Signal to Interference Plus Noise Ratio Analysis of Femtocells in Advanced Long-Term Evolution (LTE)

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***Abstract*— This work aims to investigate signal to interference plus noise ratio of femtocells for indoor users under long term evolution (LTE). Ethiopia has different cities with big buildings, companies, hotels, hospitals, condos, residential houses, and others. Signal attenuators like several walls, number of floors, and others affect the quality of the signal. For this reason, femtocells are taken as a solution to enhance the signal quality. This work considers signal to interference plus noise ratio with the system flow chart. The performance analysis used Multi-Wall Multi Floor (MWMF), an indoor propagation model. Path losses and signal to interference plus noise ratio are used to measure the performance in this work. The outcome of this work shows that femtocells are capable of enhancing signal quality for indoor users.**

***Index Terms*—Femtocell; LTE; Power Control; Signal to Interference Plus Noise Ratio.**

I. INTRODUCTION

All countries in the world exchange information and data through networking, internet computing, and different kinds of massive communication systems [1]. Since 1980, mobile technology has evolved at a very high rate and through these development phases, they provide better performance, coverage, capacity, and spectrum efficiency along with cost reduction and better controlling mechanisms [1].

Long-term evolution (LTE) is a new mobile technology that is used for increasing data rate, spectrum efficiency, throughput, and improved end-user experience of a communication system [2]. Ethiopia has started using this technology to solve existing network problems. Even though the technology is evolving, the number of subscribers is increasing from time to time, and this has an effect on the data rate of the communication system [2]. Due to a high rate of population growth, wireless data usage is a big problem for almost all users and as a result, more inventions or improvements are needed [2]. In order to reduce these problems, small cells are used as an option for covering certain dead zone areas, where the mobile network is below standard [3]. Among these small cells, femtocell is one of the best, low-power, and low-cost base stations used for increasing network capacity and coverage area [3].

The goal of this article is to study mobile network problems of indoor communications and provides the signal to interference plus noise ratio (SINR) analysis of femto and macrocells. It describes an overview of indoor propagation models and their associated performance in terms of path losses. It also describes in more detail the effect of walls and floors on SINR performances for indoor users using the MATLAB tool. This paper presents the mathematical analysis of SINR considering wall and floor losses and describes the improvements that femtocells deliver. It also provides some results to show their advantages.

II. LITERATURE REVIEW

There have been variety of researches on the use of small cells as a way of improving the performance in relation to homogenous networks. Among those researches are as listed in Table 1.

Table 1
Literature Review of Selected Papers

No.	Paper Title	Objective	Outcome of the Paper	Gaps
1.	Mikko Jarvinen, 2009: Femtocells Deployment in 3rd Generation Networks.	This paper studies the possible problems in femtocell rollouts and evaluate the status of standardization and available devices in 3G network.	The simulations studies service coverage and throughput. It shows how the coverage is improved by femtocells and how the total network capacity gains can be up to 5 times.	Losses associated with walls and floors are not considered
2.	Chandrasekhar, J. Andrews, and A. Gatherer, 2008: Femtocell Networks: A Survey.	It shows the technical and business arguments for femtocells and describe the state-of-the-art on each front. It describes the technical challenges facing femtocell networks, and give some preliminary ideas for how to overcome them.	The simulation shows Cumulative distribution function of femtocell and macro cell. It also shows Femtocell outage probability	Losses associated with walls and floors are not considered
3.	Jeffrey G. Andrews, Holger Claussen, Mischa Dohler, Sundeep Rangan, Mark C. Reed, 2012: Femtocells: Past, Present, and Future.	This article overviews the history of femtocells and interprets their key aspects, and provides a preview of small cell technology	It shows the economic and capacity benefits femtocells which provides optimistic sales forecasts. It shows that there is nothing fundamental preventing very dense femtocell deployments.	Losses associated with walls and floors are not considered

No.	Paper Title	Objective	Outcome of the Paper	Gaps
4.	Siemens Networks Finland, 2011, White Paper: Improving 4G Coverage and Capacity Indoors and at Hotspots with LTE Femtocells.	This paper explains how LTE femtocells work and what they can do, and presents a viable solution for service providers. It studies LTE femtocell security and management structures. It studies LTE femtocell network architecture	It highlights points to consider when deploying LTE femtocells	Losses associated with walls and floors are not considered

III. Research Methodology

The methods used to achieve the objectives of this work are:

- *Literature Review*
  This leads to reading different books, different IEEE articles and journals, 3GPP standardization documents, exploring the internet, studying MATLAB simulation and so on.
- *System Design*
  It includes analyzing system flow for the signal to interference plus noise ratio.
- *Simulation*
  It involves transforming the proposed flow chart into MATLAB simulation.
- *Performance Comparison*
  It involves SINR analysis of LTE cellular network with and without femtocells deployment.

