# MEASUREMENTS ON HSUPA WITH UPLINK DIVERSITY RECEPTION IN INDOOR ENVIRONMENT

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## ABSTRACT

The target of the paper is to study performance of high speed uplink packet access (HSUPA) in indoor environment, applicability of uplink diversity reception for HSUPA, and to provide guidelines for HSUPA coverage planning indoor environment.

The single-user measurements show that with the tested antenna configuration without diversity, maximum practical throughput varies between 1.4 and 1.6 Mbps, and it can be achieved when pilot coverage is above -95 dBm. HSUPA was also measured with spatial and polarization diversity reception, and they were noticed to provide about 4.5 dB improvement in uplink reception, providing 20-40 % improvement in HSUPA throughput with pilot coverage below -95 dBm. Diversity reception can provide provide modest gain in system performance, but with planning threshold RSCP > -95 dBm, almost the same performance can be achieved without diversity antennas.

## I. INTRODUCTION

About ten years ago the first version of WCDMA (wideband code division multiple access) based UMTS (Universal Mobile Telecommunications System) specifications (3GPP Release 99, R99) were introduced, providing maximum downlink (DL) data rate of 384 kbps per user. The need for higher capacity in 3rd generation (3G) cellular networks was fulfilled when the networks received update for high speed downlink packet access (HSDPA) specified in 3GPP Release 5 (R5). Depending on the network configuration and mobile station capabilities, HSDPA can provide DL data rate higher than 10 Mbps [1]. Uplink and downlink became rather unbalanced after HSDPA, and HSUPA was introduced in 3GPP Release 6 (R6) specification. The amount of speech calls is slowly increasing, but the increase in date rates seems to remain steep. Data users requiring high throughput are often located indoors, which puts more and more load on macro/microcellular outdoor networks planned to provide also indoor coverage. As the loading in certain areas gets too high, operators should continue building denser and denser outdoor networks. A tempting option is to deploy dedicated indoor network on the highest loaded areas, e.g. office buildings and city centers. To be able to efficiently plan and optimize dedicated indoor networks, it is important to study the behavior of cellular systems in indoor environment

Studies on WCDMA and HSDPA indoor performance and planning have been performed in [2], [3]. The results for optimizing antenna configuration in WCDMA should apply also for uplink, but the special characteristic of HSUPA have to be taken into consider. Performance measurements for HSUPA are provided in e.g. [4], [5], but measurements for HSUPA in indoor environment are lacking. Diversity is usually implemented on the base station end for improving uplink reception (Rx). It can be easily deployed in indoor pico and femto cells, but it is not typically used in indoor coaxial distributed antenna system (DAS) because of more complicated installation (double cabling needed). The target of the paper is to provide basic understanding of HSUPA performance in indoor environment, and study the applicability of uplink diversity reception for indoor HSUPA system.

The paper is organized as follows: In Section 2, the basics of the diversity reception are summarized, and Section 3 gives introduction to HSUPA. The setup of indoor field measurements is shown in Section 4, and the measurement results are explained in Section 5. The paper is concluded in Section 6.

## II. DIVERSITY RECEPTION

Diversity reception is a traditional and well known technique for improving received signal quality. Among many possible diversity techniques, especially space and polarization diversity are widely used in macro- and microcellular networks to improve uplink reception. Also transmission (Tx) diversity can be used, but it is not that revealing because of additional transmitter capacity needed. Microscopic diversity gain is based on uncorrelated Rayleigh fading channels, which are received with close to equal power, and are combined at the receiver. [6] In case of UMTS/HSUPA uplink, the diversity combining is done at the Node B RAKE receiver, where maximal ratio diversity and multi-path combining is done, but with limited number of branches. Using two antennas doubles the antenna area, providing 3 dB gain (double power) even without diversity combining, thus values above 3 dB can be treated as diversity combining gain.

