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Evaluation of Percentage Capacity Loss on LTE Network Caused by Intermodulation Distortion in a Coexistence Scenario

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Abstract- The paper evaluates the effects of third order Intermodulation Distortion (IMD3) on the Long Term Evolution (LTE) receiver due to coexistence between LTE and GSM networks. Amongst the various existing IMD orders which include first order, second order, third order, fifth order and seventh order. Third order is known to have the greatest distortion effects on a receiver due to its strength and its proximity to the frequency band of interest. It occurs as a result of the non-linear behavior of components or circuit at both the transmitter and receiver ends of wireless communication networks. IMD has potential negative effects on a victim receiver which majorly leads to increase in noise floor level and system capacity degradation. Deterministic approach was implemented in the work assuming worst case scenario. MATLAB software simulation was deployed to evaluate the capacity loss at the receiver end relative to a range of distances apart. Results obtained showed severe uplink capacity degradation when VISAFONE LTE network was interfered by INTERCELLULAR LTE downlink and ETISALAT GSM uplink. Various distances ranging from 500m to 3000m were varied between the ETISALAT GSM network and the VISAFONE LTE network. The results obtained showed that at 500 meters, the percentage capacity degradation was as high as 80. The least percentage capacity loss was obtained as 5.97 at 3000 meters.

Keywords- *Intermodulation Distortion, Coexistence, Long Term Evolution (LTE), Global System for Mobile Telecommunication (GSM), Capacity Loss, Uplink and Downlink.*

I. INTRODUCTION

The growth and swift spread of mobile communication systems across the globe has necessitated the mobile network companies to strategize advance techniques for quality service delivery. This has brought about the proliferation of base station masks from different network operators aimed at improving the system coverage and capacity. The increase has led to various coexistence settings. The coexistence of networks is typically classified as coordinated and uncoordinated setting. The coordinated scenario refers to a case in which the coexisting networks belong to the same network while the uncoordinated scenario is when the networks belonging to different network providers exist in the same geographical area [1]

The key setback to coexistence of networks is the issue of interference. One of the prominent interferences suffered in such scenario is the Intermodulation Distortion (IMD). Others include transmitter noise and receiver blocking (receiver desensitization). IMD is a phenomenon caused by coexistence. It is a multi-tone distortion product that results when two or more signals are present at the input of a non-linear device [2]. The non-linear device leads to a generation of intermodulation products which are sums and differences of multiples of the fundamental frequencies [2]. These frequencies on their own are harmless. However, when two or more of these IMD products fall within the pass band of a receiver, it interferes with the genuine received signal leading to loss of the signal strength, channel capacity degradation and reduced signal to interference ratio.

Of all the interference issues plaguing mobile and wireless communication systems, it is observed from literature that the least attention was paid to IMD. Conversely, as communication systems become more advanced with increase in collocation and coexistence deployment and the need to achieve optimal signal to noise ratio, IMD analysis becomes very vital to be neglected.

The frequency spectrum in theory is an unlimited resource. But then, practically it is limited. This is because different frequencies have their characteristic properties which may make them unsuitable for certain applications. When the fourth generation telecommunications standard -Long Term Evolution (LTE) was deployed, there was no defined frequency of operation. Since most parts of the spectrum where already occupied by other wireless systems, the Third Generation Partnership Project (3GPP) recommended that LTE be deployed on any available frequency slot from 700MHz upwards [3]. This connotes the affirmation that the operating frequencies for LTE could vary from one country or region to the other.

In Nigeria, there are four major telecom operators namely MTN, AIRTEL, GLOBACOM and ETISALAT. These networks are referred to as major players by virtue of the market share they control and their network coverage. Altogether, these companies own over 98% of the mobile telecommunication market in Nigeria [4]. Also, Base Transceiver Stations (BTS) belonging to these firms can be seen scattered all over the country. They offer voice and data services on the Global system of Mobile Telecommunication (GSM) 900, GSM 1800 and Universal Mobile Telecommunication System (UMTS) 2100MHz bands. Recently, the Nigerian Communication Commission (NCC) granted licenses to three companies which include SMILE, INTERCELLULAR and VISAPHONE, to deploy LTE services on the 800MHz band [5]. These LTE networks are yet to have nationwide coverage but have already been deployed in three major cities in Nigeria, namely, Lagos, Abuja and Port Harcourt. The deployment of LTE services in areas already dominated by GSM and Wideband Code Division Multiple Access (WCDMA) networks could lead to interference due to close frequencies of operation.

