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LTE-Advanced for Rapid Mobile Broadband Penetration in Developing Countries

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Abstract

Mobile broadband has a huge potential for achieving digital transformation towards a knowledge-based economy. Ubiquitous access to broadband will impact entertainment, agriculture, commerce, education, governance, civic engagement, healthcare, public safety, smart grid, and environment management. However, there is a wide digital divide between the developed part of the world and the developing countries in terms of broadband access, use, affordability, speed and quality of service. This is majorly attributed to insufficient bandwidth, lack of open access and infrastructure sharing, and unreliable power grid. In this paper, the authors identify and discuss the key technologies of Long Term Evolution-Advanced (LTE-Advanced) that promote rapid broadband penetration in developing countries. Carrier aggregation offers the flexibility of supporting multiple frequency bands to provide wider bandwidths, reduce inter-cell interference, improve handover, save energy, and perform load balancing. Advanced Multiple Input Multiple Output (Advanced MIMO) achieves very high data rates through spatial diversity, spatial multiplexing, beamforming, and spatial division multiple access. Coordinated Multi-Point (CoMP) improves system efficiency, cell-edge throughput, and network coverage. Mobile network operators may reduce capital and operating expenditures using relay nodes. Deployment of Heterogeneous Networks (HetNets) increases system capacity. Self-Organizing Networks (SONs) introduces network function automation for faster execution of processes. Therefore, low- and middle-income countries can take advantage of the fourth generation (4G) cellular technology to leapfrog and attain higher broadband penetration level for sustainable development.

Keywords: LTE-Advanced; Mobile Broadband; Developing Countries; Sustainable Development; Broadband Penetration

INTRODUCTION

Broadband has become a foundation for economic growth, job creation, global competitiveness and a smarter citizenry in the digital transformation agenda towards a knowledge-based economy [1]. This technology is the current ‘big thing’ in the global economic revolution that will impact entertainment, agriculture, commerce, education, governance, civic engagement, healthcare, public safety, smart grid, and environment management. It will improve healthcare service delivery and lower costs through health information technology. It will also equip teachers and students with digital tools for effective teaching and learning. In the same vein, broadband offers vast opportunities for women's empowerment and environmental sustainability, and contributes to enhanced government transparency and accountability [2]. It also facilitates social development of communities, even beyond national boundaries. With the rapid evolution of wireless technologies, broadband has also become an enabling platform for smart infrastructure in the transportation and electricity industries. For instance, broadband-enabled Smart Grid has enormous capacity to increase energy independence and efficiency. Furthermore, a nationwide public safety mobile broadband communications network will aid the responses of security outfits to emergency incidences [1].

Despite the numerous opportunities that broadband offers, the data released by the International Telecommunication Union (ITU) showed that 3.9 billion people are yet to be connected to the abundant digital resources available on the Internet [3]. Developing countries now account for the vast majority of Internet users, with 2.5 billion users compared with one billion in developed countries. However, developing countries and the Least Developed Countries (LDC) still have relatively low Internet penetration rates of 40% and 15% respectively [3]. These percentages are far below the experience in the developed countries where the rate has increased to 81%. Meanwhile, mobile broadband Internet access has a huge potential to facilitate the efforts of the international community towards the timely realization of the 17 Sustainable Development Goals (SDGs) and the associated 169 targets [4]. SDGs are quite ambitious and can only be realized through formidable efforts and greater progress in which broadband Internet is critical.

With about 95% global population coverage, mobile phone has become nearly ubiquitous. Yet, the growth of mobile broadband penetration in developing countries remains slow [3]. Currently, the active mobile broadband penetration in Nigeria is 20.95% while the Internet penetration stood at 47.44% [4, 5]. The 'digital divides' within countries have negative effect on rural communities and the poor commonly due to low revenue potential. The landings of high capacity submarine cable systems in Nigeria has significantly reduced the prices of international bandwidth [6]. Nevertheless, lack of sufficient bandwidth remains a major challenge to improved Internet connectivity due to unequal distribution and transmission of available bandwidth. All the submarine cable landings are concentrated in Lagos and access to other parts of the country has become difficult due to limited infrastructure for effective distribution. Extension of the cable systems to other coastal regions will promote even distribution of the underutilized bandwidth. Also, there is a need for open access and infrastructure sharing of already built transmission networks in order to facilitate an integrated national backbone. Lack of a reliable power grid is another major hindrance.

