HCS in UMTS/HSPA Systems

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***Abstract* — New applications put out by the service providers require high data rates in order to enjoy the best performance of its functionalities, hence to have a good Quality of Service (QoS). To provide the system with a solution to enable a good service to user equipments one can adopt the HCS (Hierarchical Cell Structure) model. The model is considered to improve the system's capacity, coverage and quality of service. In this paper, several HCS scenarios are implemented over the UMTS, HSDPA and HSUPA technologies. Four distinct profile users are considered and a snapshot method was used to simulate the mobile users. The scenarios are individually analyzed and submitted to performance comparisons. The results show that the deployed scenario with higher number of co-located cell partitions is the one that provides a higher system capacity, i.e. better cell throughput, and also higher service rates (near 95%). The model with cell-edge topology allowed the increase of the inter-cell area throughput.

Keywords – UMTS, HSDPA, HSUPA, Cell Partitioning, Hierarchical Cell Structure

I. INTRODUCTION

To provide high data rates it is essential to increase the network's capacity and also the quality of service. Recently introduced technology like HSDPA, in 3GPP's Release 5, and HSUPA, in Release 6, can provide theoretically data rates up to 14.4 Mbps and 4 Mbps respectively [1].

It is expected an increase of the system's capacity with the deployment of the HCS model in the UMTS system. Several models are proposed and evaluated in the following sections.

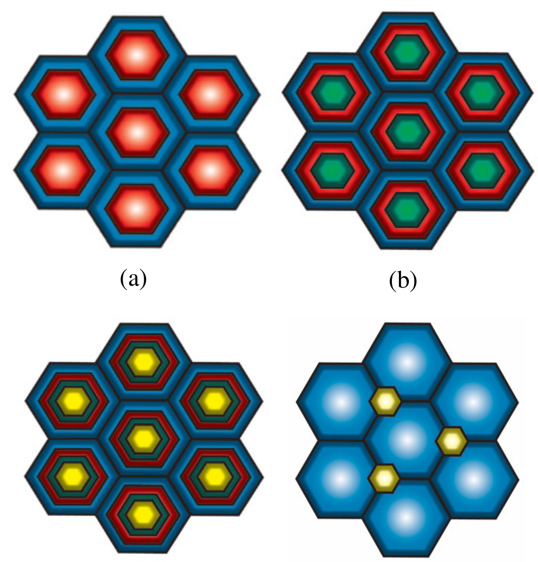
The system's analysis is performed concerning the downlink and uplink connections. This paper evaluates the hierarchical system performance of HSDPA and HSUPA in WCDMA networks underlying the development of cell deployment strategies. Some of the scenarios have already been used in previous works [2] and [3]

Section II presents the system model used in the simulation process. The simulator's main functions and implementation are presented in Section III. Simulations results are presented and analyzed in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODELS

Four distinct HCS models were adopted to simulate a network environment. The deployed scenarios are presented in Figure 1.

As shown in the figure, three of the strategies use cell partition with co-located base stations, in Figure 1-(a), (b) and (c). The other scenario uses a micro-cell located at the macro-cell edge, as shown in Figure 1-(d).



(a) (b) (c) (d)

Figure 1. Cell deployment strategies for the HCS model

In Figure 1 the colors represent distinct frequency carriers and also distinct emitted base station power.

The macro-cell is used to provide the system with a better coverage area while the micro-cells have the utility of serving the most demanding users in terms of bit rate, i.e., a better quality of service, functioning as a hot-spot.

The macro cell base stations are spaced by 600 meters. Tri-sectored, with 65 degrees antennas, and omni-directional antenna pattern are used with different power levels for different frequency carriers (a step of 5 dB was selected as used in [4]).

III. Simulator aspects

The simulator developed for this work is based on the *Nokia*'s NPSW (Network Planning System for WCDMA), which can be found in [5]. This simulator is employed to perform radio network planning. As this simulator version did not present the needed requirements for this work, i.e. the HSDPA and HSUPA technologies, these have been developed, as well as the HCS models and specifications.

The simulator can be denominated as a static simulator, since it does not apply any mobility model to the mobile stations (MS). Instead it produces consecutive snapshots to the network varying the mobile station's position.

The simulation environment consists in a 4000X4000 meters area, where the base stations are positioned and the mobile stations are randomly spread throughout the area with a pre-defined type of service and frequency carrier.

The COST 231 Walfisch-Ikegami was the propagation model used in a dense urban scenario.

In what concerns the base stations, its configuration is a fundamental step in the definition of the simulation scenario playing a fundamental role in the network planning process.

