Re-Farming of Existing 1800 MHz GSM Spectrum for LTE/LTE-A Deployment in Ghana*

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Abstract

Communication has been an essential need of human kinds from prehistoric time till date. The ever-increasing needs have led to the development of new standards and technologies. These technologies strive on the limitations of radio spectrum. Licensing of this spectrum is costly to operators and significantly affects their capital expenditure. Regulatory authorities, like the National Communications Authority (NCA), also face much bigger challenge of availability of spectrum. This research proposed re-farming of 1800 MHz GSM spectrum for Third Generation Partnership Project's Long Term Evolution (LTE) deployment in Ghana is given. Bandwidths of 10, 15, and 20 MHz within the 1800 MHz spectrum were simulated. This is to validate how compliant the proposal will be with regard to practical standards of spectral efficiency and throughput in the LTE market. The results of the simulation show that for bandwidths of 10, 15, and 20 MHz, the maximum and minimum spectral efficiency achieved are 3.19, 3.23 and 3.06 bits/s/Hz and 1.02, 1.06, and 1.06 bits/s/Hz, respectively, with speeds varied from 0 to 200 km/h. Throughput per cell was good across all three bandwidths with 20 MHz band recording the highest of 44.67 Mbps at 0 km/h and 14.09 Mbps at 200 km/h. User Equipment throughput at worst ratio conditions ranged from 2.02 Mbps to 0.35 Mbps for 20 MHz bandwidth for 0 and 200 km/h, respectively. These results compared favourably with LTE standards and data from actual deployed networks across the globe. The findings of this research will be meaningful to stakeholders like the NCA, telecommunication companies in Ghana and other decision making/interested parties in the spectrum management and licensing in Ghana.

Keywords: LTE/LTE-A, Re-farming, 1800 MHz GSM Spectrum, Ghana

1 Introduction

The need for communication is ingrained in humans and various systems have been developed to accomplish communication ubiquity. The ability to convey information quickly, accurately, and efficiently has always been one of the main focuses driving human innovation. Prehistoric communications involve the use of talking drums, fire, horns and smoke signals in Africa, the Americas and Asia. From prehistoric man with their signal fires to the smartphone-wielding executives of today, communication still remains a key for survival and success. The history of telecommunication exemplifies this never-ending push for progress as it increasingly parallels human growth, becoming more widespread and efficient as the development of modern civilisation unfolds.

First Generation (1G) mobile system were analogue voice-based and established the foundation of mobile networks. Spectrum licensing, frequency reuse and mobile networks were among the new discoveries that characterised the 1G. However, this incredible technology was limited due to the need for large gap of spectrum between users to avoid interference. It supports only one user per channel, limited capacity due to inefficient use of spectrum, limited scalability and high cost. As a solution to these, the second Generation (2G) of mobile network were developed under the concept of Global System for Mobile Communication (GSM) for Europe and later accepted by other parts of the world. GSM supports multiple users per channel, efficient use of spectrum, scalable and deliver more secure signal. Code Division Multiple Access (CDMA) is the counter part of GSM develop for United States of America. The need for data services led to the introduction of General Packet Radio Service (GPRS) and Enhanced Data for GSM Evolution (EDGE) in the 2G domain.

After the standardisation of the GSM system, the continuous evolution of telecommunication standard drove the need for quality and low latency voice, data and multimedia services. These led to the introduction of the 3rd Generation (3G) of mobile network; officially given the name Universal Mobile Telecommunications System (UMTS) by the Third Generation Partnership Project (3GPP). UMTS uses Wideband Code Division Multiple Access (WCDMA) technology in its deployment. UMTS was further improved to give higher data rates under the name High Speed Packet Access (HSPA). UMTS could not live to the developing demand for higher data rates and low latency, hence the 3GPP search for newer and improved standards to meet these requirements. The 4th Generation (4G) of mobile networks, known as the Long Term Evolution (LTE) and Long Term Evolution-Advanced (LTE-A) were designed to give high data rates and multimedia services by the 3GPP. Table 1 shows evolution

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time of various generations of cellular technologies in Ghana.

During these evolution processes, both the core and radio access networks have been greatly impacted. The legacy GSM and UMTS network elements have been greatly modified to pave way for LTE. LTE and its radio access technology, called Evolved Universal Terrestrial Radio Access Network (E-UTRAN), are expected to provide high speed data transmission, low latency, and high spectral efficiency as well as support for high mobility.

