Evaluating the level of inteference in UMTS/LTE heterogeneous network system

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ABSTRACT

The study evaluated interference in a dense heterogeneous network using third-generation universal mobile telecommunication systems (UMTS) and fourth-generation long term evolution (LTE) networks LTE. The UMTs/LTE heterogeneous network determines the level of interference when the two communication systems coexist and how to improve the network by migrating from UMTs to LTE, which has a faster download speed and larger capacity. Techno lite 8 on third generation (3G) and Infinix Pro 6 on fourth generation (4G) were used to measure network the received signal strength (RSS) during site investigation. UE interference was detected and traced using a spectrum analyzer. UMTS and LTE path loss exponents are 2.6 and 3.2. Shannon's capacity theorem calculated LTE and UMTS capacity. When signal to interference and noise ratio (SINR) was used as a quality of service (QoS) indicator, MATLAB channel capacity plots did not match Shannon's due to neighboring interference. UMTS had an R2 of 0.54 and LTE 0.57 for the Shannon channel capacity equation. Adjacent channel interference (ACI) user devices reduce network capacity, lowering QoS for other customers.

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1. INTRODUCTION

Wireless communication systems are speedily changing, and actively adding meaning to better human existence. People around the world absolutely depend on the network technology and telecommunication daily to have a useful and productive life. Co-existence of heterogeneous wireless communication system opened up to operators a significant idea in telecommunication for cost effectiveness but it breeds interference from different radio access technologies (RAT) [1]. Interference is responsible for the degradation of quality of service (QoS) of a network. The combined operation between different wireless RAT has been an area of research consideration in the recent past few years as in [2], [3]. As defined by heterogeneous wireless networks, heterogeneous wireless networks refer to the integration and interoperability of wireless networks with various access technologies that have distinct characteristics in terms of mobility management, security support, and QoS provisioning [4], [5].

Historically, the addition of more base station (BS) has been the most essential component in boosting the capacity of cellular networks. But in recent times there is more to worry about because the presence of additional BS in order to increase the system capacity, makes the system more complex hence higher the challenge of interference experienced in the system as asserted by [6]. The consistent demand for staying connected to internet services and personal communications services has supported the development of broadband connection services. For cellular systems particularly, there is a reflection of high interest for mobile broadband capacity systems, namely the universal mobile telecommunication systems (UMTS), known as a third generation (3G) technology [7]. However, it has its own limitations, which necessitated the introduction of long term evolution (LTE) systems received as fourth generation (4G) [8]. LTE systems was introduced in order to handle the lapses in UMTS in terms of better spectrum efficiency higher data rate, latency, capacity across the cell, better coverage, and better support for mobility. Therefore, the more these qualities are improved upon, the more the complexity of the terrain is increased [9]. Hence, due to the presence of this newly introduced network technology, the system ultimately become a heterogeneous network and dense at the same time and of course with the heavy presence of interference in the network. Wireless communication system has an inherent challenge of interference within its networks. The concept of wireless heterogeneous networks is centered on the coexistence and interoperability of different types of RAT in a common wireless heterogeneous network system and as such the need to evaluate the level of interference in the heterogeneous [1], [10]. The focus of this research is on downlink (DL) performance in terms of signal to interference and noise ratio (SINR) at the mobile station (MS) or user device, where the MS connects to the eNodeB (LTE BS) or the access point with the highest SINR. The SINR at the user is a critical parameter for determining the capacity of the cellular networks studied (UMTS and LTE).

Therefore, this study tries to carefully characterize the channels and evaluate the problem of adjacent channel interference (ACI) in UMTS and LTE networks, with specific attention to the impact of interference on the network capacity with increase in the number of users and distance. Achieving this goal will enable the network operators understand the level at which interference affects or has impaired their QoS at the detriment of the subscribers. Which ultimately may affect their customer base negatively.

2. OVERVIEW OF INTERFERENCE IN HETEROGENOUS NETWORK

2.1. Interference model

The level of interference is determined by the signals received at the moment from all transmitters in the channel. The more transmitting power from irrelevant nodes in the same channel, the more interference the receiver experiences. In this investigation, the SINR model given by [11] was applied.