In theory, space diversity can utilize an unlimited number of branches (spatially separated antennas), but in practice, only few branches are used, two antennas being the most used solution. The expected diversity gain from additional antennas drops quickly after 3-4 antennas [6], and also practical installation of more than 4 antennas is complicated. The needed spatial separation depends of the angular spread of the propagation environment, i.e. in rich multipath environment smaller separation is enough for receiving uncorrelated channels. The needed separation at the macrocellular base station can be even 60-80 wavelengths ($\lambda$), when there are no scatterers close the antennas [6]. At the mobile station end, the scattering environment is typically rich close to the antennas, and the needed separation for good uncorrelation can be even below one wavelength [6]. In indoor environment, also the base station antennas are in rich multi-path environment, similar to mobile station, and the needed separation is expected to be at the level of a few wavelengths.

Polarization diversity utilizes two antenna elements with 90° difference in polarization, which are placed in the same antenna case. Although mobile station antennas are typically vertically polarized, the reflection and diffraction processes can produce rotation of the polarization [6], and also the mobile station antenna alignment is random. With polarization diversity, the number of diversity branches is limited to two, but polarization diversity can be combined with e.g. space diversity, resulting in 2x2 branch diversity reception, using two spatially separated polarization diversity antennas.

The majority of existing WCDMA/UMTS base stations are equipped with a possibility to connect two antennas, one for transmission and reception, and the other for diversity reception, thus enabling only two-branch diversity reception. However, in future, when multiple-input-multiple-output (MIMO) technique is implemented on the base stations (and mobile stations), also the possibilities and interest for multi-branch diversity at the base station end are increased.

## III. HSUPA

The use of 3rd generation networks has been increasing continuously after the launch of the first UMTS networks around 2003. Due to rapidly increasing data rates, the operators are eagerly looking for efficient techniques to update base station capacity to meet the needs. Release 5 with HSDPA introduced theoretical 14.4 Mbps downlink data rate, which 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. HSDPA and HSUPA together are called high speed packet access (HSPA).

The higher data rates in HSUPA are based on higher number of channelization codes per user with multicode transmission, adaptive channel coding, fast Node B 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 2 channels on I branch, and two channels with spreading factor 4 channels on Q branch, but with no channel coding [1]. Thus it can be achieved only at very good channel conditions. In practice, with e.g. 30 % channel coding, the maximum bit rates are expected to remain at about 4 Mbps on physical layer (about 3.5 Mbps on application layer).

HSUPA Release 6 introduced new channels. The user data is carried on enhanced dedicated channel (E-DCH), which can carry multiple enhanced dedicated physical data channels (E-DPDCH). Different from HSDPA, E-DCH is not a shared channel, but dedicated for each user, and the channel is also power controlled. In addition to E-DCH, several other channels were introduced for e.g. scheduling control. [1]

## IV. MEASUREMENT SETUP

The measurements were carried out on a WCDMA network in a university building, consisting of an RNC (radio network controller) connected to a core network, commercial WCDMA base station, and antenna system. The frequencies for uplink and downlink were approximately 1.9 GHz and 2.1 GHz, respectively, resulting in wavelength of approximately 15 cm for both directions. The network was supporting 3GPP Release 6 specification [7]. Antenna system (Fig. 1) consisted of feeder cables, transmission/reception antenna, and uplink diversity reception antenna, when diversity reception was enabled. In addition, the antenna line had an additional 20 dB attenuator. The primary common pilot channel (P-CPICH) transmission power at the base station was +33 dBm. Two types of antennas were used. For space diversity measurements, two directional antennas with vertical polarization, gain 7 dBi, horizontal beamwidth 90° [8], and spatial separation of 1 m were used. For polarization diversity measurements, directional antenna with ±45° polarizations (Xpol), gain 8.7 dBi, and horizontal beamwidth 65° [9] was used.

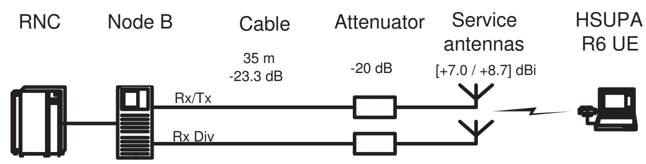



Fig. 1. System block diagram and antenna configuration.

The antenna locations and measurement routes are shown in Fig. 2. Antennas were installed at the end of the corridor, 0.5 m down from the ceiling level, antenna mainbeam direction pointing along the Route 2. The measurements were carried out on three different routes. Route 1 was used for non-line-of-sight (NLOS) measurements, Route 2 for line-of-sight (LOS) measurements, and Route 3 for testing HSUPA at cell edge. The 20 dB attenuation was selected so that on the NLOS Route 3, throughput begins to drop in the beginning of the route, but the coverage is never lost in the end of the route.

