Assessment of repeaters for WCDMA UL and DL performance in capacity-limited environment

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Abstract—**The target of this paper is to analyze the applicability of repeaters in capacity-limited environment through static Monte Carlo simulations under varying traffic distributions. The simulations have been conducted with different repeater gain setting targeting in evaluation of the optimum gain setting. The simulation results indicate reasonable capacity enhancements from the repeater configuration in the downlink. The downlink capacity gain increases as more traffic is forwarded through the repeater than straightly through base station. Moreover, a higher repeater gain results in larger downlink capacity gain. However, uplink direction limits the whole network performance as typically capacity loss is observed in the uplink. Therefore, also practical maximum downlink capacity gains are limited to 10-35%.**

Keywords-capacity analysis; network performance; repeaters; WCDMA.

I. INTRODUCTION

The target of a repeater is to enhance the signal level in a way that the same quality is achieved from the mobile station and from the base station (BS) point of view with a smaller required transmit (TX) power. Intuitively, this provides an enhancement for coverage, which makes the use of repeaters an attractive solution in coverage-limited environments. However, a reduction of the required TX power can be directly converted to a reduction of other-cell interference as well, which is known to increase the system capacity in wideband code division multiple access (WCDMA) systems.

Repeaters and their impact on CDMA system have been studied to some extent. The most recent studies in [1] assessed the hot-spot capacity of CDMA system when using repeaters. The results showed that repeaters provide almost double capacity in the downlink (DL) for hot-spot traffic load. However, the uplink (UL) provided merely 20% more traffic load with optimal repeater gain settings for the hot-spot. In [1], a purely hexagonal cell structures were used for both base stations and repeaters without utilization of soft handovers (SHO). On the contrary, slightly differing conclusions were drawn in [2] and [3] where the results revealed the reduction of the downlink capacity for repeater configurations in dense urban areas. However, in these studies, the number of repeaters was comparatively large respect to the number of base stations. Nevertheless, the results clearly showed that repeaters in CDMA system require a careful configuration planning, which includes definitions of repeater loss[1], donor and serving antenna heights, downtilt angles, and directions (if directional antennas are used). In [4], the uplink service probability was observed to increase with a repeater implementation under a coverage-limited network configuration. Moreover, downlink capacity was expected to increase with repeaters. It was also concluded that a reasonable increase of the uplink noise floor does not have impact on the system performance.

Field measurements under repeater configuration have verified their enhancing impact on the system performance. In [5], results showed that repeaters do not provide additional capacity in the uplink, which is inline with simulated results in [2]-[3]. However, enhancements in call quality were observed by means of improved CPICH (common pilot channel) E_c/N_0 (energy per chip over the interference spectral density) and FER (frame error rate) together with decreased number of drop calls. The same conclusion concerning the downlink performance was drawn in [6], where the motivation was in decreasing pilot polluted areas (improving the dominance) through repeaters. However, the results in [5] concluded also that repeaters cannot be used in pilot polluted areas (in this context, the areas with relatively strong signals but low E_c/N_0). In CDMA networks, problem is faced in a configuration of multiple repeaters under one cell, since each repeater increases the uplink interference level. This leads eventually to a worse system performance due to lack of uplink coverage (possibly higher interference level also in the downlink). A possible solution for increasing the uplink service probability was introduced in [7], where the repeater is switched off (i.e., it is not contributing to the uplink interference level) for the time moments when mobiles are not connected through it. This actually provides capacity gain in the uplink, if several tens or hundreds of repeaters are connected to a single cell.

The aim of this paper is to present a throughout analysis of the suitability of repeaters for capacity-limited macrocellular UMTS FDD (Universal Mobile Telecommunications System Frequency Division Duplex) network in uplink and downlink directions. Furthermore, the target is to show how an optimum repeater gain and the corresponding capacity gain depend on the traffic distribution between the repeater cell and mother cell.

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[1] The repeater loss (G_t) is defined as a function of path loss from the mother cell antenna to donor antenna, donor antenna gain, repeater gain, and cable losses before the repeater.

