PERFORMANCE EVALUATION OF POWER CONTROL ALGORITHMS IN CELLULAR UTRA SYSTEMS

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ABSTRACT

The CDMA based UMTS transmission technology in which all users simultaneously share the same common range of spectrum gets rather affected by system interference. The reduction of interference is therefore a key issue in the development of optimal radio transmission in order to increase system capacity. Power control is a well-known technology to improve system performance. Different methods and their application within UMTS are presented. In this paper, level-based and interference-based control algorithms are introduced. An analytical approach for the capacity estimation is presented. The power control performance is compared by means of simulations and the optimal parameters for the algorithms are derived from the results.

1 INTRODUCTION

The UMTS standard will play a key role in creating a mass market for high quality wireless multimedia communications. It is the preferred mobile delivery platform for tomorrow's content-rich services and applications expected to approach 2 billion users by the year 2010. By providing increased capacity, data capability, and a far greater range of services using an innovative radio access scheme and an enhanced core network, it seeks to build on and extend the capability of today's mobile, cordless and satellite technologies. UMTS is suited to a variety of users and new and improved service types [1,2].

The *UMTS Terrestrial Radio Access* (UTRA) will support flexible operation with high spectral efficiency and service quality. Two different modes of operation will be adapted in UTRA networks – the *Frequency Division Duplex* (FDD) mode in paired frequency bands and the *Time Division Duplex* (TDD) mode in the remaining unpaired spectrum [1,3]. Due to the *Code Division Multiple Access* (CDMA) scheme in which all users share the same frequency band at a time, *Multiple Access Interference (MAI)* is the main capacity restriction to UMTS. The reduction of interference is therefore the key issue for the development of optimal radio technologies [4].

In this regard it is worthwhile to examine the abilities and properties of *Power Control* (PC), because it has been proven that this method has great potential to increase system capacity and *Quality of Service* (QoS). Firstly, it upgrades the *Carrier to Interference Ratio* (CIR) and with that the user's *Bit Error Ratio* (BER), that means more traffic can be handled. Secondly, a reduction of the mean transmission power can be achieved, which leads to lengthened period of battery-lifetime at the *User Equipment* (UE). Moreover, within the interference limited CDMA system, PC algorithms can reduce overall MAI and with that allow to carry more traffic in the available shared spectrum.

Whereas in [5] PC schemes have been compared for data connections in fixed wireless access networks, we focus here on interference limited CDMA UTRA networks. Simulation results of a level-based PC scheme for the use in UTRA-TDD are presented. Furthermore, a CIR equalling method for UTRA-FDD is introduced. The proposed algorithms are compared to the UMTS standardized CIR-based PC mechanisms [6,7]. The remainder is organized as follows. An analytical approach to estimate the impact of interference in CDMA networks is given in Sec. 2. In Sec. 3 the different PC schemes are described. The simulation scenario and results are presented in Sec. 4, whereas Sec. 5 concludes the paper.

2 INTERFERENCE IN CDMA

Based on the proposals made in [3] it is possible to do relatively precise calculations on behalf of the interference levels which can be estimated when one of the above mentioned power control algorithms is employed. This section will show that the two methods presented here show totally different behaviour in terms of the overall interference that is generated. To keep the calculations as simple as possible, only the *Uplink* (UL) direction is regarded.

The relation between CIR (expressed by C/I) and E/N_0 is the following

$$\frac{E}{N_0} = \frac{SF}{\log_2 M} \cdot \frac{C}{I} = G_p \cdot \frac{C}{I} \ , \tag{1}$$

where E denotes the energy of a bit at the demodulator/decorrelator output and before the channel decoder. The factor $G_p = SF/\log_2 M$ is called *Processing Gain* in the following. If we call C_j the received signal power of an arbitrary UE number j, the above becomes

$$\left(\frac{E}{N_0}\right)_j = G_p \cdot \frac{C_j}{I_{total} - C_j} \ , \tag{2}$$

where I_{total} is the total received power at the BS, including thermal noise power N. Solving for C_j by using Eq. 1 gives

$$C_j = \frac{I_{total}}{1 + G_p / \left(\frac{E}{N_0}\right)_j} = \frac{I_{total}}{1 + 1/\left(\frac{C}{I}\right)_j} \ . \tag{3}$$