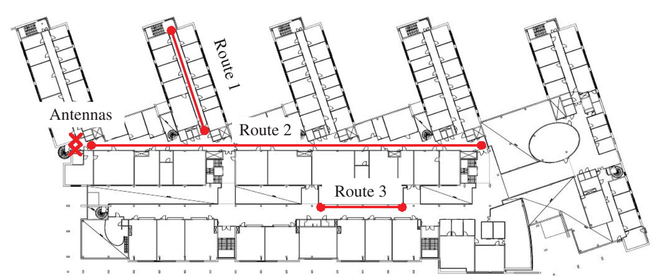
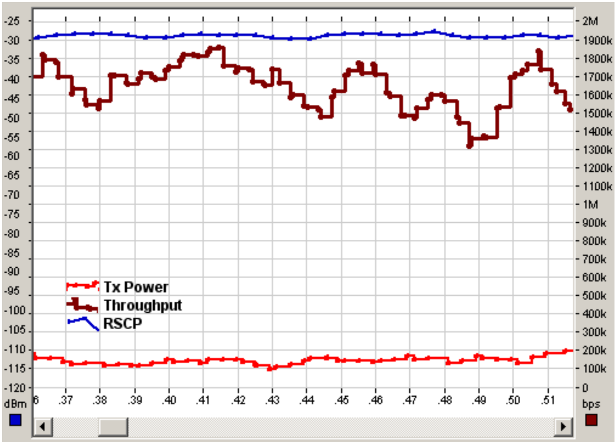
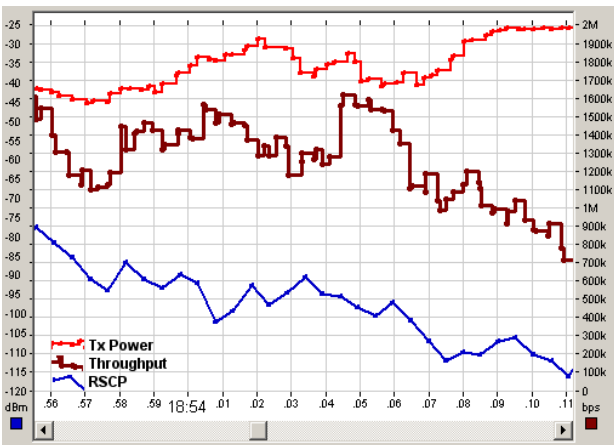



Fig. 2. Antenna positions and measurement routes 1-3.

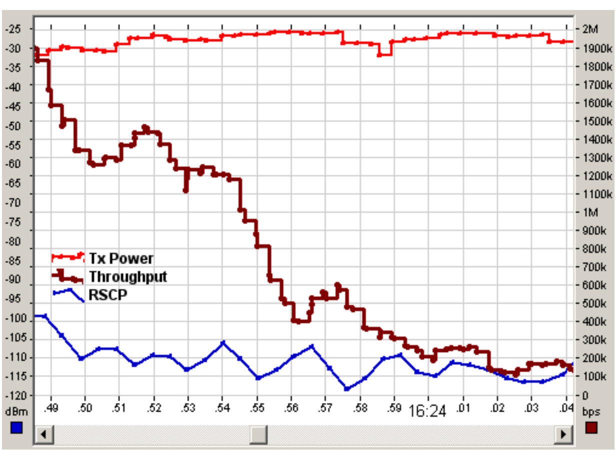
Measurement equipment consisted of a category 5 HSUPA data card [10] (max. 2 Mbps on physical layer with 2xSF2) connected to an air interface measurement software [11]. The cell scenario was isolated, i.e., the amount of inter-cell interference was minimal. Measuring mobile requested full uplink throughput via FTP file transfer, and no other




(a) Example measurement close to antennas.




(b) Example measurement on Route 1.




(c) Example measurement on Route 3.

