Utilization of an Indoor DAS for Repeater Deployment in WCDMA

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Abstract—**The aim of this paper is to assess the applicability of a repeater connected to a distributed antenna system for improving indoor capacity in UMTS radio network. A guarantee of sufficient coverage and capacity for in-building areas constitutes a considerable issue in topology planning, because in both links, indoor users produce high interference to the outdoor network due to significant indoor propagation losses. Presented configuration effectively exploits effectively a repeater system that amplifies the signal from the outdoor network and delivers it for indoor locations through distributed antenna system. Implementation of the analyzed repeater system is straightforward as it does not require usage of separate carrier. Moreover, any separate scrambling codes do not have to be dedicated either. Conducted measurement campaigns reveal improvement of radio conditions due to repeater implementation that results in 35% gain of downlink capacity for indoor locations. Furthermore, in the analyzed scenario, the average value of SIR is improved by 3.41 dB that might lead to an increase of capacity in HSDPA as well. Simultaneously, the executed measurements illustrate the positive impact of the indoor DAS solution on the downlink capacity of the surrounding macrocellular network.**

Keywords-Capacity, indoor, radio interface measurements, radio network planning, repeaters, WCDMA.

I. INTRODUCTION

Typically, cellular networks providing service in majority of indoor locations must support high capacity requirements due to expected presence of active business subscribers using packet-based applications. Performance of the WCDMA (Wideband Code Division Multiple Access) network without specified approach supporting indoor traffic is limited, because high power required by indoor users produces interference that naturally limits the overall network capacity [1]-[2]. Moreover, appropriate operation of HSDPA (High Speed Downlink Packet Access) in UMTS (Universal Mobile Telecommunication System) requires favorable radio conditions, which in indoor environment can be achieved only when dedicated antenna system is used [1]. Therefore, from early stages of topology planning, indoor traffic with associated capacity requirements needs to be carefully considered.

A straightforward approach for improving indoor capacity constitutes a method of dedicating an additional carrier for indoor coverage in addition to the existing macrocellular layer. However, in long term while the traffic of surrounding macrocellular cells increases, operators prefer to retain this opportunity for immediate capacity enhancements. Alternative solution for supporting indoor traffic is an assignment of HCS (hierarchical cell structure) with a separate cell dedicated only to indoor environment. With this approach, indoor users that are served by an indoor cell do not cause that much interference to the other connections in surrounding network. Hence, the capacity of indoor and also neighboring cells significantly increases, as presented in [3], where indoor pico base stations are considered. The capability of an indoor cell for handling high load can be further enhanced by deployment of DAS (distributed antenna system) [1], [4]. Due to high probability of LOS (line of sight) connections to indoor antennas, radio conditions are significantly improved resulting in, e.g., better code orthogonality. Moreover, favorable radio conditions improve HSDPA capacity, since it allows transmission with higher order MCS (modulation and coding scheme) [5].

Efficient deployment of HCS with dedicated indoor cell requires proper optimization of RRM (radio resource management) algorithms. For instance, performance during possible SHO (soft handover) with an indoor cell and macrocell is relatively low due to unequal strength of radio links included in the AS (active set) that negatively affects the system capacity. Namely, an UE (user equipment) entering the building in the *CONNECTED* state may hold on to the outdoor cell while causing significant interference due to high DL (downlink) power. Also, when the UE is leaving the building with dedicated connection on, it can stay connected to the indoor cell with significant power [6]. Other major challenges related to DAS implementation include proper choice of antennas and selection of antenna locations [7]-[8].

In cellular communication, repeaters are classically used for providing coverage in deadspots, which mainly constitute hardly accessible areas for regular base station deployment [9]-[12]. In most of the scenarios, utilization of repeaters is very cost effective, as it decreases the number of required base stations. Moreover, in [13]-[16] it was presented that properly deployed and configured repeaters constitute an effective capacity enhancement in CDMA-based networks. Hence, repeater systems can provide flexible and inexpensive solutions for varying traffic conditions, for hotspots (i.e., areas with high capacity requirements), and also for serving indoor users.

