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Outer-Loop Power Control in a Live UMTS Network: Measurement, Analysis and Improvements

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Abstract— **The Outer Loop Power Control (OLPC) in WCDMA systems allows to achieve a defined Quality of Service (QoS) for every link. This reduces resources and interference, hence, increases the system-wide throughput. In this paper we present uplink OLPC related large-scale measurements, performed on live Iub-interfaces. Evaluations of the actual implemented algorithm show that it converges slowly; the reason being that the QoS is estimated by CRC. As the uncoded Bit Error Ratio (BER) holds information about the QoS, this parameter can be used to increase convergence speed of the OLPC. We present a statistical model of the control path of the OLPC which takes the uncoded BER information into account. Additionally, we propose a new OLPC algorithm that shows fast convergence in simulations, resulting in a reduction of 0.2 dB to 1 dB of the mean required signal-to-interference ratio, depending on the user mobility.**

I. Introduction

In Wide-band Code Division Multiple Access (WCDMA) systems all users share the same time and frequency resources. This leads to the problem that users located far from the Base Station (NodeB) suffer strong interference from users closer to the NodeB, *near-far effect*. The current solution is a power control, which guarantees that the received power levels from all User Equipments (UEs) are equal at the NodeB. Hence, the power control algorithm aims to reduce transmission power and interference level, and to maximize system capacity.

In WCDMA Frequency Division Duplex (FDD) at uplink a feedback control-loop is implemented in form of an Inner Loop Power Control (ILPC) and an Outer Loop Power Control (OLPC). The ILPC controls the transmission power of the UE with the aim of keeping a target Signal to Interference Ratio (SIR) defined by the OLPC, see [1]. This mechanism involves two network components, the NodeB and the UE. The first is measuring the SIR and sending up/down commands to the UE by means of the downlink channel. The UE has to adjust the transmission power accordingly. This procedure is executed every 0.667 ms, hence, fast enough to compensate fast fading. The OLPC is locked on the Quality of Service (QoS), in terms of Block Error Ratio (BLER), requested by the application the radio connection is established for. The involved network components are Serving RNC (SRNC) and NodeB. The NodeB has to receive data from the UE and forward it to the SRNC. The SRNC has to combine the data streams from different NodeBs, estimate the BLER of the data and determine a new target SIR for the ILPC. Iterations of this algorithm are triggered every 10-100 ms. The realization of the OLPC algorithm is not standardized, see [2]; only communication interfaces are defined.

The OLPC is necessary for CDMA systems, because the BLER of a radio link is not corresponding to a fixed value of SIR after ILPC. The SIR is log-normal distributed assuming a constant BLER, see [3]. This is due to varying radio channel properties, such as Doppler-spectrum and fading conditions, in association with the imperfect ILPC, as described in [4]. A static mapping of SIR to BLER would have to be designed according to worst-case conditions.

The commonly accepted OLPC algorithm was proposed in [5] and is described in the following. The estimation of the BLER is performed in a binary way by evaluating the current received Transport Block (TB). If the Cyclic Redundancy Check (CRC) attached to the TB yields an error, the BLER is *high*, otherwise *low*. Accordingly, the new target SIR for the ILPC is determined to be lowered for a value Δ in case of no error (low BLER), otherwise raised for $K\Delta$. The resulting BLER converges to the desired value, if K is chosen according to

$$K = \frac{1}{\text{BLER}} - 1. \quad (1)$$

This algorithm will be referred to as *step-algorithm* in the following.

The fact that this algorithm relies only on the CRC makes it simple and robust. On the other hand, it has long convergence times if the SIR is higher than expected, because of the low amount of information contained by the CRC. It is especially a problem in case of a channel with dynamic SIR demands. This has been noticed by different authors, which proposed alternative power control algorithms, see [6], [7]. Thereby the suggestions where to distinguish between static and dynamic channel conditions and, accordingly, to adjust the OLPC step sizes. Nevertheless, the idea of the step-algorithm, to base the BLER-estimation on the CRC errors only, remained.

In literature, see [4], [8], also the *uncoded Bit Error Ratio (BER)* parameter has been identified to hold information about the BLER. This parameter is an estimate of the BER before channel-decoding at the receiver. Like the CRC, it is attached to every received data block (TB), hence, available for the OLPC mechanism at the SRNC. Its advantage is that, in contrary to the CRC, it contains soft information about the quality of the connection.

