

IMPACT OF INDOOR NETWORK ON THE MACROCELL HSPA PERFORMANCE

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Abstract

In this paper, the impact of the high speed packet access (HSPA) indoor network on the macrocell HSPA performance is studied based on field measurements. The indoor network configuration and the indoor antenna locations were varied for the measurements. The performance evaluation was based on data throughput and link quality parameters in downlink and in uplink. According to the measurement results an indoor network has an impact on the macrocell performance on both downlink and uplink. The downlink E_c/N_0 and throughput measurements show degradation in signal quality and downlink performance close to indoor antennas. The uplink measurements indicate that indoor network users may raise uplink interference levels at macro cell and thus cause performance or coverage degradation. However, the impact measured close to the indoor network was rather local, thus it is still recommended to exchange a small portion of the macrocell performance for a significant indoor traffic boost gained by implementing an indoor network.

Keywords: HSPA, indoor network, macrocell, radio network planning, UMTS.

1 Introduction

UMTS is a 3rd generation mobile system standard used in Europe. It is based on wideband code division multiple access (WCDMA) technology where the frequency band is shared between users. After the first UMTS specification, Release 99, the system has been upgraded in order to cope with an increased amount of mobile data traffic. Upgrades released are based on international standardization and effort. HSPA technology, consisting of high speed downlink packet access (HSDPA) and high speed uplink packet access (HSUPA), is an upgrade for the standard UMTS. HSDPA was introduced in Release 5 specification and HSUPA in Release 6 specification. HSPA improves

significantly the performance of the mobile data transmission in downlink and uplink. [1,2]

In a WCDMA network, every new user adds interference to the network. The increased interference impairs the capacity and the performance of the network. The target of radio network planning is to plan the network in a way that coverage and capacity are provided where needed, and interference levels are minimized. By reducing the size of the cells and increasing their number, the capacity over certain area can be increased. [3] A major part of mobile data traffic is generated indoors. Thus, implementation of a dedicated indoor network is a tempting way to increase network capacity. There are several different approaches for providing indoor coverage, e.g. outdoor-to-indoor repeaters, or dedicated indoor solutions consisting of distributed antenna system (DAS), pico-, or femtocell layout [4]. An indoor network improves considerably the performance of indoor users [5] and naturally also offloads outdoor macrocells. However, if indoor and outdoor network layers utilize the same frequency band, it is possible that indoor network interferes outdoor network causing performance degradation for outdoor users. The target of the paper is to study the possible impact of indoor network with different loading and different antenna topologies on the macrocell HSPA performance, and to provide guidelines for planning multi-layer radio networks.

2 High speed packet access

2.1 High speed downlink packet access

One of the main targets of Release 5 [6] was to enhance downlink data transmission capabilities, and it resulted in introducing HSDPA. The key features of HSDPA are fast physical layer retransmissions, base station (BTS) based scheduling, higher order modulation schemes, and adaptive modulation and coding scheme (MCS). First HSDPA capable networks were launched in 2005 providing only 1.8 Mbps throughput. Latest

Release 5 mobiles support about 10 Mbps throughput, and theoretical data rates are up to 14.4 Mbps, which requires 15 codes, 16QAM (quadrature amplitude modulation) and no effective channel coding. Thus it can be achieved only at very good channel conditions.

In addition to changes on physical layer, Release 5 introduced also new uplink and downlink channels in the system, as well as changes in system functionalities, such as power control and handover control. More comprehensive description of HSDPA can be found in e.g. [2,6].

2.2 High speed uplink packet access

Release 5 with HSDPA did not provide updates for uplink performance, leaving uplink with only about 450 kbps physical layer throughput, and was soon followed by Release 6 specifications [7], where the enhanced uplink was introduced. The enhanced uplink enabled theoretical data rates up to 5.76 Mbps in uplink direction. The term enhanced uplink has not been widely used, and in practice it is called HSUPA.

