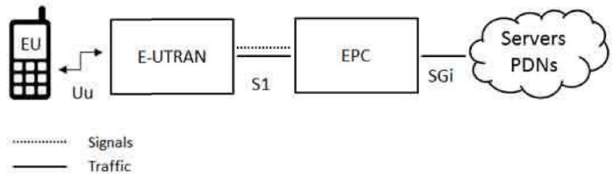
Introduction to LTE (4G)

- The high-level network architecture of LTE is comprised of following three main components:
- The User Equipment (UE).
- The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).
- The Evolved Packet Core (EPC).



Introduction to LTE (4G)

- The evolved packet core communicates with **packet data networks** in the outside world such as the internet, private corporate networks.
- The interfaces between the different parts of the system are denoted Uu, S1 and SGi .
- **The User Equipment (UE)**
  - Mobile Termination (MT)
  - Terminal Equipment (TE)
  - Universal Integrated Circuit Card (UICC)
- **The E-UTRAN (The access network)**
  - UMTS Terrestrial Radio Access Network (E-UTRAN)
  - E-UTRAN handles the radio communications between the mobile and the evolved packet core just has one component, the evolved base stations, called **eNodeB** or **eNB**

Introduction to LTE (4G)

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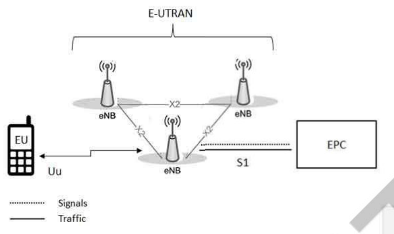

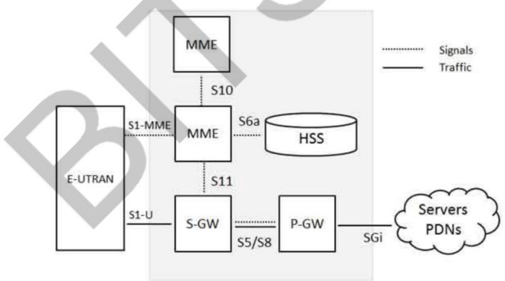

Introduction to LTE (4G)

- The architecture of Evolved Packet Core (EPC) has
  - The Home Subscriber Server (HSS):
    - Contains information about all the network operator's subscribers.
  - The Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world
  - The serving gateway (S-GW) acts as a router.
  - The mobility management entity (MME) controls the high-level operation of the mobile
  - The Policy Control and Charging Rules Function (PCRF)
    - responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities

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Introduction to LTE (4G)

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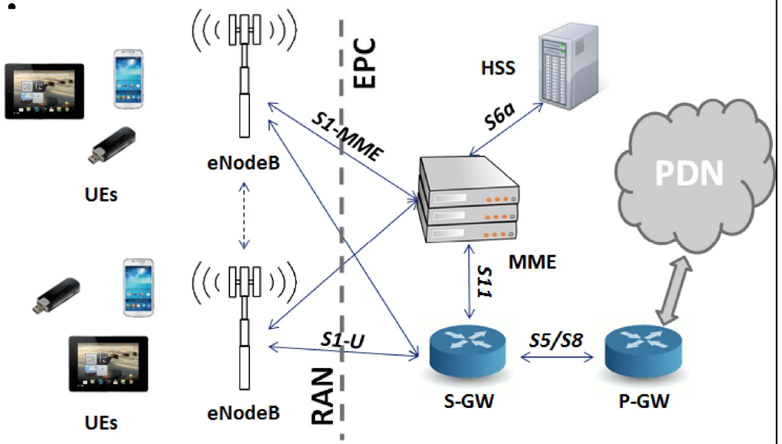

Introduction to LTE (4G)

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	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE
Max downlink speed bps	384 k	14 M	28 M	100M
Max uplink speed bps	128 k	5.7 M	11 M	50 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

Design Principles

- LTE standard was designed as a completely new standard with **new numbering** and **new documentation**
- **Network Architecture**
- LTE was designed to support packet-switched traffic with support for various QoS.
- LTE is a clean slate design and supports packet switching for high data rate services from the start.
- The LTE radio access network, E-UTRAN, was designed to have the minimum number of interfaces, while still being able to provide efficient packet-switched traffic

Design Principles

- **Data Rate and Latency**:
- The design target for downlink and uplink peak data rates for LTE are 100 Mbps and 50 Mbps when operating at the 20MHz frequency division duplex (FDD) channel size.
- The **user-plane latency** is defined in terms of the **time** it takes to **transmit a small IP packet from the UE to the edge node(eNB)** of the radio access network or vice versa.
- Transition time between a **dormant state** and an **active state** should be less than 50 ms

Design Principles

- **Performance Requirements**
- The target performance requirements for LTE are specified in terms of **spectrum efficiency**, **mobility**, and **coverage**
  - **Spectrum Efficiency**
    - The average **downlink user data rate** and spectrum efficiency target is **three to four times** that of the baseline HSDPA network
    - The **uplink the average user data rate** and spectrum efficiency target is **two to three times** that of the baseline HSUPA network
  - **Mobility**
    - The mobility requirement for LTE is to be able to support hand-off/mobility at different terminal speeds.
    - 0 - 15 km/h (optimised), 15 - 120 km/h (high performance)
    - LTE is expected to be able to sustain a connection for terminal speeds up to 350 km/hr but with significant degradation
  - **Coverage**
    - For cell ranges up to 30 km, a slight degradation of the user throughput is tolerated

Design Principles

- **Multimedia Broadcast and Multicast Service (MBMS) Service**
- LTE should also provide enhanced support for the Multimedia Broadcast and Multicast Service (MBMS)
- Designed to provide efficient delivery of broadcast and multicast services, both within a cell as well as within the core network

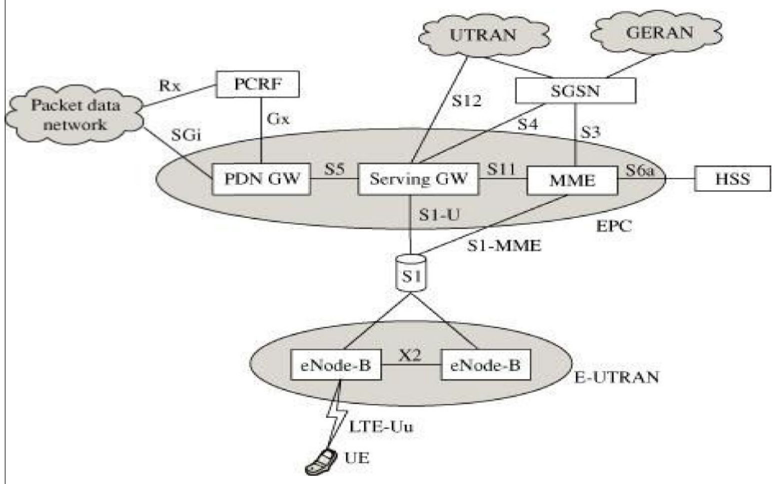
Design Principles

- **Radio Resource Management**
- The radio resource management requirements cover various aspects such as
  - Enhanced support for end-to-end QoS.
  - Efficient support for transmission of higher layers
  - Support for load sharing/balancing and
  - Policy management/enforcement across different radio access technologies.
- **Deployment Scenario and Co-existence with 3G**
- LTE shall support the following two deployment scenarios
  - Standalone deployment scenario, where the operator deploys LTE either with no previous network deployed in the area or with no requirement for interworking with the existing UTRAN/GERAN(GSM EDGE radio access)

Design Principles

- **Interoperability with 3G and 2G Networks**
  - Multimode LTE terminals, which support UTRAN and/or GERAN operation, should be able to support measurement of, and handover from and to, both 3GPP UTRAN and 3GPP GERAN systems with acceptable terminal complexity

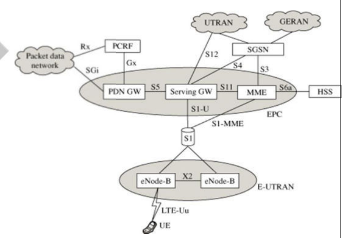
LTE - Network Architecture



LTE End-to-End network architecture of LTE

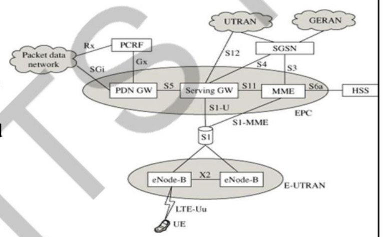
LTE - Network Architecture

- **UE:** The mobile terminal.
- **eNode-B:**
  - Also called the base station, terminates the air interface protocol and is the first point of contact for the UE
  - eNode-B is the only logical node in the E-UTRAN, so it includes some functions
    - Radio bearer management,
    - Uplink and downlink dynamic radio resource management and
    - Data packet scheduling, and
    - Mobility management.
- **Mobility Management Entity (MME):**
  - It manages mobility aspects in 3GPP access such as gateway selection and tracking area list management.