In this paper, applicability of the repeater-to-DAS configuration for indoor locations with high capacity requirements is evaluated by measurement trials. In the analyzed repeater system, signal from the macrocell is amplified by the repeater and provided to the indoor users through DAS. Performed studies include assessment of the impact of the considered repeater system on the DL radio conditions in indoor as well as in the surrounding network. The analysis includes estimation of the DL capacity from E_c/N_0 (energy per chip over interference spectral density) measurements; the referred method is described in details in [19].

II. MEASUREMENT SCENARIO

Considered indoor hotspot was generated in a building surrounded by a macrocellular, capacity-limited urban UMTS network (Fig. 1). The building with dimensions of about 150 m x 60 m was located in approximately 300 m distance from the nearest and the best hearable site (site 2), see Fig. 1. The capacity-limited conditions of the considered indoor locations were confirmed by tracking the mobile-station transmit power in the scenario without the repeater that maintained at the level of -10 dBm. Similarly, in surrounding macrocellular network, an average transmit power of the UE over the outdoor measurement route did not drop below -20 dBm. The sites of the surrounding network were deployed mainly in 3-sectored manner with 500 m mean site spacing. DAS was deployed in the considered, four storey building, which has as well open areas (halls) and number of narrow corridors, as illustrated in Fig 2. Implemented indoor DAS consisted of one omnidirectional antenna with 2 dBi gain, three horizontally wide (90º) directional antennas with 7 dBi gain, and radiating cable (1/2'') with approximately 80 dB coupling loss and 13 dB longitudinal loss when operating at UMTS frequency. Locations of the indoor antennas were selected in order to provide sufficient coverage in the entire hall and the selected corridors on the first and the second floor (Figs. 2 (a)-(b)). Omnidirectional antenna was deployed on the second floor for providing service in an open area, while directional antennas and the radiating cable were installed in narrow corridors on the first and the second floor, as illustrated in Figs. 2 (a)-(b). Indoor antennas were installed at the average height of 2 m and radiation cable was mounted at the ceiling of 2.5 m height.

Signal to the DAS was provided by the repeater [17] that received signal from the surrounding macrocellular network (Cell 2). The donor antenna of the repeater was installed on the roof of the considered building (height 20 m) in an approximate distance of 350 m from the mother cell (Cell 2), see Fig. 1. The donor antenna had LOS connection to the mother cell with the corresponding path loss of 100-105 dB. Moreover, at this location, contribution from the interfering cells was minimal. For the donor antenna, the horizontal and vertical half-power beamwidths were respectively 65º and 6.5º, and the gain was 17.1 dBi [18]. The received signal was amplified by the repeater with 65 dB and transmitted to the DAS. Since the donor and indoor antennas were separated by number of walls, the isolation requirement was satisfied with a big margin. Overall losses of cables and connectors used in the repeater system did not exceed 5 dB. Thus, the gain of the repeater system was 77.1 dB. Total gain of indoor antennas did not overcome losses of feeder cables, splitters, and connectors used in the DAS implementation. In result, the total gain of the system was 61.1 dB for directional antennas, 67.1 dB for omnidirectional antenna, and 62.4 dB for radiating cable.

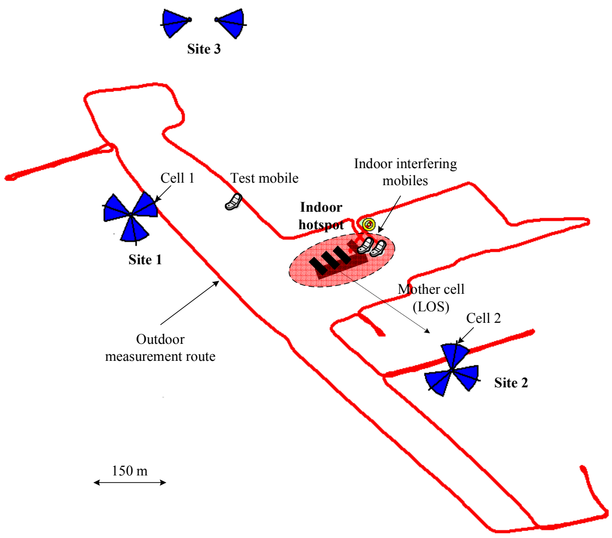

Fig. 1. A part of the outdoor network with location of the indoor hotspot, mother cell (cell 2), and neighboring cells. Red line represents the outdoor measurement route.

