Practical Performance of UMTS/HSPA Networks in High Buildings

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Abstract: This paper deals with the performance of UMTS/HSPA radio mobile networks in high buildings using passive distributed antenna system, which was initially designed and implemented for the GSM network. Field measurements were performed with drive/walk test equipment (network scanner, mobile terminal and handy), field measurement software, and a functional UMTS/HSPA network, using 10 codes per session. The impact of the use of passive distributed antenna system on the UMTS/HSPA network performance was studied inside the dominant, 150-meters-high and about 25-meters-wide twist tower of 38 floors, situated in the city of Sarajevo.

Key-Words: performance, UMTS, HSPA, coverage, high-buildings, DAS, field measurements

1 Introduction

High buildings are commonly referred to as objects whose height exceeds cluster structures in the area where they are located. In this paper we consider those parts of high buildings that are significantly higher than the buildings surrounding them. Factors affecting the radio performance of UMTS/HSPA cellular networks in high buildings depend on the characteristics of radio wave propagation such as *line-of-sight* (LOS) availability to external nodes B, as well as on isolation of indoor areas of a building with large number of obstacles to radio signals coming from outside [1-3].

LOS availability to a large number of external nodes B in *wideband-code-division-multiple-access* (WCDMA) radio access network generates the so-called pilot pollution, when there are a number of common pilot channel signals from cells that cannot be found in the neighbor list, which further results in degradation of quality. In addition to pilot pollution, WCDMA networks in high buildings suffer from the problem of large soft handover areas. On one hand, large soft handover areas multiply network load due to constant communication of mobile terminals with more cells, while on the other hand, data rates are reduced due to the presence of interference [1,4]. UMTS/HSPA mobile radio networks in high buildings also suffer from weak or no signal coverage from external nodes B within the inner parts of the building. With this respect, this research aimed to identify and characterize factors that impact the radio performance of UMTS/HSPA networks. So, in this paper, in addition to theoretical considerations, experimental investigation are carried out in real-life conditions of the high tower exemplar building in Sarajevo, the Avaz Twist Tower, and the 3G mobile network of BH Telecom. Appropriate coverage of this high building with UMTS/HSPA mobile radio networks was achieved by means of dedicated indoor system using passive *distributed-antenna-system* (DAS), which was initially designed and implemented for the GSM network.

In the central part of the paper, we described the most commonly used *key-performance-indicators* (KPI), by means of which the performance of radio UMTS/HSPA mobile networks in high buildings can be assessed.

Finally, the paper presents the conclusions obtained on the results of the experimental investigation.

2 UMTS/HSPA in high buildings

WCDMA has a very high rejection of narrowband interference, and is very robust against frequency-selective fading. It offers good multipath resistance due to the use of rake receivers. The handovers in WCDMA are smooth and imperceptible due to the use of soft handovers. During handover the mobile is serviced by more cells at the same time, offering macro diversity gain.

UMTS radio planning is all about noise and power control. Very good radio planning discipline must be applied and cells must only cover the intended area, without spilling the radio signal energy elsewhere. Therefore one must try to minimize the handover zones to well-defined small areas, or the soft handover can destroy the capacity of the network. This is of particular concern when two or three cells that are supporting the soft handover are serviced by separate base stations, and different *radio network controllers* (RNC) – this will cause added load to the backhaul transmission interfaces.

When a mobile receives CPICH signals at similar levels from more cells it is supposed to enter soft handover – if it does not, the quality will be degraded and the call might be dropped. However there can be cases where a distant cell is not defined in the neighbor list, and thus the mobile is not able to enter soft handover. This will cause interference of the serving cells' CPICH; this is referred to as pilot pollution and it is one of the main concerns during the design of UMTS indoor solutions.