2.1.1. Adjacent channel interference

According to Faramarz [12] the quality of a received wireless signal can be degraded not only due to equipment noise or the environment, but also because of collision of two signals and their respective bandwidth (BW). Transmitted signal does not have its energy focused in the center frequency but spread randomly over its BW. The power spectral density (PSD) expresses the mode of energy distribution over the BW of the signal. Transmitters use emission mask to curtail out of band emissions. Interference caused by extraneous power from a transmission in a neighboring channel is known as ACI. Inadequate filtering, improper tuning or poor frequency control can all cause ACI. To evaluate the impact of ACI in the DL, it is expected that the interference power from a single adjacent channel BS (I_{BS}) would first be determined. Secondly, is the determination of the interference power from a single MS in one adjacent channel cell at a victim mobile station (IMS). These interference powers are given by the following (1) as asserted in [13]:

$$I_{BS} = \frac{(P_{BS} \times U_{BS})}{PL_{BS-MS}} \tag{1}$$

where P_{BS} is the adjacent channel BS transmission power, U_{BS} is the number of users served by this BS, and PL_{BS-MS} is the path loss between the adjacent channel BS and the victim MS.

2.1.2. Interference in long term evolution

LTE networks suffers from both intra-cell and inter-cell interference, with more attension being paid to the inter-cell interference since intra-cell interference can be neglected as LTE users are orthogonal. Cross-tier and co-tier interference are associated with inter-cell interference. To mitigate these interferences, the 3 GPP has introduced inter-cell interference coordination for LTE interference management. The overall transmission power in LTE is spread equitably among the subcarriers assigned to the same user [14].

2.1.3. Interference issues in UMTS/FDD networks

Each radio channel in the UMTS system has a band width of 5 MHz, and the channels are allocated in uplink (UL) and DL bands separated by 190 MHz [7], [15]. The technique for reducing interference and achieving the best feasible capacity entails determining the optimal spacing between carriers in the accessible radio frequency. A specific frequency arrangement must be examined for this reason, as it may differ from country to country.

2.2. The network channel capacity

In the architecture of future digital telecommunications systems, channel capacity is a critical performance measure. In a Gaussian environment, shannon channel capacity gives an upper bound on maximum transmission rate as emphasized by [15]. The Shannon capacity of a signal with BW transmitted over the additive white Gaussian noise (AWGN) channel is defined as $C = BW\ log2(1+\gamma)$, where γ is received signal to noise ratio (SNR). The capacity of a signal broadcast across a fading channel can be thought of as a random variable:

$$C = BW\ log\_2\ (1 + SNR) \tag{2}$$

where; C is channel capacity and BW is bandwidth of frequency. The noise power σ_N^2 is calculated as (3) [16]:

$$\sigma_N^2 = kT + 10\log_{10}(BW) + NF \tag{3}$$

where kT is the thermal noise density, and in LTE specifications, it is defined to be -174 dBm/Hz where k is Boltzmann's constant (1.380662×10^{-23}) and T is the temperature of the receiver (assumed to be 15 °C). BW is the channel BW in Hz. NF is the noise figure which is defined to be 5 for the eNodeB in LTE [16], [17].

According to Shannon–Hartley theory [18], in the presence of noise and interference, the Shannon capacity bound (5) is used to compute the maximum amount of error-free digital data in bits/s/Hz that can be conveyed with a given BW. The system capacity of heterogeneous networks was assessed in this study, taking into account interference and the type of service. The effects of intra-network and inter-network interference, as proposed by [19], were taken into account.

