# A Complete Femtocell Network Modeling and Development Platform

**Elias Chavarria Reyes**, **David M. Gutierrez-Estevez** and **Ian F. Akyildiz**
Broadband Wireless Network Lab
School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA
Email: {elias.chavarria, david.gutierrez, ian}@ece.gatech.edu

***Abstract*—Femtocells have emerged as an alternative solution for operators to improve coverage and throughput in indoor environments. However, modeling and development platforms are still needed in order to test implementation-specific characteristics of femtocells, such as interference mitigation techniques and self-organizing algorithms. Using OPNET, a high fidelity simulation environment for wireless networks, a femtocell modeling and development platform is created, closely following the specifications dictated by 3GPP regarding the entities, functionalities, procedures, and message formats for femtocell networks. It is shown how the platform reflects the effect of both interference and backhaul degradation on the overall performance of the network, which represent the key concerns for operators nowadays regarding femtocell deployments.**

## I. Introduction

Femtocells have emerged in the last few years as a solution for operators to increase capacity and coverage in indoor environments. As such, they have been introduced in most current cellular communication standards: UMTS/HSPA, LTE, CDMA2000, WiMAX. Among these, UMTS/HSPA networks are currently the most widely deployed. Together, they account for more than 70 percent of commercial 3G networks [1]. 3GPP, in charge of developing UMTS/HSPA, first introduced femtocells in its Release 8 [2] and has continued adding enhancements in subsequent releases. Throughout the specifications, 3GPP has left several aspects of their functioning as implementation specific. This leaves room for continuous research and development to improve the performance of femtocells, and differentiate the femtocell offerings from different manufacturers and operators.

Due to the relevance that UMTS/HSPA currently have and will continue having, even with the introduction of newer standards (e.g. LTE-Advanced), it is of great importance to count with tools where femtocell-related development can be perfomed and evaluated. These tools should address not only the link-level characteristics but also the system level behavior associated with UMTS/HSPA networks. Based on OPNET Modeler Wireless Suite and 3GPP's standards, we have developed the simulation models and implementation of the main elements of a femtocell enhanced UMTS network: the Home Node-B (HNB) and Home Node-B Gateway (HNB-GW), as well as their related procedures and standard messages according to 3GPP's ASN.1 definitions. OPNET provides a platform for high fidelity modeling, simulation and analysis of a broad range of wireless networks, allowing the design and optimization of proprietary wireless protocols [3]. To the best of our knowledge, there aren't any publicly available simulation tools that address the needs satisfied by our OPNET-based femtocell modeling and development platform.

The rest of the paper is organized as follows. Section II describes the basic architecture of a UMTS Cellular Network enhanced to support femtocells. In Section III, we describe the design and implementation of these elements in OPNET. Simulation results are then provided in Section IV. Conclusions and future work are provided in Section V and Section VI.

## II. Architecture

In addition to the typical elements found in the packet switched (PS) section of a UMTS Network, namely Node-B, Radio Network Controller (RNC), Serving GPRS Support Node (SGSN), and Gateway GPRS Support Node (GGSN), two new main entities must be added in order to support femtocells: the HNB and the HNB-GW, as depicted in Fig. 1. The HNB-GW appears as a typical RNC towards the UMTS core network (CN) (i.e. SGSN and GGSN for the PS section). Therefore, to communicate with the CN, it utilizes the same Iu interface [4] as the one used by RNCs for this purpose (Iu-PS towards the PS section, and Iu-CS towards the circuit switched section). Its main role is to act as an aggregator for all the HNB connections. On the other hand, the HNB appears as any other Node-B to the user equipments (UEs), providing the same Uu air interface as Node-Bs do. Between the HNB-GW and the HNB a new interface is defined, the Iuh interface [2], to support HNB-specific procedures and a lightweight mechanism for carrying data and control traffic between the HNB-GW and the HNBs. In addition to the HNB and HNB-GW, additional support elements are also introduced in the network: the Security Gateway and HNB Management System. They provide a secure connection between HNB and HNB-GW, and provide configuration information to HNBs, respectively.

