A New Cell Selection and Handover Approach in Heterogeneous LTE Networks

Additional Criteria Based on Capacity Estimation and User Speed

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***Abstract*–Long Term Evolution (LTE) heterogeneous networks represent an interesting approach to the ever increasing demand for coverage and Quality of Service (QoS) by the mobile users. Small cells play an important role in dealing with this demand by providing a means for the mobile user to overcome the problem of lack of mobile network resources or, when these resources are available, a way to dodge their poor quality in certain scenarios. However, the cell selection and handover procedures found in LTE Release 8 are inefficient in heterogeneous scenarios, since they are based only on Reference Symbol Received Power (RSRP) for cell selection and handover, and Reference Symbol Received Quality (RSRQ) for handover only parameters. In this paper, the implementation of two additional criteria is proposed as an improvement for the cell selection and handover procedures: base station capacity estimation and user speed. As the results show, the proposed algorithm has the benefit of contributing to the macrocell offloading, network load balancing, and user QoS.**

Keywords-LTE; Handover; Load Balancing; Capacity Estimation; User Speed.

I. INTRODUCTION

The explosion in the use of mobile devices and applications in recent years has led to an overload of the network infrastructure responsible for handling this traffic flow, affecting both the network performance and the user experience. To meet this growing demand for more resources, Long Term Evolution (LTE) networks are introduced as a radio access solution that provides a smooth migration path to fourth generation networks (4G), being designed to increase the capacity, coverage and speed when compared to earlier wireless systems [1]. Meanwhile, the cell selection and handover processes of the 3GPP LTE Release 8, which are based only on Reference Symbol Received Power (RSRP) and Reference Symbol Received Quality (RSRQ) [2], are inefficient because they ignore one of the main requirements demanded by the user, which is the Quality of Service (QoS) guarantee.

This paper proposes the development of additional criteria for cell selection and handover procedures in order to improve load balancing and, as a consequence, the QoS for user applications, as well. The effectiveness of these criteria is based on the ability of the base stations to send both their utilization rate estimation and base station type. Also, both User Equipment (UE) for cell selection and base station (eNodeB) for handover should be able to compute the average user speed, as this is part of the algorithms proposed in this paper.

The motivation that drives this research is the pursuit for alternative solutions for the problem of uneven load distribution over mobile networks, which leads to issues, such as call blocking and poor QoS, for example. Even though many studies have been carried out about this problem, our work brings one more contribution to the community by modeling a straightforward solution that results in macrocell offloading and network load balance by enabling low power nodes (picocells and femtocells) to take on more traffic.

In summary, our proposal has the objective of improving the overall system capacity, as well as reducing congestion by introducing a new cell selection and handover approach for LTE heterogeneous networks.

The rest of this paper is organized as follows: Section II presents some works that are related to the solution proposed in this paper. Section III introduces the basics of LTE networks with topics that are related to this paper. Section IV details the additional criteria proposed for our new cell selection and handover approach. Section V shows the main configurations adopted for the simulation environment used to validate and evaluate the proposed algorithm. In Section VI, results are discussed. Section VII presents the conclusion of the work, as well as points out to future work.

II. RELATED WORK

This section presents some works relating to the objectives of this research.

Becvar and Mach [3] presented an algorithm to mitigate the problem of redundant handovers to femtocells by estimation of throughput gain. It is stated in the paper that the gain in throughput is derived from the estimated evolution of the signals levels of all involved cells measured by the User Equipment (UE) and from an estimated time spent by the users in the Femtocell Access Point (FAP). The core of the proposed solution (estimation of throughput gain) seems to follow the idea of a kind of mapping of an RSRP value to a Modulation and Coding Scheme (MCS) index value, which in turn would be translated into a maximum bit rate value that would be granted by a candidate eNodeB. The solution tries to promote user satisfaction by trying to provide throughput values as high as possible based on mitigation of redundant handovers to femtocells.

The validation of the proposal is carried out by system level simulations in MATLAB [4].

Zhang et al. [5], whose paper is referenced by [3] mentioned above, proposed a new handover algorithm based on the UE speed and QoS with the purpose of reducing unnecessary handovers.

As for the UE speed parameter, that solution classifies the speeds as:

- Low mobile state (0 to 15 km/h);
- Medium mobile state (15 to 30 km/h);
- High mobile state (above 30 km/h).

Thus, in the algorithm proposed, the handover decision process does not perform any handover to femtocells if the UE is in the high mobile state. If the UE is in the medium mobile state and the user application is not so sensitive to delay and packet loss, in contrast to applications like IPTV, VoIP, and real time games [5], then handover to femtocell is allowed. Finally, if the UE is in the low mobile state, handover to femtocell is performed.

Further, regarding the QoS parameter, that proposal basically checks if the bandwidth requirement is satisfied in order to decide if a handover will be performed or not, mainly based on cell maximum capacity and its current load.

No simulation tool was used for the validation of the proposal.

Ulvan et al. [6] presented a handover decision policy based on mobility prediction, where the position of the UEs should be known in advance. The movement prediction of the UEs is based on Markov chain transition probabilities.

Reactive and proactive handover strategies are proposed with the purpose of mitigating the frequent and unnecessary handovers in a heterogeneous mobile network scenario caused by the short coverage radius of femtocells.

