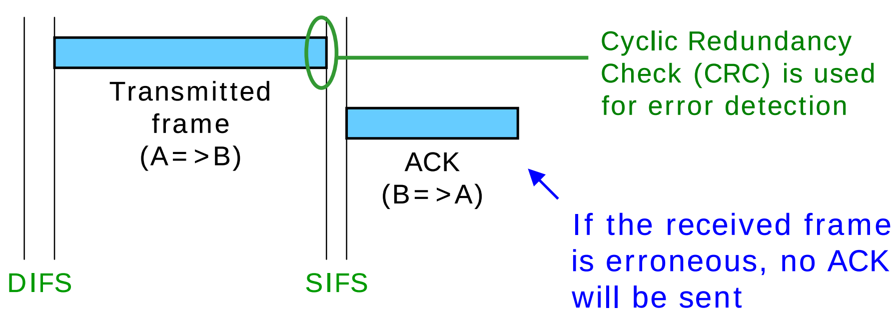
transmission in downlink (from the AP) and uplink (from a station) is similar.

DCF (CSMA/CA) vs. PCF

Designed for contention-free services (delay-sensitive real-time services such as voice transmission), but has not been implemented (yet)

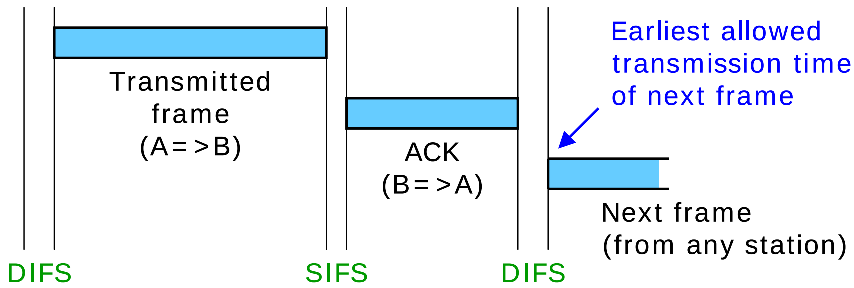


Wireless medium access (1)



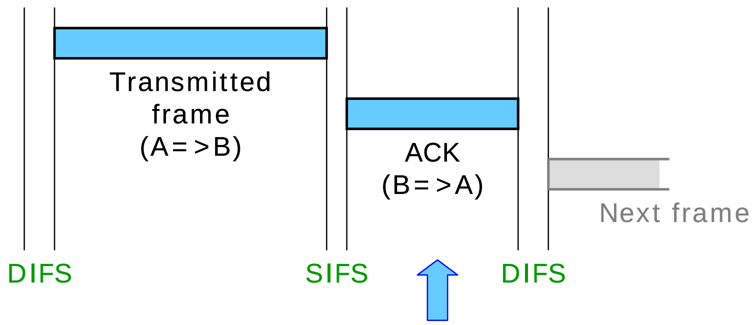
When a frame is received without bit errors, the receiving station (B) sends an Acknowledgement (ACK) frame back to the transmitting station (A).

Wireless medium access (2)



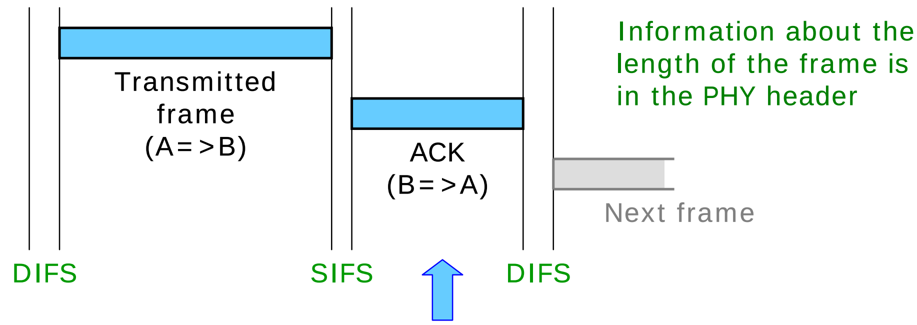
During the transmission sequence (Frame + SIFS + ACK) the medium (radio channel) is reserved. The next frame can be transmitted at earliest after the next DIFS period.

Wireless medium access (3)



There are two mechanisms for reserving the channel:
Physical carrier sensing and Virtual carrier sensing using the so-called Network Allocation Vector (NAV).

Wireless medium access (4)



Physical carrier sensing means that the physical layer (PHY) informs the MAC layer when a frame has been detected. Access priorities are achieved through interframe spacing.