Wireless technology is the primary means to the Internet in most developing countries. With the high proliferation of smart devices and mobile applications, mobile broadband is considered to be the fastest-growing broadband technology [4]. LTE and System Architecture Evolution (SAE) were developed by the 3rd Generation Partnership Project (3GPP) in response to the continuously increasing demand for mobile broadband services. These new technologies formed the Evolved Packet System (EPS) that became a major breakthrough for wireless communication system to deliver mobile services of better quality [7]. The LTE system became the first cellular system to utilize Orthogonal Frequency Division Multiple Access (OFDMA), and it achieved a peak data rates of 300 Mbps in the downlink [8, 9]. At the radio access network layer, LTE utilizes Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO) techniques to handle the challenge of inter-symbol interference and to increase data rates respectively. An all-Internet Protocol (IP) flat architecture was designed for the core network operations. In addition to sustaining the competitiveness of third generation mobile technology, LTE technology has the capacity to reduce both capital and operating expenditure of mobile network operators. Although LTE network performance is much better than the previously deployed High Speed Packet Access (HSPA) technology, it does not completely satisfy the requirements for 4G cellular systems.

The evolution of LTE towards LTE-Advanced (Release 10) was initiated by 3GPP primarily to provide rapid mobile broadband in a cost efficient way, and equally achieve higher peak data rates, peak spectral efficiency, and scalable bandwidth [10]. The target performance requirements are specified in the International Mobile Telecommunications Advanced (IMT-Advanced) set by the International Telecommunications Union-Radio (ITU-R) in [11]. One of the main advantage of the LTE-Advanced systems is its backward compatibility with LTE systems. In addition, the spectrum flexibility in LTE-Advanced allows the deployment of the system in different allocated frequency bands. This feature readily accommodates the regional differences in terms of spectrum regulations and national policies. LTE-Advanced supports higher peak data rate (3 Gbps for downlink, and 1.5 Gbps for uplink transmission), higher spectral efficiency (up to 30 bps/Hz), increased number of simultaneously active subscribers, and better cell edge performance (at least 2.40 bps/Hz/cell for 2x2 MIMO downlink transmission) [10]. 3GPP Release 10 featured carrier aggregation, advanced MIMO antenna techniques, relay nodes, and SONs.

Subsequent enhancements beyond LTE Release 10 offers efficient support for different mobile traffic scenarios, flexible and cost-effective deployment strategies, and energy efficiency solutions. Enhanced Inter-Cell Interference Cancellation (eICIC) and mobility management were introduced in LTE Release 11 as important components of HetNets [12]. The use of LTE technology for emergency and security services and the development of technical specifications for mission-critical application layer functional elements and interfaces were the priorities of Release 12 [13]. Other features include small cells and network densification, Device-to-Device communications (D2D), LTE Time Division Duplexing-Frequency Division Duplexing (TDD-FDD) joint operation, and the integration of Wi-Fi into mobile operator services. Besides the enhancement of existing services and features, Release 13 introduced the first complete set of specifications for mission-critical Push-To-Talk, an essential functionality for private mobile radio voice communication [14]. Release 14 focused on mission critical enhancements, LTE support for Vehicle-to-X (V2X) services, enhanced Licensed Assisted Access (eLAA), four-band carrier aggregation, and inter-band carrier aggregation [15].

New technologies have demonstrated tremendous capacity towards accelerating human progress, bridging the digital divide, and developing knowledge societies. The evolution of LTE towards LTE-Advanced is primarily driven by the need to provide rapid mobile broadband in a cost efficient way, and equally achieve higher peak data rates, peak spectral efficiency, and scalable bandwidth. In this paper, we identify and discuss the key technologies of LTE-Advanced that promote rapid broadband penetration in developing countries. This work covers the main technical features of LTE-Advanced namely: the use of carrier aggregation, advanced use of multiple antennas at both the transmitter and receiver, CoMP transmission and reception, support for relay nodes, HetNets, and SONs.

LTE NETWORK ARCHITECTURE

A. Evolved Packet System (EPS)

LTE evolved as a radio access technology in parallel to High Speed Packet Access (HSPA). EPS was developed to support the packet-data capabilities provided by the LTE radio interfaces as specified by System Architecture Evolution (SAE). The main components of the network architecture of LTE are the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC) shown in Figure 1.