2.3. Signal to interference and noise ratio

The raw bit rate in bits per second divided by the BW in Hertz and given in bits/s/Hz, that is, throughput divided by BW, is a popular definition of spectral efficiency in wireless networks. It's important to remember that, according to the Shannon-Hartley theorem, there's a hard limit on how much data can be transferred in a given BW. In the presence of noise, this theorem describes the maximum rate at which information can be sent through a communications channel. It established a limit on the amount of non-error information per time unit that may be sent with a certain BW in the presence of noise interference, provided that the signal power is bounded and the Gaussian noise process has a known PSD [16]. Average subcarrier SINR can be defined as (4):

$$\text{SINR} = \frac{Received\ Signal\ Power}{Niose\ Power + Interference\ Power} \tag{4}$$

which is also represented as $SINR = \frac{RSRP}{(I+N)}$. Where I is the average interference power and N is the thermal BW noise power, as stated in [18]–[21]. All quantities are normalized to one subcarrier BW and measured across the same BW. Own cell interference is frequently believed to be insignificant in orthogonal frequency division multiplexing (OFDM), implying that I is solely attributable to other cell interference.

$$C = BW \log_2(1 + SINR) \tag{5}$$

3. FIELD SCANNING

Field scanning with a spectrum analyzer (azimuth scanner) with a serial number of 1,038,086 base version V5.19, application version V6.55, model number MS2725 C, and a diabola antenna was carried out as part of this investigation at trade fair (Festac town) in Lagos. The parameters in the Table 1 was obtained from mobile network operator (MTN). These parameters were required to enable the scanning of the cell or environment which the network is transmitting, the frequency, BW and the bench mark of their received signal strength indicator (RSSI) were inputted into the spectrum analyzer as required to carry out the scanning exercise of the network environment.

The technique for conducting an interference scanning test in Lagos' trade fair (Festac town) are as follows; firstly, in order to have access to the right data required for this study, the parameters in Table 1 was obtained from the network operators. Secondly, the diabola antenna and the spectrum analyzer were assembled. Thirdly, turning on the spectrum analyzer and fine-tuning the settings in accordance with the obtained parameters. Fourthly, starts the movement within the cell to see if the network is being affected with and, if so, where the interference is coming from. Finally, after the drive, the scanning equipment acquired and saved the data in the device memory for later processing and analysis. For analysis and interpretation, the collected data is downloaded to a personal computer (PC). Table 1 is the expression of parameters made available by network operators for the purpose of field scanning in order to identify and confirm the claimed problems of interference encountered by network users, which results in customer complaints and a current drop in their generated revenue.

Table 1. LTE and UMTS parameters from MTN at trade fair (Festac town)

Technology	Band	DL/UL	Ranges start	Range stop	Bw (MHz)
UMTS	2,100	DL	2,110	2,120	10
UMTS	2,100	UL	1,920	1,930	10
LTE	2,600	DL	2,640	2,650	10
LTE	2,600	UL	2,520	2,530	10

3.1. Path loss characterization of the test-bed environment

To completely characterize the propagation path loss model of the test-bed, values were established for all the parameters namely; path loss at a reference distance, L_P (do), the measured path loss, the predicted path loss, the path loss exponent n, and shadowing factor X, which is a Gaussian random variable with standard deviation (values in dB). Path loss is defined as the steady loss of signal intensity (power) as the distance between the transmitter and receiver (T-R) increases (6). Where (6) is then used to evaluate the path loss using measured data (average received power) and the result tabulated in Table 2.

$$Path\ loss = L_P(d_i)dB = 10\ Log\left[\frac{P_t}{P_r}\right](dB) \tag{6}$$

Table 2. LTE and UMTs mean RSS, measured and developed path loss from the test-bed

Distance (km)	Mean Rxav (dBm) LTE	Measured PL (dB) LTE	LTE developed model (dB)	Mean Rxav (dBm) UTMs	Measured PL (dB) UTMs	UMTs developed model (dB)
0.10	-54	66	45.00	-57	69	55.00
0.20	-60	72	54.63	-67	79	62.83
0.30	-83	94	60.27	-65	77	67.41
0.40	-82	94	64.27	-69	81	70.65
0.50	-87	99	67.37	-69	81	73.17
0.60	-70	82	69.90	-91	82	75.23
0.70	-72	84	72.04	-73	85	76.97
0.80	-80	92	73.90	-77	89	78.48
0.90	-88	100	75.54	-87	100	79.81
1.00	-89	101	77.00	-95	101	81.00
1.10	-89	101	78.32	-75	107	82.08
1.20	-100	112	79.53	-85	97	83.06
1.30	-95	107	80.65	-83	95	83.96
1.40	-84	96	81.68	-85	96	84.79
1.50	-97	109	82.63	-81	109	85.58
1.60	-96	108	83.53	-91	108	86.31
1.70	-80	92	84.37	-83	95	86.99
1.80	-83	95	85.17	-83	95	87.64
1.90	-98	110	85.92	-98	110	88.25
2.00	-106	118	86.63	-103	118	88.83

