EVALUATING CO-CHANNEL INTERFERENCE IN LONG TERM EVOLUTION-ADVANCED (LTE-Advanced) NETWORKS ON NS-3 SIMULATOR

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***Abstract* — Long Term Evolution Advanced (LTE-Advanced) networks enables the use of new and wider radio frequency spectrum and other new technologies that facilitates high data rates and lower latency. Furthermore, LTE-Advanced adopt the use of small cells as a traffic offloading mechanism. However, the use of small cells generates interference, which may lead to capacity loss. This paper analyse the downlink interference problem in LTE-Advanced small cell augmented macrocell network. We first analyse the interference observed in homogeneous network formed by configuring macrocell only. Secondly, we evaluate the co-channel interference of the heterogeneous network as results of the configuration between macrocell and small cell. We performed all simulations via extensive NS-3 simulations on LTE-Advanced topology and C++ programming language. Notable, our simulations demonstrate that confirm the interference observed when introducing small cell in a macrocell coverage area while they enhance the network.**

Keywords*— Macrocell, femtocell, co-channel interference, capacity, NS3, signal-to-interference-noise-ratio (SINR), homogeneous, heterogeneous, NS-3

I. Introduction

The increasing customer subscription to mobile networks, and the wide use of smartphones and their associated applications, implies a very high demand for mobile networks that supports high data rates. It is anticipated that by 2020, the existing wireless systems such as Long Term Evolution (LTE) and Long Term Evolution-Advanced (LTE-Advanced) would not be able to accommodate the expected 1000-fold increase in total mobile data rate demand [1]. It is therefore vital to develop superior technological solutions that can enhance the capacity of the network.

One such invention is small cells, which are low powered access points adequate for hot spot, dead zone within macrocell coverage and for coverage extension. Their contribution is towards better coverage and capacity enhancement. Types of small cells include microcell, picocell and femtocell. Femtocell has the lowest transmit power as compared to the other two. They have been the ideal solution for indoor coverage due to their minimal transmits power [2]. Femtocells are the key solutions for meeting the indoor high data rate demand. However, their introduction in a co-channel configuration implies the introduction of interference.

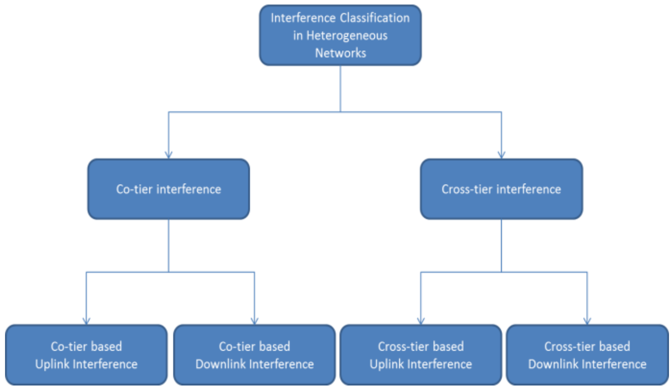

Figure 1: Interference classification for heterogeneous networks

There are four types of interferences classified into two groups: co-tier interference and cross-tier interference as depicted in Figure 1. Within these two groups, there are sub interference types differentiated by their link type. This is either uplink or downlink, hence the four types of interferences [3]. In order to analyse the interference, we need to consider the network topology. For this work, we consider LTE-Advanced topology as the recent standards for mobile communication.

LTE-Advanced is a mobile communication standard by the 3GPP that evolved from LTE. LTE is an emerging mobile technology with new features while preserving backward compatibility. The first two releases (release 8/9) are known as LTE [4]. On the other hand, LTE-Advanced is based on release 10 and it supports even higher data speed. Both LTE and LTE-A technologies are enablers for new and wider spectrum while they complement third generation (3G) networks with higher user data rates, lower latency, and a flat Internet Protocol (IP)-based network architecture.