Define $C_j = L_j \cdot I_{total}$ and obtain the *Load Factor* of one connection (i.e. the contribution of the UL connection j to the total amount of interference)

$$L_j = \frac{1}{1 + 1/\left(\frac{C}{I}\right)_j} \ . \tag{4}$$

When each terminal j contributes the fraction L_j to the total interference while the remaining part is represented by the thermal noise, the overall interference excluding the noise can be written as the sum of the received powers from all n users in the same cell by

$$I_{total} - N = \sum_{j=1}^{n} C_j = \sum_{j=1}^{n} L_j \cdot I_{total} \ . \tag{5}$$

Using Eq. 5 and solving for I_{total} yields

$$\frac{I_{total}}{N} = \frac{1}{1 - \sum_{j=1}^{n} L_j} = \frac{1}{1 - \eta_{UL}} \ . \tag{6}$$

This ratio of the total received power to the noise power is defined as the *Noise Raise* and the value η_{UL} is called the *Load Factor*.

So far only intra-cell interference is included in the calculations. But since a cellular radio network will most likely consist of several cells, the problem of interference originated in neighbouring cells has to be faced. To take this into account we define a ratio i of inter-cell to intra-cell interference. Using this, the UL load factor can be written as

$$\eta_{UL} = (1 + i) \sum_{j=1}^{n} L_j \ . \tag{7}$$

With Eq. 6 it is possible to precisely predict the overall amount of UL interference in a certain cell when the CIR values of every user and the fraction i of inter-cell to intra-cell interference are known. This is useful when the different power control strategies are compared.

3 POWER CONTROL SCHEMES

In this section, different ways of controlling the transmission power are introduced. Firstly, a simple level-based PC scheme is introduced. The standardised CIR based method and a CIR equalling method are presented and analysed in the following.

It is to be differed between outer and inner loop PC mechanisms. The inner loop controls the transmission power on the physical channels in a static manner. An additional outer loop may adjust parameters for the inner loop like target values for the reception level or the CIR. Control targets adjusted by the network are parameters for the outer loop PC, whereas the inner loop performs the physical implementation.

Level-Based PC

Using level-based PC, the transmission power will be adjusted by taking into account the deviations in the reception signal from a pre-determined value. It is assumed that the compensation corrections made at the transmission are unaffected by other factors and directly take effect at the receiver side. To keep the mechanism simple, the actual path loss value is neglected. An adjustment is made in UL and *Downlink* (DL) according to the same target level.

The transmission power P_{new} is adopted by

$$P_{new} = P_{old} + \left(P_{target} - P_{received}\right) , \tag{8}$$

where P_{target} holds the required target level for the reception power. This method requires signalling of the reception power level from the opposite side instead of an explicit control command.

Such PC scheme has been evaluated in [8] for a macro-cellular UTRA environment.

UMTS CIR-Based PC

In the CIR-based PC method transmission power is adjusted according to a required target CIR at the receiver side. The inner loop control mechanism can be expressed by

$$P_{new} = P_{old} \begin{cases} +\Delta_{PC} & \text{if } \left(\frac{C}{I}\right)_{est} < \left(\frac{C}{I}\right)_{target} \\ -\Delta_{PC} & \text{if } \left(\frac{C}{I}\right)_{est} \geq \left(\frac{C}{I}\right)_{target} \end{cases} , \tag{9}$$

where Δ_{PC} is a constant power step width of 1, 2 or 3 dB signalled by the opposite station via a *Transmit Power Control* (TPC) command. This mechanism requires a value as the target CIR for every user which is set by the outer loop dependent on the service type, physical channel settings, and the current environment.