The new Iuh interface can be seen as a simplified version of the Iu interface, as shown in Fig. 2. It removes heavy-weight protocols from the Iu interface and introduces two new protocols: Radio Access Network Application Part -RANAP-User Adaptation (RUA) Signaling [5], and Home Node B Application Part (HNBAP) [6]. RUA's main objective is to transparently transfer RANAP messages between the CN and the HNB, using the HNB-GW as intermediate entity. On the

978-1-4673-0921-9/12/$31.00 ©2012 IEEE

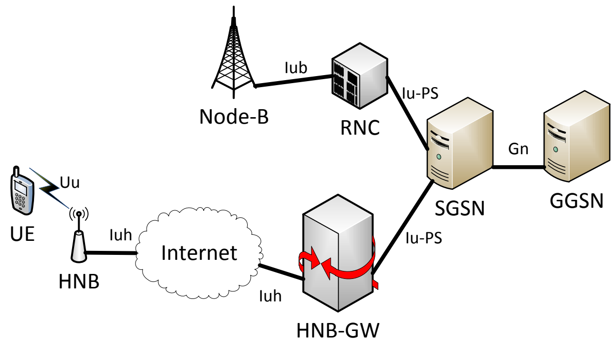


Fig. 1. UMTS Network - Packet Switched Section

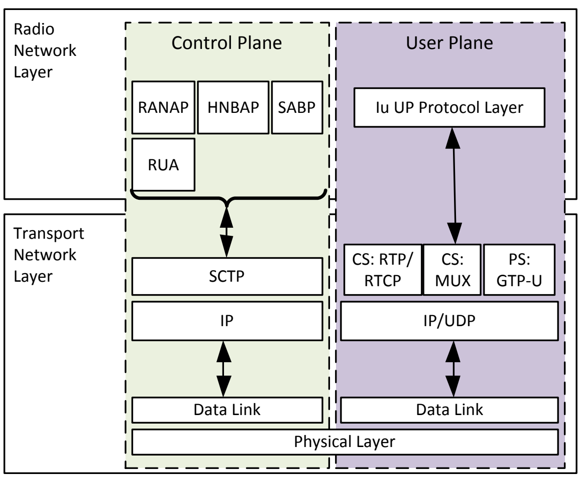


Fig. 2. Iuh Interface [2]

other hand, HNBAP's main objective is to support the (de-)registration of HNBs and UEs, and Radio Network Subsystem Application Part (RNSAP) relocation. Both protocols utilize specific procedures to support these functionalities, and their respective messages are defined by 3GPP through ASN.1.

## III. Modeling and Implementation

The detailed modeling and corresponding implementation of this platform is where the value of this work resides. To the best of our knowledge, no research tool has been developed to such a level of detail, capturing both the physical and architectural effects of femtocell networks. In addition, communication between entities always takes place respecting UMTS legacy and new femtocell-supporting protocols.

This section deals with the OPNET modeling and implementation of a femtocell subsystem in the network, mainly consisting of the new HNB and HNB-GW nodes, and the RUA and HNBAP protocols. Subsection III-A briefly summarizes the OPNET modeling paradigm and subsection III-B explains

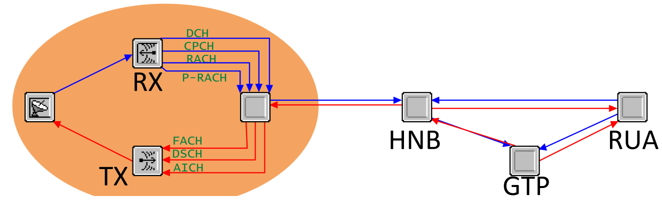


Fig. 3. Section of HNB Node model

the different models that we have implemented.