Furthermore, both technologies have an air interface based on orthogonal frequency-division multiplexing (OFDM) which is different from the 3G technology that is based on code-division multiple access (CDMA). Bandwidth extension in LTE-A is supported via carrier aggregation, where it allows a maximum bandwidth deployment of 100 MHz, this bandwidth deployment enables a peak target data rates of 1 Gbps in the downlink (DL) and 500 Mbps in the uplink (UL) [5]. As much as this data rates are supported, it is not enough, as it cannot meet the anticipated data rates. This explains the attempt to use femtocell as a capacity enhancement mechanism in the deployment of LTE-Advanced macrocells [6] [7]. As explained before, this introduces interference, in order to analyse the associated interference, we will need to invest in the equipment and deploy a test-bed. However, this will require a lot of money, which can be a constrain for R&D.

Network simulations such as NS-3 becomes a vital tool to setup large-scale networks and test Quality of Service (QoS) parameters without having to buy the equipment. Modelling/simulating is the best way of testing ideas before their costly real implementation [8].

The rest of the paper is organised as follows. Section II discusses previous work and other solutions for prototyping co-channel interference designs. Section III discusses the simulation set up of the performed experimental network topologies performed on NS-3. Section IV presents analysed results from the simulation data in terms of the SINR and the capacity of the network topologies. Section V draws conclusions and outlooks the future perspectives on the current progress. Section VI makes recommendations to the study.

II. Related Works

a) LTE-Advanced Co-Channel Interference

LTE-A mainly focuses on Three Factors Carrier aggregation, Cell based (like femtocell, macrocell etc.) stations in a network and extended multiple-input multiple-output (MIMO) support [2]. Due to the increasing demand for higher data rates and for the quality of service by home users (indoor userse), it became a necessity for mobile communication operators to develop suitable design criteria to meet the rising expectations [9].

While in a co-channel deployment scenario, interference is more likely to appear when femtocells use the same radio frequency bands and when femtocells (HeNB) share the same radio frequency bands with macrocell (eNodeB), this choice provides higher system capacity for the cellular operators.

In [10], it is shown that when deploying femtocells within the coverage area of a macrocell, many interference scenarios may occur within the same tier or on different tiers. The paper also shows that the worst-case interference scenario occurs in two cases; the first case is the co-channel interference when sharing the same or part of the bandwidth; and the second one is the interference on the downlink of the macro-base station when the femtocells operate in closed access systems.

b) Network-Simulator-3 (NS3)

NS3 (Network Simulator version3) is an open source discrete-event network simulator that is primarily used for research and educational use. NS3 is licensed under the GNU GPLv2 license, and is available for research and development.

It contains high quality, well-maintained and validated network models. NS-3 comprises of C++ [11], which implies that the implementation of simulations and the core model is in C++. Furthermore, NS-3 is built as a library that may be statically or dynamically linked to a C++ main program.

The approach of this paper is to perform a simulation using NS-3 to analyse the system capacity of homogeneous networks. We use the results of the homogeneous network as a reference to the results observed in the analysis of capacity because of the interference introduced when simulating the deployment of femtocells. As explained above, the deployment of femtocells is in the same frequency band as an existing macrocell network, forming a heterogeneous network.

III. Simulation Procedure

For this study, a simulation method [12] will be adopted in the case of a discrete-event simulation approach [13]. It will be used to investigate an existing occurrence.

This study investigates the co-channel interference on the downlink of eNodeB and HeNB when deployed separately in a homogeneous environment. Then the study will also investigate the interference caused when a HeNB is deployed together with an eNodeB on the same bandwidth.

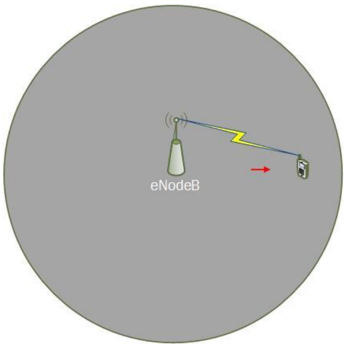

Figure 2: Macrocell homogeneous environment with a single UE

eNodeB with a cell coverage of 500m with a single UE moving constantly from the BS to the edge of the cell coverage as shown in Figure 2 above.

