MODULE – 3

Overview and Channel Structure of LTE:

Introduction to LTE

As mentioned previously, LTE is the next step in the evolution of mobile cellular sys tems and was standardized as part of the 3GPP Release & specifications. Unlike 2G and 3G cellular systems that were designed mainly with yoice services in mind, LTE was designed primarily for high-speed data services, which is why LTE is a packet-switched network from end to end and has no support for circuit-switched services. However, the low latency of LTE and its sophisticated quality of service (QoS) architecture allow a net work to emulate a circuit-switched connection on top of the packet-switched framework of LTE.

Design Principles

The LTE standard was designed 15 a completely new standard, with new numbering and new documentation, and it is not built on the previous versions of 3GPP standards. Earlier elements were brought in only if there was 1 compelling reason for them to exist in the new standard. The basic design principles that were agreed upon and followed in 3GPP while designing the LTE specifications include:

Network Architecture: Unlike 3G networks, LTE was designed to support packet-switched traffic with support for various QoS classes of services. Previous generations of networks such as UMTS/HSPA and IxRIT/EvDO also support packet-switched traffic but this was achieved by subsequent add-ons to the initial version of the standards. For example, HSPA, which is a packet-switched protocol (packet-switched over the air), was built on top of the Release 90 UMTS network and as a result carried some of the unnecessary burdens of a circuit-switched net work. LTE is different in the sense that it 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 (i.e., the minimum. number of network elements) while still being able to provide efficient packet-switched transport for traffic belonging to all the Qos classes such as conversational, streaming, real-time, fob-real-time, and background classes.

Data Rate and Latency: The design target for downlink and uplink peak data rates for LTE are 100 Mbps und 50 Mbps, respectively, 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 rode of the radio access network or vice versa measured on the IP layer. The target for one-way latency in the user plane is 5 ms in an unloaded network, that is, if only a single UE is present in the cell. For the control-plane latency, the transition time from a camped state to an active state is less than 100 ms, while the transition time between a dormant state and an active state should be less than 50 MS.

Performance Requirements:

The target performance requirements for LTE are specified in terms of spectrum efficiency, mobility, and coverage, and they are in general expressed relative to the 3GPP Release 6 HSPA.

– **Spectrum Efficiency** The average downlink user data rate und spectrum efficiency target is three to four times that of the baseline HSDPA network. Similarly, in uplink the average ser data rate and spectrum efficiency .

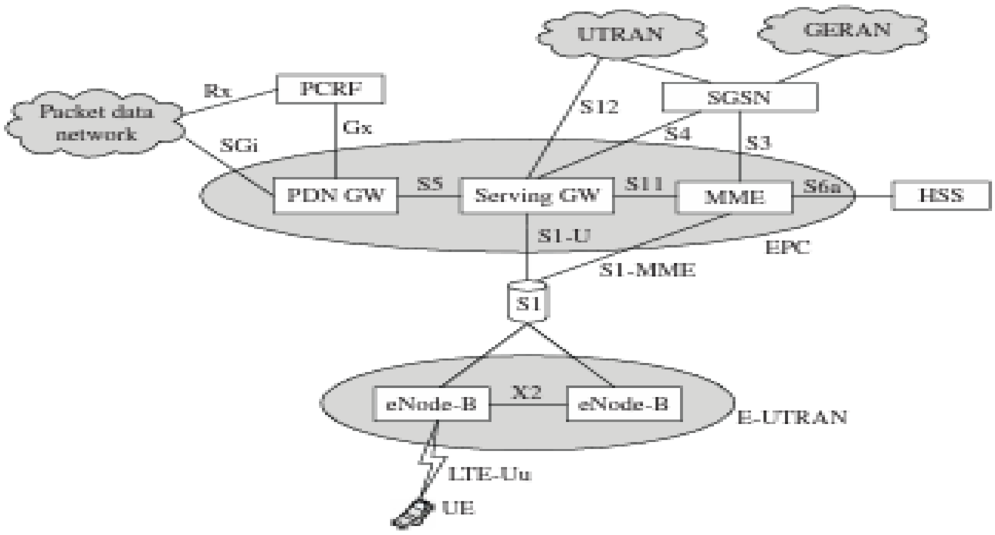
Mobility The mobility requirement for LTE is to be able to support hand off/ mobility at different terminal speeds. Maximum performance is expected for the loves terminal speeds of 0 to 15 km/hr, with minor degradation in performance at higher mobile speeds up to 120 km/hr. LTE is also expected to be able to sustain a connection for terminal speeds up to 350 km/hr but with significant degradation in the system performance. Coverage for the cell coverage, the above performance targets should be met up to 5 km.

Radio Resource Management:

The radio resource management requirements over various spots such as enhanced support for end-to-end Qos, efficient support for transmission of higher layers, and support for load sharing/balancing and policy management enforcement across different radio access technologies.

Flexibility of Spectrum and Deployment: In order to become a truly global standard, LTE Wis designed to be operable under a wide variety of spectrum SCC mairios, including its ability to coexist and share spectrum with existing 3G technologies. Service providers in different geographical regions often have different spectrums in terms of the carrier frequency and total available bandwidth, which is why LTE Wis designed to have a scalable bandwidth from 1.4MHz to 20MHz. In order to accommodate flexible duplexing options, LTE Wils designed to operate in both frequency division duplex (FDD) and time division duplex (TDD) modes.

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 ind to, both 3GPP UTRAN und 3GPP GERAN systems with acceptable terminal complexity and network performance.



LTE end to end network architecture

Network Architecture Figure 6.2 shows the end-to-end network architecture of LTE and the various components of the network. The entire network is composed of the radio access network (E-UTRAN) und the core network (EPC), both of which have been defined is new components of the end-to-end network in Release of the 3GPP specifications. In this sense, LTE is different from UMTS since UMTS derined a new radio access network but used the same core network as the previous-generation Enhanced GPRS (EDGE) network. This obviously has some implications for the service providers who are upgrading from a UMTS network to LTE. The main components of the E-UTRAN and EPC are

• UE: The mobile terminal.

• eNode-B: The eNode-B (also called the base station) terminates the air inter face protocol and is the first point of contact for the UE. the eNode-3 is the only logical node in the E-UTRAN, so it includes some functions previously defined in the RNC of the UTRAN, such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

• **Mobility Management Entity** (MME): MME is similar in function to the control plane of legacy Serving GPRS Support Node (SGSN). It manages mobility aspects in 3GPP access such as gateway selection and tracking area list management.

• **Packet Data Network Gateway (PDN GW)**: The PDN GW terminates the SGi interface toward the Packet Data Network (PDN). It routes data pickets between the EPC and the external PDN, and is the key node for policy enforcement and charging data collection. It also provides the anchor point for mobility with non-3GPP access. The external PDN can be any kind of IP network as well as the IP Multimedia Subsystem (IMS) domain. The PDN GW and the Serving GW may be implemented in one physical mode or separated physical nodes.

• **Si Interface**: The SI interface is the interface that separates the E-UTRAN and the EPC. It is split into two parts: the SI-U, which carries traffic data between the eNode-B and the Serving GW, and the SI-MIME, which is a signalling-only interface between the eNode-B and the NME.

• **X2 Interface**: The X2 interface is the interface between eNode-Es, consisting of two parts: the X2-C is the control plane interface between eNode-Es, while the X2-U is the user plane interface between eNode-Es. It is assumed that there always exists an X2 interface between Node-Bs that need to communicate with each other, for example, for support of handover.

Radio Interface Protocols As in other communication standards, the LTE radio interface is designed based on a layeredi protocol stack, which can be divided into control plane and user plane protocol stacks und is shown in Figure 6.3. The packet flow in the user plane is shown in Figure 6.4. The LTE ndio interface protocol is composed of the following layers

Radio Resource Control (RRC): The RRC layer performs the control plane functions including paging, maintenance and release of an RRC connection-security handling-nobility management, and QoS management.

