From 3GPP LTE to 5G: An Evolution

Oluwadamilola Oshin, Matthew Luka and Aderemi Atayero

Abstract All-IP network architecture is fast becoming a norm in mobile telecommunications. The International Telecommunications Union—Radio communication sector (ITU-R) recognizes a technology as 4G after haven met the International Mobile Telecommunications Advanced (IMT-A) specification of a minimum of 100 Mb/s downlink data rate for high mobility and 1 Gb/s for low mobility. The Long Term Evolution specified by the 3GPP, provides a minimum downlink data rate of 100 Mb/s and marks a new beginning in Radio Access Technologies (RATs). It also notably implements an all-IP network architecture, providing higher data rates, end-to-end Quality of Service (QoS) and reduced latency. Since the first release of the LTE standard (3GPP release 8), there have been a number of enhancements in subsequent releases. Significant improvements to the standard that enabled LTE to meet the IMT-A specifications were attained in release 10, otherwise known as LTE-Advanced. Some of the enhancements such as the use of small cells (known as femtocells) are envisioned to be the basis of fifth generation (5G) wireless networks. Thus, it is expedient to study the LTE technology and the various enhancements that will shape the migration towards 5G wireless networks. This paper aims at providing a technical overview of 3GPP LTE. With a brief overview of its architecture, this paper explores some key features of LTE that places it at the forefront in achieving the goals of wireless access evolution, enabling it to become a key element of the ongoing mobile internet growth. The migration to 5G may be radical, thus some enabling technologies that will shape the 5G cellular networks are also examined.

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S.-I. Ao et al. (eds.), *Transactions on Engineering Technologies*,
DOI 10.1007/978-981-10-1088-0_36

Keywords 4G · 5G · E-UTRAN · GSM · IMT-A · LTE · LTE-A · UMTS

1 Introduction

LTE is designed to meet the IMT-2000 requirements set out by International Telecommunications Union—Radio communication sector (ITU-R). As at February 2014, the Global mobile Suppliers Association (GSA) confirmed a total of 274 LTE networks launched in 101 countries thus far, with majority deployed on the 1800 MHz frequency band [1]. LTE is a phenomenal technology—it enables operation under a vast set of conditions and still delivers excellent performance. LTE (Long Term Evolution) was developed and standardized by 3GPP as Release 8. It builds on 3GPP GSM/UMTS cellular concept and uses E-UTRAN (Evolved-UMTS Terrestrial Radio Access Network) as its radio access: it is therefore sometimes referred to as E-UTRAN. Compared to previous 3GPP telecommunication standards, LTE marks a departure from the normal circuit switched or a combination of circuit and packet switched networks, to an all-IP/packet-based network. LTE is a wireless access technology, which provides high quality experience. 3GPP LTE is a significant advancement in cellular technologies. The motivations for LTE as outlined by 3GPP are: need to ensure the continuity of competitiveness of the 3G system for the future, user demand for higher data rates and quality of service, packet-switched optimized system, continued demand for cost reduction in terms of both capital and operational expenditure (CAPEX and OPEX), low complexity and to avoid unnecessary fragmentation of technologies for paired and unpaired band operation [2]. The spectrum bandwidth of LTE is scalable with subsets of 1.4, 3, 5, 10, 15 and 20 MHz using the 20 MHz bandwidth, LTE is capable of achieving peak data rate of 100 Mbps in the downlink and up to 50 Mbps in the uplink for a 1×2 antenna configuration. The spectrum efficiency and throughput are up to 3–4 times better for the forward link and 2–3 times better for the reverse link than 3GPP release 6. Latency is significantly reduced by using a flat architecture with reduced number of network nodes. User plane and control latency are less than 30 and 100 ms respectively. Internetworking with backend systems such as 3GPP GERAN/UTRAN and non-3GPP systems such as WiMAX and Wi-Fi is supported via various interfaces. The use of self-organizing network operations, specification of uniform interfaces for multi-vendor interoperability and reduced terminal nodes are all envisioned to reduce cost. LTE also supports operation in both unpaired spectrum (Time Division Duplex) and paired spectrum (Frequency Division Duplex Modes). LTE supports Voice over Internet Protocol (VoIP) with an end-to-end quality of service comparable to that of UMTS circuit switched network [3]. Leveraging on these features LTE wireless access technology provides rich experience and high performance, connectivity, coverage and roaming, ecosystem richness, efficiency and cost effectiveness.