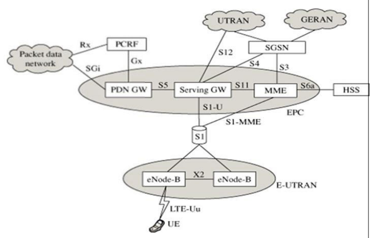
LTE - Network Architecture

- **Serving Gateway (Serving GW):**
  - The Serving GW terminates the interface toward E-UTRAN, and routes data packets between E-UTRAN and EPC
  - Anchor point for inter-eNode-B handovers
- **Packet Data Network Gateway (PDN GW):**
  - The PDN GW terminates the SGi interface toward the Packet Data Network (PDN).
  - It routes data packets between the EPC and the external PDN
- **S1 Interface:**
  - It is the interface that separates the E-UTRAN and the EPC.
  - It is split into two parts:
    - The <u>**S1-U**</u>, which carries traffic data between the eNode-B and the Serving GW, and
    - The <u>**S1-MME**</u>, which is a signaling-only interface between the eNode-B and the MME.



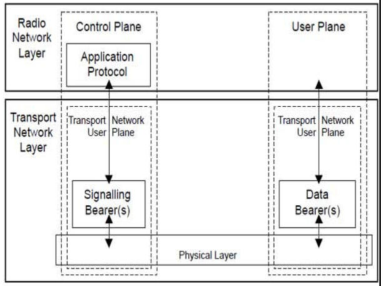
LTE - Network Architecture

- **X2 Interface:**
- The interface between eNode-Bs, consisting of two parts:
- The X2-C is the **control plane** interface between eNode-Bs, while
- The X2-U is the **user plane** interface between eNode-Bs.



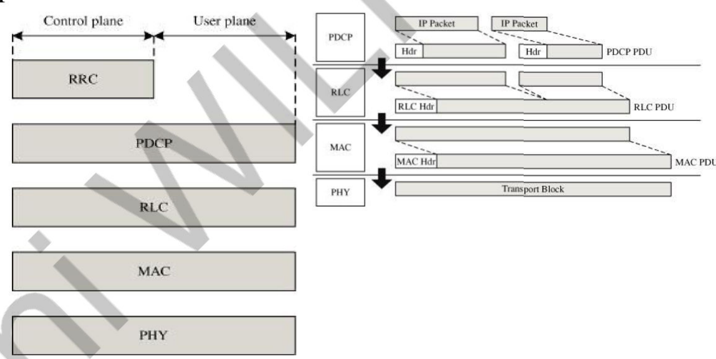
LTE - Network Architecture

- At user plane side, the application creates data packets that are processed by protocols such as TCP, UDP and IP
- The control plane, the radio resource control (RRC) protocol writes the signaling messages that are exchanged between the base station and the mobile.



Radio Interface Protocols

- As in other communication standards, the LTE radio interface is designed based on a layered protocol stack, which can be divided into control plane and user plane protocol stacks



Radio Interface Protocols

- **Radio Resource Control (RRC):**
- The RRC layer performs the control plane functions including **paging**, **maintenance** and **release of an RRC connection, security handling**, **mobility management**, and **QoS management**.
- **Packet Data Convergence Protocol (PDCP):**
- The main functions of the PDCP sublayer include
  - IP packet header compression and decompression
  - Ciphering of data and signaling, and integrity protection for signaling.
- There is only one PDCP entity at the eNode-B and the UE

Radio Interface Protocols

- **Radio Link Control (RLC):**
- The main functions of the RLC sublayer are
  - Segmentation and concatenation of data units,
  - Error correction through the Automatic Repeat reQuest (ARQ) protocol, and
  - In-sequence delivery of packets to the higher layers.
- It operates in three modes:
  - **The Transparent Mode (TM):**
    - The TM mode is the simplest one, it is used for specific purposes such as random access.
  - **The Unacknowledged Mode (UM):**
    - The UM mode allows the detection of packet loss and provides packet reordering and reassembly, but does not require retransmission of the missing protocol data units (PDUs).
  - **The Acknowledged Mode (AM):**
    - The AM mode is the most complex one, and it is configured to request retransmission of the missing PDUs in addition to the features supported by the UM mode.
- There is only one RLC entity at the eNode-B and the UE

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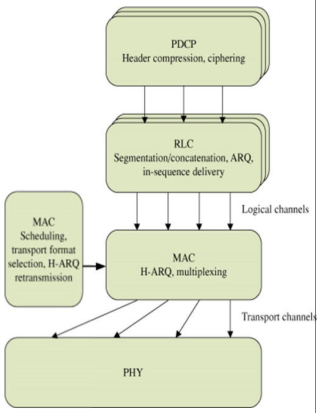
Radio Interface Protocols

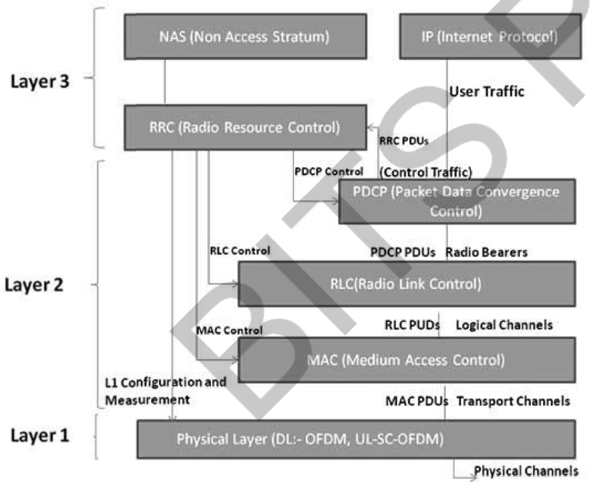
- **Medium Access Control (MAC):**
- The main functions of the MAC sublayer include
  - Error correction through the Hybrid-ARQ (H-ARQ) mechanism
  - Mapping between logical channels and transport channels
  - Multiplexing/demultiplexing of RLC PDUs on to transport blocks
  - Priority handling between logical channels of one UE, and
  - Priority handling between UEs by means of dynamic scheduling
- **Physical Layer (PHY):**
- The main function of PHY is
  - The actual transmission and reception of data in forms of transport blocks.
  - The PHY is also responsible for various control mechanisms such as signaling of H-ARQ feedback,
  - Signaling of scheduled allocations, and
  - Channel measurements.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- To efficiently support various QoS classes of services, LTE adopts a hierarchical channel structure.
- There are three different channel types defined in LTE
  1. Logical channels
  2. Transport channels, and
  3. Physical channels
- Each associated with a service access point (SAP) between different layers.
- These channels are used by the lower layers of the protocol stack to provide services to the higher layers
- **Logical channels** provide services at the SAP between MAC and RLC layers
- **Transport channels** provide services at the SAP between MAC and PHY layers.
- **Physical channels** are the actual implementation of transport channels over the radio interface.



