Protocol Architecture of LTE Release 12

Abhishek Agarwal*

*PhD Student, Department of Electronics and Communication Engineering, Shri Venkateshwara University, Gajraula, Uttar Pradesh, INDIA.
E-Mail: er.abhishek.agarwal.77{at}gmail{dot}com

***Abstract*—**Protocol architecture made for interfaces in the LTE network, contains user plane and control plane. For network infrastructure, protocols are divided into two layers, radio network layer and transport network layer and for air interface, non access stratum and access stratum. Transport channels from physical layer mapped into logical channels in medium access control sublayer through medium access control protocol data units. Data is send to packet data convergence protocol sublayer from radio link control sublayer by transparent mode, unacknowledged mode and acknowledged mode depending on accuracy. Packet data convergence protocol sublayer transfer user plane and control plane data to application layer after integrity protection. Radio resource control layer broadcast system information while application protocols control signalling messages. A complete description of protocol architecture is presented in this paper. Paper explains the structure of protocol data units. Specifications are defined in general approach.

***Keywords*—**Evolved Universal Terrestrial Radio Access Network; Medium Access Control; Mobility Management Entity; Multimedia Broadcast Multicast Service; Packet Data Convergence Protocol; Radio Link Control.

***Abbreviations*—**Evolved Universal Terrestrial Radio Access Network (E-UTRAN; Long Term Evolution (LTE); Medium Access Control (MAC); Mobility management Entity (MME); Multimedia Broadcast Multicast Service (MBMS); Packet Data Convergence Protocol (PDCP); Protocol Data Unit (PDU); Radio Link Control (RLC); User Equipment (UE).

I. INTRODUCTION

PROTOCOL architecture is designed for reducing complexity of networks and communication between devices working on different algorithms. A program or hardware is made for each layer to obey the protocols so that they can communicate with each other and different implementations are possible for each layer. Interfaces follow the protocol stack to minimize the information that passed through between a pair of layers.

Purpose of the paper is to understand protocol stack of LTE for release 12. Description of protocol stack is sectioned in eight parts. In section II, overall architecture, in section III, physical layer, in section IV, data link layer, in section V, radio resource control layer, in section VI, S1 interface, in section VII, X2 interface, in section VIII, MBMS and SLm interface is described.

II. OVERALL ARCHITECTURE

In Protocol architecture of LTE [Abhishek Agarwal, 1], at each interface protocol stack has two planes. User plane to handle data generated by user and control plane to handle signalling messages in the network. In overall architecture [2] E-UTRAN consists of evolved Node Bs(eNB), interconnected by X2 interface and in evolved packet core with mobility management entity (MME) by S1-MME interface and with serving gateway (S-GW) by S1-U interface. Multiple hybrid E-UTRAN node Bs (HeNBs) can be connected through HeNB gateway (HeNB GW) to Evolved Packet Core (EPC) with S1 interface shown in overall architecture in figure 1.

At S1 interface [3-8] there are two planes, user plane and control plane and two layers, radio network layer and transport network layer. For relay operation, eNB is connected to relay node (RN) by interface Un and called donar eNB (DeNB). This works as MME, eNB and S-GW because of providing proxy functions of S1 and X2 interfaces. So that RN terminates S1, X2 and Un interfaces. Multiple eNBs can be connected to MBMS gateway (MBMS GW) that contain MBMS user plane (MBMS UP) and MBMS control plane (MBMS CP) through M1 interface. For session management signalling and radio configuration signalling, a multi-cell/multicast coordination entity (MCE) can be connected to multiple eNBs with same MBMS single frequency network (MBSFN) through M2 interface. For MBMS session management signalling M3 interface is used to connect MCE and MME. Protocol stack for S1-MME, S1-U, X2, M1 between eNB and MBMS-GW, M2 between eNB and MCE and M3 between MME and MCE is shown in figure 2.