Assuming that all n users in one cell use the same service and therefore have the same target C/I_{target}, Eq. 4 and Eq. 6 yield

$$\frac{I_{total}}{N} = \frac{1}{1 - (1+i) \cdot n \cdot \frac{1}{1 + 1/\left(\frac{C}{I}\right)_j}} \ . \tag{10}$$

This strategy reaches a pole capacity (the noise raise reaches infinity) when the denominator of the above fraction becomes zero. The pole capacity only depends on i and the target C/I_{target} and can be written as

$$n_{pole} = \frac{1 + 1/\left(\frac{C}{I}\right)_{target}}{1 + i} \ . \tag{11}$$

With an optimal target $C/I_{target} = -18.75$ dB to guarantee a user BER of less than 10^{-3} for 8 kbps speech connections with spread factor 128 and ⅓ rate channel coding, and $i = 0.3$ (this value is empirical and was calculated by means of simulations; a value of $i = 0.55$ is proposed in [3]) a pole capacity of 58 UE simultaneously operating can be estimated. Due to *Discontinuous Transmission* (DTX) with voice activity factor of 50 % the analytical pole capacity for 8 kbps speech will be twice as much.

CIR Equalling Outer Loop PC

A PC scheme is developed which aims to provide all users n in each cell with the same C/I_{target} independent from their position. It is adopted by

$$\left(\tfrac{C}{I}\right)_{target} = \frac{A}{n-1} \ . \tag{12}$$

with $A<1/(1+i)$ as an empirical *Attenuation Factor* to allow operation in the presence of additional inter-cell interference and limit the noise raise for high traffic. This mechanism for the UTRA-FDD mode always sets a target CIR which can be achieved by every UE. Due to this fact, the target decreases with an increasing number of terminals. This leads to a nearly constant interference level for any number of UE because with a decreasing CIR of every single station j, the load factor L_j also decreases. Hence, the cell can support any number of users at the same interference level up to the point where the target is so low that the required QoS cannot be guaranteed any more.

The noise raise function for this PC method is

$$\frac{I_{total}}{N} = \frac{1}{1-(1+i)\cdot n\cdot\frac{1}{1+\frac{n-1}{A}}} \ . \tag{13}$$

The advantage of a constant interference level of course has to be paid by a slight loss in capacity. Worst case environments with $i = 0.55$ would require an attenuation factor $A = 0.64$ for stable operation. A required CIR of −18.75 dB sets already in with approximately 49 UE per cell, compared to up to 58 with the CIR based PC.

4 SIMULATIONS

Scenario Description

The simulations of the level-based PC are carried out using TDD mode in a Manhattan grid urban micro-cellular environment containing 60 *Base Stations* (BS) similar to the proposal in [9]. The inner six BS are evaluated, the outer ones yield a realistic traffic and interference floor.

TABLE 1 - Simulation parameters for TDD and FDD

Parameter	TDD	FDD
Scenario	Manhattan	Hexagonal
No. of BS	60	19
Cell radius [m]	460	1000
UL Frequency [MHz]	1900-1905	1920-1925
DL Frequency [MHz]	1900-1905	2010-2015
Noise N [dBm]	−102	−102
Path loss modell	Berg [9]	Hata [10]
Timeslots (DL/UL)	8/7	15/15
Modulation	QPSK (M=4)	
Service (Activity)	Speech 8 kbps (50 %)	
Spreading Factor	16	128
PC target C/I [dB]	−8…−12	−16…−22
PC target P [dBm]	−60…−100	-