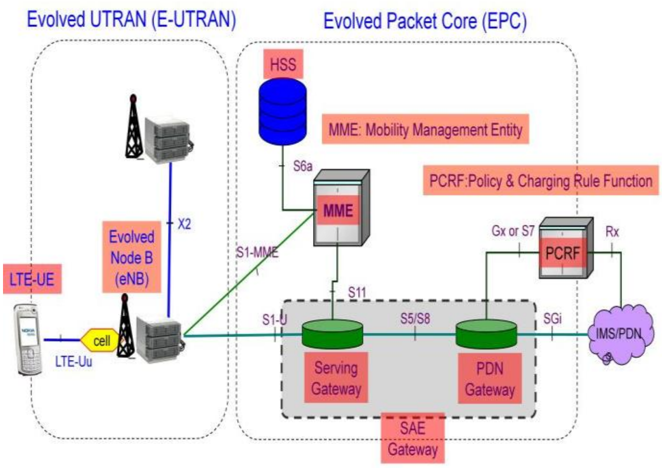

Figure 1: LTE Network Architecture [16]

The E-UTRAN is the radio access part of the EPS while the EPC serves as the core network. The EPS is an all-IP network that establishes connectivity between a wireless terminal and an external network such as the Internet. The E-UTRAN allocates IP address to 'active' wireless devices and performs both real time and data services using the IP protocol. The IP address is released immediately the mobile unit is switched off.

B. Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

The radio access network consists of evolved NodeBs (eNBs) without any centralized intelligent controller (flat architecture). The eNBs are usually inter-connected via the X2-interface while the S1-interface links the eNBs to the core network. Faster connection set-up and handover is achieved through distributed intelligence among eNBs. This will result in better quality of service in critical services which require low latency. In addition, the Medium Access Control (MAC) protocol layer is now limited to the UE and the eNB, resulting in high-speed communication between the eNB and the UE. The E-UTRAN achieves high spectral efficiency, high peak data rates, very low latency, and supports flexibility in frequency and bandwidth. Table 1 highlights the essential parameters of 3GPP LTE Release 8. The various protocols utilized in both the user plane and the control plane include: the Medium Access Control (MAC), the Packet Data Convergence Protocol (PDCP), the Radio Link Control (RLC), the Physical Layer (PHY), and the Radio Resource Control (RRC) protocols.

Table 1: Key Parameters of LTE Release 8

Multiple Access Scheme	• Orthogonal Frequency Division Multiple Access (OFDMA) for downlink transmission • Single Carrier-Frequency Division Multiple Access (SC-FDMA) for uplink transmission
Allowable Bandwidth	1.4, 3.5, 10, 15, 20 MHz
Minimum Transmission Time Interval	1 millisecond
Sub-Carrier Spacing	15 kHz
Cyclic Prefix Length	• 4.7 microsecond (short) • 16.7 microsecond (long)
Modulation Schemes	• Quadrature Phase Shift Keying (QPSK) • 16-Quadrature Amplitude Modulation (16-QAM) • 64- Quadrature Amplitude Modulation (64-QAM)
Spatial Multiplexing	• Single Layer for uplink per user • Up to 4 Layers for downlink per user • MU-MIMO supported for uplink and downlink

C. Evolved Packet Core (EPC)

The EPC allows easy handover between 3GPP and non-3GPP radio access to enable mobile network operators to use a single core network for different mobile services. The security functions in LTE-Advanced network is managed by the Mobility Management Entity (MME). It also handles the idle state mobility, roaming and handovers. The Serving-Gateway (S-GW) coordinates inter-eNB handover, inter-3GPP mobility, inter-operator charging, and packet routing and forwarding. The Packet Data Network Gateway (PDN-GW) assigns an IP address to the mobile device and ensure secure connections between mobile devices and the untrusted external network using Internet Protocol Security (IPSec).

KEY TECHNOLOGIES OF LTE-ADVANCED

The evolution of LTE towards LTE-Advanced was mainly driven by the need to provide rapid mobile broadband in a cost efficient way in accordance with the IMT-Advanced performance requirement set by ITU [10]. The modifications in the radio capabilities of LTE-Advanced, as highlighted in the 3GPP LTE Release 10, will significantly increase the peak data rates to 3 Gbps and 1.5 Gbps for downlink and uplink transmissions respectively. The fourth generation (4G) technology will provide mobility support up to 100 Mbps data rate at 350 km/h. The spectral efficiency has leaped from a maximum of 16bps/Hz available in LTE to 30 bps/Hz. At cell edges, LTE-Advanced guarantees an improved performance of at least 2.40 bps/Hz/cell for DL 2x2 MIMO. The main features of the evolution of LTE towards LTE-Advanced are highlighted in Table 2.