Basically, the proactive handover strategy tries to estimate the characteristics of a specific position before the UE reaches that position, and that information is used so that the system can decide if it triggers a handover process or not, before a normal handover takes place. According to the authors, this strategy is expected to minimize packet loss and high latency during handover.

As for the reactive handover strategy, the handover procedure tends to be postponed as long as possible, even though a new candidate base station is discovered. The handover process is triggered only when the UE is almost losing the serving base station signal. According to the authors, this strategy is a potential mechanism to mitigate the unnecessary handovers.

The results are based on MATLAB simulation.

Compared to those works, ours promote both a relief on the network load on the system side and an improvement on the quality of service on behalf of the user by optimizing not only the handover procedure, but also the cell selection procedure, as well, by taking into account both base station capacity estimation and user speed.

Our capacity estimation method is based on the average resource availability within a period of time, as described in Section IV, while our UE speed calculation method is based on average speed in order to reduce the possibility that sudden shifts in UE speed may lead to a wrong cell selection and handover process decision making. Moreover, our solution uses a discrete event LTE simulator (OPNET Modeler), as described in Section V, which favors a more complete and realistic validation environment for the proposed algorithm.

It is worth mentioning that the use of the OPNET Modeler 17.5.A (Educational Edition) [7] forced us to adopt LTE Release 8, instead of a more up-to-date version of the mobile environment specification, which, however, does not affect the usefulness of our solution.

In short, none of the related works take into consideration average base station capacity estimation and average user speed in conjunction, so that femtocells can be dealt with accordingly, since vehicular user speed is of special importance in avoiding LTE home base stations (HeNB) from being selected or handed over to, which may contribute to service degradation for femtocell users. So, in addition to dealing properly with short radius coverage femtocells, our solution gives preference to base stations that, by estimation, have more available bandwidth resources.

These two additional criteria, adopted as proposed in Section IV, promote better load balancing by avoiding overloaded base stations from being chosen, as well as by avoiding that outdoor high speed users drain network resources from HeNB users. The result is an improvement both in the distribution of network load and user QoS, as shown in Section VI.

III. BACKGROUND

This section presents the basics of LTE networks with the topics most related to the proposal of this work.

A. *LTE Heterogeneous Networks*

According to Dahlman et al. [8], heterogeneous networks are a mix of cells that use different downlink transmit power, operating (partially) with the same set of carrier frequencies and with geographic coverage that overlaps, as shown in Figure 1, being also referred to as HetNets. A typical example is a picocell or a femtocell placed within the coverage area of a macrocell, as shown in Figure 1. As found in [9], in heterogeneous environment, UEs may move along the different access networks, benefitting from the different characteristics of each of them as coverage, bandwidth, latency, power consumption, costs, etc. Besides, according to 4G Americas' Board of Governor [10], in LTE networks femtocells may be office or home stations, and in the latter case they are known as Home eNodeBs (HeNB).

B. *Cell Selection*

As found in [11], the cell selection mechanism determines the base station that provides service to a mobile station, and this process is executed whenever the mobile station joins the network (cell selection) or when the mobile device moves around in idle mode (cell reselection), as illustrated in Figure 2.

C. Handover

As it can be understood from [9], handover is an essential mechanism that guarantees mobility in a LTE network and its main function is to keep traffic flowing as the UE moves along the network. The idea behind this is simple: when a UE loses radio coverage from the serving eNodeB as it draws near another eNodeB radio coverage, a new connection has to be established to this new base station and the connection with the old one has to be undone. Therefore, handover usually happens when the serving eNodeB signal deteriorates, causing poor communication quality between the UE and the network.

Further, handover may be needed in order to promote network load balancing even if the current serving base station signal strength and quality are good. Other potential reasons to trigger a handover process is the need of the UE for better QoS, lower costs, more bandwidth, etc, which can cause the UE to search for base stations that offer better service conditions.

D. Quality of Service (QoS)

According to Sesia et al. [2], many applications may be running at the same time on the UE, each of them with its own QoS requirement. QoS is mainly about priority, packet delay, and packet loss error rate, in accordance with Table I. For instance, a UE may be on a Voice Over Internet Protocol (VoIP) phone call while navigating the Internet with a web browser and/or downloading files via File Transfer Protocol (FTP), all at the same time. While VoIP has more critical QoS requirements, such as delay and jitter, FTP file transfer requires a much lower packet loss error rate.

With the purpose of supporting multiple QoS requirements, different Evolved Packet System (EPS) bearers - logical channels that are bound to specific QoS Class Identifiers (QCIs) - are configured in the system. These EPS bearers are classified into two categories: Guaranteed Bit Rate (GBR) bearers, used for applications like VoIP, to which resources are allocated by the network in a permanent fashion, usually performed by the admission control process of an eNodeB as long as there are available system resources to establish them, and Non-Guaranteed Bit Rate (Non-GBR) bearers, which do not guarantee any particular bit rate for user applications, no permanent allocation scheme, and they are more appropriate for best effort style services like Hypertext Transfer Protocol (HTTP) and FTP.

Still according to [2], every bearer has a QCI and an Allocation and Retention Priority (ARP) bound to it. The ARP parameter is used for admission control and it decides if a certain bearer should be admitted or not, and in the case it should, it is also used to decide if a lower priority level bearer should be dropped to make room for the new one in case of network congestion.

