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Coverage and Capacity Planning for 3G and beyond Mobile Networks.

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Abstract

Cell Coverage and Capacity are strongly related in W-CDMA-based 3G and beyond networks. In this paper we propose a novel approach for coverage and capacity planning suitable for multiple deployment environments. Our approach produces results which are more comprehensive for 3G and beyond networks, such as UMTS and Enhanced-UMTS, compared to results obtained using related approaches. The evaluation takes into account a mixture of user traffic types and the scenario dependencies that W-CDMA networks impose.

Keywords

UMTS, W-CDMA Simulations, Coverage, Capacity, Planning, 3G

Working Group 3

I. INTRODUCTION

The success of 2nd generation mobile networks and the rapid growth of mobile and Internet users led towards the development of the 3rd generation of mobile telecommunication systems. This 3rd generation is standardized by the 3G Partnership Project (3GPP) [1] in Europe, and is named UMTS (Universal Mobile Telecommunication System). Initially in the first release of UMTS, 3GPP R99 [2], the UMTS transport network technology was ATM-based, but in the later specification of 3GPP UMTS R5 [3] the aim is to have an "All IP" architecture, i.e. the transport technology in all the parts of the UMTS network is IP-based.

The goal of the all-IP network is, while minimizing network operation costs, to enable broadband access operators to move from being mere connectivity providers to being full-service providers, providing Internet connectivity, voice services and next generation broadband services to end users, all from a single network.

In order for multiple users to be able to co-exist and share the same air interface simultaneously, several radio communication techniques exist. Such a technique used in UMTS and Enhanced-UMTS networks is the Wideband Code Division Multiple Access (W-CDMA) technique.

W-CDMA coverage and capacity planning is a planning methodology with two main objectives: providing coverage and providing capacity, in a way as to meet the demand for acceptable QoS and maximizing throughput.

This paper presents a novel approach for coverage and capacity planning for W-CDMA-based UMTS and Enhanced E-UMTS networks. The evaluation is performed using an Enhanced-UMTS dynamic system level simulator, developed within the IST funded SEACORN project [4]. The simulator takes into account a mixture of user traffic types and can evaluate multiple deployment scenarios.

Section II presents related work published in the area of W-CDMA network planning. Section III illustrates the coverage and capacity planning approach. Section IV focuses on simulation results and comparisons. Section V concludes this work.

II. RELATED WORK

Planning of a W-CDMA network should consider both coverage and capacity to determine the values for each that provide the best support of the objective traffic mix.

Most 3G planning tools are based on some form of Monte Carlo simulation, although analytical approaches also exist. Theoretical calculations on coverage and

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capacity planning as in [5] may provide some hard bounds on the usage values, but usually suffer from assumptions on ideal conditions such as the availability of spreading codes, no intra- or inter-cell interference, or perfect power control. The simulator-based approaches are more realistic.

Dehghan, Lister, Owen and Jones address several W-CDMA capacity and planning issues in [6]. To support their arguments, the authors present an example W-CDMA network, with results for a realistic site location in central London. They aim to locate parameters, which affect the capacity of a W-CDMA network both from a theoretical point of view as well as through a static simulation planning tool.

Hoppe, Buddendick, Wolfle and Landstorfer also address WCDMA radio network performance in [7]. They present a dynamic simulator that aims to support the planning process of a W-CDMA network by analyzing the performance results obtained through simulation. The proposed dynamic simulation tool is supported by a simulation example that outputs coverage maps for different bit rate data services and specific user distributions. The topology of the scenario aims to replicate downtown Munich.

Hoppe, Wolfle, Buddendick and Landstorfer further presented work on Fast Planning of W-CDMA networks in [8]. The paper elaborates on a proposed simulation tool that supports the W-CDMA coverage and capacity planning by evaluating the performance of specific network configurations. The results mostly focus on the voice service and present a coverage map for the specific scenario.

Wacker, Laiho-Steffens, Sipila and Jasberg [9] address similar planning issues. They propose a static simulator that allows analyzing coverage, capacity and quality of service related issues. An example scenario is provided to illustrate the interactions between coverage and capacity and further to study different strategies for optimal planning of W-CDMA networks.

III. COVERAGE AND CAPACITY PLANNING APPROACH

In this section we present the simulator structure and the planning approach and evaluating scenarios.

