Antenna Configuration in WCDMA Indoor Network

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***Abstract*— The target of the paper is to provide guidelines for indoor antenna selection for distributed antenna system or radiating cable implementation. Distributed antenna system is a commonly used antenna system for indoor installations, and radiating cables are often used in tunnels, airplanes, or similar constricted areas. However, guidelines for optimizing WCDMA indoor network antenna configuration are lacking in the literature. Distributed antenna system with variable amount of antennas is compared to radiating cable, and the behavior of the system is analyzed by a number of indicators. The results show that distributed antenna system is a favorable solution compared to radiating cables. In addition, it can be concluded that the capacity of the network is not highly proportional to the number of antennas in distributed antenna system, but they affect more the coverage of the network.**

Keywords–DAS, field measurements, indoor, radiating cable, WCDMA

I. Introduction

Optimization of existing networks is the next step towards higher capacities in the 3G networks. A significant number of high data rate users will be located at indoor locations. Therefore, providing good indoor coverage and capacity also for indoor users is an important topic for network operators. High density of indoor users without dedicated solution for in-building coverage easily deteriorates the performance of the entire network. This phenomenon is caused by high required transmission power due to significant indoor propagation losses. This can be avoided by building dedicated indoor systems [1]. Distributed antenna system (DAS) is predicted to be the most preferred solution [2], but also pico base stations or radiating cables (RC) might be solutions worth considering. Regardless of the solution, planning and optimization guidelines will be needed to ease the operators' work for building 3rd generation cellular networks in indoor locations.

II. WCDMA Indoor Planning

A. Indoor Environment

System is considered wideband, if the transmission bandwidth is much wider than the coherence bandwidth of the radio channel. The coherence bandwidth of macrocellular environment varies between 0.053 MHz and 0.16 MHz, which is clearly less than the bandwidth of WCDMA (wideband code division multiple access) system (3.84 MHz). Therefore, WCDMA system is robust for frequency selective fast fading in typical outdoor environments. However, in indoor environment the coherence bandwidth can be more than 16 MHz. [3] This leads to WCDMA signal being flat fading in most of typical indoor environments, which might cause some unintended behavior and lowered the system performance in indoor locations.

B. Configuration Planning

Due to interference limited nature of WCDMA networks, single user requiring high throughput in the cell edge or in an indoor location can consume great amount of the capacity of the whole cell. High bitrate users are rather often in positions with high propagation loss, such as buildings or cars. If outdoor network is not planned to provide coverage and capacity for indoor users, or some indoor location is introducing high load to some cells, a dedicated indoor solution inside the building is worth considering for providing good indoor coverage [4], [5].

Different antenna configurations have been studied in various cellular technologies, i.e., [6], [7]. Moreover, simulations have been performed to analyze the capacity of a dedicated WCDMA indoor system [5], [8]. However, measurement-based comparison of different antenna configurations and radiating cable providing background information and guidelines for planning an indoor network can not be found in the literature.

There are some possible solutions for building indoor coverage. Macro/microcellular networks can be planned in such a manner that in-building coverage is taken into consideration, which reduces the need for deploying dedicated indoor systems. However, the high in-building penetration loss makes it an inefficient solution. Most typical solution is implementation of independent indoor base station, with either DAS, RC [9], or even distributed base station system [2].

The indoor environment constitutes a challenge for radio network planning, due to the difficulty to perform accurate simulations in indoor environment. In macrocellular radio network planning, estimating the propagation of the signal can be based on propagation models, such as Okumura-Hata. In indoor, simple models can be used, for instance 3GPP path loss model for indoor environment [10], but very high accuracies should not be expected. On the other hand, ray-tracing or similar accurate models can be exploited, but this requires very detailed information on the building, which may lead to higher planning cost. Practical knowledge on earlier successful installations has been used in GSM indoor planning, but a part of the phenomena caused by WCDMA system remain currently undiscovered.

C. Indoor Antenna Systems

Distributed antenna system is the most common approach for providing in-building coverage. Antennas used in DAS are small discrete antenna elements designed specially for indoor use. Typically they are either omnidirectional, or directional 65-90° antennas. In DAS implementation, signal is transferred from base station by network of feeder cables, connected by splitters and tappers. Advantages of DAS are easy planning and good coverage, while drawbacks include high installation costs compared to, e.g., indoor pico cells or outdoor to indoor repeaters [11].