The path loss exponent, n, can be calculated statistically using the linear regression analysis technique, which involves minimizing in the mean square error. The difference between the measured path loss and the predicted (estimated) path loss, n is given as (7):

$$n = \frac{\sum_{i=1}^{k} L_p(d_i) - L_p(d_o)}{\sum_{i=1}^{k} 10\ \log_{10}(\frac{d\_i}{d_o})} \tag{7}$$

where the term L_p (d_i) represents measured path loss or (P_m), and L_p (d_o) represents predicted path loss or P_r and k is the number of measured data or sample points. The path loss exponents were calculated for both UMTS and LTE and the results are expressed as follows; for UMTS, n=2.6 and LTE n=3.2.

3.2. Signal to interference plus noise ratio calculation for long term evolution network

The amount of interference is determined by the signals received at the moment from all transmitters in the channel. The higher the transmission power from irrelevant sources, the better. Nodes in the same channel, the higher the interference experienced at a receiver.

$$Interference\ path\ loss = Measured\ Path\ Loss - Developed\ Path\ Loss$$

The measured and developed path loss values were calculated and tabulated in Table 2. The interference power and SINR were calculated for various distances from 0.1 to 2.0 km as recorded in Table 3 using the same procedure produced the subsequent results.

Table 3. LTE channel capacity (Mbps) and SINR (dB)

D (Km)	Interference power (dB)	Interference power in (dBm)	SINR (dB)	Channel capacity (Mbps)
0.1	0.79	-1.01	35.32	51.82
0.2	0.96	-0.18	18.67	42.98
0.3	0.49	-3.09	15.93	40.82
0.4	0.56	-2.52	17.31	41.95
0.5	0.53	-2.79	16.86	41.59
0.6	5.75	7.75	10.16	34.80
0.7	1.39	1.43	14.72	39.75
0.8	0.92	-0.37	21.10	43.99
0.9	0.68	-1.67	21.20	44.73
1.0	0.69	-1.59	21.75	45.08
1.1	0.73	1.35	24.00	46.44
1.2	0.51	-2.90	17.20	41.86
1.3	0.63	-2.00	19.78	43.77
1.4	1.16	0.65	17.07	41.76
1.5	0.63	-2.00	19.87	43.83
1.6	0.68	-1.68	21.50	44.92
1.7	2.18	3.38	12.62	37.68
1.8	1.69	2.28	14.04	39.11
1.9	0.69	-1.61	22.00	45.24
2.0	0.53	-2.76	17.79	42.32

3.3. Channel capacity of the long term evolution and universal mobile telecommunication systems network

Channel capacity with respect to SINR is by the formula as shown in (5); C= $Bw \log_2(1 + SINR)\ Mbps$. For example to finding the capacity at 0.1 km using the value of SINR.

$$C = 10\log_2(1 + 35.32)\ Mbps$$
$$C = 10 \times 10^6 \frac{\log 36.32}{\log 2}\ Mbps$$
$$C = 51.82\ Mbps$$

The systems channel capacity for both LTE and UMTS were calculated for various distances from 0.1 to 2.0 km as recorded in the Tables 3 and 4 respectively.