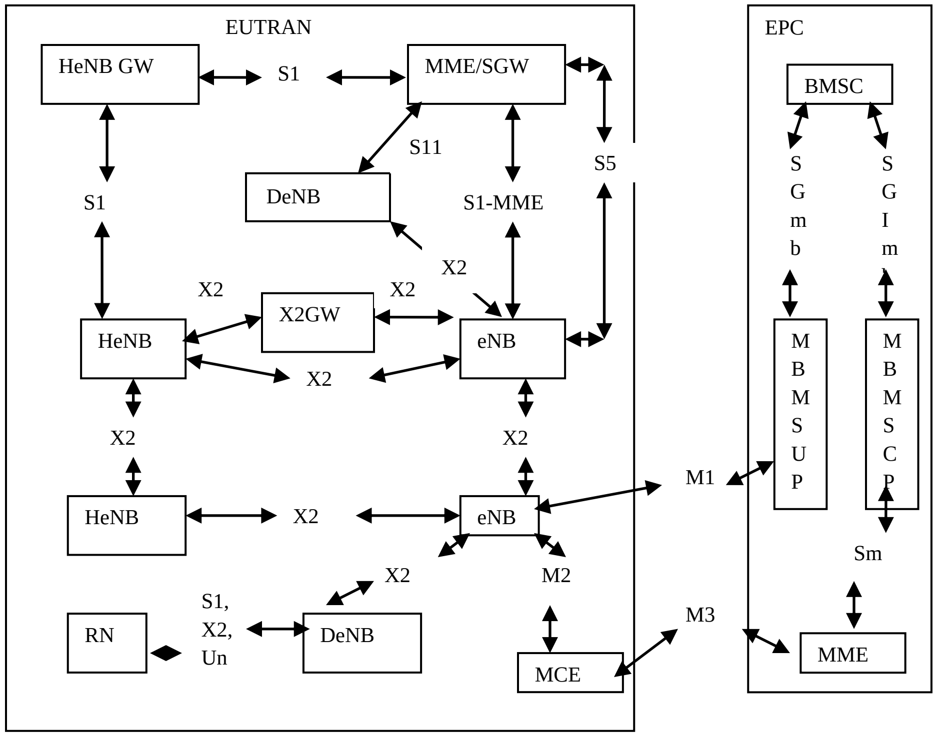

Figure 1: Overall Architecture of E-UTRAN with Relay Network and MBMS

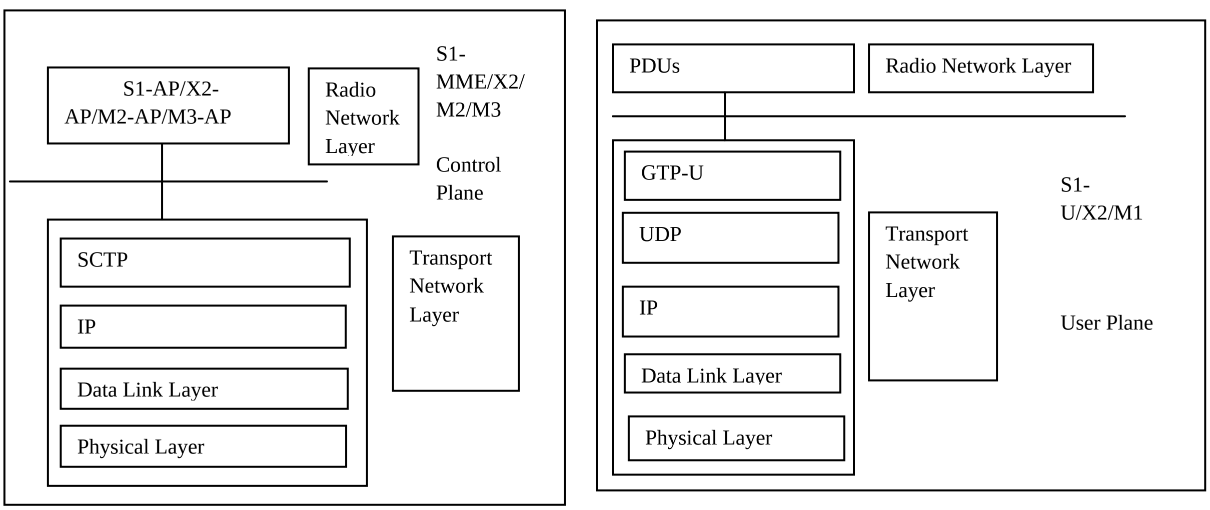

Figure 2: Interface Protocol Structure of S1-MME, S1-U/X2/M1 (between eNB, MBMS GW)/M2 (between eNB, MCE)/M3 (between MME, MCE)

At air interface protocol stack in figure 3, upper layer is for high level signalling messages and called non access stratum (NAS). Lower layer is for transportation and called access stratum. Access stratum protocols contain Uu and S1 interface protocols. Uu interface [1] transport protocols are called air interface transport protocol.

