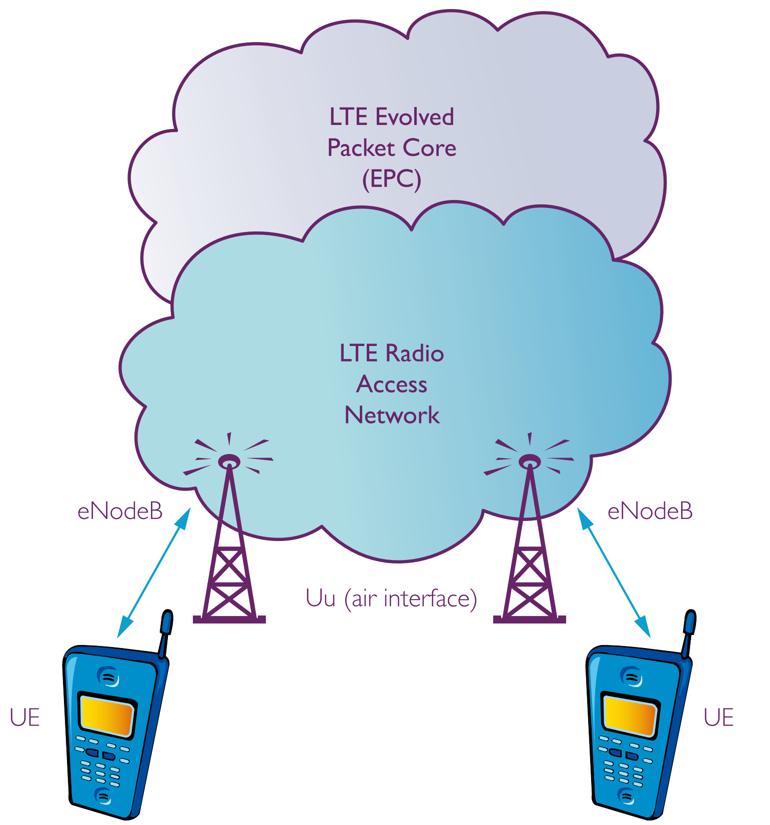
# LTE eNodeB MAC Scheduler Introduction


## Abstract

LTE introduces a new OFDM-based air interface and a flat, IP-based network architecture. The basic structure of the LTE air interface and the role of the MAC sublayers in the UE and eNodeB are described. The eNodeB MAC sublayer is responsible for scheduling transmissions over the LTE air interface in both the downlink and uplink directions. The eNodeB MAC sublayer contains the MAC Scheduler which schedules the downlink/uplink transmissions and allocates the Physical layer resources to be used. The MAC Scheduler is a complex component and presents a number of design challenges. Roke has many years experience with QoS, OFDM-based wireless communications and scheduling. This experience is being used to research and develop pluggable eNodeB MAC schedulers.


## Introduction

Long Term Evolution (LTE), introduced in 3GPP Release 8, represents a significant change to the 3G UMTS/HSPA radio access and core networks. LTE uses a flat, IP-based network architecture. A common, packet-based infrastructure is used for all services (voice and data), removing the need for the dedicated circuit-switched and packet-switched domains which are present in 3G UMTS/HSPA networks. The radio access network is simplified in LTE with the base station, or evolved-NodeB (eNodeB), implementing the functions which were previously distributed between the 3G RNC and NodeB.




*LTE Network*

The LTE air interface uses Orthogonal Frequency Division Multiplexing (OFDM) together with advanced antenna techniques and adaptive modulation and coding to achieve significant throughput and spectral efficiency improvements. Higher spectral efficiency enables operators to transfer more data per MHz of spectrum, resulting in a lower cost-per-bit. The OFDM-based air interface also provides much greater deployment flexibility than 3G UMTS/HSPA with support for multiple channel bandwidths as well as time and frequency duplexing modes (TDD & FDD). A 20MHz FDD channel (3GPP Release 8) supports peak rates of at least 100Mbps in the downlink and 50Mbps in the uplink.