Wireless medium access (5)

The two most important interframe spacing times are SIFS and DIFS:

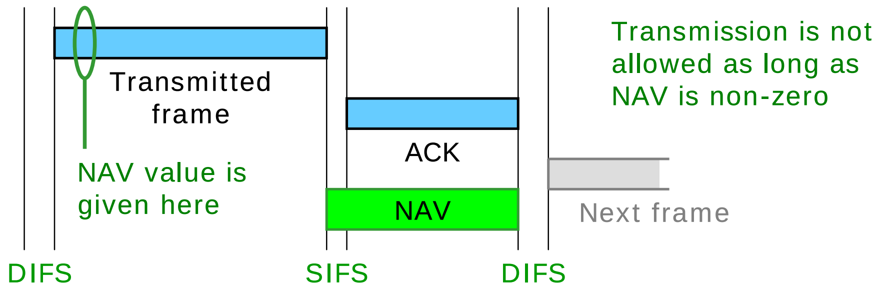
SIFS (Short Interframe Space) = 10 μs (16 μs)

DIFS (DCF Interframe Space) = 50 μs (34 μs)

802.11b 802.11g

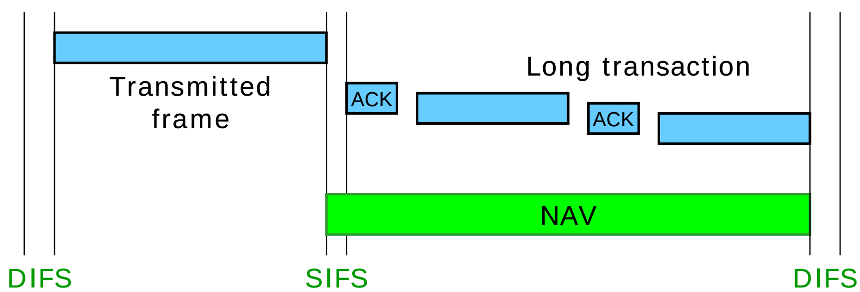
When two stations try to access the medium at the same time, the one that has to wait for the time SIFS wins over the one that has to wait for the time DIFS. In other words, SIFS has higher priority over DIFS.

Wireless medium access (6)



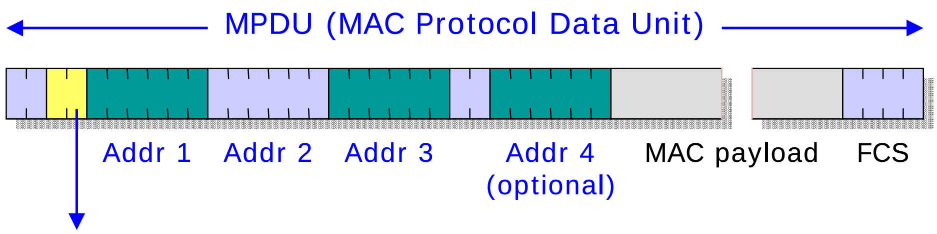
Virtual carrier sensing means that a NAV value is set in all stations that were able to receive a transmitted frame and were able to read the NAV value in this frame.

Wireless medium access (7)



Virtual carrier sensing using NAV is important in situations where the channel should be reserved for a ”longer time” (RTS/CTS usage, fragmentation, etc.).

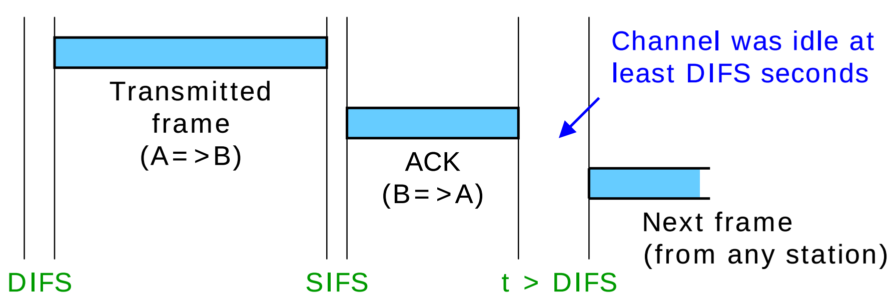
NAV value is carried in MAC header



Duration field: 15 bits contain the NAV value in number of microseconds. The last (sixteenth) bit is zero.

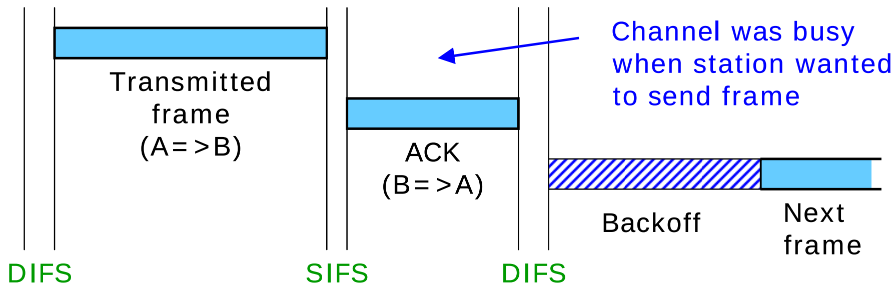
All stations must monitor the headers of all frames they receive and store the NAV value in a counter. The counter decrements in steps of one microsecond. When the counter reaches zero, the channel is available again.