3.4. Adjacent channel interference evaluation in UMTS and LTE networks

The ACI is interference between links that communicate geographically close to each other using neighboring frequency bands. ACI results also from imperfect receiver filters according to [12]. The two ACI involved are, BS to MS and MS to MS, but this work basically considered the BS to MS. To explore the impact of ACI in the DL, firstly, it is important to determine the interference power from a single adjacent channel BS (I_{BS}) and secondly the interference power from a single MS in one adjacent channel cell at a victim mobile station (IMS). These interference powers are given in (1) as, $I_{BS} = \frac{(P_{BS} \times U_{BS})}{PL_{BS-MS}}$, where P_{BS} is the adjacent channel BS transmission power, U_{BS} is the number of users served by this BS, and PL_{BS-MS} is the path loss between the adjacent channel BS and the victim MS. The LTE and UMTS transmitted BS power were calculated as 16.628 and 14.77 dBm respectively using (8).

$$P_t\ (dB) = 10\log P_t \quad (8)$$

Interference BS power for 5 active users in an LTE network is as shown:

$$I_{BS} = \frac{(16.628_{BS} \times 5_{BS})}{66_{BS-MS}}$$
$$I_{BS} = 1.2597\ dB$$
$$I_{BS} = 10 \times log\ 1.2597$$
$$I_{BS} = 1.00\ dBm$$

The system ACI for 5 active users was calculated for various distances from 0.1 km to 2.0 km. Using the same procedure, values of ACI for 10, 20, and 30 active users for both LTE and UMTS network systems, was also calculated and tabulated in Tables 5 and 6 respectively. Interference BS power for 5 active users in an UMTS network is calculated as shown:

$$I_{BS} = \frac{(14{,}77_{BS} \times 5_{BS})}{69_{BS-MS}}$$
$$I_{BS} = 1.070289855\ \text{dB}$$
$$I_{BS} = 10 \times \log 1.070289855$$
$$I_{BS} = 0.295\ \text{dBm}$$

Table 4. UMTS (WCDMA) channel capacity (Mbps) and SINR (dB)

D (Km)	Interference power (dB)	Interference power (dBm)	SINR (dB)	Channel capacity (Mbps)
0.1	1.05	0.19	16.65	41.42
0.2	0.91	-0.41	20.50	43.92
0.3	1.54	1.90	13.54	38.62
0.4	1.43	1.54	14.33	39.38
0.5	1.89	2.75	12.64	37.70
0.6	0.53	-2.75	17.17	41.84
0.7	1.84	2.64	13.00	38.07
0.8	1.40	1.45	14.97	39.97
0.9	0.72	-1.41	23.30	46.03
1.0	0.74	-1.31	24.90	46.95
1.1	0.59	-2.28	18.90	43.07
1.2	1.06	0.25	18.32	42.72
1.3	1.34	1.26	15.60	40.53
1.4	1.21	0.82	16.69	41.45
1.5	1.99	2.90	13.10	38.18
1.6	0.89	-0.53	22.83	45.75
1.7	1.84	2.65	13.56	38.64
1.8	2.00	3.00	13.17	38.25
1.9	0.68	-1.69	21.54	44.94
2.0	0.51	-2.96	17.21	41.87

Table 5. The LTE ACI

D (Km)	Interference power for 5 active users (dBm)	Interference power for 10 active users (dBm)	Interference power for 20 active users (dBm)	Interference power for 30 active users (dBm)
0.1	1.00	4.01	7.62	8.78
0.2	0.62	3.64	6.65	8.41
0.3	-0.53	2.48	5.49	7.25
0.4	0.53	2.48	5.49	7.25
0.5	-0.76	2.25	5.26	7.02
0.6	0.06	3.07	6.08	7.84
0.7	-0.05	2.97	5.98	7.74
0.8	-0.44	2.57	5.58	7.34
0.9	-0.80	2.21	5.22	6.98
1.0	-0.85	2.17	5.18	6.94
1.1	-0.85	2.17	5.18	6.94
1.2	-1.29	1.72	4.73	6.49
1.3	-1.10	1.91	4.92	6.69
1.4	-0.44	2.39	5.40	7.16
1.5	-1.18	1.83	4.84	6.61
1.6	-1.14	1.87	4.84	6.65
1.7	-0.44	2.57	5.58	7.34
1.8	-0.58	2.43	5.45	7.20
1.9	-1.22	1.79	4.80	6.57
2.0	-1.52	1.49	4.50	6.26