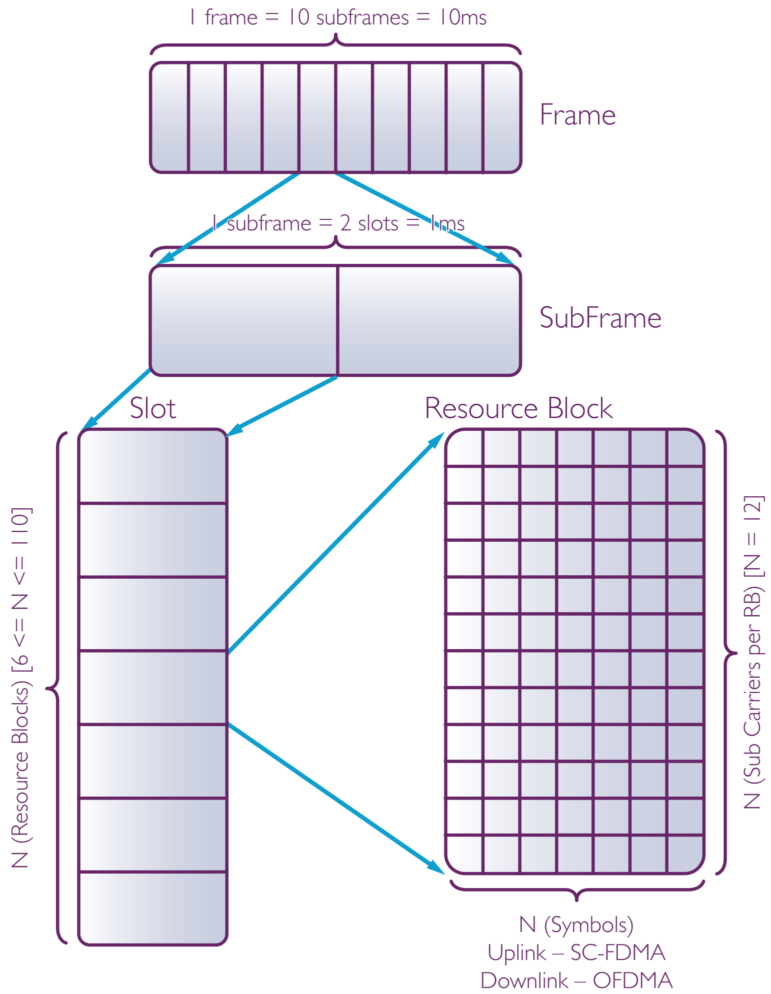



*Figure 2 : LTE Air (Uu) Interface Elements*

The LTE air interface uses a transmission time interval of 1ms which, combined with features such as hybrid-ARQ, is designed to provide lower latency.

The downlink (eNodeB to UE) and uplink (UE to eNodeB) channels in the air interface are divided into a number of elements as shown Figure 2:

- A **frame** is 10ms in length. Each frame is divided (in the time domain) into 10 subframes.
- A **subframe** is 1ms in length. Each subframe is divided (in the time domain) into 2 slots.
- A **slot** is 0.5ms in length. Each slot is divided (in the frequency domain) into a number of resource blocks. The number of resource blocks in a slot depends on the channel bandwidth.
- A **resource block** is 0.5ms in length and contains 12 subcarriers from each OFDM symbol. The number of OFDM symbols in a resource block depends on the cyclic prefix being used. The resource block is the main unit used to schedule transmissions over the air interface.

The Radio Link Control (RLC, *3GPP TS 36.322*) entity sits above the Medium Access Control (MAC, *3GPP TS 36.321*) sublayer in the eNodeB and UE protocol stacks. RLC works with logical channels. Each logical channel maps to either a signalling radio bearer (SRB) or data radio bearer (DRB).

- SRBs carry control-plane data between the Radio Resource Control (RRC, *3GPP TS 36.331*) sublayers in the eNodeB and UE.
- DRBs carry the user-plane data associated with the services provided to the end user. Each DRB is associated with a UE and a specific quality of service (QoS) – a UE may use separate DRBs for separate applications, e.g. voice and web browsing.

Data is transferred between the MAC sublayers in the UE and eNodeB using **transport blocks** which are sent via the downlink and uplink shared transport channels (DL-SCH and UL-SCH) as shown in Figure 3. The MAC sublayer is responsible for constructing the transport blocks using data from the following sources:

- RLC logical channels. Data is read from one or more logical channels and packed into transport blocks in such a way as to meet the QoS requirements for the radio bearer(s).
- MAC Control Elements. These are used for peer-to-peer control purposes between the eNodeB and UE MAC sublayers.
- Hybrid-ARQ (HARQ) retransmissions.