II. REPEATERS FOR WCDMA

A. Repeater implementation

An example of a repeater configuration is given in Fig. 1 clarifying the terminology. A repeater is a device that receives, amplifies, and transmits signals (relays) at a certain frequency band. The amount of amplification of the repeater is defined by *repeater gain*. In WCDMA network, analog repeaters are utilized due to complexity reasons, and hence a repeater does not separate any useful signal from interference, but amplifies all signals in the particular frequency. In addition to this, repeater naturally increases the noise contribution by the amount of its *noise figure*, which has to be taken into account. Moreover, in the deployment phase of repeater, an isolation requirement has to be achieved between the serving and the donor antenna in order to avoid self-oscillation of the repeater. The isolation requirement is suggested to be 15 dB above the repeater gain setting [8].

The most significant advantage of repeaters is *fast deployment capability* and *cost-efficiency*. Typically, repeaters are implemented in the network optimization phase or during the network evolution, when the network coverage needs to be improved (e.g., indoor coverage). Hence, the classical applications of repeaters are related to coverage enhancements that targets in providing a stronger signal for dead spots as tunnels, underground, and to other coverage problem areas. A repeater configuration for coverage-limited environment does not require as careful planning as for capacity-limited. However, a planner has to know how much a particular repeater configuration increases uplink interference level in order to avoid coverage holes between the repeater and mother cell. In capacity-limited environment, more careful considerations should be made regarding the repeater configuration (repeater gain and serving antenna configuration) as the repeater might easily act as a source of interference.

The repeater loss (G_t) defines unambiguously the repeater configuration from base station to the repeater serving antenna [9] (Fig. 1):

$$G_t = G_{bs} - L + G_{donor} + G_{rep} \quad [\mathrm{dB}]. \qquad (1)$$

where G_{bs} is the base station antenna gain, L is the path loss (coupling loss) between the base station antenna and the repeater donor antenna, G_{donor} is the donor antenna gain, and G_{rep} is the repeater gain (amplification). The repeater loss provides information, how much the repeater is contributing to the noise increase of the base station.

B. An Approach for a Repeater Planning

According to research conducted in [1], a properly deployed repeater is able to increase the system capacity in the downlink under heterogeneous hot-spot traffic load distribution. Therefore, repeaters could be utilized already as an integral part of the radio network planning process. Consider for example a macrocell, whose capacity starts to achieve its' maximum. Typically, the highest portion of the base station TX power is allocated for users near the cell edge or for indoor users. In such a scenario, a repeater (or repeaters) could be utilized at cell edge areas, or, on the contrary, closer to buildings (hot-spots) to lower down the required TX power. This could require deployment of multiple repeaters under a single cell. An extension to this approach would constitute an in-building solution such as distributed antenna system (DAS). In DAS approach, the donor antenna of the repeater would be deployed outdoors, whereas the serving antenna (or antenna line) would be deployed inside the building. Thus, the mobiles connected through the repeater would require considerably less TX power. In WCDMA, the possible capacity enhancements could be significant. Furthermore, during network evolution, an already existing DAS could be straightforwardly extended to independent indoor system (picocell), which could support more efficiently the capacity requirement of the hot-spot area. Analysis in [1] provides a rough threshold for the radio network planning when a separated indoor system should be deployed, and on the contrary, when it is sufficient to use repeaters to provide indoor coverage.

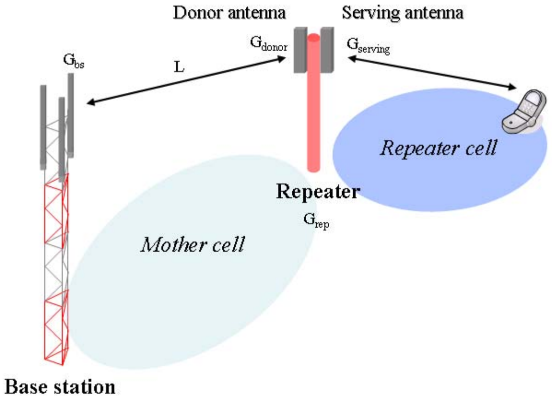


Figure 1. A repeater configuration.