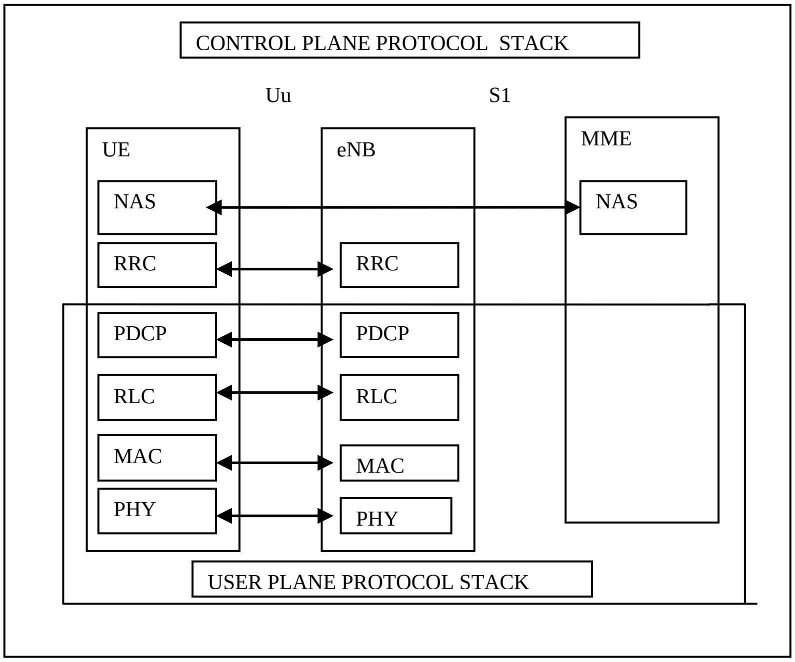

Figure 3: Air Interface Protocol Stack

III. Physical Layer

Data is transferred by physical layer. Data exchanged between Medium Access Control (MAC) layer and physical layer called Transport Block (TB) is exchanged per transmission time interval of 1 ms. Functions of physical layer are [2],

1. For Physical Uplink Shared Channel (PUSCH) 1 TB and for Physical Downlink Shared Channel (PDSCH), upto 2 TB are delivered to physical layer.
2. 24 bit Cyclic Redundancy Check (CRC) for detection of burst errors in message,
3. TB error indication to higher layers
4. Convolutional coding in forward error correction (FEC),
5. Rate matching is done by combination of transport block size, modulation scheme and resource assignment. Physical layer support Hybrid Automatic Repeat Request (HARQ) as combination of both process CRC and FEC.
6. Interleaving is used if errors within code become more than error correcting capability of burst errors.
7. Data is modulated according to modulation scheme decided by MAC scheduler, which can be QPSK, 16QAM and 64 QAM.
8. Mapping to physical resource
9. MAC scheduler partly configures mapping from assigned resource blocks to the available number of antenna ports.

IV. Data Link Layer

Data link layer contains Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Control (PDCP) sublayers.

4.1. Medium Access Control Sublayer

For data transfer and radio resource allocation MAC sublayer [9] transport channels map control plane and user plane information into control and traffic channels respectively, called logical channels. Two MAC entities are defined in E-UTRA on each side UE and E-UTRAN, that perform different functions. A possible MAC structure by E-UTRA on UE side shown in figure 4.

In MAC architecture, MAC sublayer multiplex MAC Service Data Unit (SDU) from multiple logical channels onto transport block-

1. To be delivered to physical layer on transport channels.
2. Multiplexing and demultiplexing of MAC SDUs from one or different logical channels onto TB to be delivered to or from physical layer on transport channels.
3. Schedule information reporting
4. Error correction through hybrid automatic repeat request (HARQ)
5. Priority handling between UEs by dynamic scheduling
6. Priority handling between logical channels of one UE
7. Logical channel prioritization
8. Transport format selection.