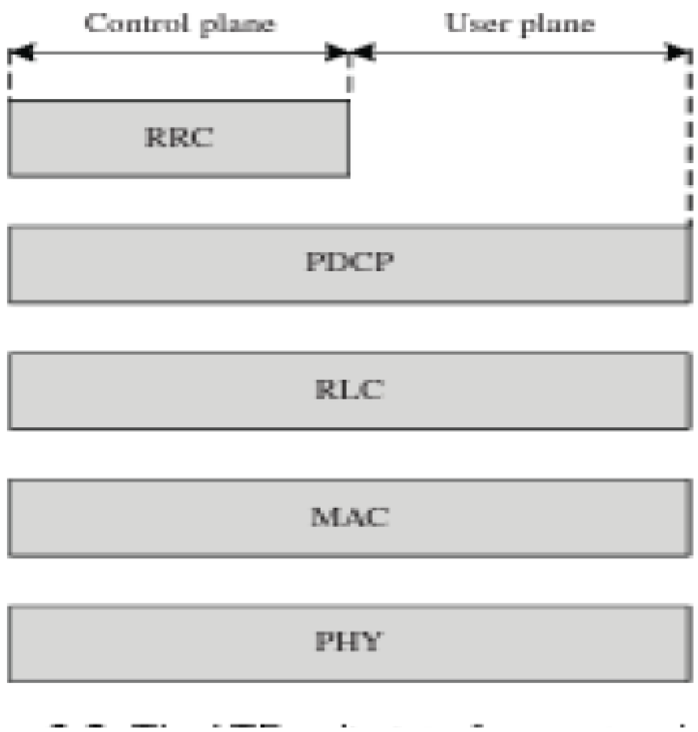


Figure 2: The LTE radio interface protocol stack

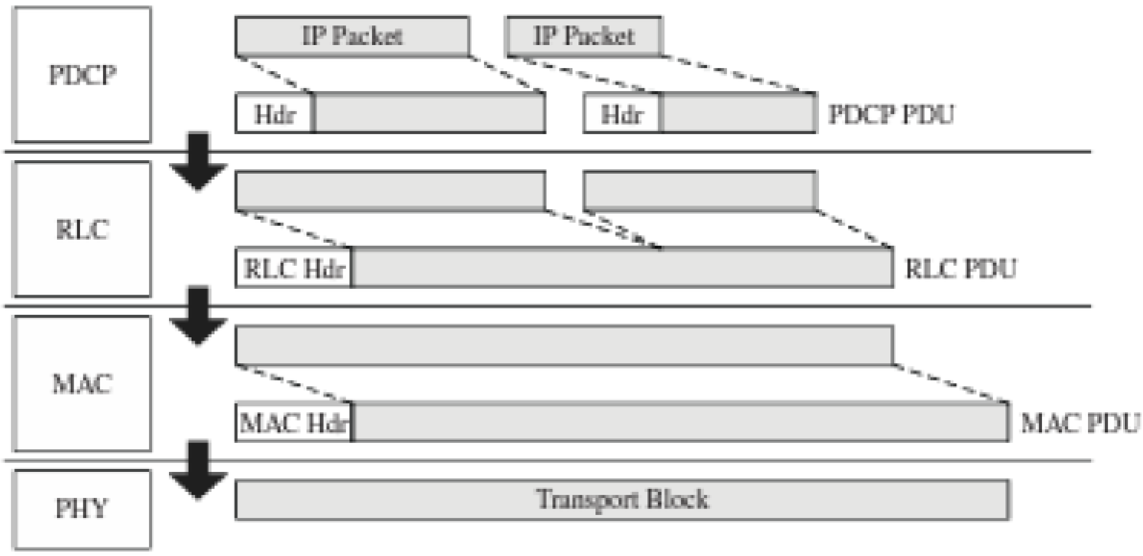


Figure 3: The packet flow in the user plane

• 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, without
RIC header addition, data segmentation, or concatenation, and 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-13 and the UE per bearer.

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 RLG PDUs on to transport blocks, priority handling between logical channels of onle UE, and priority handling between UEs by means of dynamic scheduling. The MAC sublayer is also responsible for transport format selection of scheduled UES, which includes selection of modulation format, code rate, MIMO Mink, and power level. There is only one MAC entity at the eNode-B and one MAC entity at the UE.

• Physical Layer (PHY): The main function of PHY is the actual transmission and reception of data in forms of t1118port blocks. The PHY is also responsible for various control mechanisms such as signalling of H-ARQ feedback, signalling 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 - logical channels, transport channels, and 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. The radio interface protocol architecture and the SAPs between different layers are shown in Figure 6.5. Logical channels provide services at the SAP between MAC and RLC layers, while 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.

The channels defined in LTE follow a similar hierarchical structure to UTRA/HSPA. However, in the case of LTE, the transport and logical channel structures are much more simplified and fewer in number compared to UTRA/HSPA. Unlike UTRA, HSPA, LTE is based entirely oll shared and broadcast channels and contains to dedicated channels carrying data to specific UEs. This improves the efficiency of the radio interface and can support dynamic resource allocation between different UEs depending on their traffic/QoS requirements and their respective channel conditions. In this section, we describe in detail the various logical transport, and physical channels that are defined in LTE.

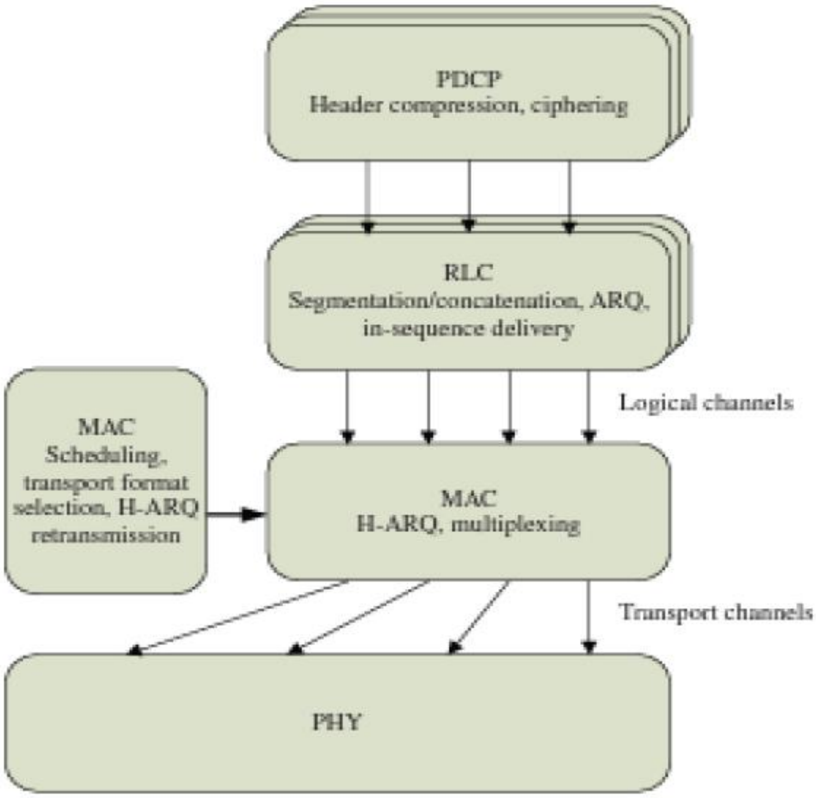


Figure 4: The radio interface protocol architecture and the SAPs b/w different layers

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. In LTE, there are two categories of logical channels depending on the service they provide: logi*cal co*ntrol channels and lo*gi*cal t*raffic cha*nnels.

• Broadcast Control Channel (BCCH): A downlink common channel used to broadcast system control information to the mobile terminals in the cell, including downlink system bandwidth, antenna configuration, and reference signal power. Due to the large amount of information carried on the BCCH, it is mapped to two different transport channels: the Broadcast Channel (BCH) and the Downlink Shared Channel (DL-SCH).

• Multicast Control Channel (MCCH): A point-to-multipoint downlink channel used for transmitting control information to UEs in the cell. It is only used by UES that receive multicast/'broadcast services.

• Paging Control Channel (PCCH): A downlink channel that transfers paging information to registered UEs in the cell, for example, in case of a mobile-terminated communication session.

• Common Control Channel (CCCH): A bi-directional channel for transmitting control information between the network and UEs when no RRC connection is available, implying the UE is not attached to the network such is in the idle state. Most commonly the COCH is used during the random access procedure.

• Dedicated Control Channel (DCCH): A point-to-point, bi-directional channel that transmitted dedicated control information between a UE and the network. This channel is used when the RRC connection is available, that is, the UE is attached to the network.

The logical traffic channels, which are to transfer user plane information, include:

• 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.

Downlink Transport Channels

• Downlink Shared Channel (DL-SCH): Used for transmitting the downlink data, including both control and traffic data, and thus 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. The concept of shared channel transmission originates from HSDPA, which uses the *H*i*g*h-*Sp*eed Downl*ink S*h*ar*ed Channe*l* (HS-DSCH) to multiplex traffic and control information among different UE.. By sharing the radio resource among different UEs the DL-SCH is able to maximize the throughput by allocating the resources to the optimum UEs. The processing of the DL-SCH is described in Section 7.2.

Broadcast Channel (BCH): A downlink channel scouted with the BCCH logical channel and is used to broadest system information over the entire coverage area of the cell. It has a fixed transport format defined by the specifications.

Multicast Channel (MCH): Associated with MCCH and MTCH logical channels for the multicast/broadcast service. It supports *M*u*l*t*ic*a*s*t*/Broadca*s*t* *Si*ngl*e* *F*requency *Net*work (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), 2nd supports UE discontinuous reception.

Uplink Transport Channels

• Uplink Shared Channel (UL-SCH): The uplink counterpart of the DL-SCH. It can be associated to CCCH, DOCH, 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 loss or, in the case of RRC, state changes.

• **Downlink Control Information (**DCI): It carries information related to downlink'uplink scheduling assignment, modulation and coding scheme, 2nd Transmit Power Control (TPC) command, and is sent over the Physical Downlink Control Channel (PDCCH). The DCI supports 10 different formats, listed in Table 6.1. Among them, Format O is for signalling uplink transmission allocation, Format 3 and 3A e for TPC, and the remaining formats ire for signalling downlink trans mission allocation.

Control Format Indicator (CFI): It indicates how many symbols the DCI spans in that sub frame. It takes values CFI = 1, 2, or 3, and is sent over the Physical Control Format Indicator Channel (PCFICH).

• **H-ARO Indicator** (HI): It carries H-ARQ acknowledgment in response to up link transmissions, and is sent over the Physical Hybrid ARQ Indicator Chanel (PHICH). HI = 1 for a positive acknowledgement (ACK) and HI = 0 for a negative acknowledgment (NAK).