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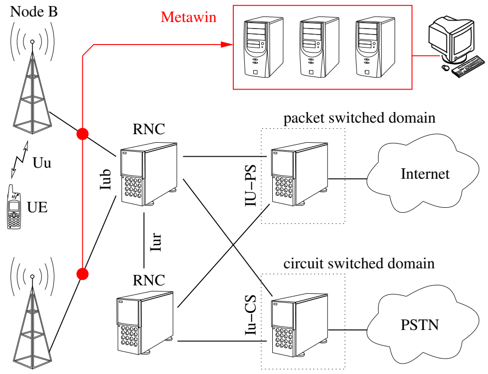

Fig. 1. Measurement Setup

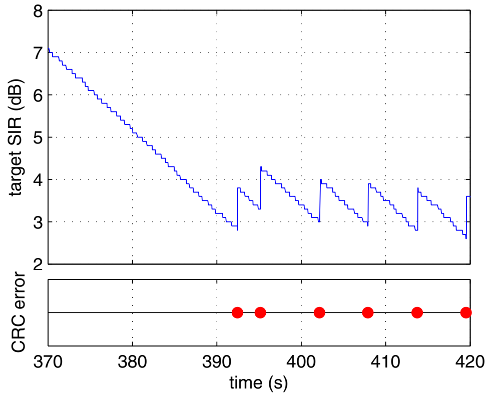

Fig. 2. OLPC algorithm in use, measurement

In this work, we analyze the uncoded BER parameter, with respect to its possible contribution to an improvement of the uplink OLPC algorithm. The research was performed by means of extensive measurements in a live network. The measurement framework is presented in Section II. With the results we built a statistical model of the ILPC, shown in Section III. Finally, in Section IV, we develop a new OLPC algorithm, referred to as *integral-algorithm*, and compare it to the step-algorithm, in order to show possible improvements by considering the uncoded BER parameter.

II. Measurement Setup

To the best of our knowledge this is the first work on WCDMA power control, which relies on data measured in a live UMTS network. Since the uplink OLPC mechanism expands to the SRNC, a significant amount of data is extractable at the interface between NodeB and RNC. This interface is called Iub-interface and specified in [9].

The measurements were performed on the Iub-interface by means of METAWIN, a passive monitoring system developed in an earlier research project [10] which is now deployed in the operational 3G network of *mobilkom austria*. For a global overview of the monitoring system see [11]. For the purpose of this study all the Iub-interfaces of a single RNC were monitored for a 5 hour period, as sketched in Fig. 1.

The METAWIN system parses the whole 3GPP protocol stack and tracks single user sessions. Live traces of single connections can be extracted along with detailed radio link information and payload statistics at the granularity of single TBs.

To meet privacy requirements the captured data are anonymized at multiple layers: the application-level payload is removed and all user identifiers (e.g. IMSI, U-RNTI) are hashed with a non-invertible function before recording.

III. Results

A. Performance of the OLPC algorithm in use

To determine the OLPC algorithm in use and evaluate its performance, we measured the target SIR values, transmitted from the SRNC to the NodeB, and the CRC error-indicators, transmitted in the other direction, see Fig. 2. We verified that the algorithm used in nowadays network equipment is the step-algorithm.

The dynamics of the algorithm in case of correct received TBs is slow, note that the slope of the target SIR curve is 0.2 dB/s. The slope is dependent on the targeted BLER, that is 1% in case of the shown connection. More precise, it decreases linearly with the BLER, for example 0.02 dB/s at 0.1% BLER. For static channel conditions this fact is not an issue, but if the required SIR of the channel is changing rapidly, the algorithm will not be able to follow. The result is a mean SIR which is oriented at the maximum of the channels SIR demands and not adjusted to the actual needs.

Another problem arising with the low dynamics of the OLPC algorithm can be identified in the connection start-up phase. During the connection establishment the OLPC has only vague information about the channel quality, thus, it has to use a coarse estimate of it (e.g. open-loop power control information) to determine an adequate initial value for the target SIR. The resulting convergence time of the OLPC algorithm after the connection setup is tremendously high. In Fig. 2 it is around 20 s, that is in the order of a call-duration.