MAC Protocol Data Unit (PDU) is byte aligned with a MAC header of variable size, multiple MAC SDUs of variable sizes, multiple MAC control elements and optionally padding. A MAC PDU header is made of MAC PDU subheaders that contain a MAC SDU, a MAC control element and padding. Only one MAC PDU can be transmitted per transport block (TB) per UE. And only one multicast channel (MCH) MAC PDU can be transmitted per transmission time interval (TTI) [9]. MAC PDU is shown in table 1.

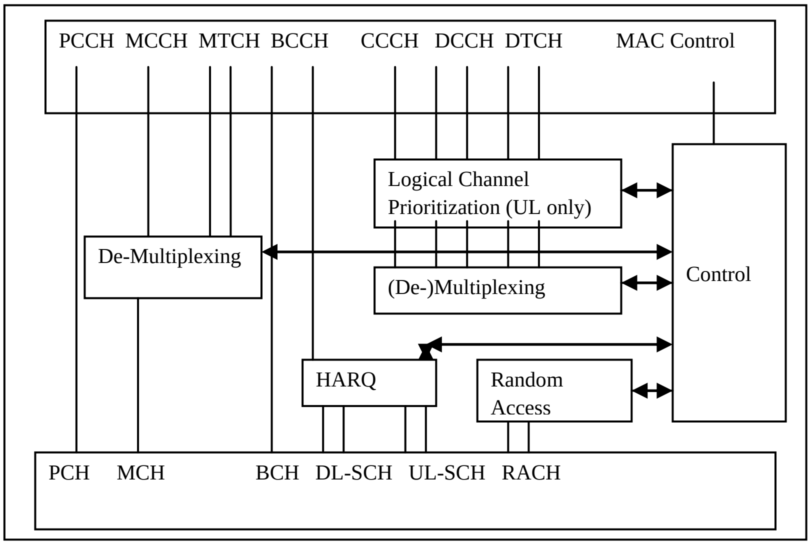

Figure 4: MAC Possible Structure on UE Side

Table 1: MAC PDU for DL/UL-SCH or RAR

MAC Header					MAC Control Element/		MAC Control Element/	MAC SDU/ MAC RAR3		MAC SDU/ MAC RARn	Padding (Optional)
For UL/DL-SCH					MAC RAR1		MAC RAR2				
R	R	E	LCID		R	TA Command					
F	L				TA Command	UL Grant					
L					UL Grant						
For RAR					UL Grant						
E	T	RAPID			Temporary C-RNTI						
					Temporary C-RNTI						
E	T	R	R	BI							

MAC PDU for uplink and downlink synchronization channel (UL-SCH and DL-SCH) contains,

1. Logical Channel Identity (LCID) of 5 bit field corresponds to MAC SDU, MAC control element or padding.
2. The length field L for MAC SDU or MAC control elements. Size of L field is indicated by the format field F.
3. If MAC SDU or variable size MAC control element is less then 128 bytes, F is ‘0’ otherwise ‘1’.
4. Extension field E set to ‘0’ indicates that either a MAC SDU, MAC control element or padding starts at next byte.
5. Reserved bit R is set to ‘0’.

MAC headers and subheaders are octact aligned. Nine MAC control elements, identified by MAC PDU subheader, are –

1. Buffer status report MAC control element to identify total amount of data in all logical channels of a logical channel group which include all data available for RLC and PDCP layer.
2. Cell Radio Network Temporary Identifier (C-RNTI) MAC control element contains C-RNTI of UE with length 16 bits.
3. Discontinuous reception (DRX) command MAC control element of zero bits.
4. UE contention resolution identity MAC control element of 48 bit size that contains uplink common control channel (CCCH) SDU.
5. Timing advance command MAC control element that contains single octet used to control the timing adjustment of UE.
6. Power headroom report MAC control element with single octet to indicate power headroom level in dB.
7. MCH scheduling information MAC control element to indicate the ordinal number of subframes within MCH scheduling period.
8. Activation/deactivation MAC control element to show the status of secondary cell (SCell) with SCellIndex i
9. Long DRX command MAC control element of zero bits.

