LTE TDD Technology Overview

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Abstract

To keep pace with the rapidly increasing demands being placed on mobile radio systems and data traffic, the 3rd Generation Partnership Project (3GPP) has standardized a further development of UMTS. The successor to UMTS is referred to as long term evolution (LTE) and will permit more powerful and more spectral-efficient mobile radio transmission. LTE uses both frequency division duplex (FDD) and time division duplex (TDD) as duplex modes. This article describes the LTE TDD (or TD-LTE) technology in detail and highlights any differences from the LTE FDD technology. Special characteristics and specific challenges to be faced during network planning are also described.

Overview of the LTE TDD technology

LTE is the next step in the evolution of the UMTS technology. As the successor to UMTS, LTE should make transmissions possible at data rates of over 100 Megabit/s in the downlink and over 50 Megabit/s in the uplink as well as reduce latency for packet transmissions. LTE supports bandwidths of up to 20 MHz. Scalable bandwidths help ensure that LTE is compatible with existing mobile radio systems.

Orthogonal frequency division multiple access (OFDMA) is the multiple access method used in the LTE downlink. The LTE uplink is based on the single-carrier frequency division multiple access (SD-FDMA) mode. This mode is similar to OFDMA, but has the advantage that SC-FDMA signals exhibit a lower peak-to-average power ratio (PAPR).

LTE has two different duplex modes for separating the transmission directions from the user to the base station and back: frequency division duplex (FDD) and time division duplex (TDD). In the case of FDD, the downlink and uplink are transmitted using different frequencies. In TDD mode, the downlink and the uplink are on the same frequency and the separation occurs in the time domain, so that each direction in a call is assigned to specific timeslots. This article describes the details of the LTE TDD (TD-LTE) technology and highlights any differences from the LTE FDD technology. Special characteristics and specific challenges to be faced during network planning are also described. See R&S Application Note 1MA111 for a complete description of the LTE FDD technology.

Frequency bands

The TDD duplex mode is used for transmissions in unpaired frequency bands. This means that the TDD bands already defined for UMTS can also be used for LTE TDD. The TDD bands defined by 3GPP are presented in *Table 1*, although it is possible that more bands will be added.

E-UTRA Band	Frequency
33	1900 MHz to 1920 MHz
34	2010 MHz to 2025 MHz
35	1850 MHz to 1910 MHz
36	1930 MHz to 1990 MHz
37	1910 MHz to 1930 MHz
38	2570 MHz to 2620 MHz
39	1880 MHz to 1920 MHz
40	2300 MHz to 2400 MHz

Table 1: LTE TDD frequency bands [2]

LTE TDD physical layer

Frame structure

Both the uplink and downlink for LTE are divided into radio ames, each 10 ms in length. *Figure 1* shows the frame structure for LTE TDD.

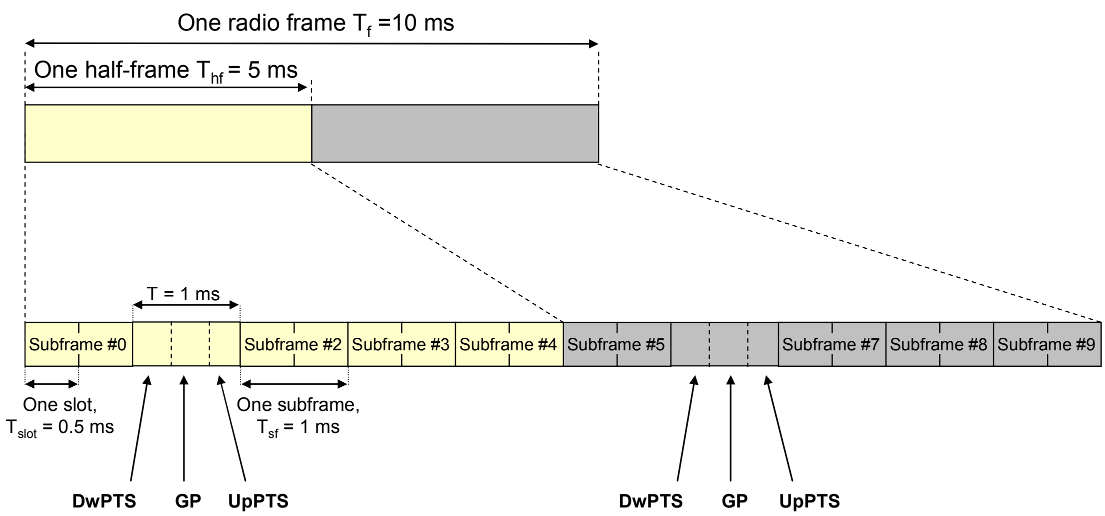

Figure 1: TDD frame structure [2]