HIERARCHICAL CHANNEL STRUCTURE OF LTE



HIERARCHICAL CHANNEL STRUCTURE OF LTE

- ***Logical Channels: What to Transmit***
- Logical channels are used by the MAC to provide services to the RLC
- Each logical channel is defined based on the type of information it carries.
- There are two categories of logical channels depending on the service they provide:
  - ***logical control channels*** and ***logical traffic channel***
- The logical control channels, which are **used to transfer control plane information**

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HIERARCHICAL CHANNEL STRUCTURE OF LTE

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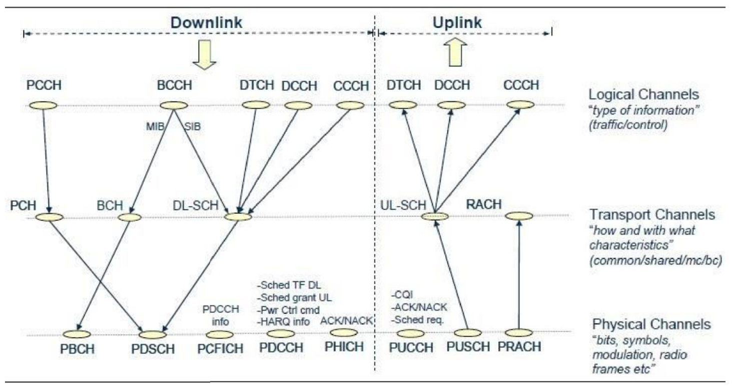
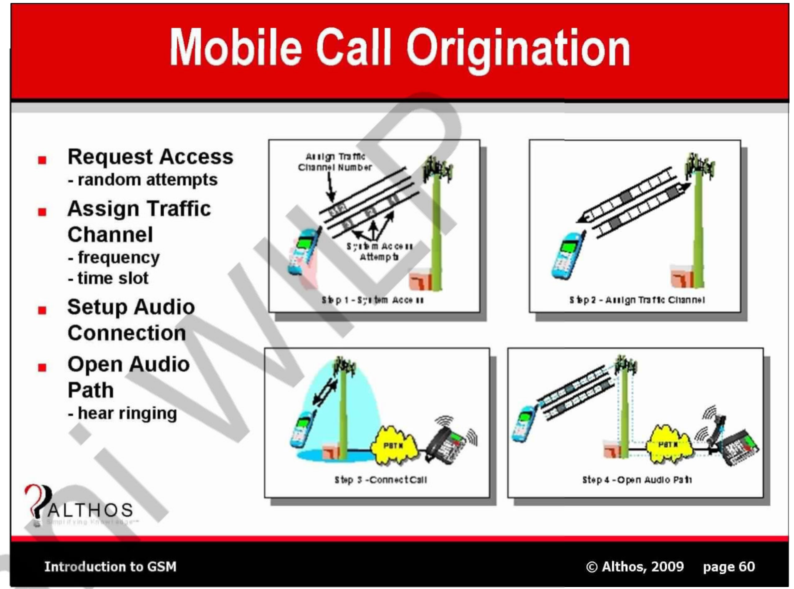
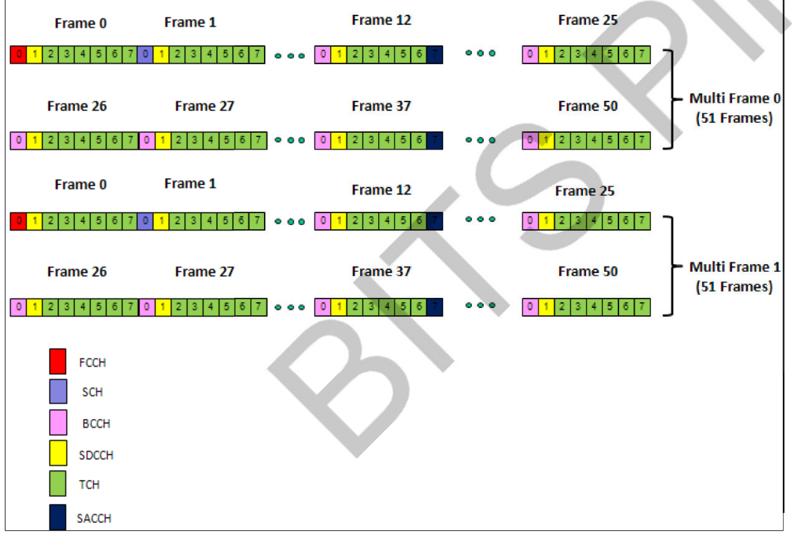




HIERARCHICAL CHANNEL STRUCTURE OF LTE



HIERARCHICAL CHANNEL STRUCTURE OF LTE

- ***Logical Control plane Channels***
- **Broadcast Control Channel (BCCH):**
  - A downlink common channel used to broadcast system control information to the mobile terminals in the cell.
  - Includes downlink system bandwidth, antenna configuration, and reference signal power
- **Multicast Control Channel (MCCH):**
  - A point-to-multipoint downlink channel used for transmitting control information to UEs in the cell.
- **Paging Control Channel (PCCH):**
  - A downlink channel that transfers paging information to registered UEs in the cell
- **Common Control Channel (CCCH):**
  - A bi-directional channel for transmitting control information between the network and UEs when no RRC connection is available i.e. UE is not attached to the network

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- ***Logical Control Channels***
- **Dedicated Control Channel (DCCH):**
  - A point-to-point, bi-directional channel that transmits dedicated control information between a UE and the network.
  - This channel is used when the RRC connection is available, i.e. the UE is attached to the network
- ***Logical traffic channels***
- **Dedicated Traffic Channel (DTCH):**
  - A point-to-point, bi-directional channel used between a given UE and the network.
  - It can exist in both uplink and downlink.
- **Multicast Traffic Channel (MTCH):**
  - A unidirectional, point-to-multipoint data channel that transmits traffic data from the network to UEs.
  - It is associated with the multicast/broadcast service

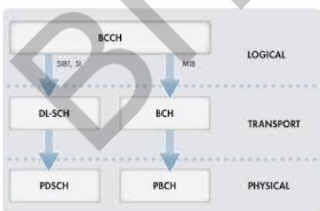
HIERARCHICAL CHANNEL STRUCTURE OF LTE

- ***Logical Control Channels***

Channel Name	Acronym	Control channel	Traffic channel
Broadcast Control Channel	BCCH	X	
Paging Control Channel	PCCH	X	
Common Control Channel	CCCH	X	
Dedicated Control Channel	DCCH	X	
Multicast Control Channel	MCCH	X	
Dedicated Traffic Channel	DTCH		X
Multicast Traffic Channel	MTCH		X

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Transport Channels: How to Transmit?**
- The transport channels are used by the PHY to offer services to the MAC
- A transport channel is basically characterized by how and with what characteristics data is transferred over the radio interface (channel coding scheme, the modulation scheme, and antenna mapping)
- LTE defines two MAC entities: one in the UE and one in the E-UTRAN



HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Transport Channels: Downlink Transport Channels**
- **Downlink Shared Channel (DL-SCH):**
  - Used for transmitting the downlink data, including both control and traffic data.
  - It is associated with both logical control and logical traffic channels.
  - It supports *H-ARQ*, *dynamic link adaption*, *dynamic and semi-persistent resource allocation*, *UE discontinuous reception*, and *multicast/broadcast transmission.*
  - *DL-SCH is able to maximize the throughput by allocating the resources to the optimum UEs*
- **Broadcast Channel (BCH):**
  - A downlink channel associated with the BCCH logical channel and is used to broadcast system information over the entire coverage area of the cell