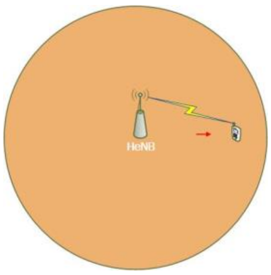

Figure 3: Femtocell homogeneous environment with a single UE

HeNB with a cell coverage of 10m with a single UE moving constantly from the FBS to the edge of the cell coverage as shown in Figure 3 above.

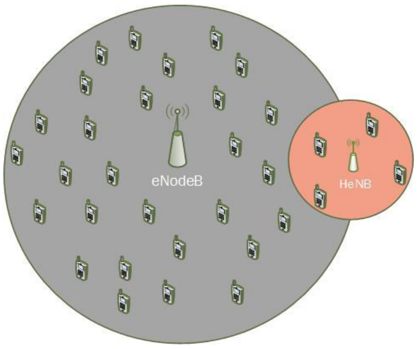

Figure 4: Macro-Femtocell HetNet environment

Heterogeneous network consisting of a macrocell with a cell coverage of 500m and a femtocell with a cell coverage of 10m placed at the cell edge of the macrocell which is shown in Fig. 4 above. In this network environment, the macrocell is allocated 100 MUE and 4 FUE to the femtocell.

Table I - Macrocell Simulation Parameters

Parameter	Value
eNodeB distance	500 m
eNodeB Tx Power	43 dBm
Bandwidth	20 MHz
Number of UE	100
Thermal Noise density	-174 dBm/Hz
UE speed	10 m/s
Number of UEs	1
Simulation run time	50 s

The system parameters are specific for a macrocell network based on LTE technology as shown in Table 1 specifically, this is for simulating a homogeneous network topology.

Table II - Femtocell Simulation Parameters

Parameter	Value
HeNB distance	10 m
HeNB Tx Power	20 dBm
Bandwidth	20 MHz
Number of UE	4
Thermal Noise density	-174 dBm/Hz
UE speed	0.2 m/s
Number of UEs	1
Simulation run time	50 s

Furthermore, the following system parameters shown in Table 2 are specific for a femtocell network based on LTE technology as shown in Figure 3 specifically; this is for simulating a homogeneous network topology.

System parameters of the co-channel deployment of a macrocell and a femtocell in an LTE based network are given in Table 3, these parameters are used for simulating the heterogeneous environment network topology.

Table III - HetNet Simulation parameters

Parameter	Value
eNodeB distance	500 m
eNodeB Tx Power	43 dBm
Bandwidth	20 MHz
HeNB distance	10 m
HeNB Tx Power	20 dBm
Bandwidth	20 MHz
Thermal Noise density	-174 dBm/Hz
UE speed	10m/s when within the eNodeB coverage area, 0.2 m/s when within the HeNB coverage area
Number of UEs	1

IV. Results Analysis

A. *SINR Analysis*

From the simulation results, RSRP was used to compute *SINR (w)* for the discrete-event simulations (from all three simulations performed) using [14]

$$\gamma_i = \frac{P_i}{I_i + \sigma_i} \qquad (1)$$

γ_i represents (SINR) signal-to-interference-noise-ratio of the user equipment $(UE_m/UE_f/UE_{mf})$ in equation (1); P_i represents the signal power of the UE, while I_i indicates the channel interference signals from other cells in the current system (since the macrocell system consists of a single homogeneous cell there would not be any interference).

The same applies to the single homogeneous cell system of the femtocell, whereas in the HetNet there would be interference of the femtocell to the macrocell; σ_i represents the background noise in the network environments, which would be used as the thermal noise density.

After calculations to obtain *sinr(w)* were done, *sinr(w)* was converted into decibels using [15] as shown in equation (2):

$$sinr(dB) = 10log_{10}\left(sinr(w)\right) \qquad (2)$$

The HetNet SINR analysis with the UE attached to the eNodeB results to decreasing values as the UE device moves away from the BS towards the edge of the MBS coverage.