Channel Mapping

From the description of different channel types, we see that 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. Such channel mapping is not arbitrary, and the allowed mapping between different channel types is shown in Figure , while the mapping between control information and physical channels is shown in Figure. It is possible for multiple channels mapped to a single channel, for example, different logical control channels and logical traffic channels are mapped to the DL-SCH transport channel.

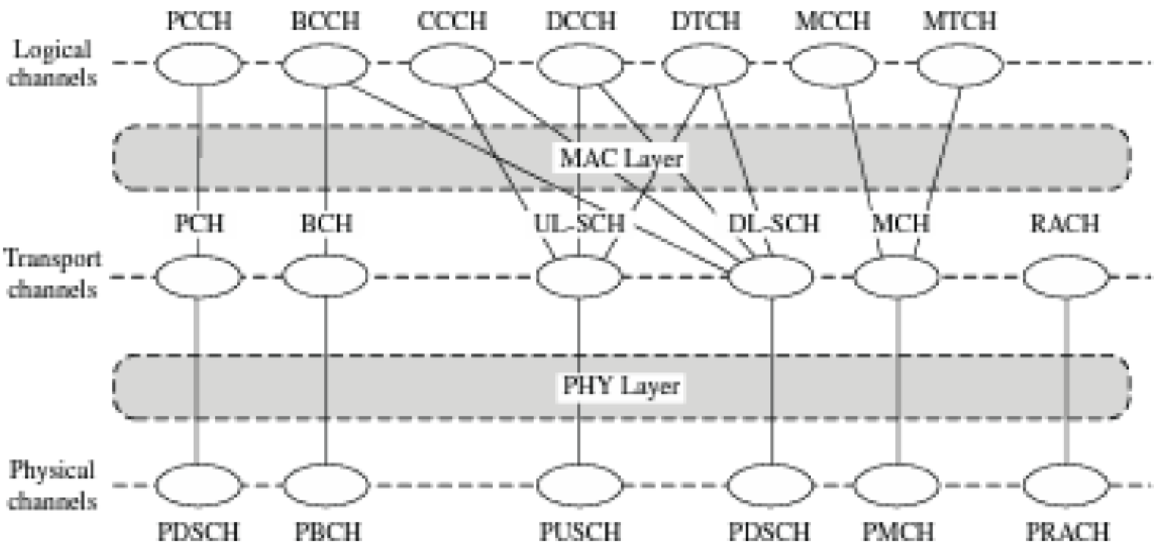


Figure 5: Mapping between different channel types

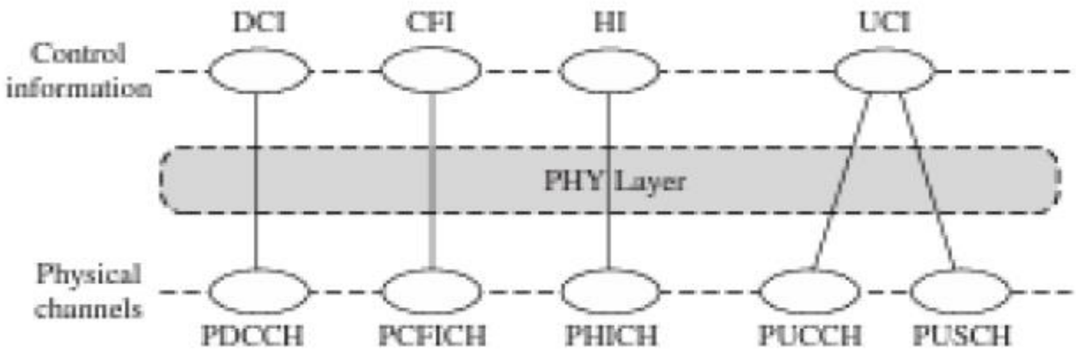


Figure 6: Mapping of control information to physical channels

Downlink OFDMA Radio Resources

In LTE, the downlink and uplink use different transmission schemes due to different con siderations. In this and the next section, we describe downlink and uplink radio transmission schemes, respectively. In the downlink, a scalable OFDM transmission/multi-access technique is used that allows for high spectrum efficiency by utilizing multiuser diversity in a frequency selective channel. On the other hand, SC-FDMA transmission, multi-access technique is used in the uplink since this reduces the peak-to-average power ratio (PAPR) of the transmitted signal.

The transceiver structure of OFDM with FFT/IFFT enables scalable bandwidth operation with a low complexity, which is one of the major objectives of LTE.

As each subcarrier becomes a flat fading channel, compared to single-carrier trans TILISSION OFDM makes it much easier to support multi-antenna transmission, which. is a key technique to enhance the spectrum efficiency.

• OFDM enables multicast/broadest services on a synchronized single frequency network, that is, MBSFN, is it treats signals from different base stations is propagating through a multipath channel and can efficiently combine them.

The multiple access in the downlink is based on OFDMA. In each TTI, a scheduling decision is made where each scheduled UE is signed a certain amount of radio resources in the time and frequency domain. The radio resources allocated to different UEs are orthogonal to each other, which means there is no intra-cell interference. In the remaining part of this section, we describe the frame structure and the radio resource block structure in the downlink, as well as the basic principles of resource allocation and the supported MIMO modes.

Frame Structure Before going into details about the resource block structure for the downlink, we first describe the frame structure in the time domain, which is a common element shared by both downlink and uplink.

In LTE specifications, the size of elements in the time domain is expressed as a number of time units T = 1/(15000 x 2048) seconds. As the normal subcarrier spacing is defined to be Af = 15kHz, T, can be regarded as the sampling time of an FFT-based OFDM transmitter/receiver implementation with FFT size NEET = 2048. Note that this is just for notation purpose, as different FFT sizes are supported depending on the transmission bandwidth.

Frame Structure Type 1

Frame stricture type a is applicable to both full duplex and half duplex FDD. There are three different kinds of units specified for this frame structure, illustrated in Figure. The smallest one is called a slot, which is of length. 7.dot = 15360 - T) = 0.5 ms. Two Consecutive slots are defined as a sub frame of length a FELS, and 20 slots, numbered from O to 19, constitute a radi*o th*eme of 10 ms. Channel-dependent scheduling and link adaptation operate of a sub frame level. Therefore, the sub frame duration corresponds to the minimum downlink TTI, which is of 1 ms duration, compared to a 2 ms TTI for the HSPA and a minimum 10 Ins ITI for the UMTS. A shorter T'II is for fast link adaptation and is able to reduce delay and better exploit the time-varying channel through channel-dependent scheduling.

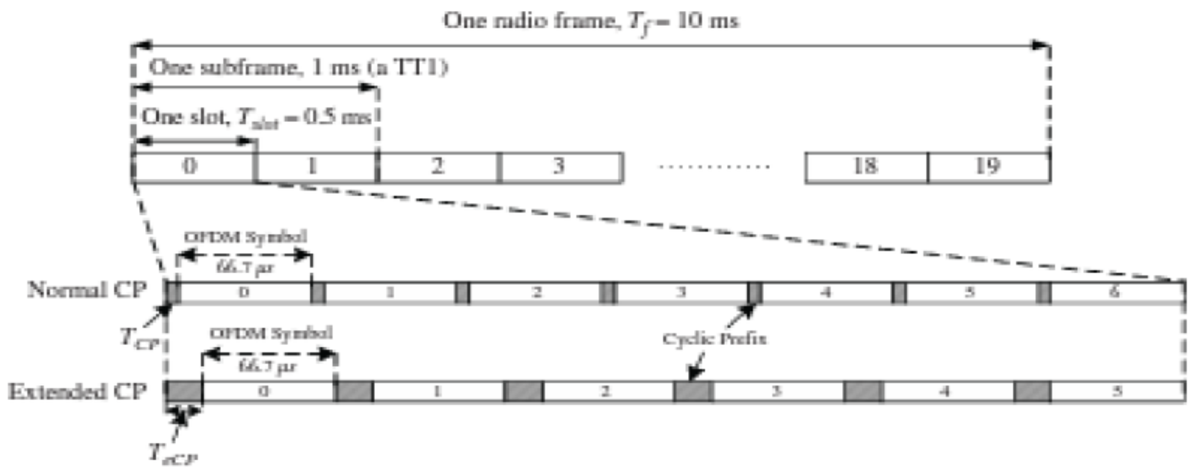


Figure 7: Frame structure type 1

Frame Structure Type 2:

Frame structure type 2 is applicable to the TDD mode. It is designed for coexistence with legacy systems such as the 3GPP TD-SCDMA-based standard. As shown in Figure. each radio frame of frame structure type 2 is of length T; = 30720 - T. = 10 ms, which

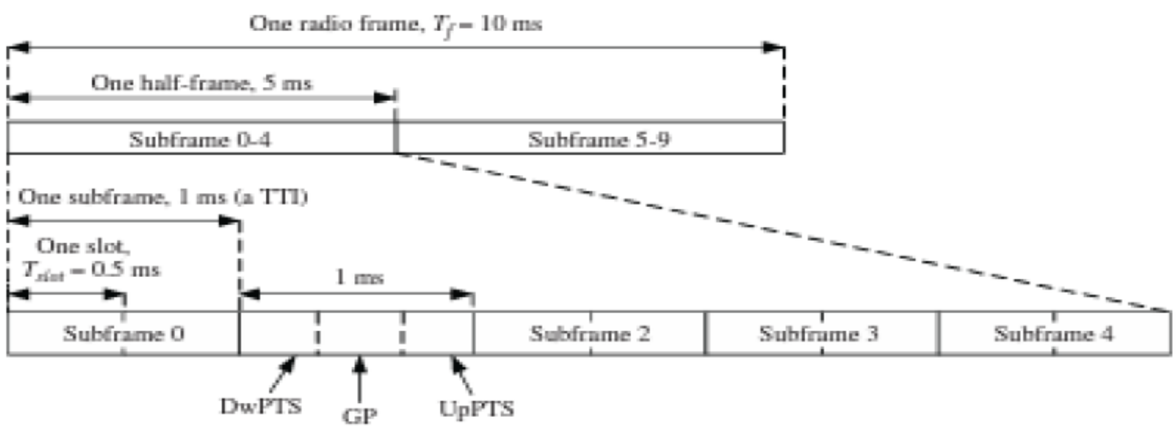


Figure 8: Frame structure type 2

The DwPTS field: This is the downlink part of the special sub frame, and can be regarded is as on ordinary but shorter downlink sub frame for downlink data transmission. Its length can be varied from three up to twelve OFDM symbols.