According to Holma and Toskala [12], as part of the connection procedure of the UE to the network, an Internet Protocol (IP) address is assigned by the Packet Data Network Gateway (P-GW) to the UE and at least one bearer is established: the default bearer, which is always of Non-GBR type.

This bearer remains established for all the time period of the connection to the Packet Data Network (PDN), and it has its initial values assigned by the Mobile Management Entity (MME), a component of the Evolved Packet Core (EPC). Meanwhile, additional bearers, known as dedicated bearers, may also be established at any moment during or after the connection process is accomplished. A dedicated bearer may be a GBR or Non-GBR one.

E. Resource Allocation Mechanisms

LTE radio access makes use of a set of technologies that assures high spectral efficiency (data capacity) in its wireless interface with the UE. The main technologies adopted by LTE features high data flow in the downlink direction [12]. LTE makes use of Orthogonal Frequency-Division Multiple Access (OFDMA) in the downlink direction, whereas Single Carrier Frequency Division Multiple Access (SC-FDMA) is adopted in the uplink direction. These two technologies provide orthogonality for their subcarriers, thereby reducing interference, as well as improving network capacity. For LTE Release 8, the maximum bandwidth occupied in the frequency spectrum is 20 MHz.

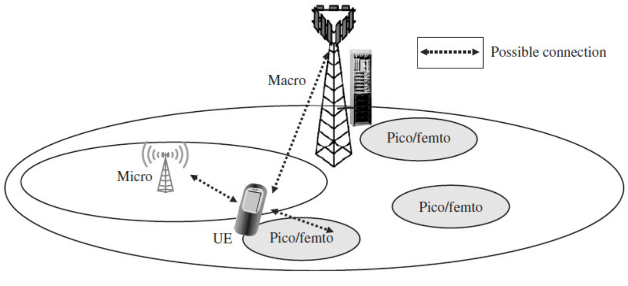


Figure 1. Example of heterogeneous network [12]

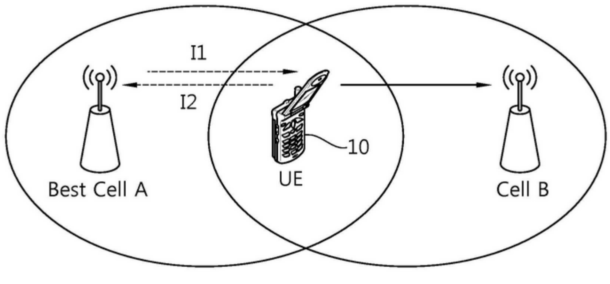


Figure 2. Cell selection and reselection [13]

TABLE I. LTE QCI TABLE, ADAPTED FROM [2,12]

QCI	Bearer Type	Priority	Packet Delay (ms)	Packet Loss Error Rate	Services
1	GBR	2	100	10^{-2}	Voice conversation (VoIP)
2		4	150	10^{-3}	Video conversation (live *streaming*)
3		5	300	10^{-6}	Video without conversation (buffered *streaming*)
4		3	50	10^{-3}	Real time gaming
5	Non-GBR	1	100	10^{-6}	IMS Signaling
6		7		10^{-3}	Voice, video (live *streaming*), and interactive
7		6	300	10^{-6}	Video (buffered *streaming*)
8		8			Applications based on TCP protocol like www, e-mail, chat, FTP, p2p file sharing, progressive video, etc.
9		9			

Resource allocation in frequency domain happens with a resolution of 180 KHz per Resource Block (RB) both in downlink and uplink directions. Each RB is composed of 12 subcarriers with 15 KHz bandwidth each (15 KHz subcarrier spacing). That is, 1 RB = 12 subcarriers x 15 KHz = 180 KHz, and it fits into a time slot duration of 0.5 ms, which is also equivalent to 1 Physical Resource Block (PRB). As found in [9], the resource allocation happens in every Transmit Time Interval (TTI), which corresponds to a pair of RBs (or PRBs) time interval of 1 ms. Thus, for the minimum allocated bandwidth of 1.4 MHz, 6 RBs are provided, while with the maximum allocated bandwidth of 20 MHz, 100 RBs are provided, reaching a maximum of up to 1,200 subcarriers. Table II summarizes bandwidth capacities for LTE Release 8 [14].

The data throughput that can be obtained from RBs depends on the modulation scheme, which can be Quadrature Phase Shift Keying (QPSK), 16 levels Quadrature Amplitude Modulation (16QAM) or 64 levels Quadrature Amplitude Modulation (64QAM), as well as the channel coding rate. Regarding the coding rate, as the radio condition deteriorates, the system increases the coding rate thus reducing the allocated transport block size (TBS).

Throughput also depends heavily on the number of antennas used to obtain independent transmission streams by using Multiple-Input Multiple-Output (MIMO) schemes. It is worth noting that for MIMO operations, two other parameters are used, the Rank Indicator (RI) and the Precoding Matrix Index (PMI), which will not be covered here due to lack of space.

In summary, for LTE Release 8 with a 20 MHz frequency division duplexing (FDD) bandwidth, it is possible to obtain a 150 Mbps data rate in the downlink direction when using MIMO 2x2. In the case of MIMO 4x4, LTE can provide up to 300 Mbps data rate. For the uplink direction, the peak data rate can reach up to 75 Mbps.

