Sensitivity of optimum downtilt angle for geographical traffic load distribution in WCDMA

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***Abstract*— The target of this paper is to evaluate the impact of geographical traffic load distribution the optimum downtilt angle of macrocellular WCDMA network. Moreover, the aim is to solve the feasibility of the usage of fast rate RET and to evaluate its possible capacity gain with respect to distribution of traffic load. The simulation results have revealed how allowed range of downtilt angles varies between 6° and 14° depending on whether the traffic is concentrated closer to cell edge or closer to base station. However, with this particular network configuration, 8° downtilt angle would provide almost the maximum uplink and downlink capacities with all simulated traffic distributions (maximum 5% degradation in downlink capacity). This indicates that there is no use for fast-rate adaptation of tilt angle with respect to changes in the geographical user distribution due to its low capacity gain and possibly complex implementation algorithm. This does not totally exclude the use of RET as it facilitates network optimization regarding tilt angles. Also, fast rate RET algorithm can be used for load balancing in high loaded networks.**

Keywords*—antenna downtilt, RET, optimum downtilt angle, geographical traffic load distribution, WCDMA.

I. Introduction

The concept of antenna downtilt has been widely studied, and it is known to increase the system capacity in cellular WCDMA (wideband code division multiple access) networks [1]-[2]. Due to more efficient bearing of the antenna vertical radiation pattern, a reduction of inter-cell interference allows enhancements of capacity. Moreover, electrical downtilt (EDT) has been observed to provide slightly better results than mechanical downtilt in terms of system capacity improvements and mitigation of pilot pollution [3]. In addition, utilization of EDT antennas might become more attractive due to better capability to change the tilt angle remotely or automatically. This is actually the fundamental idea in remote-controlled electrical tilt (RET) concept, or, continuously adjustable electrical downtilt (CAEDT). In RET, tilt angle can be changed remotely from base station cabinet without any tower climb. In an *ultimate* situation, adjustment can be handled from network management system (NMS). The usage of RET facilitates significantly the effort required for antenna downtilt optimization. On the contrary, a simple and automatic algorithm could be deployed in order to further automate the optimization process, and use the RET, e.g., for load balancing in highly loaded networks. The need of a common interface for base station equipment to support RET has been also recognized within the 3GPP specification body, which is currently specifying RET concept for the Release 6 [4].

The latest research results have indicated the potential capacity gains that could be achieved by utilizing remote electrical downtilt. In [5], an optimum downtilt angle, which was evaluated based on minimization of uplink transmit power, was observed to change even with a homogenous traffic distribution according to number offered traffic load. In [6], the idea was extended to include the impact of inhomogeneous traffic distribution. Moreover, with simultaneous usage of RET and pilot power adjustment, capacity gain was achieved–mainly through traffic load balancing. In [7], a method for load balancing with tilt angle control was presented. The tilt angle optimization criterion was based on minimization of uplink (UL) load for a cluster of three cells. Achieved capacity gains were approximately 20-30% respect to constant, network-wide tilt angle as the traffic hot-spot locations were shifted.

In this paper, the impact of geographical traffic distribution on the optimum downtilt angle is studied using static Monte Carlo simulations in macrocellular UMTS (Universal Mobile Telecommunications System) FDD (Frequency Division Duplex) network. Hence, the target is to solve whether a fast rate RET concept is justified merely due to changing geographical traffic load distribution, or are the capacity gains observed only through load balancing. Summarizing the targets of the paper:

- to find out the changes in optimum downtilt angle with respect to variations of the geographical traffic load distribution,
- to provide throughput analysis in downlink and uplink directions, and
- to observe possible capacity gains of RET concept with respect to varying traffic distribution.

II. Remote-controlled Electrical Tilt (RET)

The fundamental idea in RET concept is the facilitation of the adjustment process of a base station antenna tilt angle. Using a sophisticated control mechanism (or system), tilt angles can be changed remotely even without any site visit. This already entitles the use of RET in any cellular system.