From the theoretical perspective, it was observed that when GSM network coexists with LTE network due to their close frequency bands, could lead to a third (3rd) order IMD. The incongruity could be prominent between the downlink of INTERCELLULAR network and the uplink of ETISALAT GSM network. Hence, this necessitated the study to analyze the interfered frequencies and evaluate their system capacity loss when interfered.

II. RELATED WORKS

From the articles of [1], carried out an analysis on the effect of transmitter end intermodulation interference and spurious emissions on a base station receiver in a co-located arrangement. The interference scenario considered was CDMA2000 Base Station and Mobile receivers degraded by Intermodulation generated by the transmitters of GSM 900 base station. Deterministic approach was used to define received signal strength and its degradation as a function of distance. Results obtained showed that co-located base stations suffered greater degradation of received signal strength than standalone base station.

The author of [6] carried out a study on the coexistence between LTE and GSM in order to identify potential interference issues that may be encountered. The author used a statistical method based on the Monte Carlo technique. The coexistence scenario considered was one in which LTE was deployed in the 900 MHz band also used by GSM. The interference mechanism considered where Unwanted emissions and receiver blocking. In this scenario, receiver blocking was over 5% which is the recommended threshold by 3GPP. Hence, the author recommended the use of a receiver with a blocking response 8dB higher than the 3GPP minimum requirement. This work mainly considered the interference effect caused by one mobile station but failed to investigate the effects of Intermodulation Distortion which is a prominent interference challenge.

The authors of [7] investigated the impact of interference from CDMA 2000 base station transmitter and a UMTS base station receiver in a co-location arrangement. Deterministic technique was used in the analysis by supposing a worst case scenario for both the interfere and the interfered. However the authors admitted that the real life spurious emissions and blocking specifications of the UMTS receiver are better than the values used. Results showed that an isolation of 65dB would be required between the CDMA 2000 and UMTS antennae to avoid blocking. This will only be effective when a filter installed at the UMTS receiver end must have introduced an attenuation of 60 dB. Also a 5 MHz guard band between the CDMA downlink and the UMTS uplink was recommended.

III. METHODOLOGY

With the proliferation of wireless communication systems which resulted to coexistence and co-location scenario. It is usually very important to identify potential interfering systems before a new system is deployed in any environment. While it is relatively easier to identify co-channel and adjacent channel interferers, identifying interferers which causes Intermodulation Distortion is somewhat more challenging. This is because frequencies when operated in isolation are observed harmless but could pose serious threats at a receiver front end when it mixes non-linearly with more than one frequencies.

From the study, we chose the interferers as the downlink of INTERCELLULAR LTE and the uplink of ETISALAT GSM networks while the interfered system is the uplink of VISAFONE LTE.

The following steps were deployed to calculate the 3rd order IM products generated by these two interferers.

1. Specify the Victim receiver’s pass band: the pass band for the VISAFONE LTE eNodeB receiver is 790 – 800 MHz.
2. Specify the operating frequency range of the two interfering systems: intercellular downlink has an operating frequency range of 842 – 852 MHz while the ETISALAT Uplink has a frequency range of 890 – 895 MHz.
3. Let the interferers be labelled f_a and f_b respectively, where f_a is {842, 843, … , 852MHz} and f_b is {890, 891, … , 895 MHz}
4. All combination pairs of the individual f_a and f_b frequencies are evaluated using models to derive the third order IM products generated
5. For any IM product derived in the preceding step, a quick check is carried out to verify if the frequency falls within the victim receiver pass band. IM products which fall outside this range are of no interest as they do not pose any threat to the system. IM products which fall within this range are harmful and will interfere with the VISAFONE LTE receiver.