The UpPTS fleld: This is the uplink part of the special sub frame, and has a short duration with one or two OFDM symbols. It can be used for transmission of uplink sounding reference signals and random access preambles.

The GP field: The remaining symbols in the special sub frame that have not been allocated to DwPIS or UpPTS are allocated to the GP field, which is used to provide the guard period for the downlink-to-uplink and the uplink-to-downlink switch.

Physical Resource Blocks for OFDMA

The physical resource in the downlink in each slot is described by a time-frequency grid, called a FESOWI*E grid*, is illustrated in Figure . Such a time-frequency plane representation is 1 common practice for OFDM systems, which makes it intuitive for radio resource allocation. 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. The detail of these resource units is described as follows.

Resource Grid

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 $N_{RB}^{min,DL} \leq N_{RB}^{DL} \leq N_{RB}^{max,DL}$, where $N_{RB}^{min,DL} = 6$ and $N_{RB}^{max,DL} = 110$ are for the smallest and largest downlink channel bandwidth, respectively. The values of N_{RB}^{DL} for several current specified bandwidths are listed in Table 6.2.
- **The number of subcarriers in each resource block (N_{sc}^{RB})**: It depends on the subcarrier spacing Δf, satisfying $N_{sc}^{RB}\Delta f = 180\text{kHz}$, that is, each resource block is

• Cell-specific reference signals support 1 configuration of 1, 2, or 4 antenna ports
and the antenna port number p shall fulAll p= 0, PE (0.1), and pe {0,1,2,3}, respectively

• MBSFN reference signals are transmitted on antenna port p=4.

• UE-specific reference signals are transmitted on antenna port p=5.

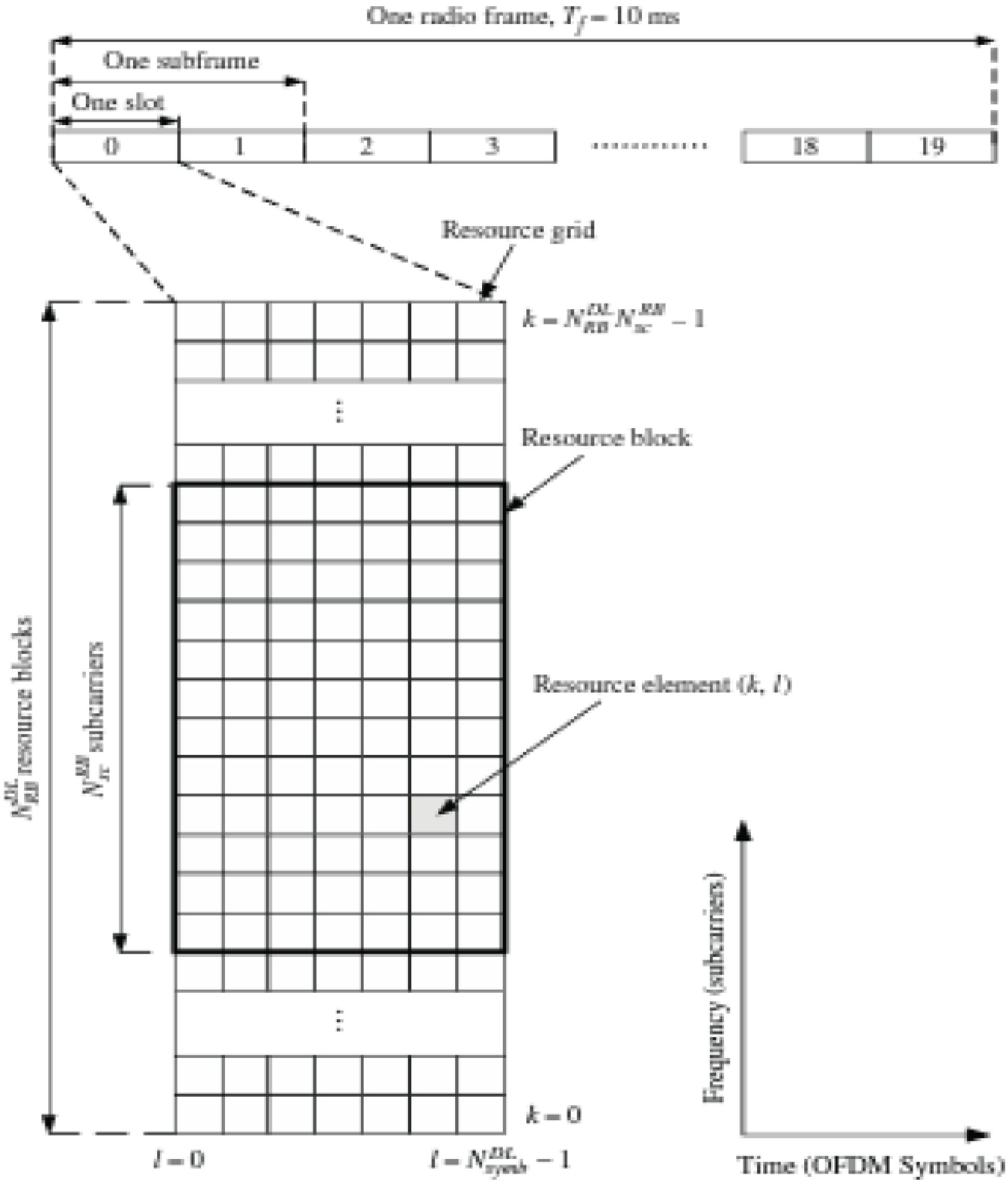


Figure 10: The structure of the downlink resource grid

Uplink SC-FDMA Radio Resources

For the LTE uplink MSMİNİON, SC-FDMA with i CP is adopted. SC-FDMA possess 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. In LTE, the SC-FDMA signal is generated by the DFT-spread-OFDM. Compared to conventional OFDM, the SC-FDMA receiver has higher complexity, which, however, is not considered to be an issue in the uplink given the powerful computational capability at the base station.

Frame Structure The uplink frame structure is similar to that for the downlink. The difference is that 10% We talk about S*C-FDMA sy*mbols and S*C-FDM*A subcarriers. In frame structure type 1. at uplink radio frame consists of 20 slots of 0.5 mns each, and one sub frame consists of two slots, is in Figure G.8. Frame structure type 2 consists of ten subframes, with one or two special sub frames including DwPTS, GP, and UpPIS fields, as shown A CP is inserted prior to each SC-FDMA symbol. Each slot carries seven SC-FDMA symbols in the case of normal CP, and six SC-FDMA symbols in the case of extended CP.

Physical Resource Blocks for SC-FDMA As SC-FDMA Can be regarded as conventional OFDM with a DFT-based precoder, the f our *g*rid for the uplink is similar to the one for the downlink, illustrated in Figure , that is, it comprises a number of resource blocks in the time-frequency plane. The number of resource blocks in each resource grid, NH depends on the uplink transmission bandwidth configured in the cell and should satisfy

$$N_{RB}^{min,UL} \leq N_{RB}^{UL} \leq N_{RB}^{max,UL},$$

where $N_{RB}^{min,UL} = 6$ and $N_{RB}^{max,UL} = 110$ correspond to the smallest and largest uplink bandwidth, respectively. There are $N_{sc}^{RB} \times N_{symb}^{RB}$ resource elements in each resource block.