RET concept can be generally divided into slow and fast rate modes. The selection of the mode depends on the target of usage. With a *slow rate RET*, the adjustment process of tilt angles can be accelerated and facilitated during network evolution, e.g., to fasten the network optimization according to new dominance areas. With the aid of slow rate RET, also possible errors in initial downtilt angles can be more easily corrected. As such, slow rate RET is tailor-made for adjusting tilt angle cell-by-cell basis, e.g., to mitigate pilot pollution problem [8]. With deployment of slow rate RET, an operator could also implement an algorithm that updates tilt angles separately according to day time (morning, day, evening) if traffic distribution is known to significantly change. This kind of an algorithm could be based on a look-up table of statistical data of user locations.

Geographical traffic load distribution of a cell might change considerably between tilt adjustments of slow rate RET. For example, if most of the users were near the base station, possibly larger tilt angle would be required in order to still achieve maximum system capacity. For this purpose, an algorithm for *fast rate RET* could be implemented. This algorithm would be able to adjust tilt angles based on changes in short-term traffic load distribution. Naturally, the algorithm could not be based on any statistical data, but should rely on estimates of real-time parameter values. In a fast rate RET algorithm, the updating rate would be naturally higher. Moreover, the algorithm could be based on minimization of certain parameter (such as UL load [7] or downlink (DL) transmit (TX) power) by using some certain of cost function of coverage and capacity-related parameters. The most sophisticated method would be to use location information of the mobiles. This could be simply implemented using round trip time (RTT), which is a standardized physical layer measurement in WCDMA [9]. Consequently, tilt angles in this approach would be adjusted according to a pre-defined geometrical model. This provides an example of location-based radio resource management.

III. Simulations

A. Simulation Environment and Parameters

Monte Carlo simulations were used to evaluate the impact of different geographical traffic load distributions in a 19 base station hexagonal grid. This iterative simulation approach estimates the average performance of the network through service connection attempts. By performing numerous independent snapshots of the network performance, statistically reliable results should be achieved. A merit that evaluates the network performance is called *service probability*. It is defined as the ratio of successful connection attempts and total connection attempts. The description of the static WCDMA simulator used in for the analysis can be found from [10].

Network configuration was formed of 3-sectored sites with 65° horizontally and 6° vertically wide beamwidth. Antenna radiation pattern was adopted from [11] and is depicted in Fig. 1. The network topology (layout) consisted of 1.5 km site spacing and 25 m antenna height. The simulation environment was regular residential suburban environment. A digital map was used to model the exact environment with topographical and morphological information. In addition, an extended COST-231-Hata propagation model was utilized. The model

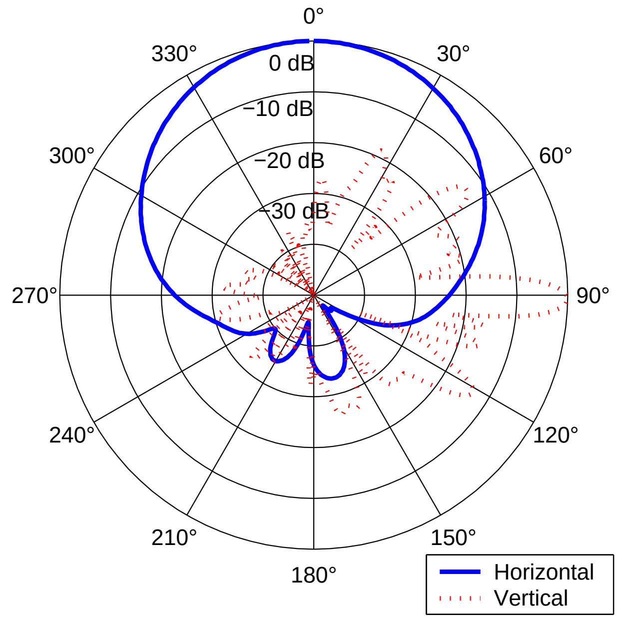


Fig 1. Horizontal (azimuth) and vertical (elevation) antenna radiation patterns. The corresponding half-power (-3 dB) beamwidths were 65° and 6° for horizontal and vertical directions

TABLE I
General simulation parameters.