Wireless medium access (8)



When a station wants to send a frame and the channel has been idle for a time > DIFS (counted from the moment the station first probed the channel) => can send immediately.

Wireless medium access (9)

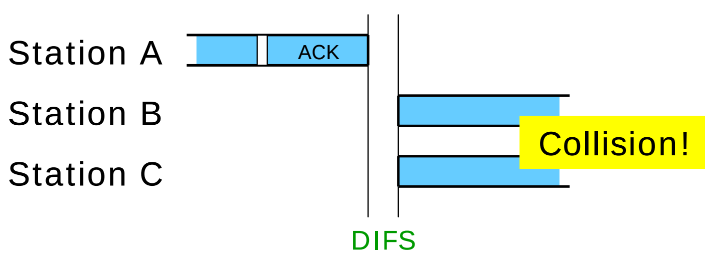


When a station wants to send a frame and the channel is busy => the station must wait a backoff time before it is allowed to transmit the frame. Reason? Next two slides...

No backoff => collision is certain

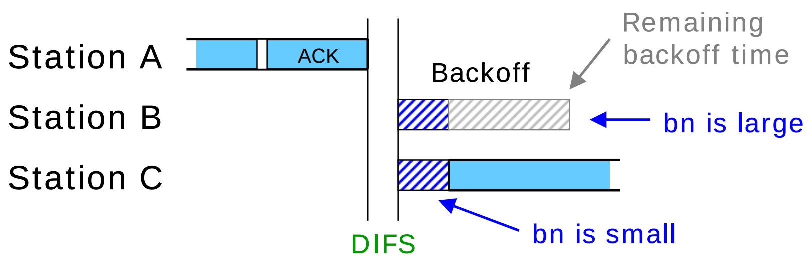
Suppose that several stations (B and C in the figure) are waiting to access the wireless medium.

When the channel becomes idle, these stations start sending their packets at the same time => collision!



Backoff => collision probability is reduced

Contending stations generate random backoff values bn. Backoff counters count downwards, starting from bn. When a counter reaches zero, the station is allowed to send its frame. All other counters stop counting until the channel becomes idle again.



Usage of RTS & CTS

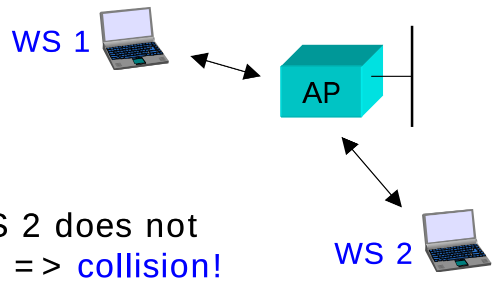
The RTS/CTS (Request/Clear To Send) scheme is used as a countermeasure against the "hidden node" problem:

Hidden node problem:

WS 1 and WS 2 can "hear" the AP but not each other

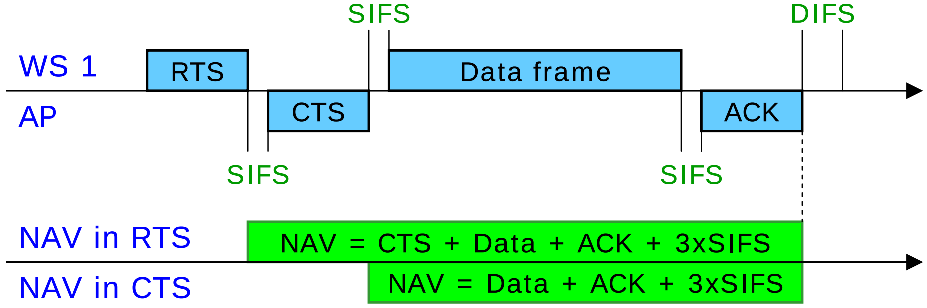
=>

If WS 1 sends a packet, WS 2 does not notice this (and vice versa) => collision!



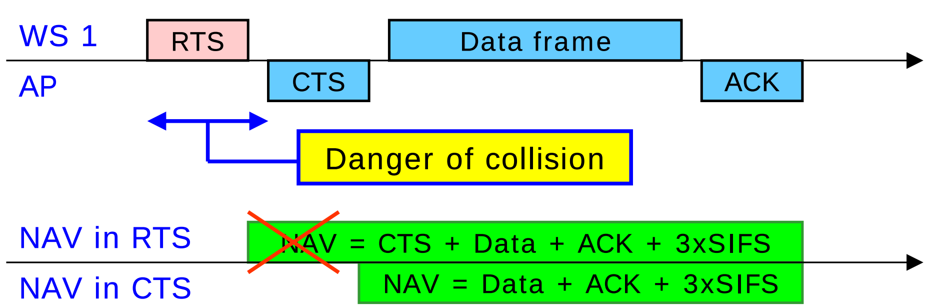
Reservation of medium using NAV

The RTS/CTS scheme makes use of “SIFS-only” and the NAV (Network Allocation Vector) to reserve the medium:



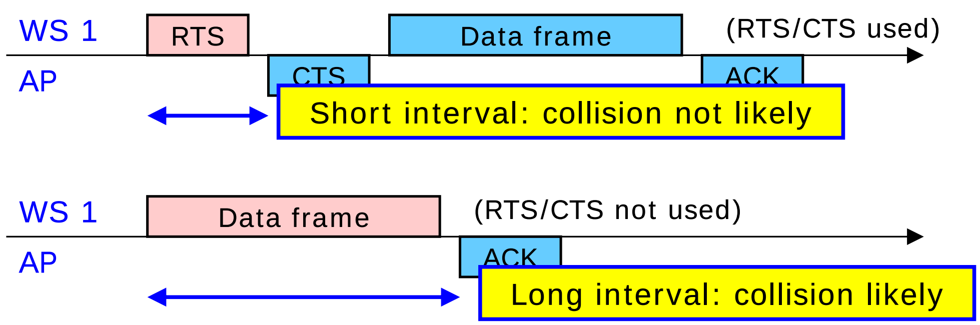
Danger of collision only during RTS

WS 2 does not hear the RTS frame (and associated NAV), but can hear the CTS frame (and associated NAV).



Advantage of RTS & CTS (1)

Usage of RTS/CTS offers an advantage if the data frame is very long compared to the RTS frame:



Advantage of RTS & CTS (2)

A long "collision danger" interval (previous slide) should be avoided for the following reasons:

- Larger probability of collision
- Greater waste of capacity if a collision occurs and the frame has to be retransmitted.

A threshold parameter (dot11RTSThreshold) can be set in the wireless station. Frames shorter than this value will be transmitted without using RTS/CTS.

Worldwide Interoperability for Microwave Access (WiMAX)

IEEE 802.16

The standard IEEE 802.16 defines the air interface, including the MAC layer and multiple PHY layer options, for fixed Broadband Wireless Access (BWA) systems to be used in a Wireless Metropolitan Area Network (WMAN) for residential and enterprise use. IEEE 802.16 is also often referred to as WiMax. The WiMax Forum strives to ensure interoperability between different 802.16 implementations - a difficult task due to the large number of options in the standard.

IEEE 802.16 cannot be used in a mobile environment. For this purpose, IEEE 802.16e is being developed. This standard will compete with the IEEE 802.20 standard (still in early phase).

IEEE 802.16 standardization

The first version of the IEEE 802.16 standard was completed in 2001. It defined a single carrier (SC) physical layer for line-of-sight (LOS) transmission in the 10-66 GHz range.

IEEE 802.16a defined three physical layer options (SC, OFDM, and OFDMA) for the 2-11 GHz range.

IEEE 802.16d contained upgrades for the 2-11 GHz range.

In 2004, the original 802.16 standard, 16a, and 16d were combined into the massive IEEE 802.16-2004 standard.

Uplink / downlink separation

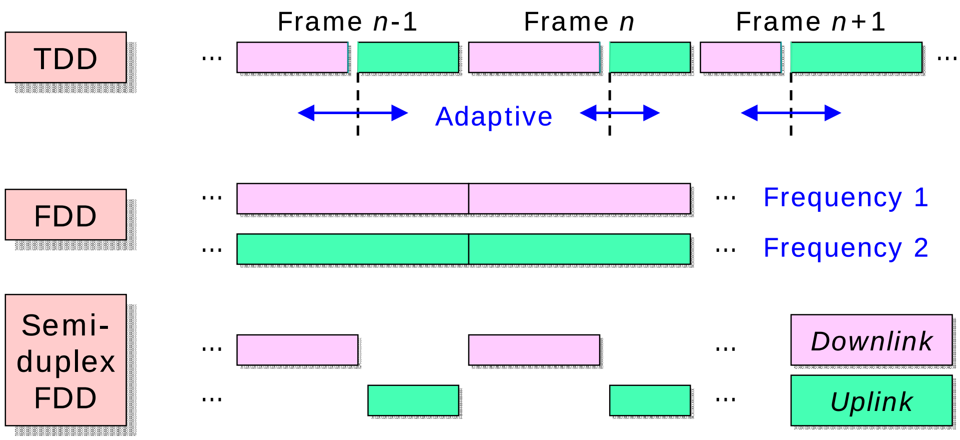
IEEE 802.16 offers both TDD (Time Division Duplexing) and FDD (Frequency Division Duplexing) alternatives.

Wireless devices should avoid transmitting and receiving at the same time, since duplex filters increase the cost:

- TDD: this problem is automatically avoided
- FDD: IEEE 802.16 offers semi-duplex operation as an option in Subscriber Stations.

