The Evolution to 4G Cellular Systems: Architecture and Key Features of LTE-Advanced Networks

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***Abstract*—The era of new wireless communications is upon us. Eventually it will penetrate into our daily life and change the way we live just like many technological innovations whose original research came from the life needs. To achieve these requirements, the society of 3rd Generation Partnership Project (3GPP) is presently evolving Long Term Evolution Advanced (LTE-Advanced) as a development of the standard of LTE. The goal of this generation is to produce specifications for a new radio-access technology geared to higher data rates, low latency and greater spectral efficiency. LTE-Advanced is therefore not a new technology; it is an evolutionary step in the continuing development of LTE The description in this article is based on LTE release 10 and thus provides a complete description of the LTE-Advanced radio access from the bottom up. Also it provides a deeper insight into some of the technologies that are part of LTE and its evolution and introduces describing to the background for the development of the LTE system, in terms of events, activities, organizations and other factors that have played an important role. This paper provides detailed coverage of the air-interface technologies and protocols that survived the analysis of the highly sophisticated technology evaluation process typically used in the LTE-Advanced networks.**

Keywords-LTE, LTE-Advanced, E-UTRAN

I. INTRODUCTION

The future scenario is open to several alternatives: thoughts, proposals, and activities of the near future could provide the answer to the open points and dictate the future trends of wireless world [1]. The fourth generation, 4G, of mobile networks that will supersede the 3G and 2G families of standards, is already upon us. A new mobile generation has appeared every 10th year since the first 1G system was first introduced in 1981, followed by the 2G system that started to roll out in 1992, and 3G, which appeared in 2001.

The development of 4G systems started in 2002. The real new revolution started with 3GPP in December 1998. 3G systems are designed for multimedia communication: with them person-to-person communication can be enhanced with high quality images and video, and access to information and services on public and private networks will be enhanced by the higher data rates and new flexible communication capabilities of third generation systems [2].The next step was 3GPP Long-Term Evolution (LTE). LTE aims to improving the Universal Mobile Telecommunication System (UMTS) mobile phone standard to cope with future requirements. The LTE project is not a standard itself, but it will result in the new evolved Release 8 of the UMTS standard, including most or all of the extensions and modifications of the UMTS system [3]. With the deployment of LTE, the wireless revolution will achieve an important milestone.

For the first time, a wide-area wireless network will be universally deployed that has been primarily designed for IP-centric broadband data (rather than voice) from the very beginning. LTE also is rapidly becoming the dominant global standard for fourth generation cellular networks with nearly all the major cellular players behind it and working toward its success [4]. The fourth generation of cellular communication systems is the emerging technology of future wireless networks. For the past years, many researchers and scientists from all over the world have been working on projects funded by governments and business institutions whose goals are efficient wireless networks by merging all current technologies and adapting new solutions for the enhanced telecommunication which provides superior quality, efficiency, and opportunities where wireless communications were not feasible. Some researchers define 4G as a significant improvement of 3G where current cellular networks' issues will be solved and data transfer will play more significant role. For others, 4G unifies cellular and wireless local area networks and introduces new routing techniques, efficient solutions for sharing dedicated frequency band, and increases mobility and bandwidth capacity.

II. EVALUATION OF LTE-ADVANCED

Long term evolution (LTE) specified by 3rd Generation Partnership Project (3GPP) as very high flexible for radio interfacing. LTE deployment started in the last of 2009, where the first LTE release is providing greatest rate reaches to 300 Mbps, delay of radio network not as much of than 5msec, a spectrum significant increasing in efficiency of spectrum if comparing with any other cellular systems, and a different regular architecture in radio network that is designed to shorten the operations and to decreasing the cost [5]. LTE systems are supporting Frequency Division Duplex (FDD) with Time Division Duplex (TDD) technique as a varied array of bandwidths to operating in a wide amount of dissimilar spectrum allocations. The standardization of LTE in 3GPP is gotten an established state, and the modifications in the design are narrow. Form the end of 2009, the LTE system has been installed as a normal growth of GSM (Global system for mobile communications) and UMTS. The ITU (International Telecommunication Union) has devised the IMT-Advanced term to recognize the new mobile systems that capable to going beyond IMT 2000 (International Mobile Telecommunications). Exactly, the requirements of data rate have been amplified. To providing applications and other advanced facilities, then, 1Gbps for low and 100Mbps for high mobility scenarios should be comprehended. Since 2009, 3GPP has operated on a research with objective to identify the required enhancements for LTE systems to achieve the requirements of IMT-Advanced. In September 2009 the partners of 3GPP have prepared the official suggestion to the proposed new ITU systems, represented by LTE with Release 10 and beyond to be the appraised and the candidate toward IMT-Advanced. After attaining the requirements, the main object to bring LTE to the line call of IMT-Advanced is that IMT systems must be candidates for coming novel spectrum bands that are still to be acknowledged [6,7].