TABLE II. OCCUPIED BANDWIDTH, ADAPTED FROM [14]

Bandwidth (MHz)	1.4	3	5	10	15	20
No. of RBs	6	15	25	50	75	100

F. *Physical Downlink Shared Channel (PDSCH)*

According to [2], the PDSCH is the main data-bearing downlink channel in LTE, and it is used for all user data, as well as for the broadcasting of system information. The PDSCH channel carries data in units known as Transport Blocks (TBs), each of them corresponding to one Protocol Data Unit (PDU) from the Medium Access Control (MAC) layer. The data transmission is done during the subframe duration of 1 ms, which corresponds to 1 TTI. When the PDSCH channel is used for data transmission, one or two TBs can be transmitted per UE per subframe. For details about the PDSCH channel, please refer to [2].

IV. PROPOSED ADDITIONAL CRITERIA

This section presents the methodology adopted to perform user speed calculation and eNodeB capacity estimation, as well as it describes how cell selection and handover decision processes work, according to our proposed algorithm.

A. *Overview*

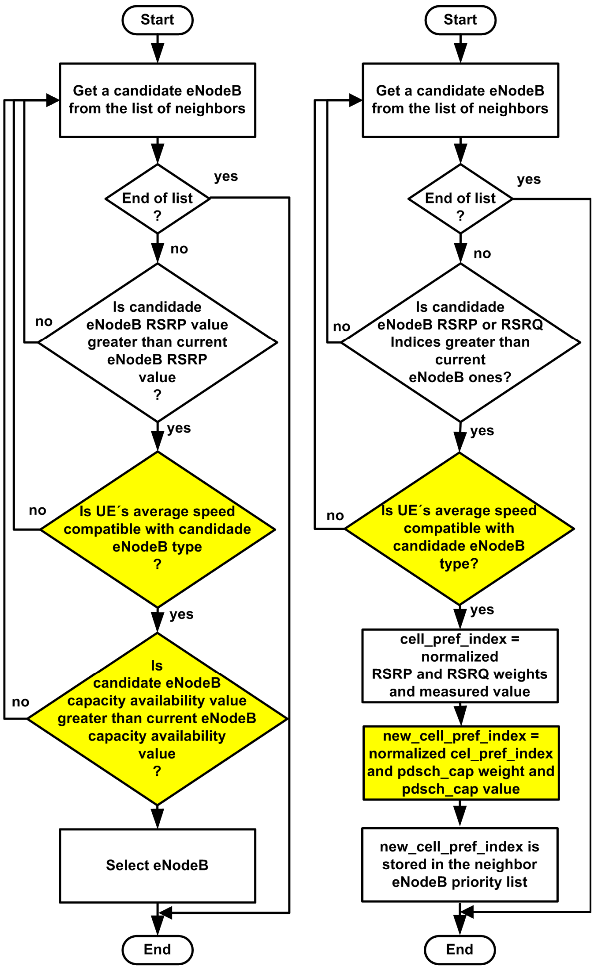
The purpose of the additional criteria is to promote a condition in which signal strength + quality and capacity availability, in certain proportions, may affect the cell selection and handover decision processes in such a way that preference may be given to the capacity availability parameter when choosing a serving cell, without sacrificing the connections quality. For that end, a weight of 25% for the signal strength + quality parameter against 75% for the capacity availability parameter is adopted. These weights (or proportions) were chosen from various empirical experiments and, then, they were manually assigned. Please, notice that further investigation is suggested in Section VII regarding the adoption or development of a more elaborate calculation method for the weights.

The proposed additional criteria have implied modifying the C++ source code of the UE and eNodeB models of the OPNET simulator at the LTE access stratum layer, where cell selection and handover events take place.

As highlighted in the algorithm flowchart in Figure 3.a, the cell selection process had two more decision steps added: the check for UE average speed compatibility with candidate eNodeB type and the check for the enodeB with the highest capacity availability value. Regarding the handover process, as highlighted in Figure 3.b, two more steps were added: the check for UE average speed compatibility with candidate eNodeB type and the ranking of the capacity availability estimation value, as calculated from the PDSCH channel.

B. *UE Speed Calculation*

A software function and a data structure were created at the UE model to calculate user speed at 1s intervals, then storing the last 10 speed samples in UE´s memory. The Euclidean distance method was used to calculate the distance traveled (in meters) for every 1 second interval, based on the (x,y) coordinates variables present in the OPNET's development environment for each UE device model (in the real world, maybe GPS coordinates would be used).



(a) (b)

Figure 3. Flowchart of the proposed algorithm: (a) New proposed cell selection process run on UE; (b) New proposed handover process run on eNodeB

Then, the speed is obtained by dividing the calculated distance by the time spent to travel it, resulting in a speed sample expressed in m/s. Then, the arithmetic mean is calculated to obtain the average speed for the last 10 second interval, and that is the UE speed adopted by our algorithm.

Also, another software function was created to be invoked both by UE and eNodeB to calculate the average speed based on the last 10 speed samples stored on the mobile device.