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Transport Channels: Downlink Transport Channels**
- **Multicast Channel (MCH):**
  - Associated with MCCH and MTCH logical channels for the multicast/broadcast service.
  - It supports Multicast/Broadcast Single Frequency Network (MBSFN) transmission, which transmits the same information on the same radio resource from multiple synchronized base stations to multiple UEs.
- **Paging Channel (PCH):**
  - Associated with the PCCH logical channel.
  - It is mapped to dynamically allocated physical resources, and is required for broadcast over the entire cell coverage area.
  - It is transmitted on the Physical Downlink Shared Channel (PDSCH), and supports UE discontinuous reception.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Transport Channels: Uplink Transport Channels**
- **Uplink Shared Channel (UL-SCH):**
- The uplink counterpart of the DL-SCH
- It can be associated to CCCH, DCCH, and DTCH logical channels.
- It supports H-ARQ, dynamic link adaption, and dynamic and semi-persistent resource allocation
- **Random Access Channel (RACH):**
- A specific transport channel that is not mapped to any logical channel.
- It transmits relatively small amounts of data for initial access.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Transport Channels:**
-

Channel Name	Acronym	Downlink	Uplink
Broadcast Channel	BCH	X	
Downlink Shared Channel	DL-SCH	X	
Paging Channel	PCH	X	
Multicast Channel	MCH	X	
Uplink Shared Channel	UL-SCH		X
Random Access Channel	RACH		X

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- The data on each transport channel is organized into *transport blocks*, and the transmission time of each transport block, also called Transmission Time Interval (TTI)
- Besides transport channels, there are different types of control information defined in the MAC layer.
- The defined control information includes:
- **Downlink Control Information (DCI):**
- It carries information related to **downlink/uplink scheduling assignment**, **modulation** and **coding scheme**, and **Transmit Power Control** (TPC) command

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Downlink Control Information (DCI):**
-

Format	Carried Information
Format 0	Uplink scheduling assignment
Format 1	Downlink scheduling for one codeword
Format 1A	Compact downlink scheduling for one codeword and random access procedure
Format 1B	Compact downlink scheduling for one codeword with precoding information
Format 1C	Very compact downlink scheduling for one codeword
Format 1D	Compact downlink scheduling for one codeword with precoding and power offset information
Format 2	Downlink scheduling for UEs configured in closed-loop spatial multiplexing mode
Format 2A	Downlink scheduling for UEs configured in open-loop spatial multiplexing mode
Format 3	TPC commands for PUCCH and PUSCH with 2-bit power adjustments
Format 3A	TPC commands for PUCCH and PUSCH with 1-bit power adjustments

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Control Format Indicator (CFI):**
- It indicates how many symbols the DCI spans in that subframe.
- It takes values CFI = 1, 2, or 3
- **H-ARQ Indicator (HI):**
- It carries H-ARQ acknowledgment in response to uplink transmissions
- HI = 1 for a positive acknowledgment (ACK)
- **Uplink Control Information (UCI):**
- It is for measurement indication on the downlink transmission, scheduling request of uplink, and the H-ARQ acknowledgment of downlink transmissions

HIERARCHICAL CHANNEL STRUCTURE OF LTE

-

Field Name	Acronym	Downlink	Uplink
Downlink control information	DCI	X	
Control format indicator	CFI	X	
Hybrid ARQ indicator	HI	X	
Uplink control information	UCI		X

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels: Actual Transmission**
- Each physical channel corresponds to a set of resource elements in the time-frequency grid that carry information from higher layers.
- The basic entities that make a physical channel are resource elements and resource blocks.
- A **resource element** is a single subcarrier over one OFDM symbol.
- A **resource block** is a collection of resource elements and in the frequency domain this represents the smallest quanta of resources that can be allocated

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels: Actual Transmission**
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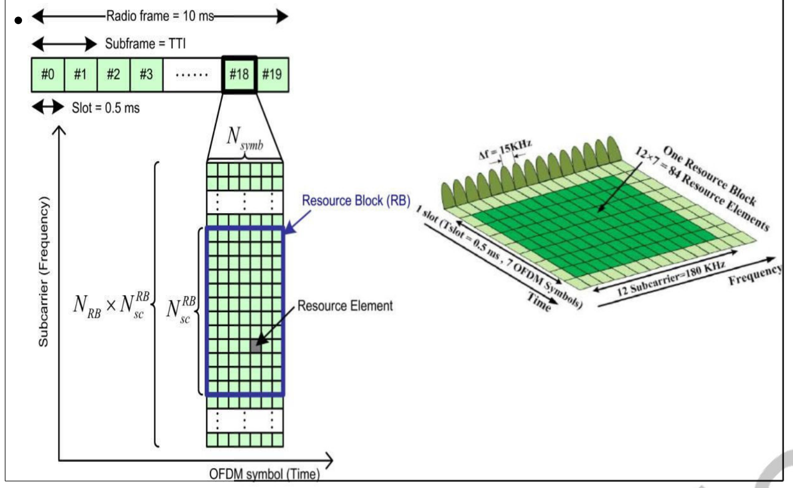


HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels: Downlink Physical Channels**
- **Physical Downlink Control Channel (PDCCH):**
- It carries information about the transport format and resource allocation related to the DL-SCH and PCH transport channels, and the H-ARQ information related to the DL-SCH
- It also informs the UE about the transport format, resource allocation, and H-ARQ information related to UL-SCH
- **Physical Downlink Shared Channel (PDSCH):**
- This channel carries user data and higher-layer signaling
- **Physical Broadcast Channel (PBCH):**
- It corresponds to the BCH transport channel and carries system information

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels: Downlink Physical Channels**
- **Physical Multicast Channel (PMCH):**
- It carriers multicast/broadcast information for the MBMS service.
- **Physical Hybrid-ARQ Indicator Channel (PHICH):**
- This channel carries H-ARQ ACK/NAKs associated with uplink data transmissions
- **Physical Control Format Indicator Channel (PCFICH):**
- It informs the UE about the number of OFDM symbols used for the PDCCH. It is mapped from the CFI transport channel.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels: Uplink Physical Channels**
- **Physical Uplink Control Channel (PUCCH):**
- It carries uplink control information including Channel Quality Indicators (CQI), ACK/NAKs for H-ARQ in response to downlink transmission, and uplink scheduling requests.
- **Physical Uplink Shared Channel (PUSCH):**
- It carries user data and higher-layer signaling
- **Physical Random Access Channel (PRACH):**
- This channel carries the random access preamble sent by UEs.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Physical Channels:**

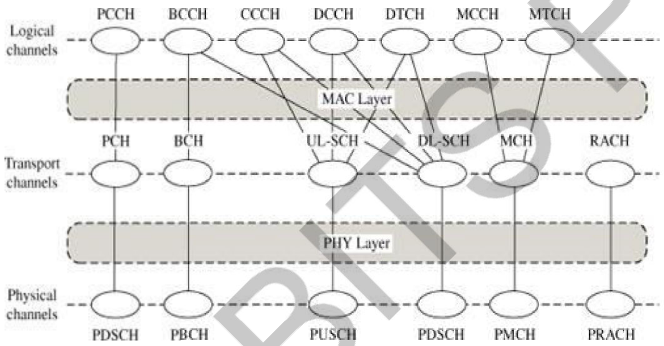
Channel Name	Acronym	Downlink	Uplink
Physical downlink shared channel	PDSCH	X	
Physical broadcast channel	PBCH	X	
Physical multicast channel	PMCH	X	
Physical uplink shared channel	PUSCH		X
Physical random access channel	PRACH		X

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Channel Mapping**
- **Types of Information**
- Broadcast Information - BCCH
- Signaling Information – CCCH, DCCH
- Application Data - DTCH
- Paging – PCCH
- Multicast – MCCH, MTCH

HIERARCHICAL CHANNEL STRUCTURE OF LTE

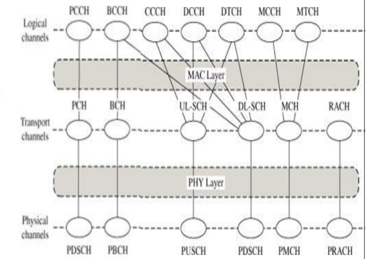
- **Channel Mapping**



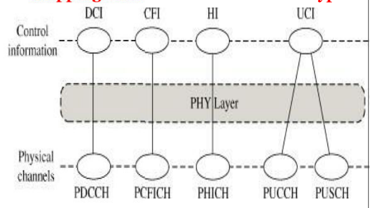
Mapping between different channel types.