### A. Overview

Within OPNET, the creation of new network elements entails hierarchical development at multiple levels: network, node, and process levels. At the network level, it suffices to generate a component with the appropriate interfaces (wired or wireless) and the necessary configuration parameters. Then, the node model representing the internal architecture of the element must be defined. This involves the selection of the processes that will constitute the node, the configuration parameters of the processes within the specific node, and the interconnection of the processes. Each process is in charge of a specific set of functionalities (e.g. a specific protocol) within the node. A typical node model looks as the one shown in Fig. 3, where each block represents a process running within the node. The lines interconnecting the processes represent unidirectional packet streams, which are used to exchange packets between processes. For example, a UDP process would use an outgoing packet stream towards the IP process in order to transfer UDP packets that need to be encapsulated by the IP layer.

The third level in the hierarchy defines the capabilities of each process model through state transition diagrams (STD). Each state is composed by a set of instructions executed when the state is reached, and a set of instructions executed when the state is left. In addition, each transition can be chosen according to specific events. At the same time, each transition can trigger the execution of code as it is traversed.

In the case of the development of new protocols, as in our case, new message types need to be defined. OPNET provides a flexible environment for the definition of new packet types. Essentially, it allows the definition of each field within the packet, as well as their data type and size in bytes. A typical message definition is depicted in Fig. 4. Each block represents a field within the packet, while the size of the block is proportional to the size (in bytes) of the field. In order to support encapsulation and decapsulation of packets, OPNET allows the definition of "packet fields" whose size can be dynamically assigned during the simulation according to the size of the packet that is being encapsulated/decapsulated.

### B. Models

Specifically, we developed two new node models, one for the HNB and one for the HBN-GW. For these models, we reused several of the process models already defined in

OPNET (e.g. IP, UDP, TCP), and we updated others (e.g. gtp, sgsn) in order to support the new node models. In addition, we developed new process models: hnb, rua, and hnb-gw process models. These are in charge of the core functionalities performed by the HNB and HNB-GW nodes. Furthermore, we created new packet formats for the RUA and HNBAP protocols, as per the ASN.1 definitions provided by 3GPP in order to maintain compliance with the standard.

*1) HNB:* In UMTS, the HNB is responsible for the functionalities provided by the Node-B and most of the functions corresponding to the RNC. An exception is the management functionality for supporting multiple Node-B's at the RNC, analog to the management of multiple HNBs at the HNB-GW, which does not reside in the HNB node. Yet radio resource management and some mobility management functions do need to be implemented at the HNB. Taking these issues into account, we utilized as baseline the existing models in OPNET for the Node-B and RNC node and process models in order to develop the node and process models of the HNB, as shown in Fig. 3. The HNB contains the radio transmitter and radio receiver, as the Node-B, while at the same time utilizes the GTP protocol for the transmission of Iu-PS related data, as the RNC. We updated the gtp process model in order to seamlessly integrate with our new hnb process model for the transmission and reception of control and user data. Two additional processes were integrated: a multiplexer module enabling future sectorized femtocells, and the module in charge of executing the RUA protocol.

Within OPNET, the code related to the physical layer processing in the transmitting and receiving ends, is grouped in "pipeline stages". In addition to modifying the existing pipeline stages of the Node-B and UE, we also created dedicated code to deal with the pipeline stages of the radio transmitter and radio receiver of the HNB. By doing so, we provide a platform that facilitates the development, implementation and testing of interference mitigation techniques that affect only the HNBs within the network.

The developed HNB models can be configured in each of the three access modes defined by 3GPP:

- Open mode: Any user can connect to the femtocell.
- Closed mode: Only a specific set of users, the ones belonging to the Closed Subscriber Group (CSG) are allowed to connect to the femtocell.
- Hybrid mode: Any user can connect. However, users belonging to the CSG will receive prioritized service.

*2) HNB-GW:* Since the HNB-GW requires a small subset of the functionalities of an RNC, the core functionality of the HNB-GW we developed goes into supporting the termination of both RUA and HNBAP protocols, and the management capability for supporting multiple femtocells. Similarly to the HNB, we updated the gtp process model in order to seamlessly work with our new hnb-gw process model for the transmission of control and user data in both, the Iu-PS and the Iuh interface. Due to OPNET's current approach of initializing the relation between SGSNs and RNCs, we also updated the sgsn process model in order to initialize a relation not only with RNCs but also with HNB-GWs. The HNB-GW model we developed can support multiple HNBs configured as any combination of open, closed, and hybrid femtocells.