Figure 1 illustrates the step-by-step approach towards evaluating the interfering third order intermodulation products while Table 1 represents the obtained interfering intermodulation frequencies.

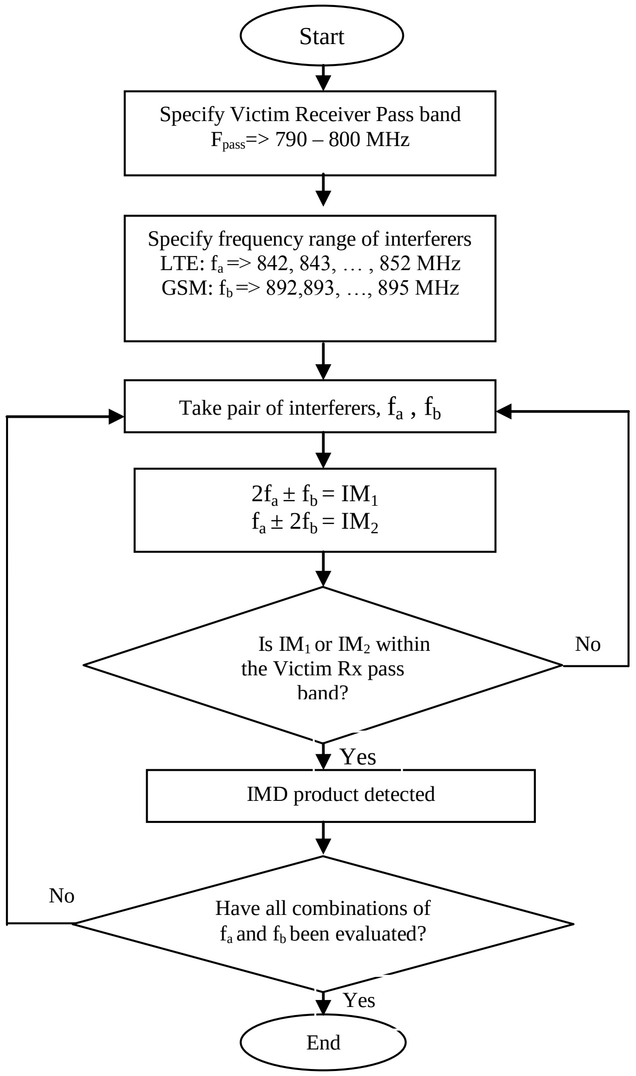

Figure 1. Flowchart for evaluating interfering third order IM products

The values obtained from the evaluation of the third order IM products generated by the downlink of INTERCELLULAR LTE frequencies and uplink of ETISALAT GSM frequencies are presented in Table 1. Only the IM products capable of causing interference are shown on the table. Other IM products that fall outside the pass band of the VISAFONE enodeB receiver are not included because they exert no treat on the system capacity.

Table 1 showed that the downlink frequencies of INTERCELLULAR Network ranging from 842 – 847 MHz will generate distortive IM products with the entire uplink frequencies of ETISALAT which may interfere with the operation of any nearby VISAFONE LTE enodeB receiver.

TABLE I. INTERFERING IM FREQUENCIES

Intercellular (MHz)	Etisalat (MHz)	IM Products
842	890	794
”	891	793
“	892	792
“	893	791
843	890	796
“	891	795
“	892	794
“	893	793
“	894	792
“	895	791
844	890	798
“	891	797
“	892	796
“	893	795
“	894	794
“	895	793
845	890	800
“	891	799
“	892	798
“	893	797
“	894	796
“	895	795
846	891	801
“	892	800
“	893	799
“	894	798
“	895	797
847	893	801
“	894	800
“	895	799

A. *Evaluation of Uplink Capacity Loss*

The loss of capacity can serve as an indicator as to the impact of an interference mechanism on a victim network. In LTE, any significant capacity loss can have an adverse effect on the services offered to users on the network. LTE network was designed to carry high data rate demanding services such as multimedia streaming, video conferencing, real-time internet gaming etc. These activities involve transfer of lots of information bits hence any shrink in network capacity will frustrate users especially when network load is high. LTE demands high Signal to Noise Ratio (SNR) and to achieve this, it is necessary to reduce to the barest minimum the effects of all sources of interference.