The information that characterizes the base stations is stored in a text file, which is used in the main window of the simulator. The information can be summed in four important characteristics: location coordinates; antenna specifications (tri-sectored or omnidirectional); frequency and transmitted power.

The mobile stations have several characteristics: geographic position; height; transmitted power; frequency carrier used; type of service used; maximum and minimum service throughput in DL and UL and QoS priority.

In order to provide a non-uniform mobile station distribution in the scenario, the simulator performs a MS generation, allocating users containing the previously referred specificities and with a random geographic position, concerning the scenario limits. Afterwards the MSs are distributed by the frequency carriers available in the scenario.

In addition to the mobile station's characteristics mentioned before, four users' profiles were employed in order to simulate the HCS model's applicability for different end user's conditions (pedestrian, vehicular, indoor low loss and indoor high loss). Details for these can be found in [7].

After allocating the users with a type of service and with one of the profiles mentioned above, they are distributed by the frequency carriers available in each scenario. In Table I the distribution of users per number of carriers is specified.

TABLE I. Distribution of user's percentage by available carriers

Scenario	Percentage of Total users [%]			
	Carrier 1	Carrier 2	Carrier 3	Carrier 4
1	65	35	–	–
2	50	30	20	–
3	45	30	15	10
4	80	20	–	–

Following the users distribution some primary calculations are performed including link losses, SINR and E_c/N_0. The link losses are estimated in order to be possible to confer them the best base station signal situation. After that, the SINR and the E_c/N_0 parameters are computed in order to be able to define the user's state, i.e., connected, delayed or outage.

The SINR is then used to compute the maximum available throughput, using the expressions in [6]. This parameter plays an important role in the simulations, since it is the downlink sensibility parameter. The same can be said in relation to the uplink parameter, E_c/N_0.

In what concerns the possibility of an excess of service requests to a given base station a reduction strategy is implemented. The strategy adopted for this simulator has the main goal to decrease the throughput available for every user of the base station on which the strategy will be applied. The amount of throughput reduction can be defined by the simulator user in the main settings window. The default value, which was also the one considered for this work was a 10% reduction of user's throughput. This strategy is implemented in both HSDPA and HSUPA.

Concerning the post processing, it is executed when the iteration process ends, providing several information data such as the number of served users by each used carrier, the user's average throughput or the service rates for each profile mentioned above.

IV. Results

The results attained with the simulator are intended to study each scenario maximum throughput, aimed capacity and coverage, in terms of number of served users for both HSDPA and HSUPA technologies. Some parameters for HSDPA and HSUPA were defined and are presented in Table II. These parameters are essential for the link budget estimation.

TABLE II. Values used in HSDPA and HSUPA simulations

Parameter	HSDPA	HSUPA
Number of HS-PDSCH codes	10 and 15	-
Mobile terminal transmission power [dBm]	-	24
Mobile terminal antenna gain [dBi]	0	0
Mobile terminal height [m]	1.8	1.8
Node B antenna gain [dBi]	17	17
User losses [dB]	1	1
Cable losses [dB]	3	3
Noise Figure [dB]	9	5
Interference Margin [dB]	6	6
Diversity Gain [dB]	-	2
SHO Gain [dB]	-	2
Signalling and power control percentage power [%]	R99: 25 HSDPA: 10	-
Reduction Strategy	Throughput Reduction	Throughput Reduction

Simulations were performed for the four defined scenarios, considering 2500 and 4000 initial users, in order to observe the systems capabilities of supporting distinct amounts of users. In Figures 4-(a) - (e) the maximum available throughput in DL are presented, in this case for 15 HS-PDSCH codes, for scenario 1, 2, 3, 4 with omnidirectional antennas and 4 with tri-sectored antennas, respectively.

