HSDPA Measurements for Indoor DAS

Tero Isotalo and Jukka Lempiäinen
Institute of Communications Engineering, Tampere University of Technology
P.O.Box 553 FI-33101 TAMPERE, FINLAND
Tel. +358 3 3115 5128, Fax +358 3 3115 3808
tero.isotalo@tut.fi, http://www.cs.tut.fi/tlt/RNG/

Abstract—The target of the paper is to study performance of HSDPA in indoor environment, and to provide guidelines for HSDPA coverage and capacity planning and antenna configurations selection. Field measurements with a HSDPA data card, field measurement software, and a fully functional HSDPA enabled UMTS network were performed. Indoor corridor environment was used to study the impact of different distributed antenna configurations on a HSDPA performance. In addition, pico cell configuration is compared to corresponding distributed antenna configuration, and the effect of coverage limitations on HSDPA capacity is studied.

The results show, that ensuring sufficient coverage is the key factor in planning HSDPA indoor network. Signal quality can be enhanced by increasing the number of antennas in DAS, which is also visible as improved capacity. Better signal level can be achieved by pico base stations, but taking benefit of added capacity is problematic. The measurement results show that distributed antenna configuration provides better performance compared to pico cells. As a conclusion, adequate coverage planning plays an important role in planning indoor networks for HSDPA, and some additional capacity can be gained by antenna configuration optimization.

Keywords—DAS, field measurements, HSDPA, indoor, pico cell, UMTS.

I. INTRODUCTION

First version of UMTS (Universal Mobile Telecommunications System) standard produced by 3GPP (3rd Generation Partnership Project), Release 99, provided practical data rate of 384 kbps in downlink direction using WCDMA (wideband code division multiple access) air interface access technology. Release 4 included minor changes from the radio network planning point of view. HSDPA was introduced in Release 5, and HSUPA (high speed uplink packet access) in Release 6. Release 7 and beyond releases will introduce e.g. enhanced radio access technologies, such as orthogonal frequency division multiplexing (OFDMA) and multi-antenna technology (MIMO, multiple input multiple output). [1], [2]

The need for higher capacity in 3rd generation (3G) cellular networks was recently fulfilled, while operators started to update the networks capable of high speed downlink packet access (HSDPA) specified Release 5. Practical user data rates close to 2 Mbps are already available, and even higher data rates will be available in near future.

The load of macro cellular 3G networks remain still at rather low level, thus some kind of indoor coverage can be provided by outdoor networks. While the amount of 3G subscribers and load of 3G networks increases, indoor users consuming relatively high part of resources due to high in-building penetration loss may reduce available capacity for outdoor users. Therefore dedicated indoor UMTS systems are likely to come in operators’ interests in near future.

Dedicated indoor systems can be implemented using pico cells, distributed antenna system (DAS). Additionally, e.g. outdoor-to-indoor repeaters or optical solutions can be considered. Distributed antenna solution consists of a base station connected to a network of antenna connected to the base station via splitters, tappers, and coaxial cables. [3] In pico cell solution, each base station is equipped with an antenna, either mounted on base station, or connected via a coaxial cable. In distributed antenna system, only one base station can be used, and installation costs of antenna system are in key role. In pico cell solution, base stations are easier to install, but replacing distributed antennas with a pico base stations increases hardware expenses. In addition, each pico base station represent an own capacity resource, whereas in distributed solution all antennas use the are limited to the capacity of one base station. However, difficulty of controlling inter-cell interference is in key role in planning dense installation of pico base stations.

Distributed antenna system configuration for WCDMA air interface in Release 99 UMTS system was studied in [4] by idle mode and scanner measurements. The results indicated that increasing the antenna density in distributed antenna system does not provide corresponding enhancement in signal quality as long as decent coverage can be ensured. Measurements for HSDPA in [5] show that HSDPA data rates up to 3.6 Mbps can be achieved in practise. However, practical requirements for HSDPA radio channel quality or guidelines for indoor planning of UMTS/HSDPA system are not available.

II. HIGH SPEED DOWNLINK PACKET ACCESS

One of the main targets of Release 5 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 (MCS).

First HSDPA capable networks were launched in 2005 providing 1.8 Mbps downlink capacity, using five downlink orthogonal codes with spreading factor of 16, QPSK (quadrature phase shift keying) modulation, and maximum channel coding rate of about 3/4. Also versions providing 3.6 Mbps using 16QAM (16 quadrature amplitude modulation) have already
been launched. Further versions will provide theoretical data rates up to 14 Mbps, which requires 15 codes, 16QAM and no channel coding. However, practical user data rates are likely to remain below 4 Mbps.

Release 5 / HSDPA introduced also new uplink and downlink channels in the system. User data transmission in downlink is carried on high-speed downlink shared channel (HS-DSCH). HS-DSCH does not use fast power control. Instead, MCS is taking care of channel adaptation. Hence, modulation and channel coding of HS-DSCH can be changed every 2 ms. In addition, soft handovers are not supported for HS-DSCH.