Fig. 3. Screenshots of the measurements for Tx power, HSUPA MAC throughput, and pilot RSCP. RSCP on the left y-axis and TP on the right y-axis. The limits for Tx power are [-55 +24] dBm, and the time on x-axis is in seconds.

users were connected to the Node B. Uplink interference level in empty network was measured to be -106 dBm at the Node B antenna connector.

Several parameters were recorded from the air interface, but the analysis of the results is mainly based on three performance indicators: P-CPICH received signal code power (RSCP), uplink transmission power (Tx Power), and medium access control (MAC) layer throughput (TP) for the dedicated HSUPA connection. RSCP is a pure coverage indicator on downlink, but can be used also in uplink with reasonable accuracy. Tx Power is indicating uplink coverage, but is power controlled. MAC layer throughput changes with physical throughput, with about 1 % overhead, indicating achievable HSUPA capacity.

## V. MEASUREMENT RESULTS AND ANALYSIS

### V-A HSUPA performance in indoor environment

Fig. 3 illustrates measured single-user performance of HSUPA in different parts of the cell. Measurements are done with Xpol antenna without diversity reception. All the measurements are screenshots from the measurement tool, and all the indicators are averaged over 2 second window. The measurement close to the antenna Fig. 3(a) shows the highest achievable practical HSUPA throughput in good coverage (RSCP > -30 dBm). The instantaneous non-averaged throughput is hitting maximum, but due to variations the average throughput remains at about 1.6-1.7 Mbps. The second screenshot closer to the cell edge (Fig. 3(b)) is measured on the Route 1 (-115 < RSCP < -75 dBm). The throughput remains at about average 1.4 Mbps until RSCP -95 dBm, and then starts to drop with the RSCP. Tx power saturates to maximum at RSCP about -105 dBm. The third screenshot close to cell edge (Fig. 3(c)) is measured on the Route 3. The coverage is poor (-100 < RSCP < -120 dBm), Tx power is continuously close to maximum, and the average throughput drops from the practical maximum down to 0.1 Mbps.

The target of the measurements is to provide guidelines for HSUPA coverage planning. With the used network configuration, based on all measurements, planning threshold RSCP > -95 dBm seems to provide reasonable HSUPA performance, and improving coverage in low loaded network provides only modest improvement in throughput (about 200 kbps). Since the earlier studies with HSDPA [3] concluded that planning threshold of RSCP > -80 dBm ensures good HSDPA performance, there should be no need to pay special attention on HSUPA coverage planning, when HSDPA coverage planning is done according to this planning rule.

### V-B The impact of diversity reception on HSUPA throughput

In Table I, results from all measurements are shown. All values are averaged over the whole measurement route. The RSCP is always transmitted only from one antenna on downlink, and the antenna configuration for RSCP is always independent of the diversity antenna. Therefore the RSCP can be used to verify that the measurements with and without diversity reception are repeated exactly the same way, and the diversity gain result is reliable. In all three measurement scenarios, the $\Delta$ RSCP remains inside 1 dB, and therefore error in diversity gain values should be below 1 dB. Since HSUPA is fast power controlled, the diversity gain can be read from the improvement in Tx power.

The NLOS measurements performed on the Route 1 show that uplink diversity reception provides gain of about 4.5 dB in Tx power with both, space and polarization diversity. Since micro diversity combining gain requires uncorrelated fading channels, polarization diversity gain

TABLE I
AVERAGED HSUPA DIVERSITY MEASUREMENT RESULTS

| | RSCP [dBm] | Tx Power [dBm] | TP [Mbps] |
|---|---|---|---|
| NLOS space diversity | | | |
| No Div | -98,1 | 15,1 | 1,15 |
| Space Div | -98,0 | 10,6 | 1,39 |
| Δ | 0,1 | -4,5 | 0,24 |
| NLOS polarization diversity | | | |
| No Div | -100,6 | 18,6 | 0,90 |
| Xpol Div | -100,8 | 13,9 | 1,28 |
| Δ | -0,2 | -4,6 | 0,38 |
| LOS polarization diversity | | | |
| No Div | -73,5 | -7,2 | 1,37 |
| Xpol | -74,2 | -10,8 | 1,38 |
| Δ | -0,7 | -3,6 | 0,01 |

in LOS environment is expected to be very low, and the measurements showing diversity gain of only 3.6 dB verify this. The CDF of Tx power for all measurements are shown in Figs. 4(b) 5(b) and 6(b).