The SINR ratio was decreasing as it was coming closer to the HeNB while being connected to the MBS, contrary the SINR increased as it entered the coverage area of the HeNB after the handover process (the UE was now connected to the HeNB).

B. Capacity Analysis

Shannon's Capacity Theorem is used to determine the theoretical maximum information transfer data rate of the channel for a particular noise level and bandwidth.

The following equation demonstrates how the theoretical maximum user throughput (C) that can be experienced by a UE is converted from the calculated SINR of that UE [16] as shown in equation (3);

$$C=\frac{B}{n_{ue}}.log_2(1+SINR) \quad (3)$$

Where B is the bandwidth of the transmitting node, and n_{ue} is the number of user equipment that is present in the network topology, which is shown in the simulation parameters for the network topologies simulated.

In the macrocell capacity analysis, it was assumed that the macrocell had the maximum number of devices it could be allocated with of 100 MUE ~ $n_{ue} = 100$.

In the femtocell capacity analysis, it was also assumed that the femtocell had its maximum number of devices, of 4 FUE ~ $n_{ue} = 4$.

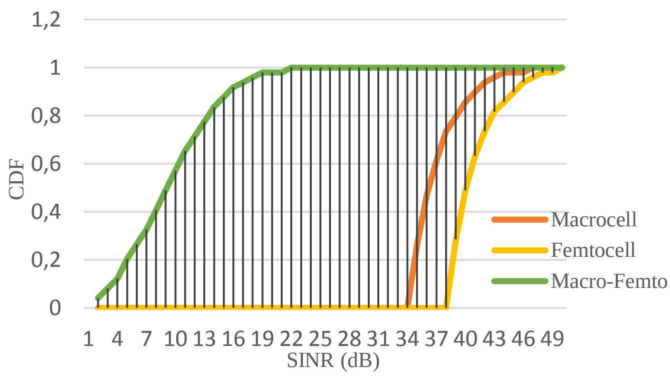

Figure 5: CDF of downlink SINR (dB)

In Figure 5, the CDFs on the downlink channel of all three simulations were computed based on the SINR (dB) of the macrocell, femtocell and combination of both in a HetNet environment.

The simulation results show that the SINR is superior in heterogeneous environment when the UE move to within the femtocell and are connected to the Femtocell than the macrocell. This confirms the literature that femtocell does improve the capacity when deployed in the macrocell coverage.

In the macrocell homogeneous environment, as we move away from the center of the macrocell towards the edges, the interference increases and since it is a homogeneous environment with a single UE the interference caused comes from thermal density known as white Gaussian noise.

The interference in the femtocell peaks up later and is higher as compared to the homogeneous environment of the macrocell and this is due to the inter-site distance of the cell.

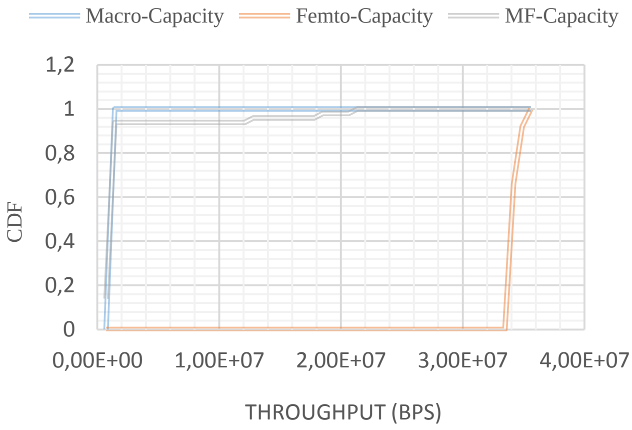

Figure 6: CDF vs Capacity

Figure 6 shows a CDF over the capacity results for the simulated environments (macrocell, femtocell, macro-femto network). The user throughput is directly proportional to the SINR and therefore exhibits the same behaviour as the latter.

Heterogeneous networks made from a macrocell and a small cell as simulated in the study, provide an attractive means of expending mobile network capacity and the coverage area of a macrocell. The results show that the throughput of the macrocell has been improved due to the deployment of the femtocell.