The frame consists of two "half-frames" of equal length, with each half-frame consisting of either 10 slots or 8 slots plus the three special fields downlink pilot time slot (DwPTS), guard period (GP) and uplink pilot time slot (UpPTS) in a special subframe. Each slot is 0.5 ms in length and two consecutive slots form exactly one subframe, just like with FDD. The lengths of the individual special fields depend on the uplink/downlink configuration selected by the network, but the total length of the three fields remains constant at 1 ms.

Resource structure

The resource structure is exactly the same for both LTE TDD and LTE FDD. The smallest resource unit in the time domain is an OFDM symbol in the downlink and an SC-FDMA symbol in the uplink. The number of OFDM/SC-FDMA symbols in a slot depends on the length of the cyclic prefix being used as a guard period between the symbols. The smallest dimensional unit for assigning resources in the frequency domain is a "resource block" (RB) with a bandwidth of 180 kHz, which corresponds to N_{sc}=12 subcarriers, each at 15 kHz offset from carrier. The uplink and downlink parameters are listed in *Table 2*. *Figure 2* shows the resource structure for LTE.

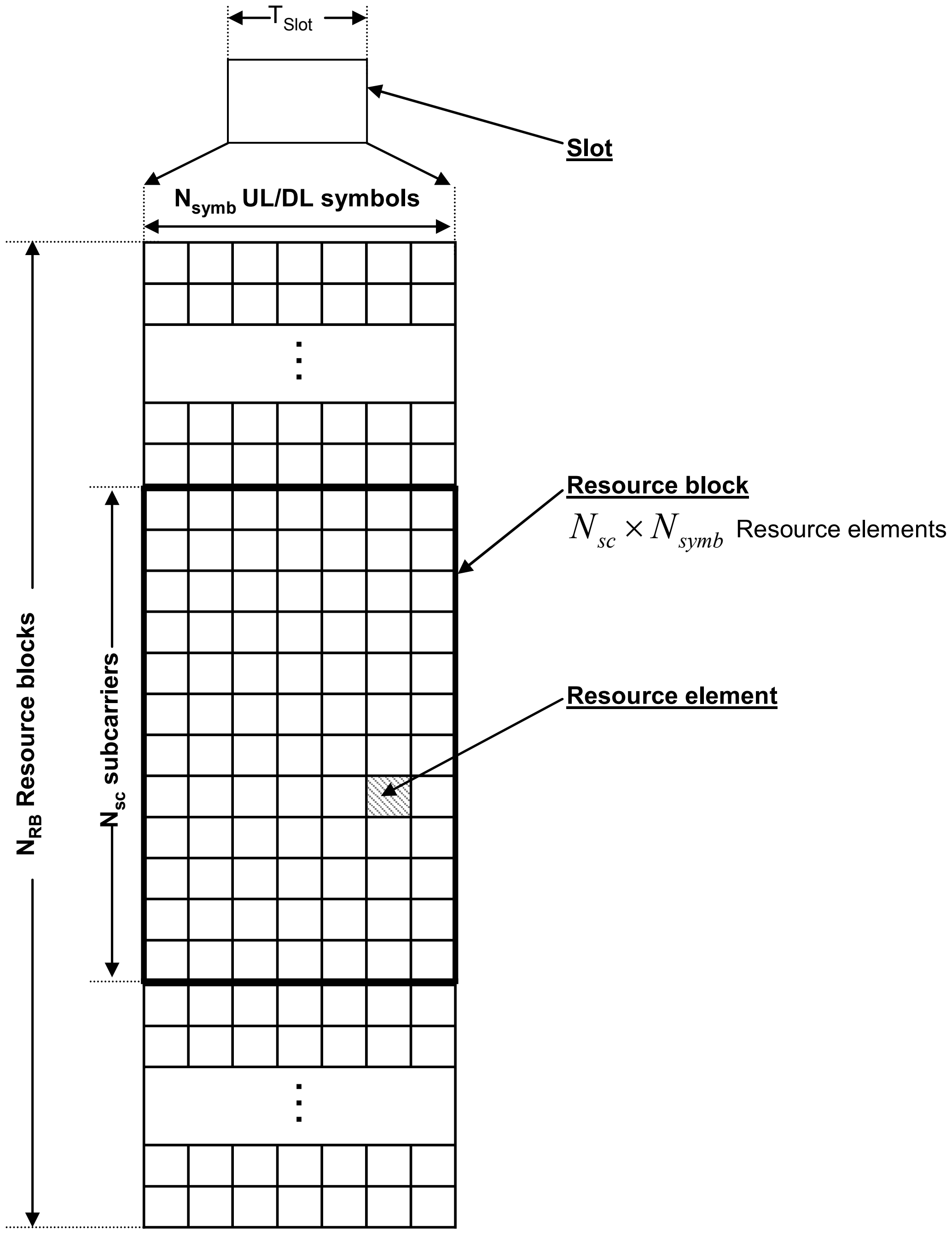

Figure 2: Slot structure [2]

	Configuration	Subcarrier spacing Δf	N_{sc}	N_{symb}
Downlink	Normal cyclic prefix	Δf = 15 kHz	12	7
	Extended cyclic prefix	Δf = 15 kHz	12	6
		Δf = 7 kHz	24	3
Uplink	Normal cyclic prefix	Δf = 15 kHz	12	7
	Extended cyclic prefix	Δf = 15 kHz	12	6

Table 2: Uplink/downlink parameterization of LTE [2]

In contrast to UMTS WCDMA/HSPA, various different bandwidths are supported for LTE, making it compatible with existing mobile radio networks. The channel bandwidth is defined by the number of available resource blocks N_{RB} and is scalable. This scalability allows radio resources to be used efficiently. *Table 3* lists the bandwidths supported by LTE and the associated number of resource blocks N_{RB}. These parameters are defined the same for LTE TDD and LTE FDD.

Channel bandwidth [MHz]	1.4	3	5	10	15	20
N_{RB}	6	15	25	50	75	100

Table 3: LTE bandwidths [2]

Uplink/downlink configurations

