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EVALUATION OF SOFT HANDOVER MICRO DIVERSITY GAIN ON THE UMTS SYSTEM CAPACITY AND QoS

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ABSTRACT

In this paper the impact of the soft handover micro diversity gain on the UMTS system performance is investigated. First, by means of link layer simulations the micro diversity gain is measured in terms of reduction of the average E_b/N_0 requirement. After modelling this effect, by some system level simulations we show the high influence of this usually neglected gain in the overall performance of UMTS, demonstrating that in downlink soft handover improves not only the quality of service but also the overall system capacity.

I. INTRODUCTION

Nowadays the initial rolling-out stages of WCDMA-UMTS systems have been completed in most parts of Europe. As a consequence the research interest is shifting from the development of specifications to the design and evaluation of network configuration strategies and algorithms that help operators to maximise capacity and service quality.

Soft Handover (SHO) is a key technique used in WCDMA mobile networks in order to improve the perceived Quality of Service (QoS). During the SHO process, mobile terminals near cell boundaries communicate with more than one Base Station (BS) simultaneously. The primary purpose of soft handover is to provide seamless handover and added robustness to the system. This robustness improvement is achieved thanks to three types of gain provided by the soft handover mechanism [1]: the macro diversity gain, the micro diversity gain and the downlink load sharing.

Despite these three gain factors are generally accepted their modelling in system simulations has not been completely considered since it has been assumed that the effect of the micro diversity gain is insignificant. So far, and due to this partial underestimation, some erroneous conclusions have been extracted in several works (e.g. [2]-[4]) with respect to the influence of SHO in the system QoS, most of all when the forward link is under consideration. This way it is stated that in downlink the use of SHO technique reduces the system capacity.

This paper describes the factors that constitute the SHO gain, focusing mainly on the current implementations of these effects that are used in system level simulation tools. Next, a model who takes into account the micro diversity gain – which is usually neglected or not properly considered – is proposed. Finally some results are obtained in the worst case (i.e. high multipath diversity environment and high speed) evincing the underestimation in the system capacity and QoS that the omission of the micro diversity effect provokes.

II. THE SOFT HANDOVER GAIN

A. *Macro Diversity Gain*

First of all, SHO gives a gain against slow fading or shadowing that either natural or man-made big structures provoke in the signal strength. This gain appears because the slow fading is partly uncorrelated between the base stations, and by making a handover the mobile can select a better base station.

To take under consideration this SHO effect in the system performance it is fundamental to model the cross-correlation of signals coming from different base stations [8]. Some studies (e.g., [5]) have actually corroborated that such cross-correlation is present in real systems. This is due to the fact that the random component of the loss consists of the sum of two components: one resulting from obstacles in the vicinity of the receiving unit and a second one from the specific surroundings of each base station. As a result, the fading phenomena that affect different signals received by a user from surrounding base stations might experience some correlation. Some studies such as [5] claim that the shadowing cross-correlation depends on the geometrical angle between the different links considered. Other studies based on experimental analysis as [6] claim that this correlation also depends on the relative distance between base stations. However such claims have been sometimes questioned and a fixed cross-correlation factor value of 0.5 for any couple of base stations is generally included in simulations studies [7].

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B. *Micro Diversity Gain*

Soft Handover gives an additional macro diversity gain against fast fading by reducing the required E_b/N_0 relative to a single radio link, because the fast fading is uncorrelated from the two transmit antennas [1], [9]. The gain is larger when there is less multipath diversity. This diversity gain is usually referred to as *micro diversity gain* in order to avoid confusions with the previous gain.

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The mobile can coherently combine the signals from the different BSs that are included in the active set since it sees them as just additional multipath components. Normally Maximum Ratio Combining (MRC) strategy is used, which provides the additional macro diversity benefit.