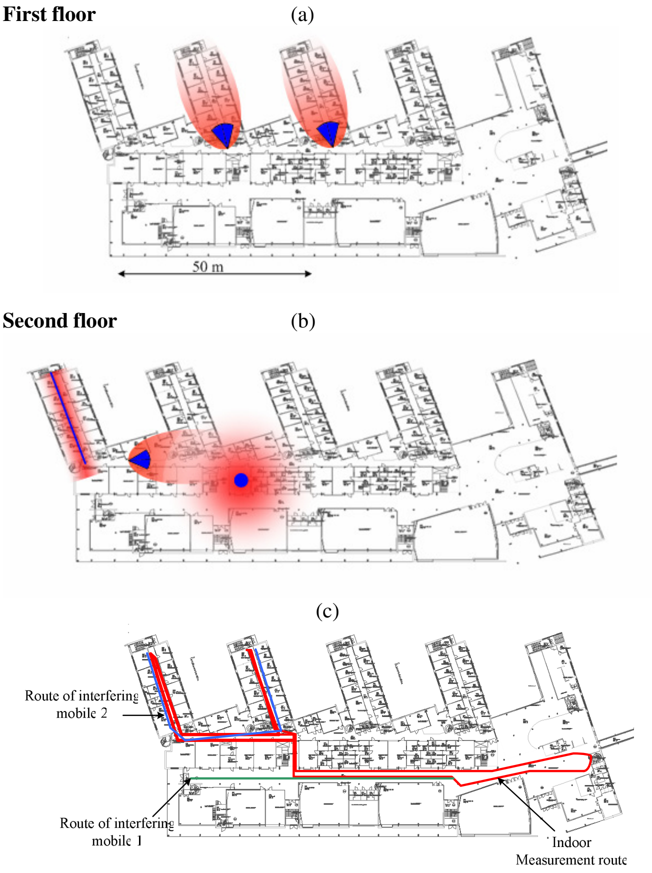

Fig. 2. Layout of the considered building (indoor hotspot) with the locations of the antennas; (a) – location of directional antennas on the first floor, (b) – location of antennas and radiating cable on the second floor, (c) – indoor measurement route on the second floor (red line), routes of interfering mobiles on the second floor (blue and green line).

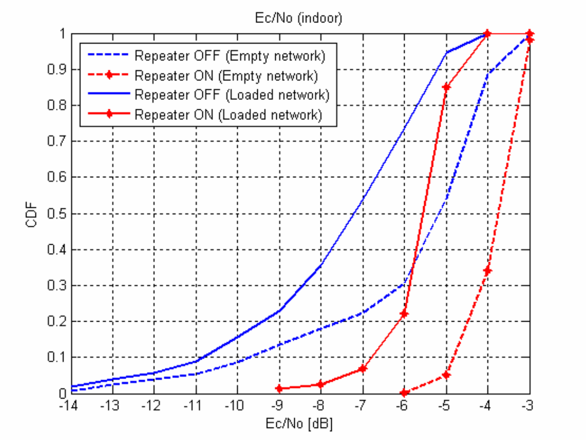

Fig. 3. CDF of E_c/N_0 measurements in indoor environment for two different load configurations (dashed and solid lines). Results are presented for the original topology (blue line) and for the indoor repeater system (red line).