A. System Simulator

The system level simulation framework aims to capture the overall end-to-end network behavior.

Its modules include dynamic user behavior models (e.g., mobility and variable traffic demands), as well as representations of the radio interface, Radio Access

Network (RAN), and Core Network at an appropriate level of abstraction. The transport technology in all parts of the wireless/cellular network is IP-based.

The simulator is based on the system architecture of UMTS for packet-switched operations.

B. Planning Approach and Simulation Scenarios

Coverage and Capacity planning is scenario-dependent; thus the first step is to select the parameters that will characterize the specific scenarios. The two environments we study include a Business City Centre and an Urban environment.

For the business city center environment we consider a Manhattan-grid like topology with users moving in the roads between blocks according to a Manhattan mobility model which specifies that the nodes move only on predefined paths along a Manhattan Grid (only parallel to either the x- or y-direction). The users move with pedestrians speeds of around 3Km/h.

For the urban environment we consider two topologies: a 7-cell and a 19-cell topology as shown in Fig. 1. Users follow a Gauss-Markov mobility model. In a Gauss-Markov mobility model, users move in a random manner. What characterizes this model is that the users move with relatively high speeds (around 50Km/h)

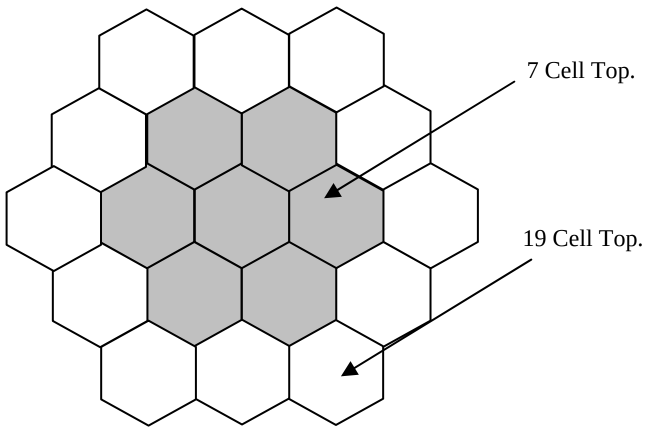

Fig.1: Urban topologies

Given the environments and the mobility and propagation models we make a first educated guess of a reasonable set of cell radii to be checked and the number of supported users that will give us a number of call blocks suitable for comparison. The number of users to be used can be reached by trial and error or by prior similar system knowledge.

Two sets of simulations are run for each scenario. First, with a given number for expected users (or a set of numbers), we determine the values of the optimal cell radii for best coverage by measuring the number of call blocks as we increase the cell radius. In this step we observe a decrease in the call blocks at or around the optimum distance.

Second, we determine the maximum capacity that can be supported at the given cell radius by keeping the radius constant and increasing the number of users. We record again the call blocks created and we consider as the capacity of the cell the maximum number of users that create a blocking probability of less than 3 percent.

Furthermore, two traffic models are applied to each environment. The first is a traffic model with a single type of traffic (voice) for all users and the second is a traffic mix model (voice, multimedia, narrowband and wideband services).

The single traffic simulations gives us the upper bounds of capacity and coverage, whereas the traffic mix simulation gives us the average operational values.

The best coverage is found by the least number of call blocks for the distances and number of users in these scenarios. Similarly, the best capacity is the maximum number of users that give the maximum acceptable number of call blocks for the chosen best coverage.

IV. SIMULATION RESULTS AND COMPARISONS

This section presents and analyzes results on Enhanced-UMTS coverage and capacity planning obtained using the all-IP system level simulator. Furthermore, it provides an evaluation by comparison of the obtained results.

A. Capacity and Coverage Results

The first set of results (voice service) aim to examine the behavior of the network in a situation where a single type of traffic is used before examining its behavior in situation where a traffic mix is applied, because it gives a more predictable behavior of the network.

There are two reasons for calls to be blocked in these scenarios. The first reason is no admittance from the Admission Control mechanisms because of lack of appropriate codes for the call. Since only low bit rate users are considered in these scenarios, namely voice, this does not happen. The second reason is because of power, either too much detected power, i.e. interference, or not enough power to support the call (lack of sufficient coverage).