III. KEY FEATURES OF LTE-ADVANCED

LTE-Advanced is applying various bands of spectrum which are already valid in LTE along with the future of bands of IMT-Advanced. More developments of the spectral efficacy in downlink and uplink are embattled, specifically if users serve at edge of cell.

Also, LTE-Advanced aims quicker exchanging between the resource of radio states and between additional enhancements of the figures of latency. All at once, the bit cost must be decreased [8]. IMT-Advanced represents the next generation in systems of wireless communications, which aim to accomplish other main advance of the current third generation systems, by reaching to uplink (UL) rate of 500 Mbps and to 1Gbps in downlink (DL) [9]. With LTE-Advanced starting, there are many key of requests and features that are up come to the light. Presently, several of the core significant intentions for LTE-Advanced can be illustrated below [10, 11]:

- The data rate with peak uplink of 500Mbps and peak downlink of 1Gbps.
- Provide spectrum efficiency with more than three times that provided by LTE.
- Offer spectrum efficiency in uplink 15 bps/Hz and in downlink 30 bps/Hz.
- The spectrum using the capability to backing the scalable bandwidth and the aggregation of spectrum where noncontiguous spectrum is need to using.
- The link latency in case from idle status to connected status are a smaller than 50msec and less than 5msec for one-way in single packet transferring.
- The throughput of edge of user cell to be doubles that in LTE.
- The average throughput of any user is to be triple that in LTE.
- The mobility environments is the similar that used in LTE
- LTE-Advanced can provide compatibility by interworking with 3GPP and LTE.

It not considered in system specifications yet, there are high level purposes for the new specifications of LTE-Advanced. Its need to verifying and much effort rests to be accepted before going fixed it in the specifications.

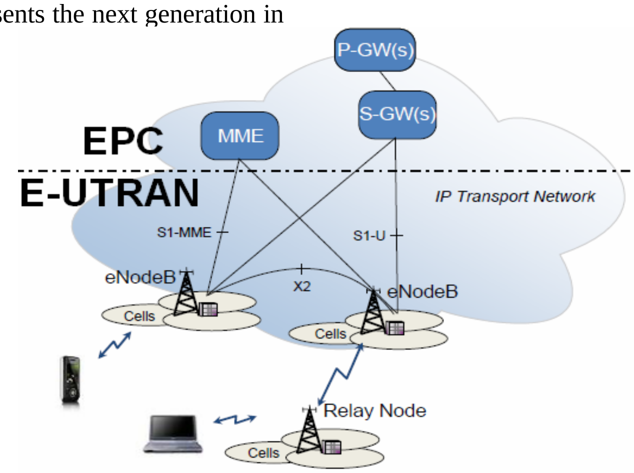

Fig. 1. LTE-Advanced E-UTRAN architecture

IV. LTE-ADVANCED AND E-UTRAN

3GPP identified in Release 8 the requirements and features and requirements of the architecture of Evolved Packet Core (EPC) which that serving as a base for the next generation systems [12]. This identification specified two main work objects, called LTE and system Architecture Evolution (SAE) that leading to the description of the Evolved Packet Core (EPC), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), and Evolved Universal Terrestrial Radio Access (E-UTRA). Each of these parts is correspond respectively to the network core, system air interface, and the radio access network. EPC is responsible to provide IP connection between an external packet data network by using E-UTRAN and the User Equipment (UE). In the environment of 4G systems, the radio access network and the air interface are actuality improved, while the architecture of core network (i.e., EPC) is not suffering large modifications from the previously systematized architecture of SAE.