III. SIMULATIONS

A. Repeater implementation

The impact of repeater deployment on WCDMA system performance was simulated using a static network simulator (NPSW [10]) with a repeater implementation. In the simulator, the path losses between repeaters and corresponding mother cells are calculated using free space loss model. In addition, an implementation loss is added to the path loss. The assumption of LOS (line of sight) is typically valid, since repeaters are commonly deployed to have LOS to the mother cell. Path losses from repeaters towards other base stations (UL) and other mobiles (DL) are calculated using Okumura-Hata model. In some scenarios, this might underestimate the interference power from the repeater, especially, if repeater antennas are implemented above the roof top level. Fig. 2 clarifies other-cell interference calculation in the uplink and downlink.

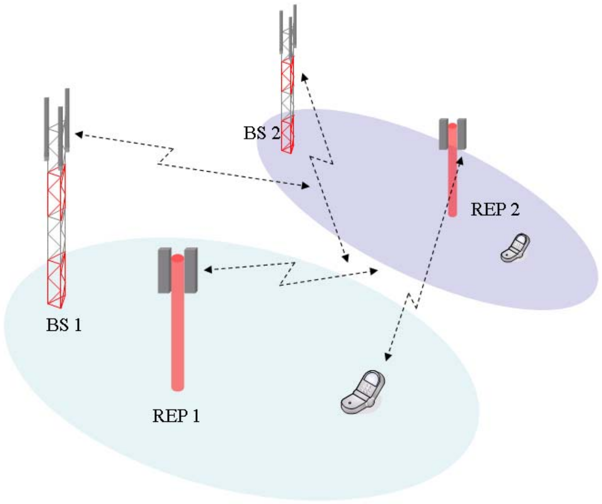


Figure 2. Other-cell interference from base station and repeater in the uplink and downlink.

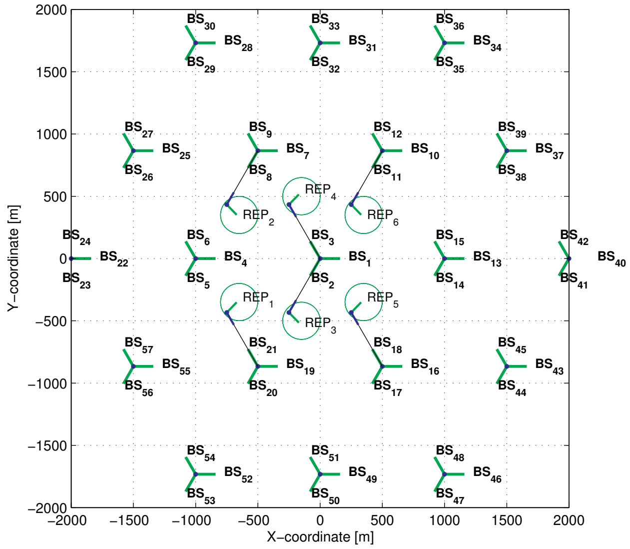


Figure 3. Network layout and repeater locations. Circles within repeaters represent hot-spot areas.

In the repeater implementation, isolation between the donor antenna and serving antenna is assumed to be infinite. The reason for this is the assumption that isolation (if achieved) does no have any impact of the capacity of a repeater network, but merely on the whole functionality of the repeater cell (if the isolation requirement is not achieved). Moreover, in the simulation model, repeaters amplify thermal noise, which can be seen as increased noise levels in base station. In the uplink, the effective noise figure of each base station (with a repeater connection) is calculated as in [9]. In general, the effective noise figure is a function of G_t (the higher is the G_t, the higher is the base station effective noise figure).

TABLE I. SIMULATION PARAMETERS.