Signal bandwidth in LTE is about 90% of the channel bandwidth. Hence a 10 MHz channel will have a signal bandwidth of 9 MHz [8].

Using Shannon formula for finding maximum channel capacity in bits per second [9].

$$C = B \log_2 (1 + SNR) bits / \sec \qquad (1)$$

where B is the signal bandwidth, SNR is the Signal to Noise ratio.

SNR is a ratio of the Power of the received signal to the noise inherent in the system. This is expressed as [9].

$$SNR = {}^{P}\!/_{N} \tag{2}$$

where P is the strength of the received signal strength of the LTE enodeB , N is the Noise Power.

Noise Power (N) is generated in the receiver circuitry and is expressed as

$$N = kT_0B \tag{3}$$

where k is the Boltzmann Constant given as $1.38x10^{-23}J/k$

T_0 is the receiver operating temperature in Kelvin. The widely accepted value is 290K at an ambient temperature of approximately 17°C.

B is the receiver noise bandwidth

Lets represent P in equation 2 as P_{rx} which is given as

$$P_{rx} = P_{tx}L_uG \tag{4}$$

where P_{tx} is the strength of the transmitted signal

L_u is the path loss

G is the gain of the receiver antenna

P_{tx} is assumed to be 22dBm which is the maximum transmit power of an LTE MS [10].

The path loss is estimated using the Hata Model for urban area as shown in equations (5) and (6) [11].

$$L_u = 69.55 + 20.16\log f - 13.82\log h_B - C_H + [44.9 - 6.55\log h_B] \tag{5}$$

$$C_H = 3.2(\log 11.75h_m)^2 - 4.97 \tag{6}$$

Where h_B is the base station antenna height in meters, h_m is the height of the mobile station in meters, f is the frequency in MHz, d is the distance between the Transmitter and Receiver and C_H is the antenna height correction factor.

The interferers are the LTE enodeB transmitter of another operator (INTERCELLULAR) and the Mobile Station transmitters of a GSM operator (ETISALAT). It is assumed that the interferers are transmitting at maximum power.

Let the LTE enodeB transmit at maximum power P_{LTEMAX} and the GSM MS transmit at maximum power P_{GSMMAX} , the loss on the path from the interfering MS to the victim BS is calculated from equations (5) and (6).

Taking h_m = 1.5meters and h_B = 30 meters, the path loss from GSM MS to LTE enodeB is given as

$$L_{UMB} = 49.137 + 20.16\log f + 35.225\log d \tag{7}$$

Similarly taking h_m = 30 meters and h_B = 30 meters, the path loss from the interfering LTE enodeB transmitter to the victim is given as

$$L_{UBB} = 33.348 + 20.16\log f + 35.335\log d \tag{8}$$

Interfering signals $P_{IRX\,1}$ and $P_{IRX\,2}$ reaching the victim enodeB station from both interferers has to take into account the path loss.

Hence,

$$P_{IRX\,1} = P_{LTEMAX} - L_{UBB} \tag{9}$$

$$P_{IRX\,2} = P_{GSMMAX} - L_{UMB} \tag{10}$$

The signal strength degradation (η) is the difference between the signal strength in a non interfering environment and an interfering environment.

This is calculated thus

$$\eta_1 = P_{LTEMAX-}p_{IRX\,1} \tag{11}$$

$$\eta_2 = P_{GSMMAX-}p_{IRX\,2} \tag{12}$$

Where η_1 is the LTE signal degradation, η_2 is the GSM signal degradation.