Parameter		Value
BS TX P_{max}	[dBm]	43
Max. BS TX per connection	[dBm]	38
BS noise figure	[dB]	5
CPICH TX power	[dBm]	33
CCCH TX power	[dBm]	33
SHO window	[dB]	4
Standard deviation of shadow fading	[dB]	8
UL target noise rise limit	[dB]	6
Service bit rate UL / DL	[kbps]	64 / 64
E_b/N_0 target UL / DL	[dB]	4 / 6
DL code orthogonality		0.6
Maximum active set size		3

was tuned particularly for this environment based on measured data. Typical simulation parameters can be found from Table I.

The range of EDT angles for the antennas was from 0° to 18° with a resolution of 2°. In the simulations, all antennas are downtilted by the same amount. An optimum downtilt angle is hence an average of all monitored cells.

B. Geographical user distributions

Changes in the geographical user locations were modeled by having different allowed user locations in the simulation area. These areas were identical for each sector, and hence any differentiation to exploit load balancing was not utilized. Moreover, all parameters (including pilot powers) were identical for each sector. The following geographical user distributions were used:

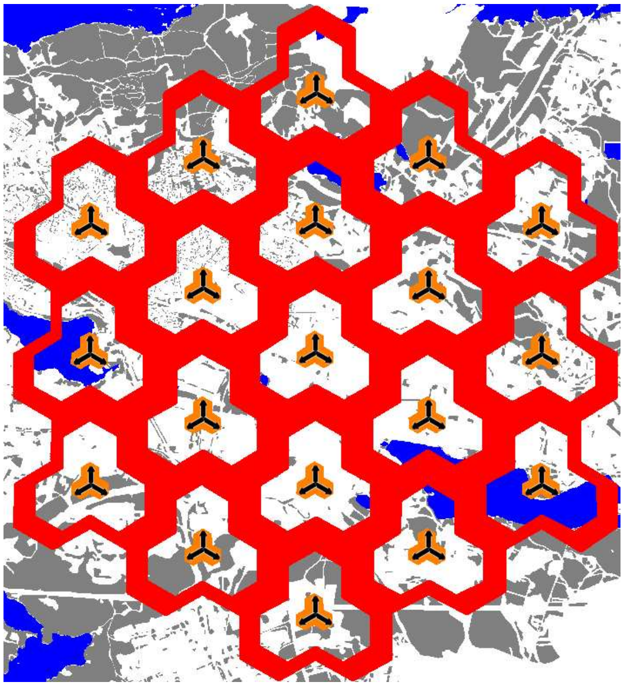


Fig 2. Illustration of the traffic distribution into smaller hexagons close to the base stations and of the traffic distribution at the edges of hexagons.

- Homogenous user distribution,
- Users only inside a small hexagon to close proximity of base stations, and
- Users only at the edges of the nominal hexagon.

Fig. 2 shows the network layout and the allowed user locations with each traffic distribution. With user distribution concentrating to close proximity of the base stations, users were homogenously located only in the small hexagonal areas (orange/light areas). The length of this small hexagon was $\frac{1}{4}r$, where *r* stands for the nominal hexagonal cell range. Note that for a 3-sectored hexagonal grid, *r* is $\frac{2}{3}$ of the site-to-site distance. Hence, the farthest possible mobile-to-base station -distance in this scenario was 250 m. Finally, in the user distribution concentrating at the cell edges, users were located homogenously within red/dark areas (Fig. 2). The area consisted of distances between $\frac{3}{4}r$ and the hexagonal cell edge (*r*), i.e., in the area between the distances of 750 m and 1000 m.