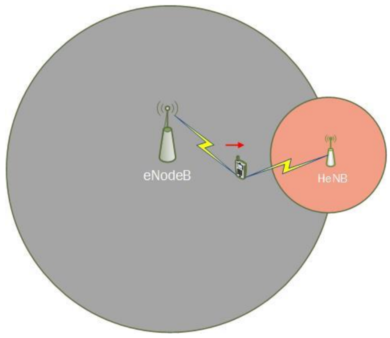

Figure 7: Macro. & Femto. Handover process in the HetNet environment

In the heterogonous network simulation involving the eNodeB and HeNB, a handover process (shown in Figure 7) took place while the UE was moving from within the MBS to the edge of the HeNB. While the UE approached the edge of the eNodeB coverage area the data session of the UE to the eNodeB, to avoid termination, the data session of the UE was transferred to the channel of the HeNB. This was because the UE was now within range of the femtocell, with a poor signal from the macrocell.

Network densification means adding more cell sites to increase the amount of available capacity. In the heterogeneous network simulation performed, the femtocell introduced in the network environment added more capacity where it was most needed. Consequently, this enables the offloading of data traffic from the eNodeB to the HeNB. This implies that users were offloaded to the femtocells data channel leaving the network capacity of the macrocell less strained.

V. CONCLUSIONS AND FUTURE WORK

Since HeNBs are randomly distributed and fully deployed by customers, they are the main source of co-channel interference in an eNodeB coverage area. In this study, analysis of co-channel deployment was investigated in terms of system capacity and SINR. The study also showed that deploying a low power node (femtocell) gives higher effect if it is deployed on the edge of a macrocell. Co-channel interference (CCI) is the most important capacity limiting source in cellular systems.

A simulation framework of three network environments was developed under 3GPP LTE systems using NS3. NS3 models were implemented and NS3 documentation was also made use of for code integrity. From the simulation results, it was shown that while femtocells provide more system throughput to a HetNet deployment network, they also bring interference into the network. Certain constraints were not included when running the simulation while some constraints were assumed in the study. The constraints were assumed to make the simulation more focused and easier to implement while trying not to render the simulation unrealistic.

VI. RECOMMENDATIONS

This section provides some recommendations to overcome the simulation assumptions. The following can be considered as future work:

a) Adding Support to Uplink using NS3

Attention to the data channel in this study was targeted to downlink channel only, as downlink frequency assignment was easier to deal with due to the fact that assigned resources do not have to be contiguous. To add more analysis to CCI in HetNet, the interference on the uplink channel from the NS3 simulation results can also be done.

b) Adding an antenna type

Antenna selection is a key decision in today's LTE wireless network design. Special attention need to be explored on several antenna options available that would be ideal in analyzing CCI. It is therefore recommended that the antenna type be researched in future studies.

c) Considering path loss Model

The radio wave propagation model or path loss model plays a very significant role in the planning of any wireless communication system. Software simulations based on empirical models make it possible to estimate path loss propagation in a mobile environment.

d) HeNB deployment

The HeNB deployment within an eNodeB is unpredictable since users deploy indoor femtocells anywhere within the macrocell. For future work, a study can be based on femtocell deployment.

e) Interference mitigation techniques

Interference is characteristic to any LTE-A HetNet deployment. LTE-A offers a variety of complex and advanced techniques at both the network and the device level to mitigate interference. The techniques to mitigate interference in LTE can be done as future work.

f) Evaluating the impact of the MIMO systems in HetNet systems using NS3

While the proposed simulation done through NS3 presented a single channel for input and output, MIMO could be implemented through NS3 which would increase throughput by transmitting distinct data streams over different antennas using the same resources in both frequency and time whereby these two properties are handled well by the discrete-event simulator.

ACKNOWLEDGMENT

This work was carried out at the Council for Scientific and Industrial Research (CSIR), Pretoria, and was submitted as a research project for a BSc honour's in Computer Science degree at the University of Venda, South Africa.

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