Performance Analysis Of Femtocell in an Indoor Cellular Network

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***Abstract*—This paper investigates the use of femtocell as a solution to improve indoor coverage and off-load mobile data indoors on the macro cellular networks. Specifically, the article deals with a performance analysis of femtocell in an indoor cellular network. This is achieved by designing and modelling femto-cell network in an indoor cellular network using OPNET modelling and simulation software. The user satisfaction criteria for the various traffic types including voice, video conferencing, email, web and file transfer protocol traffic were defined and simulated. The modelled femto-cell network and traffic types were simulated with each simulation instance carried out with ten different seeds in OPNET version 14.5 and average values recorded. The performance metrics of the femtocell were obtained by measuring the Quality of Service, Mean Opinion Score, delay and the throughput of these user traffic types and also the throughput of femtocell node in the indoor network. These performance metrics were discussed and compared to the macro cellular networks. The results demonstrate that femtocell assures improved indoor coverage, provides better network capacity than the 3G macro cellular networks. This research re-affirms that Femtocell is able to support the high demand of mobile data indoors, off-load traffic from the macro cellular networks and also provide solutions to coverage issues experienced when using macro cellular network for indoor communications.**

Keywords-Femtocell, Indoor communications, OPNET simulation, Delay, Throughput.

I. INTRODUCTION

The demand for mobile data indoors is increasing rapidly due to the influx of smartphones, USB modem and tablets among other mobile devices [1]. The applications used on these mobile devices generate large amount of data traffic on macro cellular networks to the extent that the macro cellular networks are not able to handle this high data traffic demand effectively. Some of the applications of data users include surfing the internet, receiving and sending emails, social networking, chatting, video and music downloads, video streaming, voice and video calls, news feeds among others [2].

This poses great challenges to mobile network operators in managing their networks as macro cellular networks are not able to provide better coverage indoors and may not be able to meet the high and ever increasing demand for mobile data indoors. The arrival of 3G networks and other emerging technologies such as High Speed Packet Access (HSPA) and Long Term Evolution (LTE) have also encouraged mobile data services and have presented network operators with new challenges [3] and [4]. Consumers on the other hand rely heavily on mobile devices for their daily communications need and are not satisfied with the current coverage and quality of service indoors. This has necessitated the study of an alternative and cost effective solution to provide users with better coverage indoors and off-load the current data traffic on macro cellular networks.

Consequently, this article investigates the use of Femtocell as an effective alternative to off-load traffic on the macro network and improve cellular coverage in indoor environment. This has led to the following questions: Will Femtocell be able to support the high demand for mobile data and provide users with good coverage indoors whiles providing network operators high return on their investment? What are the performance characteristics of Femtocell that enables it to off-load mobile data better than the traditional 3G macro network in an indoor set-up? Specifically, the article will consist of designing and modelling, with OPNET modelling tool, a 3G cellular network in a commercial area using Femtocell as access point. Simulations will then be carried out to measure QoS parameters of Femtocell and also comparison will be made with 3G macrocell network performances in an indoor environment.

II. FEMTOCELL NETWORK MODELLING AND ASSUMPTIONS

The model of cellular network adopted in this article consists of dropping a single Femtocell in a cellular network of macro base stations as shown by figure 1. Key assumptions are listed as follow

A. Assumptions

The proposed femtocell model, developed with OPNET Modelling software in the next paragraph will work under the following considerations

• In the downlink, the interference to the femtocell user is assumed to be only from the various macrocells, which in a fairly sparse femtocell deployment, is probably accurate.

• In the uplink as well, the strong interference is bound to come from nearby mobiles transmitting at high power up to the macro base station, so the model may be reasonable.

• Since OPNET does not readily support the UMTS femtocell model, a macro-cell node-B UMTS model will be adopted and attributes and properties will be customised to behave like a UMTS femtocell model.

B. Home Node-B (femtocell) modelling

The home Node-B (Femtocell) node models [5-6] include one node-B processor module for each sector it manages. The node-B processor module is connected to an ATM or IP protocol stack, a transmitter module, and a receiver module. Each packet stream between the node-B module and the transmitter represents a downlink channel and each stream between the node-B module and the receiver represents an uplink channel. Fig. 1 illustrates the Home Node-B model.