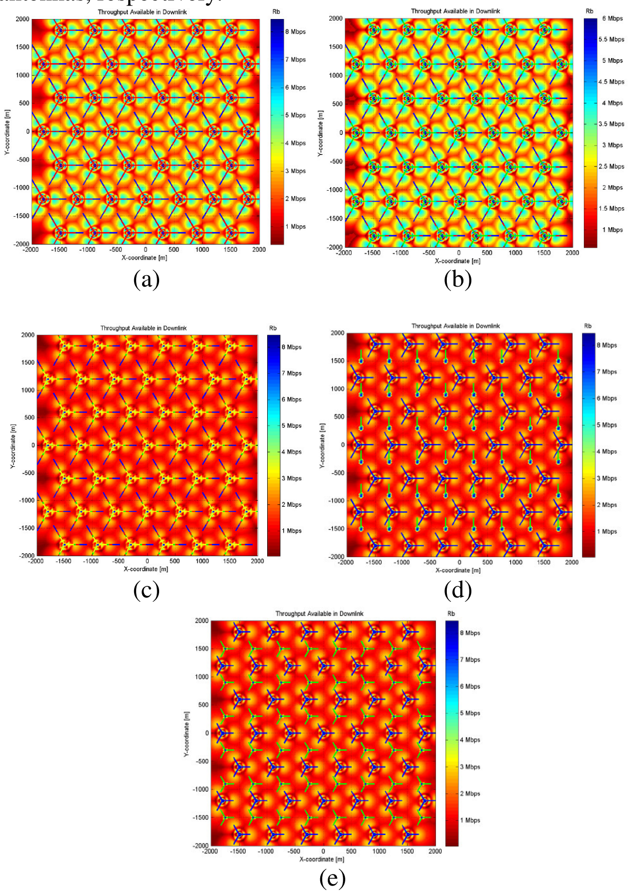


Figure 2. Maximum available throughput in downlink

From the graphs presented in Figure 4-(a) - (c) one can conclude that the best throughput situation is achieved in areas near the center of the cell, i.e. near the Node B. In Figures 4-(d) - (e) the available throughput is more spread given the introduction of micro-cells at the macro-cell's edge, not allowing a sharp drop of the macro-cell's signal when a user is moving away from the center of that cell.

In what concerns the HSUPA results, in Figure 5 one presents the maximum available throughput in uplink, for the same scenarios. It can be seen that the best throughput is achieved in locations near the base station. An increase of the available throughput is verified when the number of carriers also increases, as presented in Figure 5-(a) - (c). From Figures 5-(d) - (e) it is possible to observe that the introduction of base stations at the macro-cell's edge avoided the throughput drop in locations far from the center of the macro-cells.

In Table III, the HSDPA and HSUPA most relevant results are presented. For HSDPA, in the first three scenarios, which have a similar structure, the maximum served user's rates achieved are very close to each other. One can observe a small decrease in the percentages when comparing the scenarios with 2500 and 4000 initial users, with the exception of scenario 3. The highest percentage is achieved in scenario 1, for 15 codes,

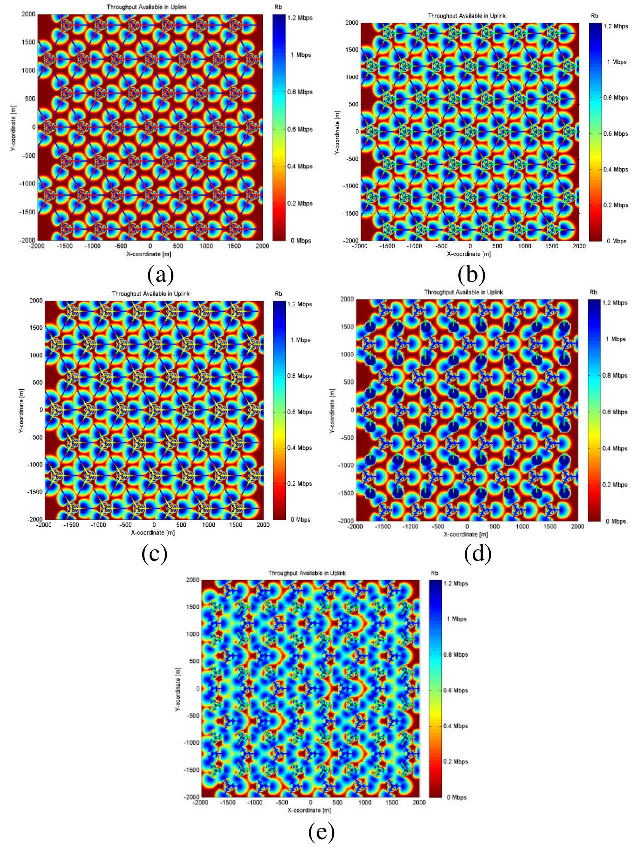


Figure 3. Maximum available throughput in uplink

TABLE III. RESULTS ATTAINED FOR HSDPA AND HSUPA SIMULATIONS

			HSDPA		HSUPA	
Scenario	Antenna Type	Number of Initial Users	Total Served User's Rate [%]	Average User's Rb [Mbps]	Total Served User's Rate [%]	Average Users's Rb [Mbps]
1	Tri sectored	2500	98,6	0,467	74	0,328
		4000	90,5	0,491	73,2	0,310
2		2500	94,8	0,399	78	0,306
		4000	92,6	0,457	77,9	0,287
3		2500	93,68	0,494	81	0,279
		4000	94	0,502	83	0,256
4		2500	89,24	0,207	73,4	0,165
		4000	87,48	0,232	70,3	0,152
	Omni directional	2500	85,68	0,186	71,04	0,162
		4000	84,8	0,197	70,1	0,149