Fig. 2 presents coverage for the Business City Centre environment (using voice users only) as a function of increasing distance between Node Bs vs. Number of call blocks for each simulation. This simulation was run twice with a different number of users (600 users and 700 users). Fewer users would not generate a large enough number of call blocks to allow us to make observations about the coverage.

The choices for candidate best distances are 130m, 230m, 330m, 430m, 530m and 630m. The choice for these distances results from recommendations made within the SEACORN project for the BCC topology. The roads have a length of 30m, while the building blocks are squares with a side that varies between 100m, 200m, 300m, 400m, 500m and 600m for our simulation purposes. A distance between any two Node Bs includes a building block side and a road, hence the resulting values for candidate best distance.

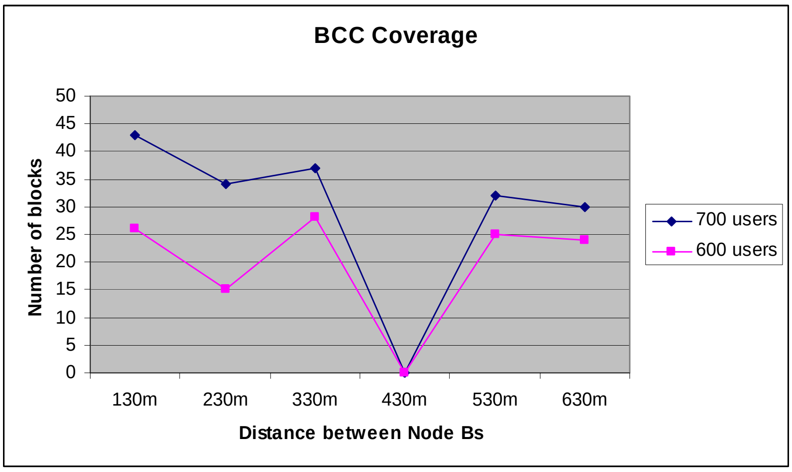

Fig. 2: BCC Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks

The two obtained curves behave in a similar manner. It is obvious that in both simulation runs the distance 430m generates the least number of call blocks. The reason for the observed blocks is power: as the Node Bs are located closer together signal interference causes the calls to be blocked, while as the Node Bs are located further away from each other, the signal strength is insufficient to support all the calls.

Fig. 3(a) presents the coverage results for the urban environment. The results show that for the voice service, the best distance between Node Bs is 900m. The above results were obtained using a 7-cell topology and 2000 users. We observe that in all simulations we have a very large number of blocks. To improve the accuracy of the results we run the simulation again on a 19-cell topology with 4000 users (to ensure there is adequate number of blocks). The results are shown in Fig. 3(b).

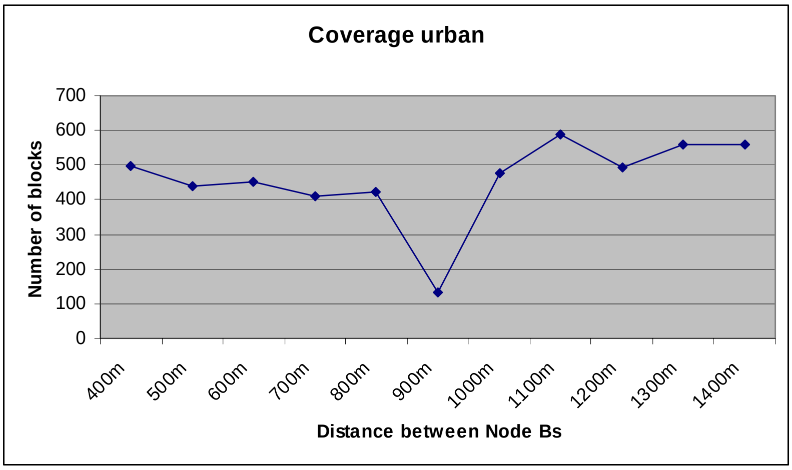

Fig. 3 (a): Urban Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks (7-cells)