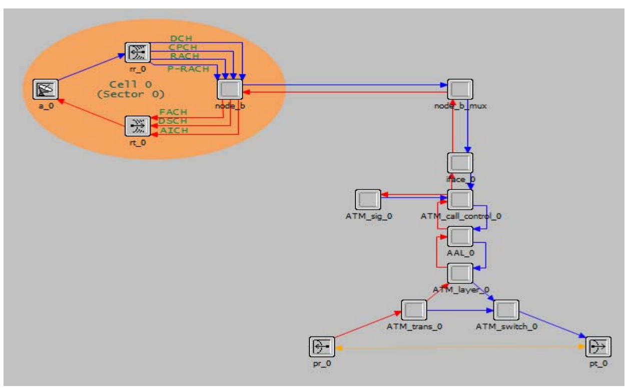

Figure 1. Home Node-B Node Model

C. Radio Air Interface

The OPNET Wireless module includes 13 pipeline stages [7] to model the radio interface. The air interface between the UE and the Femtocell network was modelled by modifying some of these pipeline stages.

• Received Power

The standard received power from the pipeline stage was modified to include a path loss model and shadow fading model that depends on the indoor office environment. The received power for an Indoor Office environment is given by:

$$L_{pMax} = 30 \cdot \log_{10}(R \times 100) + 18.3 \times n^{\left(\frac{n+2}{n+1} - 0.46\right)} + 37$$

Where:

• L_{pMax} is the valid received power in non-line-of-sight case and described worst case propagation.

• n is the number of stages in the path

• R is the distance between the user and home node B base station in kilometers.

In addition to the above models, the Hata model for frequency between 1500 MHz and 2000 MHz and the free space model were also supported.

Moreover:

• Shadow fading was modeled as a log-normal distribution with zero mean and a standard deviation dependent on the indoor office environment used for the simulation set-up.

• The background noise pipeline stage includes thermal noise and noise figure of the mobile and base station receiver.

• Interference Noise is calculated in the following pipeline stages. RACH and AICH channels and also DCH and FACH channels.

• Bit Error Rate

The bit-error rate pipeline stage is modified to include the signal-to-noise ratio (SNR) versus block error ratio (BLER) curves that depend on the coding scheme, the rate, the transmission time interval for each transport channel and the transport-format combination chosen. The model supports convolutional codes in AWGN and in multipath conditions with three major paths and assumes perfect power control. Bounds on the BLER have been developed under these different conditions. These bounds have then been verified using detailed link-level simulations of the W-CDMA air interface for uplink and downlink reference measurement channels [7].

D. The simulation scenario set-up

The simulation area of this case study is 10km^2. The set-up contains one (1) femtocell and six (6) users. The femtocell is placed such that it falls within an office building. The indoor office environment was modelled using the OPNET office network with scale type dimension of 100 x 100 m.

The UMTS femtocell network [8-9] was realised by setting up a UMTS network using the UMTS network nodes; GGSN, SGSN, RNC, a node-B and User Equipment (UE) as shown in figure 2.

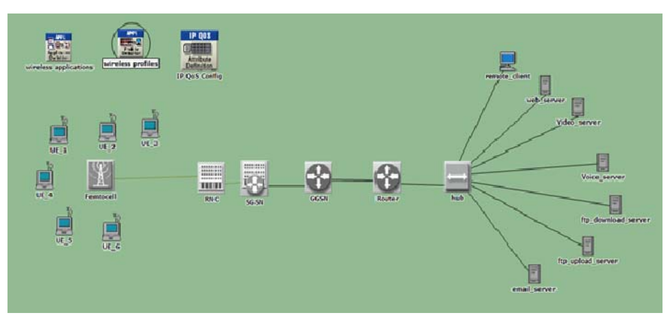

Figure 2. Femtocell Network Setup

The UMTS node-B was modelled to behave like a femtocell by changing the power settings, antenna parameters and other parameters.

The performance of femtocell in an indoor environment is monitored by a set of performance metric indicators. Measurements can provide raw numeric data like throughput values and error rates. In addition, quality can be evaluated on a more humane level by measuring Quality of Experience (QoE) and Mean Opinion Score (MOS). The traditional Key Performance Indicators (KPI) for mobile telecommunication networks, including call success and drop rates, service availability, signal strength and quality, call setup times, data connection setup times and throughputs were measured in this network setup after simulation of the femtocell in an indoor office environment.