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Channel Mapping**
- There exists a good correlation based on the purpose and the content between channels in different layers.
- This requires a mapping between the logical channels and transport channels at the MAC SAP and a mapping between transport channels and physical channels at the PHY SAP.
- Channel mapping is not arbitrary, and the allowed mapping between different channel types is shown in Fig.1
- Mapping between control information and physical channels is shown Fig.2
- It is possible for multiple channels mapped to a single channel.



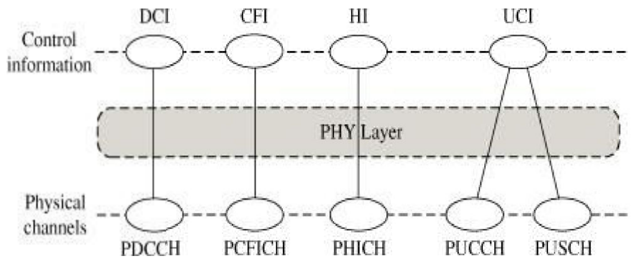
Mapping between different channel types.



Mapping of control information to physical channels

HIERARCHICAL CHANNEL STRUCTURE OF LTE

- **Channel Mapping**



Mapping of control information to physical channels

DOWNLINK OFDMA RADIO RESOURCES

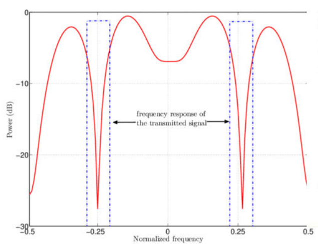
- The downlink and uplink use different transmission schemes due to different considerations.
- In the downlink, a scalable OFDM transmission/multiaccess technique is used that allows for high spectrum efficiency by utilizing multiuser diversity in a frequency selective channel
- A scalable SC-FDMA transmission/multiaccess technique is used in the uplink since this reduces the peak-to-average power ratio (PAPR) of the transmitted signal.
- The downlink transmission is based on OFDM with a cyclic prefix (CP)

DOWNLINK OFDMA RADIO RESOURCES

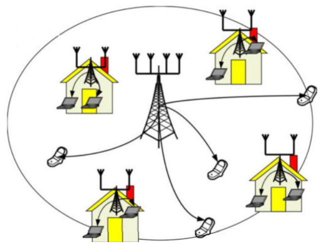
- Key advantages of OFDM that motivate using it in the LTE downlink:

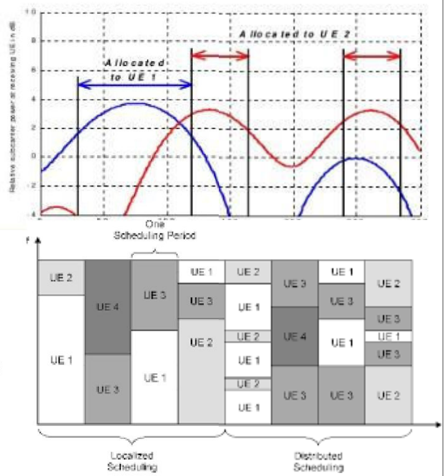
1. OFDM is efficient in **combating the frequency-selective fading** channel with a simple frequency-domain equalizer.
2. It is possible to exploit **frequency-selective scheduling** with OFDM-based multiple access (OFDMA), while HSPA only schedules in the **time domain.**
3. The transceiver structure of OFDM with FFT/IFFT **enables scalable bandwidth** operation with a low complexity.
4. It much easier to support **multiantenna transmission**
5. OFDM enables **multicast/broadcast** services on a synchronized single frequency network

DOWNLINK OFDMA RADIO RESOURCES



Frequency Fading

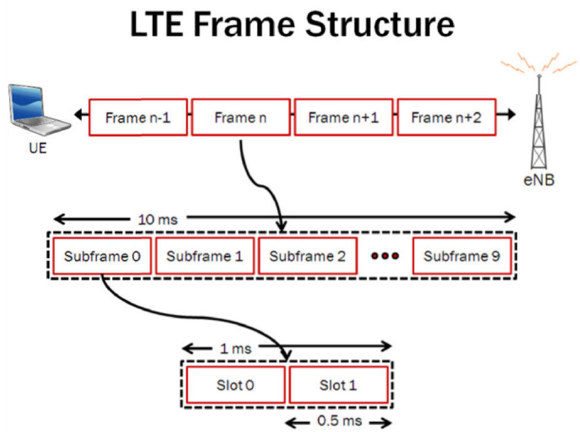




Frequency Selective Scheduling

DOWNLINK OFDMA RADIO RESOURCES

- A set of parameters for typical transmission bandwidths for LTE in the downlink

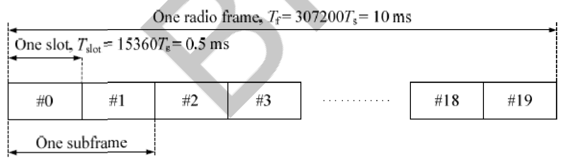


DOWNLINK OFDMA RADIO RESOURCES

- The multiple access in the downlink is based on OFDMA.
- In each TTI, a scheduling decision is made where each scheduled UE is assigned a certain amount of radio resources in the time and frequency domain.
- ***Frame Structure in the time domain***
- the size of elements in the time domain is expressed as a number of time units $T_s = 1/(15000 \times 2048)$ seconds

DOWNLINK OFDMA RADIO RESOURCES

- Time duration for one frame (One radio frame, One system frame) is 10 ms.(i.e. 100 radio frame per second)
- The number of samples in one frame (10 ms) is 307200 (307.200 K) samples. (i.e. number of samples per second is 307200 x 100 = 30.72 M samples.)
- Number of subframe in one frame is 10.
- Number of slots in one subframe is 2. This means that we have 20 slots within one frame



DOWNLINK OFDMA RADIO RESOURCES

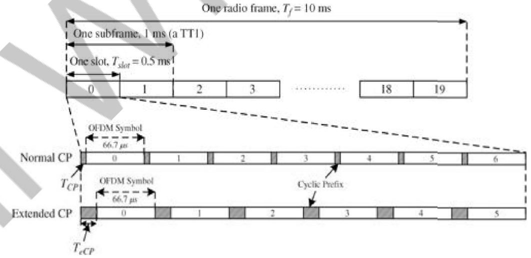
- The duration of one LTE radio frame is 10 ms.
- One frame is divided into 10 subframes of 1 ms each, and each subframe is divided into two slots of 0.5 ms each.
- Each slot contains either **six or seven OFDM** symbols, depending on the Cyclic Prefix (CP) length.
- The useful symbol time is 1/15 kHz= 66.6 mircosec.
- Since normal CP is about 4.69 microsec long, seven OFDM symbols can be placed in the 0.5-ms slot as each symbol occupies (66.6 + 4.69) = 71.29 microseconds.
- When extended CP (=16.67 microsec) is used the total OFDM symbol time is (66.6 + 16.67) = 83.27 microseconds.
-