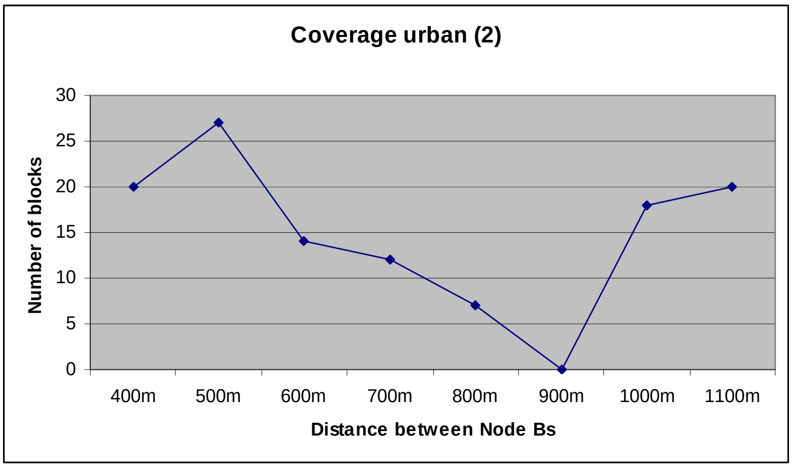

Fig. 3 (b): Urban Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks (19-cells)

The above results show a negligible number of blocks for the chosen coverage. The recommended corresponding capacity for each scenario is the number of users in the scenarios. For example, a distance of 400m to 500m (430m value from our simulation results) in the Business City Centre and a population of up to 700 sound users are recommended for coverage and capacity planning of this scenario. For the urban scenario the best distance appears to be 900m and the acceptable capacity is 4000 users for the 19-cell scenario.

A traffic mix is used for the next set of results. The number of users in the BCC scenario is 3000 and in the Urban scenario the number is 5000.

The results for the BCC scenario (Fig. 4) give 230m to be the best distance between the Node Bs. As expected, this value is less than 430m, the best distance in the voice simulations. The higher bit rates that exist in the traffic mix used in this set of scenarios require the Node Bs to be closer together to support the multi-rate users in the best possible manner.

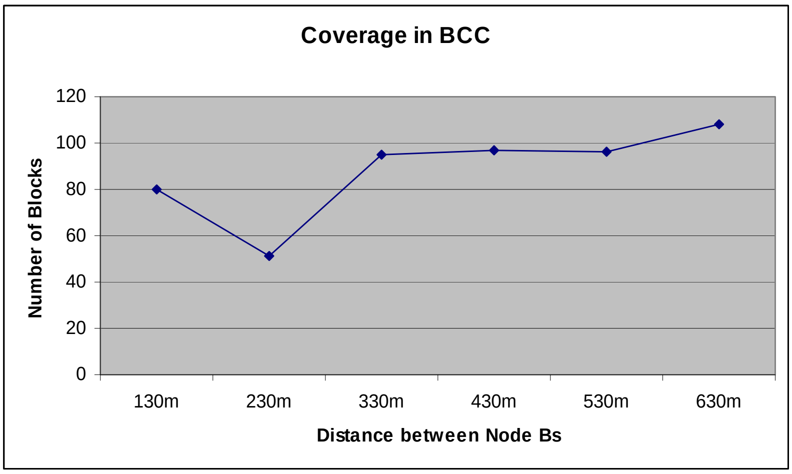

Fig. 4: Coverage in the BCC scenario in terms of distance between Node Bs vs. number of call blocks.

The best coverage in the Urban environment is provided when the distance between the Node Bs is 800m (Fig.5).

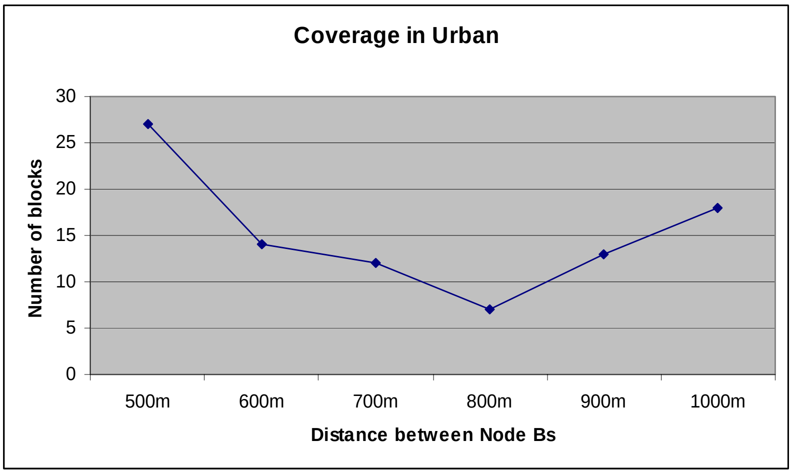

Fig. 5: Coverage in the Urban scenario in terms of distance between Node Bs vs. number of call blocks

The following set of results aims to find the maximum acceptable capacity for each environment by performing simulations with different numbers of users. The same traffic mix model is used for each environment scenario.