IV. Theory

A. Introduction to Long Term Evolution

Technology is evolving at an enormous rate starting from the 1st generation, and LTE is the recently new technology used for increasing the data rate [2]. The LTE specification provides downlink peak data rates of at least 100 Mbit/s, and uplink of at least 50 Mbit/s and radio access network (RAN) round-trip times of less than 10 ms [2,4]. The main advantages within LTE are high throughput, low latency, higher spectral efficiency, plug and play, an improved end-user experience, and a simple architecture resulting in low operating costs [2]. The final outcome from this project is a new set of standards defining the functionality and requirements of an evolved, packet- based, and radio access network [3,5]. It supports carrier bandwidths, from 1.4 MHz to 20 MHz and both frequency division duplexing (FDD) and time division duplexing (TDD) [6]. The LTE architecture consists of the evolved NodeB (eNB), evolved packet core (EPC), and user equipment (UE) [7]. The eNB delivers the E-UTRA User Plane and Control Plane protocol terminations towards the UE [4,7]. The S1-interface supports a many-to-many relation between eNBs and mobility management entity/serving-gateway (MME/SGWs) [5,8]. Deploying femtocells in an LTE advanced environment may include, realizing the full potential of LTE like coverage, capacity, and all the required parameters [6,9].

B. Multi Wall Multi Floor (MWMF)

Deployment of wireless technologies for digital signal processing with advanced antennas are used for determining the performances of a communication system through different outdoor channel models. The drawback of these models is that, they do not provide information on the losses associated with walls and floors of any building. Therefore, indoor propagation models are very important in determining the performances of small cells in a building. Among these, multi-wall multi-floor (MWMF) is one of the most effective indoor models used for analyzing losses associated with walls and floors of any building. The penetration losses owing to walls and floors between the source and destination have a substantial effect on the overall capacity [10].The penetration loss plays a significant role and has a large effect on estimating the overall system capacity, particularly for SINR manipulations

This Multi-Wall-and Multi-Floor (MWMF) model has been derived from ray-tracing simulations and has been developed by Motley and Keenan [10,11]. It considers all losses associated with thickness and material of walls and floors. Attenuation due to the first traversed wall is larger than the incremental attenuation caused by each additional wall [12]. The MWMF model used in this paper takes into account the decreasing penetration loss of walls and floors of the same category as the number of traversed walls/floors increases**.** The mathematical equation is indicated in Section 6.2 and the performance of this model is determined by the path loss at a distance of 1m (L_O), power decay index (n), floors and walls categories, number of traversed walls and floors and losses associated with walls and floors categories.

V. Testing and Analysis

Figure 1 shows the general flow chart of this work and it starts with identifying a place to deploy femtocells. These could be home deployments, outdoor or enterprise deployments. It also includes urban and sub-urban deployments. The other scenario can be a row of houses adjacent to each other having reasonable separation between each other. The basic application areas of user’s interest are voice, data, video streaming and other social net workings.

The number of femtocells required for installation depends on a place of deployment, and it is calculated from equation (1). Once the number of femtocells is determined, then all the required parameters of the LTE base station and the neighboring small cells are scanned and interferences are calculated from equations (6) and (7). For manipulation of these parameters, the Okumura-Hata model is used for LTE and the Multi-wall multi-floor (MWMF) is used for indoor propagation mechanism. The information scanned is used for evaluating the interference of each user of either macro or femtocells. The signaling exchange is used to determine path loss and signal to interference plus noise ratio. The cause of this interference might be factor-like Co-channel operation versus adjacent channel operation, power difference and femtocells access methods. Signal to interference plus noise ratios are calculated by considering interferences from neighboring macro and femtocells. After that, SINR is calculated, and depending on these values, the usable channels are ranked in descending order. These computations are done in radio resource management (RRM) and sent to all femtocells. Based on the pre-computation of channel states, spectrums are allotted for femto and macro users. The calculated values of SINR are compared with the threshold values. If the calculated signal to interference plus noise ratio is below standard (threshold), then power control can be done.