Table 2: Evolution of LTE toward LTE-Advanced	**Release 13**	• Programming of mission critical applications. • Carrier aggregation [up to 32 separate carriers, up to 640 MHz bandwidth]. • LTE operation in a combination of licensed and unlicensed spectrum. • Inter-site carrier aggregation. • Enhanced M2M communication. • Interworking with Wi-Fi, licensed assisted access (at 5 GHz). • Indoor positioning. • Single-cell point to multipoint. • New antenna techniques [high-order MIMO systems with up to 64 antenna ports]. • Advanced receivers to maximize the potential of large cells.
	Release 12	• Enhanced small cells for LTE, introducing a number of features to improve the support of HetNets. • Inter-site carrier aggregation to coordinate the capabilities and backhaul of adjacent cells. • M2M communication. • D2D interface to support public safety communications systems, and proximity services (ProSe) for discovery and group communications. The LTE D2D interface is called a sidelink. • Interworking between LTE and WiFi or HSPDA. • Higher order modulation schemes of up to 64-QAM. • LTE operation in unlicensed spectrum
	Release 11	• Enhancements to Carrier Aggregation, MIMO, relay nodes, and eICIC. • CoMP to enable simultaneous communication with multiple cells. • Enhanced PDCCH (EPDCCH), which uses PDSCH resources for transmitting control information. Previously, from Release 8, control information could only be transmitted in the PDCCH region of subframes. • Introduction of new frequency bands.
	Release 10	• Higher order MIMO antenna configurations supporting up to 8×8 downlinks and 4×4 uplinks. • Data throughput of up to 3 Gbps downlink and 1.5 Gbps uplink. • Carrier aggregation, allowing the combination of up to five separate carriers to enable bandwidths of up to 100 MHz. • Relay nodes to support HetNets containing a wide variety of cell sizes. • Enhanced inter-cell interference coordination (eICIC) to improve performance toward the edge of cells
	Release 9	• Evolved multimedia broadcast and multicast service (eMBMS) for the efficient delivery of the same multimedia content to multiple destinations. • Location services (LCS) to pinpoint the location of a mobile device by using assisted GPS (A-GPS), observed time difference of arrival (OTDOA), and enhanced cell-ID (E-CID). • Dual layer beamforming

	Release 8	• Up to 300 Mbps downlink and 75 Mbps uplink. • Latency as low as 10 ms. • Bandwidth sized in 1.4, 3, 5, 10, 15, or 20 MHz blocks to allow for a variety of deployment scenarios. • Orthogonal frequency domain multiple access (OFDMA) downlink. • Single-carrier frequency domain multiple access (SC-FDMA) uplink. • Multiple-input multiple-output (MIMO) antennas. • Flat radio network architecture, with no equivalent to the GSM base station controller (BSC) or UMTS RNC, and functionality distributed among the eNBs). • All IP core network, the SAE

A. Carrier Aggregation

Carrier aggregation involves the combination of different carrier components of multiple frequency bands to increase transmission bandwidths. A sufficiently wide spectrum bandwidth is required to achieve higher network throughput. However, available frequency spectrum in Nigeria is unevenly distributed. LTE-Advanced readily supports both intra-band and inter-band carrier aggregation for bandwidth extension up to 100 MHz in multiple frequency bands. In cases where contiguous spectrum is not available, mobile network operators can adopt the intra-band non-contiguous approach wherein the carriers are of different spectrum bands. Intra-band non-contiguous carrier aggregation encourages frequency reuse for improved service delivery. Carrier aggregation introduces significant flexibility that satisfies the IMT-Advanced requirements by adjusting the configuration of the carriers to support both LTE and LTE-Advanced mobile devices.

Besides bandwidth extension, carrier aggregation helps to significantly reduce inter-cell interference, improve handover performance, save energy, and achieve load balancing. A cellular network with minimum inter-cell interference improves network coverage, particularly at the cell edge. With carrier aggregation, a smooth handover among the eNBs can be achieved. Also, turning off the carriers at off-peak periods will reduce the energy consumed by the radio access network. The mobile devices that are connected to the eNBs unevenly can be reconfigured for load balancing.