DOWNLINK OFDMA RADIO RESOURCES

- **Frame Structure Type 1**
- Type 1 frame structure is applicable to both full duplex and half duplex FDD
- Three different kinds of units specified for this frame structure.
- The **smallest one is called a *slot***, which is of length $T_{slot} = 15360$
- **Two consecutive slots** are defined as a ***subframe*** of length 1 ms, and 20 slots, numbered from 0 to 19, constitute a *radio frame* of 10 ms.
- Channel-dependent scheduling and link adaptation operate on a subframe level
- Each slot consists of a number of OFDM symbols including CPs.
- CP is a kind of guard interval to combat inter-OFDM-symbol interference, the length of CP depends on the environment where the network operates

DOWNLINK OFDMA RADIO RESOURCES

- **Frame Structure Type 1**
- LTE defines two different CP lengths: a *normal CP* and an *extended CP*
- The **extended CP** is for multicell multicast/broadcast and very-large-cell scenarios
- **normal CP** is suitable for urban environment and high data rate applications



DOWNLINK OFDMA RADIO RESOURCES

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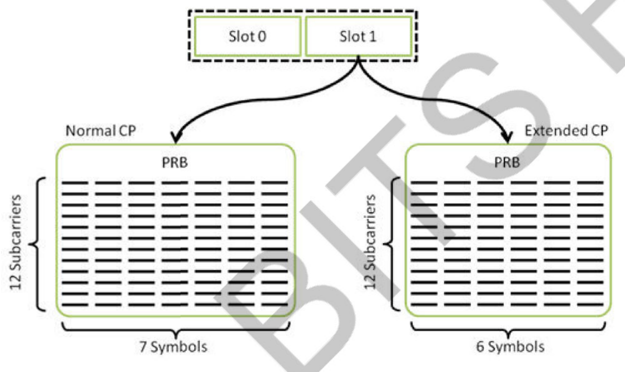
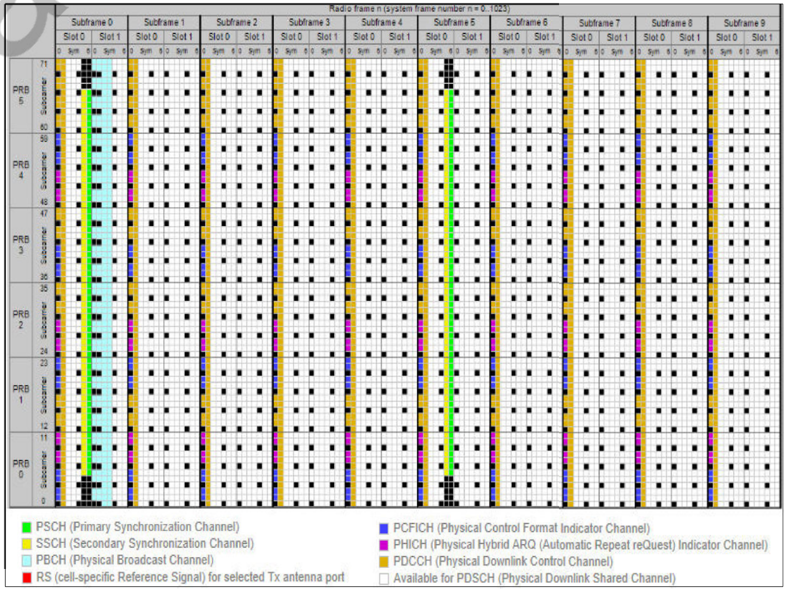
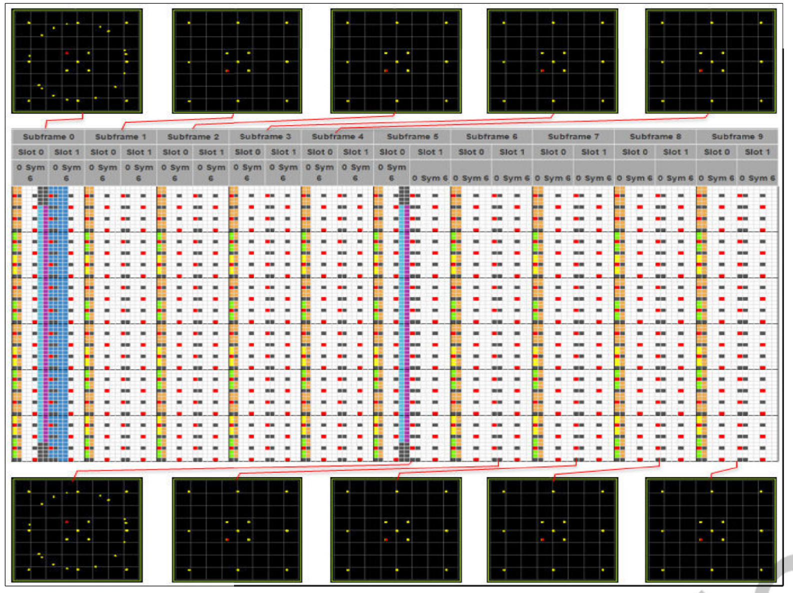




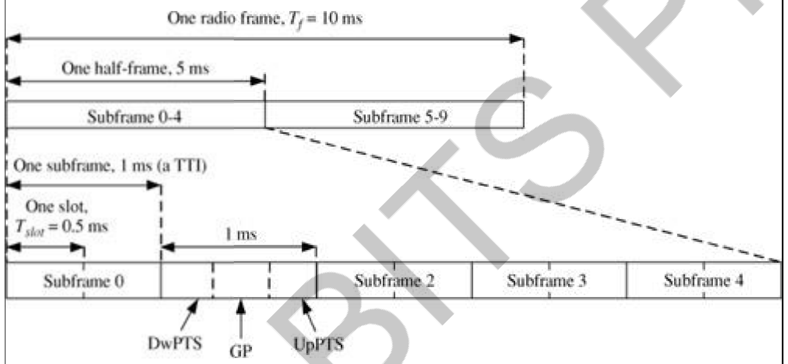


DOWNLINK OFDMA RADIO RESOURCES

- **Frame Structure Type 2**
- Applicable to the TDD mode.
- It is designed for coexistence with legacy systems such as the 3GPP TD-SCDMA-based standard.
- each radio frame of frame structure type 2 is of length $T_f = 30720 \cdot T_s = 10$ ms which consists of two half-frames of length 5 ms each.
- Each half-frame is divided into five subframes with 1 ms duration.
- There are special subframes, which consist of three fields: Downlink Pilot TimeSlot (DwPTS), Guard Period (GP), and Uplink Pilot TimeSlot (UpPTS).

DOWNLINK OFDMA RADIO RESOURCES

- **Frame Structure Type 2**



DOWNLINK OFDMA RADIO RESOURCES

- **Frame Structure Type 2**
- **The DwPTS field**(Downlink Pilot TimeSlot)**:** This is the downlink part of the special subframe, and can be regarded as an ordinary but shorter downlink subframe for downlink data transmission
- **The UpPTS field**(Uplink Pilot TimeSlot)**:** This is the uplink part of the special subframe. It can be used for transmission of uplink sounding reference signals and random access preambles.
- **The GP field**(Guard Period)**:** used to provide the guard period for the downlink-to-uplink and the uplink-to-downlink switch.
- The second half-frame has the similar structure, which depends on the uplink-downlink configuration.
- Seven uplink-downlink configurations with either 5 ms or 10 ms downlink-to-uplink switch-point periodicity are supported

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DOWNLINK OFDMA RADIO RESOURCES

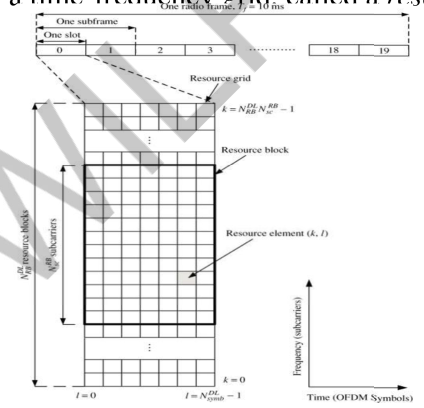
- **Frame Structure Type 2**
-

Uplink-Downlink Configuration	Downlink-to-Uplink Switch-Point Periodicity	Subframe Number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

- where “D” and “U” denote subframes reserved for downlink and uplink, respectively, and “S” denotes the special subframe

DOWNLINK OFDMA RADIO RESOURCES

- ***Physical Resource Blocks for OFDMA***
- The physical resource in the downlink in each slot is described by a time-frequency grid, called a *resource grid*



DOWNLINK OFDMA RADIO RESOURCES

- Each column and each row of the resource grid correspond to one OFDM symbol and one OFDM subcarrier, respectively.
- The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a *resource element*
- Each resource grid consists of a number of *resource blocks*, which describe the mapping of certain physical channels to resource elements.