LTE-Advanced leverages on an increased bandwidth of up to 100 MHz to target a peak data rate of up 1 Gbps in the downlink and up to 500 Mbps in the uplink for low mobility scenarios. With support of up to 8×8 antenna configuration, LTE advanced offers a peak spectral efficiency of up to 30 bps/Hz (approximately 2 times that of release 8) which translates into an improved user throughput. LTE-Advanced also supports higher mobility speeds of up to 350–500 km/h, which is a significant improvement over the 10 km/h mobility speed for release 8. The use of relay nodes (particularly layer 3 relay technology) significantly improves system coverage at a reduced cost [4]. In order to meet up with mobile traffic explosion, LTE-Advanced uses low cost small cells to improve system capacity. The use of small cells also improves user experience by reducing transmit-receive distance. The most obvious bottleneck for the currently deployed network to meet up with increasing traffic is scarcity of frequency spectrum. This challenge can be surmounted by using the vast spectrum in the millimetre band for 5G mobile network to support multi-gigabit communications services. The evolution towards 5G can be achieved by either continuous enhancements to the LTE radio access network or developing a new radio access network technology that departs from the concepts of LTE. Continuous enhancements to LTE will primarily focus on further enhancements to small cells and other general cellular enhancements for beyond release 13. For example in [5], MIMO-OFDM technology (on which LTE is based) was enhanced using an 8×16 antenna configuration in the 11 GHz frequency band to achieve a data rate of 10 Gbps. Defining a new Radio Access Technology (RAT) should prioritize the achievement of more gains over backward compatibility with LTE [6]. 5G is expected to combine sub 6 GHz and the band beyond 6 GHz to support extreme services such as low data Internet of Things applications to high data Ultra High Definition Video (UHDV) as illustrated in Fig. 1.

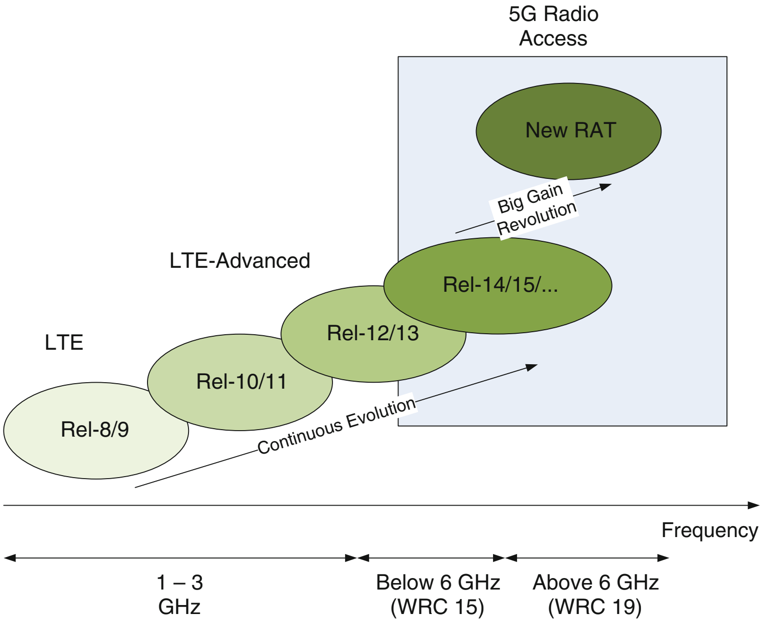

Fig. 1 Evolution paths from LTE to 5G

2 LTE Network Architecture

LTE network architecture is a generally simplified access network which marks a total departure from previous standards, characterized by the absence of a circuit-switched domain. It employs a non-hierarchical (distributed) structure. The LTE network architecture incorporates new network elements. As shown in Fig. 2, LTE network architecture can be sub-divided into three major groups: air interface, radio access network and core network. Transmission of data and control information between the user equipment (UE) and the evolved base stations (eNBs) take place within the air interface. LTE uses various mechanisms (as discussed later in this paper) within the air interface to provide highly reliable and efficient means of carrying out these operations.

The RAN of LTE consists only of a network of fully interconnected eNBs; hence the network is described as being flat or distributed. This RAN is called the E-UTRAN i.e. the Evolved-UMTS Terrestrial Radio Access Network. It is an evolved RAN from UTRAN, used by 3G networks but in LTE, all radio network controller (RNC) functions are transferred to the eNBs. Some of the functions of the eNB include:

- Radio Resource Management: This involves functions such as scheduling, dynamic allocation of resources, radio bearer control and mobility control.
- IP Header Compression.
- Security.
- Connection of users to the core network.