LTE TDD uses the same frequency bands for the uplink and the downlink. The transmission directions are separated by carrying the UL and DL data in different subframes. The distribution of subframes between the transmission directions can be adapted to the data traffic and is done either symmetrically (equal number of DL and UL subframes) or asymmetrically. *Table 4* shows the UL/DL configurations that are defined for LTE TDD. In this table, "D" means that DL data is transmitted in this subframe. Similarly, "U" indicates uplink data transmission and "S" specifies that the special fields DwPTS, GP and UpPTS are transmitted in this subframe.

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	10ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Table 4: Uplink/downlink configurations [2]

Table 4 shows that subframes 0 and 5 are always used for the downlink and that the subframe that immediately follows the special fields always transmits UL data.

DwPTS, GP, UpPTS

Within a radio frame, LTE TDD switches multiple times between downlink and uplink transmission and vice versa. In the process, the different signal transit times between the base station and the various mobile stations must be taken into consideration in order to prevent conflicts with the neighboring subframe. The timing advance process prevents conflicts when switching from the uplink to the downlink. Every mobile station (MS) is informed by the base station (BS) as to when it must start transmitting. The greater the distance between the BS and the MS, the earlier the MS starts transmitting. This helps ensure that all signals reach the BS in a synchronized manner. When switching from the downlink to the uplink, a guard period (GP) is inserted between the DwPTS and the UpPTS field. The duration of the GP depends on the signal propagation time from the BS to the MS and back as well as on the time the MS requires to switch from receiving to sending. The duration of the GP is configured by the network based on the cell size.

Because the overall length of the special subframe remains constant and the GP length varies based on cell size, the lengths of the DwPTS and UpPTS also have to be adjusted. Nine different special subframe configurations are provided for LTE TDD as shown in *Table 5*.