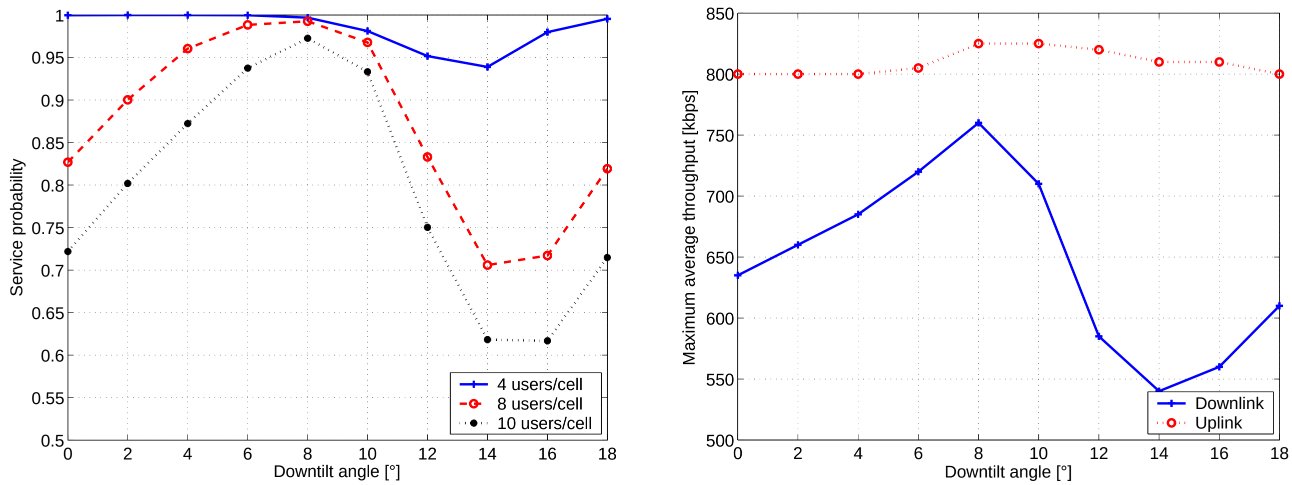
IV. Simulation results

Figs. 3-5 show the attained average service probabilities for simulated downtilt angles for different traffic distributions and for different traffic loads, and the maximum average capacities. The statistics for the analysis have been gathered only from the center site and first tier of base station sites. In Fig. 3(a), average service probability is illustrated for purely homogenous user distribution for different user traffic loads (either 4, 8, or 10 users per cell). With the smallest traffic load, the service probability is maximum in the range of downtilt angles from 0° to 6°. After this range, service probability decreases slightly due to coverage constraints resulting from excessive downtilt angle. The poorest coverage is observed with 14° downtilt angle. After this, the upper side lobe in the antenna vertical radiation pattern (see Fig. 1) is actually able to increase again the coverage for the mobiles at the cell edges resulting in an increase of service probability. With medium and high traffic loads, higher level of other-cell interference causes a degradation in service probability without any downtilt. By using downtilt, other-cell interference can be mitigated efficiently, and also the service probability improved. However, coverage constraints are still present for excessive downtilt angles. With the highest traffic load, downtilt angle of 8° seems to provide the best service probability in the network. Lower downtilt angles suffer from higher level of other-cell interference, and correspondingly, higher downtilt angles introduce coverage constraints.

Fig. 3(b) provides the estimated maximum average sector capacities for downlink and uplink directions. The downlink capacity is based on average 39 dBm transmit power for traffic channels (TCH) of all monitored base station sectors. Correspondingly, the uplink capacity is based on 3 dB average noise rise. In the downlink, the maximum capacity is achieved with 8° downtilt angle with approximately 20% capacity gain against 0° downtilt. However, the improvement in uplink capacity is only around 5%. Hence, the enhancements observed from downtilt are more related to downlink performance. In the uplink, the highest capacity is achieved with 8° and 10° downtilt angles. Note that this capacity analysis does not take into account possible coverage constraints as accurately as service probability analysis.