(Note that expensive duplex filters are also the reason why IEEE 802.11 WLAN technology is based on CSMA/CA instead of CSMA/CD.)

Uplink / downlink separation

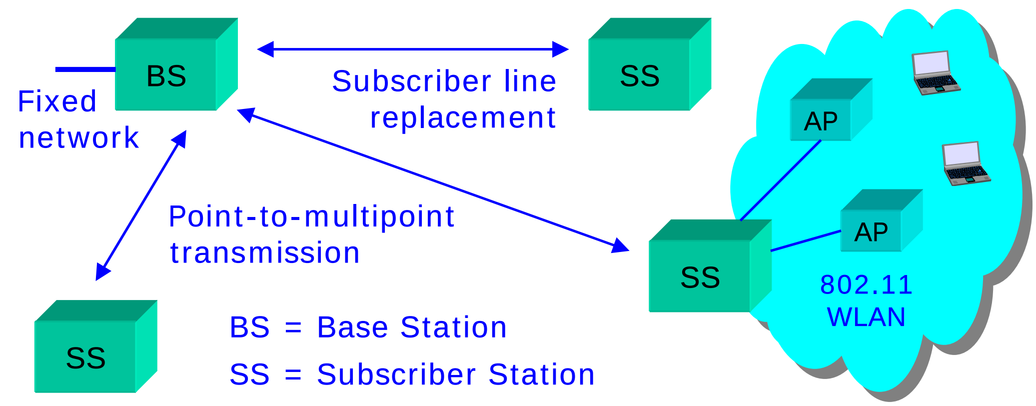


IEEE 802.16 PHY

IEEE 802.16-2004 specifies three PHY options for the 2-11 GHz band, all supporting both TDD and FDD:

- WirelessMAN-SCa (single carrier option), intended for a line-of-sight (LOS) radio environment where multipath propagation is not a problem
- WirelessMAN-OFDM with 256 subcarriers (mandatory for license-exempt bands) will be the most popular option in the near future
- WirelessMAN-OFDMA with 2048 subcarriers separates users in the uplink in frequency domain (complex technology).

IEEE 802.16 basic architecture



Overall TDD frame structure (1)

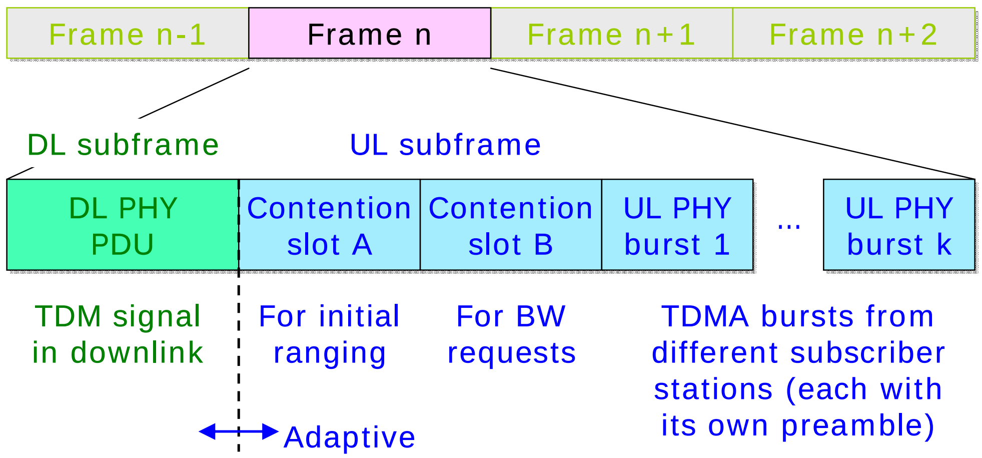
The following slides present the overall IEEE 802.16 frame structure for TDD.

It is assumed that the PHY option is WirelessMAN-OFDM, since this presumably will be the most popular PHY option (in the near future). The general frame structure is applicable also to other PHY options, but the details may be different.

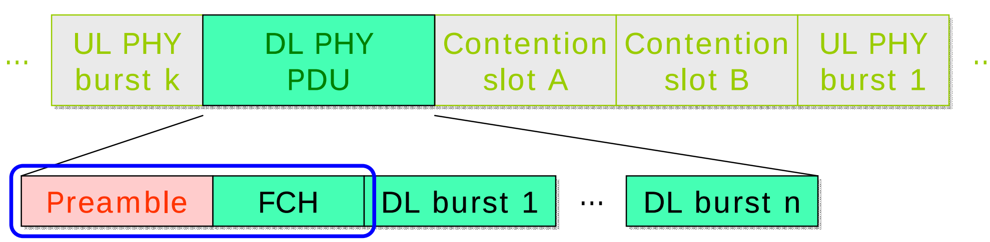
Frame n-1	Frame n	Frame n+1	Frame n+2

Frame length 0.5, 1 or 2 ms

Overall TDD frame structure (2)