GSMA reports of 4.8 billion unique subscribers for mobile networks globally and forecasts regional penetration from 50% in Sub-Saharan Africa to 87% in Europe by 2020. The generational shift from voice to data connections continues to gain momentum with broadband connections accounting for 55% of total connections in 2016. Fig. 1 shows global connections by technology excluding Machine-to-Machine (M2M) connections. 4G connection is forecasted to be almost double between 2016 and 2020 from 23% to 41% (Anon., 2017a).

According to World Bank, developing countries are adopting internet and related technologies faster than previous technological innovations such as electricity. There is a steady rise in acquisition of mobile phones in developing countries with an average of 8 in 10 individuals owning a mobile phone. Fig. 2 gives a summary of digital divide across demographic groups in Africa (Anon., 2016a).

Ericsson projects LTE to be the dominant mobile access technology globally by 2019. Further, LTE and WCDMA/HSPA subscription will be more than double the GSM/EDGE-only subscriptions in 2021. Fig. 3 projects mobile subscription by technology (Anon., 2016b).

Ghana is not left out of this growth in cellular technologies. NCA reports of almost 100% rise in mobile data subscriptions between 2013 and 2017. Table 2 gives detail of mobile subscription from 2013 to 2017 per telecommunication companies in Ghana (Anon., 2017b). There are nine operators in the telecommunication market of Ghana. Six multinational mobile cellular and three broad band data operators. Table 3 summaries the technologies deployed by these operators (Anon., 2017b).

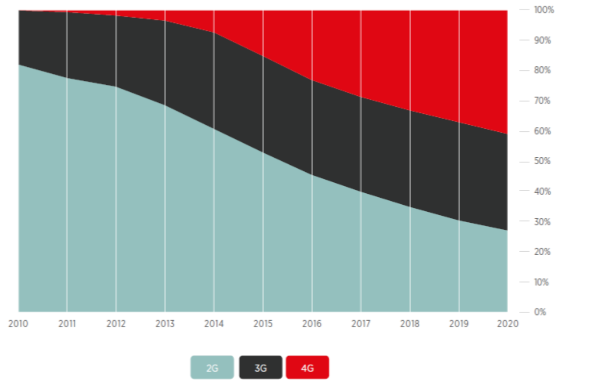

Fig. 1 Global Connections by Technology excluding M2M

Table 1 Evolution of Cellular Technologies in Ghana

Generation	Technology	Data Rates
1G (1980s) 1992 in Ghana	Analogue	2.4 kbps
2G (1990s) 1996 in Ghana	GSM/CDMA	9.6 kbps
	GPRS	56 - 114 kbps
	EDGE	up to 237 kbps
3G (2000s) 2008 in Ghana	UMTS	14.4 Mbps
	HSPA	21 Mbps
4G (2010s) 2014 in Ghana	LTE	100 Mbps
	LTE-A	Up to 1 Gbps