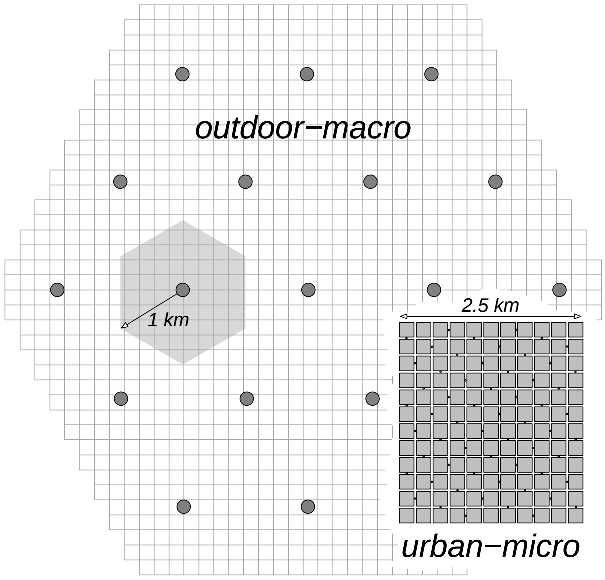

FIGURE 1 - Macro-cellular and Manhattan like urban simulation environment

In FDD mode a hexagonal cell scenario containing 19 BS as a macro-cellular outdoor environment is applied. Evaluation is limited to the centred cluster of seven BS. CIR equalling PC is simulated herewith. For further parameters see Tab. 1.

Results

Simulation results for the level-based PC illustrate its functionality, e.g. the reduction in reception power according to the target level. Fig. 2 presents the complementary distribution function of the UL reception level and CIR at the BS side. Depending on the desired target the distribution of the carrier levels appear as step-functions. From the CIR distributions a considerable raise for low values between –10..–5 dB is seen if PC is applied which means an improvement for the worse links. CIR is reduced otherwise but without effect for the link quality, e.g. BER of the connection. In Fig. 3 the according results for the DL transmission are presented. As the BS transmitter's dynamic range is limited to 30 dB to allow joint detection at the mobile receivers, PC is restricted to a smaller interval in DL. Hence, interference is far less reduced for that link direction. Level-based PC increases the link quality although the mean CIR is reduced with the target level as illustrated in the left hand plot of Fig. 4. Furthermore, the improvement in the *Satisfied User Criterion* (SUC) [9] has been simulated to estimate the system's optimal target level. Call failure in case of BER above 10^{-3} for more than 5 s call duration or unsatisfied users experiencing a BER above 10^{-3} for 5 % of the call duration are considered. Derived from the right hand plot in Fig. 4 the optimal target level is about –90 dBm.

Performance evaluation of the CIR-based PC for TDD show a significant improvement of SUC criteria although the CIR distributions presented in Fig. 5 suggest a decreased QoS. Even with an offered traffic of 70 Erlang per cell the SUC stays close to 100 %.

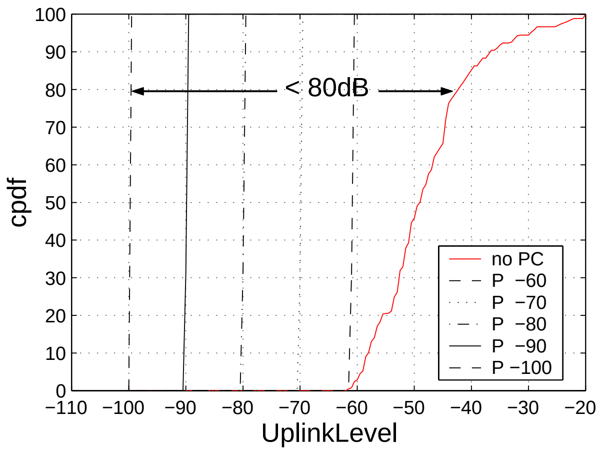

FIGURE 2 - Level-based PC; reception carrier level and CIR at the TDD BS (UL)

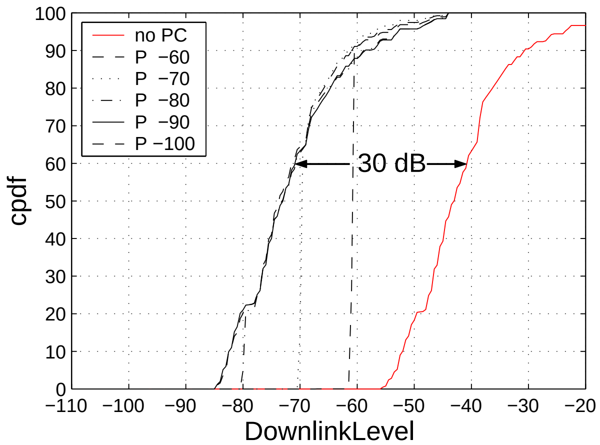

FIGURE 3 - Level-based PC; reception carrier level and CIR at the TDD UE (DL)