This problem is often of big concern in high buildings, predominantly in the topmost section of the building, where mobiles are able to detect outdoor cells. When providing radio coverage for mobile users inside buildings, we are facing several radio planning challenges. The UMTS RF channel efficiency is sensitive to degradation of the 'RF environment', typically caused by multipath reflections. Without going into mathematical details, the efficiency of the UMTS RF-channel is expressed using the term 'orthogonality'. The higher the orthogonality of the radio channel, the higher the efficiency of the radio link. In practice, a particular UMTS base station will be able to serve LOS users with high data throughput, whereas indoor users served by the same base station will only be serviced at lower data rates, due to the degraded orthogonality. The modulation on HSPA service is very sensitive to interference and degradation of the radio channel. HSPA need a high-performing RF link, in order to support the highest possible data rates. In reality this means that HSPA will only be served in the buildings in direct line-of-sight to the serving macro, and only in the part of the building facing the nearby macro site. To provide coherent and high-performing indoor HSPA coverage, dedicated indoor coverage solutions are needed. To add even more complexity, the higher up a building the users are, the more likely it is that they will receive non intended distant base stations (pilot pollution). This is especially of concern in high buildings in the topmost floors that rise over the clutter of other buildings in the area, where the pilot pollution will degrade the quality of the UMTS signal. UMTS macro cells close to the building must always be in the neighbor list (monitored set) as soft handover will be active whenever the pilot signals from outside the building are high, in order to prevent pilot pollution and dropped calls. However, soft handover will also pose a potential problem; when the mobile inside the building enters soft handover, more links are used to maintain the same call, so all the degraded orthogonality and power load will in reality hit even more outdoor base stations, draining even more resources from the macro network. In some high buildings, especially the ones with ordinary windows (with no metallic coating), one can experience very high interference levels from the outside macro network; even strong signals from distant macro bases will reach indoor users at surprisingly high signal levels. Despite these physical factors, one needs to insure isolation from the high-level outdoor signal and dominance of the indoor coverage system throughout the building. The solution is to make the indoor cell the dominating one throughout the building. As a general guideline, we should boost the indoor cell with 10–15 dB more power with regard to any outside macro signal. However this must be a fine balance ensuring that the indoor system does not leak too much signal outside the building, thus pushing the soft handover zone outside the building. The performance of any radio link, UMTS and HSPA included, is not related to the absolute signal level but rather to the quality of the signal that is mostly described as the *signal-to-noise ratio* (SNR), i.e. between the desired signal from the serving indoor cell and the unwanted signals from the macro layer. Traditionally, passive distributed antenna systems have been used extensively for GSM throughout the past 15 years. Therefore, radio planners often consider this as the first choice when designing indoor coverage for 3G systems. However, it is a fact that, for UMTS and especially for HSPA, active distributed antenna systems will often give the best radio link performance and higher data rates. The main degrading effect from the passive systems is determined by the high losses, degrading the power level at the antenna points and increasing the base station noise figure at the higher frequencies, used for UMTS/HSPA.

3 UMTS/HSPA performance indicators

UMTS/HSPA performance indicators can be categorized as signal quality indicators and UMTS/HSPA capacity indicators. The mobile station continuously measures the received power level of the downlink *primary common pilot channel* (P-CPICH), commonly referred to as the *received signal code power* (RSCP), which can be used as a coverage indicator for the cell. In addition, the total received wideband power is measured for the used channel as indication of the current interference level at the cell. The measurement indicator is referred to as the *received signal strength indicator* (RSSI). The coverage quality indicator – *energy-per-bit-to-power-spectral-density* E_c/N_0, can be calculated from RSCP and RSSI measurements as it follows:

$$\frac{E_C}{N_0} = \frac{RSCP_{P-CPICH}}{RSSI} \qquad (1)$$

In addition, the HSPA mobile station incorporates the *channel quality information* (CQI) indicator that is based on several radio interface measurements and indicators, such as E_c/N_0, *signal-to-interference-ratio* (SIR), multipath environment parameters, other-to-targeted cell interference, receiver type, as well as the expected HSPA power available at the base station [4]. CQI is used at the base station to estimate the highest possible instantaneous data rate at which the mobile is capable of receiving via the radio channel. The reported CQI is used at the base station determining suitable coding and modulation schemes (MCS) for downlink transmission [5].