Table 6. The UMTS ACI

D (Km)	Interference power for 5 active users (dBm)	Interference power for 10 active users (dBm)	Interference power for 20 active users (dBm)	Interference power for 30 active users (dBm)
0.1	0.29	3.31	6,32	8.08
0.2	-0.29	2.72	5.73	7.45
0.3	-0.18	2.83	5.84	7.60
0.4	-0.40	2.61	5.62	7.38
0.5	-0.40	2.61	5.62	7.38
0.6	-0.45	2.56	5.57	7.33
0.7	-0.61	2.40	5.41	7.17
0.8	-0.81	2.20	5.21	6.67
0.9	-1.32	1.69	4.70	6.47
1.0	-1.36	1.65	4.66	6.42
1.1	-1.61	1.39	4.41	6.17
1.2	-1.18	1.81	4.84	6.60
1.3	-1.10	1.92	4.93	6.69
1.4	-0.14	1.87	4.88	6.64
1.5	-1.69	1.32	4.33	6.09
1.6	-1.65	1.36	4.37	6.13
1.7	-1.10	1.92	4.93	6.68
1.8	-1.10	1.92	4.93	6.68
1.9	-1.73	1.28	4.29	6.05
2.0	-2.04	0.97	3.99	5.75

4. RESULT AND DISCUSSION ON SINR (DB) ESTIMATION AND CHANNEL CAPACITY (MBPS) FOR LTE AND UMTS NETWORK

Tables 3 and 4 are implemented in MATLAB and excel statistics to graphically show the SINR estimation against the channel capacity of the LTE and UMTS networks of the testbeds considered for this study.The capacity of the networks of LTE and UMTS were calculated using shannon's capacity theorem considering SINR as a QoS indicator as seen in [22], [23]. The MATLAB plots of the calculated channel capacity showed inconsistency with Shannon's capacity plot, due to interference from nearby interferers. From Figures 1 and 2, it was observed that the higher the SINR, the better the channel capacity of the network and as the SINR becomes small, the channel capacity reduces. It can also be seen that both SINR and channel capacity are higher at smaller distance why SINR and channel capacity reduces as the distance increases except in few cases which can be due to handoff. At some distances, there are more obstacles that can cause excess blocking of the network and as such degrades, the SINR and reduces the channel capacity.

In Figures 3 and 4, the value of distance 0.1 to 2.0 km is represented by 1 to 20 in the plot. From Figures 3 and 4, it was observed that the higher the SINR, the better the channel capacity of the network and as the SINR becomes small, the channel capacity reduces. It can also be seen that both SINR and channel capacity are higher at smaller distances but SINR and channel capacity reduces as the distance increases except in few cases which can be due to handoff. At some distances, there are more obstacles that can cause excess blocking of the network and as such degrades, the SINR and reduces the channel capacity.