In MAC PDU for Random Access Response (RAR) MAC header consists of multiple MAC PDU subheaders.

1. Extension field E equal to '1' indicates that at least another same set of subheader follows and '0' indicates MAC random access response (RAR) or padding starts at the next byte.
2. Type field T equal to '1' indicates 'backoff indicator (BI)' and '0' indicates 'random access preamble ID (RAPID)' present in subheader.
3. Reserved bit R is zero.
4. Backoff indicator of 4 bits shows overall condition of the cell.
5. RAPID identifies transmitted random access preamble with 6 bits size.
6. Timing advance command to indicate the index value TA with 11 bit size used to control the amount of timing adjustment for UE.
7. The uplink grant field UL grant with 20 bit size to indicate the resource to be used on the uplink.
8. And temporary C-RNTI for temporary identity to be used by UE during random access with size of 16 bits.

4.2. Radio Link Control Sublayer

RLC does the following functions [2].

1. RLC transfer upper level PDUs
2. Error correction through ARQ
3. Concatenate, segment and reassemble RLC SDUs
4. Re-segment RLC data PDUs
5. Re-order RLC data PDUs
6. Duplicate detection
7. Protocol error detection
8. Discard RLC SDU and re-establish RLC.

An RLC sublayer architecture is shown in figure 5.

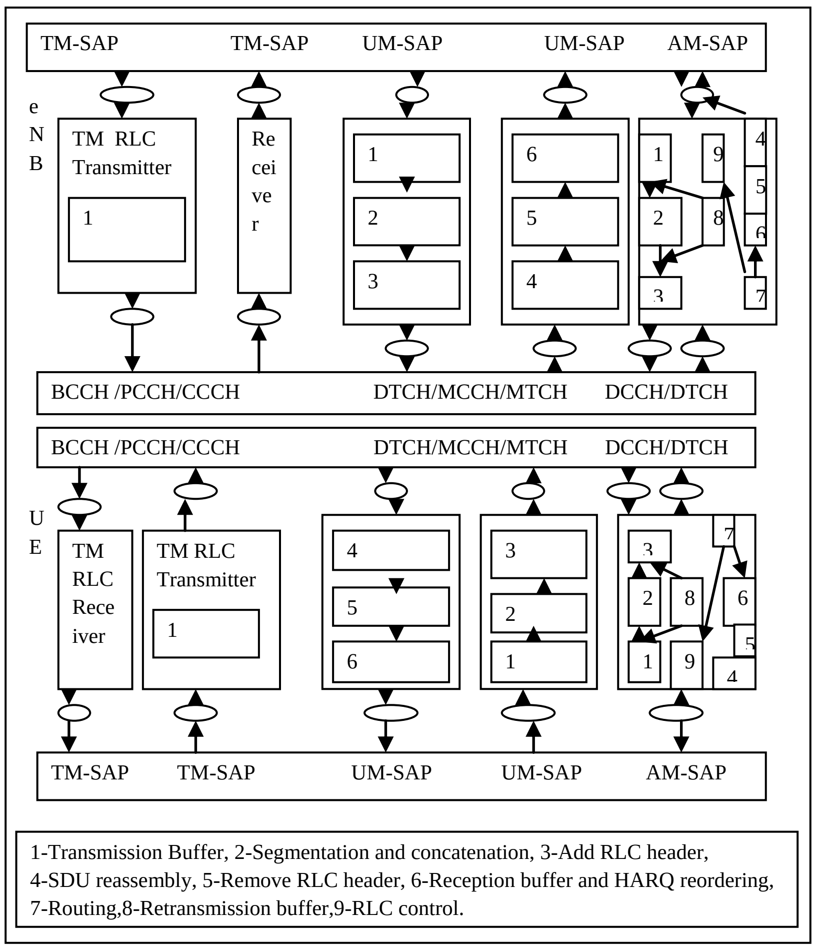

Figure 5: RLC Architecture

RLC data PDUs [10] can be transferred in three modes.