<table>
<tr><th rowspan="2">Special subframe configuration</th><th colspan="3">Extended cyclic prefix length in OFDM symbols</th><th colspan="3">Normal cyclic prefix length in OFDM symbols</th></tr>
<tr><th>DwPTS</th><th>GP</th><th>UpPTS</th><th>DwPTS</th><th>GP</th><th>UpPTS</th></tr>
<tr><td>0</td><td>3</td><td>8</td><td rowspan="4">1</td><td>3</td><td>10</td><td rowspan="5">1</td></tr>
<tr><td>1</td><td>8</td><td>3</td><td>9</td><td>4</td></tr>
<tr><td>2</td><td>9</td><td>2</td><td>10</td><td>3</td></tr>
<tr><td>3</td><td>10</td><td>1</td><td>11</td><td>2</td></tr>
<tr><td>4</td><td>3</td><td>7</td><td rowspan="3">2</td><td>12</td><td>1</td></tr>
<tr><td>5</td><td>8</td><td>2</td><td>3</td><td>9</td><td rowspan="4">2</td></tr>
<tr><td>6</td><td>9</td><td>1</td><td>9</td><td>3</td></tr>
<tr><td>7</td><td>-</td><td>-</td><td>-</td><td>10</td><td>2</td></tr>
<tr><td>8</td><td>-</td><td>-</td><td>-</td><td>11</td><td>1</td></tr>
</table>

Table 5: Special subframe configurations [2]

While the GP separates between the UL and the DL, the other special fields are used for data transmission. The DwPTS field carries synchronization and user data as well as the downlink control channel for transmitting scheduling and control information. The UpPTS field is used for transmitting the physical random access channel (PRACH) and the sounding reference signal (SRS).

Physical channels

Physical channels transmit higher-layer information. The same channels are defined for both LTE TDD and for LTE FDD. However, the positions of these channels within the radio frame are somewhat different for TDD and FDD.

- **Physical downlink shared channel (PDSCH):** The PDSCH is used only to transmit user data. The data rate can be increased by using the MIMO method of spatial multiplexing, in which multiple data streams are transmitted simultaneously via a multiple antenna system. The PDSCH modulation modes are QPSK, 16QAM and 64QAM. If PDSCH data is received from the mobile station without errors, the mobile station returns an acknowledgement (ACK) in the uplink. If errors occur during the transmission, a request is sent to repeat the transmission (NACK). In contrast to LTE FDD, LTE TDD can send a single ACK/NACK response for multiple PDSCH transmissions (for multiple subframes).
- **Physical downlink control channel (PDCCH):** The PDCCH contains the downlink control information (DCI), whereby the DCI formats differ somewhat for LTE TDD and LTE FDD. The PDCCH is transmitted at the start of every subframe and informs the mobile station where the PDSCH data intended for it is located in the downlink and which resources it may use for transmitting in the uplink.
- **Physical control format indicator channel (PCFICH):** The PCFICH is transmitted in the first OFDM symbol of the subframe or of the DwPTS field and reports how many OFDM symbols (1, 2, 3 or 4) carry PDCCH data in that subframe.
- **Physical hybrid ARQ indicator channel (PHICH):** The PHICH carries the ACK/NACK responses for transmitted uplink packets. The PHICH is mapped to the resource elements differently for LTE TDD and LTE FDD.
- **Physical broadcast channel (PBCH):** The PBCH is a broadcast channel. It contains information used during cell searches. This includes the system bandwidth, and the system frame number.

Uplink channels

- **Physical uplink shared channel (PUSCH):** The PUSCH transmits the user data from the mobile station to the base station. The uplink control information such as channel quality, scheduling requests and ACK/NACK responses for downlink packets, are also transmitted via this channel. Like for PDSCH, a bundled ACK/NACK response can be sent for multiple PUSCH transmissions from the base station in LTE TDD mode.