3GPP has significantly modified the functionalities of the LTE protocol stack in order to maximize the benefits listed above. The Radio Resource Control (RRC) protocol [17] will now maintain a single connection regardless of the number of carrier components employed by the mobile device. At the Medium Access Control (MAC) protocol [18] layer, each component carrier is entitled to a single hybrid-ARQ entity. Also, without spatial multiplexing, only one transport block is sent per transmission time interval (TTI) from each serving cell. Multiple timing advance was introduced to compensate for propagation delay in mobile devices.

B. Advanced MIMO

The MIMO technology is primarily designed to achieve higher data rates in wireless communication systems through the use of multiple antennas both at the transmitter and the receiver. Spatial diversity, spatial multiplexing, beamforming, and Spatial Division Multiple Access (SDMA) constitute the basic modes of operation of MIMO techniques in LTE systems. Spatial diversity, spatial multiplexing, and beamforming are used for Single-User MIMO (SU-MIMO) scenarios while multiple users are served on the same frequency and time resources using the SDMA.

In LTE systems, maximum antenna configurations of 2 x 2 and 4 x 4 are allowed in the uplink and downlink respectively. Spatial diversity involves the transmission of precoded versions of the same data stream using multiple antennas at the transmitter. The signals received in diversity mode by multiple receiving antennas are combined in different ways to achieve better signal-to-noise ratio (SNIR). Spatial diversity technique generally improves the reliability of the transmission. Simultaneous transmission of different data streams through the use of multiple antennas at the transmitter and the receiver is regarded as spatial multiplexing. In order to achieve orthogonality in data streams, precoding is performed at the transmitter. This increases the data throughput of mobile users. LTE systems support both codebook-based and non-codebook-based beamforming methods to improve the directivity of the transmission. This will enhance network performance at the cell edges. Also, LTE supports Multiple-User MIMO (MU-MIMO) based on codebook precoding. By co-scheduling different users on the same frequency and time resources, the capacity of the cellular network can be significantly increased.

Advances in MIMO technology are targeted at achieving significant improvement in the data rates of LTE-Advanced systems [19-21]. A maximum antenna configuration of 8 x 8 in the downlink and 4 x 4 in the uplink is allowed in LTE-Advanced systems.

Table 3: Network Performance Requirements of LTE, IMT-Advanced, and LTE-Advanced

	Antenna	LTE Release 8	IMT-Advanced	LTE-Advanced
Peak Data Rate		300 Mbps (DL) 75 Mbps (UL)	100 Mbps (high mobility) 1 Gbps (low mobility)	1 Gbps (DL) 500 Mbps (UL)
Peak Spectrum Efficiency		15 (DL) 3.75 (UL)	15 (DL) 6.75 (UL)	30 (DL) 15 (UL)
Capacity (bps/Hz/ Cell)	2 x 2 (DL)	1.69	-	2.4
	4 x 2 (DL)	1.87	2.2	2.6
	4 x 4 (DL)	2.67	-	3.7
	1 x 2 (UL)	0.74	-	1.2
	2 x 4 (UL)	-	1.4	2.0
Cell-Edge User Throughput (bps/Hz/Cell/User)	2 x 2 (DL)	0.05	-	0.07
	4 x 2 (DL)	0.06	0.06	0.09
	4 x 4 (DL)	0.08	-	0.12
	1 x 2 (UL)	0.024	-	0.04
	2 x 4 (UL)	-	0.03	0.07

Table 3 compares the requirements of LTE, IMT-Advanced, and LTE-Advanced. A dynamic framework for SU-MIMO/MU-MIMO switching at the base station was also introduced. This will allow a more transparent adaptation of the mode of operation to higher layers in a fast timescale. MU-MIMO have been identified as the main driver of meeting the spectral efficiency targets in LTE-Advanced systems.