High-speed shared control channel (HS-SCCH) is used in downlink for carrying time critical signalling, e.g. information of modulation and coding scheme of HS-DSCH. High-speed dedicated physical control channel (HS-DPCCH) is used in uplink direction to provide channel quality information for HS-DSCH. MCS selection based on mobile measurements. User dedicated uplink transmission and signalling are carried on DCH (dedicated channel) as in Release 99. [2]

III. DOWNLINK PERFORMANCE INDICATORS

HSDPA performance indicators can be divided in signal quality indicators and HSDPA 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). Pilot RSCP measurement can be used as a coverage indicator for the cell. 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:

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

In addition, 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]. CQI is used at the base station to estimate the highest possible instantaneous data rate the mobile is capable of receiving via the radio channel.

The reported CQI is used at the base station end to determine suitable coding and modulation schemes (MCS) for the downlink transmission. In the scope of the paper, maximum HSDPA physical layer capacity is 1.8 Mbps using only QPSK (quadrature phase shift keying) modulation, five codes, and highest coding rate of 3/4. Thus MCS does not have an impact on modulation, only the coding rate. MAC (medium access control) layer measurements were selected for indicating HSDPA capacity. The maximum MAC layer throughput is 1.72 Mbps (overhead from physical layer is about 5%), thus providing rather accurate estimate of HSDPA physical layer performance. The error rate (quality) in transmission is indicated as MAC block error rate (BLER).

IV. MEASUREMENT SETUP

The measurements were carried out in a new university building on long and wide corridor (length 100 m, width 8 m, height 10 m, approximately). From one to four antennas with even antenna separation were placed on 50 m route. In addition, configurations with two cells at 50 m route and one antenna at 100 m route were used. Antenna locations for measured antenna configurations are shown in Fig. 1 (a)-(d), (f), and measurement routes for 50 m and 100 m routes are shown in Fig. 2 (e) and (g), respectively. Antennas did not have LOS (line-of-sight) to each others, and the connection between the base station and the mobile station antennas consisted of both, LOS and NLOS (non line-of-sight) link.

![Antenna line configurations](image-url)
Measurements were performed in a UMTS indoor system, consisting of a fully functional RNC (radio network controller) connected to the core network, commercial HSDPA capable WCDMA base stations, and antenna system. Measurement system consisted of a category 12 [6] HSDPA data card connected to a laptop computer, and WCDMA field measurement software. Measurement equipment were located at 1 m height on a trolley, and measurements were conducted at walking speed. HTTP (hyper text transfer protocol) download was used to create traffic on downlink. Measuring mobile requested full downlink throughput, and no other users were connected. Measurements were repeated several times to increase reliability.

V. MEASUREMENT RESULTS AND ANALYSIS

A. The Impact of Antenna System Configuration on HSDPA Capacity

Results for all measurements are shown in Table I. All values are averaged over the whole measurement route. With one antenna at 100 m route, average throughput of about 1 Mbps can be achieved. Measured average RSCP, -92.38 dBm, indicate incipient coverage problems on the measurement route, which is visible also in lowest $E_c/N_0$ values. Shortening the route to 50 m with one antenna configuration improves RSCP by 6.34 dB to -86.04 dBm, and throughput is increased about 400 kbps to 1403 kbps.

Impact of increasing the antenna density i.e. the amount of antennas on the measured area, was studied on the 50 m route, and it has a positive impact on both, RSCP and throughput. Increasing the antenna density from one to four antennas per 50 m, the RSCP is increased by 3.36 dB, where throughput is increased by about 100 kbps. Three antenna configuration provides almost equal capacity compared to four antennas, thus capacity improvement seems be almost saturated at four antennas per 50 m, and gain of adding more antennas is likely to be minimal. Two antenna configuration results in relatively high RSCP values, which compared to low throughput values seem not to be exactly in line with other results.

Mostly due to the highest EIRP, the two cell configuration provides the best RSCP, -79.43 dBm. However, the measured throughput is 100 kbps lower compared to the two antenna DAS. This is mainly caused by long delay (2-4 s) in handover between the cells. Therefore, potential system performance improvement by handover procedure optimization could be expected.

The CQI values in all measurements vary between 13.05 and 16.37, and the values are rather well in line with the measured throughput values. $E_c/N_0$ of serving cell remains at decent level also in two cell configuration, although inter-cell interference should exist, but it remains at low level in empty network (average level of neighboring cell $E_c/N_0$ in two cell configuration was -18.58 dB).

B. HSDPA Indoor Coverage

One target of the measurements was to provide useful information for HSDPA coverage planning. In Fig. 3, a typical example is captured from the measurements tool from the 1-antenna configuration at 100 m route. The antenna is located on the left hand side, and the user is moving away from the antenna. The blue line (left axis) denotes RSCP, the red line (right axis) HSDPA MAC layer throughput, and the thin green line (no axis, scale 0..100 %) MAC BLER. All the curves are averaged over 1000 ms time window.