- **Physical uplink control channel (PUCCH):** If a mobile station does not have any packets to be transmitted on the PUSCH, the control information is sent via the PUCCH. The PUCCH is therefore never sent simultaneously with the PUSCH from the same mobile station. LTE TDD does not use the UpPTS fields for PUCCH transmission.
- **Physical random access channel (PRACH):** The PRACH contains the "random access preamble". The random access preamble is configured by the physical layer as well as by the higher layers. The format of the random access preamble is shown in *Figure 3*. The preamble consists of the sequence of length T_{SEQ} and the cyclic prefix of length T_{CP}. LTE supports five preamble formats for various access configurations. Formats 0 to 3 are used for TDD as well as for FDD; however format 4 is used only for TDD. The random access preambles are generated as Zadoff-Chu sequences. There are 64 random access preambles per cell. As a result of the differences in the radio frame structure between LTE TDD and LTE FDD, the resource elements are also configured differently.
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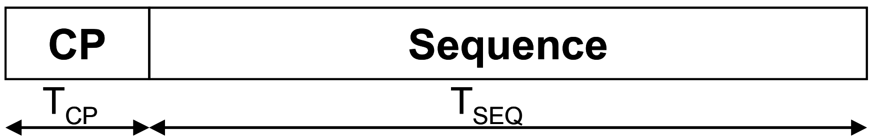

Figure 3: Random access preamble format [2]

Physical signals

Physical signals are used in LTE to allow cell synchronization and channel estimation. The same signals are defined for both TDD and FDD mode.

Downlink signals

- **Reference signal:** The reference signal is used for downlink channel estimation. *Figure 4* shows the structure of the signal for transmissions with 1, 2 and 4 antennas, whereby the different colors represent the reference signals from the various antennas. Each antenna uses only the resources defined for it in the time and the frequency domain.