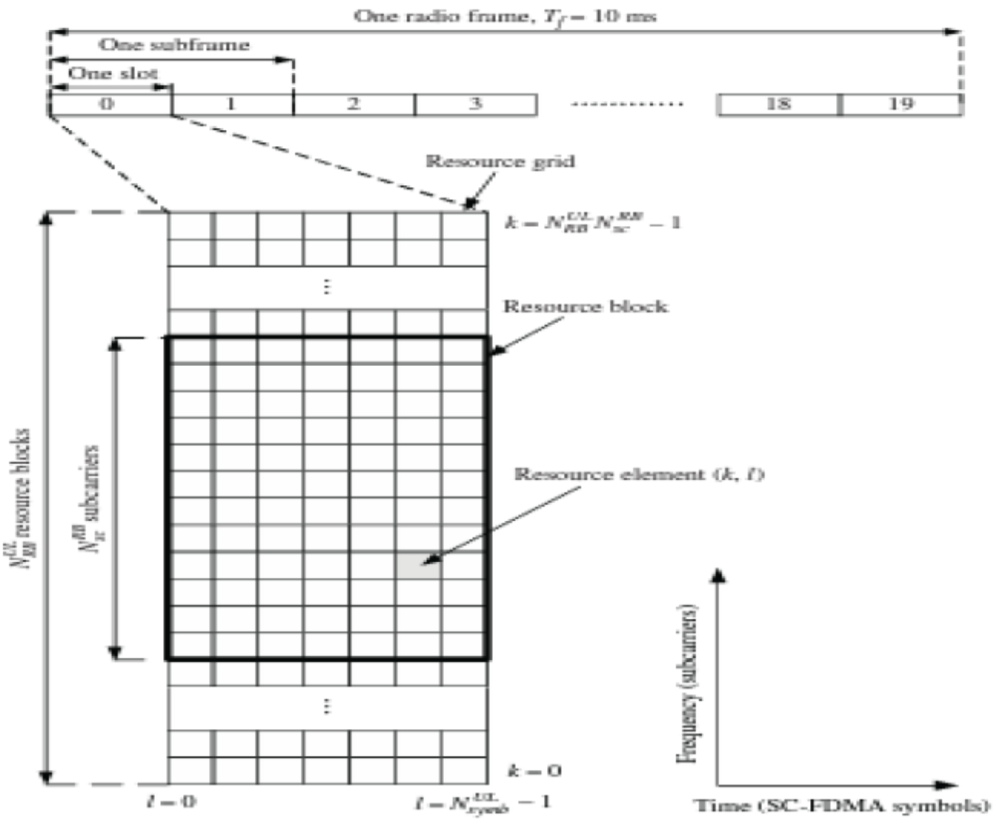


Figure 11: The structure of the uplink resource grid

Resource Allocation

Similar to the downlink, shared-channel transmission and channel-dependent scheduling are supported in the uplink. Resource allocation in the uplink is also performed at the eNode-B. Based on the channel quality measured on the uplink sounding reference signals and the scheduling requests sent from UES, the eNode-B signs a unique time frequency resource to a scheduled UE, which achieves orthogonal intra-cell trallisimission. Such intra-cell orthogonality in the uplink is preserved between UEs by using timing advance such that the transport blocks of different UEs are received synchronously at the eNode-3. This provides significant coverage and capacity gain in the uplink over UMTS, which employ's non-orthogonal transmission in the uplink and the performance is limited by inter-channel interference. In general, SC-FDMA is able to support both localized and distributed resource allocation. In the current specification, only localized resource allocation is supported in the uplink, which preserves the single-carrier property and can better exploit the multiuser diversity gain in the frequency domain. Compared to distributed resource allocation, localized resource allocation is less sensitive to frequency offset und also requires fewer reference symbols.

Supported MIMO *M*odes For the MIMO modes supported in the uplink, the terminal complexity and cost are among the major concerns. MU-MIMO is supported, which allocates the same time and frequency resource to two UEs with each transmitting on 1 single antenna. This is also called Spatial Division Multiple A (SDMA). The advantage is that only one transmit antenna per UE is required. To separate streams for different UEs, channel state information is required at the eNode-B, which is obtained through uplink reference signals that are orthogonal between UES. Uplink MU-MIMO also requires power control, 15 the near-fur problem a rises when multiple UEs are multiplexed on the same radio **resource.**

Downlink Transport Channel Processing

Channel Coding Processing

his section describes generic channel coding procedures that are used for various data and control transport channels. These common aspects of channel coding are applicable to both downlink and uplink transmissions. Channel coding for the downlink is a combination of error detection, EITOT correction, mate matching, interleaving, and trans port channel control information mapping onto physical channels.

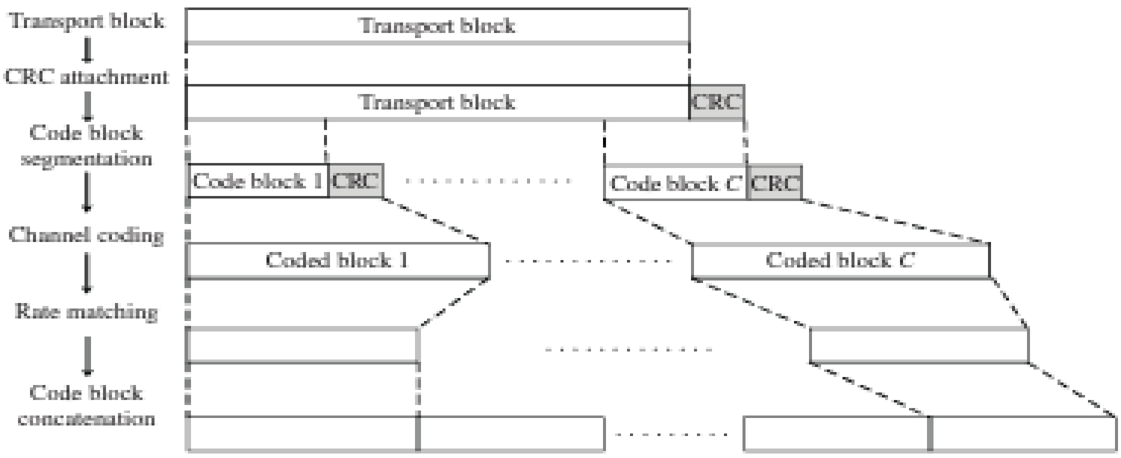


Figure 12:: channel encoding processing

channels such as the shared channel, the error-control mechanism is coupled with the re transmission mechanism using what is called the Hybrid-ARO (H-ARO) protocol. This combined error-control and retransmission mechanism improves the link reliability signif icantly in fading channels, as opposed to performing these two steps separately. In LTE.

Downlink Shared Channels

we describe the physical layer processing for specific transport channels including the downlink shared channel, the downlink control channel, the broadcast channel, and the multicast channel. Although most of the transport channels implement the various aspects of transport channel processing such as channel coding, rate matching symbol mapping, MIMO processing, and OFDM modulation, the specifics of each step vary from one transport channel to the other

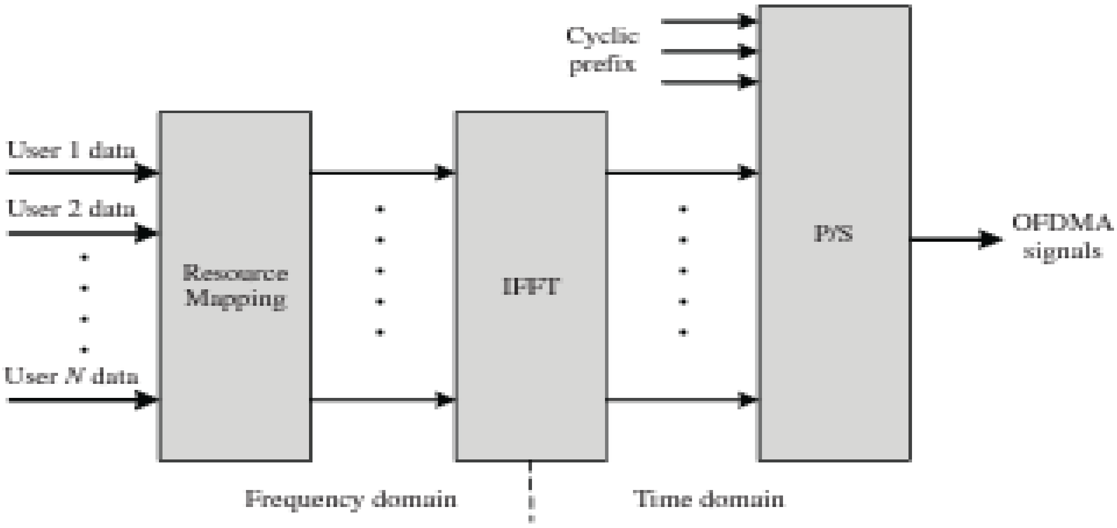


Figure 13: OFDMA signal generation with N users

The DL-SCH is carried on the Physical Downlink Shared Channel (PDSCH). Data transmission in the PDSCH is based on the concept of shared-channel transmission, where the PHY layer resources, that is, resource blocks available for PDSCH, is treated as a Common resource that can be dynamically shared among different UEs. The dynamic multiplexing of UEs on the PDSCH is done by the schedules on a 1-Insec interval. This way, a large portion of the radio resource can be allocated to a specific UE, which is suitable for packet-data applications.