4.2.1. *Transparent Mode (TM)*

In Transparent Mode (TM) mode, TM Data (TMD) PDU is transmitted by TM RLC transmitter through BCCH, DL/UL CCCH and PCCH and delivered by TM RLC receiver through a single Service Access Point (SAP) in the TM entity without any modification. TMD PDU is without header. Maximum data field size is equal to maximum TB size minus sum of minimum MAC PDU header size and minimum RLC PDU size and same for all modes. For TMD PDU, only RLC SDU is mapped to data field of one TMD PDU.

4.2.2. *Unacknowledgement Mode (UM)*

In Unacknowledged Mode (UM) mode, transmitting UM RLC entity segment and/or concatenate RLC SDUs and makes UM PDUs and include relevant RLC header with UM PDU. Receiving UM RLC entity detects duplication, reorder, detect loss, reassemble and deliver UM Data (UMD) PDUs. It discard remaining UMD PDUs and initialize relevant state variables and stop timers. UMD PDU header with fixed part contains

1. Framing Info (FI), extension field E and a Sequence Number (SN) with length 1 byte for 5 bit SN and contains three reserved fields R1 fields more with FI,E and SN fields for 10 bit SN.
2. While extension part exists for multiple data fields with E(s) and length indicator LI(s) for every data field except last for which odd number of LIs, four padding bits exist after last LI.

A 10 bit SN UMD PDU is shown in table 2.

Table 2: UMD PDU/AMD PDU with 10 Bit SN/11 Bit LI

R1 or D/C	R1/RF(Re-segmentation flag)	R1/P	FI	E	SN
SN					
LSF(for AMD PDU)			SO(For AMD PDU0		
SO (For AMD PDU)					
E	LI1				
LI1		E	LI2(if K>=3)		
LI2					
… …..					
E	LI(k-2)				
LI(k-2)		E	LI(k-1)		
LI(k-1)					
E	LI(k)				
LI(k)		Padding			
DATA					
…..					
OCT(N)					

1. Here oct N is equal to x+1.5*k+n where n is an integer and x equal to 2.5 for odd number of LIs and x equal to 2 for even number of LIs. Data field mapping is same for UMD and AMD PDUs. Only RLC SDUs and one or two RLC segments in different RLC SDUs with multiple RLC SDUs can be mapped to the end of data field for size more than 2047 octets otherwise in beginning.
2. SN field indicates the segment number from which UMD or AMD PDU is constructed.
3. E field is '0' for fixed part or LI field followed by data field and '1' if followed by a set of E and LI field.
4. LI field is of 11 bits indicate the corresponding length of data field element.
5. FI field is of 2 bit with '0' or '1' in MSB indicates RLC SDU segment present at the beginning of data field and at end for LSB or not present.
6. R1 is reserved field of 1 bit set to '0' for transmitting entity.

4.2.3. Acknowledgement Mode (AM)

In Acknowledgement Mode (AM) mode, AM RLC entity is configured to deliver and receive RLC PDUs through the DL/UL DCCH or DL/UL DTCH logical channels by same procedure as UM mode.RLC data PDUs contain AMD PDU and AMD PDU segment and RLC control PDU contains Status PDU to perform ARQ procedures. In ARQ procedures retransmission is done by negative acknowledgement, polling to trigger status reporting which provide positive or negative acknowledgement.SDU is discarded when indicated by PDCP layer.

AM Data (AMD) PDU is byte aligned and in fixed part contains

1. Data/Control Field (D/C) field of 1 bit, where '1' and '0' indicate data and control AMD PDU respectively
2. Polling bit (P) field of 1 bit, with '1' indicating that transmitting side of an AM RLC entity requests a status report from its peer AM RLC entity.
3. Extension part contains E field
4. LI field with field length of 11 bits
5. Segment Offset (SO) field of 15 bits to indicate position of AMD PDU segment, which is starting from '000000000000000'
6. Last Segment Offset (LSF) field of 1 bit with '1' indicating that last byte of AMD PDU segment corresponds to last byte of AMD PDU with AMD PDU fields.
7. Octet N equals to x+1.5*k-n, where n is an integer and x equal to 2.5 for AMD PDU with odd number of LIs, 2 with even number of LIs, 4.5 for AMD PDU segment with odd number of LIs and 4 with even number of LIs. For LI field length of 15, N equals to 2*k+n. An AMD PDU segment with LI field of 11 bits is shown in table.2.

