Design and Development of Medium Access Control Scheduler in LTE eNodeB

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ABSTRACT

Long Term Evolution (LTE) is a major step in mobile radio communications, and is beyond 3G systems and is the next generation cellular system of 3GPP .3GPP's Long Term Evolution is defined by the standardization body's Release 8. LTE uses OFDMA and SC-FDMA as its radio access technology with advanced antenna technologies such as Multi-Input Multi-Output (MIMO), for both downlink and uplink. LTE is a system with complex hardware and software. In case of Long Term Evolution (LTE), the scheduler in the Medium Access Control (MAC) layer of the eNodeB allocates the available radio resources among different UEs in a cell through proper handling. LTE schedulers are part of layer 2 protocol stack and are one such module which can dramatically increase or decrease the performance of the system. In this paper, we are presenting various types of scheduling schemes of LTE and their advantages. The output conditions such as memory usage and execution time for varying number of users are investigated for three of the scheduling methods: Proportional Fair (PF), Modified-Largest Weighted Delay First (MLWDF) and EXP-Proportional Fair (EXP-PF) scheduling algorithm. Developed algorithms are tested for single-cell/multi-cell with multiple-user scenarios in both TDD/FDD frame structure.

Keywords:*Evolved Packet Core (EPC),* Evolved UMTS (Universal Mobile Telecommunication System) Terrestrial Radio Access Network (EUTRAN),*Long Term Evolution (LTE), and Medium Access Control (MAC) layer Scheduling.*

I. INTRODUCTION

LTE of UMTS is just one of the latest steps in an advancing series of mobile telecommunications systems and introduced in 3rd Generation Partnership Project (3GPP) Release8. LTE uses orthogonal Frequency Division Multiplexing (OFDM) and Single- Carrier Orthogonal Frequency Division Multiple Access (SC-FDMA) as its radio access technology with advanced antenna technologies such as Multi-Input Multi-Output (MIMO). Duplexing is a method for two-way transmission in either frequency domain or time domain. Downlink carries information from eNodeB to UE while uplink carries information from UE to eNodeB. Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are two duplexing schemes used in LTE. TDD uses single channel for both downlink and uplink transmission. Separate time slots are allocated for downlink and uplink. FDD and TDD both require guard band or guard interval for effective operation and to avoid channel interference. LTE scheduler algorithm's needs to be designed at layer 2 (called as MAC layer) stack of LTE for both uplink and downlink. Uplink supports the SC-FDMA technology whereas downlink supports OFDMA technology as an access method [1].

OFDMA facilitates distribution of subcarriers to different users at the same time. In practice group of contiguous subcarriers are allocated to single user. OFDM is a popular multicarrier scheme in which closely spaced subcarriers are used to carry data in LTE downlink. LTE uses novel SC-FDMA scheme in uplink which has lower power amplification ratio compared to OFDMA and thus facilitating low-complexity and frequency-domain equalization at the receiver. One of the major drawbacks of using OFDM is high power amplification ratio [2]. Power amplification ratio is the measure of high dynamic range of input amplitude.

II. LTE ACCESS NETWORK ARCHITECTURE

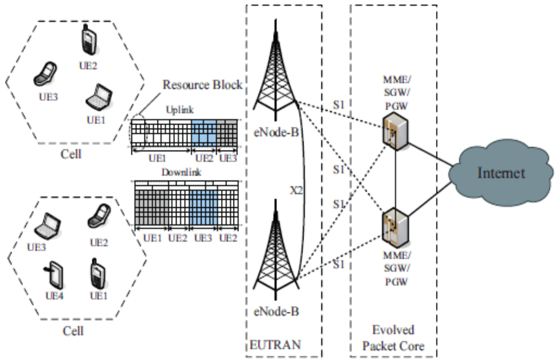

Figure1: 3GPP LTE access network (E-UTRAN) architecture

Figure1 shows an architecture of LTE network. Its functionality is divided into 3 main domains: User Equipment (UE), Evolved UMTS(Universal Mobile Telecommunication System) Terrestrial Radio Access Network (EUTRAN), and System Architecture Evolution (SAE) core also known as Evolved Packet Core (EPC). EUTRAN consists of eNodeBs which are connected by another eNodeBs by the X2 interface, and they connect to EPC networks by S1 interface. The EPC network serves as the equivalent GPRS network via 3 components: Mobility Management Entity(MME) which provides tracking and paging for idle mode UEs , Serving Gateway (SGW) which provides switching and routing for user data packets and PDN(packet data network) gateway(PGW) which provides access to external networks such as internet.