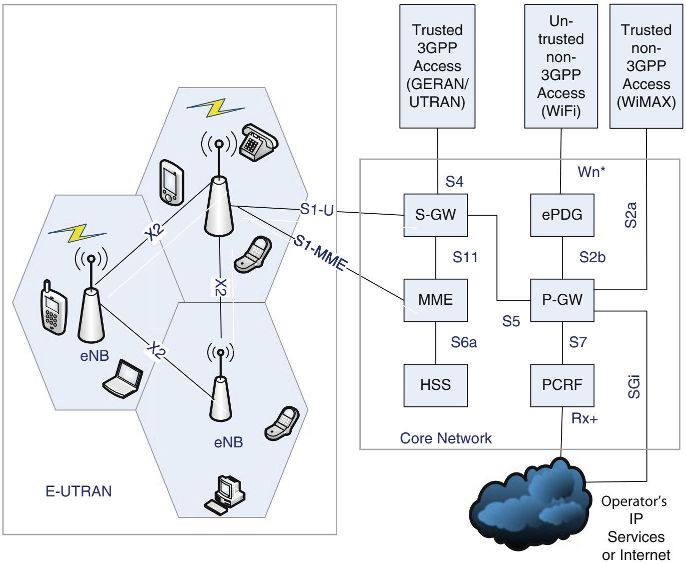

Fig. 2 LTE network architecture

The core network of LTE differed significantly from previous standards. All others had their core networks either entirely circuit switched or split into circuit switched domain and packet switched domain, but LTE core network is entirely packet switched and it is called the Evolved Packet Core (EPC). The EPC in conjunction with the E-UTRAN is called the Enhanced Packet System (EPS), whose details have been defined by 3GPP's study of System Architecture Evolution (SAE).

A Summary of the functional elements of the EPC are outlined below [7]:

- Mobility Management Entity (MME): this handles user authentication, it tracks and maintains the location of a user equipment, performs signalling operations, MME selection for inter-MME handovers.
- Serving Gateway (S-GW): while the MME handles control distribution functions, the S-GW handles data bearer functions where it handles user data functionality, routes and forwards data packets to the P-GW, performs mobility anchoring for inter-3GPP mobility and is responsible for lawful interceptions.
- Packet Data Network Gateway (P-GW or PDN-GW): It handles packet filtering for every user, allocation of IP addresses to the UEs, supports service level charging by collecting and forwarding call data records, handles DL data rate enforcement to ensure that a user does not surpass his traffic rate subscription level, provides interworking for the user plane, between some 3GPP access systems and all non-3GPP access systems, supports QoS differentiation between multiple IP flows. It is also capable of handling multiple lawful interceptions of user traffic to promote government intelligence services fighting criminal activities. The P-GW enforces PCRF policies.
- Home Subscriber Server (HSS): this is a major database, which houses all subscription-related information, to perform call control activities and session management functions.
- Policy and Charging Control Function (PCRF): The PCRF ensures QoS regulation within the network based on definite policies. It is responsible for framing policy rules from the technical details of Service Date Flows (SDFs) that will apply to the users' services, and then forwarding these rules to the P-GW for enforcement.
- Evolved Packet Data Gateway (ePDG): The ePDG provides interworking with un-trusted non-3GPP IP access systems. It ensures security by having a secured tunnel between the UE and the ePDG. It can also function as a local mobility anchor within un-trusted non-3GPP access networks.

As observed in Fig. 2, LTE uses interfaces as indicated for communication between its entities. In general, LTE network architecture implements a simplified, flat all-IP architecture which leads to reduced latency, reduced CAPEX and OPEX, increased scalability and efficiency among other benefits. Increased cost savings and increase capacity can be realized by using LTE *femtocells* known as Home eNodeB (HNB). Can be backhauled to the cellular operator network through a

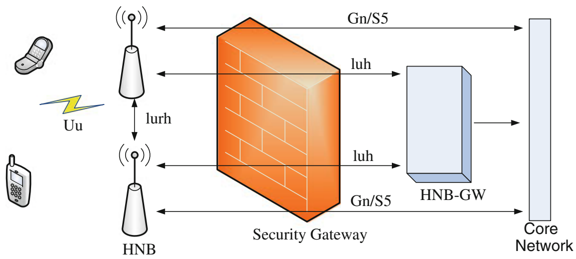

Fig. 3 HNB access radio access network reference model

broadband gateway such as fiber optic cable over the internet. The reference model of the HNB is shown in Fig. 3.