The Interference power I_P at the victim LTE enodeB receiver is given by

$$I_P = (KTB + NF) + 10\log(10^{\frac{\eta}{10}} - 1)dBm \tag{13}$$

Where (kTB+NF) is the receiver noise floor of each interferer. It is calculated using values derived from equation 13.

Thus, I_P from LTE enodeB is given by

$$I_{PLTE} = (KTB + NF) + 10\log(10^{\frac{\eta_1}{10}} - 1)dBm \tag{14}$$

Also from GSM MS is given by

$$I_{PGSM} = (KTB + NF) + 10\log(10^{\frac{\eta_2}{10}} - 1)dBm \tag{15}$$

Since the number of interfering GSM MS is greater than one at any given instance, the total I_P from a population of GSM MS (maximum of 60 MS) is given by

$$I_{PTGSM} = \sum_{x=1}^{60} I_{PTGSM}\,dBm \tag{16}$$

The power of the 3rd order IM products, IP3, generated by I_{PLTE} and I_{PTGSM} interfering signals are calculated thus;

$$IP3 = 2I_{PLTE} + I_{PTGSM} - 2IIP3 \tag{17}$$

Where IIP3 is the 3rd order Intermodulation intercept point of the LTE receiver.

Then, the Signal to Interference plus Noise ratio is calculated using

$$SINR = \frac{P}{I + N} \qquad (18)$$

Where P is the received signal strength, I is the interference and N is the Noise

Replacing I with IP3 from equation 18 and P_{rx} from equation 4, equation 19 then becomes

$$SINR = \frac{P_{rx}}{IP3 + N} \qquad (19)$$

Using Shannon's Capacity formula, the LTE Uplink capacity in the presence of interference is given by

$$C_{\text{int}} = B\log_2(1 + \frac{p_{rx}}{IP3 + N}) bits / \sec \qquad (20)$$

Where C_{int} is the victim LTE Uplink capacity due to interference.

Capacity loss is given by

$$C_L = 1 - \frac{c_{\text{int}}}{c} \qquad (21)$$

And the percentage loss is computed using

$$\%C_L = (1 - \frac{c_{\text{int}}}{c}) X 100 \qquad (22)$$

The flowchart of figure 2, summarises the procedure for calculating the uplink percentage capacity loss.

IV. RESULTS

The interference effects suffered by the LTE uplink was evaluated in terms of uplink capacity loss. The interfering networks are the INTERCELLULAR LTE Downlink and the ETISALAT Uplink. The scenario deployed a concept that the distance between the two base stations (INTERCELLULAR and VISAFONE LTE) are fixed while the distance and number of simultaneously transmitting mobile stations are varied. The distance between the base stations was fixed at 1000 meters with the mobile stations. The victim VISAFONE LTE receiver was incremented by 500 meters. Table 2 shows the percentage uplink capacity loss as obtained from equation 22. The GSM interferer power reduces with distance and increases as the number of MS increases. Figures 3 to 7 illustrated plots of the number of base stations versus the percentage capacity loss for distances ranging from 500m to 3000m.