As concluded in the previous section, the achievable HSUPA throughput is almost independent of the coverage above RSCP > -95 dBm. The CDF of RSCP for space diversity measurement is shown in Fig. 4(a), and for polarization diversity measurement in NLOS in Fig. 5(a) and in LOS in Fig. 6(a).

In the LOS measurement, 95 % of the measurement samples are in RSCP > -95 dBm, and the throughput gain is small, as the measurement results show. Average throughput is exactly the same with and without diversity, which is also visible from the CDF of TP (Fig. 6(c)).

Although the diversity gain for both NLOS measurements is same, throughput gain is slightly higher for polarization diversity measurements (0.38 Mbps) compared to space diversity measurements (0.24 Mbps). This does not mean that polarization diversity would provide better gain in throughput. For the NLOS measurements, 25 % of RSCP samples are > -95 dBm for space diversity, and 40 % for polarization diversity (Figs. 4(a) and 5(a)). This is caused by a different antenna pattern and gain, and therefore the measurements are not directly comparable. However, this emphasizes that the worse is the coverage, the more can be gained in throughput from the diversity reception.

## VI. CONCLUSIONS AND DISCUSSION

From the indoor performance measurements without diversity reception it can be concluded that HSUPA works well in indoor environment. With the measured 2xSF2 configuration theoretical maximum 2 Mbps can not be achieved with moving mobile even with good coverage. Average throughput of 1.4 - 1.6 Mbps can be achieved in practise when RSCP > -95 dBm, thus as long as the transmission power is not hitting maximum.

The diversity gain was measured for LOS and NLOS environment. In LOS measurements, Tx power gain was modest 3.6 dB, and because the coverage was good, throughput could not be improved. The diversity gain measurements for NLOS environment were done close to cell edge, where average RSCP was below -95 dBm. The diversity gain in Tx power was about 4.5 dB for both space and polarization diversity, and achieved throughput gain varied between 20 % (0.24 Mbps) and 40 % (0.38 Mbps).

When operating above RSCP -95 dBm, diversity reception is not providing any throughput gain in single user performance. However, gain in Tx power should ensure smaller uplink interference levels in more heavily loaded network, thus uplink diversity reception should provide some system level gain throughout the cell. Accurate numbers, however, should be measured with multi-user measurements in high loaded network.

Implementation of diversity reception for HSPA indoor system provides modest link-level gain in Tx power. It can always be recommended for cell coverage improvement, but also some capacity gain can be expected due to lower transmission power. In future, higher order modulations and the use of multi-antenna techniques is expected to raise interest in diversity reception studies for indoor environment.