In LTE DL(downlink) and UL(uplink), the systems bandwidth is divided into separable chunks denoted as Resource Blocks(RBs) in figure1. It is considered as the minimum scheduling resolution in the time-frequency domain. The frequency domain packet scheduling(FDPS) allocates different RBs to individual users according to their current channel conditions. This FDPS policy is conducted during each Transmission Time Interval (TTI) which is 1ms.

III. THE EPC NETWORK ELEMENTS

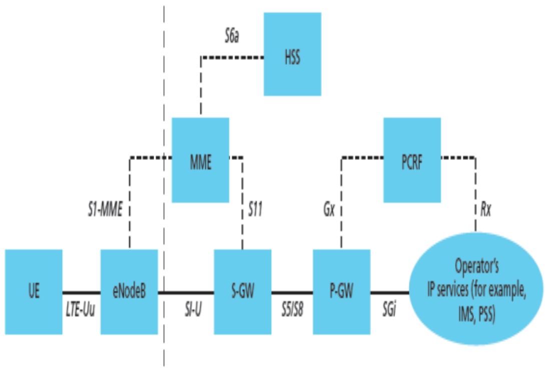

Figure2: The EPS network elements

EPC provides the user with IP connectivity to a PDN for accessing the Internet, and also for running services such as Voice over IP (VoIP). An EPC bearer is typically associated with a QoS. Many bearers can be established for a user in order to provide different QoS streams or connectivity to different PDNs. As an example we consider, a user might be engaged in a voice (VoIP) call while at the same time performing web browsing or FTP download. The network must also provide sufficient security and privacy for the user and protection for the network against fraudulent use. This is achieved by means of several EPC network elements that have different roles. Figure2 shows the overall network architecture, which includes the network elements. The network is comprised of the Core Network (CN) EPC and the access network E-UTRAN. CN consists of many logical nodes, but the access network is made up of essentially just one node, the evolved NodeB (eNodeB), which connects to the UEs.

The logical CN nodes are shown in Figure2 consists of:

- PCRF – The Policy Control and Charging Rules Function (PCRF) is responsible for policy control decision-making and for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW. The PCRF provides the QoS authorization that decides how a certain data flow will be treated in the PCEF and ensures that this is in accordance with the user's subscription profile.
- HSS – The Home Subscriber Server (HSS) contains users SAE subscription data such as the EPS subscribed QoS profile and any access restrictions for roaming. It contains information about the PDNs to which the user can connect. It could be in the form of an access point name (APN) (which is a label according to DNS naming conventions describing the access point to the PDN) or a PDN address indicating subscribed IP address. In addition the HSS holds dynamic information such as the identity of the MME to which the user is currently attached. The HSS may also integrate the authentication centre (AUC), which generates the vectors for authentication and security keys.
- P-GW – The PDN Gateway is responsible for IP address allocation for the UE, QoS enforcement and flow-based charging. It is responsible for the filtering of downlink user IP packets into the different QoS-based bearers which is performed based on Traffic Flow Templates (TFTs). The P-GW performs QoS enforcement for guaranteed bit rate (GBR) bearers which also serves as the mobility anchor for interworking with non-3GPP technologies such as CDMA2000 and WiMAX networks.
- S-GW – All user IP packets are transferred through the Serving Gateway (S-GW) which serves as the local mobility anchor for the data bearers when the UE moves between eNodeBs. S-GW retains the information about the bearers when the UE is in the idle state and temporarily buffers downlink data while the MME initiates paging of the UE to reestablish the bearers. The S-GW performs some administrative functions in the visited network such as collecting information for charging. It also serves as the mobility anchor for interworking with other 3GPP technologies such as general packet radio service (GPRS) and UMTS.
- MME – The Mobility Management Entity (MME) is the control node that processes the signalling between the UE and the CN and the protocols running between the UE and the CN are known as the Non Access Stratum (NAS) protocols.

IV. E-UTRAN LAYERED ARCHITECTURE

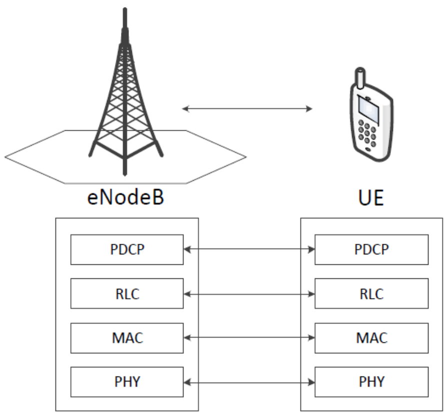

Figure 3: E-UTRAN architecture

Figure3 provides an overall illustration of the protocol architecture at the E-UTRAN level . The top three protocols are the sublayers of the TCP/IP Layer 2, while the PHY layer forms LTE's TCP/IP Layer 1.