C. eNodeB Capacity Estimation via PDSCH Channel

A software function and a data structure were created at the eNodeB model to calculate the available amount of bandwidth resources at the moment the eNodeB is assembling its radio subframes, which happens at 1 ms intervals (1 TTI). Basically, the calculation is based on the free system resources against the busy ones, as read from the PDSCH data channel. So, the last 6,000 samples (6 seconds of information) of this calculation are stored on the eNodeB´s memory and that happens for every eNodeB present on the network. So, at the moment a handover event is triggered, the serving eNodeB accesses this information from the candidate eNodeB and calculates the arithmetic mean of its available bandwidth resources for the last 6 seconds, and that information is used to decide if a handover will happen or not.

D. New Cell Selection and Handover Decision Processes

Besides the highest RSRP value for cell selection and RSRP (50% weight) plus RSRQ (50% weight) normalized value for handover procedures, as adopted by LTE Release 8, the proposed improvements in this paper takes into consideration UE average speed and eNodeB capacity estimation as calculated from PDSCH data traffic channel, as shown in the flowchart depicted in Figure 3.

For the handover process, according to OPNET´s source code inspection, the RSRP and RSRQ weights are normalized and applied to the normalized measurements of the RSRP and RSRQ parameters, resulting in a priority index for each neighbor eNodeB. Then, the serving eNodeB will initiate handover to the eNodeB with the highest priority index. Thus, following this idea, the capacity estimation information is also assigned a weight of 75% against the 25% weight for the eNodeB priority index (cell_pref_index in the flowchart) for handover. The purpose of assigning a 75% weight for the capacity estimation value is to make the base station resource availability value to prevail over base station signal strength and signal quality values. Then, both capacity information and its corresponding weight are normalized together with the eNodeB priority index (cell_pref_index), resulting in a new index (new_cell_pref_index) which is more influenced by the eNodeB capacity estimation value than by the signal strength and signal quality values. Then, this new index value is stored in the candidade eNodeB´s priority list for upper layer decision making relating to the handover process.

Therefore, user speed and eNodeB capacity estimation additional criteria are used in the cell selection decision process in order to avoid any UE from selecting a femtocell whenever it is in vehicular speed (above 5 km/h, for example), as it will cause another almost immediate cell reselection or handover procedure to be invoked, since the UE will soon get far from the femtocell coverage radius. These information are also used to avoid the UE from being handed over to an overloaded eNodeB whenever possible. In conjunction, both user speed and capacity estimation parameters can improve network load balancing, as well as QoS for the mobile user.

V. LTE SIMULATION ENVIRONMENT

This section presents the configuration of the LTE network scenarios used for the purposes of this work.

A. Simulated Scenarios

In order to validate our algorithms, three scenarios with the same LTE simulation parameters, as depicted in Figure 4, as well as detailed in Table III, were deployed on the OPNET simulator, with the following characteristics:

- *Baseline Scenario (REF):* Reference LTE scenario based on the standard 3GPP Release 8 specification.
- *Capacity Algorithm Scenario (CAP):* The same as the REF scenario, but with the capacity estimation algorithm enabled.
- *Capacity and Speed Algorithms Scenario (C&S):* The same as the REF scenario, but with both the capacity and the user speed algorithms enabled.

Figure 4 depicts the layout of the LTE network devices as configured in the simulator.

As for the user devices, UEs are randomly dropped, with some of them strategically placed near small cells, which is the case for femtocell users (1 stationary UE per femtocell).

The mobility profile used is random waypoint for 50 UEs with average pedestrian speed of 4.9 km/h and vehicular speed of 18 km/h.

Regarding the network traffic load, 4 stationary UEs are placed near the macrocell coverage radius in order to maintain heavy load traffic on the macrocell (4 Mbit/s high quality videoconference and 1.6 Mbit/s on-demand traffic) with the purpose of making the algorithm to give preference to less overloaded base stations (small cells) against the overloaded macrocell. Besides, 6 UEs are configured with specific trajectory, forcing the crossing of the 3 femtocells coverage radius to guarantee femtocell traffic flow, as well as to test the user speed dependency behavior of the algorithm.

Concerning the remaining user devices and their applications and QoS profile, 44 UEs run VoIP plus 3 UEs with VoIP and videoconference, all of them with bronze QoS class, 11 UEs run VoIP with silver class, and 2 UEs run VoIP and videoconference with gold class. On-demand traffic is configured as streaming multimedia of 1.6 Mbit/s in best effort mode and it is run bidirectionally between 2 UEs and the macrocell.

