User Guided Energy and Capacity Optimization in UMTS Mobile Networks

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Abstract—**The power levels of cellular network User Equipment (UE) may vary considerably in both the receiver and the transmitter side, especially in indoor locations. With an indirect guidance method, the users are self-optimizing their UE to a better location with the help of an application. Thus, the user distribution is weighted more on high quality connection areas, which results in saving the UE batteries and reducing the overall radiation. This power reduction can also be understood as a capacity increase, especially in radio networks based on Code Division Multiple Access (CDMA), such as the Universal Mobile Telecommunications System (UMTS) technology.**

The aim of this paper is to show the possibility and the opportunity to save energy or to increase the capacity in cellular networks when the users are indirectly guided to optimize their UE locations. In this study, energy and capacity optimization is verified for residential indoor users in the measurements where the users are served by signals coming from several outdoor Base Stations (BSs) in a typical urban environment. The results obtained show that a path loss (PL) improvement of up to 10–25 dB can be achieved when the user locations are optimized and the signals are coming from the outdoor BSs.

Keywords—Indoor, user location, energy, optimization

I. INTRODUCTION

Currently, mobile network users expect a ubiquitous and very high quality service. However, since the users are frequently located indoors, one of the most difficult challenges is to offer good coverage and signal quality to these locations. Therefore, implementation of outdoor BSs and separate indoor systems (indoor BSs) is required in order to cover indoor areas. In both approaches, the typical target is to guarantee a predefined minimum signal power level for a user with a good signal quality and data throughput. The distribution of dense outdoor BSs or, in particular, indoor antenna distribution in indoor systems is required to achieve this minimum power requirement at the majority of the indoor locations. As a result, several very high-power signal level locations can also be achieved indoors.

Mobile networks are very densely deployed in urban areas, and BS sites still include several technologies from Global System for Mobile Communications (GSM) to UMTS and Long Term Evolution (LTE) due to the speech and data throughput requirements. This automatically yields to high-energy consumption due to the low efficiency of the transmitters (especially in CDMA) and to the needs of air conditioning requirements. Hence, high radio frequency radiation results naturally in the substantial amount of transmitters.

Despite this very dense multi-technology deployment, the distribution of the received power levels may still vary, especially in indoor locations within a small area of few meters depending on the BS and UE locations [1]. This is typical for a time and space variant indoor propagation channel, especially when the UE is served by one BS, and when the environment is active. The received power level deviations are neither measured nor reported in residential apartments nor even in the offices when the indoor coverage is served by several outdoor BSs in an urban area, and when the power levels of interest are clearly better than the coverage threshold.

Typically, radio network planning guidance targets to offer minimally acceptable received power levels everywhere, resulting in higher received power level than needed in several indoor locations [2]. Similar aspects can be noted when UEs are located in vehicles. Moreover, these high-quality planning guidelines are controversial, because it is expected that the UE locations are homogenously distributed and the users are not trying to – or do not need to – optimize their terminal location.

If it is assumed that the behavior of mobile users could be influenced in indoor or in-vehicle locations, the received power level could be significantly improved by moving the terminals just a little. These movements could be guided by some behavior rules, or by new approaches like Mobile Performance Gaming (MPG), which would continuously guide the user to locate his or hers terminal optimally and send statistics e.g. to an operator. The target of the guidance is not to limit the mobility, but instead to avoid bad locations, and guide users to better connections whenever easily possible.

In case of optimal or even partially optimally located indoor terminals, the required energy consumption, as well as the amount of radiated power, could decrease dramatically. Moreover, the changed user distribution would have impacts on channel modeling and to other research areas.

A practical measurement campaign is carried out in a typical residential apartment environment to show the impact of user behavior on the received power levels and the reductions in the required energy consumption. Measurements are carried out in an urban area in a commercial 3GPP networks including several serving BSs. A key target of the measurements is to show the deviation of the measured signal power levels above the minimum acceptable power level, that is values better than a certain threshold. This shows the opportunity to improve the mobile connection with small-scale terminal movements.