Radiating cable (RC), often called leaky feeder, is simply a feeder cable with small holes or groove in the outer conductor of coaxial cable, and the signal leaks in a controlled way from the cable. The end of a radiating cable needs to be either terminated, or one can install a discrete antenna there. Radiating cables are typically used in, e.g., tunnel installations. Due to small EIRP (effective isotropic radiated power) of RC, it is also a good choice for interference sensitive environments, such as hospitals or airplanes.

One possible approach for indoor building an indoor systems is usage of pico cells; a single pico cell or a dense enough network of small base stations with, e.g., in-built omnidirectional antenna in desired area for indoor coverage.

III. WCDMA Network Load

A. Load Equations

Increasing load, i.e., the amount of users or user bitrates in the network, raises the total interference level in the network, and it is modeled by interference margin (IM):

$$IM = -10\log_{10}(1 - load). \tag{1}$$

Uplink (UL) and downlink (DL) directions need to be considered separately, since the loads in uplink and downlink directions are not identical. In uplink direction, mobiles share the same radio interface, and interference in the receiving end is the same. In downlink direction, the data sent to different users consumes the shared transmit (Tx) power of Node B, and also the interference is different in different locations.

In downlink direction, the load factor is defined [12]:

$$\eta_{DL} = \sum_{j=1}^{N} \frac{1}{\frac{W_c}{(E_b/N_0)_j R_j \nu_j}} [(1-\alpha_j) + i_j], \tag{2}$$

where N is the number of users in the network connected to Node Bs, W_c is the chip rate, $(E_b/N_0)_j$ is the (E_b/N_0) requirement of user j, R_j is the bitrate of user j, ν_j is the activity factor of user j. i_j is the other-to-own-cell interference, which is in this case different for each user due to different location. α_j is the orthogonality factor, which describes the orthogonality of the codes being used. In optimal case, when codes are fully orthogonal, α_j equals to 1, but multipath fading deteriorates orthogonality. The effect of the orthogonality on WCDMA system and distance dependence of orthogonality are known issues [13]. However, the effect of indoor environment and antenna configuration on the code orthogonality remains unclear.

B. Orthogonality Evaluation

Downlink orthogonality can not be directly measured by the UE (user equipment), but it can be evaluated by the equation used in open-loop power control to calculate the initial Tx power for dedicated DL connection [14]:

$$P_{Tx}^{Initial} = \frac{R \cdot (E_b/N_0)_{DL}}{W} \cdot \left(\frac{CPICH_{TxPower}}{(E_c/N_0)_{CPICH}} - \alpha \cdot P_{Tx}^{Total} \right), \tag{3}$$

where R is the user data rate, W is the WCDMA chip rate, $(E_b/N_0)_{DL}$ is the planned E_b/N_0-value, $CPICH_{TxPower}$ is the Tx power for common pilot channel, $(E_c/N_0)_{CPICH}$ is the E_c/N_0 of the pilot channel, α is downlink orthogonality factor, and P_{Tx}^{Total} is the total DL Tx power. 3 can be solved with respect to α:

$$\alpha = \frac{\frac{R}{W} \cdot (E_b/N_0)_{DL} \cdot \frac{CPICH_{TxPower}}{(E_c/N_0)_{CPICH}} - P_{Tx}^{Initial}}{\frac{R}{W} \cdot (E_b/N_0)_{DL} \cdot P_{Tx}^{Total}}. \tag{4}$$

Moreover, 4 needs to be modified to be used with the measurement results. $P_{Tx}^{Initial}$ can be replaced with user dedicated Tx power (P_{Tx}^{DPDCH}), and P_{Tx}^{Total} consists of common channel powers P_{Tx}^{Common}, and P_{Tx}^{DPDCH}. Replacing $(E_b/N_0)_{DL}$ with DL SIR target ($SIR_{TargetDL}$) might cause some small error to the orthogonality values, but the relative differences remain true. Also the resolution of the $(E_c/N_0)_{CPICH}$ measurement in the UE is 1 dB, which can cause some random error to the results. Finally, the relative DL orthogonality, α_r can be evaluated:

$$\alpha_r = \frac{\frac{R}{W} \cdot SIR_{TargetDL} \cdot \frac{CPICH_{TxPower}}{(E_c/N_0)_{CPICH}} - P_{Tx}^{DPDCH}}{\frac{R}{W} \cdot SIR_{TargetDL} \cdot \left(P_{Tx}^{DPDCH} + P_{Tx}^{Common} \right)}. \tag{5}$$

IV. Field Measurements

The aim of the measurements is to provide information on the effect of antenna configuration on a WCDMA network behavior, and to find optimal configuration for WCDMA indoor implementation. A DAS consisting of 1 to 4 antennas is compared to radiating cable, where 1-antenna DAS can be treated also as a pico cell scenario.