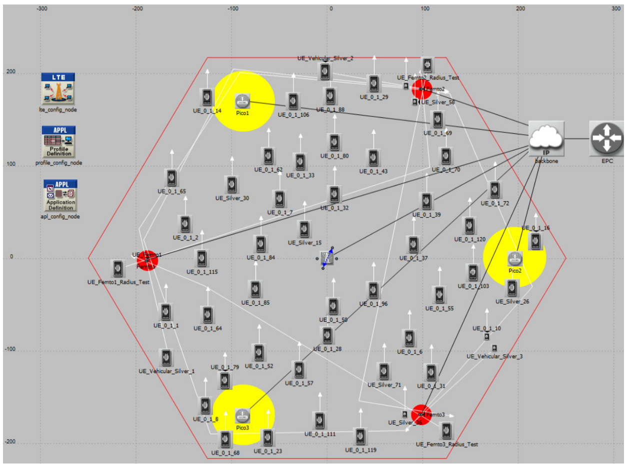


Figure 4. OPNET LTE simulated scenario layout

TABLE III. LTE SIMULATION PARAMETERS

Parameter	Macrocell	Picocell	Femtocell
No. of Base Stations	1	3	3
No. of User Devices	60 UEs Randomly Dropped		
No. of Femto Users	N/A	N/A	3
Antenna Gain	15 dBi	15 dBi	15 dBi
Max Tx Power	31 dBm	21 dBm	18 dBm
Base Station Radius	250 m	N/A	10 m
No. of Tx/Rx Antennas	2	1	1
Pathloss	Outdoor to Indoor and Pedestrian Environment (ITU-R M.1225)		UMi – Outdoor-to-indoor (ITU-R M.2135)
PHY Profile	LTE 3 MHz FDD		
Handover Type	Intra-Frequency		
Frequency Reuse	1 (2.1 GHz Carrier)		
X2 Capability	Enabled		N/A
eNodeB Selection Policy	Best Suitable eNodeB		
UE Mobility	Random Waypoint, trajectory, and fixed.		
UE Speed	4.9 km/h and 18 km/h		
User Applications	VoIP with PCM quality speech (64 Kbit/s), high quality videoconference (4 Mbit/s), and on-demand traffic (1.6 Mbit/s) .		
EPS Bearer Configuration	Bronze (QCI=6): 44 UEs with VoIP and 3 UEs with VoIP and videoconference. Silver (QCI=4): 11 UEs with VoIP, 2 of which with on-demand traffic. Gold: 2 UEs with VoIP and videoconference.		
Simulation Time	150 s with warm up time of 90 s.		

The simulation time has the duration of 150 seconds, with a warm up time of 90 seconds approximately, resulting in an effective simulation time of about 60 seconds for results collection. This simulation time is due to hardware and software constraints when simulating this realistic heavy weight LTE setup, and it was used to guarantee a stable environment at runtime, since a huge amount of events were generated during each simulation run (about 60 million events per scenario). However, after extensive work on planning and deploying variations of the given scenarios on OPNET, we concluded that the 150 s simulation time does not compromise both the algorithms behavior and the results.

B. Simulation Assumptions

In this paper, it is assumed that macro and femtocells send their respective eNodeB types, even though we implement this behavior by means of memory variables which are shared between eNodeB and UE devices. In conjunction with UE speed (vehicular or pedestrian), the eNodeB type is used to decide if a UE is allowed or not to connect to a HeNB.

Also, since OPNET Modeler 17.5.A (Educational Edition), which was used for the simulations, does not have LTE femtocell models, eNodeB models were used with femtocell parameters, instead.

VI. SIMULATION RESULTS

In this paper, the cell selection and handover procedures were identified as key points to be worked on in order to enhance mobile network load balance and user QoS perception, as stated in Section I. So, as an improvement proposal, besides RSRP and RSRQ parameters, two additional criteria were introduced in Section IV: capacity estimation and user speed. Then, to validate the proposed solution, the algorithms depicted in Figure 3 were developed in C++ programming language and implemented on the OPNET discrete event simulator, as well as three LTE scenarios (REF, CAP, and C&S) were planned and deployed on the simulator both for testing and statistics collection.

Thus, after extensive testing through multiple experiments performed in the realistic LTE simulation environment presented in Section V, the following metrics were chosen to evaluate the performance of the proposed algorithms:

- LTE PHY PDSCH Utilization (%);
- Total Admitted GBR Bearers;
- Total Rejected GBR Bearers;
- Downlink Dropped Packets/sec;
- LTE Delay.

The rest of this section presents the performance evaluation of the proposed solution.

A. *Network Load Balance*

From the PDSCH Utilization metric, which shows the percentage of the base stations resource utilization, as depicted in Figure 5.a, as well as numerically detailed in Tables IV and V, the load balance effect on the simulated network is clearly shown.

TABLE IV – REF SCENARIO - LTE PHY PDSCH UTILIZATION (%)