- Layer 2 (L2)
  - Packet Data Convergence Protocol (PDCP)
  - Radio Link Control (RLC)
  - Medium Access Protocol (MAC)
- Layer 1 (L1)
  - Physical Layer(PHY)

PDCP Layer:

PDCP layer is mainly responsible for header compression/decompression of IP packets that are received from/transmitted to IP layer above, respectively. The header compression is critical in reducing the overhead of data communication over the wireless interface, which in turn increases the system's spectral efficiency. PDCP also ensures in-sequence delivery of data packets either up to the IP layer or down to the RLC layer. This sequential delivery mechanism ensures that PDCP detects missing packets for which it can initiate retransmissions, or duplicate packets that are to be discarded. PDCP also performs packet ciphering and packet encryption to ensure the secure delivery of data packets over the radio interface.

RLC Layer:

RLC layer facilitates the transfer of data units between PDCP and MAC sublayers. In doing so, RLC performs tasks similar to PDCP, such as in-sequence packet delivery and duplicate packet detection. RLC performs error correction of data packets received from MAC layer below through window-based Automatic Repeat reQuest (ARQ) operation. RLC also performs segmentation and re-assembly of data units that are passed down to/received from MAC sublayer below. To perform such a task, RLC layer contains the transmit/receive data buffers for different traffic flows, which are alternatively known as Radio Bearers (RBs). RB refers to a traffic flow, or a group of traffic flows, between a UE and the eNodeB over the radio interface that is characterized with certain QoS attributes. It ensures that RLC tailors its services to RBs according to their QoS needs, such as providing ARQ services to RBs with best effort traffic low very tolerance to packet loss.

MAC Layer:

The main task of MAC sublayer in LTE is to map between logical channels and PHY's transport channels. The Logical channels are services provided by MAC to RLC sublayer above to accommodate different types of data exchange. Logical channels can be categorized into data traffic channels (for transferring data traffic), and control channels, for transferring control signals between UE and eNodeB. Each logical channel service is provided to a certain RB from RLC layer to ensure proper RB prioritization according to their QoS requirements.

MAC sublayer performs priority handling operation to map user and control data flows from different RBs to their appropriate physical channels on PHY layer via PHY's transport channels interface. The priority handling mechanism is performed either on RBs from different UEs, or between RBs within the same UE. In addition, MAC layer is responsible for, detecting data transmission errors and correcting them via allocating time and frequency resources for data retransmissions. Data retransmissions are handled at the MAC sublayer through a process termed as Hybrid ARQ (HARQ), which is a combination of forward error-detection and correction via decoding process.

PHY Layer:

HSPA employs Wideband Code Division Multiple Access (WCDMA) as the transmission method over HSPA's physical wireless channels within a 5 MHz spectrum. When it comes to LTE, WCDMA is a non-valid choice for fulfilling LTE requirements due to the difficulty of supporting bandwidth sizes larger than 5 MHz using single carrier radio interface like WCDMA. LTE targets flexible spectrum allocations up to 20 MHz, so the use of WCDMA would require a high Signal-to-Noise-Ratio (SINR) and more complex filter design and equalization schemes at the receiving antennas. Henceforth, WCDMA, as well as almost any single-carrier transmission scheme, becomes a poor choice for LTE. The 3GPP directed its attention to the use of multiple-carrier transmissions for providing high data rates as efficiently as possible in terms of SINR. Hence, OFDM modulation scheme was a more appropriate choice for LTE due to the multicarrier nature of OFDM that provides significant advantages in terms of high data rate support. According to the 3GPP standard, Orthogonal Frequency Multiple Access (OFDMA) was chosen for the downlink direction, while Single Carrier Frequency Division Multiple Access (SC-FDMA) was chosen for the uplink.