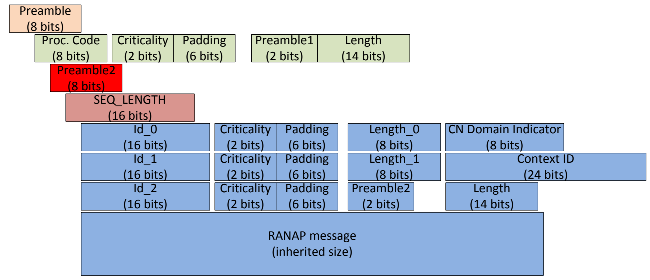


Fig. 4. Packet format of RUA Direct Transfer Message

*3) RUA and HNBAP:* A major task for enabling femtocell standardized networks was the development of both the RUA and HNBAP protocols, specifically defined by 3GPP for the Iuh interface. While the HNBAP protocol was integrated into the higher layer process models (hnb and hnb-gw), the RUA protocol was developed as an independent process. Therefore, the gtp process model was also updated to support data exchange with the RUA process model.

Within the RUA process model, we implemented the Direct Transfer and HNB Originated Connect procedures as defined in [5]. These two procedures support the establishment of an initial connection for the UEs and the subsequent exchange of RANAP control signaling between the HNB and HNB-GW. The corresponding message format for these procedures were generated from their 3GPP ASN.1 definition. As an example of the message formats that were developed, Fig. 4 depicts the message format for the RUA Direct Transfer Message used to carry RANAP messages between the HNB and HNB-GW.

For the HNBAP protocol, we followed a similar approach to the Node-B Application Protocol (NBAP) implemented in OPNET. The NBAP has as termination entities the RNC and the Node-B, and takes care of the radio link establishment, modification and removal at the Node-B. In OPNET, the RNC has a common process implementing RANAP and NBAP as separate states of the same process. Following a similar approach, the HNBAP is implemented between the HNB and HNB-GW termination entities, and its functionality is integrated as a separate state of the same process as RANAP.

The main functionality of HNBAP is the UE Registration Procedure. This procedure enables the registration of a UE at the CN. Based on the 3GPP ASN.1 definition, we generated the message format for the three possible messages associated with this procedure: UE Register Request, UE Register Accept, UE Register Reject. In addition, we took into account the node where access control based on CSG should be performed, according to the type of HNB from which the UE is attaching and the CSG capabilities of the UE [6]. In order to do this, we updated the UE node model to include a CSG list of allowed CSG IDs.

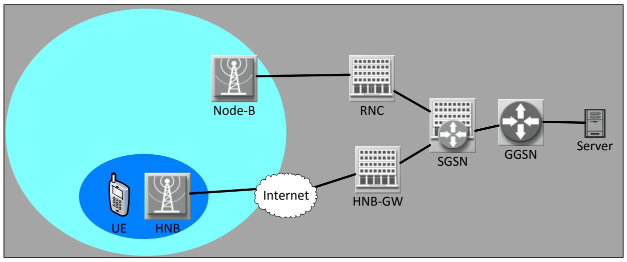


Fig. 5. Scenario 1: VoIP

TABLE I
SIMULATION PARAMETERS

| | |
|---|---|
| Silence Length (s) | expontially distributed. mean 0.65 |
| Talk Spurt Length (s) | exponentially distributed. mean 0.352 |
| Encoder Scheme | GSM FR |
| Voice Frames per Packet | 1 |
| Type of Service | Interactive Voice (6) |
| (De-)Compression | 0.02 |

## IV. SIMULATION RESULTS

The performance of a femtocell network, like the one shown in Fig. 1, is usually limited by the level of interference between the macrocell and the femtocell, and by the quality of the backhaul link between the femtocell and the core network. These two parameters can be easily configured in the environment that we have developed, and their effect on the performance of the network can also be evaluated.

