

LTE eNodeB MAC Scheduler Interface

An interface which enables smart MAC Scheduler solutions to be easily integrated with third party core MAC implementations leading to improved user experience and system performance

Abstract

The MAC Scheduler within the eNodeB MAC sublayer determines how the downlink and uplink channels in the LTE air interface are used. Resources are assigned to UEs enabling them to receive data via the downlink and transmit data via the uplink. The scheduler assigns these resources in such a way as to satisfy QoS requirements and optimise system performance. The eNodeB MAC Scheduler design and functionality is largely vendor specific. Different schedulers may result in significantly different levels of user and system performance. An open interface between the MAC Scheduler and the rest of the eNodeB MAC sublayer enables equipment vendors, operators and users to benefit from advanced, third-party MAC Scheduler solutions. This white paper provides an overview of the LTE eNodeB MAC Scheduler interface defined by Roke.

Introduction

The MAC sublayers in the LTE base station (eNodeB) and user devices (UE) are responsible for multiplexing the user-plane and control-plane traffic over the air interface. Each UE may have multiple active bearers – logical connections within the LTE network. Each bearer is used to transfer user-plane data with a given quality of service (QoS). The MAC sublayers within the eNodeB and UE are responsible for constructing, sending, receiving and processing transport blocks which contain a combination of user-plane data from one or more bearers, control-plane data and MAC control messages.

The MAC Scheduler can be viewed as the L2 'brains' within the eNodeB whilst the rest of the MAC sublayer performs the 'heavy lifting' associated with multiplexing, transport block processing, HARQ, subframe construction, etc. Two eNodeBs with the same core MAC sublayer can exhibit significantly different levels of user and system performance as a result of their MAC Scheduler implementations. These differences can include user throughput, cell capacity, QoS and UE power consumption.

An open, well defined eNodeB MAC Scheduler interface enables innovative, smart MAC Scheduler solutions to be integrated with core MAC sublayer implementations. This has the following benefits:

- Equipment manufactures benefit by being able to tailor and enhance the performance of their eNodeB products with third-party MAC Scheduler solutions.
- Network operators benefit by having eNodeBs which can be optimised for air interface utilisation and service delivery – reducing operating expense and supporting revenue growth.
- End users benefit from enhanced throughput, improved battery life and support for a greater range of potential services.

Roke Manor Research Ltd (Roke) has defined a MAC Scheduler interface for use in LTE eNodeB products. The interface enables advanced MAC Scheduler implementations to be incorporated into third party MAC layer products.

MAC Scheduler

The MAC Scheduler is responsible for scheduling the transfer of user data and control signalling via transport blocks in downlink and uplink subframes over the LTE air interface. The MAC Scheduler assigns the downlink and uplink physical layer resources used by the eNodeB and UEs within the cell. The scheduling decisions are based on information from various sources within the eNodeB radio protocol stack and the UE. A simplified view of the eNodeB protocol stack is shown in Figure 1.

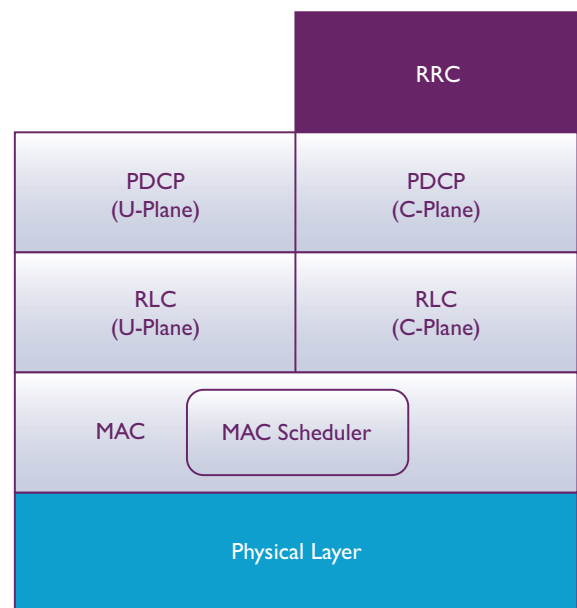


Figure 1: LTE eNodeB Radio Protocol Stack

In the downlink, the MAC Scheduler allocates resources which are used by the core eNodeB MAC sublayer to send transport blocks to specific UEs via the DL-SCH transport channel. These downlink transport blocks contain:

- Upper layer data: All upper layer data, whether this is user data or signalling messages, will feed into the MAC sublayer through an RLC logical channel. Whenever one of these logical channels has any data to send over the LTE air interface, a Buffer Status indication is provided by RLC to the MAC Scheduler.
- MAC layer data: This can either take the form of a HARQ retransmission or MAC Control Element. In both cases, the MAC layer will provide an indication to the scheduler that it has data ready to send over the LTE air interface.