V. E-UTRAN ARCHITECTURE

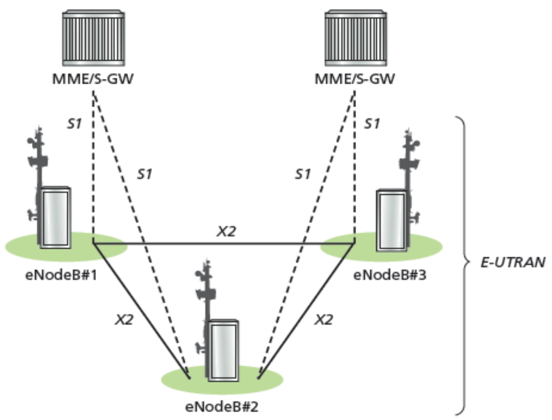

Figure 4: E-UTRAN architecture

In Figure4 we can see that eNodeBs are normally interconnected with each other by means of an interface known as "X2" and to the EPC by means of the S1 interface by means of the S1-MME interface and to the S-GW by means of the S1-U interface.

The E-UTRAN is responsible for all radio-related functions, which can be given as:

- Radio resource management (RRM) – This covers all functions related to the radio bearers, such as radio bearer control, radio admission control, radio mobility control, scheduling and dynamic allocation of resources to UEs in both uplink and downlink.
- Header Compression – This helps to ensure efficient use of the radio interface by compressing the IP packet headers that could otherwise represent a significant overhead, especially for small packets such as VoIP.
- Security – All data sent over the radio interface is encrypted.
- Connectivity to the EPC – This consists of the signalling toward MME and the bearer path toward the S-GW.

VI. SCHEDULING IN LTE

Scheduling is defined as allocating pre-determined number of sub-carriers for a fixed time to each requesting UEs. There are various methods of scheduling, such as channel dependent or channel aware scheduling methods and channel unaware scheduling. LTE scheduler algorithm need to be designed at layer2 (called as MAC layer) stack of LTE for both uplink and downlink. Schedulers are one such module which can dramatically increase or decrease the performance of the system. Uplink supports the SC-FDMA technology whereas downlink supports the OFDMA technology as an access method. LTE supports for advanced antenna techniques such as MIMO. Since Uplink supports the SC-FDMA technique as its access technology, each users need to be allocated a contiguous resource blocks (RBs) which leads to the complexity of the system.

Uplink scheduling determines which UEs is allowed to transmit and with which resource blocks during a given time interval. However, unlike downlink scheduling, uplink scheduling cannot automatically know the transmission demand from a UE. Thus, before the UE can transmit data to the eNodeB, it first sends a Scheduling Request (SR) to request the transmission permit. When the scheduler in the eNodeB receives the SR, it replies with a scheduling grant for the request [6]. In addition, the scheduler determines the time/frequency resource which the UE should use as well as transport format. After the UE has received the information of assignment, it can transmit data with required parameters over a sub-frame when the grant is valid. In this, LTE uplink scheduler module will be designed to handle both real and non real time data supporting both TDD and FDD frame structure for improving performance.

VII. DESIGN AND DEVELOPMENT OF SCHEDULING ALGORITHMS

This section discuss about the system development phase of the uplink scheduling algorithms using open source framework of LTE simulator. It contains requirement gathering, requirement analysis and system structure design using block diagram. *LTE-Sim* has been written in C++.

Design of Proportional Fair Scheduling Algorithm

Proportional fair is a compromise-based scheduling algorithm. It is basically Based upon maintaining a balance between two competing interests: Trying to maximize total wireless network throughput while at the same time allowing all users at least a minimal level of service which is done by assigning each data flow a data rate or a scheduling priority (depending on the implementation) that is inversely proportional to its anticipated resource consumption.

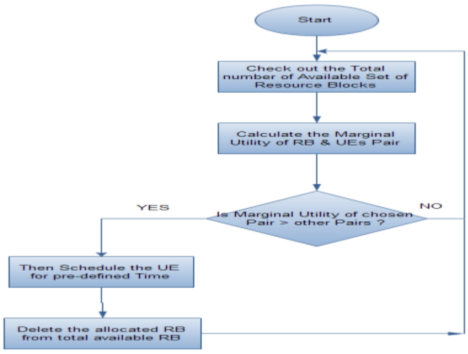

Figure5: Flow Chart of Proportional Fair Algorithm

Design of M-LWDF Scheduling Algorithm

The Modified-Largest Weighted Delay First (MLWDF) algorithm belongs to the LWDF family. It tries to meet delay guarantees by prioritizing data according to the queuing delay the packets have experienced. A delay guarantee violation occurs when the packets of user *i* experience a steady-state delay Ti, which exceeds some delay threshold Di. The value of Di is one of the defining characteristics of the different data types and depends on the negotiation process initiated before any data is transmitted. QoS guarantees require that the probability of such violations must be smaller than some pre-fixed threshold δi. The M-LWDF is a very attractive scheduling protocol used for wireless networks, as it varies the transmission rates of packets, depending on the channel condition.