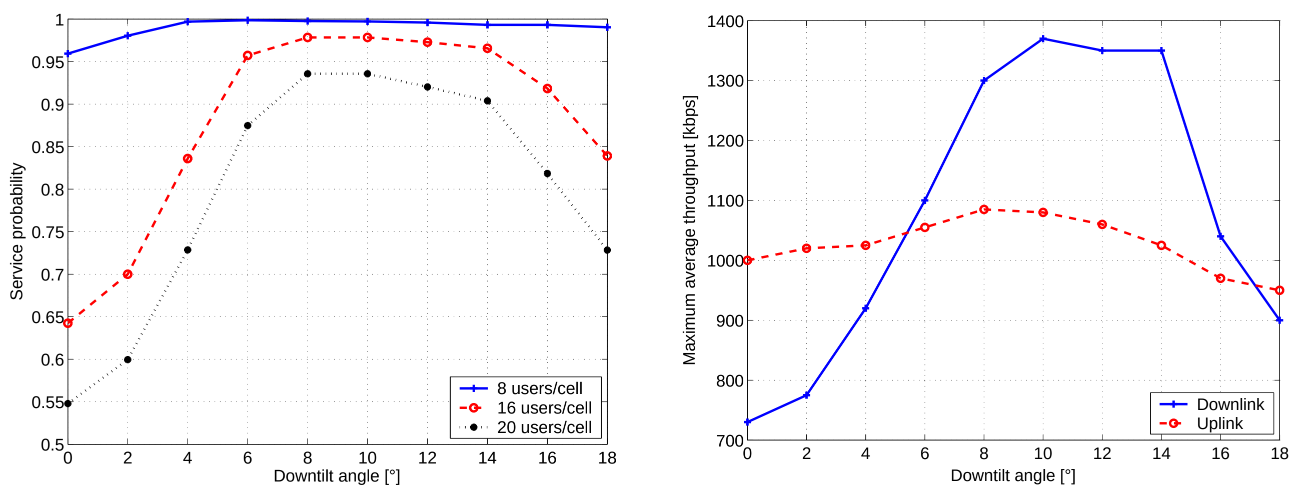
Fig. 4(a) and Fig. 4(b) depict the service probabilities and capacities from the users distribution concentrating closer to base station. With the lowest traffic load, only the lowest downtilt angles suffer from degradation of service probabilities. Thus, the acceptable range of downtilt angle reaches the highest simulated downtilt angle as well (Fig. 4(a)). However, with the medium traffic load, the acceptable range of downtilt angles reduces to 6°-14°. Moreover, with the highest traffic load, downtilt angles of 8° and 10° provide obviously the highest service probabilities. Hence, it seems that only the allowed range of downtilt angles increases as the users are located closer to base station, not the optimum downtilt angle. The capacity analysis in Fig. 4(b) reveals that 10° downtilt angle provides the highest capacity in the downlink with roughly 5% gain respect to 8° downtilt angle. Moreover, the capacity gain against 0° downtilt angle is close to 90%. However, in the uplink, the deviation of capacity is again lower than in downlink direction. Here, 4 dB threshold for noise rise was used for uplink capacity analysis.

Finally, Fig. 5(a) and Fig. 5(b) provide the outcomes from the simulations with user distribution concentrating on the edges of the hexagons. Compared to the service probabilities with homogenous traffic distribution, it can be observed that the coverage constraints are only slightly higher as a function of downtilt angle. Part of this phenomenon is also caused due to higher load, and hence higher cell breathing. Users



(a) (b)

Fig 3. Simulation results from homogenous traffic distribution. (a) Service probability with different offered traffic loads, and (b) maximum average capacities in downlink and uplink directions. Uplink noise rise threshold for capacity analysis was 3 dB.