Indeed, if perfect channel estimation is assumed, the Rake receiver behaves as an L-order MRC diversity combiner, being L the number of arms in the Rake. Only the propagation paths that are at least one chip interval apart from each other are resolvable. If the number of resolvable propagation paths is lower or equal than L, a pure MRC combining procedure applies and there is a closed expression for the physical bit error probability [10]:

$$P_b = \frac{1}{2}\sum_{k=1}^{L}\pi_k\left[1-\sqrt{\frac{\gamma_k}{1+\gamma_k}}\right] \tag{1}$$

where P_b is the mean BER (Bit Error Rate), γ_k is the mean E_b/N_0 ratio in the *kth* diversity path and

$$\pi_k = \prod_{\substack{i=1\\ i\neq k}}^{L}\frac{\gamma_k}{\gamma_k-\gamma_i} \tag{2}$$

When MRC is applied in the mobile terminal, the received E_b/N_0 is equal to the sum of the E_b/N_0 perceived from all the BSs in the active set. However, in the literature, this equivalent E_b/N_0 is used as the input to figure out the user QoS in terms of BER o FER (Frame Error Rate). This generalised simplification (e.g. [2]-[4]) is not in consonance with (1) and therefore do not take into account the micro diversity gain.

C. Downlink load sharing

A User Equipment (UE) in soft handover receives power from multiple BSs, which implies that the maximum transmit power to a UE in x-way soft handover is multiplied by factor x. This fact allows the system to provide better service to these users placed near the boundaries of the cells increasing the coverage.

In system level simulators this gain is inherent to the MRC concept. After considering the sum of x partial E_b/N_0 as the resulting E_b/N_0, the power consumption and consequently the interference power rise is shared among the BSs active in the SHO process. In the best-case scenario, when the E_b/N_0 perceived by the UE from each BS is the same, the power consumption of the global system to give service to the UE will not change in comparison with the non-SHO case, whereas the total load is proportionally distributed among every active cell. On the contrary, if the E_b/N_0 is not the same – being this the most general common instance – then the resulting system load will be higher than in the case where no SHO is considered. At least cell load will continue being distributed.

As a conclusion, to support soft handover in the downlink, more resources are required. So, in the downlink direction, the performance of the soft handover depends on the trade-off between the macro diversity and micro diversity gain and the extra resource consumption.

III. LINK LEVEL ANALYSIS

Both macro diversity gain and downlink load sharing are usually included and evaluated in system level simulations whereas the micro diversity gain characterisation must be carried out by means of a link level analysis and has not been completely considered yet at system level. As in [9], but in this case considering downlink, this section intends to demonstrate the impact of SHO micro diversity gain in the relation BER-E_b/N_0. It is worth noting that bit energy is defined as the useful signal power at the receiving antenna over the network bit rate, as specified in the Radio Access Bearer (RAB) table [11].

With this aim, a C++ program has been developed to simulate the UTRA air interface. The slot format of the physical channel (in this paper DPDCH) has been generated including all the standardized fields. The services have been implemented according to the correspondent RAB as specified in [11]. All the important parameters of the service, like the Transport Format (TF), Transmission Time Interval (TTI), type of logical channel, type of channel coding, size of the TB, etc. have been applied as specified in the service's RAB table. In this paper the 12.2 kbps speech service and the conversational RAB at 64 kbps characteristic of the video call service are employed to assess the effect of the micro diversity of the SHO in downlink. Not only the physical layer but also the MAC and RLC layers have been implemented, forming the different subflows of the network traffic and processing data as described in the specifications [12].

The rate matching has been taking into account by only performing bit stuffing since puncturing is not implemented. The interleaving period corresponds to the TTI defined in the RAB table.

A multipath channel has been considered. The number of components, the relative delay and average power of each multipath component and the Doppler frequency defines completely the propagation channel. On the other hand, the Rake receiver has a time resolution of one chip period. It has been implemented with the fingers dynamically updated to track the points of maximum energy in the impulse response and a perfect knowledge of each multipath delay component has been assumed. The number of fingers of the Rake receiver assumed is 6.

A closed loop fast power control mechanism is used to minimize the interference levels present in the receiver and maximize the capacity. The power control procedure updates once per slot (i.e., 1500 times per second), the transmitted power in order to meet the target quality for the service even if the channel conditions vary. In contrast with others referenced simulators [13], this algorithm is implemented according to the 3GPP specifications. Shadowing fading is not included because the closed loop power control is able to compensate for it.

Pilot symbols are implemented in the Control Channel following the slot format recommended by the 3GPP. Channel estimation is achieved through matched filters that integrate the signal only during the period in which the pilot bits are being received. Thus, a new set of estimated channel samples is available every time slot. Based on the original channel estimates, a multi-slot averaging of the samples is realised.

Two base stations have been included in the simulation model. The average required received E_b/N_0 ensuring a specific quality – in terms of BER – has been measured as a function of the level difference between the two base stations.