The higher data rates in HSUPA are based on higher number of channelization codes per user with multicode transmission, adaptive channel coding, fast base station based scheduling, fast retransmissions, and shorter transmission time interval (TTI). As a difference to HSDPA, the modulation is not changed. The maximum theoretical data rate is 5.76 Mbps, which is achieved by two channels with spreading factor (SF) 2 channels on I branch, and two channels with spreading factor 4 channels on Q branch, but with no channel coding [1]. Current mobiles support typically only two times SF 2 transmission, providing maximum throughput of about 2 Mbps. Also HSUPA Release 6 introduced new channels, but there were fewer changes in functionalities, e.g. soft handovers and fast power control remain. More comprehensive description of HSUPA can be found in e.g. [2,7].

3 HSPA performance indicators used in the measurements

Performance indicators can be divided in signal quality indicators and HSPA capacity indicators. A mobile continuously measures the received power level of downlink primary common pilot channel (P-CPICH). This measurement is called RSCP (received signal code power). In addition, the total received wideband power is measured for the used channel in order to have indication of the current interference level at the cell. The measurement indicator is called RSSI (received signal strength indicator). So called coverage quality indicator,

E_c/N_0 , can be calculated from RSCP and RSSI measurements:

$$E_c / N_0 = \frac{RSCP_{P-CPICH}}{RSSI}. \quad (1)$$

Uplink interference level is the sum of all received transmission (Tx) power at base station caused by all UE:s that are transmitting. Uplink capacity of high loaded cells is typically limited by uplink interference. Uplink interference can be measured at the base station, but the increase in uplink interference level can also be estimated at own cell UE Tx power increase, assuming that other transmission parameters remain constant.

A HSDPA mobile constitutes so called channel quality information (CQI) indicator. The CQI is not a pure radio interface measurement, but calculated by mobile based on several radio interface measurements and indicators, such as E_c/N_0 , SIR (signal-to-interference ratio), multipath environment, other-to-own cell interference, receiver type, and expected HSDPA power available at base station [2]. The CQI is used at the base station end to determine suitable MCS for the downlink transmission, thus the highest possible instantaneous data rate the mobile is capable of receiving via the radio channel.

In the scope of the paper, maximum HSDPA physical layer throughput (TP) for measuring mobiles is 10.8 Mbps using 16QAM, 15 codes, and coding rate of 3/4. For HSUPA, maximum physical layer throughput is 2 Mbps, using 2xSF2, QPSK, and coding rate of 3/4. MAC (medium access control) layer measurements were selected for indicating HSDPA capacity. The overhead from physical layer is below 5 %, thus providing rather accurate estimate of HSPA physical layer performance.

4 Measurement configurations

The measurement campaign was carried out at campus area of Tampere University of Technology. Indoor base stations were located in an office/lecturing building, and the sector antenna of macrocell base station was mounted on top of a nearby 4-storey office building at about 500 m distance from the indoor network, shown in Figure 1.

Transmission power of indoor network and indoor users were causing interference in uplink and downlink, and the impact of the interference was measured on the outdoor route with two mobiles. Different indoor cell and antenna layouts were used to study the amount of leaking signal and its impact on macrocell performance. The indoor antenna positions and the measurement route for indoor and outdoor measurements are shown in

Figure 2. Two antenna locations were used: isolated scenario where antennas were in the middle of the building, and antennas near windows, causing more leakage from the indoor network towards the outdoor network.

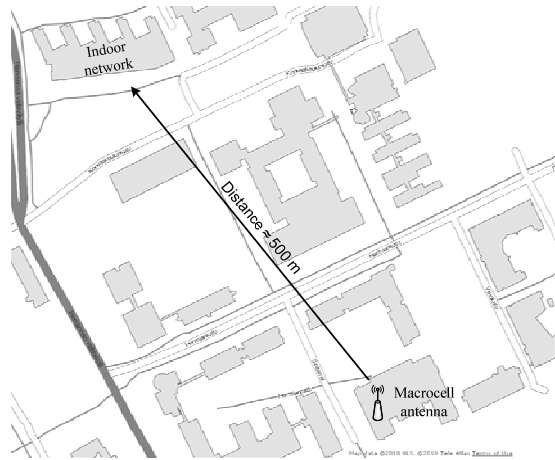


Figure 1. The location of the macrocell antenna and the building with indoor network.