with 98,6%. As for scenario 4, with cell-edge topology, the results have different dimensions than those attained with the previous three scenarios, with a rate variation from 84,79% to 89,23%. Once again, a slight reduction of the served users' rate is detected when 4000 initial users are considered. Concerning the antenna type, it is possible to conclude that a micro-cell with a tri-sectored antenna achieves better results in terms of served users' rate, with rates up to 89% compared with omnidirectional antennas with rates around 85% .

The highest percentages of served users, presented in Table III, were all achieved with resource to 15 HS-PDSCH codes.

The co-located cell topology, used in the scenarios 1-3 is the one that presents better results, not only in the number of served users but also with the users' average throughput, in comparison with the cell-edge topology adopted in scenario 4. Comparing scenarios 1 and 4, given the fact that both employ two distinct carriers in the system, one can conclude that scenario 1 achieves better results than scenario 4, not only in terms of number of served users but also in average throughput per user. The increase in the available throughput is most noticed in the cell-edge topology than in the co-located one, since in the former the signal provided by the micro-cell at the macro-cell edge is less influenced and overlaid than in a co-located cell topology, and given the fact that the macro-cell transmits its power at a higher level compared to the micro-cell, allowing a larger covered area.

Concerning HSUPA results, one can easily observe that there is a constant increase in the served users' rate from scenarios 1 to 3, due to the carrier addition in each scenario allowing the system to serve more users. In what regards the uplink average data rate, this is mostly related to the MTs locations. The systems' load of number of users is another constraint factor, so if a system is required a higher number of service and it is reaching its limits, than a reduction in the throughput is a primary action, causing an overall decrease of the system's average throughput.

As can be observed in Table III, the average throughput is decreasing with the raise in the systems' number of carriers. This can be viewed as a trade-off between having more users with smaller data rate or having a less number of users but achieving higher data rate. As before mentioned the maximum theoretical data rate in HSUPA is 1,22 Mbps, but given the service's throughput requirements, an average throughput of near 0,245 Mbps is required. Therefore, the data rate results shown in Table III are quite acceptable.

V. Conclusions

The main objective of this work was to analyze the behavior of 4 distinct network topologies in UMTS/HSPA. HSDPA results show that increasing in the number of carriers in the system provides service rates from 90% up to 98%, for the co-located carriers scenarios, being the highest value achieved with a two co-located carrier scenario.

A divergent conclusion is taken when the average delivered throughput is considered. The overall throughput values achieved are below 500 kbps, which is quite lower than the theoretical 14 Mbps. This corroborates the idea of a necessary closeness between the HSDPA base station and the end user to afford data rates higher than 1 Mbps.

With the exception of the third scenario, in every scenario a small decrease of the served users' rate is verified, when 4000 users are initially allocated instead of 2500, however an increase of average throughput is evidenced in each scenario.

For scenario 4 with omnidirectional and tri-sectored antennas an increase of the average throughput is verified, which can be explained by the increase in the number of users spread across the scenario that can afford a better Node B signal condition, since a higher number of initial users implies an augment of the probability of being closer to the base stations. In what regards HSUPA, smaller service rates are attained, which can in some way be explained not only by the values achieved for E_c/N_0 and the maximum available throughput are shown but also by the lower theoretical data rate value, which is 1,22 Mbps. From Figure 5, one can observe that the best signal conditions are restricted to a tight limited perimeter surrounding the base stations. This can explain the reason of not achieving service rates as high as the HSDPA. The most interesting service rates results are attained for scenario number 3, reaching up to 83% of served users. One can notice a constant increase in the service rate when the number of carriers is also increasing, from scenarios 1 to 3. However, there is also a lower offered throughput connection between the MT and the Node B, as one can behold in Table III.

Concerning scenario number 4, with cell-edge topology, the served user's rates achieved vaguely lower than the previous referred scenarios, with rates around 70% to 73% of the total initial users. From Figure 5, it is possible to conclude that the scenario number 4 provides a more efficient data rate distribution, serving areas that the macro-cell may not support the introduction of new co-located base stations with an emitted power not high enough leading to difficulties of communication between the Node Bs and the MTs, if the distance between them increases.

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