E. Traffic Modeling for Wireless User Application set-up

Traffic models are used in Discrete Event Simulation in order to simulate the behavior of a given application or service, in the case of this study, VoIP, email, web, video conference and FTP. The femtocell performance simulation study was obtained using the OPNET application traffic models which offers a more detailed characterization of the different types of applications (FTP, E-mail, HTTP, video conferencing and voice):

• Video Conferencing: The video conferencing wireless application was simulated in the femtocell indoor office network using the video conferencing attributes. The Video conferencing application uses discrete traffic mix with a frame inter-arrival time of 10 frames per second and Interactive Multimedia as its service type in establishing video calls.

• VoIP: The voice wireless application was simulated in the femtocell indoor office network using the voice attributes. The VoIP application uses GSM Fixed Rate (FR) encoding scheme and Interactive Voice as the type of service in establishing the voice calls.

• Email: The email wireless application was simulated in the femtocell indoor office network using the email attributes. The email application introduces background traffic to the network and uses the Best Effort (BE) service type in delivering an email.

• Web browsing: The web browsing (http) wireless application was simulated in the femtocell indoor office network using web browsing attributes.

• FTP download: The FTP download wireless application was simulated in the femtocell indoor office network using the FTP attributes. The FTP session consists of a sequence of file transfers, separated by reading times. The key parameters of this model are the size of the file to be transferred, and the length of the reading time. The type of Service used is Best Effort.

• The FTP upload wireless application was simulated in the femtocell indoor office network using the FTP attributes and values.

• Simulation Data Collection

OPNET global (network level) and individual node statistics data collection was set in order to collect the KPIs of the Simulation Kernel's Statistic package before the simulation was run. The OPNET Modeler has three modes of the statistics collection for processing the statistics, which include All Values, Sample and Bucket.

For the purposes of this study, the bucket mode was used to collect statistics because the results of this mode are useful as they show the general trend of the statistic's variations. Bucket mode is also referred to as the default mode in OPNET.

F. Performance Measures

The performance measures used in the paper to analyse the femtocell performances in an indoor cellular network are given below:

• Application Throughput (Kbits/sec)-- This is the average amount of application data transmitted across all connections from the source to the destination tier.

• Network Throughput (Kbits/sec)-- This is the average amount of network data transmitted across all connections from the source to the destination tier. This statistic measures throughput of all application data and network protocol overhead. The network throughput could also be measured in packets/sec

• Jitter is defined to be the variation of delay between consecutive packets. If two consecutive packets leave the source node with time stamps t_1 and t_2 and arrive at the destination at time t_3 and t_4 after re-assembly and play back, then the jitter will be represented by equation 2 below:

$$Jitter = (t_4 - t_3) - (t_2 - t_1)$$

• Mean Opinion Score (MOS) Rating-- This performance parameter gives the estimated mean opinion score for all of the demands in the network model. This is a subjective parameter that measures for example the quality of voice or video received by the server, judging the end-user experience. Calculations follow the definition given by the ITU-T recommendation G.107 which is presented in Equation 3:

$$R = R_0 - I_S - I_d - I_e + A$$

Where R represents a factor that varies between 0 and 100, with 100 representing the best quality and 0 the worst quality

R_0 is the SNR (Signal to Noise Ratio),

I_S is the simultaneous impairment factor,

I_d represents the impairment caused by delay,

I_e is the equipment impairment factor as a results of low-bit codec and packet loss and

A is the advantage factor that compensates for the loss caused by other factors.

G. *Simulation Process and Performance Run-Time*

The Simulation technique used for this work is the Discrete Event Simulation (DES). The DES technique is able to model all traffic (data, signaling, and management) using packets, account for all timers in every protocol layer and perform every state/event transitions of all protocol layers.

The Configure/Run DES interface in OPNET shown in fig. 3, was used to run the discrete event simulation for the indoor cellular network and the duration for the simulation set is 2 hours. All applications generating traffic (voice, email, web, video conferencing and FTP) started simultaneously between 0 and 10 seconds of the simulated time and were randomly repeated until the end of the simulation.