In the uplink, the MAC Scheduler allocates resources to specific UEs which enable them to construct and send transports blocks to the eNodeB via the UL-SCH transport channel. Each UE needs to request the uplink resources (except where Semi Persistent Scheduling is used) needed to send a transport block. This can be done in a number of ways:

- When a UE does not have an active connection in a cell, it performs the Random Access Procedure to join (or re-join) the cell.
- When the UE has uplink control resources on the PUCCH physical channel, it sends a Scheduling Request indication to request uplink resources.
- When the UE already has resources to send data in the uplink on the UL-SCH transport channel, it may indicate to the scheduler that it has more data to send, and therefore requires more uplink resources. The UE does this by sending a Buffer Status Report MAC Control Element.
- Based on HARQ feedback at the eNodeB, the scheduler might need to allocate uplink resources for HARQ retransmissions by the UE.

The output of the scheduling algorithm is a scheduling assignment per uplink and downlink subframe, which is signalled to UEs on the PDCCH physical channel.

- The downlink assignment information will be used by the eNodeB MAC layer to generate the transport blocks which are passed to the eNodeB Physical layer and subsequently sent over the air.
- The uplink assignment information indicates which UEs have been allocated uplink resources within the subframe. It is also used by the eNodeB MAC layer to identify uplink transmissions in the corresponding uplink subframe.

Before any user data can be transferred over the air, the scheduler needs to be configured with a cell specific configuration, a UE specific configuration and finally a bearer specific configuration for each active UE bearer. Reconfiguration of each UE and/or bearer is also possible.

In order to make full use of the information available within the Roke MAC Scheduler, certain event triggered or periodic feedback information is provided to higher layers. Based on this information, the higher layers are able to reconfigure the operation of the cell to provide a more efficient air interface.

For monitoring purposes, the Roke MAC Scheduler will also output detailed information about subframe utilisation. This could include but is not limited to the following

- Subframe map showing utilised Physical Resource Blocks (PRBs)
- A percentage of utilised versus unutilised PRBs
- Number of Logical Channels/MAC Control Elements not scheduled 'first-time'

MAC Scheduler Interface

The Roke LTE eNodeB MAC Scheduler interface consists of two parts as shown in Figure 2:

- the Control Interface
- the Scheduling Interface.

The MAC Scheduler interface has been designed as a push-based interface. All information needed by the scheduler is passed in via functions defined in the Control and Scheduling interfaces. Callback functions are defined by the Control and Scheduling interfaces to pass control and information to external entities.