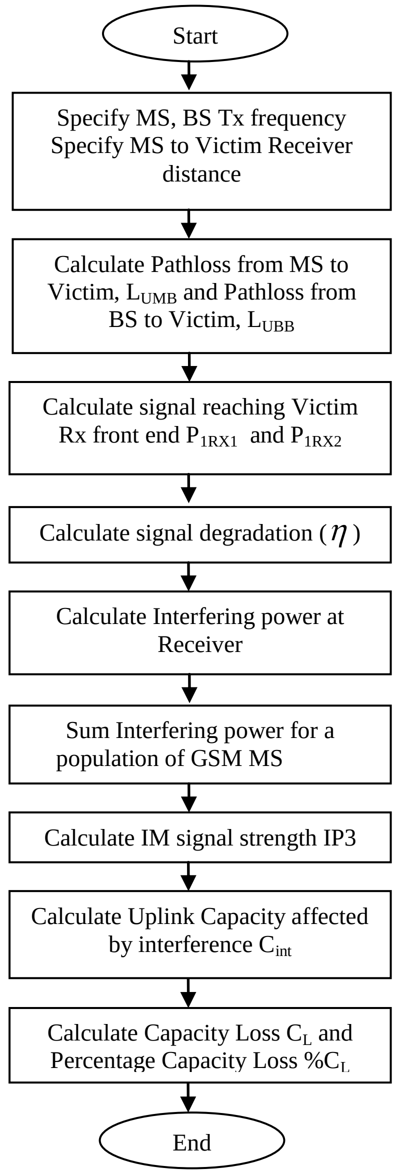

Figure 2. Steps to calculate the capacity loss

TABLE II. PERCENTAGE VISAFONE LTE UPLINK PERCENTAGE CAPACITY LOSS

	% Capacity Loss				
No of MS	500m	1000m	1500m	2000m	3000m
10	60.32	25.44	15.09	10.32	5.97
20	69.36	30.2	18.3	12.74	7.56
30	74.53	33.04	20.25	14.21	8.55
40	78.03	35.01	21.62	15.27	9.26
50	80.61	36.5	22.67	16.07	9.81
60	82.6	37.67	23.51	16.73	10.26

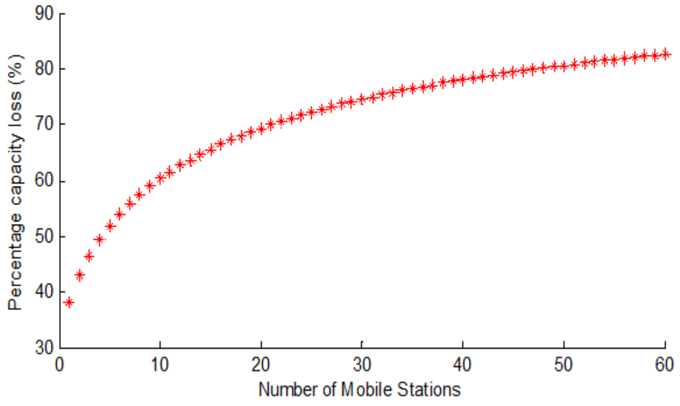

Figure 3. Capacity Loss at a distance of 500 meters between the mobile and base stations denoted as D_{MS} = 500 meters