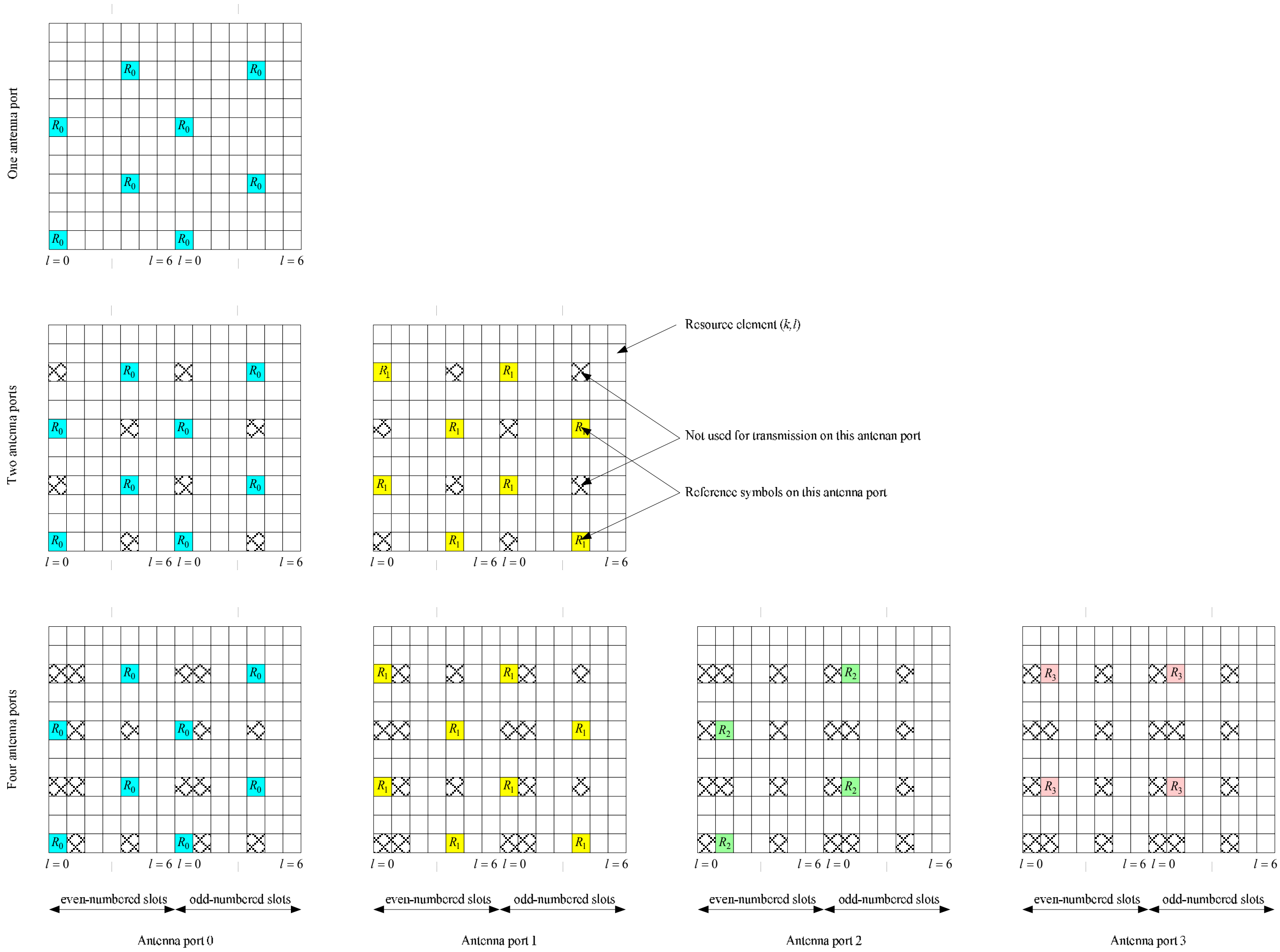

Figure 4 Structure of downlink reference signal (for normal cyclic prefix)

- **Primary** and **secondary synchronization signal (P-SYNC, S-SYNC):** These signals contain information needed for the cell search. The names "primary" and "secondary" represent the sequence in which they are read by the mobile station during the cell search.

The position of these signals within the radio frame is different for LTE TDD and LTE FDD.

Uplink signals

- **Demodulation reference signal:** This signal is used for channel estimation on the base station in order to detect and demodulate the receive data correctly.
- **Sounding reference signal:** This signal supplies information about the channel quality needed by the base station for scheduling decisions.

MIMO

One of the most important developments for LTE is the use of multiple input multiple output (MIMO) technology. Multiple antennas are used to send and receive the signal using one of the MIMO methods "spatial multiplexing", "transmit diversity" or "cyclic delay diversity". In the case of spatial multiplexing, separate data is transmitted in parallel in the same resource block. Spatial multiplexing can be used together with cyclic delay diversity, in which each antenna transmits the signal with a delay that is assigned specifically to it. In the case of transmit diversity, all antennas transmit the same data stream, but a different coding can be used for each antenna. Depending on which MIMO method is used, it is possible to achieve the high LTE data rates or to ensure better call quality.

Beamforming is also available for LTE. In this method, the signals for every mobile station are transmitted via a beam instead of omnidirectionally. The beam is formed by matching the directional pattern of the base station's antenna array. The use of beamforming is particularly interesting in LTE TDD because of the reciprocity between the downlink and the uplink channel. Beamforming permits an improvement in both the transmission capacity and in the receive signal quality.

LTE TDD protocol layer

In order to meet the demands for high data rates and short latency, the protocol architecture for LTE has also been modified. *Figure 5* shows the network architecture developed for LTE and the functionality of the individual nodes.