The main part in the architecture of E-UTRAN is the improved Node B (eNB or eNodeB), that is provide the air interface between the control plane protocol terminations and the user plane towards the user equipment (UE). Both of the eNodeBs is a logical element that serving one or more E-UTRAN cells and the interfacing between the eNodeBs is termed the X2 interface. The interfaces of network are built on IP protocols. The eNodeBs are connected by an X2 interface and to the MME/GW (Mobility Management Entity/Gateway) object by an S1 interface as illustrated in Fig. 2. The interface S1 is support a many relationship between eNodeBs and MME/GW [13]. The functions splitting between MME/GW and eNodeB and is shown in Fig. 2.

The two entities of the logical gateway are termed Serving Gateway (S-GW) and the other is Packet Data Network Gateway (P-GW). The Serving Gateway (S-GW) is act as limited anchor for the mobility service to receiving and forwarding packet rates from and to the eNodeB to serve the UE, while the P-GW is interface with the exterior Packet Data Networks (PDNs) for example the IMS (Internet multimedia server) and the Internet. P-GW provides other IP functions such as packet filtering, routing, policy statement, and address allocation. The MME is an entity to provide signaling only and later the user packets of the IP do not pass over the MME. The main benefit of separating the network entities is for indicating if the capacity of network for traffic and signaling can independently grow. Actually, the core tasks of MME are to idle mode the reachability of UE together with controlling the retransmission of paging, roaming, authorization, P-GW/S-GW selection, tracking area list management, bearer management including dedicated bearer establishment, authentication, security negotiations and signaling of NAS [14]. The eNodeB is implementing the functions of eNodeB along with protocols usually applied in Radio Network Controller (RNC). The eNodeB functions are ciphering, packet reliable delivery, and header compression. But in controlling side, eNodeB is incorporating functions such as:

- Radio resource management (radio bearer control, radio admission and connection mobility control, dynamic scheduling).
- Routing user plane data towards SAE Gateway.

Several benefits by using one node in the network accessing are to reducing the latency and the RNC processing distribution load in to many eNodeBs.

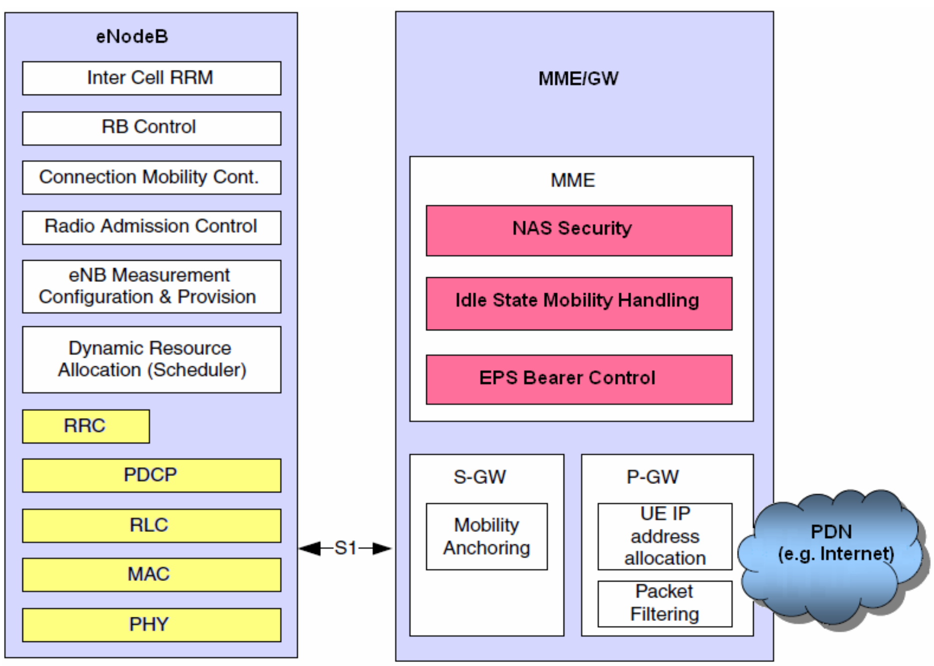

Fig. 2. Functions splitting between MME/GW and eNodeB

V. USER PLANE PROTOCOL AND CONTROL PLANE PROTOCOL STACK

The stack of user plane protocol is shown in Fig. 3. Form the Fig. 3, the Radio Link Control (RLC) and the Packet Data Convergence Protocol (PDCP) layers usually concluded in RNC on the network side are now concluded in eNodeB. The control plane protocol stack demonstrates in Fig. 4, where the Radio Resource Control (RRC) functional conventionally applied in RNC is integrated in to eNodeB [15]. The layers of Medium Access Control (MAC) and Radio Link Control (RLC) are implementing similar roles to user plane.