The simulation is implemented in OPNET Modeler 14.5.

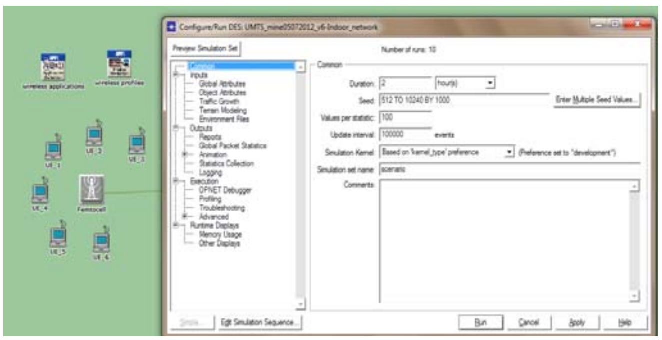

Figure 3. Snapshot of Configure/Run DES used in simulation

The simulation was run ten (10) times in the modeling process and completed successfully as shown in fig. 4.

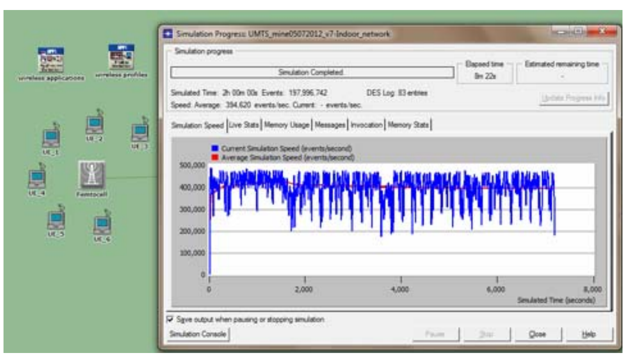

Figure 4. Snapshot of Configure/Run DES used in simulation

III. RESULTS

The results of the various user applications are presented and discussed in this section.

A. *Email Traffic Throughput*

The graphs in fig. 5 and 6 show the Email Traffic Sent (bytes/sec) and the Email Traffic Received (bytes/sec) respectively. The maximum email traffic sent and received is 83.778. This result gives an impressive throughput indoors in the sense that the traffic sent is the same as the traffic received.

Similarly, results were also generated for HTTP, VoIP, FTP applications and Video Conferencing.

The HTTP simulations give an impressive throughput indoors using femtocell cellular network. The maximum HTTP traffic sent and received is 11,417.

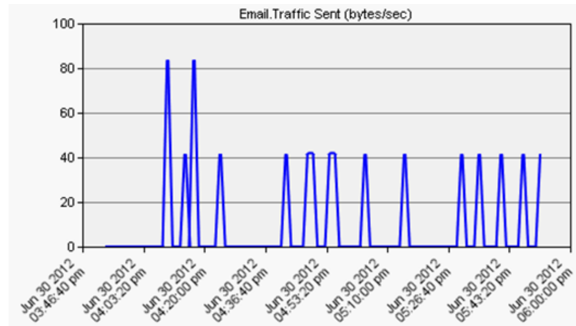

Figure 5. Email Traffic sent (byte/sec)

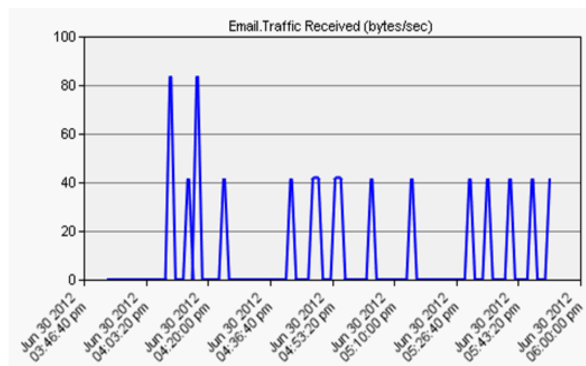

Figure 6. Email Traffic Received (byte/sec)