The best distance between the Node Bs is selected and applied to the next set of results. This set of results presents the capacity for the BCC and the Urban scenarios. The variable parameter is the number of users. The same traffic mix is applied here, as in the simulations for coverage, in order to determine the acceptable maximum capacity for these scenarios. For each scenario, we present a graph of number of users vs. call blocks.

Fig. 6 presents the capacity in the BCC. Increasing the number of users increases the call blocks in a linear manner. From the 1000 user scenario and above the number of call blocks are not acceptable compared to the numbers of active users in the scenarios. Some call blocks are generated in the 500 user scenario but the number is negligible number, as it is sensitive to other environmental simulation factors. For example, a different user distribution or mobility model could possibly eliminate these blocks.

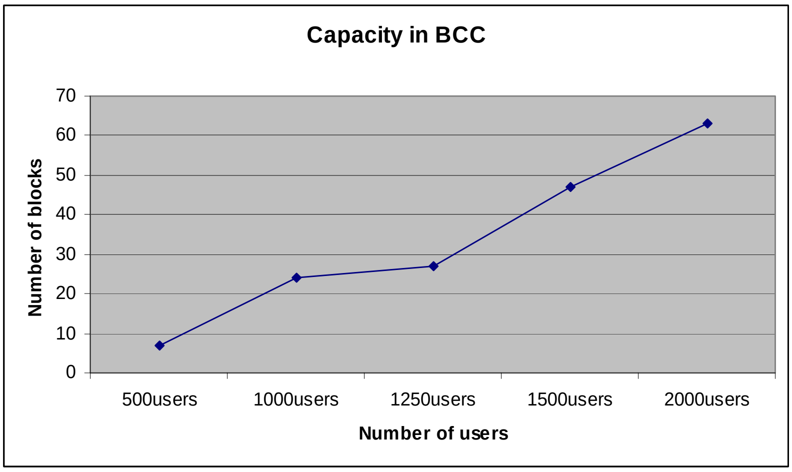

Fig. 6: Capacity in the BCC scenario in terms of number of users vs. number of call blocks

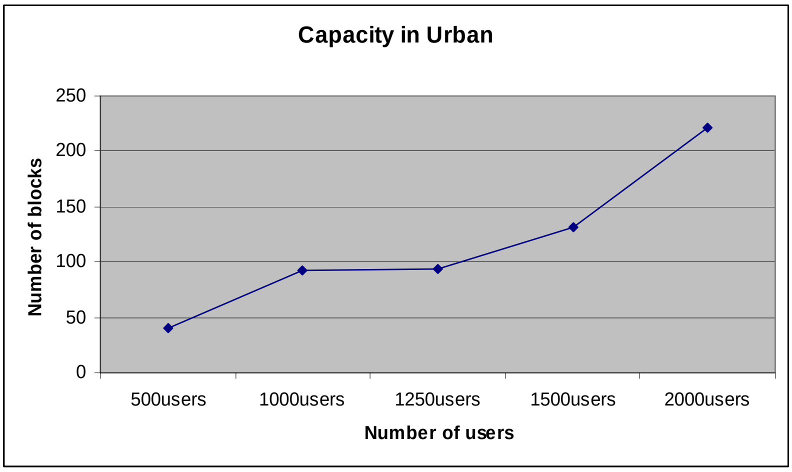

Fig. 7: Capacity in the Urban environment in terms of number of users vs. number of call blocks

For determining the capacity in the urban environment (Fig. 7), the topology has been decreased from 19 cells to 7 cells. This was done for technical reasons since the 19-cells urban scenarios are extremely computationally demanding. This scenario seems to support over 1000 users, but less than 1500.

B. Comparisons with other W-CDMA simulators

In Section II, four separate simulators used for W-CDMA coverage and capacity planning have been presented. In this section published results from these simulators are compared with similar results obtained from the Enhanced UMTS system level simulator, in order to increase the confidence in our results and consequently the tool itself.