In the downlink, enhanced SU-MIMO spatial multiplexing of up to eight transmission layers will increase spectral efficiency and data rates, particularly for users around the center of the cell. The increased number of antennas and the introduction of DM-RS based precoding has been to the advantage of MU-MIMO, particularly for high rank transmission with scattered users' locations since SU-MIMO performance is limited by antenna design constraints at the terminal. Multi-user interference minimization approaches include zero forcing [22], maximum signal-to-leakage ratio [23], and block diagonalization [24]. With a maximum antenna configuration of 4 x 4 in the uplink, LTE-Advanced supports spatial multiplexing of up to four layers and transmit diversity in the control channel and the data channel respectively.

Full Dimension MIMO (FD-MIMO), a new feature identified in 3GPP Release 12, is a potential MIMO technology that will greatly enhance the network capacity of LTE-Advanced. In this technology, a large two-dimensional array of transmit antenna ports (16, 32, or 64) at the base station makes use of Active Antenna System (AAS) technology to provide accurate 3D beamforming to targeted users [25, 26]. FD-MIMO achieves a higher degree of flexibility than conventional beamforming by allowing the transmission beams to be steered by the base station in both the azimuth and elevation dimensions. Other benefits of FD-MIMO include reduction of cable loss between the RF components and the antenna, reduced site costs of both maintenance and rental, and improved beamforming capabilities in the azimuth and elevation planes for a full utilization of the spatial domain [27]. Likewise, 3D beamforming based on AAS is an efficient way to expand capacity and boost coverage. Energy can be also saved by focusing the transmission power.

Massive MIMO comprises of antenna arrays with a large number of antenna elements. Such robust antenna configuration will accommodate a large number of users, minimize interference, and improve network performance at cell edges [28]. Also, massive MIMO can be exploited to optimize energy consumption to reduce costs [29]. This technology offers compensation for path loss in very high frequencies.

C. CoMP Transmission and Reception

CoMP exploits the benefits of downlink cooperation of multiple cell sites to improve service delivery to mobile users that are close to the cell edges. The utilization of CoMP in LTE-Advanced is a promising approach for higher system efficiency, improved cell-edge performance, and better network coverage in LTE-Advanced networks [30, 31]. In LTE-Advanced systems, the cooperation can be within the same base station (intra-site) or among different base stations (inter-site). In addition, the deployment scenario is not limited to homogeneous environments; rather the cell can equally be of varying types and sizes. Possible use cases of CoMP include: intra-eNB CoMP in homogeneous environment; inter-eNB CoMP in homogeneous environment; inter-cell CoMP in heterogeneous environment; and distributed antenna system with shared cell identity.

Downlink CoMP transmission occurs when different base stations are coordinated to transmit signals to the same user(s). This technique improves the received signal quality at the mobile device and reduce the co-channel interference [32]. Coordinated scheduling/beamforming, dynamic point selection, and joint transmission are the common methods of downlink CoMP transmission in LTE-advanced. Coordinated scheduling or coordinated beamforming is most appropriate when the amount of information that needs to be exchanged is small. Here, each user is served by a single cell while scheduling decisions and precoding for beamforming is coordinated among several base stations. This minimizes inter-cell interference and increases data throughput. On the other hand, transmission to a specific user only occur from one point at a time in dynamic point selection approach. For joint transmission method, data meant for a specific user is simultaneously transmitted from multiple sites to improve the quality of received signal in a time-frequency resource.

However, the uplink CoMP techniques is targeted at increasing the uplink data rates at cell-edges. These techniques considers the reception of signals transmitted by users located at different places. LTE-Advanced systems support both coordinated scheduling and joint reception. Uplink coordinated scheduling for mobile device precoding and scheduling are decided among a set of receiving base stations to minimize interference. However, in joint reception, the data received at different base stations must be exchanged through the backhaul link to eliminate interference and improve network performance.

D. Relay Nodes

A relay node receives and transfers information to a donor base station via the wireless connection established using the new U_n interface. This is aimed at improving the network performance. This technology, supported in LTE-Advanced, can drastically increase broadband access in developing countries where conventional backhaul links are not readily affordable. Mobile network operators in low-income countries can exploit this technology to reduce both their capital and operational expenses as the cost of site acquisition is eliminated. Also, Emerging economies are faced with the challenge of unreliable power grid. Therefore, the utilization of relay nodes for broadband access is considered appropriate for the region because of its energy saving capability. Furthermore, the location of relay nodes at cell edges will increase the network throughput at the region. By deploying relay nodes for indoor scenarios, signal strengths of mobile devices can be enhanced, thereby increasing their respective data rates.