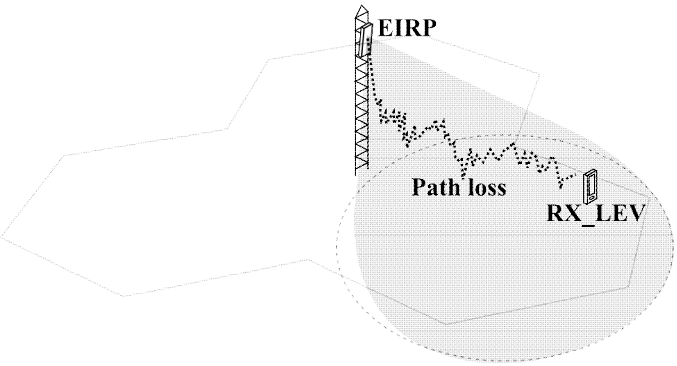

Fig. 1. Coverage of macro BS site: a PL between the BS and MS antennas.

II. THEORY

Mobile networks are deployed based on the Cellular Concept approach where recently 3-sectored macro BS sites are mostly built [3] at a certain distance by giving coverage over a certain geographical area as shown in Fig.1.

A. Transmission Power at BS

A BS antenna at each sector (Fig. 1) transmits effective isotropic radiated power (EIRP) to a radio propagation channel, and a mobile station (MS) antenna receives a power level RX_LEV at a reception location. When the EIRP and the RX_LEV are known, the PL between the BS and MS antennas can be theoretically calculated, or practically measured, for example, by using a constant transmission power such as the Pilot Signal (Common Pilot Channel, CPICH) in downlink direction in the UMTS system [4].

PL between BS and MS antennas (downlink) in UMTS indicates directly the required average transmission power $P_{\mathrm{TX}}^{\mathrm{DL}}$ to get a connection, that also includes interference, as defined in [5]:

$$P_{\mathrm{TX}}^{\mathrm{DL}} = \frac{N_{\mathrm{rf}} \cdot W \cdot \overline{L} \cdot \sum_{k=1}^{K} v_k \cdot \frac{\rho_k}{W / R_k}}{1 - \eta_{\mathrm{DL}}}, \tag{1}$$

where N_{rf} is the noise spectral density of the mobile receiver front end in watts per hertz or watt-seconds. Value for N_{rf} can be calculated as the sum of the thermal noise density N_0 in watt-seconds, and the dimensionless mobile receiver noise figure *NF*. The system chip rate W is in chips per second, $\overline{L}$ is the average dimensionless PL of the mobiles in a cell, and K is the number of all active mobiles in a cell. The dimensionless service activity of the kth user is v_k, ρ_k is the dimensionless E_b/N_0 requirement of the kth user, and R_k is the bitrate of the kth user in bits per second. The dimensionless downlink load factor is denoted by η_{DL}.

Especially in UMTS, the PL and thus also the required power per connection should be optimized because it has a direct link to the network capacity as indicated in the downlink load equation

$$\eta_{\mathrm{DL}} = \sum_{k=1}^{K} \frac{\rho_k \cdot R_k \cdot v_k}{W} \cdot \left((1 - \alpha_k) + i_{\mathrm{DL}} \right), \tag{2}$$

where α_k is the dimensionless orthogonality of the kth user, and i_{DL} is the average dimensionless other-to-own cell interference.

B. Radio Propagation in Outdoor and Indoor Locations

The variation in the received power level RX_LEV means directly variation in the required transmission level equivalent to the EIRP.

The received power level in indoor locations is time and space dependent [1] meaning that the received power level is changing when the receiver moves, or when the environment changes as people are moving, or closing and opening doors near the receiver. These deviations in the received power levels are caused by Rayleigh fading (fast fading), but also by slow fading (the average of fast fading is varying) because of the indoor walls. This special effect of the time and space variant indoor environment has to be taken into account when measurement results are analyzed.