The RSCP below the antenna is at the level of -65 dBm, and it attenuates about 40 dB to the level of -105 dBm while moving 50 m away from the antenna. Free space loss, and slow fading of about 10 dB are visible in the graph. However, fast fading is not visible due to measurement resolution and averaging.

As long as RSCP stays above -65 dBm, MAC throughput remains close to maximum (1.72 Mbps). With lower RSCP values (-65..-95 dBm), throughput remains at average level of about 1.4 Mbps, but fluctuations of ±200 kbps are typical. However, even higher drops can occur, as seen at the left side of the throughput graph rather close to the antenna. Average throughput of about 1.4 Mbps can be maintained...
TABLE I
MEASUREMENT RESULTS.

<table>
<thead>
<tr>
<th>Antenna configuration</th>
<th>1 antenna</th>
<th>1 antenna</th>
<th>2 antennas</th>
<th>3 antennas</th>
<th>4 antennas</th>
<th>2 cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route length</td>
<td>100 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>RSCP [dBm]</td>
<td>-92.38</td>
<td>-86.04</td>
<td>-82.41</td>
<td>-84.17</td>
<td>-82.68</td>
<td>-79.43</td>
</tr>
<tr>
<td>CQI</td>
<td>13.05</td>
<td>15.70</td>
<td>15.89</td>
<td>15.81</td>
<td>16.37</td>
<td>16.02</td>
</tr>
<tr>
<td>MAC BLER [%]</td>
<td>10.86</td>
<td>6.62</td>
<td>6.06</td>
<td>6.06</td>
<td>6.06</td>
<td>7.03</td>
</tr>
<tr>
<td>MAC throughput [kbps]</td>
<td>999.91</td>
<td>1403.00</td>
<td>1397.40</td>
<td>1468.80</td>
<td>1502.00</td>
<td>1302.90</td>
</tr>
</tbody>
</table>

with RSCP values down to -95 dBm, which is the practical HSDPA coverage limit to maintain good capacity. Thereafter the throughput drops down to 100-200 kbps, until RSCP is at the level of about -105 dBm. Until this point, BLER values remain on average close to 10 %. Increasing BLER values at RSCP lower than -105 dBm indicate that connection quality is rather low.

Although the described RSCP vs. HSDPA MAC throughput behavior was only a snapshot from the measurements, such behavior was typical for all measurements. Defining the RSCP thresholds for different HSDPA throughput values arises question of antenna configuration impact on the thresholds. In Fig. 4, mapping of measured RSCP and throughput values is shown for DAS configurations of one to four antennas on the 50 m route, where instantaneous throughput is mapped for each RSCP measurement sample. Majority of all the measured RSCP samples is between -95...-75 dBm, thus reliability of the analysis decreases with low RSCP values, and values below -100 dBm are not shown. As shown in Fig. 3, throughput values between 1.4 Mbps and 1.7 Mbps can be considered as practical maximum even rather close to antenna. Throughput of one and two antenna configuration drops below 1.4 Mbps at RSCP -87 dBm, whereas in three antenna configuration good throughput can be maintained until RSCP of -94 dBm, and with four antenna configuration down to -98 dBm. Two antenna configuration is again not in line with other configuration, and performs worse than one antenna. Nevertheless, impact of increased antenna density is clearly visible in enhanced HSDPA throughput. Still, the measurements were conducted only in one environment, and impact of more dense or more open indoor environment on the thresholds remain open and will require more measurements.

VI. CONCLUSIONS AND DISCUSSION

The target of the paper is to study the performance of HSDPA in indoor environment, and to provide guidelines for HSDPA coverage and capacity planning in different indoor antenna configurations consisting of pico cells and distributed antenna system.

The measurements show that for QPSK modulation with five codes, providing maximum maximum throughput of 1.72 Mbps on MAC layer, practical average throughput of 1.4 Mbps can be ensured if coverage is maintained at sufficient level. Extending the cell range, thus reducing the average pilot RSCP by about 6 dB, degraded the average throughput significantly. Increasing the antenna density, thus dividing the signal in more antennas, had positive impact on both, coverage and capacity. Ensuring sufficient coverage plays on important role in optimizing HSDPA performance in indoor environment. Keeping RSCP above threshold of about -85 dBm should provide good throughput for all antenna configurations, but improving the signal quality and smoothness by increasing the number of antennas makes it possible to have decent throughput also closer to the cell edge.

It can be assumed that higher order modulation and reduced channel coding tighten the requirements for signal level and quality. Future work consists of performing wider set of measurements in varying indoor environments, using also higher order modulation and higher number of users, thus studying also effect of different scheduling schemes.

REFERENCES