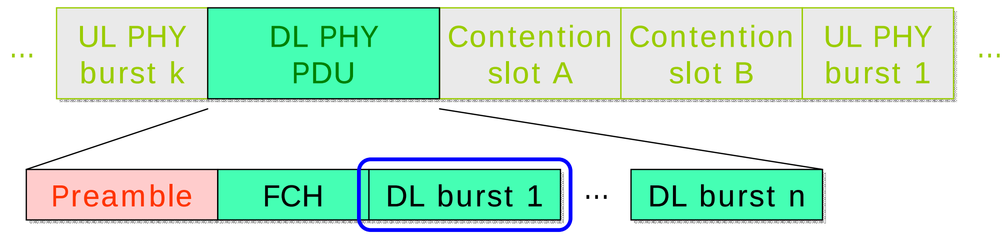


DL subframe structure (1)



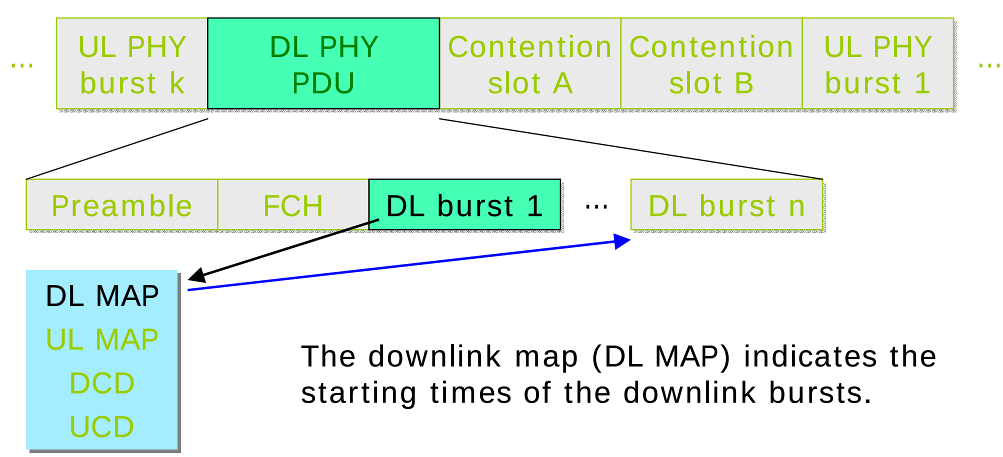
The DL subframe starts with a preamble (necessary for frame synchronization and equalization) and the Frame Control Header (FCH) that contains the location and burst profile of the first DL burst following the FCH. The FCH is one OFDM symbol long and is transmitted using BPSK modulation.

DL subframe structure (2)



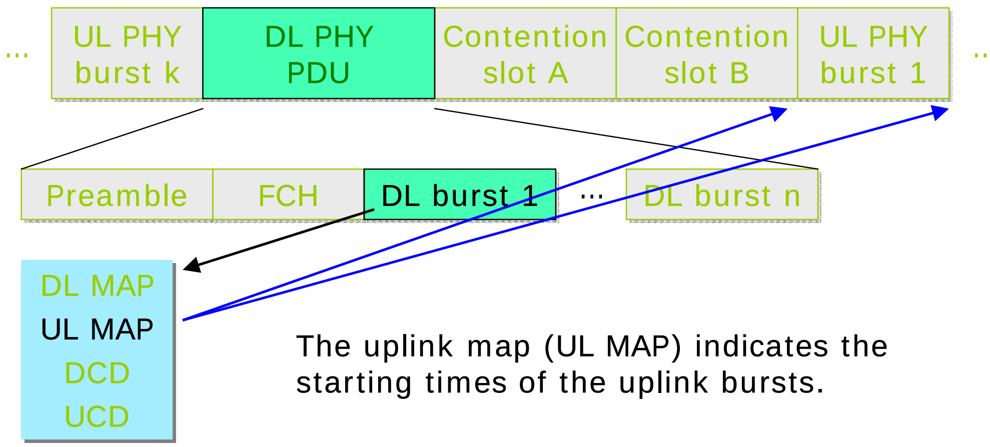
The first burst in downlink contains the downlink and uplink maps (DL MAP & UL MAP) and downlink and uplink channel descriptors (DCD & UCD). These are all contained in the first MAC PDU of this burst. The burst may contain additional MAC PDUs.