When outdoor BSs are used to cover indoor locations, the propagation between a BS and MS antennas can be predicted by using, for example, a well-known Okumura-Hata (COST-Hata-Model) equation [6].

$$\begin{aligned} L = {} & A + B \cdot \log_{10}(f_{\mathrm{MHz}}) - 13.82 \cdot \log_{10}(h_{\mathrm{BS}}) - a(h_{\mathrm{MS}}) \\ & + (C - 6.55 \cdot \log_{10}(h_{\mathrm{BS}})) \cdot \log_{10}(d_{\mathrm{km}}) + C_{\mathrm{m}}, \end{aligned} \tag{3}$$

where L is the PL in dB,
A, B and C are varying constants,
f_{MHz} is the used frequency in MHz,
h_{BS} is the BS effective antenna height in m,
h_{MS} is the MS antenna height in m,
$a(h_{\mathrm{MS}})$ is a city size dependent function,
d_{km} is the distance between BS and MS in km, and C_{m} is an area correction factor.

In (3), it has to be remembered that the equation needs to be tuned for every environment separately to get accurate results. The area correction factor, C_{m}, has to be set regarding the propagation environment. Correspondingly, the propagation slope, defined as $(C - 6.55 \cdot \log_{10}(h_{\mathrm{BS}}))$, has to be adjusted regarding the BS antenna height.

The Okumura-Hata equation gives predictions of the received power level at outdoor locations, and thus indoor penetration loss of 10–30 dB has to be added depending on the building materials and types [7] to have prediction results in indoor locations. Moreover, the coverage planning of outdoor BSs is typically based on Okumura-Hata type of predictions, which means that BS coverage needs to overlap enough with neighbor BSs to have a continuous coverage and service in indoor locations (Fig. 2).

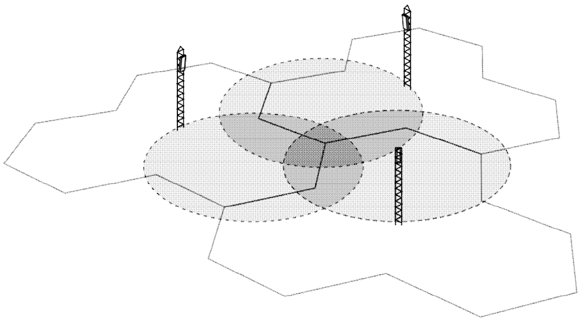

Fig. 2. Coverage overlapping of multiple BSs.

C. Multiple Coverage in Cellular Mobile Networks

In mobile cellular networks, the received power level may vary also because the signal power is coming from several BS sites, or cells as indicated in Fig. 2. Depending on the exact terminal location, one carrier may be superior compared to the others. One carrier is offering better received power at one location, and other carrier in the next location because of the slow fading, and because of the different materials like glass windows or concrete through a propagation path between the BS and MS antennas.

In coverage overlapping areas of multiple serving BSs, the typical radio planning target of location or service probability of 90–99% should be well achieved. Moreover, if the coverage planning criteria is expecting to get 90–99% connection probability from one BS, and simultaneously several BSs are covering the same location as typically in a densely deployed urban areas, the received power level may have much higher values [3].

III. MEASUREMENT CAMPAIGN

A. Measurement Environment

A practical measurement campaign was carried out at one main location in a normal urban residential apartment in downtown Helsinki, Finland. Thus, indoor locations of typical residential users were measured in a high density BS coverage and capacity area. The measurement location as well as the measurement timing was selected randomly. Two different carriers (Network 1, Network 2) were measured.

All measurements represent results in configuration where signals propagate to indoor locations from the implemented outdoor BSs. Network 1 and Network 2 have different network configurations.

Normal commercial non-calibrated mobile terminal was used in all measurements, and thus absolute values are not highlighted but relative received power levels are the most interesting ones. The data was collected with a help of an application that utilizes MPG, which sends the measured data to a server, where it can be accessed.

B. Measurement Scenarios

Four different measurement Scenarios were repeated for Network 1, and only Scenario 1 for Network 2 (Fig. 3 represents the blueprints of the measurement apartment and the measurement areas):

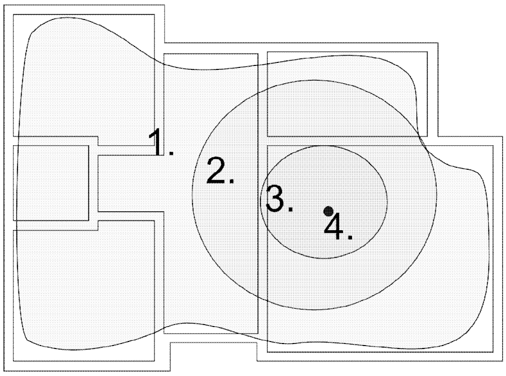

Fig. 3. Measurement Scenarios 1–4 in the apartment.