The HNB gateway is an optional entity that serves as a concentrator for HNB connections and as a Radio Network Controller (RNC) to the core network. Alternatively, the HNB can connect directly to the core network when a Local Gateway functionality is incorporated into it [8]. Enhancements to the HNB is very critical to the continuous evolution of the 3GPP LTE standard.

3 Enabling Technologies

LTE leverages on several technologies such as use of Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) antenna techniques to achieve the specified targets. Continuous improvements of these enabling technologies is the basis for the evolution of the LTE technology.

3.1 Multiplexing/Multiple Access Mechanism

The aim of multiplexing/multiple access mechanisms is to share scarce resources in order to achieve high capacity, by enabling simultaneous allocation of bandwidth/channel to multiple users. Multiplexing is a method by which multiple signals are transmitted at the same time in form of a single complex signal over a shared medium and then recovering the individual signals at the receiving end while Multiple access mechanisms define how the channel is shared in a finite frequency bandwidth i.e. it controls how to use (share) the radio resources efficiently. These operations take place within the air interface of the LTE network.

The OFDM is a data transmission multi-carrier modulation technique, which divides a high bit-rate data signal into several parallel low bit-rate data signals which are then modulated using an appropriate modulation scheme. OFDM is the core of LTE downlink transmission system. Majority of the striking features of LTE is made possible by its use of OFDM. The “low bit-rate multi-carrier” technique of OFDM, with a cyclic prefix added to it, makes the transmission robust to time dispersion on the radio channel without the need for advanced and complex receiver channel equalization. In the downlink, this leads to reduced cost of terminal equipment and reduced power consumption as well. OFDM is also used due to its resilience to multipath delays and spread, its capability for carrying high data rates and its ability to support both FDD and TDD schemes. The concept of orthogonality can be illustrated by considering two OFDM modulation symbols α_{i1} and α_{i2} used to modulate time-limited complex signals (subcarriers):

$$\int_{mT_s}^{(m+1)T_s} \alpha_{i1}\alpha_{i2}^{*} e^{j2\pi k_1 \Delta ft - j2\pi k_2 \Delta ft} dt = 0 \quad \forall k_1 \neq k_2 \tag{1}$$

where $\Delta f = 1/T_s$ is the subcarrier spacing and $k.\Delta f$ is the sampling frequency which corresponds to the sampling frequency of the signal. In essence, OFDM transmission is the modulation of a set of orthogonal functions given by [9]:

$$\beta(t) = \begin{cases} e^{j2\pi k \Delta ft} & 0 \leq t < T_s \\ 0 & otherwise \end{cases} \tag{2}$$

In the downlink, the Base Station (BS) is the transmitter while the User Equipment (UE) only receives, therefore it does not have multiple access problems in terms of collisions. Fading is a natural characteristic of radio communication channels (either in time, frequency or space domain), resulting in rapid variations in radio channel quality. A derivative of OFDM—OFDMA is used in LTE downlink, where it combines functionalities of FDMA and TDMA. With OFDMA, the UE gets scheduled to a time slot and a frequency group (which makes the system resilient to frequency-selective fading) among other features, in order to send information. Using OFDMA, LTE can use channel-dependent scheduling to take advantage of the variations resulting in more efficient use of available radio resources. This creates a lot of flexibility and makes the system robust, as not all the requirements for transmission can be bad at the same time.

In the uplink, the UEs transmit to the BSs. Due to the high peak-to-average ratio (PAR) of OFDM (characterized by the high amount of power required by the RF power amplifier to push out the RF signal from the UE antenna to the BS), 3GPP was forced to adopt a different transmission scheme for LTE uplink. SC-FDMA, a hybrid scheme, was the solution—it combines the low PAR feature (which allows high RF power amplifier efficiency in the UEs, thereby reducing battery consumption for the UE) of single-carrier schemes with the resilience of multipath interference and the flexible subcarrier frequency allocation of OFDM technology [10].

3.2 Coding and Modulation

The reduced latency and high throughput of LTE is traceable to a number of mechanisms implemented in it. The physical/MAC layer of LTE adopts two key techniques: Hybrid Automatic Repeat reQuests (HARQ) and adaptive modulation and coding (AMC). These two techniques work together to give a very adaptive transport mechanism in LTE [11]. To handle re-transmission errors, LTE uses two loops: a fast HARQ inner loop with soft combining to take care of most errors and a robust selective-repeat ARQ outer loop to take care of residual errors [12, 13]. HARQ is a technique for both error detection and correction by identifying when transmission errors occur and facilitating retransmission from the source thereby ensuring that data is transported reliably from one network node to another. LTE uses Type-II HARQ protocols. LTE demonstrates dynamic resource allocation through link adaptation. Link adaptation is achieved using the AMC mechanism, with the aim of improving data throughput in a fading channel. AMC works by varying the downlink modulation technique depending on the channel conditions of each user. Given a good channel condition, the LTE system can use a higher order modulation scheme (64-QAM with 6 bits per symbol) or reduced channel coding, making the channel more spectrally efficient, and resulting in higher data rates. But as the channel becomes noisy due to signal fading or interference, the system selects a lower modulation technique (QPSK or 16-QAM with fewer bits per symbol) or stronger channel coding.