Channel Encoding and Modulation

Rate matching is used in order to achieve 111 e*ff*ective channel *c*odin*g* rate that matches the payload capacity determined by the number of resource blocks allocated to the trans port block of the given UE and the modulation scheme. The redundancy version used for repetition or puncturing depends on the H-ARO transmission number and is indicated explicitly by the eNode-B. The modulation scheme allowed for DL-SCH includes OPSK, 1GQAM, and GQAM and is chosen based on the Channel Quality Indicator (CQI) provided by the UE and various other parameters such as the size of the transport block. The transport block size, the redundancy version, and the modulation order are

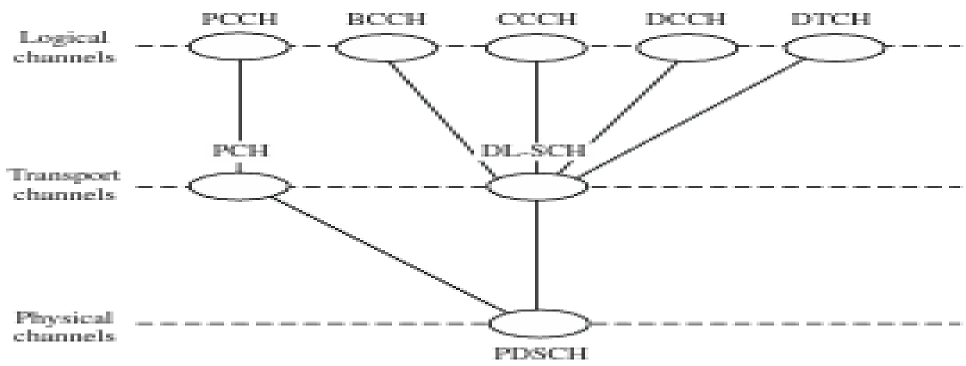


Figure 14: channel mapping around the downlink shared channel

The resource mapping of the PDSCH physical channel depends on whether UE Specific reference signals are transmitted. In resource blocks without UE-specific reference signals, the PDSCH shall be transmitted on the same set of antenna ports as the PBCH, which is one of [0), (0,1), or (0,1,2,3): if UE-specific reference signals are transmitted, the PDSCH shall be transmitted on antenna port , that is, transforming is applied. The complex-valued symbols are mapped to resource elements in the physical resource blocks corresponding to the virtual resource blocks assigned for transmission and not used for transmission of PCFICH, PHICH. PDCCH, PECH, synchronization signals, on reference signals.

Multiantenna Transmission

As the main channel for downlink traffic data transmission, the PDSCH supports all the MIMO modes specified in LTE, which makes this subsection an appropriate place to describe the transmission of the various MIMO modes. There are seven different transmission modes defined for data transmission on the PDSCH channel:

Single-antenna port (port 0): One transport block is transmitted from a single physical antenna corresponding to internal port O.

Transmit diversity: One transport block is transmitted from more than one physical antenna, that is, ports 0 and 1 if two physical antennas are used and ports 0, 1, 2, and 3 if four physical antennas are used.

Open-loop (OL) spatial multiplexing: One or two transport blocks are trans mitted from two or four physical antennas. In this case, predefined precoder matrices are used based on the Rank Indicator (RI) feedback. The preceding matrix is fixed and not adapted.

Closed-loop (CL) spatial multiplexing: One or two transport blocks are trans mitted from two or four physical antennas. The precoding in this case is adapted based on the Precoding Matrix Indicator (PMI) feedback from the UE.

Multiuser MIMO: Two UEs are multiplexed onto two or four physical antennas with one transport block to each UE. The rank-1 PMI feedback from each UE is used to create the overall precoding matrix.

Closed-loop rank-1 precoding: It is in special case of the CL spatial multiplexing with single-layer transmission, that is, a *P*x 1 precoder is applied.

Single-antenna port (port 5): A single transport block is transmitted from two or more physical antennas. The eNode-B performs beam forming to a single UE using all physical antennas.

Unlike other modes, in this use the reference signal is also transmitted using the same beam forming vector that is used for the data symbols. Thus for this mode, the beam forming technique used at the eNode-3 is transparent to the UE, and the UE is able to decode the transport block with the help of this UE-specific reference signal. Beam forming can be used to improve the received signal power and/or reduce the interference signal power, which is Especially important for cell edge user's.

Downlink Control Channels

Downlink control channels are carried over the Physical Downlink Control Channel (PDCCH) and they contain control information from the MAC layer, including downlink control information (DCI), Control Format Indicator (CFI), and H-ARQ Indicator (HI). Channel mapping between control information and physical channels in the downlink is shown in Figure 7.11. There is a specific physical channel for each type of control information. On the physical laver the PDOCH and the PDSCH are time multiplexed, such that the PDCCH is carried over the first few OFDM symbols of each sub frame and the PDSCH is carried over the rest of the OFDM symbols. The number of OFDM symbols allocated for PDOCH Cali Yary froful one to four and is conveyed by the CFI. The CFI is carried on yet another control channel known as the Physical Control Format Indicator Channel (PCFICH), which is always cried in a predetermined format over the first OFDM symbol of each sub frame. This predetermined format of PCFICH allows each UE to decode the CFI without umbiguity and thus determine the number of OFDM symbols in the beginning of each sub frame that are used as the control region.

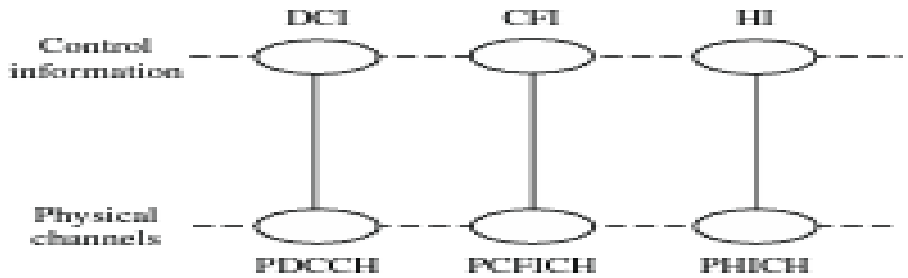


Figure 15: channel mapping for control information in the downlink

Downlink Control Information (DCI) Formats

Among the control information in the downlink, the DCI is the most important as it carries detailed control information for both downlink and uplink transmissions. Therefore, in this section, we first describe different DCI formats. Then, the coding and modulation processing for each control channel is discussed, followed by the supported MIMO transmission. The DCI carries the downlink scheduling assignments, uplink scheduling

DCI format O carries uplink scheduling grants and necessary control information for uplink transmission.

DCI format 1/1A/1B/10/1D provides scheduling information for one codeword transmission without spatial multiplexing. This category has the largest number of types in order to save signalling resources of the PDCCH, as these formats are optimized for specific use cases and transmission modes.

• DCI formats 2 and 2A provide downlink scheduling information for CL and OL spatial multiplexing, respectively.

Downlink Control Information (DCI)

The DCI is mapped to the PDCCH physical channel, and multiple PDCCHs can be transmitted in a subframe. A 16-bit CRC is attached to the control information symbols. The CRC parity bits are then scrambled 1ccording to the following rules:

UE Transmit Antenna Selection	Antenna Selection Mask
UE port 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
UE port 1	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1

If UE transmit antenna selection is configured and applicable, the CRC parity bits of PDCCH with DCI format 0 are scrambled with the corresponding RNTI and the antenna selection mask indicated in Table 7.12, which informs the UE about the selected antenna port.

The tail-biting convolution code with rate 1/3 is used as the channel coding scheme, while QPSK is the modulation scheme. After channel coding, cell-specific scrambling is applied, and the PDCCH shall be transmitted on the same set of antenna ports as the PBCH.

The PDCCH is located in the first n OFDM symbols of each sub frame, 1 <<4 Such a special location can be used to support micro-sleep that saves UE battery life, und to reduce buffering and latency, that is, the UE C20 go to sleep if it seems. For frame structure type 2, PDOCH also be mapped onto the first two OFDM symbols of the DwPTS field, while the third OFDM symbol is for the primary Synchronization signal. The set of OFDM symbols possible to use for PDOCH in a sub frame is given in Table.

H-ARQ Indicator (HI)

The control information HI is for H-ARQ acknowledgement in response to uplink trans mission. As spatial multiplexing is not supported in the uplink in current specifications, only one information bit is required for H-ARQ acknowledgement. It has two values HI = 1 for 1 positive acknowledgment (ACK) and HI = 0 for i negative acknowledgment (NAK). A repetition code with rate 1/3 is applied, which has two code words: (0,0,0) und (1,1,1). Such :1 repetition is able to provide frequency diversity by mapping different code bits to different resource elements. BPSK modulation is applied.

HI is mapped onto the PHICH physical channel. Multiple PHICHs mapped to the sine set of resource elements constitute 1 PHICH group. where PHICHs within the same group are separated through different orthogonal sequences with a spreading factor of four. A PHICH is identified by the index pair (regroup. Type), where the group is the PHICH group number and is the orthogonal sequence index within the group. The numbers of PHICH groups are different for frame structure type 1 in type 2, specified in 3 along with the orthogonal sequence. In addition, cell-specific scrambling is applied.

Broadcast Channels

Broadcast channels carry system information such as downlink system bandwidth, antenna configuration, and reference signal power. The UEs can get the necessary system information after the cell search (or synchronization) procedure. Due to the large size of the system information field, it is divided into two portions-Master Information Block (MIB) transmitted on the PBCH and System Information Blocks (SIB) transmitted on the PDSCH. The PBCH contains basic system parameters necessity to demodulate the PDSCH, which contains the remaining SIB. The transmission of the PBCH is characterized by a fixed pre-determined transport format and resource allocation, that is, there is no higher-layer control.

Error detection is provided through a 16-bit CRC, and then the CRC parity bits are scrambled according to the eNode-B transmit antenna configuration with the scram sigling sequence specified in Table 7.16. This implicitly tells the UE about the eNode-B Internal configuration. The tail-biting convolution coding with rate 1/3 is used, and the coded bits are rate matched to 1920 bits for the normal CP and to 1728 bits for the extended CP.