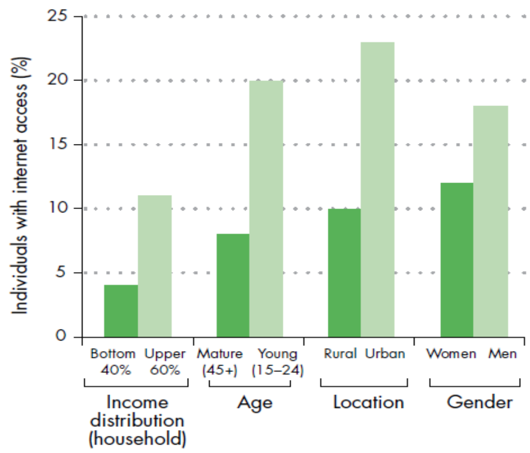

Fig. 2 Digital Divide across Demographic Groups in Africa

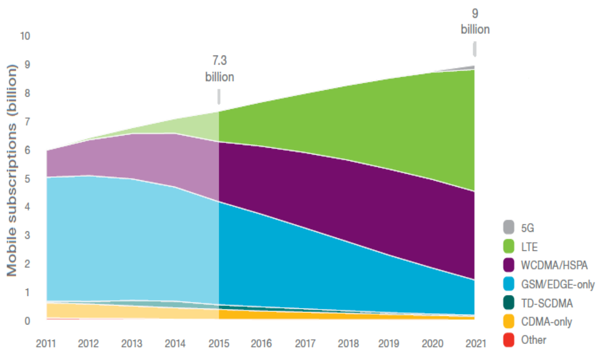

Fig. 3 Mobile Subscription by Technology

Table 2 Mobile Data Subscriptions in Ghana from 2013 to January 2017

Year	MTN	Tigo	Vodafone	Airtel	Expresso	Glo	Surfline	Broadband Home	Blu	Total	Net Addition	Growth (%)
2010	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*NIO*	*DNA*	*NIO*	0	0	0.00%
2011	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*NIO*	*DNA*	*NIO*	0	0	0.00%
2012	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*DNA*	*NIO*	*DNA*	*NIO*	0	0	0.00%
2013	4,876,302	1,577,348	1,915,300	1,915,300	38,180	301,283	*NIO*	*DNA*	*NIO*	10,623,713	10,623,713	0.00%
2014	8,004,721	2,097,167	2,868,249	2,130,033	37,331	668,424	*DNA*	*DNA*	*DNA*	15,805,925	5,182,212	48.78%
2015	8,634,914	2,732,863	3,316,343	2,879,431	48,178	419,459	*DNA*	*DNA*	*DNA*	18,031,188	2,225,263	14.08%
2016	10,226,520	2,725,489	3,474,090	2,902,009	36,672	277,372	76,919	26,402	1,081	19,746,554	1,715,366	7.97%
Jan 2017	10,505,087	2,708,016	3,579,362	2,859,238	35,572	272,084	77,306	26,394	1,051	20,064,110	317,556	1.61%

Legend
DNA - Data Not Available
NIO - Not in Operation

Table 3 Telecommunication Operator and Technologies Deployed in Ghana

Company	Technology
Airtel Ghana	GPRS/EDGE/3G/HSPA
Broad Band home	WIMAX
BLU	TD-LTE
Expresso	CDMA-EVDO
Glo Ghana	GPRS/EDGE/3G/HSPA
Millicom (tiGO)	GPRS/EDGE/3G/HSPA
Scancom Ghana (MTN)	GPRS/EDGE/3G/HSPA/FD-LTE
Surfline	FD-LTE
Vodafone	GPRS/EDGE/3G/HSPA

All these technological development strive on a limited resource called Radio Frequency. The radio spectrum is the range of frequencies used for wireless applications such as broadcast television and radio, cell phones, satellite radio and TV, wireless computer networks, Bluetooth, GPS, Police Dispatch, and countless other general and specialised applications that we use every day. It is difficult for these applications to utilise the same frequency at the same time. For most part, these will cause interference between nearby devices on same frequency. As a solution to this, the radio frequency is whittled into different portions, and each portion is allocated to one or more services that may be able to co-exist with each other.

The explosion of mobile traffic puts immense pressure on mobile networks to deliver the necessary capacity and performance. Mobile network operators and their suppliers require a variety of strategies to satisfy demand, including additional spectrum, new technologies, small cells and offloading traffic to alternative access networks. To this regard, right level of mobile industry regulation is crucial to the success of mobile services, for example in relation to competition, mobile number portability and coverage targets. A particularly important aspect of regulation is the control of wireless spectrum. Electromagnetic spectrum is a scarce resource.

In Ghana, the National Communications Authority (NCA) is charged with the regulation and allocations of spectrums. NCA reports of migration of all communications in Ghana to digital, i.e. video, voice, data, fixed and wireless. The growth of wireless data has been exponential and projected to continue for at least the next 10 years. There is massive spectrum deficit and stagnant revenues due to this growth and hence require both technical and political breakthrough for success of the industry (Djakwah, 2016).