The RRC functions are include paging, system information broadcast, radio bearer control, connection management for RRC, measurement reporting to UE, and mobility functions. In the MME network side, the Non-Access Stratum (NAS) protocol is terminated while on the terminal side, the UE executes functions such as Evolved Packet System (EPS), authentication, security control, and bearer management.

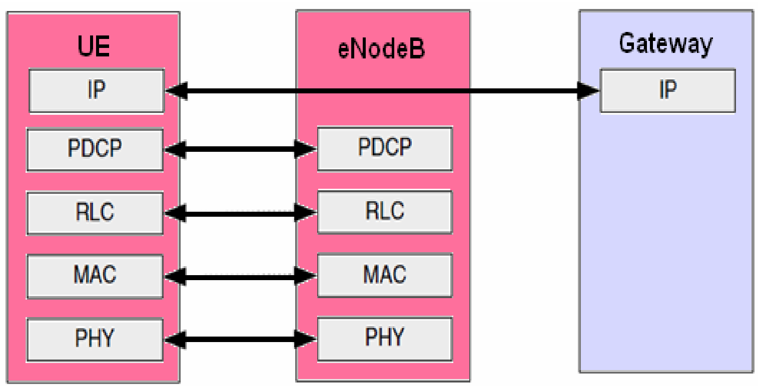

Fig. 3. User plane protocol

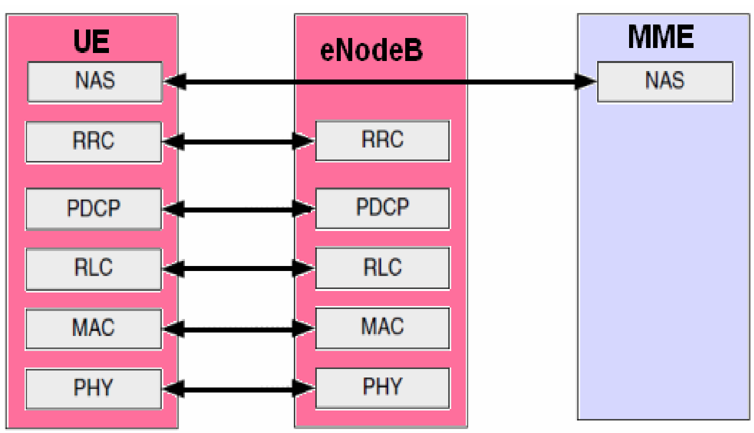

Fig. 4. Control plane protocol architecture

VI. S1 AND X2 INTERFACE PROTOCOL STACKS

In the Fig. 5 and Fig. 6, the interface protocol stacks S1 and X2 are presented where the protocols that used are similar in the two interfaces. The interface between S-GW and eNodeB are interconnected by S1 user plane interface (S1-U).

This interfacing is used GPRS Tunneling Protocol-User Data Tunneling (GTP-U) over UDP/IP transport. Also it is provide a nonguaranteed delivery to the user plane PDUs between S-GW and eNodeB [13]. GTP-U is a comparatively simple IP and is based on tunneling protocol that allows a lot of tunnels between end points sets.