The modulation scheme is QPSK, No H-ARQ is supported. For MIMO modes, PBCH supports single- mission and OL transmit diversity. Dynamic adaptation modulation and coding is not possible, due to the lack of channel quality feedback. The complex-valued modulation symbols are mapped onto the 72 subcarriers cantered the DC subcarrier in slot 1 in subframe O during four consecutive m io frames, that is, the Transmission Time Interval (TTI) for the PBCH IS 40 ms. The PBCH occupies the most narrow bandwidth supported by LTE (1.4MHz) and is located in the subframe guaranteed to be used in the downlink. Therefore, the resource mapping of the PBCH is independent of the system bandwidth and the duplex mode. This allows the UE to detect and decode the PBCH without any prior knowledge of the system bandwidth and the duplex mode. Once the PBCH is detected and the MIB is decoded, the UE can then extract the system bandwidth and the duplex mode.

Multicas**t Channels**

Multim*edia Broadcast* an*d Mu*lticast Services (MBMS), introduced in 3GPP Release G for the UTRA 2, supports multicast/broadcast services in 1 cellular system. It sends the sine content information to all the UE: (broadcast) or to 1 given set of UEs (multicast). and is envisaged for delivering services such as mobile TV. In principle, the MBMS trans mission din originate from a single base station or multiple base stations, but multicell transmission is preferred as large gains can be achieved through soft combining of trans missions from multiple base stations. For MBMS in the UTRA, to receive the same data information from multiple cells, the complexity at the receiver is high and there will be interference between signals from different base stations. One major design requirement for LTE is to provide enhanced support for the MBMS transmission, which is called *En*hance*d MSVS (E-MB*MS) and is achieved through the so-called Single-Frequency Network (SFN) operation.
With the OFDM-based transmission in the downlink, over-the-air combining of multicast, broadcast transmissions from multiple base stations is possible in LTE with an extended CP. The extended CP is used as the propagation delay from multiple cells and will typically be larger than the delay spread in a single cell. A longer CP can ensure that signals from different bike stations still fall within the CP at the receiver, which avoids inter-symbol interference at the cost of a slight reduction in path data rate. Essentially, it makes synchronous multicell multicast/broadcast transmissions appear as a single trans mission over a multipath channel,

and since OFDM is efficient in combating multipath channels, there is no resulting interference. In such Mult*icast/Broadcast* Single Frequency Networks (MBSFNS), the same information is broadcast on the same radio resources from multiple synchronized neighbouring base stations to multiple UE.. The SFN operation has already been used in the terrestrial Digital Video Broadcasting system (DVB-T).
The E-MBMS transmission in LTE occurs on the MCH transport channel, along with the 7.5kHz subcarrier spacing and the extended CP. There are two types of E-MBMS transmissions:

Single-cell transmission *(*non-MBSFN operation): The MBMS service (MTCH and MCCH) is transmitted on the MCH, und combining of MBMS trans mission from multiple cells is not supported.

Multicell transmission (MBSFN operation): The MBMS service (MTCH and MCCH) is transmitted synchronously on the MCH, and combining is supported with the SFN operation.

The MBSFN and DL-SCH transmission can be multiplexed in a time-division multiplexing (TDM) manner on 1 subcurrier basis, but cannot be transmitted within the same subframe.

In the subframes where PMCH is transmitted on a carrier supporting a mix of PDSCH und PNCH trasmissions, up to two of the first OFDM symbols of a subframe can be reserved for non-MBSFN transmission and shall not be used for PMCH transmission.

In all cell with four cell-specific antenna ports, the first OFDM symbols of a subframe are reserved for non-MBSFN transmission in the subframes in which the PNCH is transmitted

The non-MBSFN symbols shall use the same CP as used for subframe 0. - PMCH shall not be transmitted in subframes 0 und 5 of a carrier supporting 1 Mix of PDSCH and PMCH transmissions.

Downlink Physical Signals

Downlink Reference Signals

Downilink reference signals consist of known reference symbols that are intended for downlink channel estimation at the UE needed to perform coherent demodulation. To facilities the chapel estimation process, scattered reference signals are inserted in the resource grid at pre-determined intervals. The time and frequency intervals are mainly determined by the characteristics of the channels, and should make a trade-off between the estimation accuracy and the overhead.

As introduced in Chapter 6, there are three different types of downlink reference signals: cell-specific reference signals, MBSFN reference signals, and UE-specific reference signals. The reference sequence is generated from a seudo-random sequence, with different initializations for different types of reference signals. There is one reference signal transmitted per downlink antenna port. For MBSFN reference signals, identical sequence is transmitted from cells involved in the MBSFN transmission, while cell-specific sequences are used for other types of reference signals. In this subsection, we describe how the various reference signals are mapped on to the physical layer resource elements.

Cell-Specific Reference Signals Cell-specific reference signals are transmitted in all downlink subframes in a cell sup porting non-MBSFN transmission. In the subframe listed for transmission with MBSFN only the first two OFDM symbols can be used for cell-specific reference symbols. Cell specific reference signals are defined separately for antenna ports 0, 1, 2, and 3 is shown in Figure 7.12. Therefore, in LTE a maximum of four antennals can be used while transmitting the cell specific reference signal. The cell specific reference signals are defined only for the formal subcarrier spacing of Af = 15kHz.

In the time domain, for the antenna port pe {0,1}, the reference symbols are inserted within the first and the third last OFDM symbols in each slot, which are the first and fifth OFDM symbols for the normal CP and the first and fourth OFDM symbols for the extended CP; for € 2,3), the reference symbols are only inserted in the second OFDM symbol. So internal ports 1 and have twice is many reference symbols as antenna ports 2 and 3. This is to reduce the reference signal overhead but also causes an imbalance

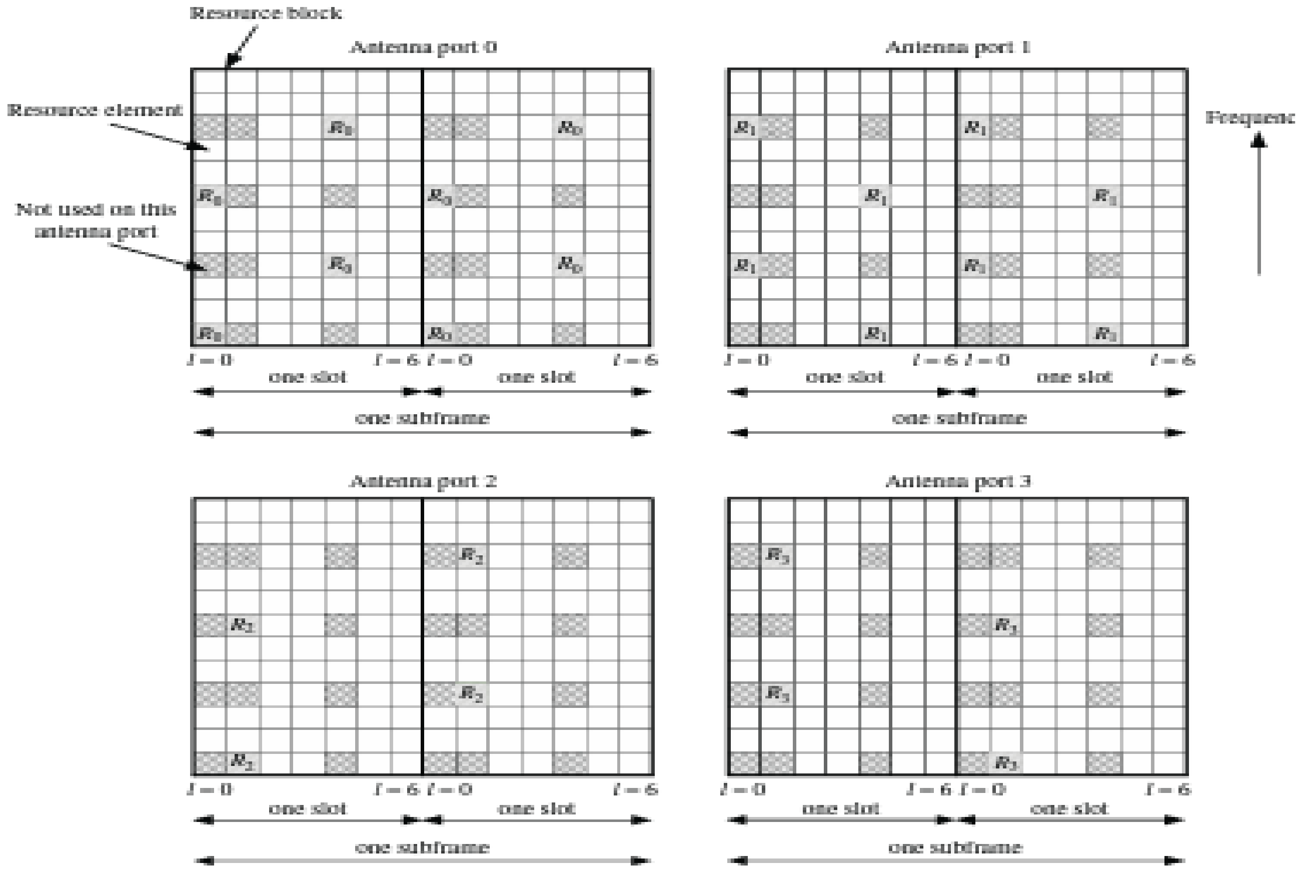


Figure 16: cell specific reference signals

MBSEN Reference Signals

MBSFN reference signals are only transmitted in sub frame allocated for MBSFN trans mission, which is only defined for extended CP and transmitted on antenna port 4.