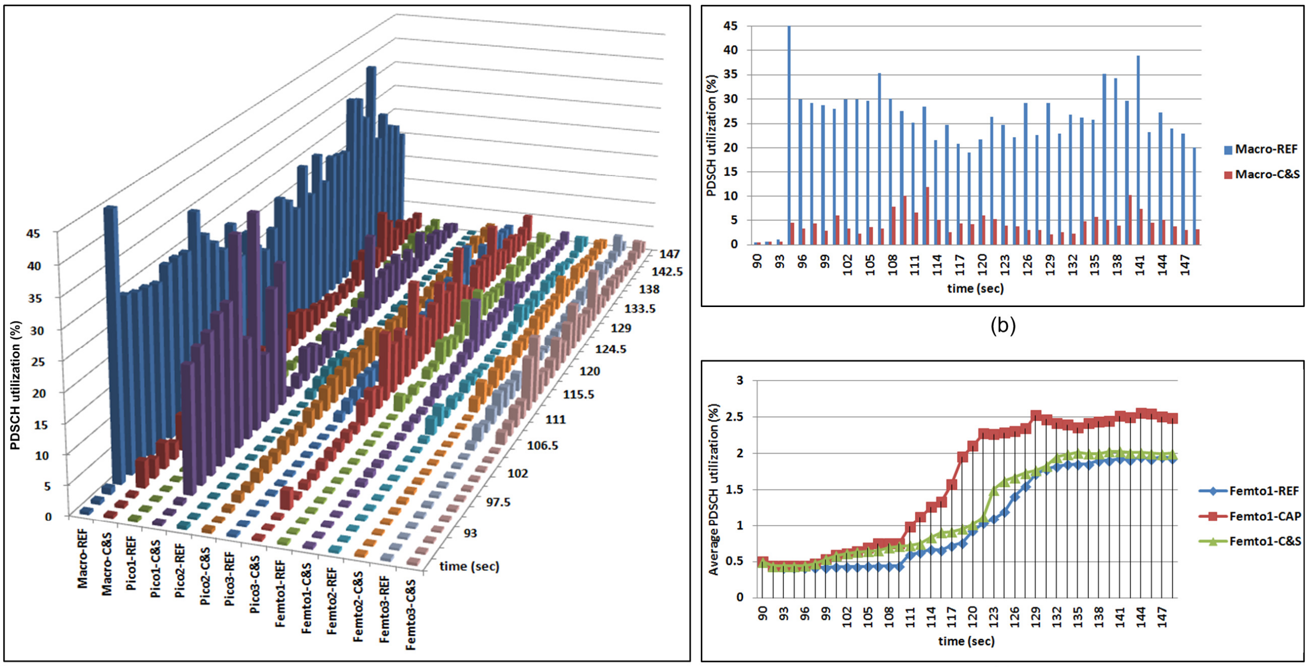
Base Station	Minimum	Average	Maximum	Std Dev
Macro	0.53603	25.465	45.059	8.6903
Pico3	0.37603	2.391	7.756	1.6539
Femto1	0.37603	1.937	6.572	1.6153
Femto3	0.35826	1.657	4.218	1.0533
Femto2	0.35826	1.380	3.969	0.9652
Pico1	0.35826	1.002	3.689	0.8392
Pico2	0.35826	0.749	2.828	0.6769

TABLE V – C&S SCENARIO - LTE PHY PDSCH UTILIZATION (%)

Base Station	Minimum	Average	Maximum	Std Dev
Pico1	0.47758	9.8548	37.542	10.136
Pico3	0.37603	5.3946	16.077	3.830
Macro	0.53603	4.4292	11.908	2.426
Femto3	0.35826	2.9768	11.703	2.719
Pico2	0.42525	2.8224	6.273	1.279
Femto1	0.37603	2.0015	9.813	1.706
Femto2	0.35826	1.8528	4.964	1.258

Figure 5.a reveals that the low power base stations (picocells and femtocells) are underutilized, while the macrocell takes on most of the network traffic in the REF scenario (standard behavior in LTE Rel-8). In contrast, in the C&S scenario (with the proposed algorithms implemented), the network traffic is offloaded from the macrocell to the low power base stations, indicating a more efficient load distribution among all the base stations. From Tables IV and V, for example, it can be seen that the macrocell had its average resource utilization decreased from 25.46 % (REF scenario) to 4.43 % (C&S scenario), which, for this specific case, represents a significant relief for the macrocell, which will have more available bandwidth for better serving UEs.

Figure 5.b highlights the macrocell traffic offloading, while the curves in Figure 5.c give an idea about the user speed influence on the cell selection and handover processes.



(a)

(b)

(c)

Figure 5. Load balancing effect of the proposed algorithm: (a) Network load balancing 3D visual effect; (b) Macrocell offloading effect; (c) Femto1 PDSCH utilization algorithms comparison

B. *QoS Improvement*

In LTE networks, the QoS guarantee for user applications is managed by the use of different EPS bearer types, as explained in Section III, item D, and it is mainly about priority, packet delay, and packet loss error rate, as shown in Table I. So, the higher the priority, as well as the lower the packet loss and the lower the network delay, the better the user QoS level.

Thus, the behavior of EPS bearers, dropped packet rate, and delay metrics is herein presented as an evidence of user QoS perception, as follows.

1) Total Admitted GBR Bearers and Total Rejected GBR Bearers

By inspecting Table VI, some conclusions can be drawn:

- There was an increase of 24.62 % (788 against 982 total bearers) in the admittance of GBR bearers, when comparing REF and C&S scenarios, which is an indication of QoS level improvement.
- There was a huge decrease in the rejection of GBR bearers (19,338 bearers from the REF scenario against 653 bearers from the C&S scenario), which is another indication of QoS level improvement.
- The huge amounts of EPS bearers (6,253, 19,338, and 26,628 bearers in the summation columns), appearing in the REF and CAP scenarios, are partially due to the excessive number of tries to establish connections to short coverage radius base stations (femtocells). An evidence of this is the lack of the user speed algorithm in the REF and CAP scenarios.

TABLE VI - GUARANTEED BIT RATE BEARERS

	Scenarios					
	Total Admitted GBR Bearers			Total Rejected GBR Bearers		
Base Station	**REF**	**CAP**	**C&S**	**REF**	**CAP**	**C&S**
Macro	434	5,355	560	495	24,975	275
Pico1	170	189	152	17,204	9	14
Pico2	44	209	135	860	350	0
Pico3	0	65	35	0	0	9
Femto1	0	14	0	0	0	0
Femto2	135	377	65	779	1,175	350
Femto3	5	44	35	0	119	5
Total	**788**	**6,253**	**982**	**19,338**	**26,628**	**653**

Figure 6 simplifies the analysis on the user QoS improvement evidence, where the best QoS case is highlighted, as shown in the graphics region corresponding to the C&S scenario, where both capacity estimation and user speed algorithms are enabled, promoting the benefit of an overall performance improvement of the system.