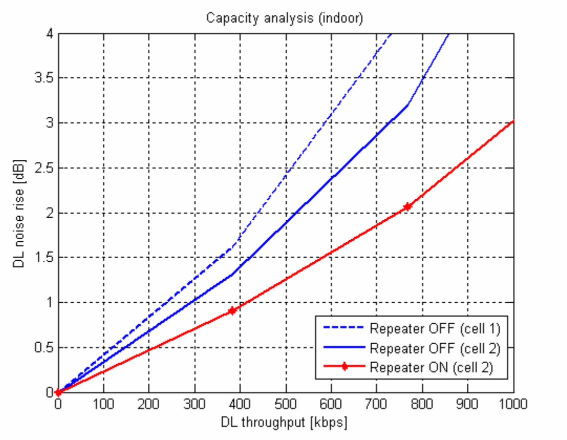

Fig. 4. The estimation of the indoor capacity in analyzed topology configurations. In scenario with the repeater ON entire measurement route was served by cell 2, thus only this capacity analysis is included.

TABLE I. AVERAGE E_c/N_0 AND DL THROUGHPUT IN INDOOR ENVIRONMENT FOR CONSIDERED TOPOLOGY AND LOAD CONFIGURATIONS.

		Serving cell (#)	**E_c/N_0 [dB]**	**Total throughput [kbps]**
REPEATER OFF	***IDLE* mode, empty network**	1 2	-6.91 -4.4	
	One served mobile	1 2	-7.45 -5	162 330
REPEATER ON	***IDLE* mode, empty network**	2	-3.37	
	One served mobile	2	-4.17	314
	Three served mobiles	2	-5.18	623

Indoor traffic was generated with two terminals that were set to download with a bit rate of 384 kbps (non-real time background service class). During the measurements, the terminals were moving along the indoor route covering as well open areas as corridors; see blue and green lines in Fig. 2 (c). The impact of deployed repeater system on indoor radio conditions was evaluated by tracking P-CPICH (primary common pilot channel) E_c/N_0 and SIR (signal to interference ratio) statistics over the route illustrated as a red line in Fig. 2 (c). The indoor route was selected such that it included diverse propagation areas (narrow corridors, open halls) and accounted contribution from all implemented indoor antennas. The impact of the deployed antenna system on the neighboring cells in the surrounding network was evaluated by measurements conducted over the outdoor route illustrated in Fig. 1. The shape of the outdoor route was chosen in order to maximize the presence of the measured UE in cell border regions and in dominance areas of the mother and the neighboring cells.

The measurement equipment consisted of a laptop PC with radio interface measurement software connected to the test mobile, scanner, and to the GPS receiver. Naturally, the availability of the positioning information was limited to outdoor measurements. The test mobile was set to download also with 384 kbps speed (non-real time background service class). Thus, the maximum throughput that could be requested simultaneously under the 'mother cell' was 1152 kbps, when both hotspot mobiles and the test mobiles were connected to the same cell. Radio conditions were evaluated in configuration with and without the repeater system. Moreover, statistics of measurements were gathered in two load scenarios: with and without the indoor interference. The presented results are averages of measurements results obtained during two measurement rounds of the defined route.

III. MEASUREMENT RESULTS AND ANALYSIS

A. *Indoor environment*

The presented capacity analysis is based on the method that exploits E_c/N_0 statistics for reliable DL capacity estimation. The referred method is comprehensively described in [19]. E_c/N_0 is a function of RSCP (received signal code power) of the P-CPICH and RSSI (received signal strength indicator). Thus, it provides a feasible reference for evaluation of the DL interference increase as a function of DL throughput. Improvement in the level of the other-to-own-cell interference (i_{DL}) in the repeater scenario can be directly estimated from the difference in the *IDLE* mode E_c/N_0 measurements conducted in an empty network [19]. Measurement results of E_c/N_0 observed with two different load situations in the same network configuration provide information about the sensitivity of the network configuration for increase of load. Hence, the maximum achievable (average) DL capacity can be estimated by an inverse load curve assuming certain allowed noise rise, see [20] for load equations. In order to evaluate the capacity by the referred method, in addition to the other-to-own-cell interference (i_{DL}), the average orthogonality factor (α) needs to be estimated. In

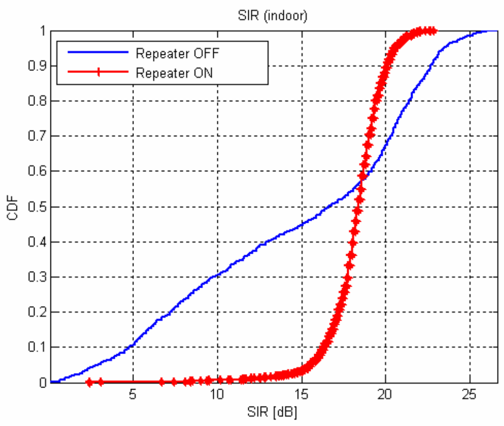

Fig. 5. CDF of SIR measurements in the indoor environment. Test mobile was in the *IDLE* mode.