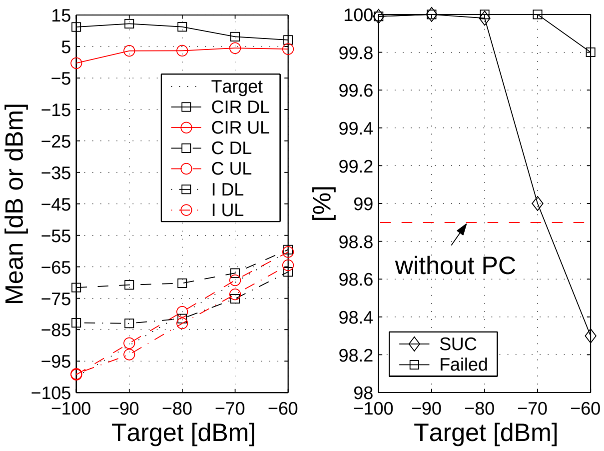

FIGURE 4 - Mean carrier (C), interference (I), CIR , and QoS at different target levels for level-based PC in UTRA-TDD

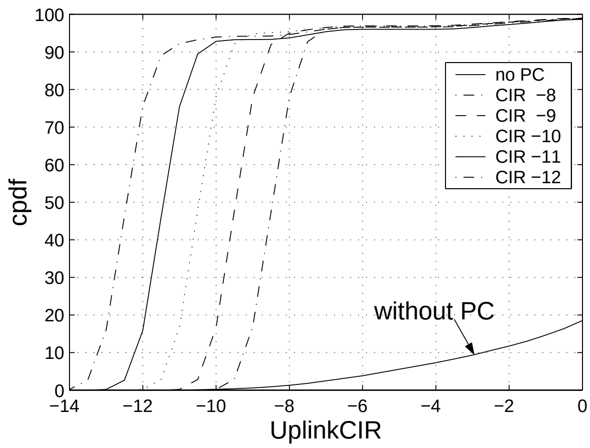

FIGURE 5 - CIR-based PC; CIR at the TDD BS (UL)

In FDD UL the CIR-based PC behaves similar (see Fig. 6). The target values are reduced by 8.75 dB compared to the TDD scheme because of a higher spreading. In DL direction a different behaviour can be seen because of a limitation of the transmission power to a small range of just a few dB. This is to take into account the near-far problem in CDMA networks [1]. Hence, the target is only reached exactly in UL direction as illustrated in Fig. 7. Furthermore the PC of TDD and FDD operation can be compared such as in both duplex modes UL is controlled according to the target whereas DL adjustment is limited to a smaller range and the target cannot be reached. Fig. 8 illustrates the performance in terms of SUC where an optimal target at –18.75 dB can be estimated.

A comparison to the analytical survey and to the CIR equalling PC is made in the right hand plot of Fig. 8. A reasonable correspondence with the analysis can be