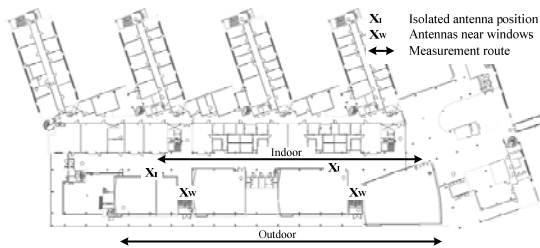


Figure 2. Layout of the building with indoor network and the indoor and outdoor measurement routes.

In addition to different antenna positions, two different indoor network configurations were used, DAS and pico cell configuration (Figure 3). In DAS configuration, two antennas were connected to one base station, and in pico cell configuration both antennas were connected to individual base stations.

Measurements were performed on macrocell with three different system statuses: no indoor network, empty indoor network, and loaded indoor network. In empty indoor network scenario, there were no

indoor mobiles, thus only downlink common channels were broadcasted. In the loaded indoor network, two mobiles were downloading (HSDPA) or uploading (HSUPA) a file with maximum throughput. Macrocell measurements for RSCP and E_c/N_0 were performed in idle mode. CQI, uplink Tx power and throughput were measured in connected mode, using two mobiles simultaneously (UE1 and UE2).

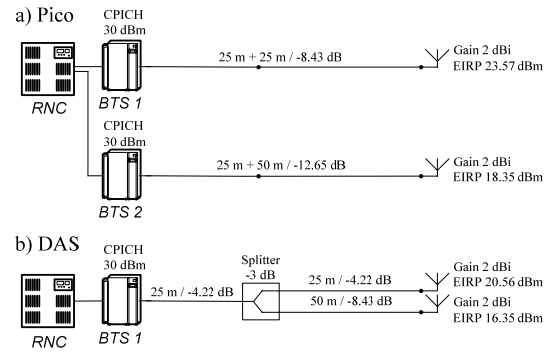


Figure 3. Antenna line configurations for a) Pico cell and b) DAS.

The indoor mobiles' HSDPA categories were 8 and 9, and HSUPA category was 5. The macrocell mobiles were HSDPA category 9 and HSUPA category 5, and were also downloading and uploading a file requesting maximum throughput. The mobiles were calibrated only for commercial use, thus a continuous error exists in all absolute values of the RSCP and E_c/N_0 measurements. The measuring mobiles were connected to a field measurement software [8]. HSDPA and HSUPA measurements were performed separately and independently.

5 Measurement results

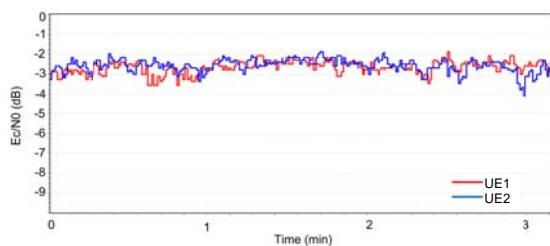
5.1 Downlink idle measurements

The Table 1 shows the impact of indoor network on average and minimum E_c/N_0 . The increased interference caused by indoor network was visible in all configurations. The drop in average E_c/N_0

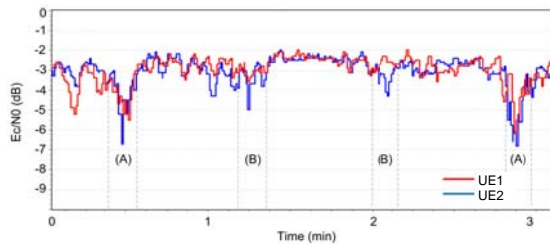
Table 1. Averaged measurement results for HSDPA measurements.