A. Link Level Results

Once described the link level simulator, a vehicular A scenario [14] at 50 km/h has been selected.

Figures 1 and 2 show the effect of SHO micro diversity as a function of the power level difference ΔP between the two base stations for both the speech and video call services respectively.

Initially the system features at link level have been obtained in the absence of diversity. The values obtained shown in the figures are in agreement with others previous results [13].

Considering a BER target of 10^{-3} and 10^{-4} for speech and video call respectively, Table I resumes the gain (in dB) obtained in the E_b/N_0 target due to the SHO micro diversity. Notice that the gains are relevant for the vehicular scenario considered. If a less multipath diversity scenario (e.g. a pedestrian environment) had been taken into consideration this gain would have been even larger.

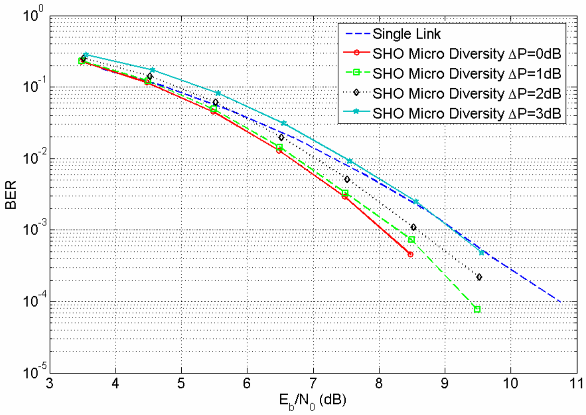

Figure 1. BER vs E_b/N_0 for Speech at 12.2 kbps

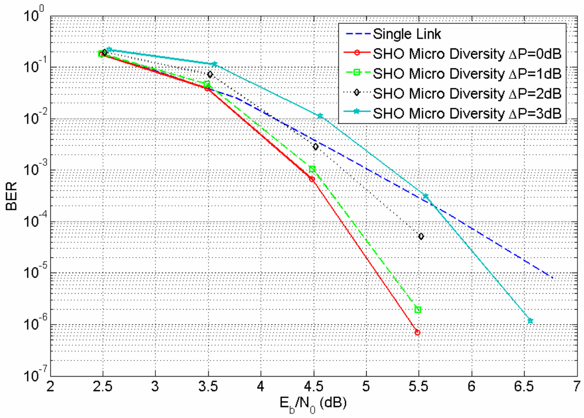

Figure 2. BER vs E_b/N_0 for Conversational at 64 kbps

Table 1. SHO gain in the E_b/N_0 target

	E_b/N_0 (dB)	Gain (dB)
Speech		
Single Link	9.14	0
ΔP=0	8.05	1.09
ΔP=1	8.28	0.86
ΔP=2	8.57	0.57
ΔP=3	9.11	0.03
Video Call		
Single Link	5.89	0
ΔP=0	4.76	1.13
ΔP=1	4.86	1.03
ΔP=2	5.35	0.54
ΔP=3	5.76	0.13

These results complement the work carried out in uplink in [9] and represent only an example for two realistic services in WCDMA-UMTS.

IV. LINK TO SYSTEM MODEL

If the UE presents only an active communication link the link-to-system model is the classic one, i.e. one look-up tables relates the perceived E_b/N_0 with BER. In this case there is only one table for each service considered.

When two cells constitute the active set then first of all it is fundamental to obtain a characterisation of the micro diversity as shown in section III. Therefore, in order to calculate the mean BER, it is necessary to determine the equivalent E_b/N_0 (i.e. the addition of the two partial E_b/N_0 perceived from each link) and ΔP as follows:

$$\Delta P = \left| 10\log_{10}\left(\frac{E_b/N_0|_1}{E_b/N_0|_2} \right) \right|, \quad \Delta P \in \left[0, AS_{Th}\right] \qquad (3)$$

where AS_{Th} is the SHO add threshold. The variable ΔP must be quantified (for instance in this paper a 1 dB step has been assumed) and for each ΔP value one specific look-up table has to be calculated by means of the link-level simulator. This set of look-up tables will be employed in the system level simulator that firstly will determine ΔP and will select the correspondent look-up table, and subsequently will use the equivalent E_b/N_0 as the table input.