Introduction of relays in LTE-Advanced can be harnessed to overcome the problem of site acquisition during deployment of networks in new areas. Due to ease of deployment, relays can also be used for temporary network deployments. The use of relays at cell edges will boost throughput. Furthermore, a co-located relay can improve mobility performance for high speed scenarios. 3GPP considers Type 1 and Type 1a of relay nodes to be most appropriate for the 4G technology [33, 34]. The introduction of relays in LTE-Advanced has changed the overall network architecture of the cellular system. Network architecture named *Alt 2* was favoured by 3GPP for to support relays at the radio access network and the core network of LTE-Advanced [35].

3GPP LTE Release 12 focuses more attention on mobile relays. Mobile relays are very useful in high-speed mobility use cases [36]. Mobile relays can be installed directly in moving vehicles and trains. The base station is connected to a wireless backhaul through an external antenna while the users within the moving vehicle connect to a wireless access through an internal antenna. Mobile relays supports efficient handover procedures.

E. HetNets

HetNet is a network deployment strategy which comprises of several low-power small cells (microcells, picocells, femtocells, metrocells) underlaid on existing macrocell to increase overall system capacity. In this arrangement, each of the cells maintains its own transmission power and backhaul technology. To achieve higher uplink data rate, users are linked with the base station with the minimum path loss. With the view of increasing the overall network capacity, users are assigned to the small cell base station when the system load is high. On the other hand at low loads, the conventional approach of associating to the base stations with the best downlink signal strength or SINR helps achieve downlink higher data rates.

However, inter-cell interference (ICI) can affect the performance of heterogeneous networks if not properly managed. The use different carrier frequencies for different cell layers is a common approach of overcoming ICI in LTE-Advanced [37]. Although this approach is effective, it is at the cost of utilizing more frequency resources which are limited. In cases where cell layers operate at the same carrier frequency, power control techniques must be utilized to reduce the transmission power of at least one of the cell layers. This will reduce the interference on other layers. Boudreau *et al.* [38] proposed adaptive fractional frequency reuse, spatial antenna techniques including MIMO and SDMA, and adaptive beamforming for ICI cancellation.

F. SON

Mobile network operators in developing countries can take advantage of the automation capabilities of SON to cut down operational expenses and speed up network processes. SON facilitates self-configuration [39-41] and self-healing

[42] of base stations. Automation of the reconfiguration of system, network and radio related parameters enables efficient coverage and capacity optimization, load balancing, handover parameter optimization, interference control, and RACH optimization in LTE-Advanced [43].

CONCLUSION

Emerging economies are plagued with quite a number of extreme factors which hampers the rapid penetration of broadband in the region. These factors include: a majority low-Average Revenue per User (ARPU) multi-SIM subscriber base; diverse settlement patterns ranging from low density rural areas to rapidly expanding ultra-dense urban/periurban informal settlements; highly unreliable power grid networks; pure mobile networks built without existing wired networks; and rigid regulatory frameworks that stifle business and service innovations.

However, new technologies have demonstrated tremendous capacity towards accelerating human progress, bridging the digital divide, and developing knowledge societies. The evolution of LTE towards LTE-Advanced is primarily driven by the need to provide rapid mobile broadband in a cost efficient way, and equally achieve higher peak data rates, peak spectral efficiency, and scalable bandwidth. Carrier aggregation offers the flexibility of supporting multiple frequency bands to provide wider bandwidths, reduce inter-cell interference, improve handover, save energy, and perform load balancing. Advanced MIMO achieves very high data rates through spatial diversity, spatial multiplexing, beamforming, and spatial division multiple access. CoMP improves system efficiency, cell-edge throughput, and network coverage. Mobile network operators may reduce capital and operating expenditures using relay nodes. Deployment of HetNets increases system capacity. SON introduces network function automation for faster execution of processes.

Recent advances in LTE-Advanced technology, as highlighted in 3GPP Release 13, include: programming of mission critical applications; carrier aggregation [up to 32 separate carriers, up to 640 MHz bandwidth]; LTE operation in a combination of licensed and unlicensed spectrum; inter-site carrier aggregation; enhanced M2M communication; interworking with Wi-Fi, licensed assisted access (at 5 GHz); indoor positioning; single-cell point to multipoint; new antenna techniques [high-order MIMO systems with up to 64 antenna ports]; and advanced receivers to maximize the potential of large cells.

Competing Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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