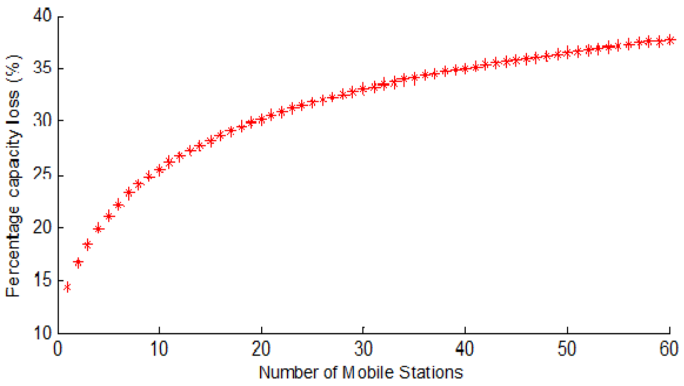

Figure 4. Capacity loss at D_{MS} = 1000 meters

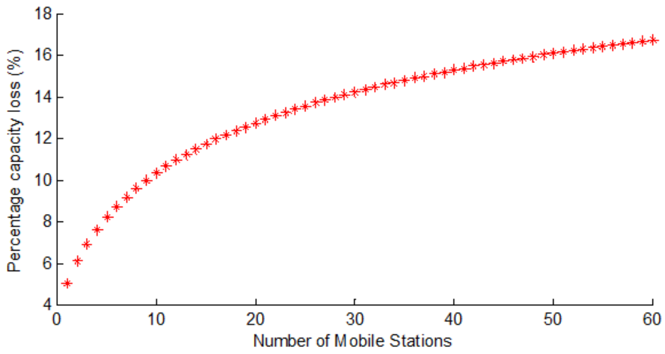

Figure 5. Capacity loss at D_{MS} = 1500 meters

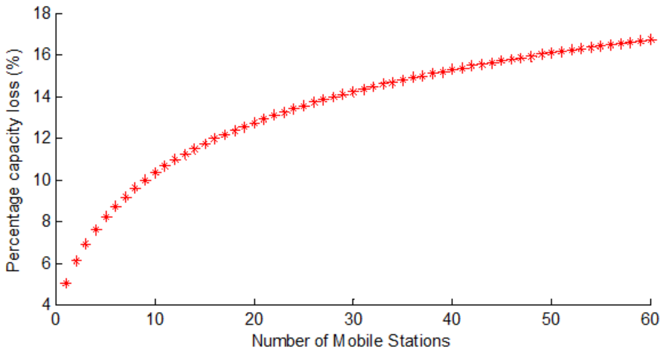

Figure 6. Capacity loss at D_{MS} = 2000 meters

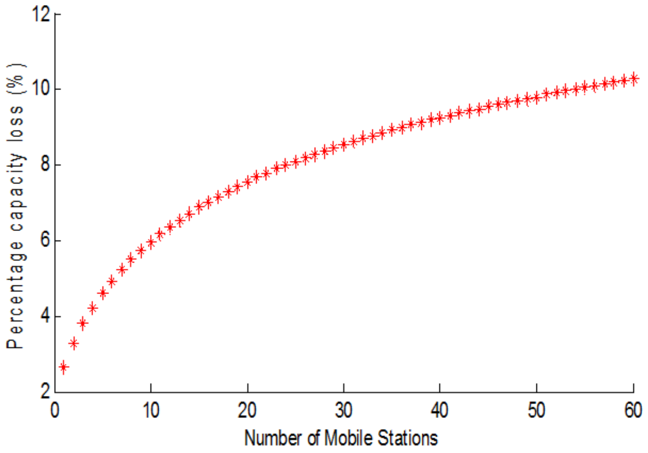

Figure 7. Capacity loss at D_{MS} = 3000 meters

Figure 3 shows the uplink capacity degradation when the mobile stations are positioned 500 meters from the enodeB receiver. As can be seen from figure 3, capacity degradation was very severe. A loss of 82.6% was observed when the 60 mobile stations were transmitted simultaneously. From figure 4, the capacity loss stood at 30.2% for 20 mobile stations while 60 transmitted mobile stations resulted in a 37.67% capacity loss. At 1500 meters the severity of the loss in uplink capacity was further reduced for 60 mobile stations to 23.51% as shown in figure 5. For 2000 meters and 3000 meters respectively, the capacity loss dropped below 20% as illustrated in figures 6 and 7. Although a 20% capacity loss is a relatively low percentage, it is still significant because in peak periods, subscribers will be short-serviced due to reduced capacity. The results obtained have shown severe degradation of the network capacity. This demonstrates that the IMD generated due to this interference scenario is not suitable for the operation of the VISAFONE enodeB receiver owing to the fact that Third Generation Partnership Project recommended a maximum tolerable loss of 5% capacity [10]. It therefore requires implementing mitigation techniques such as filtering to reduce the power effect.

V. CONCLUSION

This work evaluated the effects of Intermodulation Distortion on the uplink capacity of an LTE network due to coexistence with other networks. Using computational method, the IM frequencies capable of causing interference where derived. The signals from an INTERCELLULAR LTE downlink and ETISALAT uplink were observed to generate distortive Intermodulation frequencies when incident on the front end of VISAFONE LTE base station receiver. An evaluation of the effects of IMD on a receiver was carried out using deterministic method. Worst case scenario in which the interferers were transmitting at maximum power was assumed. The interference scenario in this work consists of one LTE enodeB interferer at a fixed distance and a population of GSM mobile station interferers at varying distances from the victim LTE receiver. The degradation suffered by the receiver due to IM interference capacity was evaluated in terms of uplink capacity loss. Loss of capacity was observed to be as high as 80% in some cases and the least capacity loss at 3000m was 5.97%.

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