V. SYSTEM LEVEL ANALYSIS

A. Simulation Tool Description

The objective of the simulations is to assess the performance of UTRAN analysing the effect of the SHO micro diversity gain. Dynamic simulations are required since they are able to model movement, call set-up and release, service demand variations and quality changes in received signal. Specifically, simulations consist in a specific area where a certain traffic distribution is assumed. Service demanding mobiles are generated according to such distribution and they move throughout the whole zone; if they surpass limits, then wrap-around is applied. As mobile units wander within the described scenario, they receive data packets, perform power control, undergo handover and may be dropped if quality falls beyond a limit.

The first step in the system design lies in selecting a concrete scenario. COST273-MORANS [15] initiative is a very useful action in this sense since it allows, by only collecting the proper elements of the different layers, to define multiple types of scenarios in a simple and exact way. These scenarios are valid for any sort of simulation not only synthetic but also realistic. In this paper, the macrocellular synthetic scenario has been selected. Table 2 summarises the most relevant parameters.

Table 2. Synthetic scenario parameters

Parameter	Value
Target Eb/No for Speech Vehicular Users	9.14 dB
Target Eb/No for VC Vehicular Users	5.89 dB
Speech Session Spreading Factor	128
VC Session Spreading Factor	32
Speech Bit Rate	12.2 kbps
VC Bit Rate	64 kbps
Average Speech Session Duration	120 s
Average Speech Activity Period Duration	5 s
Speech Load	35 Erl/Cell
Average VC Session Duration	120 s
VC Load	10 Erl/Cell
Carrier Frequency	2.170 GHz
Noise Spectral Density	-174 dBm/Hz
Receiver Noise Density	7 dB
Shadowing Decorrelation Distance	20 m
Shadowing Standard Deviation	8 dB
Shadowing Site-to-Site Cross-Correlation	0.5
Orthogonality Factor	0.5
Isotropic Gain	0 dBi
BS Transmitter Noise Figure	3 dB
Maximum BS Power	43 dBm
CPICH Power	33 dBm
Other Common Channels Power	0 dBm
Maximum Power per Session	30 dBm

Next, the main aspects of the applied RRM algorithms are concreted. Since Power Control and Soft Handover algorithms have been standardised by the 3GPP, their descriptions are not reported here. Table 3 summarizes the principal parameters considered in the performed simulations.

Table 3. RRM parameters

Parameter	Value
Power Control Step	1 dB
Maximum Active Set Size	2
SHO Add Threshold AS_{Th}	Variable dB
SHO Time to Trigger	0 s
Call Admission Threshold	75 %
Load Control Time to Trigger	5 s

1) Admission Control

Admission control is based on setting a limit on the base station load in terms of transmitted power. Each time a new service demand occurs, the base station performs an open loop power control and obtains an estimation for the demanded power increase $L_{increase}$ in the system. The incoming session is admitted if

$$L_{measured} + L_{increase} \le L_{threshold} \tag{4}$$

where $L_{measured}$ is the actual power transmitted in downlink, and $L_{threshold}$ is the product of the chosen Call Admission Control Threshold (in terms of downlink load factor) and the maximum BS power and in this case results in 15 W.

2) Load Control

Concerning load control, it is implemented for each call independently. If the measured quality for a call is below the target BER for a certain period (5s), then that call is dismissed.

B. System Level Results

In this section, system performance with different soft handover margins AS_{Th} is analysed. Results in terms of mean number of active users per cell are depicted in Fig. 3 and Fig. 4 for the speech and video call services respectively. These graphs compare the effect of modelling or not the micro diversity gain. Without modelling it, the maximum number of users is obtained for null handover margin, which corresponds with the conclusions attained in [2]-[4]. However, if the micro diversity gain is modelled, the optimum is shifted to higher values of AS_{Th} (around 1 and 2 dB), hence evidencing the important effect of SHO in the system performance. Moreover the expected number of users per cell increases up to 6%.

The maximum shown in Figures 3 and 4 does not indicate an optimum, since system performance must also be studied from other points of view, such as dropping probability or outage probability. Figure 5 depicts the dropping probability evolution as the handover margin grows. The reduction in system capacity is compensated by an important increase in the QoS, i.e. the dropping probability and outage probability are reduced when the SHO active set threshold is increased. Finally it is worth noting that this increment in the QoS is clearest if SHO micro diversity gain is taken into account.