| Configuration | TP [Mbps] | | | CQI | | | Average E_c/N_0 [dB] | | Minimum E_c/N_0 [dB] | |
|--|-----------|------|----------|------|------|------|------------------------|------|------------------------|------|
| | UE1 | UE2 | Total TP | UE1 | UE2 | Mean | UE1 | UE2 | UE1 | UE2 |
| No indoor network | 3.36 | 3.42 | 6.73 | 20.9 | 21.1 | 21.0 | -2.6 | -2.6 | -3.6 | -4.1 |
| Empty pico network, isolated | 3.12 | 3.29 | 6.48 | 20.3 | 20.6 | 20.5 | -2.9 | -2.9 | -7.2 | -6.6 |
| Empty pico network, antennas near windows | 3.13 | 3.28 | 6.35 | 20.0 | 20.7 | 20.4 | -2.9 | -2.9 | -6.3 | -7.4 |
| Loaded pico network, isolated | 3.08 | 2.98 | 6.00 | 19.6 | 19.9 | 19.8 | -3.3 | -3.2 | -8.2 | -8.1 |
| Loaded pico network, antennas near windows | 2.83 | 2.84 | 5.67 | 19.1 | 19.4 | 19.3 | -3.0 | -3.0 | -6.8 | -7.3 |
| Loaded DAS network, antennas near windows | 3.00 | 2.84 | 5.76 | 20.0 | 19.9 | 20.0 | / | / | / | / |

was between 0.3 and 0.7 dB, and drop in minimum E_c/N_0 was between 2.6 and 4.6 dB. As an example, part of the E_c/N_0 measurement for loaded indoor network, antennas near the windows, is shown in Figure 4. The drops in E_c/N_0 near the antennas are clearly visible, and it is evident that the indoor network interference causes degradation in macrocell downlink signal quality. However, changes between configurations are rather small, and the isolated antenna locations caused in fact lower signal quality. Idle mode measurements for DAS are not available. The measured RSCP on the macrocell route was measured to be -72.0 and -73.7 for UE1 and UE2, respectively. Since the macrocell configuration remained unchanged, the RSCP values are valid for all indoor network configurations.



a) no indoor network



b) loaded indoor network, antennas near the windows

Figure 4. Measured macrocell E_c/N_0 on the outdoor route. Indoor antenna locations are marked with A (left antenna on Figure 2) and B (right antenna on Figure 2).

5.2 HSDPA throughput measurements

The achieved throughput with different indoor configurations is shown in averaged values in Table 1. Also the CQI values are shown to provide information about the signal quality in reported to the base station. The measured throughput per mobile varies a little because of individual scheduling, thus the summed total cell throughput is more interesting indicator, and is also illustrated in Figure 5, where degradation in throughput caused by interfering indoor network interference is clearly visible.

As an example, part of the throughput measurement for loaded indoor network, antennas near the windows, is shown in Figure 6. As the drops in E_c/N_0 , also the drops in both users'

throughput caused by interfering indoor network are clearly visible in the measurements. The drop in total throughput was between 0.25 and 1.06 Mbps. Also the cumulative probability of throughput is shown on Figure 7 for the same configuration, showing the clear degradation on cell throughput caused by interfering indoor network.

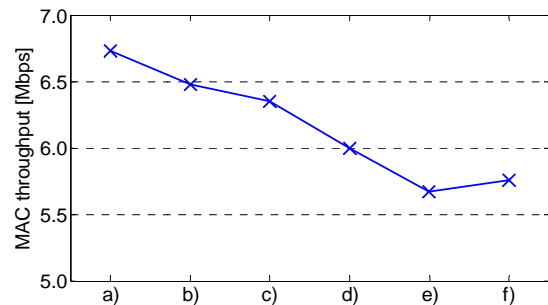
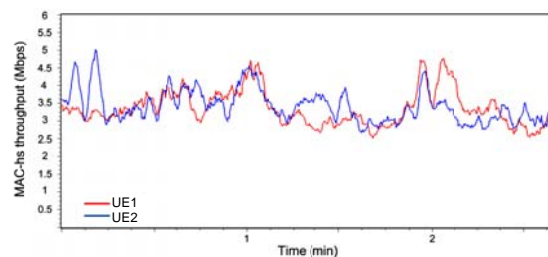
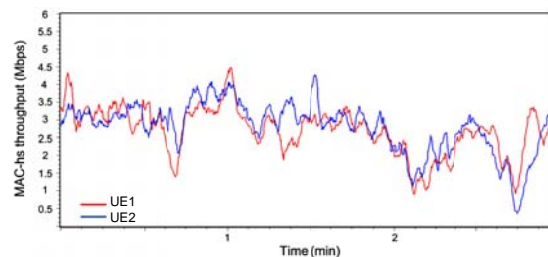