A. Measurement Setup

Measurements were conducted in a university building, in an open corridor area. The dimensions of the building were about 150 x 60 m. The building layout is shown in Fig. 1, where the measurement area is pointed out with the dotted line.

The measurements were carried out in an experimental WCDMA network, consisting of a RNC/Iub (radio network controller) simulator running on a PC, and a commercial WCDMA base station, connected to the antenna system. Antenna system consisted of 60 m feeder cable, connected

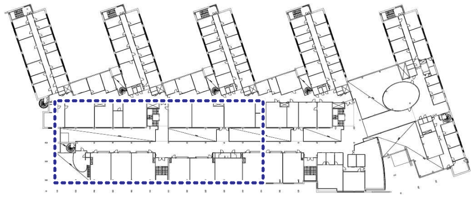

Fig. 1. Second floor layout of the building used for the measurements. Measurement area is pointed out with the dotted line.

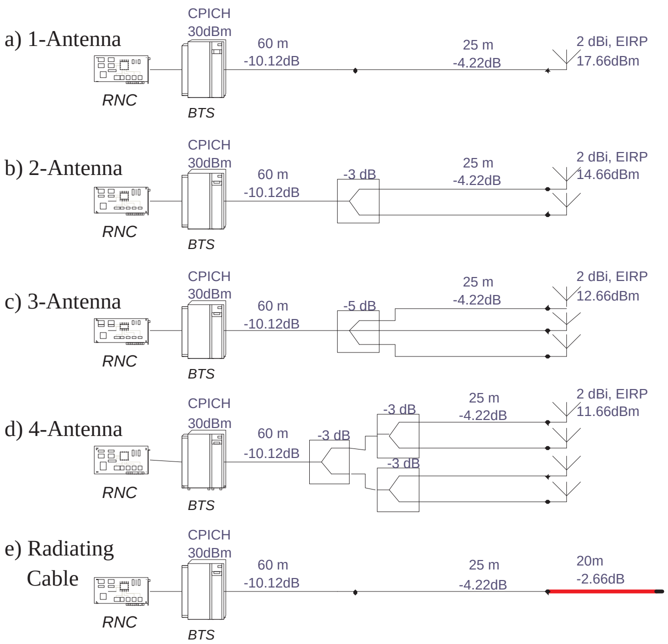

Fig. 2. System block diagram and antenna configuration scenarios.

(a) 1-antenna (b) 2-antenna (c) 3-antenna (d) 4-antenna (e) Radiating cable (f) Measurement routes

Fig. 3. Antenna positions for 1-4 -antenna scenarios (a)-(d), radiating cable (e), and measurement route (f). (a)-(e) are located on the second floor and (f) on the first floor.

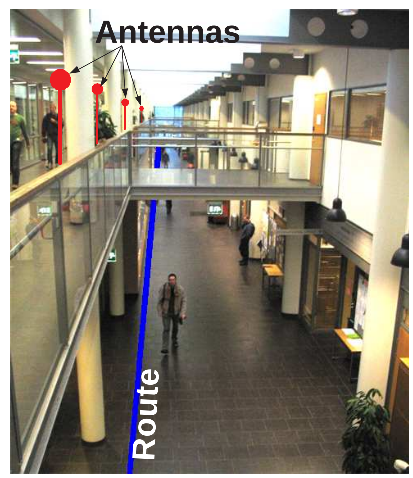

Fig. 4. Illustration of measurement environment, measurement route, and antenna placement.

to varying antenna configuration. Measured antenna configurations, including RNC and base station, are shown in Fig. 2. Antennas were omnidirectional indoor antennas with 2 dBi gain, and radiating cable and feeder cable were 1/2" coaxial cables [15]. In 1-antenna and RC scenarios, the signal was directly transmitted via one antenna/RC, and in 2-, 3-, and 4-antenna scenarios the signal is split in 2, 3, or 4 equal parts, respectively. EIRP of a single antenna varied along the configuration, being highest in 1-antenna and lowest in 4-antenna scenario (excluding RC-scenario, where the EIRP is not so unambiguous term).

Measurement equipment consisted of a WCDMA UE, connected to an air interface measurement software [16]. The cell scenario was isolated, i.e., no inter-cell interference was present. DL Tx power was recorded by RNC, and all other parameters were recorded by the measurement software.