DL subframe structure (3)



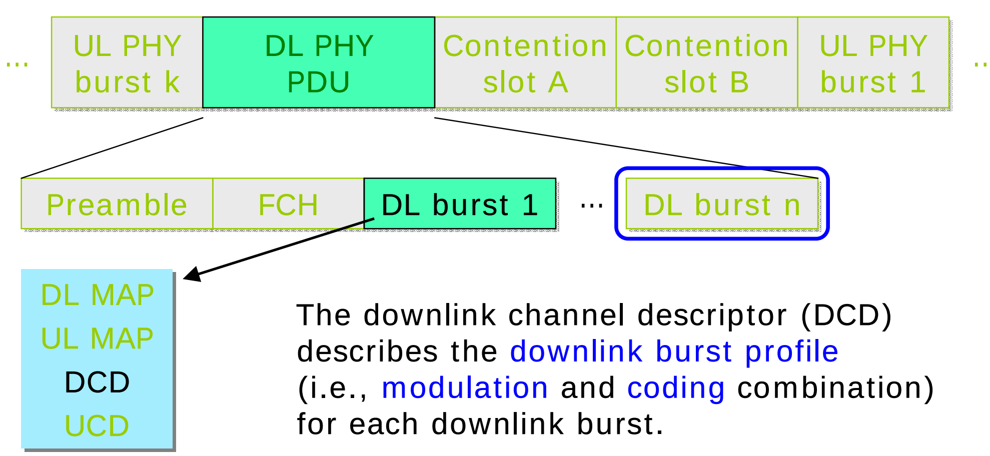
The downlink map (DL MAP) indicates the starting times of the downlink bursts.

DL subframe structure (4)



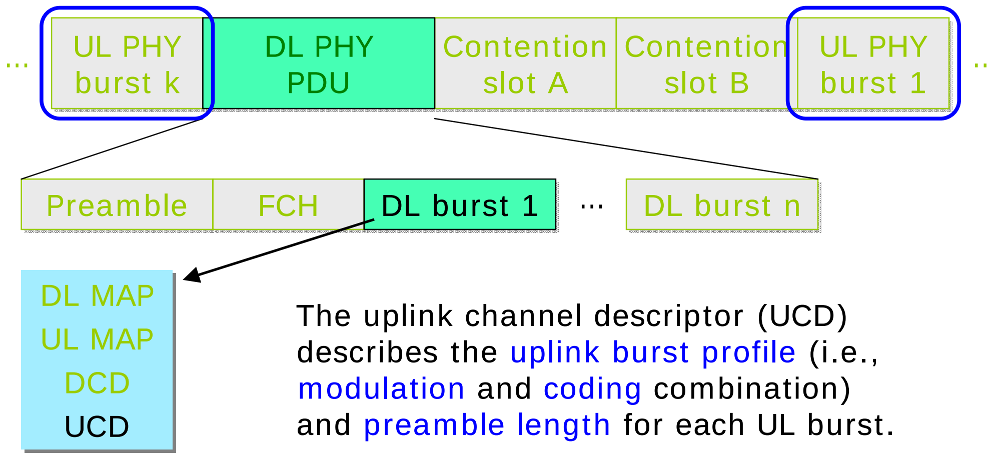
The uplink map (UL MAP) indicates the starting times of the uplink bursts.

DL subframe structure (5)



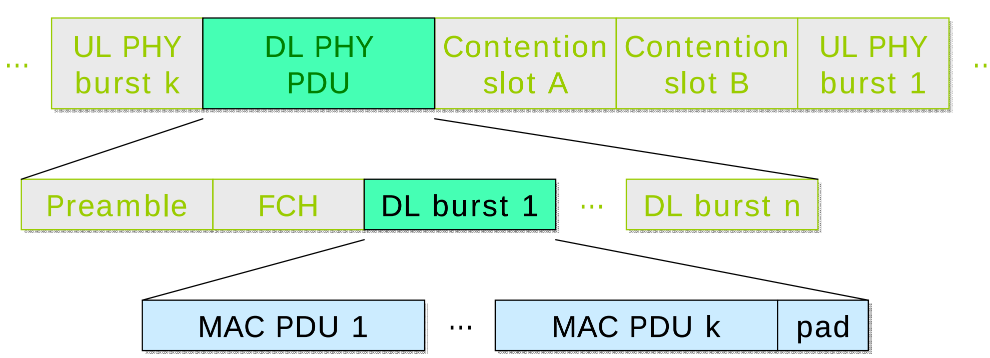
The downlink channel descriptor (DCD) describes the downlink burst profile (i.e., modulation and coding combination) for each downlink burst.

DL subframe structure (6)



The uplink channel descriptor (UCD) describes the uplink burst profile (i.e., modulation and coding combination) and preamble length for each UL burst.

DL subframe structure (10)



IEEE 802.16 offers concatenation of several MAC PDUs within a single transmission burst.

UL subframe structure (1)

DL PHY PDU	Contention slot A	Contention slot B	UL PHY burst 1	...	UL PHY burst k

The uplink subframe starts with a contention slot that offers subscriber stations the opportunity for sending initial ranging messages to the base station.

A second contention slot offers subscriber stations the opportunity for sending bandwidth request messages to the base station.