The LTE and its advanced form came with much demand for higher bandwidth and higher centre frequencies. Due to the limited nature of Radio spectrum for telecommunication purposes, regulatory bodies are now faced with a challenge of either denying new service providers' licenses or reducing spectrum for existing companies to enable new ones to operate. Spectrum reduction comes with degradation in services rendered to customers. The release of new spectrum and the re-farming of existing spectrum for use by LTE and 4G wireless technologies will be critical to the successful growth of mobile broadband services over the coming years. Due to fast data traffic growth and decline in voice services, introduction of Voice over LTE (VoLTE), and need for good coverage and susceptible signal, it is necessary to re-farm available GSM spectrum for LTE deployment. 1800 MHz band is the most preferred candidate due to its ready availability in many regions, balanced capabilities to provide both capacity and coverage and technologically available for LTE.

Spectrum licensing is usually costly to cellular operators and greatly affects their Capital Expenditure (CAPEX). In 2016, India auctioned a spectrum in the 700 MHz band for LTE at US$ 1.82 billion while South Africa auctioned the 700/800/2600 MHz spectra for US$ 213 million. MTN bought a spectrum in the 800 MHz for LTE in Ghana at US$ 67.5 million whilst its competitors in the broadband wireless space had their licenses at a far cheaper price of US$ 6 million each. Other three companies registered to compete with MTN for the LTE slot in the 800 MHz failed to show up for the auction after paying a non-refundable participation fees of US$ 64 100. Other operators such as Vodafone, Tigo and Airtel could not apply for the license due to the high cost of the spectrum (Anon., 2017c).

This research seeks to look into the possibility of re-farming 1800 MHz spectrum assigned to GSM in Ghana for deployment of LTE and LTE-A in Ghana.

2 Resources and Methods Used

The 3GPP release 8 for LTE specifications introduces the evolution of 3G technology. LTE evolved the physical layer and the core networks into a novel reformed system with much improvements over previous technologies such UMTS and HSPA. The purpose of this evolution in Radio Access Networks (RAN) system is to improve upon quality of service and more multi-user flexibility than previous network deployments. Besides the novel physical layer, LTE contains other remarkable innovations. These includes the redevelopment of the system architecture called SAE, the definition of network self-organisation and the introduction of home base stations (Dahlman *et al*., 2010).

Simulations are used to test and optimise algorithms and procedures of new technologies. LTE is not an exception to this process. LTE development and standardisation saw the simulation of both physical layer (link-level) and the network (system-level). Investigations of issues such as MIMO gains, Adaptive Modulation and Coding (AMC) feedback, Channel encoding and decoding models are catered for by the link-level simulations, while system-level simulations are centred on network-related issues such as scheduling, mobility handling and interference management (Ikuno *et al*., 2010).

2.1 System Simulators

Optimisation of LTE network is essential to both industry and academia communities. To enable commercial deployment of LTE, various equipment vendors have developed their own proprietary LTE simulator solutions. Further, other research and institutions of higher learning have also developed such simulators in which source codes are not available to the public. Examples of simulators developed for purposes of testing LTE are Network Simulator (NS) (Piro *et al*., 2011a), open source framework to simulate LTE networks (LTE-Sim) (Piro *et al*., 2011b) and the Vienna LTE/LTE-A Simulator (Abreu *et al*., 2015).

The Vienna LTE Simulator has been used as a reference for algorithms validation, generation of LTE signals that are realistic in nature and as a reference for LTE-compliant measurement (Mehlführer *et al*., 2011).

The Vienna LTE Simulator was selected for this thesis due to its use of scripting and mathematical language processor and Object-Oriented Paradigm in MATLAB/Simulink. Also it has improved computational load, allows addition of new modules (capable of adding and deleting users during simulation) and implementation of a scheduling policy for voice cases.

2.2 Simulation Parameters

This section gives a description of the simulation scenarios and parameters used for the simulation. Various simulations were run with same band frequency (1.8 GHz) but varying bandwidths and speeds.

Table 4 shows the simulation parameters for 20, 15 and 10 MHz bandwidths, respectively. UEs are randomly positioned in the cell. We assume fully loaded situation for each simulation where all resource blocks are used in each cell.