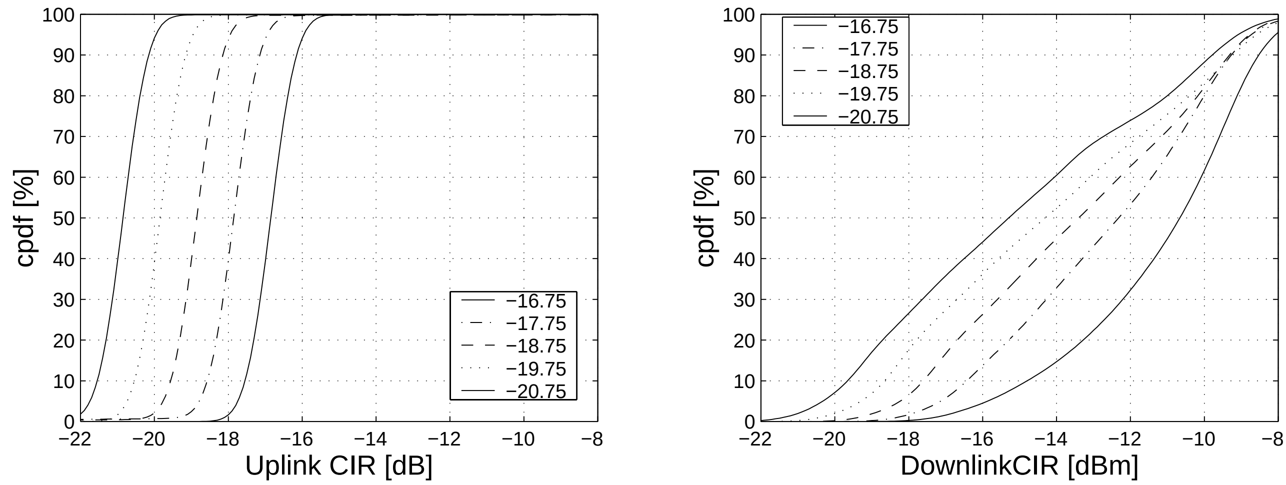

FIGURE 6 - CIR-based PC; measured CIR at the BS (UL) and UE (DL) in UTRA-FDD

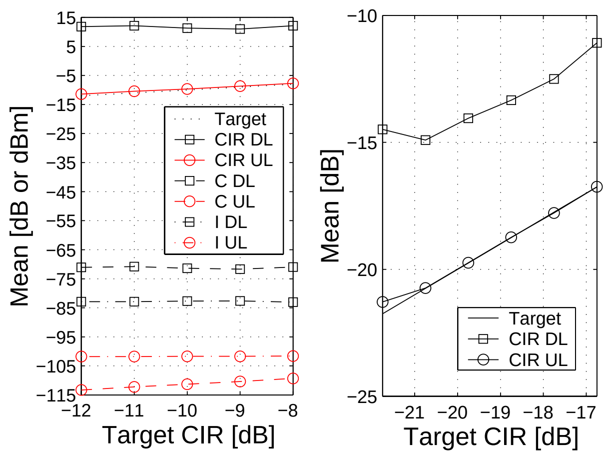

FIGURE 7 - CIR-based PC in TDD and FDD, mean values of link measurements

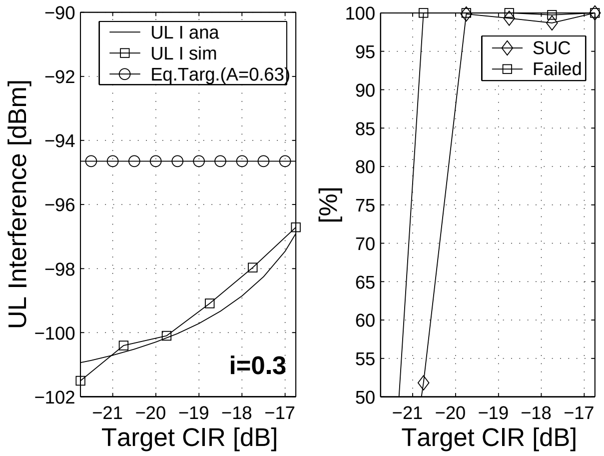

FIGURE 8 - CIR-based PC in FDD: reduction of interference and effect on QoS

seen. Moreover, the CIR-based PC performs better as the interference is always reduced to a minimum and no overhead has to be considered.

5 CONCLUSION

Different PC methods are proposed and evaluated by means of simulations. Both UTRA modes, FDD and TDD are part of this investigations. For the FDD system an optimal target CIR of –18.75 dB for the speech service is derived. In the TDD system the level-based PC performs best for a target reception power level of –90 dBm. The best CIR target is around –10 dB.

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