1. Mobile terminal on different tables around common areas in the apartment.
2. Mobile terminal at a certain small area of 3–6 m maximum difference in location. This subarea was selected based on the measurement Scenario 1.
3. Mobile terminal at a very small area of 1–2 m maximum difference in location (different parts of a table); this measurement is carried in the subarea of measurement Scenario 2.
4. Mobile terminal is constantly at one location on the table inside the area of measurement Scenario 3.

All measurements were carried such that the mobile terminal is on a table approximately 50–120 cm from the floor, and in all measurements the mobile is not having a body contact but measurement person is able to walk or stay in the surroundings of the mobile i.e. sitting, standing, or walking approximately 3–5 meters around the mobile. The measurement Scenario 4 is especially showing variations of the received power level due to these environmental changes.

All measurements were carried in the apartment on the first floor from the street level.

Measurements are carried in two commercial 3GPP networks (Network 1, Network 2) i.e. the mobile terminal is measuring received power level from all technologies: GSM, UMTS, and LTE. Measurements are done in IDLE mode i.e. the mobile terminal is not connected to the network, and thus measurement happens in the downlink direction where a BS transmits and the mobile terminal receives the signal power. In GSM, the Broadcast Control Channel (BCCH) is measured because it has a constant transmission power in downlink direction as well as the Common Pilot Channel (CPICH) has in UMTS technology. In LTE, a reference signal was measured to have a similar effect of the constant transmission power.

Typically, in 3GPP technologies, 32 neighbor BSs (or cells) can be measured, but only six bests are reported by a mobile terminal [8].

In IDLE mode, mobile terminal measures continuously, and reported samples are averages over certain seconds. Averages were recorded every 10 s meaning 6 averaged samples per minute, and 60 averaged samples in 10 minutes.

In IDLE mode in 3GPP, a mobile terminal is selecting the technology based on radio parameters. One technology can have priority given by parameter settings. This means that mobile terminal is staying in the priority technology as long as the coverage ends, or the coverage is very bad even if other technology offers better power level.

In measurements, it was noted that UMTS technology was highlighted i.e. mobile terminal tried to stay in UMTS network as long as possible due to much better data communication compared to GSM technology. At the same time, LTE coverage was still limited, and thus results of LTE technology are not significant. Thus, the highest priority and reliability of measurements and results is in UMTS technology.

IV. MEASUREMENT RESULTS AND ENERGY SAVING

In a typical radio network planning, location or service probability of 90% is calculated for a certain coverage threshold. Fig. 4 shows a cumulative curve of the received power samples in Scenario 1 (Network 1). Fig. 4 shows that 90% coverage threshold corresponds to the received power level of –125 dBm. This coverage level does not correspond to a reasonable speech quality in UMTS technology and approximately corresponds to a maximum throughput level of 0.3–1 Mbit/s when Dual Carrier technology is implemented in HSPA, and when only one user is served by one BS.

Fig. 5 shows the obtained results of the measurement Scenario 1. In Fig. 5 it can be seen that the received power levels vary 25–30 dB for both networks in different parts of the apartment even if 3–7 BS cells are offering indoor coverage at different locations inside of the apartment. It has to be highlighted, that every sample in the results represents the best received power level at each terminal location inside the apartment. Moreover, the terminal had enough time at each measurement point to change to the best serving BS cell. The mean values (μ) of the received power levels for the Networks 1 and 2 were μ_1 = –108.5 dBm and μ_2 = –114 dBm with standard deviations (σ) of σ_1 = 8.46 dB and σ_2 = 6.39 dB, respectively.

A specific small area of Network 1 was selected (Scenario 2) because the received power level was changing rapidly in this certain area. Fig. 6 shows 15 dB variation in the received power level even if the terminal was moved only 3–6 meters between the measurement points. The mean signal level was μ_3 = –104 dBm with standard deviation of σ_3 = 5.54 dB. Moreover, in Fig. 7, the obtained results show power variations when the mobile terminal has different locations at one 2 m x 1.5 m size house table (Scenario 3).