3.3 Radio Access Modes (Duplex Schemes)

A duplex scheme organizes how radio communication systems communicate in the two possible directions (uplink and downlink). 3GPP has specified LTE to operate in either unpaired spectrum for Time Division Duplex (TDD) called TD-LTE or paired spectrum for Frequency Division Duplex (FDD); where each has its pros and cons, therefore selection is made depending on the intended application.

LTE specifications emphasize on TD-LTE, as it presents significant advantages over LTE FDD. TD-LTE, asides many other advantages, provides an upgrade path for TD-SCDMA, it does not require a paired spectrum since uplink and downlink transmissions occur on the same channel making it highly spectrally efficient and TD-LTE also reduces hardware cost. LTE operation in FDD which is the same duplex method for GSM/UMTS, gives room for subscribers' migration to LTE.

LTE also supports half-duplex FDD at the UE. This mode allows the uplink and downlink to share hardware since they are never used simultaneously. The half duplex LTE FDD offers reduced complexity and therefore reduced cost [14].

3.4 Radio Channel Bandwidth

LTE is not only able to operate in different frequency bands, but can be implemented using different spectrum sizes. This makes it possible to harness the global wireless market and align with regional spectrum regulations and the obtainable spectrum. LTE implements a scalable radio channel bandwidth from 1.4 to 20 MHz with a subcarrier spacing of 15 kHz. The 20 MHz bandwidth will be required for optimum performance and to cope with the growth of the mobile internet. 3GPP has specified the LTE air interface to be “bandwidth agnostic” thereby allowing the physical layer to adapt to different spectrum allocation without severe impact on system operation.

LTE defines an enhanced mode of operation for broadcast/multicast services called eMBMS (Enhanced- Multimedia Broadcast/Multicast Service), yielding notable performance benefits compared to MBMS over WCDMA. LTE does this by enabling the support of MBSFN (Multimedia Broadcast over Single Frequency Network) yielding a possible subcarrier spacing of 7.5 kHz for standalone eMBMS operation using a dedicated carrier [15].

3.5 Multiple Antenna Techniques

Every terrestrial radio communication channel has data throughput limitations as defined by Shannon’s theorem, and multipath interference. LTE networks are expected to provide high data rate in addition to high spectral efficiency; therefore, 3GPP included the use of multiple antenna techniques to provide additional robustness to the radio link [16]. Multiple antenna techniques take advantage of the effects of multipath interference to increase data throughput significantly within the channel’s given bandwidth. The use of multiple antenna techniques introduces a concept called precoding, which is essential for obtaining the best data reception result at the receiver. It specifically maps the modulation symbols onto the different antennas. The basic principle of MIMO is illustrated in Fig. 4.

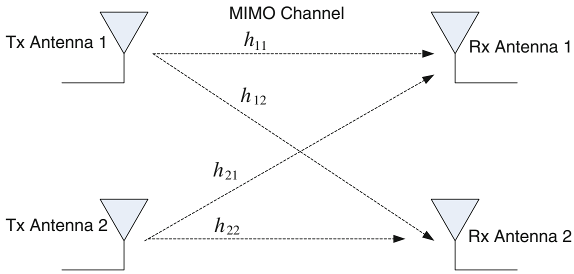

Fig. 4 Block diagram of a 2 × 2 MIMO system

The MIMO system for each subcarrier can be expressed as a system of linear equations which gives the relationship between the transmit antennas and the receive antennas. The relationship can be expressed in vector form as:

$$\vec{Y} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \vec{X} \tag{3}$$

In order to correctly recover the transmitted data, the receiver must estimate the channel response (channel state information) at each subcarrier for any pair of transmitted and received symbol. In selecting the type of multiple antenna technique to use, transmission modes were defined. 3GPP's Release 8 (LTE) specifies seven transmission modes (named TM1, TM2 etc.) for the downlink and one transmission mode for the uplink. These antenna techniques differ by the benefit they provide and the conditions required for their operation. The transmission modes differ in the number of layers or ranks and the number of antenna ports. The uplink transmission mode is Closed-loop switched antenna diversity.