The measurement route was a straight line under the antennas, which were evenly distributed over the measurement route. The measurement environment, antenna positions and measurement route are shown in Fig. 3 and illustrated in Fig. 4. In Fig. 3(a)-(d) the positions for 1-4 antenna scenarios are shown, and in Fig. 3(a) the position of radiating cable is illustrated. All antenna configurations were measured on the primary measurement route, whose length was about about 60 m (Fig. 3(f), long blue line). Since the length of the radiating cable was 20 m, and it was measured also on a shorter route, limited only under the radiating cable (Fig. 3(f), short blue line), referred as under RC -scenario. The antennas and radiating cable were located on the second floor, and the measurement route was on the first floor (there was no ceiling between the floors). The antennas did not have LOS (line of sight) to each others, whereas connection between antennas and UE consisted of both, LOS and NLOS (non line of sight).

In the measurements, a 12.2 kbps speech call was established, and the activity factor was kept in maximum all the time, which resulted in constant 60000 bps throughput in uplink DPDCH (dedicated packet data channel). The call was echoed to the downlink at the RNC, so the same activity factor and throughput was introduced also in downlink transmission.

The measurement routes were repeated several times in order to increase the reliability of the results.

B. Measurement Results

All measured and analyzed values are gathered in Table I. The presented results are averaged values over each measurement route.

The difference between discrete antennas and RC is well visible in average $RSCP$. Under the RC the average RSCP is already about 8 dB below the lowest measured value with discrete antennas, and when measuring further away from the RC, average RSCP decreases 10 dB more. Comparison between discrete antenna configurations is interesting. Namely regardless of the amount of antennas, average RSCP remains in the window of 2.5 dB, 3 antennas providing the best and 4 antennas the worst coverage.

E_c/I_{0CPICH} is defined as a relation of pilot RSCP (received signal code power) and pilot RSSI (received signal strength indicator), and it is used to measure the quality of the cell. Since there are no coverage limitations (RSCP > -95 dBm always) in the measurement area and the interference levels are low, the differences in the E_c/I_{0CPICH} are expectedly small, including radiating cable (RC) measurements.

The smallest values for the standard deviation of RSCP, STD_{RSCP}, were measured under RC, which could be expected, since the distance between the UE and the radiating cable remains constant over the measurement route. The highest STD_{RSCP} values were measured at the RC-scenario, where the distance between RC and the UE was increasing from a couple of meters up to about 30 m. From different discrete antenna configurations, the highest values were measured from the 1-antenna scenario, and smallest for the 2-antenna scenario.

The variations in average DL Tx powers, $P_{Tx}^{DCH,DL}$, fit into about 1 dB window, which shows that in a rather interference free environment, the downlink power does not very much depend on the path loss. However, the smallest values were measured from the 1- and 2-antenna scenario, and highest in the RC-scenario. Under RC the DL Tx power remains close to the 1- and 2-antenna scenario, but none of the scenarios seem to be superior by means of DL Tx power (Fig. 5).

The outer loop power control located at the UE measures the quality of DL transmission, and tunes the DL SIR target, SIR_{Target}^{DL}, accordingly. The average DL SIR target can be used to follow the overall quality of the transmission. All the measured DL SIR target values are around 9 dB, which indicates rather similar transmission quality between different scenarios. This is verified also by the small differences in the BER (bit error rate) values on the pilot channel.

In uplink direction, the differences between Tx power, P_{Tx}^{UL}, were rather obvious, and there is a clear relation between RSCP and P_{Tx}^{UL}. The smallest average UL Tx power was measured with 4-antenna scenario, and it increases while the amount of antennas decreases. The highest UL Tx powers were measured with radiating cable, which indicates that the coverage of the network is rather limited in uplink direction elsewhere than straight under the cable. The CDF of UL Tx power is shown in Fig. 6.

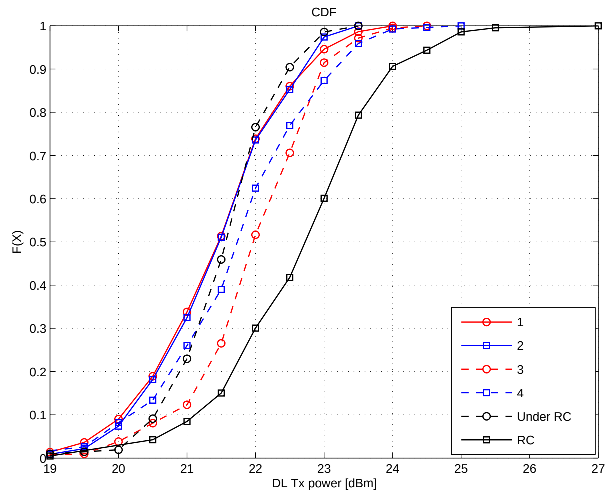

Fig. 5. CDF of downlink Tx power measurements in all antenna configurations.