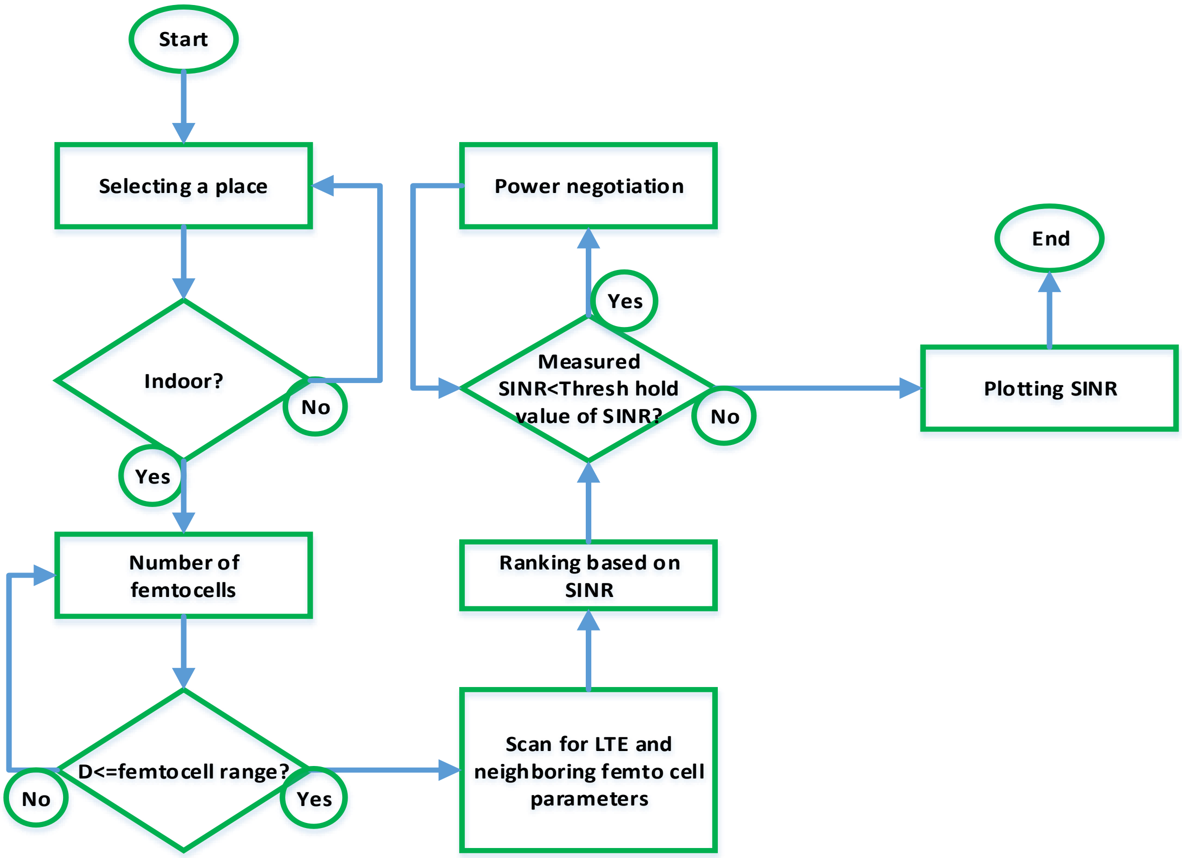

Figure 1: Flowchart of signal to interference plus noise ratio

A. Working Principle of the System

The working principle of the system starts with identifying a place to deploy femtocells. Once location is identified, the optimum number of femtocells needed to cover a given area cannot be determined a priori as it is dependent on the location of macro cells. Given the area of deployment scenarios and femtocell coverage area, the optimum numbers of femtocells required are given as shown below in equation (1)[13].

$$NF = \frac{A}{FCA} \tag{1}$$

where: NF = Number of femtocells
A = Area of the building
FCA = Femtocell coverage area

The required height for transmitting antenna (H_t) and maximum load (A) can be calculated as shown below in equations (2) and (3) [13].

$$H_t = \frac{E_c \lambda d}{I_c 120\pi} \tag{2}$$

$$A = UB\frac{T}{60} \tag{3}$$

where: U = Users number
B = Call request per minute
T = Average calling time
E_c = Cell voltage
λ = Wavelength
I_c = Cell current
d = Diameter (2*radius of femtocell)

B. Femtocell Path Loss Model

Path loss is the loss of power of a radio frequency signal travelling through space. It is expressed in dB. Path loss depends on:

- Distance
- The line-of-sight clearance between the receiving and transmitting antennas
- Antenna height

MATLAB simulation for all the indoor propagation models is done. According to the results from the simulation, the MWMF has low path loss as compared to other models. As a result, it is selected for femtocells indoor propagation analysis. The MWMF path loss is expressed as equation (4) [14].

$$L_{MWMF} = L_O + 10n\log(d) + \sum_{i=1}^{I}\sum_{k=1}^{k_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{k_{fi}} L_{fik} \tag{4}$$

where: $L_o = 20\log\left(\frac{4\pi}{\lambda}\right)$
n = Power decay index
d = Distance
I = Number of wall categories
J = Number of floor categories
k_{wi} = Number of traversed walls
k_{fi} = Number of traversed floors
L_{wik} = Loss of Kth wall traversed (dB)
L_{fik} = Loss of Kth floor traversed (dB)