Figure 5. Measured macrocell TP for a) no indoor network, b) empty pico network, isolated, c) empty pico network, antennas near windows, d) loaded pico network, isolated, e) loaded pico network, antennas near windows, f) loaded DAS network, antennas near windows.



a) no indoor network



b) loaded indoor network, antennas near the windows

Figure 6. Measured macrocell TP for UE1 and UE2 on the outdoor route.

5.3 HSUPA measurements

For HSUPA measurements, only the loaded pico network configuration with antennas near windows was used. The measured average HSUPA throughputs and Tx powers of macrocell mobiles are shown in Table 2. The difference in achieved throughput is minimal, but the total required Tx power is clearly increased (6.1 dB), which indicates raising uplink interference problems in

uplink coverage and HSUPA capacity if more than one indoor network would be implemented at the coverage area of one macrocell. However, the result is based on only one measurement configuration, thus more measurements should be done to verify the impact on uplink direction.

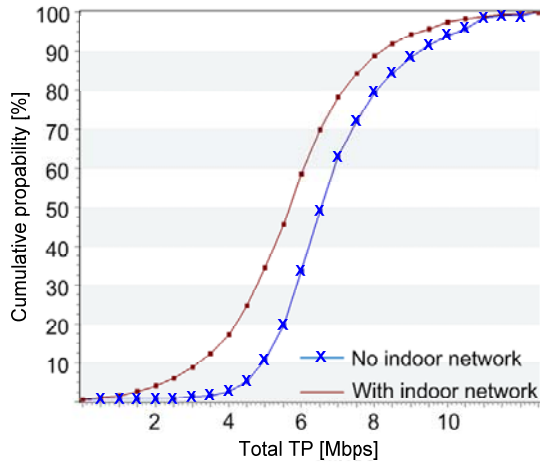


Figure 7. Measured macrocell total TP on the outdoor route for no indoor network and loaded pico network, antennas near windows.

Table 2. Averaged measurement results for HSUPA connected mode measurements.

| Configuration | TP [Mbps] | | | Tx Power [dBm] | | |
|--|-----------|------|----------|----------------|------|-------|
| | UE1 | UE2 | Total TP | UE1 | UE2 | Total |
| No indoor network | 0.96 | 0.99 | 1.95 | -8.4 | -7.8 | -5.3 |
| Loaded pico network, antennas near windows | 1.05 | 0.99 | 2.08 | -5.0 | -0.6 | 0.8 |

6 Conclusions and discussion

The purpose of the paper was to study the indoor network interference impact on the macrocell HSPA performance when different network layers operate on the same frequency band. Based on the measurement results, it is possible to observe that an indoor network has a clear impact on the macrocell performance. The macrocell average E_c/N_0 and total throughput dropped from -2.6 dB to -3.2 dB and from 6.73 Mbps to 6.48...5.67 Mbps, respectively, depending on the indoor network loading and configuration.

The impact of indoor network on HSUPA throughput was negligible, but the increased uplink transmission powers indicate uplink interference

problems if more than one indoor network is implemented under one macrocell.

The measurements showed that the highest downlink throughput degradation takes place only very close to the indoor network antennas. Thus the impact of indoor network is limited to the proximity of the indoor network building, and impact on the overall macrocell performance is rather small. Therefore it can be discussed whether the capacity boost provided by dedicated indoor networks is very beneficial compared to the small macrocell downlink performance degradation caused by indoor network. However, the uplink interference does not depend on the location of measuring macrocell mobiles, and it raises a question whether the uplink direction should be more carefully considered and is more limiting when planning multi-layer networks.

Acknowledgements

The measurements were assisted by Mr. Jaakko Penttinen. This work was partly supported by Anite Finland, Elisa, ECE Ltd, Nokia Siemens Networks, and Nokia.

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