The results we have for comparison are not extensive but sample results that are used in the corresponding papers to demonstrate the use of the proposed tools. They are taken from scenarios where the users generate voice traffic. In Section IV.A, we have presented coverage and capacity results for the Business City Centre and Urban scenarios using only voice users. We are going to use those results in our comparisons.

The proposed topology for an urban-like environment published in [9] includes the network topology and the user distribution used in the scenario. The distance between the Node Bs is 3000m.

The paper shows that a 144kbps user moving randomly around the above mentioned grid area with pedestrian speed of 3Km/h has a 72% coverage probability while a Voice user has 98% coverage probability [9]. This implies that a high bit rate user is not adequately supported in moving around this environment. Only a voice user is supported in this topology.

Similarly to our urban scenario, the topology consists of 19 cells with tri-sectored antennas. The distance in our scenarios is shown to achieve best capacity at 900m. Bigger distances up to 1400m may also acceptable as the number of blocks in the 19-cell scenario is very low for a capacity of 4000 voice users. The number of users in the scenario evaluated in [9] is 1500. This number would not generate any blocks in our scenario.

The scenario in [7] simulates a city centre environment based on the city of Munich. The results are comparable to our Business City Centre scenario results. The distance between Node Bs varies between values slightly less than 500m to values slightly more than 1000m. The average number of users in the scenario is 750.

There exist areas with no coverage in the proposed scenario, but as mentioned in the paper these areas are mostly within buildings, therefore the coverage provided for the voice service is sufficient. Further study on coverage for the 384kbps service showed that with the current topology, coverage for the higher bit rate service is poor as some areas show no coverage.

The results obtained for the best coverage of the Business City Centre for the voice traffic are comparable to the results published in [7] for the scenario replicating the city of Munich. We concluded that for voice users the recommended distance between the Node Bs is about 430m. The distances here vary around 500m, very close to the value we generated. Furthermore, the published results show that some areas do not have adequate coverage; therefore a decrease in the 500m distance could possibly cover those areas as well. Furthermore, the average number of users in our simulations is 650 (600-user scenario and 700-user scenario) instead of 750 used in the published scenario.

The next comparison involves a similar coverage map taken from [8]. The Node B configuration appears to be the same as in [7]. However, this scenario uses a smaller number of mobile users (only 300) than the scenario presented in [7]. The coverage for the users distributed uniformly across the simulation area is shown to be much better in this scenario than in [7]. This is mainly due to the decreased capacity, which causes the coverage area of each cell to increase. This also highlights the interlinking of coverage and capacity in W-CDMA networks.

The Enhanced UMTS system level simulator can support scenarios of increased capacity like the one presented in [8]. An explanation for the increased capacity is that UMTS enhancements included in our simulator support higher bit rate services and thus provide increased capacity, which is evident in a situation where only voce users are monitored.

The aims of the research presented in [6] are to analyze the capacity of a W-CDMA system in a macro-cellular environment. The simulation uses a homogeneous topology with macro-cells of radius 577m. The published work uses a Vodafone internal simulator to collect its results.

Our recommended best distance for an urban environment is 900m. For this scenario it is 1154m (577m is the cell radius). For a 99% of successful calls the recommended capacity in [6] is 50 users per cell. This translates into 950 users for the 19-cell topology. Our choice of distance supports adequately 4000 users in a 19-cell topology. The observed increase in capacity can be explained by the UMTS enhancements included in our simulation environment.

V. CONCLUSION

As has been shown cellular planning in W-CDMA networks is quite scenario dependent. The coverage and capacity of two specific environment scenarios were evaluated. The scenarios were simulated both using voice-only users and multi-traffic users.

The novelty of this work is the focus on Enhanced UMTS for coverage and capacity planning and also the use of a traffic mix that includes high bit-rate mobile users as well as voice users, instead of a single type of traffic. Moreover, the results obtained by the system level simulator were juxtaposed against published results of several W-CDMA system level simulators.

The results verify the interlinking between coverage and capacity in W-CDMA networks. More specifically, in W-CDMA networks the capacity depends on the coverage and, in turn, the coverage is dependent on the specific environment parameters and traffic mix (bit rates, traffic behavior) in the deployed environment. It is worth highlighting that the results, even though they are not sensitive to an increase of users of the same traffic type, are affected by the specific traffic mix. This is important to operators as it can facilitate the planning process of a network in a specific environment as long as they can plan the network based on a representative traffic mix.

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