C. LTE Path Loss Model

There are many models given for path loss in long term evolution (LTE) environments. Among these, Okumura-Hata model is the most widely used model. The Okumura-Hata model is expressed as equation (5) [15].

$$L_p(dB) = 69.55 + 26.16log10(f) + (44.9 - 6.55log10h_b)log10d - 13.82log10h_b - a(hmu) \quad (5)$$

where: f = Carrier frequency (MHz)
d = Distance b/n base station and user
h_b = Height of base station Antenna
hmu = Height of mobile unit Antenna
(hmu) = Correction factor for mobile unit Antenna height, (hmu) = 3.2[log10 (11.75hmu)] ^{2} -4.97

The $a(hmu)$ = 3.2 [log10(11.75hmu)]^2−4.9 for (f > = 400MHz, and $a(hmu)$ = [1.1log10(f)−0.7]*hmu−[1.56 log10 (f)−0.8] for (f < 400MHz).

D. Signal to Interference Plus Noise Ratio

The followings are different interference between macro and femtocells as well as between femtocells.

- Macro to femto interferences
- Femto to macro interferences
- Femto to femto interferences

The estimation of the received SINR of macro user on channel subcarrier, when the macro user is interfered from neighboring macro cells and all the adjacent femtocells is expressed by the following equations [16].

$$\mathrm{SINR_M} = \mathrm{P_M G_{mM}}.\frac{1}{\mathrm{N_o f} + \sum_{\mathrm{M'=0}}^{\mathrm{M'=N}} \mathrm{P_{M'} G_{M'}} + \sum_{\mathrm{F=O}}^{\mathrm{F=N}} \mathrm{P_F G_F}} \quad (6)$$

$$\mathrm{SINR_F} = \mathrm{P_F G_{fF}}.\frac{1}{\mathrm{N_o f} + \sum_{\mathrm{M=0}}^{\mathrm{M=N}} \mathrm{P_M G_M} + \sum_{\mathrm{F'=0}}^{\mathrm{F'=N}} \mathrm{P_{F'} G_{F'}}} \quad (7)$$

where: P_M = Transmit power of macro cell
$P_{M'}$ = Transmit power of neighboring macro
G_M = Channel gain of macro cell
$G_{M'}$ = Channel gain of neighboring macro
G_F = Channel gain of femtocell
$G_{F'}$ = Channel gain of neighboring femtocells
P_F = Transmit power of femtocell
$P_{F'}$ =Transmit power of neighboring femtocells
N_o = White noise power spectral density
f = Subcarrier spacing
M' = Number of neighboring macro cells
F = Number of femtocells
M = Number of macro cells
F' = Number of neighboring femtocells

E. Power Control

The power difference between macro and femtocell produces interference on each other. Different interference control mechanisms exist. Among these, power control is used to reduce interference. The followings are the steps for power control mechanism:

- Step 1: Macro cell user equipment (MUE) detects surrounding femtocells signal.
- Step 2: Macro user equipment informs macro cell to send handover request to femtocell if the signal coming from femtocell is larger than the signal coming from macro cell.
- Step 3: If the signal coming from macro cell is larger than the signal coming from femtocell, then femtocell increases its coverage.
- Step 4: In this case, femtocell should check its most outer placed user equipment and computes the difference between femtocell radius and the distance of the most outer placed femto user equipment (FUE).
- Step 5: The radio transmits power of femtocell is either increased or decreased according to the difference.

VI. Results And Discussions

In this part, femtocells impact on the LTE network performance is evaluated. The analysis is performed as a means to evaluate and compare the efficiency of signal to interference plus noise ratio of LTE with and without femtocells. It is based on the study of any building having the following elements:

- A number of apartments
- The number of floors
- The number of wall, etc.

The following key performance indicators are analyzed in this work in order to understand the improvements brought by femtocells. Those performance metrics are:

- Propagation models
- SINR

A. Propagation Models

In this section around 6, indoor propagation models are analyzed and their performances are simulated using the MATLAB tool. As shown in Figure 2, the path loss of MWMF is low as compared to others, considering one number of wall and floor. Therefore, the recommended path loss model for femtocells is MWMF. In addition, Figure 3, indicates the same idea, but it is included to show how the path loss increases as the number of walls and floors increases to three (3) and four (4) respectively. Throughout this work, the respective loss for one (1) wall is 5dB and for one (1) floor is 2dB.The distance between femtocell and LTE base station is greater than or equal to 500 meters. The maximum theoretical femtocell radius is 100 meters and the real coverage radius is 50 meters.