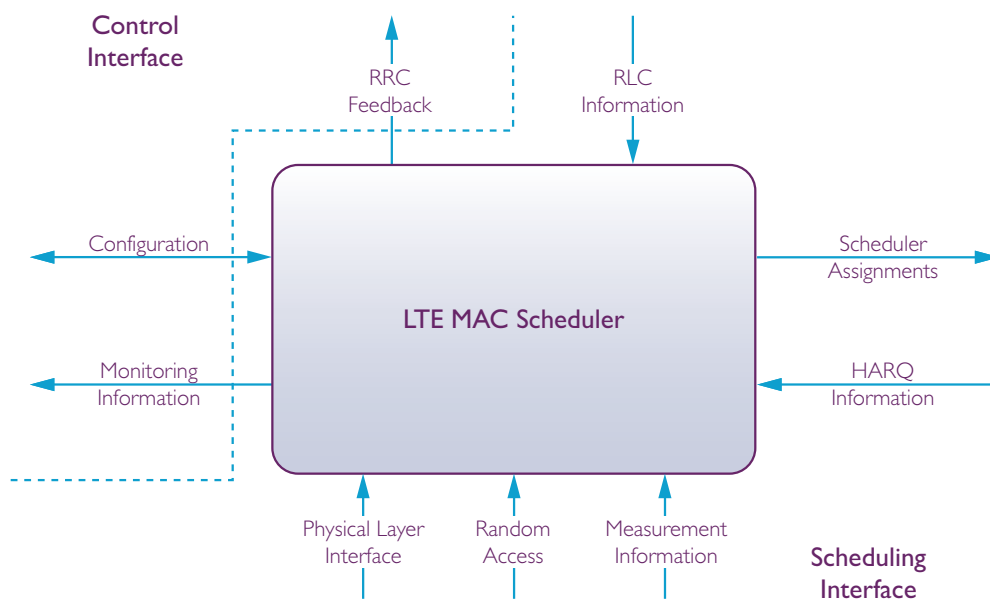


Figure 2: MAC Scheduler Interfaces

Control Interface

The Control Interface is used to prepare the scheduler for operation with a cell configuration, as well as configuring individual UEs as they become active in the cell. In addition to the initial configuration for the cell, functions are needed to reconfigure the cell and the individual UEs, which includes adding, modifying and removing bearers. Other housekeeping functions, which are primarily controlled by the eNodeB's RRC layer also use this interface.

The functions which form the Control Interface are given in Table 1 while the callback functions which are invoked by the scheduler for the notification of asynchronous events are given in Table 2.

Table 1: Control Interface Functions

Function	Description
schVersionReq	Requests the version number of the scheduler
schCellConfigReq	Provides the scheduler's cell configuration
schCellReconfigReq	Modifies the scheduler's cell configuration
schCellStopReq	Stops the operation of the scheduler, but does not remove or reset any context
schCellResetReq	Resets the scheduler to its initial state
schUeSetupReq	Adds a new UE scheduling context according to the indicated UE configuration
schUeReconfigReq	Reconfigures the UE's scheduling context in accordance with a change to the UE's MAC, RRC or SIAP configuration (e.g. measurement gaps, semi persistent scheduling, DRX or AMBR)
schUeReleaseReq	Removes all context within the scheduler related to this UE, including any established bearers
schLcAddReq	Adds a new bearer and associated configuration (e.g. QCI and bit rate requirements) to the scheduling algorithm
schLcModifyReq	Modifies a bearer's configuration in accordance with a change to the bearer's MAC, RRC or SIAP configuration.
schLcSuspendReq	Suspends one of the UE's bearers upon command from higher layers (e.g. Radio Link Failure or handover) Note: The bearers are resumed by the schLcModifyReq function
schLcRemoveReq	Removes a bearer from the scheduling algorithm

Table 2: Control Interface Callback Functions

Function	Description
schRrcFeedbackInd	Provides event driven optimisation information to higher layers based on the cell or specific UE usage
schSubframeInfolnd	Provides statistics about the current subframe, including subframe utilisation

Scheduling Interface

The Scheduling Interface is used to provide input into the MAC Scheduler's scheduling algorithm. The functions include informing the scheduler when uplink or downlink data and control elements are ready to be scheduled, as well as providing measurement information to allow the scheduler to select an appropriate Modulation and Coding Scheme (MCS) and group of PRBs for a specific UE. The MAC Scheduler uses the Scheduling Interface to output downlink and uplink resource assignment information which is used by the eNodeB MAC and Physical layers to construct and process downlink and uplink subframes and transport blocks.

The functions which form the Scheduling Interface are given in Table 3 while the callback functions which are invoked by the scheduler for the notification of asynchronous events are given in Table 4.

Table 3: Scheduling Interface Functions

Function	Description
schRlcBufferStatusReq	Informs the scheduler that a logical channel has downlink data to send
schDlRetransmissionReq	Informs the scheduler that a retransmission of a downlink (HARQ) TB is required
schMacCeReq	Informs the scheduler that a MAC CE needs to be sent to a particular UE
schRarReq	Informs the scheduler that a Random Access Response message needs to be sent. The scheduler also returns an uplink grant for each UE included in the Random Access Response message
schSrEventReq	Provides the scheduler with a Scheduling Request received from a UE
schBsrEventReq	Provides the scheduler with a Buffer Status Report received from a UE
schUlRetransmissionReq	Informs the scheduler that a retransmission of an uplink (HARQ) TB is required
schMeasChangeReq	Informs the scheduler about a change of a UE's measurements (e.g. new CQI report or timing advance information)
schNextSubframeReq	Triggers the generation of the next subframe within the scheduler

Table 4: Scheduling Interface Callback Functions

Function	Description
schDlSubframeAssignInd	Triggers the generation of the next downlink subframe within the MAC layer based on the indicated scheduling assignments
schUlSubframeAssignInd	Informs the MAC layer of the scheduled assignments for the given uplink subframe

Sequence Diagrams

This section presents two sequence diagrams which illustrate how the Control and Scheduling interfaces are used. Further sequence diagrams are provided in the full Roke eNodeB MAC Scheduler interface specification.