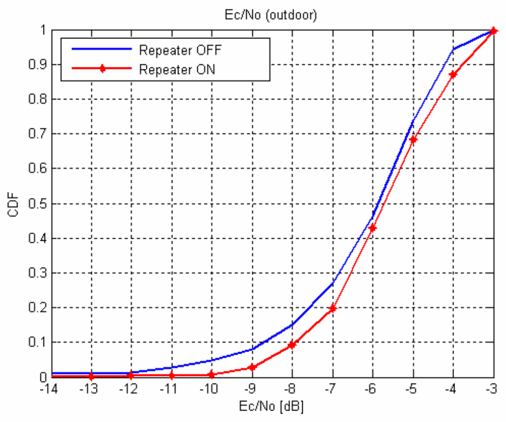

Fig. 6. CDF of E_c/N_0 measurements in the outdoor environment when network was loaded by indoor hotspot mobiles.

performed analysis, the distance dependent orthogonality model is used for the estimation of α [21].

Fig. 3 presents E_c/N_0 statistics in indoor environment that were obtained in the empty and loaded network (two interfering mobiles). Deployment of the indoor repeater system in the considered indoor location significantly decreases the interference level, as the mean value of the *IDLE* mode E_c/N_0 measurements in the empty network increases from -5.48 dB to -3.37 dB when the repeater was used. Similarly, when the hotspot mobiles were loading the indoor location, the mean value of the E_c/N_0 was improved from -7.2 dB to -5.18 dB due to the repeater implementation Fig. 3.

In the original configuration (repeater OFF), the considered in-building area was served by cell 1 and cell 2, see Fig. 1. Installation of the indoor repeater system enlarged the dominance of the cell 2 for the entire indoor location. Thus, the evaluation of the DL capacity for the scenario without the repeater is performed individually for each serving cell. Table 1 gathers mean values of the E_c/N_0 and the corresponding throughputs of the test and hotspot mobiles that were collected in different load situations. As indicated in the table, assessment of indoor radio conditions in repeater OFF scenario was performed for two load configurations, while for repeater ON scenario, E_c/N_0 and corresponding throughput were tracked in three load configurations. Fig. 4 illustrates the estimated curves of the DL noise rise that are based on observed E_c/N_0 reductions due to increase of throughput in the considered load scenarios. Without the repeater, cell 2 is less sensitive to the increase of load than cell 1. The maximum achievable throughput can be estimated by allowing certain DL noise rise. In presented analysis, 3 dB noise rise is assumed as the allowable limit that results in 590 kbps capacity of the cell 1 and 720 kbps of the cell 2. Lower capacity of the cell 1 can be explained by considerably high pathloss (140 dB) to the serving base station. Based on the estimated capacities for two serving cells, on average 655 kbps can be achieved in the indoor location without the repeater that naturally does not satisfy requirements of current packet-based services in typical indoor environments. Deployment of the indoor repeater system improves the dominance of the cell 2 for the whole indoor location, while the contribution of the interfering cells was minimized due to proper location of the donor antenna. Resulting capacity of the indoor environment with the considered topology enhancement is estimated at the level of 1 Mbps, Fig. 4. Estimated DL capacity cannot be generalized for the whole cell, as the hotspot interfering mobiles were located at the cell-edge locations. Thus, their contribution to the increase of load was more significant than, for instance, contribution of users uniformly distributed over the cell dominance area [14].