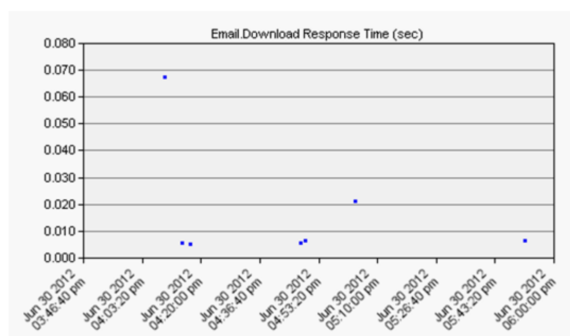

Figure 7. Email Download Response Time

In addition, the VoIP simulations were satisfactory. The voice Jitter can be approximated to zero showing that there is no noise variations during the voice call. A MOS of 3.6 (approximately 4) was recorded and this is interpreted by ITU as good enough, imperfections can be perceived, but sound still clear [10].

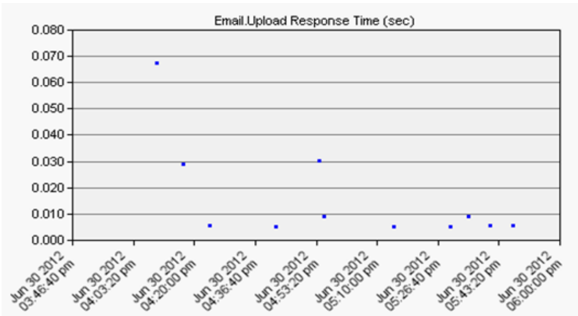

Figure 8. Email Upload Response Time

Moreover, for both FTP download and upload, a page requires a maximum response time of 5s as per ITU standards. The simulated result gives 0.2s and demonstrates better FTP user experience with femtocell network indoors.

Finally, the simulated results for video conferencing give an average end-to-end delay of 27ms and a packet loss of less than 2 %. For real time video conferencing, an end-to-end delay of less than 100 ms and a packet loss of less than 2% are required for user satisfaction. This indicates that the femtocell provides better coverage indoors.

B. Femtocell Throughput Statistics

The total Downlink (DL) and Uplink (UL) throughput statistics collected at the UMTS Home Node-B or femtocell node are shown in fig. 9 and fig. 10

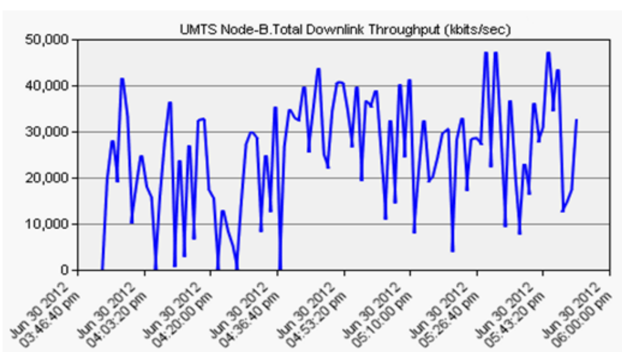

Figure 9. Femtocell Downlink Throughput (bytes/sec)

The femtocell node gives an average downlink throughput of 24 Mbps (24,436 kbps) and uplink throughput of 14 Mbps (14,090 kbps). Refer to table 1 for details of peak and average throughputs. Comparing the femtocell throughputs to the Macrocell UMTS 3G network which gives throughput value of 14.4 Mbps and 5.8 Mbps in the downlink and uplink respectively, the femtocell demonstrate and reaffirms that it performs better in an indoor cellular network environment when compared to the macrocell UMTS 3G network.

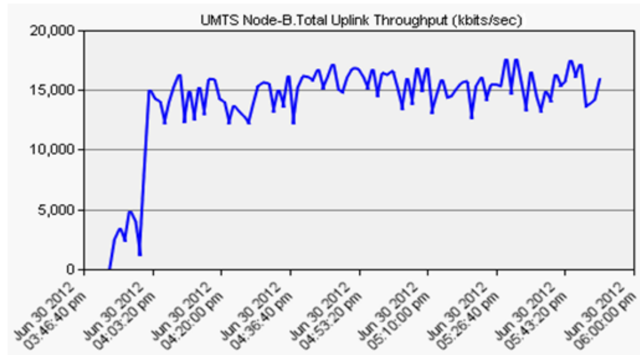

Figure 10. Femtocell Uplink Throughput (bytes/sec)

TABLE I.