### A. Backhaul

In most cases, the backhaul between the femtocell and the core network is provided through the internet connection of the final user. The perfomance of the backhaul may become the bottleneck of the performance of the femtocell. This occurs due to the variability of the performance (i.e. throughput, delay, jitter) associated with any internet connection. Furthermore, as the number of internet-enabled devices increases at homes, the amount of traffic that traverses the network increases, as well as the congestion. Therefore, it is important to understand the impact of the backhaul performance in the femtocell behavior.

In the first scenario, shown in Fig. 5, a user is configured to establish a VoIP call with an external server. In Table I, we list the most relevant parameters used for the configuration of this scenario.

The traffic received by the femtocell UE is shown in Fig. 6 for different levels of packet loss at the backhaul (during the silence periods the traffic goes down to zero). Using the case of 0% as the baseline, the average bit rate is 95.28%, 89.62%, and 85.63% of the baseline bit rate for 3%, 7%, and 10% packet loss due to the backhaul. This can cause a serious deterioration of the perceived quality during a voice call, since the perceived loss rate at the end user should be in the order of 1% [7].

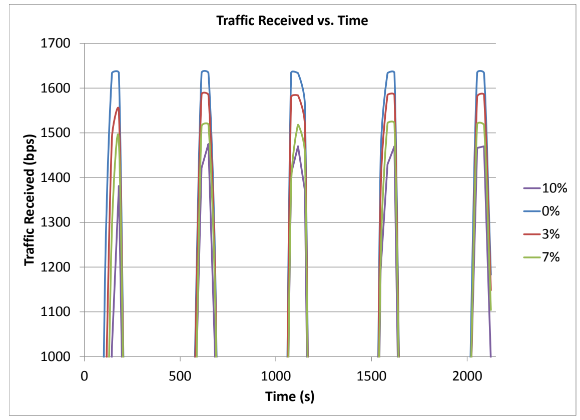


Fig. 6. Scenario 1: VoIP throughput

TABLE II
END-TO-END DELAY

| Backhaul Delay (ms) | End-to-end Delay (ms) |
|---|---|
| 0 | 154.597 |
| 50 | 204.597 |
| 100 | 254.597 |
| 150 | 304.597 |

In addition to the throughput, the end-to-end delay of the packet can significantly affect the perceived call quality by the end user. Utilizing the same scenario and parameters, Table II shows the average end-to-end delay for different levels of delay at the backhaul. As it can be seen, the end-to-end delay goes beyond 250 ms when the backhaul delay is 100 ms. A delay greater of 250ms is beyond what is acceptable for a typical VoIP call.

### B. Interference

Interference between the macrocell and the femtocell can significantly degrade the performance of both networks. Even though several techniques have been proposed in the literature to deal with this interference, extensive research is still done in order to develop improved approaches to tackle this issue. Therefore, it is of high importance that a femtocell simulation environment reflects the effect of interference over the performance of the network.

In Fig. 7, a scenario with two UEs is depicted. One of the UEs is configured to belong to the CSG of the femtocell. The second UE does not belong to the CSG of the femtocell. In addition, the distance between the first UE and the femtocell is configured as to favor the attachment of this UE to the femtocell rather than to the macrocell. With this setup, we ensure that there is interference between the macrocell and femtocell network. The second UE is positioned at different distances from the femtocell in order to validate the effect of the interference between the macrocell and femtocell as it approaches the femtocell.