MIMO is a generic term with several special cases and applications. When a point-to-point MIMO link between an eNB (base station) and a single user is involved, we have a case of single user MIMO (SU-MIMO). Multi-user MIMO (MU-MIMO) refers to use cases where several user equipment (UE) communicate with a single eNB using the same time and frequency—domain resources (David et al. 2009). Special cases of MIMO configuration include: Single-Input-Multiple-Output (SIMO), Multiple-Input-Single-Output (MISO). The main aim of the various MIMO configuration revolves around achieving either diversity gain, array gain or spatial multiplexing gain. Transmit/receive diversity involves the transmission/reception of redundant information on different antennas at each subcarrier. Diversity gain makes the link robust by mitigating the effect of multipath fading. In order words, diversity gain is aimed at improving the statistics of instantaneous Signal-to-Noise Ratio (SNR) in a fading channel. In LTE, transmit diversity gain is achieved using Space Frequency Block Codes (SFBCs) and Frequency Switched Transmit Diversity (FSTD). Beamforming is used to achieve array beamforming gain, by using multiple antenna to control the direction of wave front based on weighting the phase and magnitude of individual antenna signals [17]. Spatial multiplexing is designed to boost a link by transmitting non-redundant (independent) information on different antennas. The transmission modes for LTE based on these configurations are summarized in Table 1 [17].

3.6 Voice Over LTE/IP Multimedia Subsystem (IMS)

LTE implements an all-IP architecture; this implies that voice communication cannot be "business as usual" i.e. voice communication cannot be circuit-switched as it is with lower generation technologies. This problem also applies to SMS

Table 1 Transmission modes in LTE release 9

Transmission modes	Description	Remarks
1	Single transmit antenna	Single antenna port; port 0
2	Transmit diversity	2 or 4 antennas
3	Closed loop spatial multiplexing with cyclic delay diversity	2 or 4 antennas
4	Closed loop spatial multiplexing	2 or 4 antennas
5	Multi-user MIMO	2 or 4 antennas
6	Closed loop spatial multiplexing using a single transmission layer	1 layer (rank 1) 2 or 4 antennas
7	Beamforming	Single antenna port, port 5 (virtual antenna port, actual antenna configuration depends on implementation)
8	Dual-layer beamforming	Dual-layer transmission, antenna port 7 and 8

communication as well; therefore, new solutions for supporting voice and SMS on LTE network became an urgent need.

In order to provide these very crucial services, alliances were tasked to come up with solutions to these shortcomings, which are listed below:

- Circuit-Switched Fall-Back (CSFB): This method involves the use of a 2G/3G network alongside the LTE network. The LTE network is used for data services but on a call initiation, the network falls back to a 2G/3G circuit-switched connection while the LTE network (packet-switched) is suspended. For an SMS transmission, the mobile equipment uses an interface known as SGs (MME-MSC interface) which allows messages to be transmitted over an LTE channel.
- Simultaneous Voice—LTE (SV-LTE): This is very similar to the CSFB but in SV-LTE, the user device makes use of the 2G/3G network and the LTE network concurrently. Thus, when a call is initiated, it is routed through the circuit-switched 2G/3G connection while maintaining connection with the LTE network. This option requires the use of two radios simultaneously by the mobile device which causes a degrading impact on the battery life of the device.
- Over-the-top (OTT) VoIP: An example of an OTT VoIP solution is Skype. This concept led to the widespread usage of VoIP as a voice communication service and has advanced to an era of being pre-installed in smart phones. However, OTT VoIP solutions cannot guarantee satisfactory user experience in the absence of LTE coverage. OTT VoIP service providers do not have control over QoS in the wireless network, therefore, cannot ensure a good quality of

experience (QoE) under all load circumstances. It also lacks the capability of handing over to a circuit-switched connection.

- Voice over LTE via Generic Access (VoLGA): This method relies on the operating principles of 3GPP's Generic Access Network (GAN). The aim of GAN is to extend mobile services over a generic IP access network. For example, using Wi-Fi as an access technology to a 2G/3G network. In the case of LTE, VoLGA uses LTE as the access technology to a 2G/3G network. A GAN gateway provides a secure connection from the user to the mobile network operator's infrastructure. This connection serves as the channel for transmitting voice and other circuit-switched services such as SMS over the intermediate LTE network.
- Voice over LTE (VoLTE): This method implements 3GPP's IMS core network by deploying Multimedia Telephony (MMTel) on the IMS core as the solution for voice service delivery and other traditional circuit-switched services over the LTE network. VoLTE eliminates the need for fall-backs to 2G/3G voice, ensuring a truly flat all-IP LTE network. With VoLTE users are assured telecom grade voice and all forms of rich communication services on LTE-enabled devices. VoLTE defines three working interfaces:
  - The User Network Interface (UNI): This is the interface between the user device and the operator's network.
  - The Roaming Network Network Interface (R-NNI): This is the interface between the Home and Visited Network, for use in a roaming situation.
  - The Interconnect Network Network Interface (I-NNI): This is the interface between the networks of the two users making a call.