FEMTOCELL THROUGHPUT PERFORMANCE STATISTICS

Femtocell throughput	Average	Peak
Downlink (Mbps)	24,436	47,299
Uplink (Mbps)	14,090	17,665

Moreover, table 2 compares the throughputs of femtocell and a macrocell UMTS 3G cellular network. The simulation set-up only dealt with the femtocell network but the comparison was done using specifications of ITU on macrocells.

Results show significant throughput gain of about 41% and 59% in the downlink and uplink respectively when using femtocell to off-load mobile data and this is shown in fig. 11.

TABLE II.

THROUGHPUT COMPARISON OF FEMTOCELL AND MACROCELL

Data Throughput Statistic	Femtocell	Macrocell	Gain
Downlink (Mbps)	24,436	47,299	40,98
Uplink (Mbps)	14,090	17,665	58,57

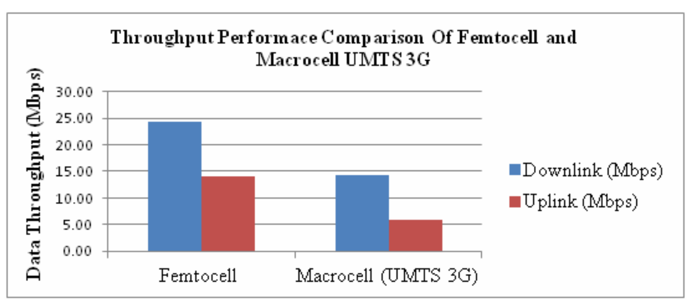

Figure 11. Femtocell and Macrocell (UMTS 3G) Throughput Comparison

One of the major improvements with Femtocell technology is in network latency or end-to-end delay for data applications. The simulated results compared the end-to-end delay to a 3G UMTS Macro network which generally has an average delay of 60ms [11]. This, as illustrated in fig. 12, again demonstrates that Femtocell improves data experience indoor and gives a performance gain of 55% as the average value recorded is 27 ms.

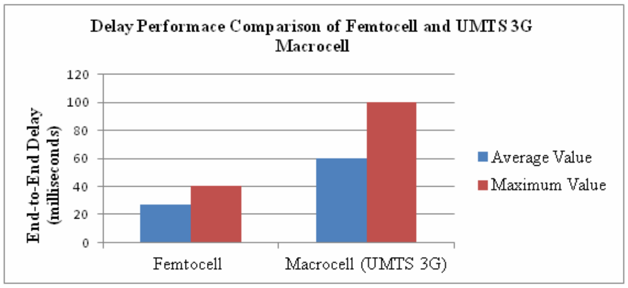

Figure 12. Femtocell and Macrocell Delay Statistics Comparison

IV. CONCLUSION

In summary, the performance metrics of femtocell in an indoor environment were simulated and measured for five main traffic classes including VoIP, FTP, Email, Web and Video-conferencing. The results were compared to specifications of ITU on Macro cellular networks and results show the multiple benefit of adopting femtocell. For VoIP, the measured MOS value in the simulated femtocell network was 3.6 and this shows good voice quality according to ITU specifications. The video conferencing end-to-end delay and packet loss ratio measured in the femtocell network were all below the acceptable real time video conferencing threshold standards of 100ms and 2% respectively. Similarly for Email, Web and FTP applications, the femtocell performance metrics were all below the standard threshold of less than 5s. These conditions offer mobile application users, better indoor coverage and good quality of service. Further to these measures, the throughput statistic was collected at the femtocell or home node-B interface and remarkable values of 24 Mbps and 14 Mbps were recorded in the downlink and uplink respectively. Comparing these to the 3G UMTS macro network which gives throughput values of 14.4 Mbps and 5.8 Mbps in the downlink and uplink respectively, it can be inferred that femtocell improves indoor coverage and provides better network capacity. The simulated MOS and end-to-end delay were better as compared to the 3G macrocell network. Therefore the MOS, throughput and delay among other performance metrics measured, confirm that femtocell can off-load mobile data traffic from the traditional macro-network and provides better coverage with higher capacity for indoor communications.

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