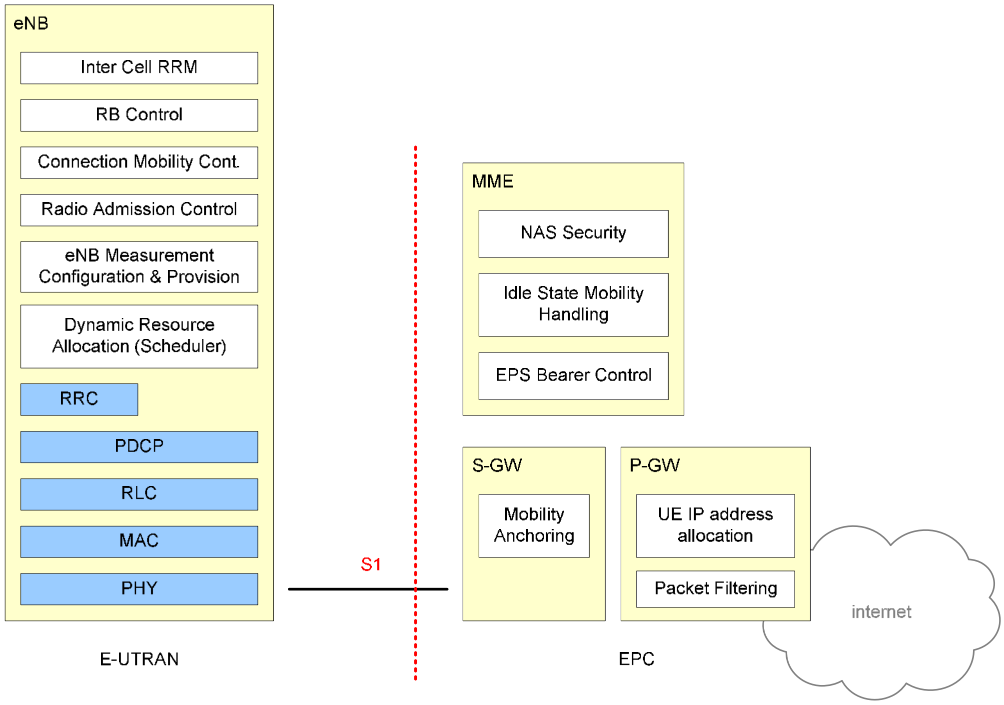

Figure 5: 3GPP SAE network architecture

The base station (eNB) handles functions such as uplink and downlink scheduling, mobility control, radio bearer and admission control. It is connected to the evolved packet core (EPC) via the S1 interface. The EPC consists of a serving gateway (S-GW), a mobility management entity (MME) and a packet data network gateway (P-GW).

The network and protocol architecture described above applies to both LTE FDD and LTE TDD. The protocol functions are also essentially the same for LTE TDD and LTE FDD. However, the control information for the radio resource control (RRC) protocol will differ as a result of the previously described differences in the physical layer between LTE FDD and LTE TDD. The RRC configures the lower layers and is also responsible for selecting the parameters for transmitting user data and control data.

The MAC protocol is responsible for assigning resources (scheduling). Here, too, the differences in the physical layer between TDD and FDD must be taken into account.

References

[1] 3GPP TS 36.104; Base Station (BS) radio transmission and reception (Release 8)

[2] 3GPP TS 36.211; Physical channels and modulation (Release 8)

[3] 3GPP TS 36.212; Multiplexing and channel coding (Release 8)

[4] 3GPP TS 36.213; Physical layer procedures (Release 8)

[5] 3GPP TS 36.300; Overall description; Stage 2 (Release 8)

[6] Peter W .C. Chan, Ernest S. Lo, Ray R.Wang: "The Evolution Path of 4G Networks: FDD or TDD?" IEEE, December 2006

[7] Harri Holma, Sanna Heikkinen, Otto-Aleksanteri Lehtinen: "Interference Considerations for the Time Division Duplex Mode of the UMTS Terrestrial Radio Access", IEEE 2000

Abbreviations

3GPP	3rd Generation Partnership Project
ACK	Acknowledgement
ARQ	Automatic repeat request
BS	Base station
DCI	Downlink control information
DL	Downlink
DwPTS	Downlink pilot time slot
eNB	E-UTRAN NodeB
EPC	Evolved packet core
E-UTRA	Evolved UTRA
FDD	Frequency division duplex
GP	Guard period
HSPA	High speed packet access
LTE	Long term evolution
MAC	Medium access control
MIMO	Multiple input multiple output
MME	Mobility management entity
MS	Mobile station
NACK	Negative acknowledgement
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
PAPR	Peak-to-average power ratio
PBCH	Physical broadcast channel
PCFICH	Physical control format indicator channel
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
P-GW	PDN gateway

PHICH	Physical hybrid ARQ indicator channel
PRACH	Physical random access channel
P-SYNC	Primary synchronization signal
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RB	Resource block
SAE	System architecture evolution
SC-FDMA	Single-carrier frequency division multiple access
S-GW	Serving gateway
SRS	Sounding reference signal
S-SYNC	Secondary synchronization signal
TDD	Time division duplex
UL	Uplink
UMTS	Universal mobile telecommunication system
UpPTS	Uplink pilot time slot
UTRA	UMTS terrestrial radio access
WCDMA	Wideband code division multiple access