Control Interface: Cell Setup

This sequence diagram shows the Control Interface being used to provide the initial cell configuration to a MAC Scheduler.

Figure 3 shows the following steps in the cell setup:

1. The Scheduler's version number is requested. Depending on the version of the scheduler, different configurations can be used by higher layers.
2. The Scheduler is configured based on the information provided by higher layers, which includes a combination of RRC parameters contained within the Master Information Block (MIB) and System Information Blocks (SIB), as well as other proprietary parameters.
3. The broadcast logical channels (BCCH, PCCH, and CCCH) are configured. NOTE: Three separate logical channels are shown for the BCCH due to the different scheduling requirements of the MIB, SIB1 and other SIBs.

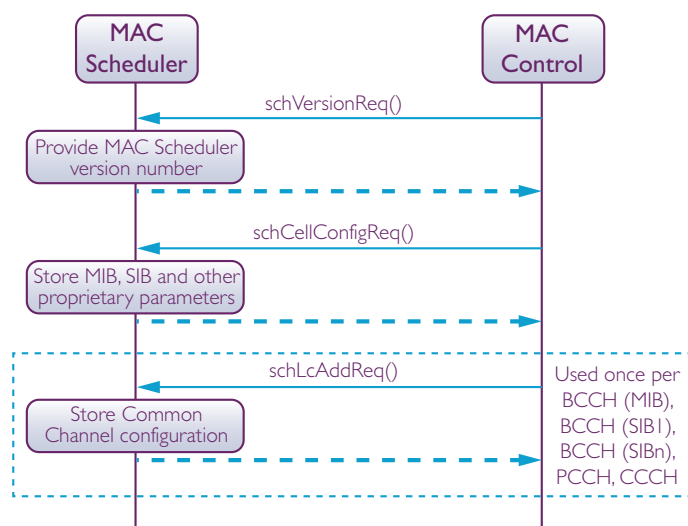


Figure 3: Cell Setup Sequence

Scheduling Interface: Downlink Data Scheduling

This sequence diagram shows the Scheduling Interface being used to provide the Scheduler with information about data to be sent on the DL-SCH transport channel. The Scheduler will consider each type of data in its scheduling algorithm based on a priority between UEs, their logical channels and other common channel/broadcast information.

Figure 4 shows the Scheduler receiving information about:

1. RLC PDUs, either on broadcast, common or dedicated logical channels
2. Downlink (HARQ) Retransmissions
3. MAC Control Elements
4. MAC Random Access Response Control Elements

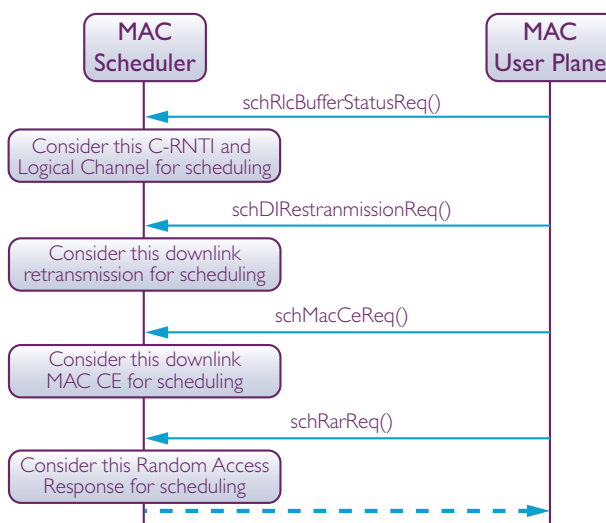


Figure 4: Downlink Data Scheduling

Summary

Roke has defined an eNodeB MAC Scheduler interface which enables smart MAC Scheduler solutions to be easily integrated with third party core MAC implementations leading to improved user and system performance. The interface has been designed so that all information is pushed to the Scheduler. Callback functions are defined to pass control and information back to the core MAC sublayer and other entities. The interface has been divided into two parts: the Control interface handles configuration and management functions, the Scheduling Interface handles the scheduling of the downlink and uplink subframes. The full eNodeB MAC Scheduler interface specification is available on request – please contact mobile@roke.co.uk or visit www.roke.co.uk for further details.

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