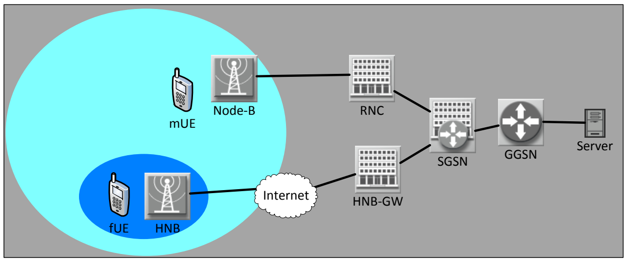


Fig. 7. Scenario 2: Interference

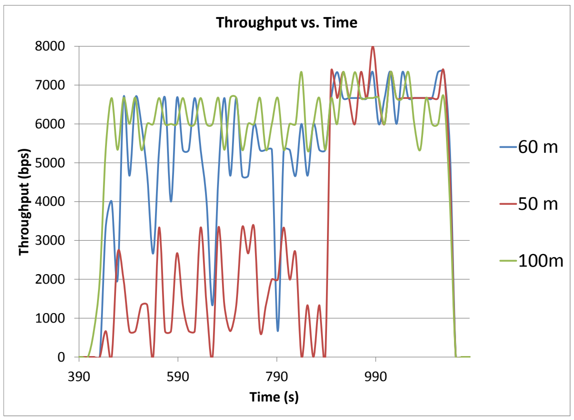


Fig. 8. Scenario 2: Throughput

The simulation is configured to have two phases. During the first phase, both users transmit simultaneously (one to the femtocell, and one to the macrocell). During the second phase, the macrocell user stops transmitting, removing any interference to the femtocell user. Fig. 8 shows the simulation result of the traffic received by the femtocell user for different macrouser distances from the femtocell. As the mUE approaches the femtocell network, the achievable throughput by the femtocell user during the first phase of the simulation decreases. Once the second phase of the simulation starts, the femtocell user is able to achieve its highest possible throughput. This behavior demonstrates that the developed simulation environment reflects the effect of interference over the performance of the network.

In addition to the behavior seen in the previous scenarios, we analyzed additional interactions between femtocell and macrocell. In Fig. 9, Fig. 10 and Fig. 11, three of these interactions are depicted. In all cases, a user (UE 1 from now on) belonging to the CSG of the femtocell starts a transmission. Afterwards, a second user (UE 2 from now on), not belonging to the CSG of the femtocell, starts a transmission and later stops it. Therefore, the interference to UE 1 is removed.

In the first instance of the interaction between both users,

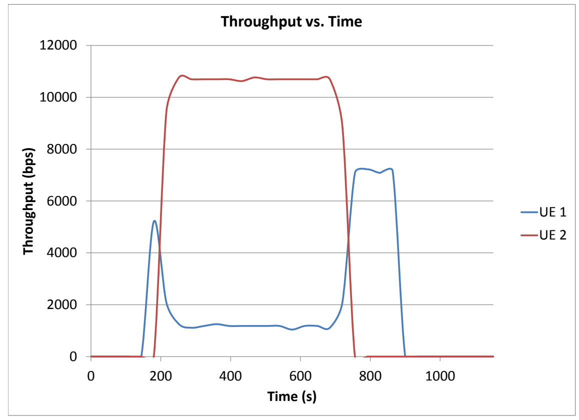


Fig. 9. Femto-macro interactions: First Instance

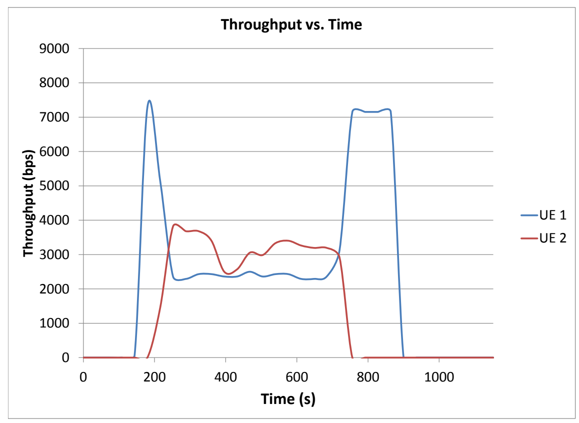


Fig. 10. Femto-macro interactions: Second Instance

UE 2 is able to achieve its maximum throughput. However, the throughput of UE 1 reduces significantly while UE 1 was trasnsmitting. Looking into the transmission power utilized by both users (which is readily available in OPNET), we identified that the UMTS power control algorithm (which is modeled in OPNET) increases the transmission power of the users in order to compensante for the additional interference. In the case of UE 2, there is enough room to increase the power and compensate for the interference. However, UE 1 reaches its maximum transmission power (27 dB) before being able to completelely compensate for the interefence cause by UE 2.