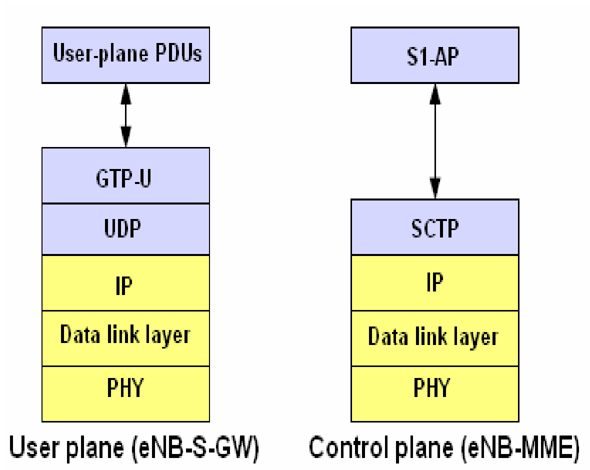

Fig. 5. S1 interface user and control planes

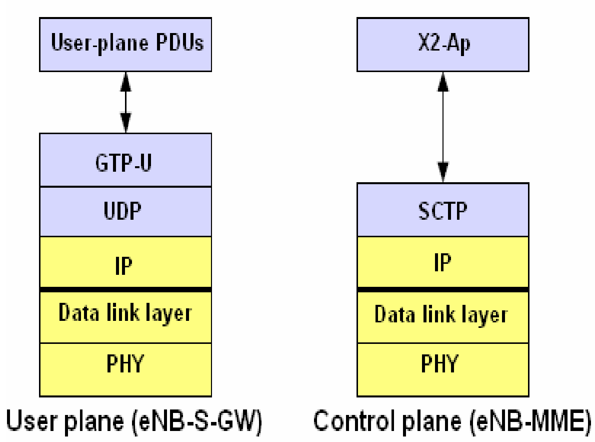

Fig. 6. X2 interface user and control planes

In details, the S1 interfacing is separating the EPC and the E-UTRAN. It is splitting in to two interfaces; the first is S1-U that is transfers traffic data among S-GW and the eNodeB, and the second is S1-MME that is a signaling the interface between the MME and eNodeB. In other hand, the X2 is the interfacing between the eNodeBs and also involving two interfaces; the first is X2-C which is the control plane interface between eNodeBs, and X2-U is the user plane interface between eNodeBs. It is supposed that always there is an X2 interface between eNodeBs which is to provide communicating between each other [4]. S1-MME represents the S1 control plane interfacing between MME and eNodeB. Similarly, the transport network layer and user plane is based on IP transport and in case of reliable transport to the signaling messages; the Stream Control Transmission Protocol (SCTP) is applied over IP top. These protocol functions analogously to TCP confirming reliable, in sequence transmission of all messages with congestion control. SCTP drives analogously to Transmission Control Protocol (TCP) certifying reliable and offer in-sequence transport of messages with congestion control. The application layer signaling protocols are mentioned to S1 application protocol (S1-AP) and X2 application protocol (X2-AP) for S1 and X2 interface control planes respectively [16]. LTE, 3GPP is also defining IP-based, flat network architecture. This architecture is defined as part of the (SAE) effort. The LTE/SAE architecture and concepts have been designed for efficient support of mass-market usage of any IP based service [17].

VII. CONCLUSION

This article has provided an impression of the evolution of LTE towards Release 10. Some of the key components: key features, E-UTRAN, EPC, user plane protocol and control plane protocol stack are described here. Also it provides an outlook of the evolution of LTE toward LTE-Advanced and the full IMT-Advanced capabilities complete in this article. Clearly, LTE-Advanced offers greatly inexpensive performance and provides a good groundwork for further evolution. This paper explained that LTE-Advanced has also been approved by ITU as an IMT-Advanced technology, thus authorizing the characteristics of LTE-Advanced as a 4G technology. LTE-Advanced supports in participating the current networks, services, new networks, and terminals to suit the escalating user demands. The technical features of LTE-Advanced may be shortened with the word of “integration”. LTE-Advanced is standardized in the 3GPP specification Release 10 and designed to achieve the requirements of 4G as defined by ITU. LTE-Advanced as a system needs to take many features into considerations due to optimizations at each level which involves lots of difficulty and challenging employment.

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Ghassan A. Abed received his B.Sc. and M.Sc. degree in Computer Engineering from University of Technology, Baghdad, Iraq, in 1996 and 2003 respectively. He was Head of Transmitters and Receivers Dept. in Microwave Research Centre in Ministry of Sciences and Technology, Iraq. Currently, he is PhD student in National University of Malaysia (UKM), Selangor, Malaysia. He is working in Mobile and Computer Wireless Networks and his research interests include developing new TCP mechanisms to improve performance of TCP over 4G systems and beyond.

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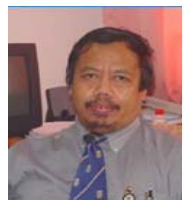

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