In the scope of this paper, maximum HSDPA physical layer capacity was 7.2 Mbps using *quadrature amplitude modulation* 16QAM, ten codes, and highest coding rate of ¾, where MCS does not have any impact on modulation, but only on the coding rate. *Medium access control* (MAC) layer measurements were selected to indicate HSDPA capacity.

The maximum MAC layer throughput was 6.84 Mbps (with the overhead to physical layer of about 5%), thus providing rather accurate estimate of the HSDPA physical layer performance. The error rate (reflecting the quality) in transmission was indicated as the MAC block error rate (BLER).

4 Measurement setup

The impact of using the same passive DAS (that was previously implemented for GSM) on the performance of UMTS/HSPA mobile network was investigated by means of dedicated equipment consisting of a base station located in the basement of building, MCB's and passive DAS with 99 omnidirectional antennas distributed throughout the building. The floors 04 through 38 were built using the same reinforced concrete base, while the facade is 2 degrees rotated relative to the floor below (therefore the “Twisted” Tower). There is a reinforced concrete slab between floors. The measurement equipment consisted of a network scanner, measuring telephone, handy measuring device and associated software for storing and analyzing the collected data.

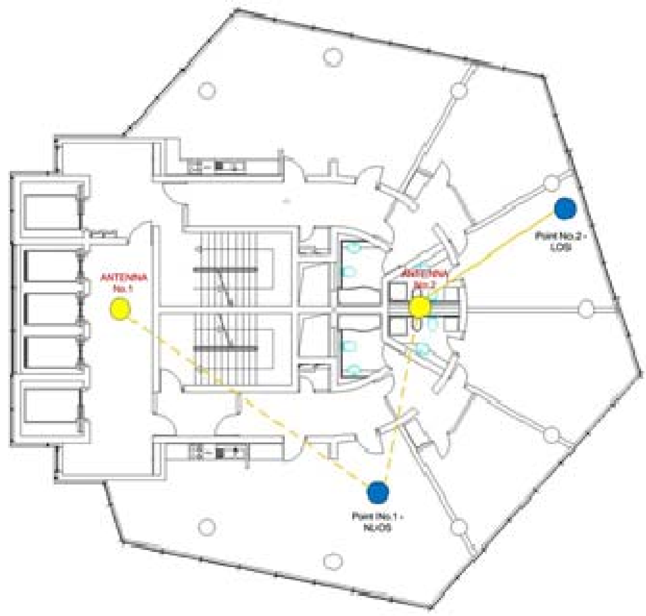

Fig. 1 The positions of indoor DAS antenna and measurements points on the 29th floor

The measurement point No. 1 was chosen as most unfavorable position with regard to the indoor DAS system, considering that there were two concrete walls between the measurement position and two indoor antennas. The point No. 2 was deliberately chosen to have a LOS to one of the indoor DAS omni antennas, but to remain opened to a number of external macro base stations, Fig.1.

In addition to the measurements in stationary positions, the walk-test measurements were performed throught the entire surface of the 29th floor, holding the measurement device (handy) approximately 1.5 m above the floor and walking slowly (1-2 km/h) to obtain a sufficient number of samples recorded for each measurement position. The measurement device did averaging and plotting of mean values. Since no LOS existed between the antennas, the connection between the antenna and test equipment included LOS and NLOS conditions.