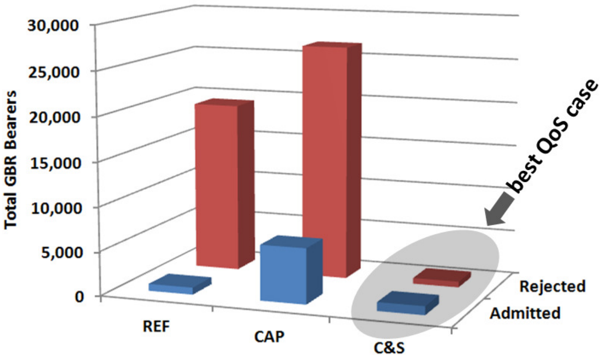


Figure 6. Best QoS case

The best QoS case is the region where 982 admitted GBR bearers meet 653 rejected GBR bearers, as highlighted in Figure 6.

2) Downlink Dropped Packets/sec

Table VII summarizes the packet loss rate for the three simulated scenarios, where it can be verified that there was a decrease of 25.35 % in the downlink packet loss rate when comparing the summations of REF and CAP scenarios, against a decrease of 24.46 % when comparing the summations of REF and C&S scenarios.

In contrast to the admitted GBR bearers versus the rejected GBR bearers analysis, conducted in B.1, where capacity estimation and user speed algorithms in conjunction were responsible for an optimum result (best QoS case), the results in Table VII indicate that the capacity estimation algorithm enabled both in CAP and C&S scenarios was indeed the responsible for the decrease in packet loss error rate, while the user speed algorithm showed a small influence of 0.89 % on this metric.

TABLE VII - DOWNLINK DROPPED PACKETS/SEC

	Scenarios		
Base Station	**REF**	**CAP**	**C&S**
Macro	2,945.90	320.68	511.55
Pico1	17.80	726.67	575.01
Pico2	12.50	544.91	475.89
Pico3	96.80	717.15	637.54
Femto1	55.00	105.97	128.78
Femto2	75.40	95.11	132.11
Femto3	64.50	96.49	164.85
Total	**3,267.90**	**2,606.98**	**2,625.73**

3) LTE Delay

Table VIII summarizes the LTE delay, which is the delay of all the traffic that flows between eNodeBs and UEs arriving at the LTE layer.

The data show that a better result was achieved with the CAP scenario (capacity estimation algorithm only), which presented an LTE delay of 1.87 seconds, against the result of 2.87 seconds for the C&S scenario (both capacity estimation

TABLE VIII - LTE DELAY (IN SECONDS)

	Scenarios		
Base Station	**REF**	**CAP**	**C&S**
Macro	3.54	1.20	1.83
Pico1	0.08	0.16	0.11
Pico2	0.09	0.08	0.12
Pico3	0.14	0.09	0.15
Femto1	0.38	0.11	0.38
Femto2	0.09	0.09	0.09
Femto3	0.10	0.14	0.16
Total	**4.42**	**1.87**	**2.84**

and user speed algorithms enabled). However, considering the overall system performance, as well as the other already presented metrics, the LTE delay of 2.84 seconds found in the C&S scenario still represents a significant reduction of 55.63 % (4.42 s against 2.84 s) in the LTE delay.

VII. CONCLUSION AND FUTURE WORK

This section summarizes the impact of our algorithms on the simulated LTE network, as well as give directions for future work.

The simulation results, with the adoption of the developed algorithms proposed here, showed that significant load balancing gains, as well as user QoS improvement can be achieved if the two additional criteria are adopted.

The load balancing effect of our algorithm is based on the adoption of these two additional criteria in conjunction: user speed to avoid short radius cells to be selected when user is in vehicular speed (moving too fast to benefit from a HeNB connection), as well as eNodeB capacity estimation to avoid overloaded base stations from being selected. As a consequence, QoS improvement can be achieved with our proposed solution, since the macrocell is freer to accept connections from more users. Also, femtocell users will not be impacted by users in vehicular speeds, which makes their home femtocells more available to themselves, while picocell take on more traffic load, despite of their low transmit power when compared to the macrocell.

It was demonstrated that the small cells took on more traffic flow, since the small cell users could benefit from higher modulation orders, such as 64QAM (and hence higher throughput values) for being closer to a base station with higher probability of good radio link quality. Besides, users that are closer to macrocell had more available resources at their disposal.

Femtocells had their workloads reduced mainly due to the user speed check algorithm, which caused vehicular users not to “notice” the presence of femtocells on the network. This could be seen from the reduced number of admitted GBR bearers, when the C&S scenario (capacity estimation + speed check algorithms) was compared to the REF scenario.

As future work suggestions, it is desirable to:

- Endeavour a deeper study on the weights calculation method used both for RSRP/RSRQ and capacity estimation value, so that load balancing effect can be fine tuned.
- Have a more detailed insight on the effect of outdoor UE speed on the quality of mobile service for the indoor femtocell users.
- Experiment with different path loss models and longer distances.

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