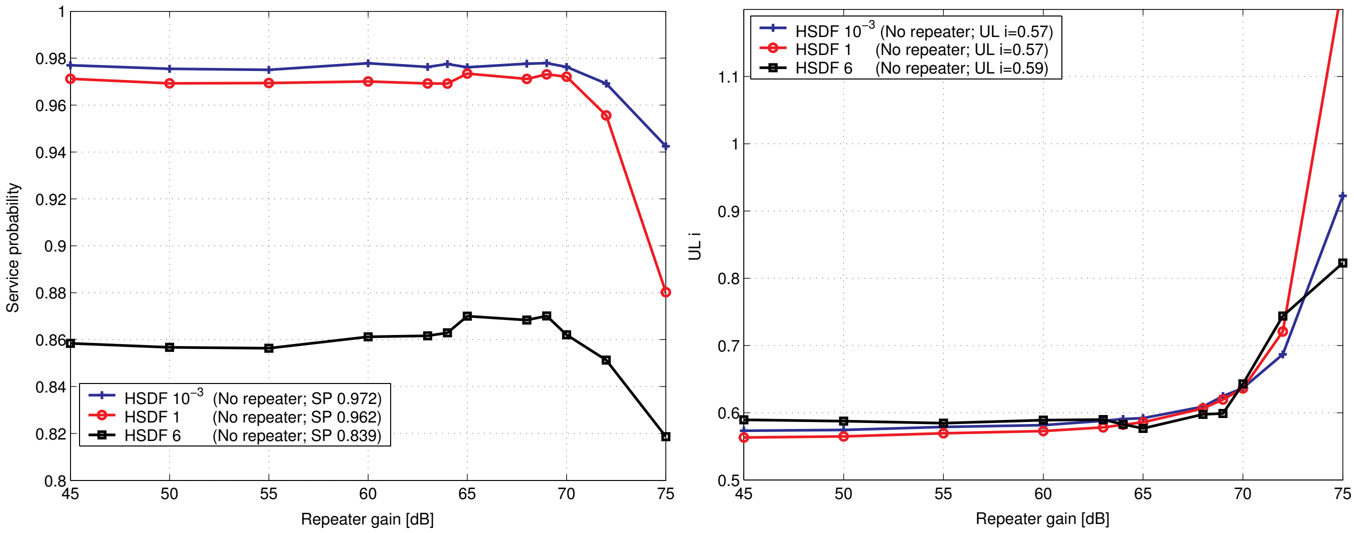
Parameter	**Value**
BS maximum power	43 dBm
CPICH	33 dBm
Other common channels	33 dBm
Maximum power per code	33 dBm
BS noise figure	3 dB
Vehicular A channel profile[a]	
MS speed	50 km/h
DL code orthogonality	0.5
Pedestian A channel probile[b]	
MS speed	50 km/h
DL code orthogonality	0.8
MS maximum transmit power	21 dBm
MS dynamic range	70 dB
SHO window (add)	3 dB
Maximum active set size	3
STD of slow fading	8 dB
Slow fading correction factor	
Inter-cell	0.5
Intra-cell	0.8
UL noise rise limit	6 dB
User service characteristics	
Speech service	12.2 kbps
Asymmetric data traffic (UL/DL)	64/384 kbps
Repeater	
Gain	Variable
Noise figure	3 dB
Repeater antennas [12]	
Donor antenna	
Gain	19.5 dBi
Horizontal/vertical beamwidth	33°
Serving antenna	
Gain	17 dBi
Horizontal/vertical beamwidth	65°
Path loss model (Okumura-Hata)	$128.9+35.7\log_{10}(d)$
Path loss from base station to repeater	100 dB

a. Default values for E_b/N_0 value, SHO gain, and other look-up table value adopted from [12].

b. For mobiles connected through repeater channel profile was changed to Pedestrian A.

B. *Simulation Parameters*

Simulations were made using 3-sectored sites with antennas of horizontally 65° and vertically 6° beamwidth providing 17 dBi gain. A regular hexagon network layout was adopted including 19 base stations and 6 repeaters (Fig. 3). Moreover, the site spacing was 1000 m and all antennas were placed at 25 m. In the simulations, the distance of the repeater from the mother cell antenna was 500 m (roughly 0.75 cell radius from the mother cell). The serving antennas of the repeaters were directed towards the intersections of three base station sites (areas without clear dominance). The utilized serving antennas of the repeaters were same as used in the base stations. The donor antennas of the repeaters were narrower (33°/6° horizontal/vertical beamwidth) in order to minimize additional interference towards other cells. The base station and repeater



(a)

(b)

Figure 4. (a) The average service probability (SP) and (b) average uplink other-to-own-cell interference (UL i) as a fucntion of repeater gain with different hot-spot density factors (HSDF) for 3000 speech users (12.2 kbps). Service probabilities without repeaters are provided in parentheses.