## LTE eNodeB MAC Scheduler

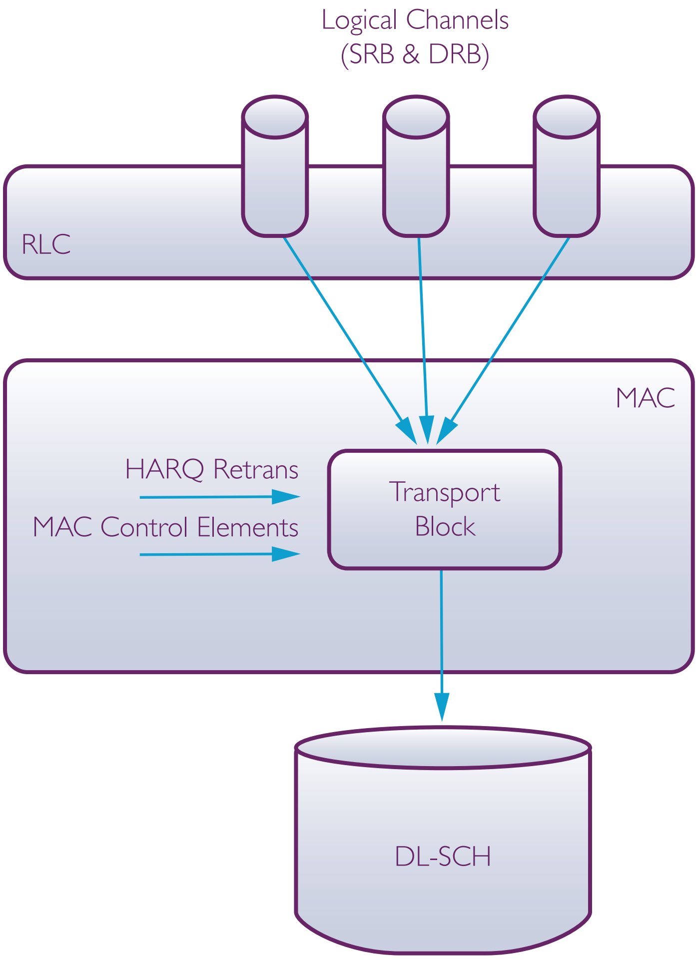



*Figure 3 : MAC Transport Block*

The eNodeB MAC sublayer is responsible for scheduling transmissions over the LTE air interface in both the downlink and uplink directions. The eNodeB MAC sublayer contains the **MAC Scheduler**. The MAC Scheduler runs the scheduling algorithms which determine what gets sent when and to/by whom. The MAC Scheduler is responsible for implementing the QoS characteristics assigned to radio bearers.

The eNodeB MAC Scheduler receives inputs from various sources which guide the scheduling algorithms. The output of the MAC Scheduler is a series of resource assignments for a downlink and uplink subframe. Resource assignments are defined in terms of resource blocks. As mentioned earlier, a resource block occupies 1 slot in the time domain and 12 subcarriers in the frequency domain – see Figure 2.

The resource assignments output by the eNodeB MAC Scheduler indicate the size of each transport block and what Physical layer resources are to be used in sending it to the UE/eNodeB via the DL-SCH/UL-SCH transport channel. This resource assignment information is broadcast to all UEs on the Physical Downlink Control Channel (PDCCH). Each UE monitors the PDCCH to determine when to receive and transmit on the DL-SCH and UL-SCH transport channels.

Figure 4 illustrates how the contents of a radio bearer are transferred between eNodeB and UE via transport blocks which in turn use a number of resource blocks at the Physical layer. For a VoIP call for example, the DRB transports the RTP/UDP/IP packets with the eNodeB MAC Scheduler scheduling regular transmission opportunities in the downlink and uplink.