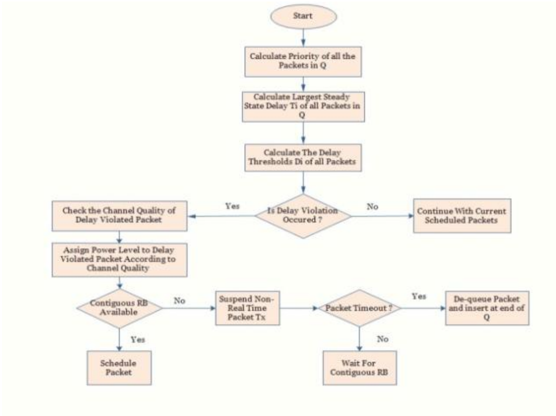

Figure6: Flow Chart of MLWDF Algorithm

Design of EXP-PF Scheduling Algorithm

In a wireless system, the system capacity is constant, so that each user's throughput is directly related to the number of allocated slots for transmission. Hence, it is easy to reserve system resource for real time service users in a wireless system. However, in an adaptive modulation and coding (AMC/TDM) system, the system capacity is time varying and depends on the service times of users, so that it is hard to find optimum priority rule for real and non-real time services. An AMC/TDM system cannot reserve service slots enough to satisfy QoS of real time service since the transmission rates per slot changes with respect to time. The EXP rule algorithm can support both real time and non-real time service users in an AMC/TDM system, but the throughput of a non-real time user is not maximized. The EXP-PF algorithm optimizes the throughput of non-real time service users and the EXP rule for real time service users.

VIII. RESULTS

The output conditions such as memory usage and execution time for varying number of users are investigated for all the three scheduling methods: Proportional Fair (PF), Modified-Largest Weighted Delay First (MLWDF) and EXP-Proportional Fair (EXP-PF) scheduling algorithm. The results are shown in Figure8 and Figure9.

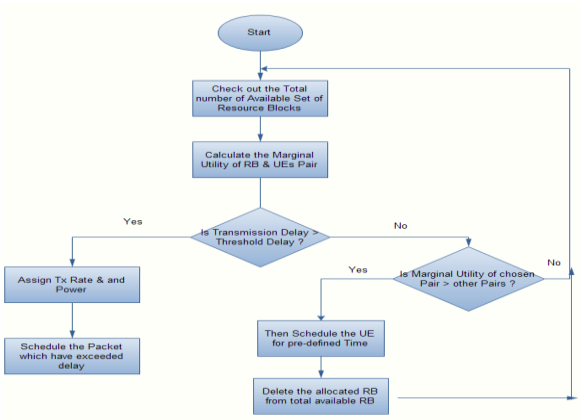

Figure7: Flow Chart of EXP-PF Algorithm

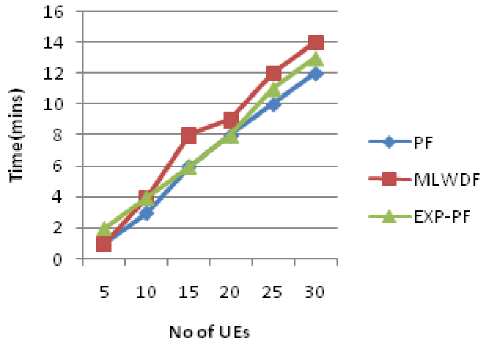

Figure 8: No:of UEs vs Time(mins)

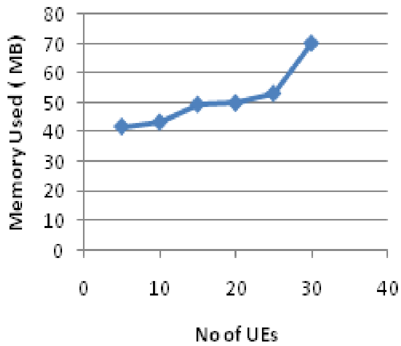

Figure 9: No:of UEs vs Memory Used MB)

IX. CONCLUSION

Memory used to simulate the process increases from 40 Mb to 70 Mb with the increase in number of UEs from 10 to 30 and it is independent on the scheduling algorithm used by the eNodeB. The time required to execute the simulation increases from 1 minute to 14 minutes with the increase in number of UEs from 10 to 30; it depends on the scheduling algorithm used by the eNodeB. In fact, the PF algorithm requires less time than other scheduling strategies due to its very simple implementation.

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