**Acknowledgment**

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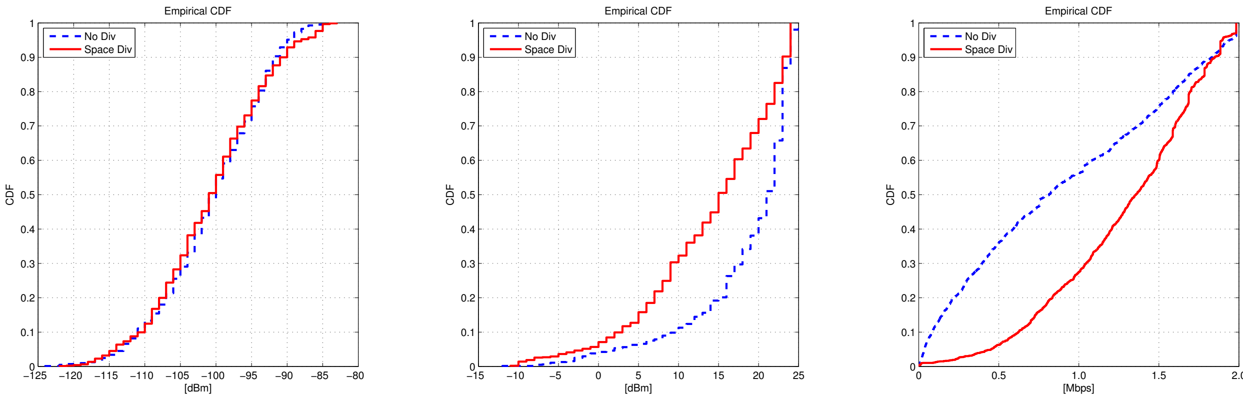
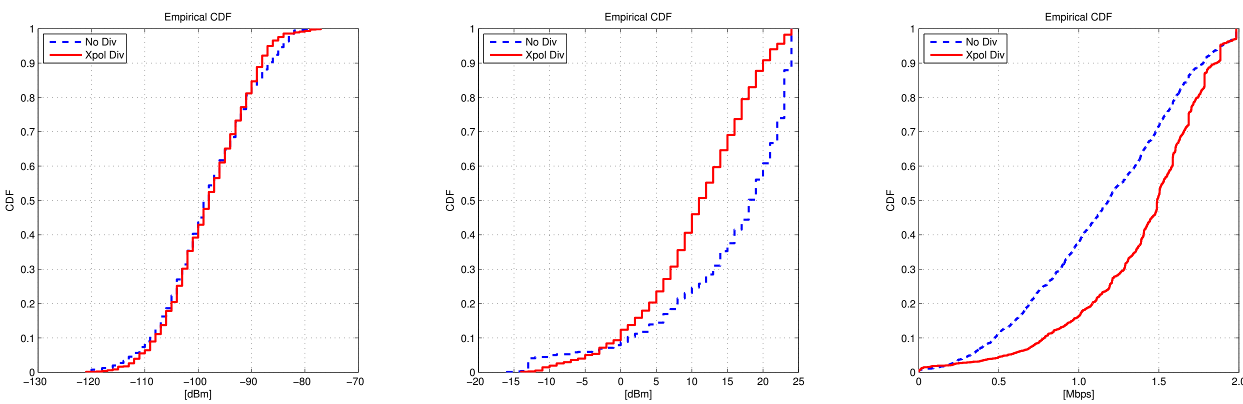


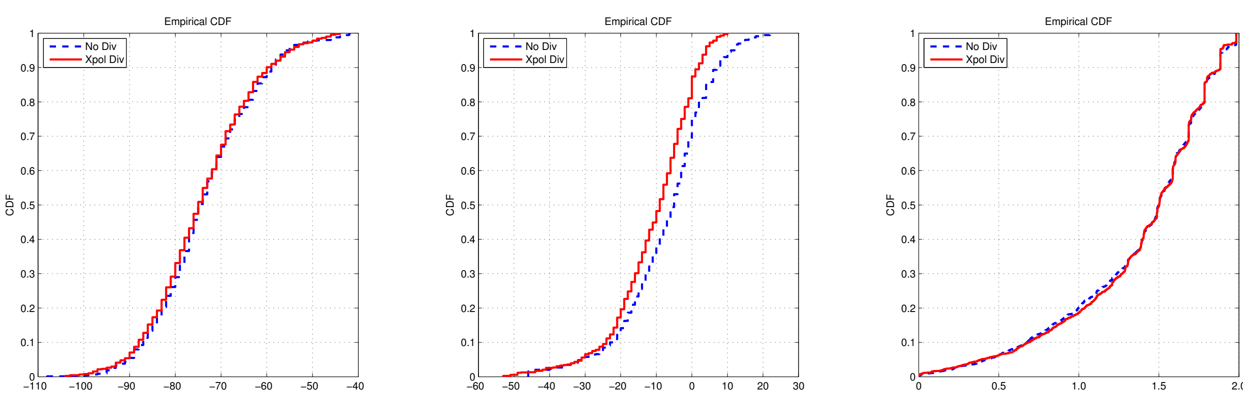

(a) CDF of RSCP (b) CDF of Tx Power (c) CDF of HSUPA TP

Fig. 4. Space diversity in NLOS environment (Route 1), CDF of RSCP, Tx Power, and TP.




(a) CDF of RSCP (b) CDF of Tx Power (c) CDF of HSUPA TP

Fig. 5. Polarization diversity in NLOS environment (Route 1), CDF of RSCP, Tx Power, and TP.




(a) CDF of RSCP (b) CDF of Tx Power (c) CDF of HSUPA TP

Fig. 6. Polarization diversity in LOS environment (Route 2), CDF of RSCP, Tx Power, and TP.