Figure 4 shows a comparison of path loss for femtocell and macrocell. Macrocell base station is placed at 500 meters away from femtocell base station. The blue color line indicates a line of sight (LOS) path loss and the red line indicates non-line of sight (NLOS) path loss of macrocell.

As shown, the path loss of macrocell is increasing up to a place where femtocell base station is deployed (up to 500 meters). But the deployment of femtocell at 500 meters away from macrocell helps to decrease pass loss and seamless transmission from macro to femtocell occurs. The black color line indicates a line of sight (LOS) path loss and the pink line indicates non-line of sight (NLOS) path loss of femtocell. Path loss beyond femtocell place increases as usual. However, the path loss for femtocell is much lower than that of macrocell base station. Parallel to that, the path loss of LOS is lower than that of NLOS as indicated in Figure 4.

B. Signal to Interference Plus Noise Ratio

In this section, the signal to interference plus noise ratio of the LTE and femtocell is explained. SINR of all the users is compared to the threshold value of a particular base station. As a result, if the SINR is less than the threshold value, it raises a situation of conflict that might happen due to interferences from the neighboring cells. If the measured SINR is greater than the threshold value, then the overall capacity of the wireless link can be obtained and reliable communication occurs. As seen on Figures 5 and 6, the closer to the base station, the higher SINR. As the distance from the base station increases, interferences from neighboring cells increases and, thus SINR value decreases. In this analysis, the graphs show SINR of macrocell and femtocell interferences with the following cases:

- Case 1: LTE interfered by macro (LTE) and femtocells
- Case 2: Femtocell interfered by macro (LTE) and femtocells

Figure 5 shows the SINR of LTE interfered by neighboring LTE and femtocells. As shown on the graph, the SINR of LTE is plotted for three number of walls, three number of floors, two interfering LTE cells and four interfering femtocells. It shows the signal to interference plus noise ratio of LTE base station interfered by two (2) neighboring LTE cells and four (4) neighboring femtocells. The material type of walls and floors and their associated losses are very important in determining the SINR of the LTE base station. Accordingly, the red color line indicates SINR of LTE interfered by four (4) neighboring femtocells only and the blue color line indicates SINR of LTE interfered by two (2) LTE cells only. In addition, the black color line indicates SINR of LTE interfered by two (2) LTE cells and four (4) femtocells. As seen from Figure 5, the SINR is high for the interferences from four (4) neighboring femtocells and low for the interferences from four (4) neighboring femtocells and two (2) LTE cells. In addition, the SINR decreases as the number of walls and floors increases.

Figure 6 shows the SINR of femtocells interfered by neighboring LTE and femtocells. As shown on the graph, the SINR of femtocell is plotted for three number of walls, three number of floors, two interfering LTE cells and four interfering femtocells. It shows the signal to interference plus noise ratio of femtocell interfered by two (2) neighboring LTE cells and four (4) neighboring femtocells. The material type of walls and floors and their associated losses are very important in determining the SINR of femtocell. Accordingly, the blue color line indicates the SINR of femtocell interfered by four (4) neighboring femtocells only and the black color line indicates SINR of femtocell interfered by two (2) LTE cells only. In addition, the red color line indicates SINR of femtocell interfered by two (2) macrocells and four (4) femtocells. As seen from Figure 6, the SINR is high for the interferences from four (4) neighboring femtocells and low for the interferences from four (4) neighboring femtocells and two (2) LTE cells. In addition, the SINR decreases as the number of walls and floors increases.

Generally, it is indicated on the graph that femtocell users have good SINR levels in the building near the femtocells. Specifically, it is shown that high SINR is observed when the femtocell is used and the results show that, it is very advantageous to deploy femtocells in buildings under LTE.