Status PDU contains [10],

1. Control PDU type field (CPT) field of 3 bits with '000' indicating 'STATUS PDU',
2. Acknowledgement SN (ACK_SN) of 10 bits to indicate SN of the next not received RLC data PDU
3. E1 field of 1 bit with '1' indicate a set of negative ACK_SN (NACK_SN)
4. NACK_SN field of 10 bit indicates SN of the AMD PDU or portions of it that has been detected as lost at RLC entity receiver.

A status PDU is shown in table 3.

Table 3: STATUS PDU

D/C	CPT		ACK_SN		
ACK_SN				E1	
NACK_SN					
	E1	E2	NACK_SN		
NACK_SN			E1	E2	
SOstart					
SO start				SOend	
SOend					
SOend			NACK_SN		
…….					

4.3. Packet Data Convergence Protocol Sublayer

PDCP is used to map signalling radio bearer carrying control plane data (SRB) and data radio bearer carrying user plane data (DRB) on DCCH and DTCH logical channels. PDCP entity functions are [11] -

1. Header compression and decompression of IP data flows using robust header compression (ROHC) protocol by its transmitting and receiving part,
2. Transfer user plane and control plane data, maintenance SNs,
3. In sequence delivery of upper layer PDUs at re-establishment of lower layers
4. Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM
5. Ciphering and deciphering of user plane data and control plane data,
6. Integrity protection and integrity verification of control plane data,
7. Verification of user plane data for RNs integrity protection,
8. Time based discard and duplicate discarding.

PDCP entity is associated with one or two RLC entities for Resource Block (RB) to be unidirectional or bidirectional. Two PDUs are PDCP data PDU and PDCP control PDU. PDCP data PDU is used

1. To transfer PDCP SDU SN
2. User plane data that contain compressed PDCP SDU or uncompressed PDCP PDU in different times,
3. Control plane data
4. A MAC-I field for SRBs or MAC-I field for DRBs.

PDCP control PDU is to transfer PDCP status report that indicates the missing PDCP SDUs and header compression control information such as interspersed ROHC feedback. PDCP PDU contains-

1. PDCP SN of length 5 bit is for SRBs and 7, 12 or 15 bit is for DRBs, if configured by upper layers.
2. Data field can be uncompressed or compressed PDCP SDU for control plane and user plane and for user plane respectively.
3. MAC-I field of 32 bits contain message authentication code. For control plane data message authentication code for integrity (MAC-I) field should be padded with padding bits set to 0.
4. R is reserved bit set to 0 and not counted by receiver.
5. D/C bit '1' indicates data and '0' for control PDU.
6. PDU type of 3 bits with '000' indicates PDCP status report, '001' for interspersed robust header ROHC feedback packet and '010-111' are reserved.
7. First missing PDCP SN (FMS) field has same length as SN field for 12 and 15 bits.
8. Bitmap field is of variable length with '0' indicates that PDCP SDU with PDP SN number (FMS+bit position) modulo (maximum_PDCP_SN+1) is missing and need to be transmitted and '1' for no retransmission.
9. Interspersed ROHC feedback packet is of variable length containing one ROHC packet with only feedback.

PDCP PDU in table 4 shows user plane PDCP data PDU with long PDCP SN of 12 bits or PDCP control PDU for PDCP status using 12 bit SN or PDCP control PDU for interspersed ROHC feedback packet. Control plane PDCP data PDU does not have D/C field. User plane PDCP data PDU with short PDCP SN of 7 bits does not have R field. And PDCP control PDU format for PDCP status report using a 15 bit SN has four R field in LSB in first octet and one R field in MSB of second octet and FMS field of 15 bit in second and third octet.