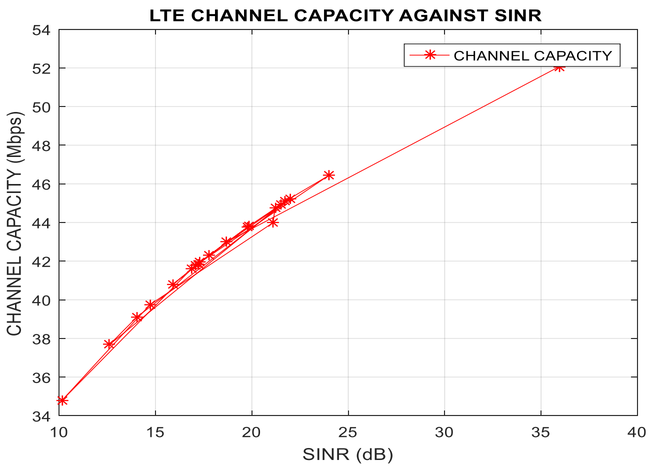

Figure 1. Plot of SINR (dB) against channel capacity (Mbps) of LTE network

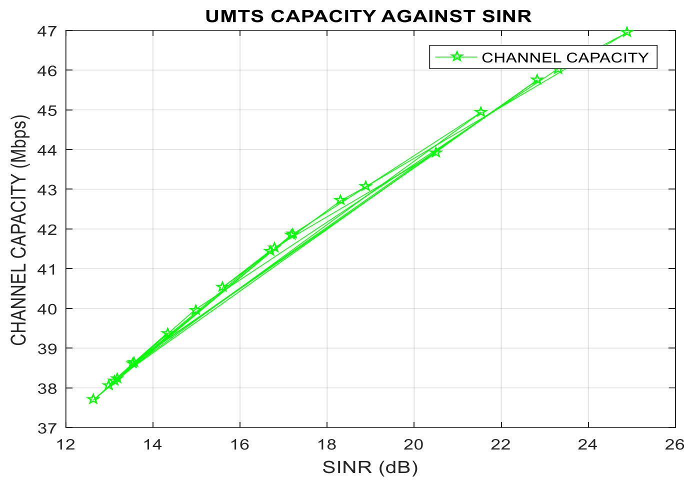

Figure 2. Plot of SINR (dB) against channel capacity (Mbps) of UMTS (WCDMA) network

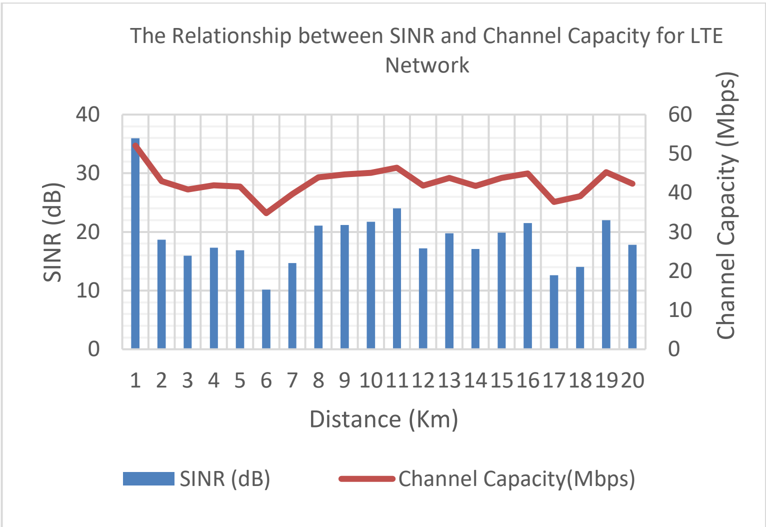

Figure 3. The plot of channel capacity (Mbps) and SINR (dB) against distance (km) of a LTE network system

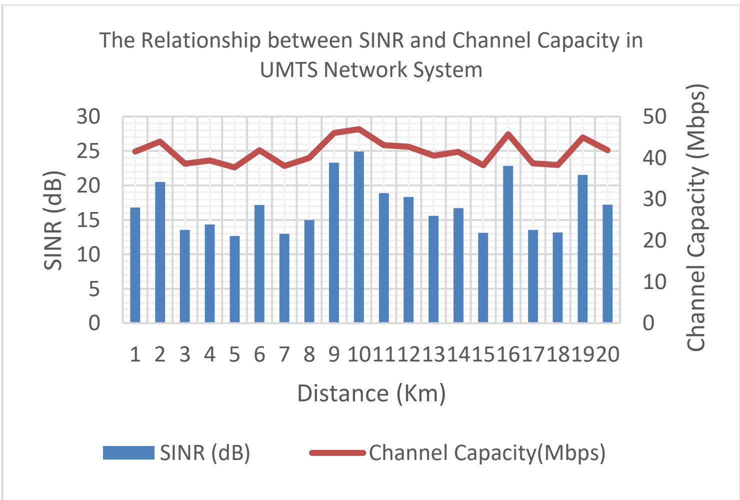

Figure 4. The plot of channel capacity (Mbps) and SINR (dB) against distance (km) of UMTS (WCDMA) network system

4.1. Discussion on adjacent channel interference with increase in distance and the number of active users

Plots 9 and 10 show the impact of the number of active users on the channel capacity with reference to distance between the victim and aggressor. The variation of ACI power according to the distance between interfering user devices (BS or MS) and interfered user devices (MS) and according to the number of active users in interfering adjacent cell and the change of the signal to ACI based on ACI power measured and obtained were shown in Figures 5 and 6 for LTE and UMTS respectively. Also the value of distance 0.1 to 2.0 km is represented by 1 to 20 in Figures 5 and 6.