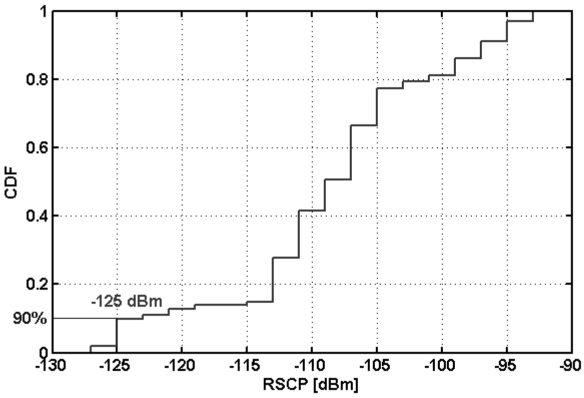

Fig. 4. Scenario 1, Network 1: the coverage threshold for 90% location probability.

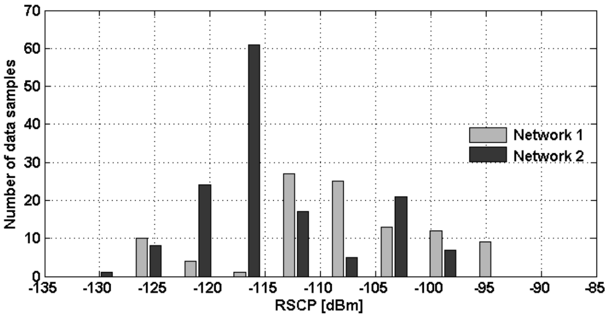

Fig. 5. Scenario 1: the received power levels of two different networks.

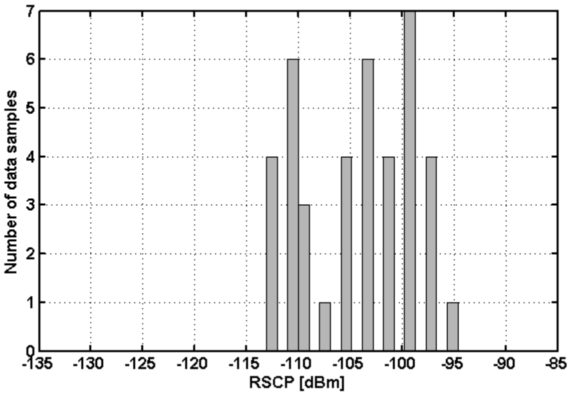

Fig. 6. Scenario 2 (Network 1): the smaller measurement area inside the measurement area in Scenario 1.

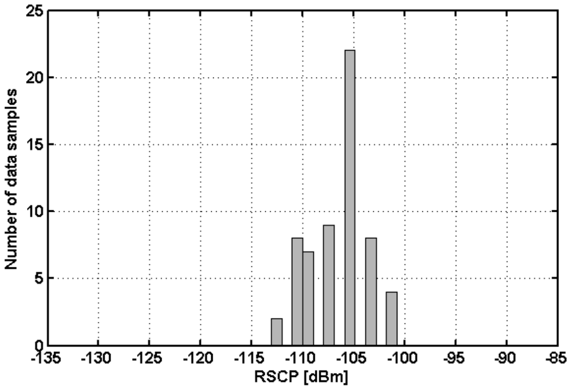

Fig. 7. Scenario 3 (Network 1): the very small measurement area inside the measurement area in Scenario 2.

Despite of only small movements, power level variations of around 10 dB can still be noted, while having μ_4 = –106 dBm and σ_4 = 3 dB.

Finally, the results of measurement Scenario 4 in Fig. 8 show the received power level variations of environmental changes that happen when the mobile terminal is at one constant measurement location (one measurement point of Scenario 3). It can be noted that the received power level vary 6–10 dB when the measurement engineer is in the surroundings of the terminal. This corresponds to a case where the user is at home and reasonably close to the mobile. The mean power level and the corresponding variance of the stationary mobile is μ_5 = –111 dBm and σ_5 = 3 dB.