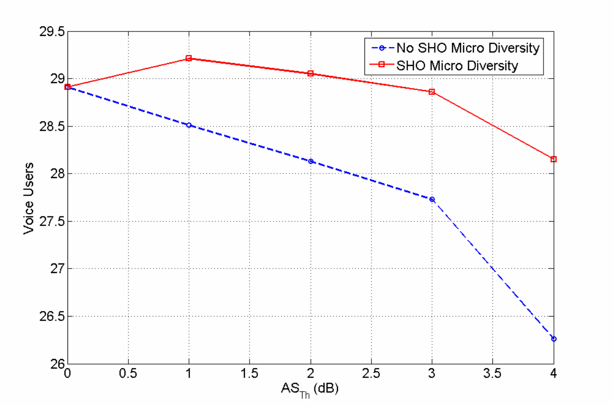

Figure 3. Mean number of Speech users per cell

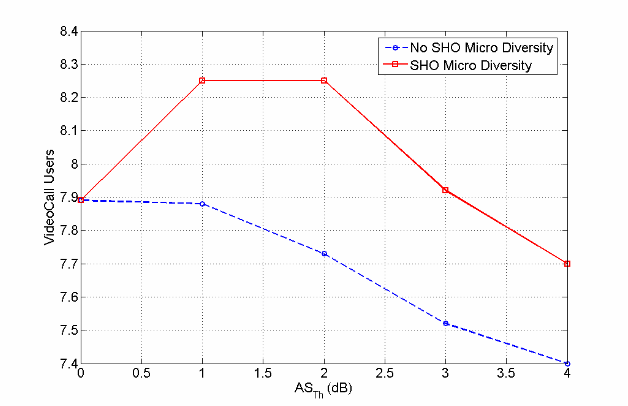

Figure 4. Mean number of Video Call users per cell

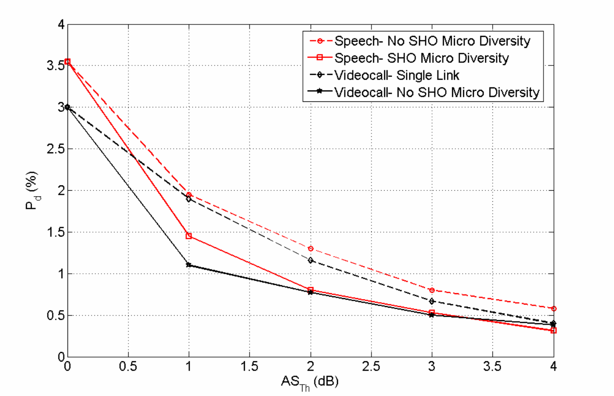

Figure 5. Dropping probability

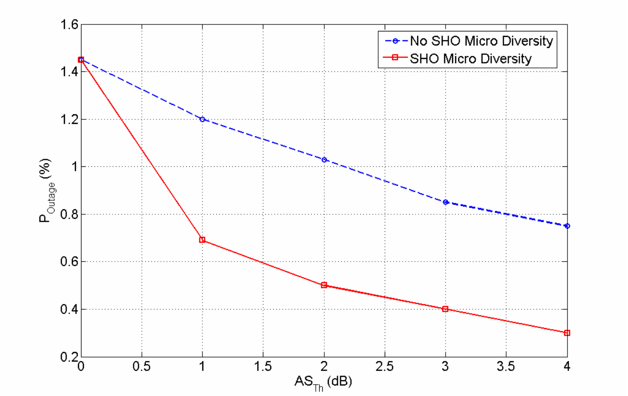

Figure 6. Outage probability

VI. CONCLUSIONS

Three types of gain provided by the SHO mechanism have been discussed in detail. In general, thanks to the downlink load sharing and macro diversity gain, as the soft handover area increase, the system is able to provide better service (lower dropping and outage probability) to the users placed near the boundaries of the cells, hence reducing the dropping and outage probability at the expense of a lessening in the overall system capacity. By means of link level simulations it has been shown that the SHO micro diversity gain is an important factor to be taken into account even in high diversity environments. Some results have demonstrated that including the micro diversity gain into system level simulations not only quantifies more accurately the QoS performance of the system, but also can be used to maximize the system capacity by optimizing the active set add threshold.

ACKNOWLEDGMENT

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