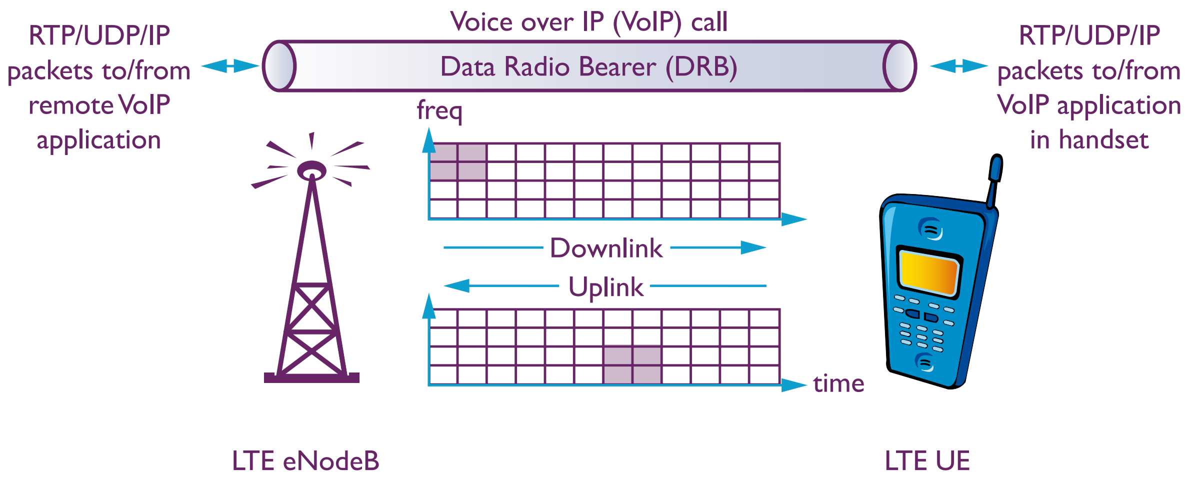



*Figure 4 : Mapping Radio Bearer Data to Packet-Based Air Interface (Uu)*

The MAC Scheduler in the eNodeB is instrumental in:

- Providing the appropriate QoS to radio bearers enabling operators to provide a mix of services. This may include emulating the QoS associated with 3G circuit-switched radio bearers, i.e. guaranteed throughput, low latency.
- Optimising and maximising the air interface utilisation to minimize the cost-per-bit to users and operators.

A pluggable MAC Scheduler as a component of the overall eNodeB MAC sublayer enables LTE networks to be deployed with a basic set of scheduling features which can then be enhanced and customized in order to achieve the true benefits of LTE.

Designing and implementing an eNodeB MAC Scheduler is a complex process involving a number of challenges:

1. Optimising UL and DL assignments for capacity, throughput and cell edge performance.
2. Appropriate selection and implementation of QoS algorithms.
3. Utilizing advanced antenna techniques, e.g. 2x2 MIMO in the DL.
4. Hard real-time requirements. The 1ms transmission time interval used by LTE places tight real-time constraints on the MAC Scheduler.
5. Minimising the amount of signalling used over the air interface.
6. Minimizing eNodeB and UE power consumption.
7. Providing a framework for future enhancements in areas such as cooperative scheduling for interference reduction.

## Summary

Roke Manor Research Ltd (Roke) is actively involved in research, development and standards activities for LTE and is investing in the research and development of pluggable LTE eNodeB MAC schedulers.

Roke is applying its extensive experience in QoS and packet scheduling to the research and development of LTE eNodeB MAC schedulers. This experience includes technologies such as mobile WiMAX (IEEE 802.16) and 3GPP HSPA and stretches back to early implementations of ATM. Roke is able to draw upon work on QoS algorithms, OFDM frame-packing and MAC Scheduler simulation.

In addition to specific experience in QoS and packet schedulers, Roke is applying its detailed knowledge and understanding of packet-based and 3GPP radio access networks to the LTE eNodeB MAC Scheduler. This includes the system design for a WiMAX ASN-Gateway, the prototyping and development of the User-Plane for a 3GPP IP-based RAN and the development of a complete 3GPP TDD NodeB picocell.

The ability to validate the operation of the LTE eNodeB MAC Scheduler and determine its performance in real-life wireless environments is vital to achieving the benefits offered by LTE. Roke has developed test environments for the validation of various 3GPP products including RNCs and femtocells. Roke has also developed a generic radio simulation tool which supports link and system-level simulation of 3GPP, mobile WiMAX and other wireless technologies.

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