UL subframe structure (2)

DL PHY PDU	Contention slot A	Contention slot B	UL PHY burst 1	...	UL PHY burst k

The usage of bandwidth request messages in this contention slot (and response messages in downlink bursts) offers a mechanism for achieving extremely flexible and dynamical operation of IEEE 802.16 systems.

Bandwidth (corresponding to a certain modulation and coding combination) can be adaptively adjusted for each burst to/from each subscriber station on a per-frame basis.

Four service classes

The IEEE 802.16 MAC layer defines four service classes:

- Unsolicited Grant Service (UGS)
- Real-time Polling Service (rtPS)
- Non-real-time Polling Service (nrtPS)
- Best Effort (BE) service

QoS increases

The scheduling algorithms needed for implementing the three first types of services are implemented in the BS (while allocating uplink bandwidth to each SS) and are not defined in the 802.16 standard. Each SS negotiates its service policies with the BS at the connection setup time.

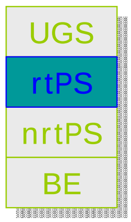
Unsolicited grant service (UGS)

UGS
rtPS
nrtPS
BE

UGS offers fixed size grants on a real-time periodic basis, which eliminates the overhead and latency of SS requests and assures that grants are available to meet the flow's real-time needs. The BS provides fixed size bursts in the uplink at periodic intervals for the service flow. The burst size and other parameters are negotiated at connection setup.

Typical UGS applications: E1/T1 links (containing e.g. delay-sensitive speech signals), VoIP (without silence suppression).

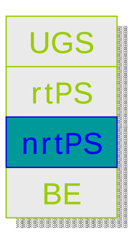
Real-time Polling Service (rtPS)



The Real-time Polling Service (rtPS) is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as VoIP (with silence suppression) or streaming video.

This service offers real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired uplink transmission burst. This service requires more request overhead than UGS, but supports variable grant sizes for optimum data transport efficiency.

Non-real-time Polling Service (nrtPS)



The Non-real-time Polling Service (nrtPS) is designed to support non-real-time service flows that require variable size bursts in the uplink on a regular (but not strictly periodic) basis.

Subscriber stations contend for bandwidth (for uplink transmission) during contention request opportunities. The availability of such opportunities is guaranteed at regular intervals (on the order of one second or less) irrespective of network load.

Best Effort (BE) service

UGS
rtPS
nrtPS
BE

The Best Effort service is intended to be used for best effort traffic where no throughput or delay guarantees are provided.

Subscriber stations contend for bandwidth (for uplink transmission) during contention request opportunities. The availability of such opportunities depends on network load and is not guaranteed (in contrast to nrtPS).

Radio Link Control in IEEE 802.16

The main task of Radio Link Control (RLC) in IEEE 802.16 systems is to provide dynamic changing of UL and DL burst profiles on a per-connection and per-frame basis, depending on radio channel characteristics and QoS requirements.

As an example, RLC provides signaling for initial access (ranging) and bandwidth allocation in the downlink direction:

- Ranging request (RNG-REQ) from SS to BS
- Ranging response (RNG-RSP) from BS to SS
- Bandwidth requests (DBPC-REQ) from SS to BS
- Bandwidth confirmation (DBPC-RSP) from BS to SS

Initial access (initial ranging)

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

During initial access, the SS sends a ranging request message in the contention slot reserved for this purpose, among others indicating which kind of DL burst profile should be used.

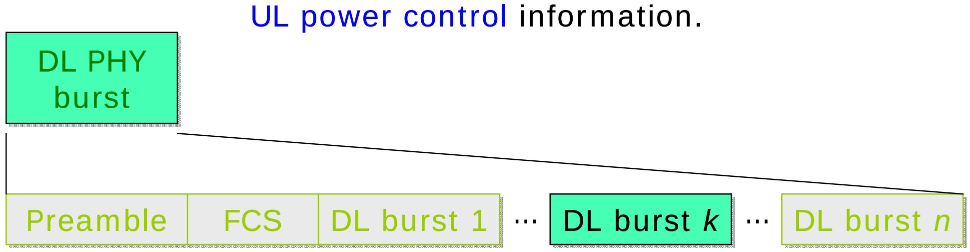
Note: There is the possibility of collision since other subscriber stations also send ranging request messages in this contention slot.

Initial access (initial ranging)

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

In response to the RNG-REQ message, the BS returns a ranging response message in a DL burst with a sufficiently robust burst profile.

This message includes the timing advance value for correct alignment of bursts in UL, as well as UL power control information.



DL burst profile change

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

The SS continuously measures the radio channel quality. If there is a need for change in DL burst profile, the SS sends a DL burst profile change request message in the contention slot reserved for this purpose, indicating the desired new DL burst profile.

DL burst profile change

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

In response to the DBPC-REQ message, the BS returns a DL burst profile change response message confirming the new burst profile.

This is done in a DL burst with the old burst profile (when changing to a less robust DL burst profile) or using the new burst profile (when changing to a more robust DL burst profile).