Table 4 Simulation Parameters as Employed for the Simulation Runtime Evaluation

Parameter	Value
Frequency (GHz)	1.8
Bandwidth (MHz)	20, 15, and 10
Nr. of eNodeB	7
UE Speed (km/h)	0 - 200
Network Geometry	Regular Hexagonal Grid
Nr. UE per Sector	10
Shadow Fading	Claussen Space-correlated
Feedback Channel Delay (TTI)	3
Simulation Time (TTI)	100
Minimum Coupling Loss (dB)	70
Scheduler	Round Robin DB
Nr. Transmitters and Receivers	4 × 4
Macroscopic Path Loss Model	Suburban
eNodeB Power (W)	40
Traffic Model	Full Buffer
Receiver Noise Figure (dB)	9
Thermal Noise Density (dBm/Hz)	-174
Distribution of UE	Spatial Distribution

For the scenario simulated, 1.8 GHz was selected as carrier frequency with 20, 15 and 10 MHz as system bandwidths, 7 eNodeB each with three sectors, UEs speed varying from 0 km/h (0 m/s) to 200 km/h (55.6 m/s), regular hexagonal grid as network geometry, claussen space-correlated as shadow fading, feedback channel delay of 3 Transmission Time Intervals (TTI), 100 TTIs of simulation, 10 UEs per sector, Tri-sector tilted with intra site CoMP configuration, Round robin DB CoMP scheduler, and a minimum coupling loss of 70 dB.

The simulations were run on HP Intel Core i7 CPU with a RAM of 8 GB, 64-bit OS, x64-based processor with Windows 8.1 operating system.

2.3 Simulation Results

2.3.1 Spectral Efficiency

Spectrum efficiency is the optimised use of spectrum or bandwidth so that the maximum amount of data can be transmitted with the fewest transmission errors. In a cellular telephone network, spectrum efficiency equates to the maximum number of users per cell that can be provided while maintaining an acceptable Quality of Service (QoS) (Rouse, 2017). It is a measure of the quantities of users that can be simultaneously supported by limited radio frequency bandwidth in a defined geographical area. It is measured in bits per symbol per Hz per unit area, in bit/s/Hz per cell or site.

Practically, there is a hard limit to how much data can be transmitted in a given bandwidth; however, Shannon-Hartley theorem tries to give a maximum rate at which information can be transmitted over a communication channel of a specified bandwidth in the presence of noise. This is usually referred to as the Shannon limit (Hranac, 2012).

Among the main objectives specified for LTE technology include spectral bandwidth from 1.4 to 20 MHz, Spectral efficiency three to four times better than HSPA release 6 in the downlink and two to three times better than HSPA release 6 in the uplink. These specifications are summarised in Table 5 for different scenarios of LTE and LTE-Advanced (Korowajczuk, 2011).

Table 5 LTE Spectral Efficiency Objectives for ITU

ITU Scenario	Downlink		Uplink	
	LTE	*LTE-A*	*LTE*	*LTE-A*
Indoor Hotspot	3.0	5.0	2.3	4.0
Urban Micro	2.6	2.6	1.8	2.2
Urban Macro	2.2	2.8	1.4	1.8
Rural Macro	1.1	2.6	0.7	2.0

2.3.2 Throughput

Throughput refers to the amount of successful data delivery over time within a specific digital setup. It is used to identify bandwidth consumption rates. This data may be delivered over a physical or logical link or pass through another network node. Throughput is usually measured in bits per second or data packet per time slot.

LTE throughput depends on the following parameters:

(i) Bandwidth: According to 3GPP specifications, LTE channel bandwidth can be 1.4, 3, 5, 10, 15 and 20 MHz. The wider the bandwidth the higher the throughput. All available spectrum is divided into Resource Blocks (RB). Table 6 represents a map of bandwidth on number of available RB.

(ii) Channel quality: Radio conditions impact user bit rates. The better the radio conditions the higher the available throughput and vice versa. UE measures radio channel quality and sends CQI to eNodeB. eNodeB selects MCS based on radio conditions. The higher the MCS, the more bits can be transmitted per unit time. Also depending on radio conditions, various multi-antenna techniques can be applied, which increase throughput as well.

(iii) Network load: Available radio resource are divided among active subscribers. This means, the more subscribers are active and receive/transmit data, the less resources are allocated to a given subscriber. It also depends on subscriber and connection (bearer in terms of LTE) priorities.

Table 6 LTE Bandwidths with Associated Resource Blocks

	Channel Bandwidth, MHz					
	1.4	3	5	10	15	20
Number of RB	6	15	25	50	75	100

3 Results and Discussion

This section presents the results of the simulations and its comparison with statistics from existing deployed LTE networks and standards. It consists of results and discussions and a brief summary of findings from the simulations.