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5 Measurement results and analysis

The tests were made using the network scanner (TSMQ™) on the 10563rd channel (Operator's UMTS Channel), with detection of Top 8 pilots, and measurement of RSSI, E_c/N_0, RSCP, delay spread and SIR parameters. In Table 1, the test results are presented as obtained at both positions by the network scanner for CPICH channel with scrambling code 145, which was used as pilot in the dedicated DAS system, as reflected by its highest value of RSCP and E_c/N_0. The RSSI values show that several CPICH pilots penetrated into building with relatively high power levels (above -70 dBm), but with a low E_c/N_0 (bellow -20 dBm). The average value of the RSCP CPICH, at the point No. 1 was approximately 20 dBm, and at the point No.2, about 15 dBm higher with respect to the level of RSCP CPICH pilot signals that penetrated the building. The average RSSI value at the point No. 1 for the observed CPICH pilot signals, was 40 and 48 within the ± 2 dBm range, while at the point No. 2 the ranged was within ± 0.5 dBm.

Table 1 Measured values of E_c/N_0, RSCP and SIR

Scr. Code	*KPI*	*Value*	*Point No.1*	*Point No.2*
145	E_c/N_0	Avg. Value (dBm)	-3,2	-2,9
		Min. Value (dBm)	-10,3	-11,1
		Max. Value (dBm)	-2,1	-1,9
		Median	-2,9	-2,6
		St. Deviation	0,827	0,815
		Variance	0,684	0,664
	RSCP	Avg. Value (dBm)	-67,3	-61,5
		Min. Value (dBm)	-82,7	-86,8
		Max. Value (dBm)	-63	-53,1
		Median	-67,2	-61,2
		St. Deviation	1,319	2,858
		Variance	1,74	8,171
	SIR	Avg. Value (dBm)	23,8	24,4
		Min. Value (dBm)	14,2	13,4
		Max. Value (dBm)	26,1	26,8
		Median	24,3	25
		St. Deviation	1,444	1,517
		Variance	2,086	2,301

Coverage of the whole area of floor where the measurements were conducted was tested by walk tests in idle mode, by the handy measuring device, with the KPI obtained values presented in Table 2.

Table 2 Coverage – IDLE mode

KPI	*Value*
Service Availability (%)	100
Avg. Best Active RSCP (dBm)	-81,9
Avg. Best Active E_c/N_0 (dB)	-4,9
Avg. G-factor	5,93
Active set (% of time - No. of cells)	100% - 1
Indoor cell Active (% of measurement time)	100

To check the quality of the coverage, the walk tests in active mode were done using handy measuring device, initiating endless calls to the voice machine. Fig. 2 shows the measured values of the best active E_c/N_0, on the surface of the 29th floor. The obtained values of some of the KPIs are presented in Table 3.

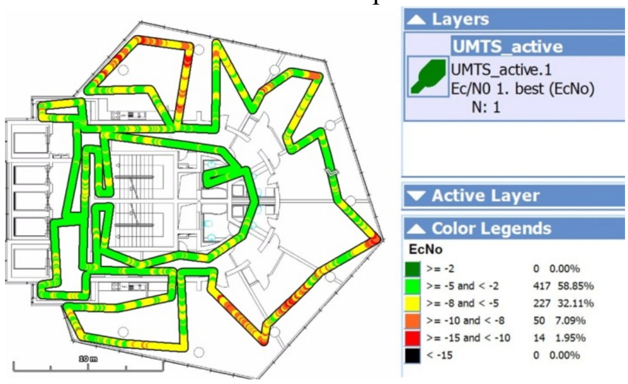

Fig.2 Walk test measurement – best active E_c/N_0

Table 3 Coverage Quality –Active Mode

KPI	*Value*
Service Availability (%)	100
Call Success Rate (%)	100
Avg. Best Active RSCP (dBm)	-77,4 (98,5% > -95 dBm)
Avg. Best Active E_c/N_0 (dB)	-5,1 (99,4% > -12 dB)
Avg. G-factor	6,49
Avg. BLER (%)	0,2
Avg. SIR	6,3
Avg. CQI	23,2 (99,7% > 10)
Number of Soft/softer HO – success	178 - 100%
Active set (% of time - cells)	73,1% - 1
	23,5% - 2
	3,4% - 3
Indoor cell Active (% of time)	100