In the second instance of the interaction between both users, both UE 1 and UE 2 achieve a limited throughput. In this case, both users reach their maximum transmission power before being able to completely compensate the interference caused by each other. Therefore, they are unable to reach their required SINR, leading to the limited throughput.

In the third instance of the interaction between both users,

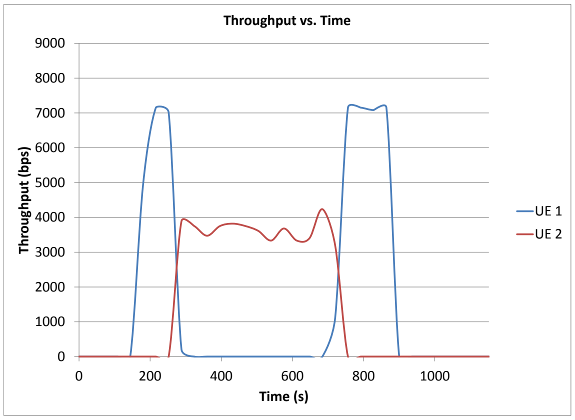


Fig. 11. Femto-macro interactions: Third Instance

UE 2 again achieves a limited throughput. However, UE 1 achieves zero throughput while UE 2 was transmitting. Compared to the previous cases, even though UE 1 reaches its maximum transmission power (27 dB), the received SINR is far below the required SINR to be able to achieve any throughput at all.

As seen from these three cases, the mutual degradation of the quality experienced by the femtocell and macrocell can greatly vary in a case by cases basis, even within a single scenario, which is clearly captured in our simulation platform.

## V. Future work

Since the current version of OPNET does not support inter-RNC mobility, and a HNB-GW appears as an RNC to the CN, we have left as further work the implementation of mobility-related procedures between HNB-GW and RNCs. The Iurh interface between HNBs, recently introduced by 3GPP, will also be implemented in a future version of our models. We have already started extending this work to OPNET's LTE Simulation framework due to LTE's growing importance as a cellular wireless standard. We will not only evaluate existing interference mitigation techniques, but also develop and evaluate new ones with the models created.

## VI. Conclusion

Femtocells have emerged as the most recent alternative for operators to improve indoor coverage and throughput. However, given that several aspects are left as implementation specific, there exists a need for development and testing tools for femtocells. To fill this need, we created a femtocell modeling and development platform based on OPNET, a high-fidelity simulation environment. This platform closely follows 3GPP specifications regarding femtocells in terms of entities, functionalities, procedures, and message formats. We have shown that the platform effectively reflects the key concerns of operators when implementing and developing solutions for femtocells; namely interference and backhaul issues. The platform that we created serves as the basis for the future development and implementation of femtocell-specific algorithms such as interference mitigation and self-organizing algorithms.


## Acknowledgment

This work was supported by SENACYT and Fundación Caja Madrid.


## References


[1] 3GPP - W-CDMA. 3GPP. [Online]. Available: http://www.3gpp.org/article/w-cdma

[2] 3GPP, "TS 25.467 UTRAN architecture for 3G Home Node B (HNB)," Tech. Rep., December 2011. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/25467.htm

[3] Wireless network simulation: Opnet modeler wireless suite. OPNET. [Online]. Available: http://www.opnet.com/solutions/network_rd/modeler_wireless.html

[4] 3GPP, "TS 25.410 UTRAN Iu Interface: general aspects and principles," Tech. Rep., June 2011. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/25410.htm

[5] ——, "TS 25.468 UTRAN Iuh Interface RANAP User Adaption (RUA) signalling," Tech. Rep., September 2011.

[6] ——, "TS 25.469 UTRAN Iuh interface Home Node B (HNB) Application Part (HNBAP) signalling," Tech. Rep., June 2011.

[7] T. Szigeti and C. Hattingh. (2004, December) Quality of service design overview. Cisco. [Online]. Available: http://www.ciscopress.com/articles/article.asp?p=357102