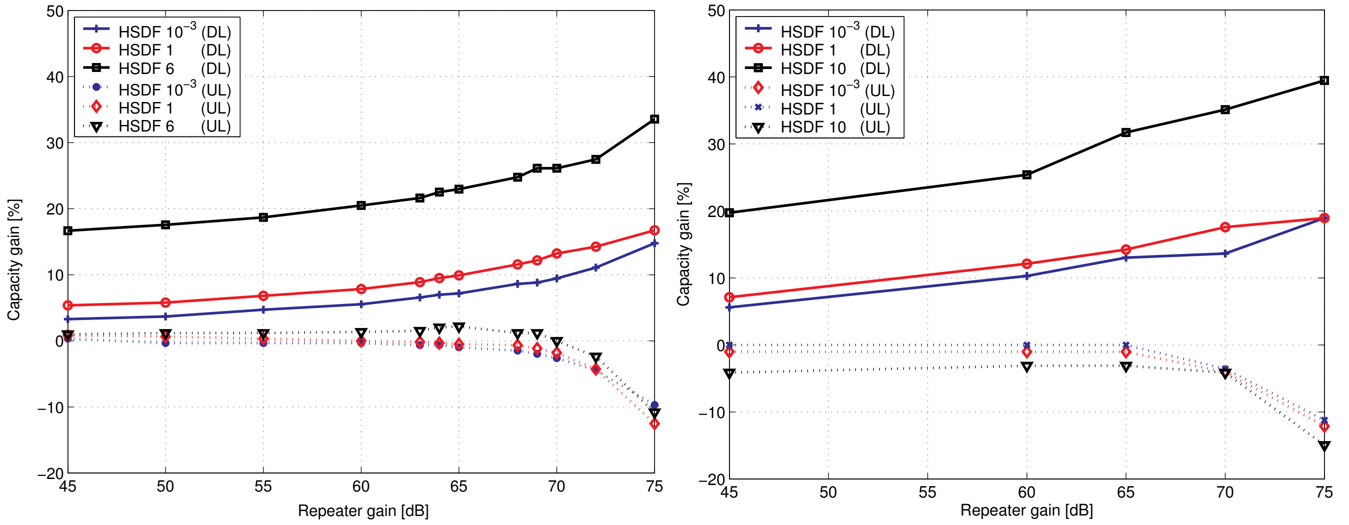
serving antennas were downtilted electrically 6°. Okumura-Hata path loss model was used as a propagation model. Table I shows the simulations parameters, which were mainly taken from [10]. For users communicating through a repeater, Pedestrian A channel model was used, whereas Vehicular A channel model was used for rest of the users. The change of the channel model was implemented because usually the distance from the serving antenna of the repeater to the user reception antenna is quite short, which results a smaller delay spread. This, on the other hand, is assumed to result in better downlink code orthogonality, but worse multipath diversity gain. The channel models were adopted directly from [10].

The traffic was homogenously and randomly distributed in the simulation area. However, for the hot-spot areas (circles in Fig. 3), traffic density was increased by multiplying the nominal traffic density with a constant (here denoted as hot-spot density factor, HSDF). Note that using HSDF=1 corresponds to homogenous traffic for the whole network. Within a hot-spot, the traffic was distributed homogenously.