VoLTE has been accepted globally by a significant number of telecom industries as the standard for carrying voice, SMS and other related services over the LTE network [18].

3.7 Self-organizing Networks (SON)

The impact or functionality of a network is not just in its deployment and usage but in its ability to achieve operational excellence. This involves continuous end-to-end network management of the system i.e. seamless operation and consistent performance. Due to the increasingly expanding and evolving wireless network, there is a crucial need to automate this management process [19, 20]. In order to achieve this, LTE adopts SON techniques which enables the network to configure itself and manage the radio resources to achieve optimum performance at all times with minimal human supervision. SON techniques cover three main areas:

- Self Configuring: As a network expands and more eNBs are deployed, self configuring networks eliminate the need to go around configuring each one; rather, they are configured using automatic installation procedures.

- Self Optimizing: After configuration, self optimizing techniques adjust the network's operational characteristics based on measurement information collected from the UEs and eNBs, and use them to auto-tune the network to best meet its needs.
- Self Healing: In any system, faults are very likely to occur; however, the self healing capability of a network enables automatic detection and fault masking by changing relevant network characteristics. For example, edges of adjacent cells can be increased by raising power levels and changing antenna elevations.

4 LTE Technological Advancements

There are two groups of technological advancements on LTE Release 8, namely LTE Release 9 and LTE Release 10 [21]. Transmission Mode 8 (TM8), Dual Layer Beamforming, was added in LTE Release 9. LTE Release 9 also focuses on features that enhance the core network of LTE Release 8. These enhancements centre on:

- Location, broadcast and IMS emergency services using GPRS and EPS.
- Support of circuit switching services over the EPS of LTE.
- Home NB or eNB architecture considerations focusing on security, QoS, charging and access restrictions.
- IMS evolution.

LTE Release 10: This is the evolution of LTE to meet the IMT-A requirements defined by ITU. It is known as LTE-Advanced (LTE-A), and its focus is on higher capacity as outlined:

- Downlink peak data rate of 3 Gb/s and Uplink peak data rate of 1.5 Gb/s.
- Higher spectral efficiency on the downlink, from an upper limit of 16 bps/Hz in Release 8–30 bps/Hz in Release 10.
- Increased number of simultaneously active subscribers.
- Improved performance at cell edges.

LTE-A centres on three new techniques that enable it achieve the above-mentioned feats [22]:

- Carrier Aggregation (CA): The most basic method of increasing capacity is by adding more bandwidth. LTE-A is increased in bandwidth through aggregation of up to five component carriers of different bandwidths to form a maximum bandwidth of 100 MHz. This also provides LTE-A backward compatibility with Release 8 and Release 9 mobiles. Carrier aggregation can be used in both FDD and TDD schemes.
- Enhanced multiple antenna techniques: It adds a ninth transmission mode to the downlink called Eight Layer Spatial Multiplexing (8×8 MIMO), and adds a second transmission mode to the uplink (4×4 MIMO).

- Relay Nodes (RN): Relay nodes bring about the possibility of efficient heterogeneous network planning in LTE-A. The Relay Nodes are low power base stations that provide enhanced coverage and capacity at cell edges and can also provide connectivity to remote areas without the need for optical fibre cables.
- Coordinated Multipoint (CoMP) Transmission/Reception: This feature was finalized in Release 11. In this technique, multiple transmit and receive points provide coordinated transmission/reception. This transmission/reception is carried out jointly and dynamically across multiple cell sites, same site or within same or different eNBs. The primary purpose of CoMP is to improve the performance at cell edge.