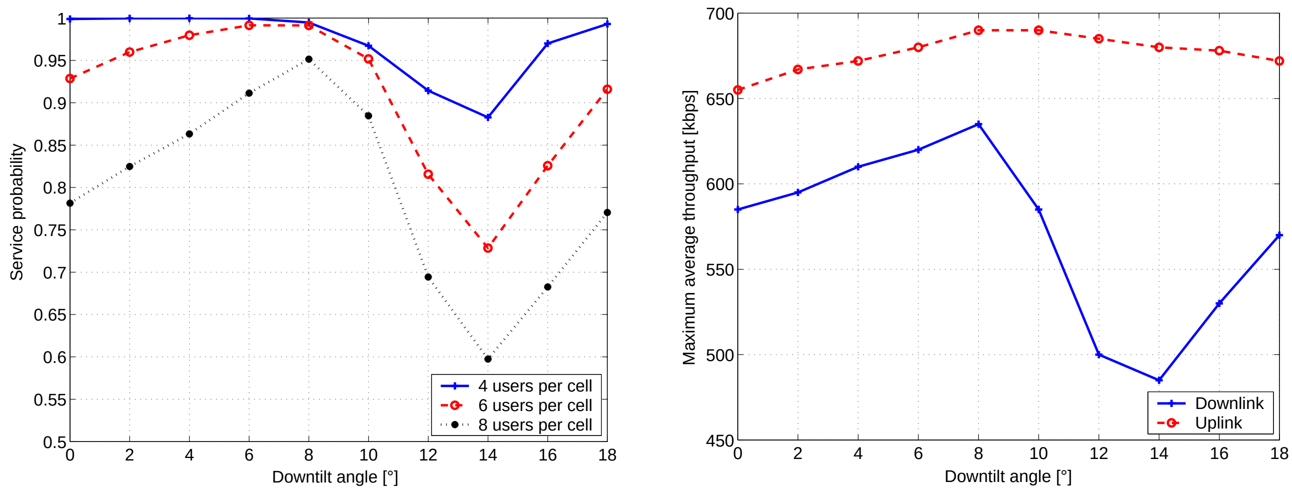
(a) (b)

Fig 4. Simulation results from distribution close to base stations. (a) Service probability with different offered traffic loads, and (b) maximum average capacities in downlink and uplink directions. Uplink noise rise threshold for capacity analysis was 4 dB.

at the cell edges rather than homogenously with in a cell will automatically require larger share of the resources, which leads to higher average load with the same traffic load request, and finally to higher cell breathing. However, in the end, the shapes of the service probability curves are almost identical between homogenous traffic distribution and in the distribution at issue. In addition, the curves of downlink and uplink maximum average capacities remind each other with only a slight offset in the absolute capacity values. Here, 2.5 dB noise rise threshold was used for uplink capacity analysis.

V. Discussion and Conclusions

The impact of geometrical traffic load distribution of the optimum downtilt angle has been evaluated in typical macro-cellular WCDMA network for residential suburban environment. The simulation results reveal that the range of allowed downtilt angle in the corresponding network topology (1.5 km site spacing and 25 m antenna height) changes from 6° to 14°, if optimum downtilt angle is defined from service probability. However, monitoring the situation from the uplink or downlink capacity point of view, the optimum downtilt angle is always between 8° and 10° downtilt angles. Moreover, the optimum downtilt angle seems to be almost totally independent of the traffic load distribution. Basically, the only thing that changes is the attainable capacity gain respect to 0° downtilt configuration. With the simulated traffic load distributions, attainable downlink capacity gains vary between 10% and 90%. The corresponding values in the uplink capacity are 5% and 9%. In addition, using 8° dowtilt angle for all simulated traffic distributions would result in maximum 1%



(a) (b)

Fig 5. Simulation results from distribution close to base stations. (a) Service probability with different offered traffic loads, and (b) maximum average capacities in downlink and uplink directions. Uplink noise rise threshold for capacity analysis was 2.5 dB.

degradation in service probability (due to coverage constraints) and approximately 5% degradation in downlink capacity in the worst scenario. With these findings, it can be concluded that geometrical traffic load distribution does not affect the required downtilt angle. Hence, this makes fast rate RET algorithm not forth deploying for adjusting tilt angle merely based on changes in the traffic distribution within a cell. Hence, all the possible capacity gain is expected to be achieved through load balancing, which requires simultaneous adjustment of tilt angle for a cluster of cells (as in [7]).

It has to be noted that this does not exclude the usage of RET, but proposes to use it only for slow rate adjustment to facilitate changing of tilt angles during network evolution and optimization process, or to load balancing. From radio network planing point of view, it is strongly recommended to use RET, since the downtilt angles are heavily sector configuration and environment specific. Moreover, by using RET, the final adjustment of tilt angles can be performed cell-by-cell basis in order to maximize system capacity and functionality from network topology point of view.

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