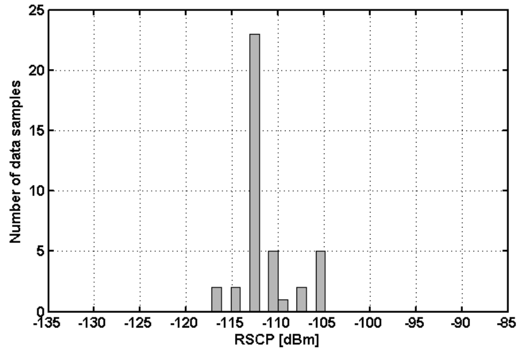

Fig. 8. Scenario 4 (Network 1): only one measurement point inside of the measurement area in Scenario 3.

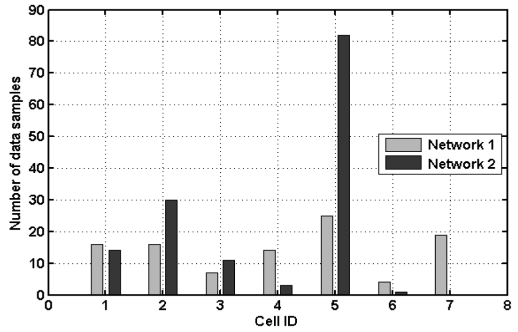

Fig. 9. Amount of samples from different BSs in Scenario 1.

The results presented in Fig. 5–8 include measurement samples from 3–7 BSs from Network 1 and Network 2, because the apartment is covered by several BSs as typically happens in an urban area where BSs are implemented densely to have enough capacity and indoor coverage. Fig. 9 shows the deviation of the samples between different BSs in Scenario 1.

As a conclusion of Fig. 5–8, it can be noted that the received power level may be improved easily 10 dB and even up to 20–25 dB in downlink direction when the mobile terminal location is optimized in small-scale movements in a residential apartment. These improvement levels already exclude variation of environment that was 6–10 dB. Moreover, improvement of 10–25 dB at the reception can be used to reduce the transmission power levels to keep constant quality, and simultaneously to increase capacity, to reduce radiation, and to reduce battery consumption of mobile terminals. Finally, similar energy savings happen also in the uplink channel, because propagation channel is reciprocal, and thus the reception level can be improved also at the BS receiving end.

Improvement of the reception power level means also improvement of PL, and capacity increase can be estimated by using equation (2).

An example calculation using equation (2) with 33 speech users (R_v = 12.2 kbit/s and E_b/N_0 = 6.0 dB), and typical values $v_k = 0.5$, $\alpha_k = 0.7$ and $i = 0.5$ results in load η_{DL} = 16.7%. Using this load value in (1) with receiver noise figure of 7 dB and average PL of 150 dB (Scenario 1: RX_LEV = –117dBm, CPICH_TX_Power = 33 dBm), the required transmission power is 42.90 dBm (= app. 20W).

When 20 dB PL improvement is considered (RX_LEV = –97 dBm) in (1), the amount of speech users can be increased up to 150 users (354% increase) still using only power of 34.86 dBm (< 4W) but causing load η_{DL} = 75.9%.

V. CONCLUSIONS AND DISCUSSION

In this paper, it was first introduced the possibility to guide users to optimize their terminal locations based on the connection quality. Moreover, this optimization directly reduces radio energy consumption at the BSs and MSs, and thus reduces costs, increases capacity, saves mobile batteries, and reduces unnecessary radiation. The user behavior at residential indoor locations was highlighted, and the practical measurement campaign in UMTS network was done to show the impact of energy reduction in indoor locations.

The obtained results show that the reception level of each location optimized mobile terminal can be increased 10–25 dB when short-term environmental changes of 6–10 dB due to moving persons in apartments are excluded. These kinds of reception improvements can cause high capacity increase in mobile networks, thus yielding to excessive capacity optimization and cost savings in the infrastructure. The results can also show a way to new possibilities in radio link budget by presenting a new variable called *UE location optimization gain* to account for possible improvements coming from optimized UE locations.

Similar results about PL improvements can be found also in other technologies, like in GSM and LTE. In addition, it can be noted that PL improvements might help significantly in disaster scenarios where only part of the BSs are operating, for example, due to lack of electricity.

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