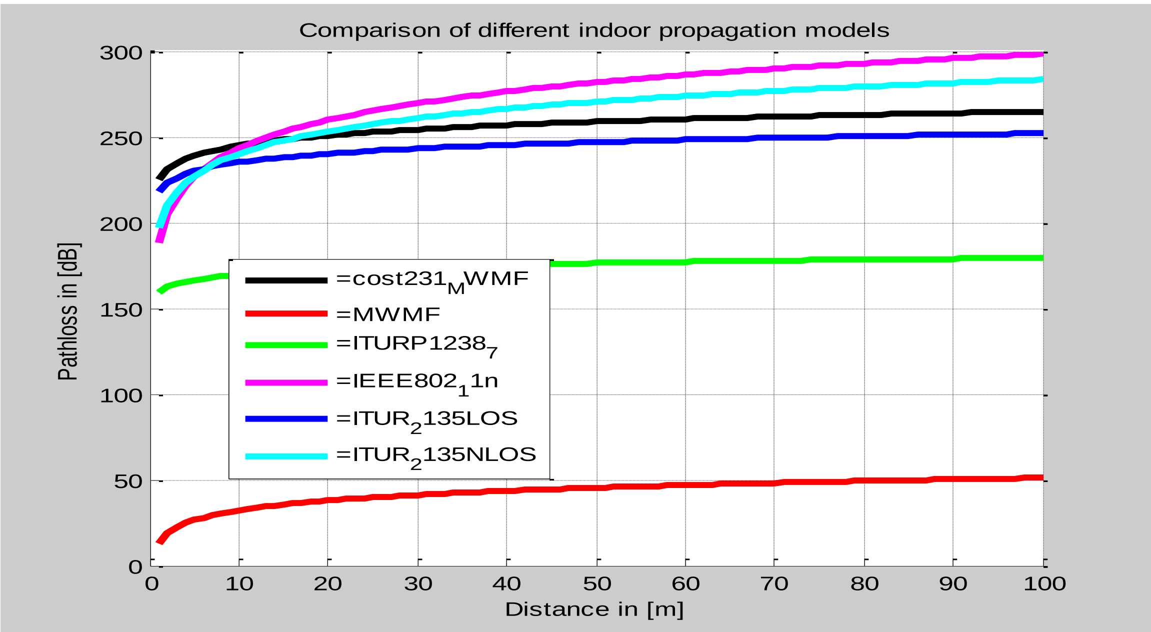

Figure 2: Comparison of indoor propagation models for 1 wall and 1 floor

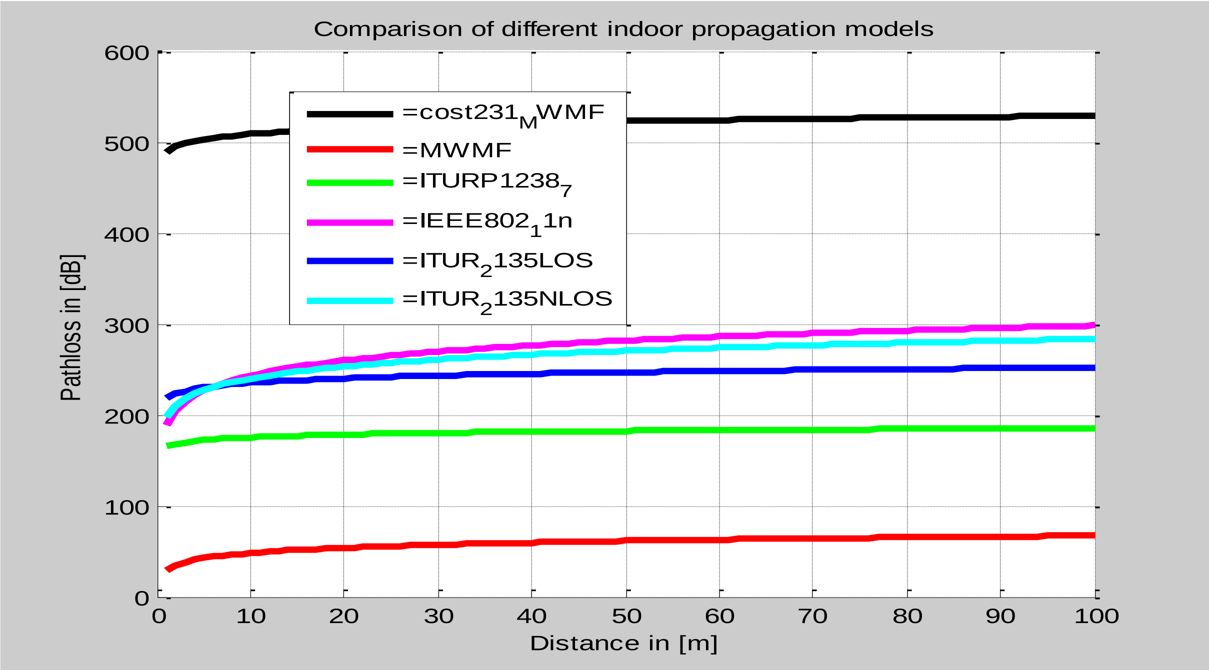

Figure 3: Comparison of indoor propagation models for 3 walls and 4 floors

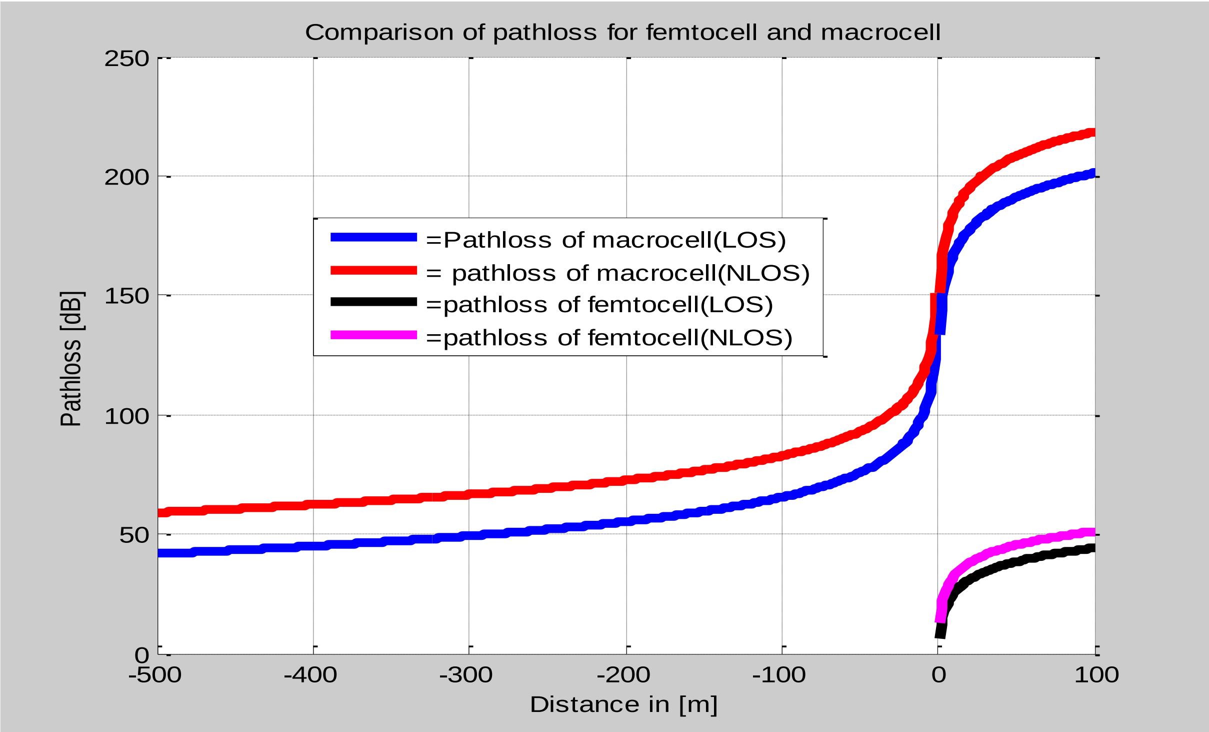

Figure 4: Improvement brought by femtocell after 500m

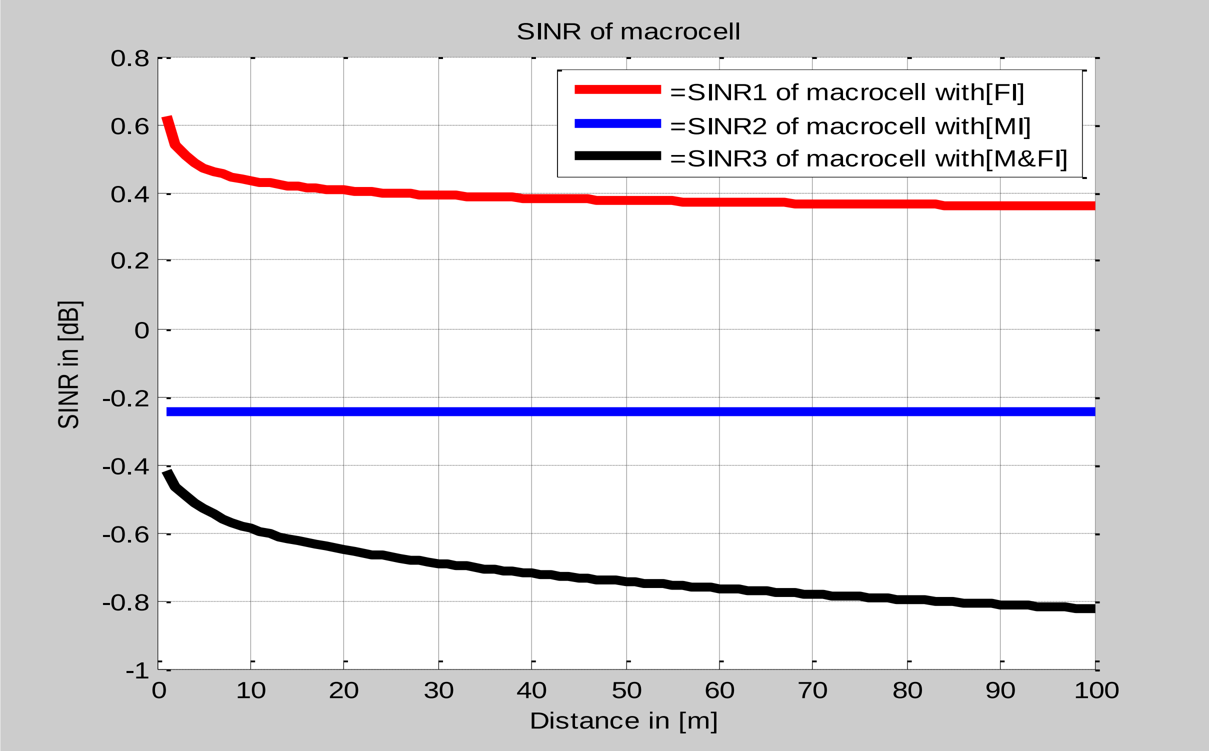

Figure 5: SINR of macro cell with interfering femto and neighboring macro cells

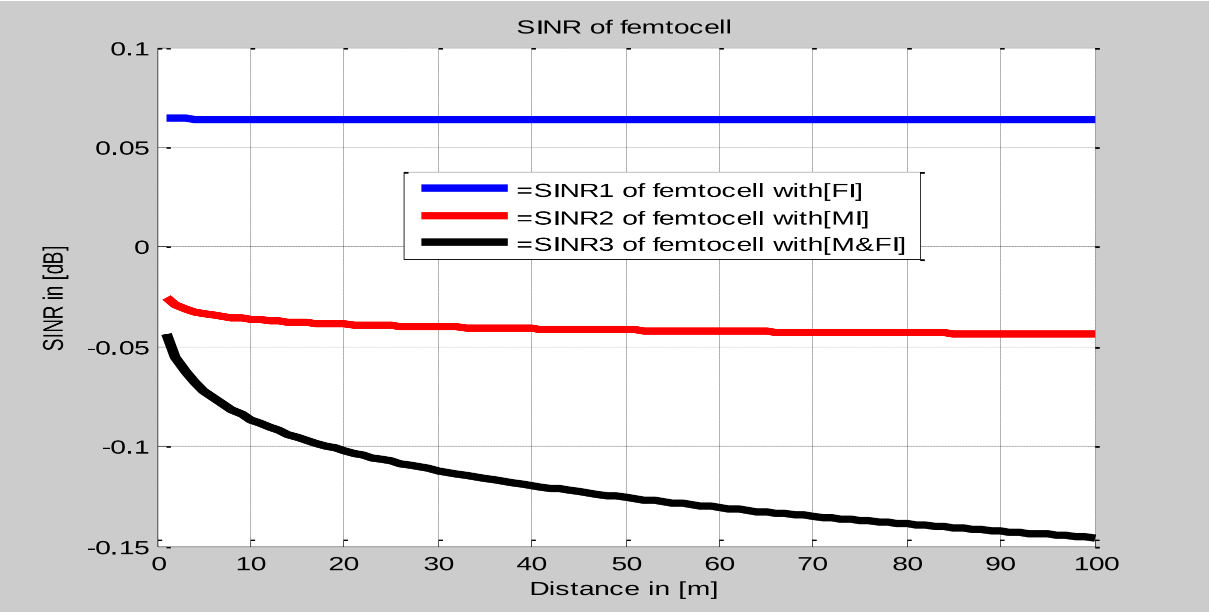

Figure 6: SINR of femtocell with interfering macro and neighboring femtocells

VII. CONCLUSION

Ethiopia is implementing a development and transformation strategy to become a middle-income country in the next 15 years. Ethio telecom is a part of this strategy that is used as an input for the successful accomplishment of this mission. LTE is the new technology that is used for increasing the capacity, coverage, and enhancing the overall performance of the network. But the entire cities of Ethiopia are under construction and development. As a result, LTE alone cannot support the ever-growing demand for bandwidth-hungry applications of indoor users. Therefore, femtocells provide an attractive solution for meeting the capacity requirements of the network in different buildings including residential houses. This work identified the signal to interference plus noise ratio and propagation loss as the performance metrics. Generally, it was investigated that the number of walls and floors attenuated the quality of the signal. Simulation results show femtocells restores the LTE SINR in indoor areas.

ACKNOWLEDGEMENT

At the very beginning, all praises and thanks to Almighty GOD who helped me to complete this work. Next to that, I would like to thanks Ethio-telecom as they were very cooperative in providing the necessary data for this work. Their fruitful technical advice and comments were unforgettable. My appreciation also goes to all my friends for their encouragement and valuable suggestions. Finally, I express my utmost gratitude to my beloved families for their prayer and everlasting love to achieve my goals.

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