DOWNLINK OFDMA RADIO RESOURCES

- The structure of each resource grid is characterized by the following three parameters:
- **The number of downlink resource blocks (N_{RB}^{DL})**
- It depends on the transmission bandwidth and shall fulfill

$N_{RB}^{min,DL} \le N_{RB}^{DL} \le N_{RB}^{max,DL}$ where $N_{RB}^{min,DL} = 6$ and $N_{RB}^{max,DL} = 110$ are for the smallest and largest downlink channel bandwidth.

- **The number of subcarriers in each resource block (N_{sc}^{RB}):**
- It depends on the subcarrier spacing Δf, each resource block is of 180kHz wide in the frequency domain
- There are a total of $N_{RB}^{DL} \times N_{sc}^{RB}$ subcarriers in each resource grid
- **The number of OFDM symbols in each block (N_{symb}^{DL}):**
- It depends on both the CP length and the subcarrier spacing
- Each downlink resource grid has $N_{RB}^{DL} \times N_{RB}^{sc} \times N_{symb}^{DL}$ resource elements

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UPLINK SC-FDMA RADIO RESOURCES

- For the LTE uplink transmission, SC-FDMA with a CP is adopted.
- SC-FDMA possesses most of the merits of OFDM while enjoying a lower PAPR.
- A lower PAPR is highly desirable in the uplink as less expensive power amplifiers are needed at UEs and the coverage is improved.

DOWNLINK OFDMA RADIO RESOURCES

- In case of multiantenna transmission, there is one resource grid defined per antenna port.
- An antenna port is defined by its associated reference signal, which may not correspond to a physical antenna.
- The set of antenna ports supported depends on the reference signal configuration in the cell
- There are three different reference signals defined in the downlink, and the associated antenna ports are as follows:

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Mobile Networks (SSWT ZG578)
Contact Session-6 :

802.11 Architecture

IEEE 802 Terminology

Access point (AP)	Any entity that has station functionality and provides access to the distribution system via the wireless medium for associated stations
Basic service set (BSS)	A set of stations controlled by a single coordination function
Coordination function	The logical function that determines when a station operating within a BSS is permitted to transmit and may be able to receive PDUs
Distribution system (DS)	A system used to interconnect a set of BSSs and integrated LANs to create an ESS
Extended service set (ESS)	A set of one or more interconnected BSSs and integrated LANs that appear as a single BSS to the LLC layer at any station associated with one of these BSSs
MAC protocol data unit (MPDU)	The unit of data exchanged between two peer MAC entites using the services of the physical layer
MAC service data unit (MSDU)	Information that is delivered as a unit between MAC users
Station	Any device that contains an IEEE 802.11 conformant MAC and physical layer

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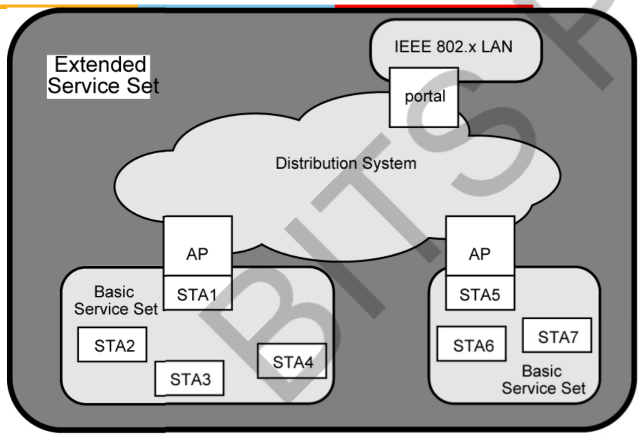
IEEE 802.11 Architecture



STA = station
AP = access point

Access Point (AP)

Logic within station that provides access to DS
- Provides DS services in addition to acting as station

To integrate IEEE 802.11 architecture with wired LAN portal

Portal logic implemented in device that is part of wired LAN and attached to DS
- E.g. Bridge or router

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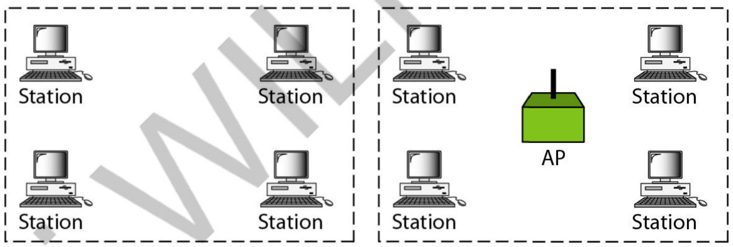
IEEE 802.11 – Architecture and Services BSS

- ✓covers the physical and data link layers.
- Smallest building block for wireless LAN is basic service set (BSS)
  - Contains Number of stations
  - With Same MAC protocol
  - Competing for access to same shared wireless medium
- BSS is made of stationary or mobile wireless stations and an optional central base station, known as the access point **(AP).**
- BSS with an AP - connect to backbone distribution system (DS) through access point (AP)
  - AP functions as bridge
- MAC protocol may be distributed or controlled by central coordination function in AP
- BSS generally corresponds to cell
- DS can be switch, wired network, or wireless network

Figure 14.1 ***Basic service sets (BSSs)***

BSS: Basic service set
AP: Access point



Ad hoc network (BSS without an AP)

Infrastructure (BSS with an AP)

(Cannot send data to other BSSs)

14.6

BSS Configuration

- **Simplest**: each station belongs to single BSS
  - Within range only of other stations within BSS
- Can have **two BSSs overlap**
  - Station could participate in more than one BSS
- **Association** between station and BSS **dynamic**
  - Stations may turn off, come within range, and go out of range

Extended Service Set (ESS)

- possible configurations:
  - simplest is each station belongs to single BSS
  - can have two BSSs overlap
  - a station can participate in more than one BSS
  - association between station and BSS dynamic
- ESS is two or more BSS interconnected by DS
- appears as single logical LAN to LLC

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Extended Service Set (ESS)

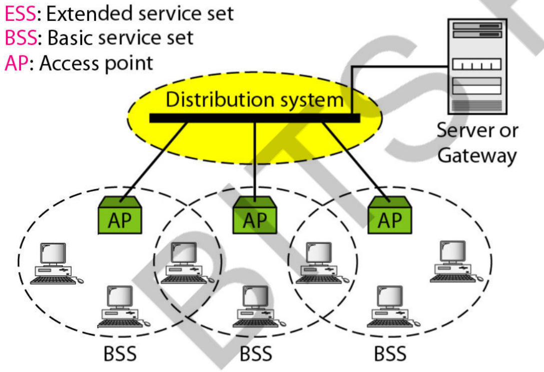
- Two or more BSS interconnected by DS (backbone distribution system)
  - Typically, DS is wired backbone but can be any network
- Appears as single logical LAN to LLC

Services - Message Distribution

distribution service
- primary service used by stations to exchange MAC frames when frame must traverse DS
- if stations in same BSS, distribution service logically goes through single AP of that BSS

integration service
- enables transfer of data between 802.11 LAN station and one on an integrated 802.x LAN