In the time domain, for even-numbered slots, the reference symbols are inserted in the third OFDM symbol for Al = 15kHz and in the second OFDM symbol for AT = 7.5kHz for odd-numbered slots, the reference symbols are inserted in the first and fifth OFDM symbols for Af = 15kHz and in the first and third OFDM symbols for Af = 7.5kHz.

In the frequency domain, the reference symbols are transmitted every two subcarriers for Af = 15kHz and every four subcarriers for Af = 7.5kHz. In the 0-th OFDM symbols, the reference symbols are transmitted from the second and the third subcarrier for Af = 15kHz and A*f* = 7.5kHz, TCSp actively, otherwise, they start from the first subcarrier.

Based on these rules, all example of the resource mapping of MBSFN reference signals is shown in Figure 7.13 with the extended CP, and Af = 15kHz. Note that the density of the MBSFN reference signal in the frequency domain is three times higher than that of the cell-specific reference signal. This is because the SFN transmission includes a highly frequency selective channel, so it requires a high density of reference signals in the frequency domain.

Synchronization Signals

The downlink synchronization signals are sent to facilitate the cell search procedure, during which process the time and frequency synchronization between the UE and the eNode-B is achieved and the cell ID is obtained. There are a total of 504 unique physical layer cell IDs, which are grouped into 168 physical-layer cell-ID groups. A physical-layer cell ID is uniquely defined as

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)},$$

where Nid = 0,1,..., 167 represents the physical-layer cell-ID group and NH = 0.1,2 represents the physical-layer ID within the cell-ID group. Each cell is 25signed a unique physical-layer cell ID. The synchronization signals are classified as primary *sync*hronization *si*gnals and secon*dary synchroni*zation *si*gnals. Primary synchronization signals identify the symbol timing and the cell ID index N . while secondary synchronization signals are used for detecting the cell-ID group index and the frame timing.

The synchronization signals are designed in such a way to make the cell search procedure fast and of low complexity. The sequence used for the primary synchronization signal is generated frolli 1 frequency-domain Zadoff-Chu sequence. The Zadoff-Chu sc quence possesses the Constant Amplitude Zero Auto-Correlation (CAZAC) property, which means low peak-to-average power ratio (PAPR). This property is desirable for synchronization signals is it improves coverage, which is an important design objective. There are three different root sequence indices, corresponding to cell indices NH = 0,1,2, which makes the primary synchronization signals for different cell IDs orthogonal to each other.

The sequence used for the secondary synchronization signal is an interleaved concatenation of two length 31 binary sequences. The two base sequences are cyclic shifts of the m-sequence, with shifts specified by the cell-ID group index No, which are then scramble with a scrambling sequence specified by the value of *N*H). Therefore, the secondary Synchronization signal can only be detected after detecting the primary synchronization signal. The usage of two length 31 sequences makes it feasible to detect all 168 cell ID groups

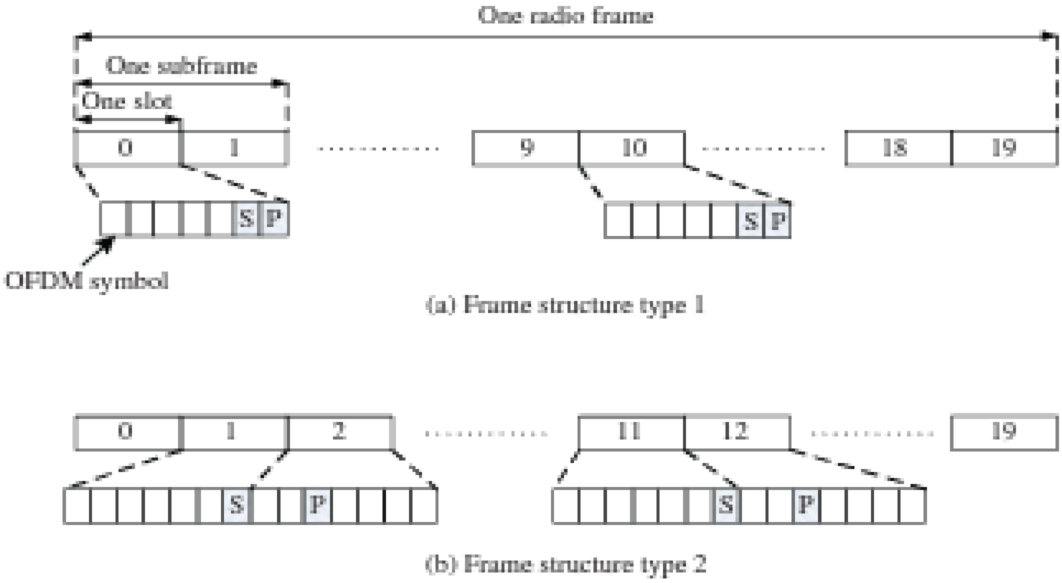


Figure 17:The mapping of primary and secondary synchronization signals

***H-A*RQ in the Downlink**

In il wireless network, due to the effects of channel fading and interference from neighbouring cells, it is nearly impossible to guarantee error-free transmission no matter how robust the channel coding is. Moreover, is the coding rate decreases, the transmission becomes more robust but at the same time power efficiency is lost, that is, a significant amount of power is used to transmit a few bits of information. An elegant approach to solve this problem is to use the H-ARQ protocol, which combines FEC and retransmission within a single framework, as described in Section 2.6.4. Similar to the HSPA system, in the case of LTE both Type I Chase *C*ombining (CC) H-ARO 2nd Type II Increm*e*nta*l* Redundaricy (IR) H-ARQ schemes have been defined. The H-ARQ operation is part of the MAC laver, while the PHY laver handles soft combining. As shown in Section 7.1., the 1/3 turbo coding is used as the FEC code while a CRC is applied for error detection .

At the receiver turbo decoding is first applied on the received code block. If this is a retransmission, which is indicated in the DCI, the code block will be combined with the previously received versions for decoding. If there is no EITOI detected in the output of the decoder, 111 ACK signal is fed back to the transmitter through the PUOCH physical channel and the decoded block is passed to the upper layer; otherwise, 10 NAK signal is fed back and the received code block is stored in the buffer for subsequent combining. The coding and modulation for H-ARO-ACK information carried in the uplink for the downlink H-ARO process is discussed in Chapter 8, while the ACK/NAK feedback is treated in Chapter 9.

At the transmitter for each (TC) transmission, the same turbo-encoded data is transmitted with different puncturing, so each of these (re)transmissions has 1. different redundancy version and each is self-decodable. Puncturing is performed during the rate matching proces as shown in Figure. The rate matcher ein produce four different redundancy versions of the original coded block. H-ARQ transmissions are indexed with the redundancy version rids, which indicates whether it is a new transmission (Vid =D) or the rud--th retransmission (ruide = 1,2, or 3).

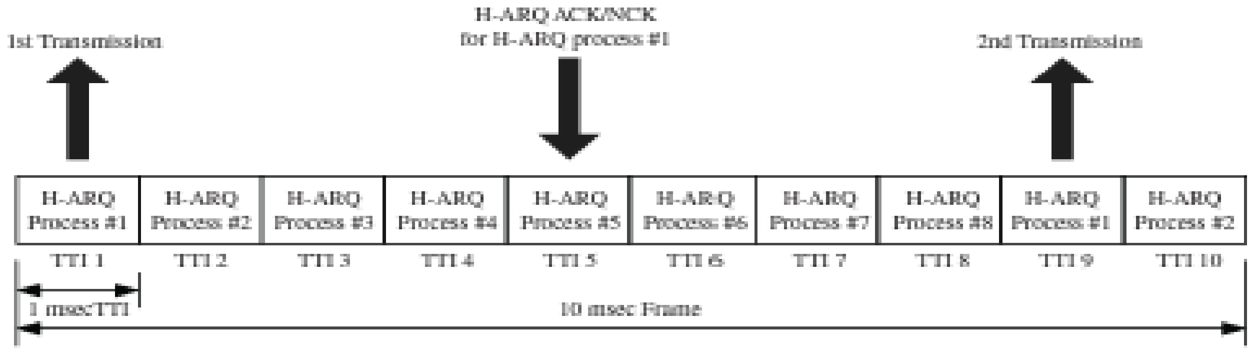


Figure 17: An example o a 10-msec frame with eight H-ARQ process.

As it takes a certain amount of time for the H-ARO ACK/NAK to be received and for the system to be ready to retransmit, there is a time interval between two Successive H-ARQ transmissions, which is typically & msec in LTE. During this 8 msec, the transport block can either be transmitted (if received with errors) or be discarded from the transmit buffer (if received without EITOTS). This implies a certain amount of inefficiency in transmission since the trafisnitter has to wait for 8 msec before it can take any action. In order to mitigate this issue, 29 N-channel Stop-and-Wait protocol is used for downlink H-ARQ operation. An N-channel Stop-and-Wait protocol consists of N parallel H-ARQ Processes. When one or more of the processes are busy waiting for the H-ARQ ACK/NAK, the processes that are free can be used to transmit other transport blocks.