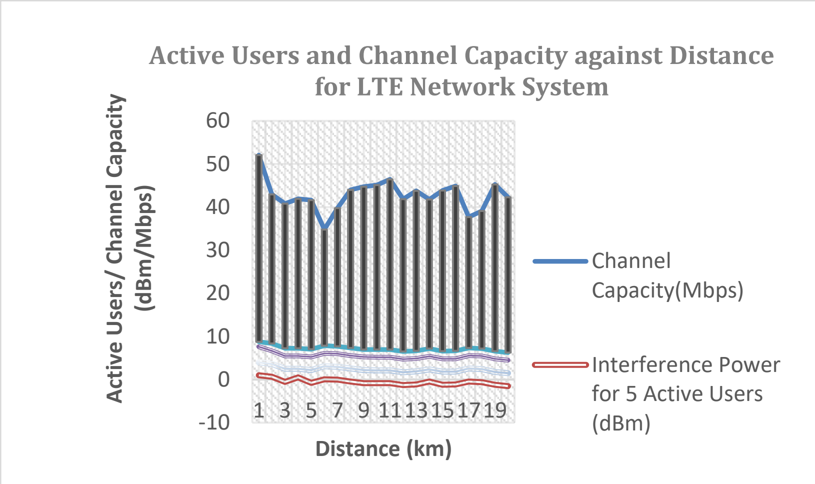

Figure 5. Plot showing the effect of increase in the active users on the channel capacity with reference to distance for LTE network

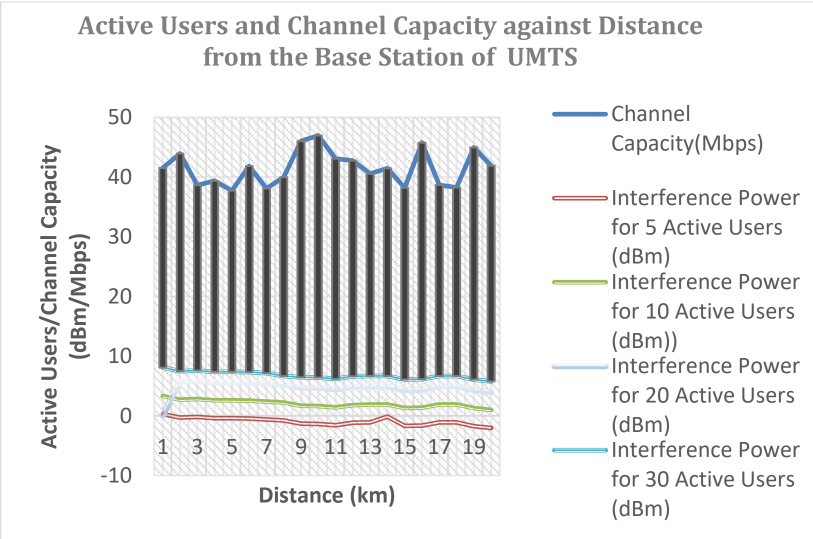

Figure 6. Plot showing the effect of increase in the active users on the channel capacity with reference to distance for UMTS network

5. CONCLUSION

The basic underlying principle of cellular telecommunication is the limitation it has with radio BW. While it has the potentials to support a large number of users by means of frequency reuse and deployments of other radio access network technologies, but these ultimately breeds the force of interference in an average cellular network. This work evaluates the level of interference, traced the sources of the interference, and determines the ACI for both LTE and UMTS cellular network in the heterogeneous network utilizing the Infinix Hot 6 Pro and Tecno L8 Lite, respectively.

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