Figure 14.2 ***Extended service sets (ESSs)***



Categorizing Services - 9

1. **Station services** implemented in every 802.11 station
   Including AP stations
2. **Distribution services** provided between BSSs
   May be implemented in AP or special-purpose device

Three services used to control access and confidentiality

Six services used to support delivery of MAC service data units (MSDUs) between stations

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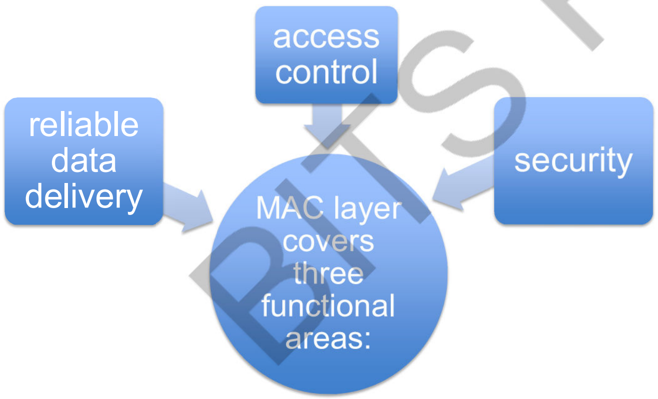
Categorizing Services - 9

1. Distribution of messages within DS
   - ✓ Distribution
   - ✓ Integration
2. Association related services
   - ✓ 3 types based on mobility(type of station)
     - No transition
     - BSS transition
     - ESS transition
   - ✓ 3 types based on association with AP
   - Association – initial. b/w station n AP
   - Reassociation – established association to be transferred from one AP to another. (so station can go from one BSS to another)
   - Disassociation – existing association terminated

Categorizing Services - 9

3. Access and Privacy Services –
   Authentication,
   Deauthentication
   Privacy

Medium Access Control



Medium Access Control (MAC) Sublayer

MAC layer covers three functional areas
- Reliable data delivery
- Access control
- Security
  - Beyond our scope

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Distributed Coordination Function (DCF) Protocol

DCF protocol uses **CSMA** as acess protocol.
If station has frame to transmit, it listens to medium
If medium idle, station may transmit
Otherwise must wait until current transmission complete
No collision detection

- Not practical on wireless network
- Dynamic range of signals very large
- Transmitting station cannot distinguish incoming weak signals from noise and effects of own transmission

DCF includes delays

- Interframe space

Figure 14.3 ***MAC layers in IEEE 802.11 standard***

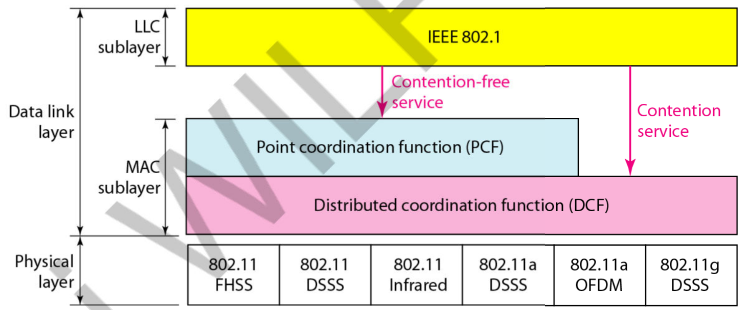
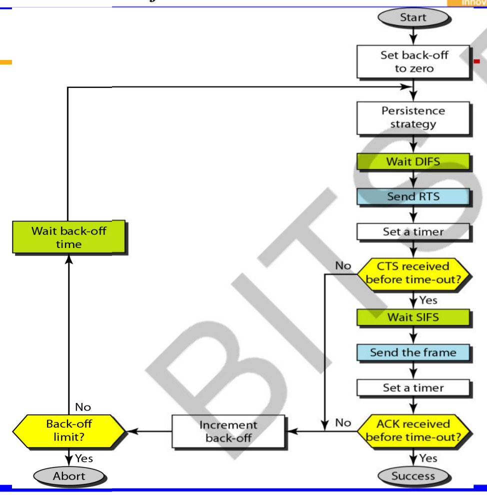


Figure 14.4 ***CSMA/CA flowchart***



Network Allocation Vector (NAV)

For collision avoidance

When one station sends an RTS frame, other stations **start** their **NAV**.

Then, before checking if channel is still busy or is now idle, check **if NAV has expired**.

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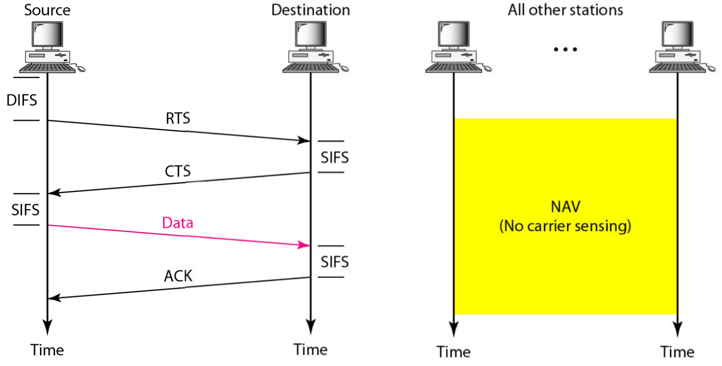
Figure 14.5 ***CSMA/CA and NAV (frame exchange time line)***



Medium Access Control Sublayer - Point Coordination Function (PCF)

Alternative access method implemented on top of DCF
Implemented only in infrastructure n/ws (not in AD Hocs)
Used in time sensitive txns
Has a **centralized contention free polling access method**
AP performs polling of stations
Uses PIFS (PCF IFS) when issuing polls
Point coordinator polls in **round-robin** to stations configured for polling

Medium Access Control Sublayer - MAC Frame Fields (1)

Frame Control:
- Type of frame
- Control, management, or data
- Provides control information
  - Includes whether frame is to or from DS, fragmentation information, and privacy information

Duration/Connection ID:
Addresses:4
- Number and meaning of address fields depend on context
- Types include source, destination, transmitting station, and receiving station

Sequence Control
Frame Body
Frame Check Sequence
- 32-bit cyclic redundancy check

Medium Access Control Sublayer - Frame Types cont…

1. **Management Frames**

Used to manage communications between stations and Aps
E.g. management of associations
- Requests, response, reassociation, dissociation, and authentication

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Medium Access Control Sublayer - Frame Types cont…

2. Control Frames

- Assist in reliable data delivery
- Power Save-Poll (PS-Poll)
- Request to Send (RTS)
- Clear to Send (CTS)
- Acknowledgment (ACK)
- Contention-Free (CF)-end
  - Announces end of contention-free period
- CF-End + CF-Ack:
  - -- Acknowledges CF-end
  - Ends contention-free period and releases stations from associated restrictions

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Medium Access Control Sublayer - Frame Types cont…

2. Control Frames

2 bytes	2 bytes	6 bytes	6 bytes	4 bytes
FC	D	Address 1	Address 2	FCS

RTS

2 bytes	2 bytes	6 bytes	4 bytes
FC	D	Address 1	FCS

CTS or ACK

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Medium Access Control Sublayer - Frame Types cont…

3. Data Frames – Data Carrying

- **Data and control info**
- **Eight** data frame subtypes
- First four carry upper-level data from source station to destination station
- Data
- Data + CF-Ack
  - Only sent during contention-free period
  - Carries data and acknowledges previously received data
- Data + CF-Poll
- Data + CF-Ack + CF-Poll

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Medium Access Control Sublayer - Frame Types cont…

3. Data Frames – Not Data Carrying

- Null Function
  - Carries no data, polls, or acknowledgments
  - Carries power management bit in frame control field to AP
  - Indicates station is changing to low-power state

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