IV. SIMULATION RESULTS

Fig. 4 (a) shows the service probability with different repeater gains for 3000 speech users. For HSDF=0.001, the service probability maintains at the level of 0.98 (also the same without repeaters) with moderate repeater gains. An optimum value for repeater gain from service probability is roughly 68 dB (even thought the differences are extremely small). However, after the gain reaches 70 dB, also the service probability starts to decrease. This actually happens with all values of HSDF. The cause for this sudden decrease can be explained with exponential increase of the uplink other-to-own-cell interference (UL i) after 70 dB gain as shown in Fig. 4 (b). The main contribution to the uplink other-cell interference increase is observed in adjacent cells of repeaters. However, up to 72 dB gain, the service probability remains better than without repeaters. The values of UL i for the repeater configurations act steadily at lower repeater gains, but illustrate an exponential behavior towards higher repeater gains. Hence, the results show how an optimal repeater gain setting can be observed with higher repeater gain. However, this particular gain is quite close to the 'crashing point'. Another observation for this particular configuration is that the level of UL i is the smallest without repeater. In the considered configuration, the repeater gain 69 dB corresponds roughly to 0 dB G_t. However, in [1], optimum G_t was observed to be 15 dB. The reason for different optimum G_t is assumed to be caused by different traffic distribution. Thus, it could be doubted that if traffic was totally concentrated under the base station, G_t should be actually negative.

The impact of repeaters and repeater gain settings on the uplink and downlink capacities is shown in Fig. 5. Fig. 5 (a) provides downlink and uplink capacity gains respect to scenario without repeater for different values of HSDF for speech users (12.2 kbps). The values used to capacity evaluation are based on statistical data of all base station sectors. Clearly, the downlink capacity gain increases as a function of increasing repeater gain. Intuitively, as more users are located within the hot-spots (for higher values of HSDF), also the downlink capacity gain is higher. However, uplink direction is characterized with capacity loss in most of the situations. Only with HSDF=6, some uplink capacity enhancements are observed. If uplink capacity is allowed to decrease by 5%, an optimum repeater gain is roughly 72 dB. With this repeater gain, the achievable capacity gains in the downlink vary from 12% to 30% depending on the traffic distribution within a repeater cell. Naturally, considering statistics only from the cell with repeaters, higher capacity



(a) (b)

Figure 5. Downlink and uplink capacity gains as a function of repeater gain and hot spot traffic density factor (HS DF). (a) Symmetric speech traffic (12.2 kbps). (b) Asymmetric data traffic (UL 64 kbps/DL 384 kbps).

gains could be observed. However, the target in here was in evaluating the performance on the network level.

The downlink capacity enhancements are observed through reduction of other-cell interference, which is caused by the reduction of the average downlink transmit power for the connections in a repeater cell. Obviously, the reduction of other-cell interference due to low mobile transmit powers from the hot-spot areas in the uplink, is not able to compensate the inherent noise contribution of repeaters. Thus, only with HSDF=6, a small uplink capacity enhancement could be observed. However, if majority of mobiles were communicating through repeater, slightly higher uplink capacity could possibly be observed.

Fig. 5 (b) provides the results from simulations with asymmetric data traffic (64/384 kbps). Very similar trend can be observed from the results, but with a bit higher capacity gains. With 5% allowed uplink capacity loss, corresponding optimum repeater gain is roughly 71 dB. Thus, the achievable downlink capacity gains would be around 15% to 35%.

V. DISCUSSION AND CONCLUSIONS

In this paper, the suitability of repeater deployment was assessed in uplink and downlink directions in capacity-limited environment through Monte Carlo simulations. The simulation results provided encouraging results regarding repeater deployment for macrocellular environment in WCDMA network. In general, repeater is able to increase the downlink capacity through reduction of other-cell interference as a result of reduction of downlink transmit power. However, the repeater performance is clearly limited by uplink direction, and normally repeater introduces uplink capacity loss. By allowing 5% uplink capacity reduction, observable downlink capacity gains were between 10% and 35% depending on the traffic distribution within a repeater cell. Optimum repeater loss (G_t) in the particular scenario varied between 0 and 5 dB, hence providing a guideline for practical WCDMA repeater deployment. However, one could consider using repeater only for downlink direction in order to avoid to uplink capacity losses. This would also allow repeaters to be used with higher gains, and to achieve even higher downlink capacity gains. Finally, future studies will consist of evaluating the capacity gains of repeater planning approach for indoor solutions introduced in Section II.

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