For a particular frequency and bandwidth to be used for LTE deployment, they must at least satisfy some basic requirements of LTE which include but not limited to spectral efficiency, throughput and SINR. To ascertain this compliance, simulations were run by varying the following parameters at proposed spectrum frequency of 1.8 GHz:

(i) Speed of UE from 0 km/h to 200 km/h at a step value of 10 km/h; and

(ii) Bandwidth; 10, 15 and 20 MHz bandwidths were tested for each speed step selected.

The following statistics were extracted from the simulation traces for analysis; spectral efficiency, throughput and SINR curves.

3.1 Spectral Efficiency

From the simulation results, spectral efficiency decreases with increasing speed of UE, these ranged from 3.23 bit/s/Hz to 1.02 bit/s/Hz for 10, 15 and 20 MHz bandwidths with slight difference between them. Fig. 4 shows the comparison of spectral efficiency as speed of UE was increased from 0 to 200 km/h. It shows that the spectral efficiency decreased with increasing speed of UE.

These spectral efficiency results are in consonance with the 3GPP release 8 standards, which targets spectral efficiency for downlink and uplink to be 5 bit/s/Hz and 2.5 bit/s/Hz, respectively for LTE 5, 10 and 20 MHz bandwidth channels as reported by Cory (2011).

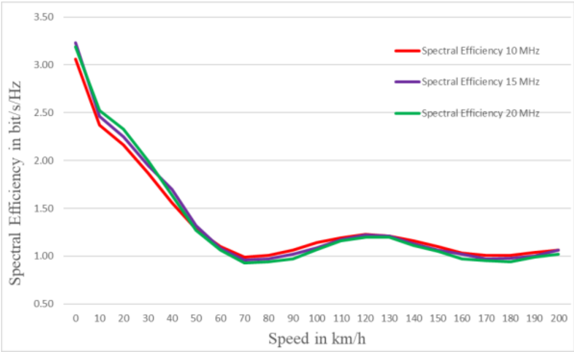

Fig. 4 Spectral Efficiency as a function of Speed for 10, 15 and 20 MHz Bandwidths

3.2 Throughput

From the simulation results, cell throughput for stationary UEs were 21.47, 33.96 and 44.67 Mbps for 10, 15 and 20 MHz bandwidths, respectively. These throughput decrease with increase in UE speed. However, there was a marginal increase in throughput between 80 to 140 km/h. This increase is to give better feel of experience to high mobility UE, since various highways and motorways have speed limits in this range. Fig. 5 shows Cell throughput for 10, 15 and 20 MHz bandwidth as a function of speed. A summary of stationary, optimum and high mobility scenario cell throughput is shown in Table 7.

Similarly, peak UE throughput for stationary UEs were 3.61, 5.51 and 7.32 Mbps for 10, 15 and 20 MHz bandwidths, respectively. Optimum throughput was realised between 80 to 140 km/h. Fig. 6 shows peak UE throughput for 10, 15 and 20 MHz bandwidth as a function of speed. Also, Fig. 7 and Fig. 8 show average UE throughput and cell edge UE throughput respectively for 10, 15 and 20 MHz bandwidths as a function of speed. The stationary average UE throughput for 10, 15 and 20 MHz were 2.15, 3.40 and 4.47 Mbps whiles stationary cell edge UE throughput for 10, 15 and 20 MHz bandwidths were 0.93, 1.60 and 2.02 Mbps. There was marginal increase in both average and cell edge throughputs between 80 to 140 km/h.

Comparatively, the throughput values for 10, 15 and 20 MHz bandwidths tested fall within the global practical values of download speeds (3 to 45 Mbps) even with high speed mobility of 200 km/h as shown in Table 7.