General improvement of radio conditions can be illustrated by statistics of indoor P-CPICH SIR measurements (Fig. 5). Due to repeater deployment the mean value of SIR increases from 14.82 dB to 18.23 dB. Achieved improvement is crucial when HSDPA is planned to be deployed in the network, since with better radio conditions, transmission with higher order MCS is possible while keeping BER (bit error rate) constant. Therefore, even slight improvement of the radio conditions affects in significant capacity gain of HSDPA.

B. Outdoor environment

Achieved capacity gain in indoor location is mainly caused by lower DL transmit power to the indoor hotspot mobiles served through the repeater. Logically, the interference produced to the neighboring cells should be considerably lower resulting in higher capacity of the macrocellular network surrounding the indoor hotspot, see Fig. 1. As expected, due to repeater deployment, mean value of the E_c/N_0 observed over the outdoor route with presence of the indoor interference was improved from -5.81 dB to -5.32 dB (Fig. 6). The measured average throughput was observed at the level of 296 kbps in the original configuration and 124 kbps for the scenario with the repeater. The capacity estimation of the network surrounding the indoor hotspot was performed in a manner that each cell was analyzed individually. Based on E_c/N_0 and load measurements observed in particular cells, the capacity was estimated for each cell separately. The resulting average capacity for the entire network matches the value obtained from the network perspective analysis (not shown

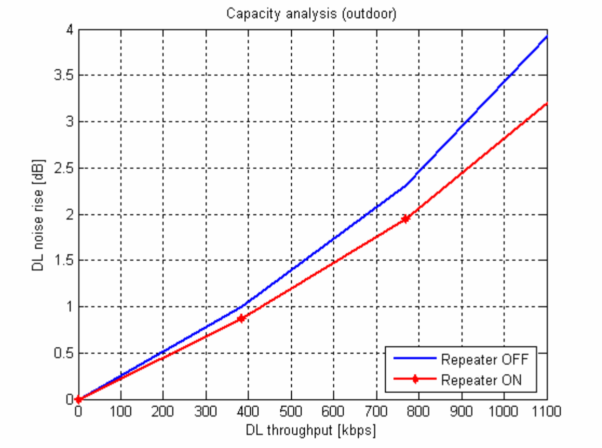

Fig. 7. The estimation of the capacity of the surrounding macrocellular network in analyzed topology configurations.

here). The capacity analysis shows that actual implementation of the indoor repeater system decreases the interference produced to the surrounding network as well. Hence, the capacity of the whole network is improved from 900 kbps to 1050 kbps (Fig. 7).

IV. CONCLUSIONS AND FUTURE WORK

In this paper, the feasibility of a repeater-to-DAS configuration for indoor hotspots was evaluated by field measurements performed in UMTS network. In the considered system, properly deployed donor antenna of the repeater delivered an amplified signal to the indoor users through DAS. Hence, superior hearability of the serving cell was ensured for indoor locations, and at the same time, the contribution of interfering cells was minimized. The measurement results indicate that the considered system is highly applicable solution for providing capacity for indoor hotspots. Based on the utilized DL capacity estimation method, the downlink capacity in the indoor environment with 3 dB DL noise rise increases from 655 kbps in the original configuration to over 1 Mbps (35% capacity gain) when the indoor repeater system is used. General improvement of indoor radio conditions was also observed by tracking SIR measurements. Due to repeater implementation, SIR increases from 14.82 dB to 18.23 dB, which in turn might boost the capacity of HSDPA.

The results clearly indicate that users served through the repeater do not require as high DL transmit power. Thus, the interference produced to the neighboring cells is significantly lowered. This phenomenon naturally influences the radio capacity of the neighboring cells that increases from 900 kbps to 1050 kbps (capacity gain 15%).

Future work will include orthogonality analysis and comprehensive evaluation of HSDPA capacity in considered indoor environment.

ACKNOWLEDGMENT

Authors would like to thank European Communication Engineering (ECE) Ltd. for helpful comments, Elisa Oyj for providing the repeater and antennas, Nemo Technologies for providing the measurement equipments, and National Technology Agency of Finland (TEKES) for funding the work.

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