The on-going enhancements in release 13 include additional enhancements for LTE to operate in the unlicensed spectrum and expansion of the carrier aggregation framework to support more than 5 component carriers. Other enhancements described in [23, 24] include:

- Enhancements for Machine-Type Communications (MTC) involves defining a new low complexity UE type that supports reduced support for downlink transmission modes, reduced bandwidth, reduced transmit power and very long battery life to support Internet of Things (IoT) markets.
- Improving multi-user transmission techniques using superposition coding for increasing spectral efficiency of the LTE system.
- Use of full dimension MIMO/Elevation Beamforming for improved spectral efficiency by the use of higher dimension MIMO of up to 64 antennas at the eNB and utilizing the vertical dimension for MIMO and beamforming operations.
- Improved indoor positioning accuracy and support for Single-cell Point-to-Multipoint (SC-PTM).

Table 2 gives a summary of the key characteristics of LTE at its inception and the current features of LTE as at today, LTE-A. However, recall that there are

Table 2 LTE—LTE-A comparison

Parameter	LTE	LTE-A
Frequency band	Country-dependent	Country-dependent
Downlink peak data rate	100–326 Mbps	1–3 Gbps
Uplink peak data rate	50–86 Mbps	500 Mbps–1.5 Gbps
Channel bandwidth (MHz)	1.4, 3, 5, 10, 15, 20	Up to 100 MHz
Peak spectral efficiency	16 bps/Hz downlink	30 bps/Hz downlink
Latency	~10 ms	Less than 5 ms

(continued)

Table 2 (continued)

Parameter	LTE	LTE-A
Duplex method	FDD and TDD (TD-LTE)	FDD and TDD (TD-LTE)
Multiplexing	OFDM	OFDM
Multiple access method	Downlink—OFDMA Uplink—SC-FDMA	Downlink—OFDMA Uplink—SC-FDMA
Modulation scheme	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM
Multiple antenna technique	Up to 4 × 4 MIMO downlink	Higher order MIMO (8 × 8 MIMO downlink; 4 × 4 MIMO uplink)

improvements on the first release of LTE as already discussed in this sub-section, before the LTE Release 10 (LTE-A).

5 5G Enabling Technologies

The most obvious paths of evolution towards 5G radio access are improved spectrum efficiency, network densification and spectrum extension. As earlier noted [25], currently deployed networks are deployed in 1–3 GHz frequency band which eventually fall short of meeting the multi-gigabit requirements of future communication services such as Ultra-High Definition Video (UHDV) [26]. The millimeter wave (mmWave) frequency band from 30 to 300 GHz offers a huge bandwidth and consequently spectrum extension for mobile networks. Millimeter communications particularly in the 28, 38, 60 GHz and the E-band (71–76 and 81–86 GHz) bands will play a critical role in 5G applications such as small cell access, cellular access and wireless backhaul [27, 28]. Some of the key radio access technologies that will pave the way for 5G mobile communications include:

- Further enhancements to low power small cells to provide network densification.
- The use of massive MIMO and large number of miniaturized antennas at high (mmWave) frequencies to provide significant increase in spectrum efficiency and user throughput.
- Use of new access techniques such as Filtered OFDM and Sparse Code Multiple Access (SCMA) to improve system efficiency, support energy saving, reduced latency and massive connectivity [29, 30].
- Use of more efficient coding schemes such as Polar codes, which can achieve Shannon capacity using a simple encoder and a successive cancellation decoder for a large code block size. Another perspective to coding in 5G is to use

network coding for interference management, which can improve security, throughput and robustness for routing of information through the network.

- Use of Full Duplex to support bi-directional communications without the use of time or frequency duplex is expected to double system capacity and reduce latency.
- Use of self-organizing network operation for a cost effective management of the massive network densification. The concept of Device-to-Device communication which allows direct communication between nearby device will depend relies on self-organizing network operations.

6 Conclusion

It is most evident that LTE gives sustainable and significant advantages over existing 3G technologies and also offers the most efficient and feasible evolution path as user/operator network demands mature. The LTE technology has undergone a significant evolution from its first release, which was aimed at meeting the IMT-2000 requirements to achieving and even exceeding the IMT-Advanced (4G) requirements. These technologies will continue to play a critical role in the new frequency spectrum below 6 GHz expected to be allocated for mobile communications at the World Radio Conference (WRC) 2015. However, for the spectrum band above 6 GHz which is expected to be allocated at WRC in 2019, a new radio access technology may be necessary. Thus 5G which is the next frontier of a broader ICT ecosystem that will enhance mobile internet and empower Internet-of-Things (IoT) will be heterogeneous across frequency spectrum. The lower frequency bands (below 6 GHz) can be used as the primary band of 5G spectrum for wide area network coverage. The high frequency bands can be used for Ultra Dense Networking and flexible backhauling. The high frequency bands are also expected to use enhanced smalls cells due to high attenuation associated with these frequencies.

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