Table 4: User Plane PDCP Data PDU with Long PDCP SN (12 Bits)/PDCP Control PDU for PDCP Status using 12 Bit SN/PDCP Control PDU for Interspersed ROHC Feedback Packet

D/C	R(for data)	R(for data)	R(for data)	PDP SN(for data PDU)			
D/C	PDU Type(for control PDU)			FMS(for control PDU,12 bit SN)			
D/C	PDU Type(for ROHC)			R(for ROHC)	R(for ROHC)	R(for ROHC)	R(for ROHC)
PDCP SN(for data PDU)/FMS(for control PDU)……………..							
Interspread POHC feedback packet(for ROHC)							
Data(for.dataPDU)…………………							
…………………………………………………..							
MAC-I(for data PDU)/Bitmap1(for control PDU)							
………………………………………………							
MAC-I(Oct N)(for data PDU)/BitmapN(for control PDU)…….							

V. RADIO RESOURCE CONTROL LAYER

Radio Resource Control (RRC) layer functions in control plane at air interface. RRC protocol broadcast system information and RRC connection control. RRC connection control includes [12] –

1. Paging
2. Establishment/ modification/ release of RRC connection.
3. Initial security activation
4. RRC connection mobility which includes intra frequency and inter frequency handover, associated

security handling e.g. key/ algorithm change, specification of RRC context information transferred between network nodes.
5. Establishment/ modification/ release of RBs carrying user data (DRBs).
6. Radio configuration control which includes assignment/ modification of ARQ configuration, HARQ configuration, DRX configuration.
7. For RNs, RN specific radio configuration control for the radio interface between RN and E-UTRAN.
8. Recovery from radio link failure

VI. S1 Interface

S1 is point to point open interface that use Stream Control Transmission Protocol (SCTP) protocol to support the transfer of S1 application protocol (S1-AP) signalling messages between eNB and MME [3-8]. S1-MME signalling bearer protocol stack –

1. Provide transfer S1-AP message over S1-MME interface,
2. Networking and routing functions,
3. Redundancy in signalling network and support for flow and congestion control.

In S1 interface protocol structure-

1. Layer 1 is for -
   i. Interfacing physical medium,
   ii. Frame delineation,
   iii. Line clock extraction capability,
   iv. Alarming extraction and generation and transmission quality control.
2. Data link layer support PPP, Ethernet etc.
3. In internet protocol (IP) layer eNB and MME support IPv6, IPv4 and diffeserv code point marking.
4. In transport layer SCTP between MME and eNB for at least one pair of stream is reserved for S1AP elementary procedures that utilize UE associated signalling and should not be change stream during communication. SCTP congestion control initiate higher layer protocols to reduce signalling traffic at the source and prioritize certain messages.
5. S1AP signalling services include UE and non UE associated services between eNB and MME. S1AP class1 procedures include handover preparation, handover resource allocation etc and class 2 procedures include handover notification, E-RAB release indication etc.

In S1 interface transport layer of user plane protocols GPRS Tunnelling Protocol User Plane (GTP-U) protocol is used towards EPC. Assembly of GTP packets at the IP layer and IPv6 or IPv4 is supported by eNB and EPC.

VII. X2 Interface

Radio signalling protocols in X2 interface include X2 application protocol (X2AP) protocol for signalling messages and terminate between two eNBs [13-17]. X2 transport network layer work same as S1 transport network layer for X2.X2AP class 1 elementary procedures include handover preparation, reset etc and class 2 include load indication, handover cancel etc.

VIII. MBMS and SLm Interfaces

M2AP protocol contain procedures between MCE and eNB for MBMS [18-23]. Radio network layer containing M2 and M3 interfaces and transport network layer containing M1 interface work same as S1 and X2 interface. SLm interface user plane and control plane also work for SLm [24-27] interface in the same way.

IX. Conclusion

Protocol architecture is described with introduction of functions of layers and structure of protocol data units. Because of separation of radio network functionality and transport network functionality new technologies and methods can be used so that different architectures are possible for different manufacturers.

X. Future Work

Specifications have MAC PDUs of variable sizes and improved MAC control elements. Further functionalities can be added by increasing the number of control elements in MAC PDU.

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Abhishek Agarwal is a PhD student in electronics and communication engineering at S.V.U., Gajraula, U.P., India, since 2011. He obtained his B.E. in electronics and communication engineering from B.S.A.C.E.T, Mathura, under Dr. B.R.A. University, Agra during 1997-2001. He obtained M.Tech in information technology during 2009-2011 from Karnataka State Open university, Mysore, Karnataka.