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The summary of test results at the points No.1 and No.2, for the idle mode, reveals that:

- The average value of the RSCP level at the point No.1 was approx. -91 dBm, while at the point No.2 it was approx. -72 dBm;
- The RSCP level serving the three strongest neighboring cells during the whole test time was within the window of 10-12 dB;
- The measurements at the point No.1 revealed that two (or three) cells were always within the window of 6 dB compared to the best cell, while at the point No.2, this number was four.

The analysis of the parameters of packet transmission via HSPA network, was based on the KPI values, presented in Table 4.

Table 4HSPA data transfer

KPI	*Point No.1*	*Point No2.*
Avg. Best E_c/N_0 (dB)	-9,7	-4,9
Avg. Best Active RSCP (dBm)	-89,3	-4,9
Avg. SIR (dBm)	3,9	12,5
Avg. BLER (%)	0,05	0,1
Avg. G-factor	-1,81	12,54
Avg. CQI	16,8	28,8
Active set (% of time - cells)	16,5% - 1	2,9% - 2
	30,3% - 2	30,2% - 3
	32,5% - 3	43,8% - 4
	0,1% - 4	17,5% - 5
Soft/softer HO (quantity - success)	215 – 100%	0
Indoor cell Active (% of time)	58,02	100
Avg. MAC layer data rate - downlink (kbps)	1224,6	2896,8
Avg. MAC layer data rate - uplink (kbps)	156,1	371,9

6 Conclusion

The aim of this paper was to present practical testing of the UMTS/HSPA performance in indoor environment, specifically in high buildings. Based on the performed measurements, we derive the following conclusions:

- Without a dedicated indoor solution it is not possible to achieve even the minimum level of performance, as the obtained measurements' results showed that the signals from external nodes B penetrate into the building with relatively low RSCP level and low E_c/N_0.
- No dominance of the indoor DAS system was achieved, most likely since it had been previously designed and implemented for the GSM network. According to the recommendations for UMTS/HSPA radio indoor planning in high buildings, in order to ensure quality coverage, signal strength of indoor system should be at least 12-15 dB higher with respect to the level of the signal from external macro network. This was not achieved with the tests in subject.
- High level of performance is confirmed for services that do not have high demands in terms of conditions on the radio interface, and which are mainly delivered via the UMTS network. However, during delivery of these services, the mobile terminal was in a soft handover for considerable time intervals, thus confirming the existence of large areas of soft handovers, as it was supposed (to be expected) in the introduction.
- Testing data transmission via HSPA network revealed that considerable percentage of the overall traffic was transferred via external macro cells, so failing to reach the required flow rate at the downlink and the uplink. This confirmed the expectation expressed in the introduction, i.e. that data rate will be reduced due to presence of radio interference.
- Indoor coverage of high buildings using previously implemented GSM-aimed passive DAS, is not the optimal way to ensure sufficient level of performance of UMTS/HSPA radio networks, as the measurement results showed that the services, which are high-demanding in terms of conditions on the radio interface, were not find to have sufficient level of performance.
- The preceding conclusion implies that satisfactory coverage of high buildings with UMTS and HSPA networks, can only be achieved by means of active DAS, or by some hybrid solution, in which the active equipment was located closer to the user, which would significantly reduce the propagation loss between node B and indoor antennas.

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In this sense the operator might be willing to review and possibly redefine the way of implementation indoor solutions, especially due to the increasing trend of adopting more and more services that require lots of bandwidth, while still striving to provide the highest quality customer service. So it is certainly of interest to consider the use of indoor solutions with active equipment (active DAS). Also, in the context of the planned introduction of LTE technology in the mobile network operator need to consider the integration of technology in one type of dedicated indoor solutions, so that the performance of all technologies were used in appropriate level.

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