Table 7 Cell Throughput for Stationary, Optimum and Very High Mobility UE

BW (MHz)	Download speed in Mbps							
	0 km/h	*50 km/h*	*100 km/h*	*110 km/h*	*120 km/h*	*130 km/h*	*140 km/h*	*200 km/h*
10	21.47	8.9	7.94	8.28	8.57	8.41	8.04	7.39
15	33.96	13.76	11.33	12.16	12.77	12.56	11.8	11.03
20	44.67	17.65	14.89	16.12	16.64	16.65	15.36	14.09

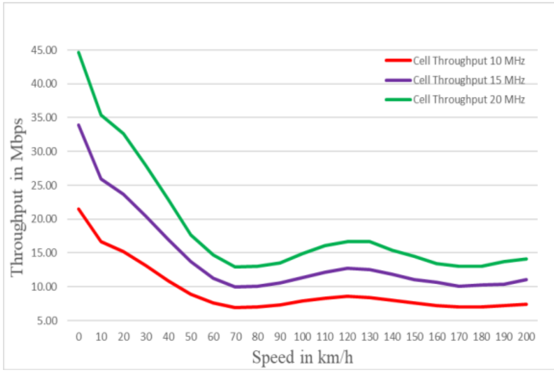

Fig. 5 Cell Throughput as a function of Speed for 10, 15 and 20 MHz Bandwidth

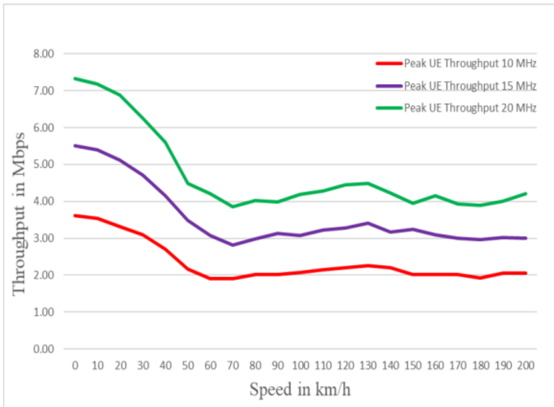

Fig. 6 Peak UE Throughput as a function of Speed for 10, 15 and 20 MHz Bandwidth

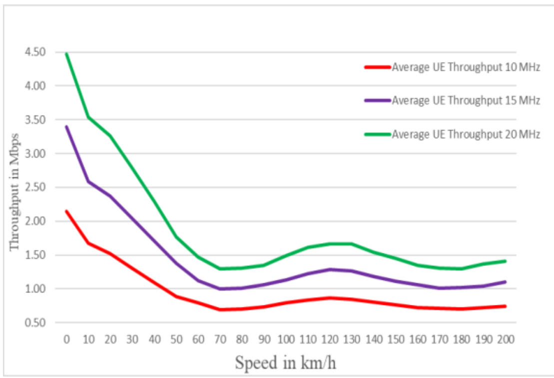

Fig. 7 Average UE Throughput as a function of Speed for 10, 15 and 20 MHz Bandwidth

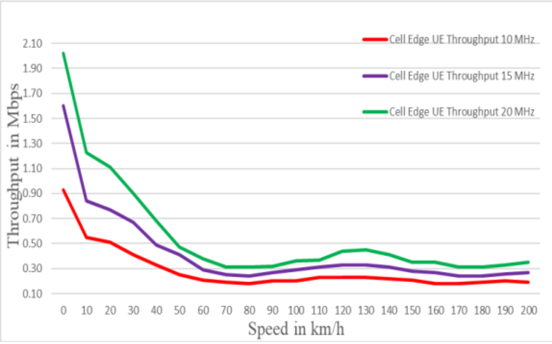

Fig. 8 Cell Edge UE Throughput as a function of Speed for 10, 15 and 20 MHz Bandwidth

4 Conclusions and Recommendations

A well-managed spectrum allocation has proven to be part of the nexus factors in accelerated deployment of new cellular technologies. Regulatory authorities like the NCA in Ghana have improved upon their operations in allocating spectrum, however, in order to meet higher demands for new spectrum, paradigm shift towards re-use of existing spectrum is eminent. The re-farmed spectrum needs to meet capacity and quality of service requirements for the new services utilising it.

This paper reported on stimulating the 1800 MHz spectrum for LTE deployment in Ghana. It focused on simulation of 1800 MHz spectrum at 10, 15 and 20 MHz bandwidths for varying speed, from 0 to 200 km/h.

The findings show that the spectral efficiency values as reported in the simulation results fall within practical values in use globally and the throughput results conform to that of the existing networks operators and LTE standards, even at high mobility of 200 km/h. Future work will address the mitigation of interference created by deployment of 1800 MHz LTE system.

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