For analyzing the influence of antenna configuration on uplink transmission, the effect of varying average RSCP values has to be compensated, and then the compensated UL Tx power is expressed relative to the 1-antenna scenario:

$$\Delta P_{UL} = -\Big(RSCP - RSCP(ref)\Big) - \Big(P_{Tx}^{UL} - P_{Tx}^{UL}(ref)\Big), \quad (6)$$

where $RSCP(ref)$ and $P_{Tx}^{UL}(ref)$ are the corresponding values from the 1-antenna scenario. The low value for the 4-antenna scenario indicates that the increased diversity against slow fading caused by the several antennas is improving the quality of uplink reception.

Relative orthogonality values, α_r, for different scenarios are calculated based on (5). α_r remains rather constant in all other scenarios except in the RC -scenario, which indicates that when going away from under the RC, the orthogonality decreases faster than in discrete antenna scenarios. This might have an effect on DL load on high loaded cells when using radiating cables.

V. Conclusions and Future Work

The target of the paper is to provide guidelines for indoor antenna selection for distributed antenna system or radiating cable implementation

The differences between different antenna configurations are lacking; only uplink coverage seems to be increased while implementing more antennas to the DAS. The results show, that building a DAS with discrete antennas in indoor environment is not very sensitive to the number of antennas. The variation of the signal level is higher in 1-antenna scenario compared to other DAS scenarios, but this does not seem to have negative impact on network performance. The results indicate, that primary concern of indoor using DAS is to ensure good coverage in the network, whereas antenna configuration do not seem to have significant effect on capacity. In the

TABLE I

MEASUREMENT RESULTS.

Antennas		1	2	3	4	RC	Under RC
$RSCP$	[dBm]	-61.82	-61.96	-60.14	-59.61	-79.64	-69.92
STD_{RSCP}	[dB]	7.17	4.66	5.81	5.82	8.63	3.57
$RSSI$	[dBm]	-57.80	-57.90	-56.17	-55.42	-75.60	-65.93
E_c/I_{0CPICH}	[dB]	-4.02	-4.06	-3.98	-4.19	-4.04	-3.99
BER_{CPICH}	[%]	0.29	0.37	0.28	0.28	0.39	0.29
SIR_{Target}^{DL}	[dB]	9.09	8.89	9.27	9.23	9.35	9.11
$P_{Tx}^{DCH,DL}$	[dBm]	21.76	21.76	22.28	22.08	23.04	21.83
P_{Tx}^{UL}	[dBm]	-28.45	-29.01	-29.52	-33.86	-11.06	-19.38
ΔP_{UL}	[dB]	0.00	-0.70	0.61	-3.20	-0.44	0.97
α_r		0.638	0.623	0.576	0.659	0.483	0.623

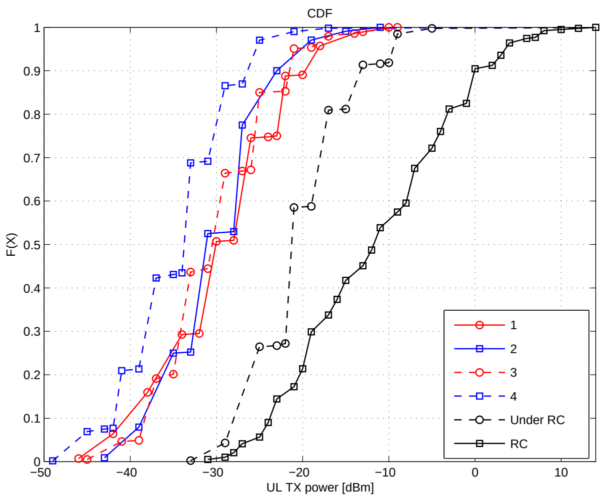

Fig. 6. CDF of uplink Tx power measurements in all antenna configurations.

measurements, measurement route and antennas were in line with each others; more fragmented antenna placing could increase differences between antenna configurations.

According to most of the indicators, discrete antenna solutions seem to outperform radiating cable. Due to weak coverage radiating cable provides, it can not be recommended as a primary solution for typical indoor planning scenario. However, small radiation power of radiating cables provides more accuracy in controlling the coverage area of the cell.

In future, scanner measurements will be performed in order to more accurately measure the phenomena in indoor environment for different DAS configurations. Moreover, multi-picocell indoor configurations will be compared to multi-antenna DAS configurations in order to provide comprehensive guidelines for indoor planning.

VI. ACKNOWLEDGEMENT

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