Additionally, we verified that the power control algorithm introduces regular error patterns in case of static SIR requirements, as mentioned in [12].

B. The uncoded BER and target SIR values

The uncoded BER information is exchanged at the Iub-interface by means of Quality Estimate (QE) values. The QE parameter maps logarithmically to the uncoded BER. It is a 8-bit value and reaches from 1 down to 1% in terms of uncoded BER. It is defined in [13] as

$$\mathrm{QE} = \left\lceil \frac{\log_{10}(\mathrm{BER}) + 2.071875}{0.008125} \right\rceil . \qquad (2)$$

Our measurements have shown that the QE parameter is superimposed by a strong noise component. The deviation from its mean shows a distribution similar to a normal distribution with a standard deviation of 20 in terms of QE. This corresponds to a deviation of 40% of the BER from its *logarithmic* mean. This noise component is independent of

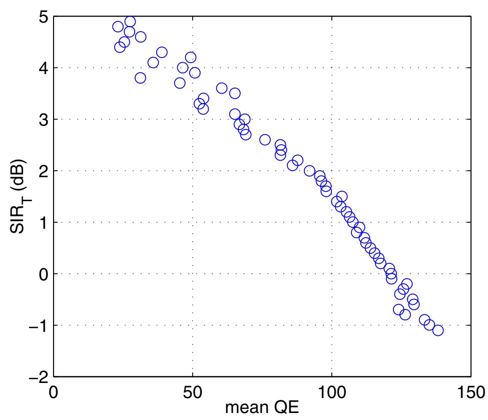

Fig. 3. Measured target SIR over mean QE, single connection

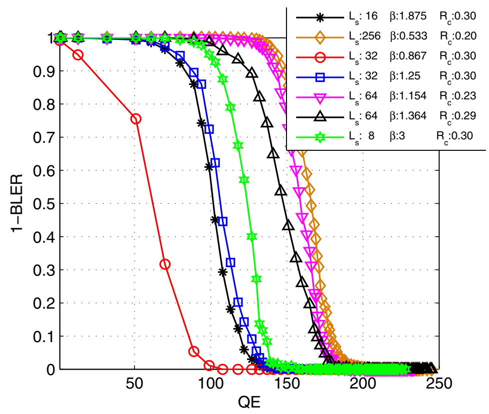

Fig. 4. Measured $1 - \text{BLER}$ over QE, different radio parameter sets

the absolute value of the BER, except if the BER is within the range of saturation of the QE parameter.

We analyzed the target SIR over the uncoded BER with suppressed noise component in order to identify a correlation. For the measurement single UEs have been evaluated separately, in order to be able to differentiate between static and moving users. In Fig. 3 the behavior of a static UE is shown, the radio channel is established to one specific cell for the duration of the whole connection. The measurement points are arranged along a sharp line. This line is convex, as expected for a SIR over BER curve, although, stronger bending towards lower values of BER, equivalent to lower values of QE, might be expected. This behavior is due to saturation effects in the conversion of the BER into a QE value.

For connections of moving users a different scenario can be observed. In this case the measurements do not form a sharp line, but are rather accumulated in a cluster around a line. This is because of the instantly changing SIR demands caused by the changing channel conditions.

In Soft Handover (SHO) scenarios, assuming a static UE, it can be observed that the measurement points obtained by the best cell still form a sharp line, comparable to Fig. 3. Those points resulting from measurements recorded from other cells are floating in regions with higher BER. The reason is that the ILPC is locked on the SIR conditions of the best cell, whereas others are neglected.

Although the offset of the target SIR over QE curves may vary, their shape remains unchanged for various connections. Performing a linear regression yields a slope of about -0.04 dB target SIR per 1 QE. At all measurements the step size of the ILPC was 1 dB.

C. Relation between uncoded BER and BLER

The uncoded BER and the BLER are expected to be strongly correlated. Unfortunately, the estimation method of the uncoded BER is not strictly defined in the standard, see [14]. It may be estimated on the data-channel or the control-channel (pilot-bits), which have different radio-parameters. By measuring BLER over BER curves for different radio-parameter settings, the estimation method can be identified. If the curves change only with the coding rate and coding scheme, the uncoded BER is estimated on the data-channel. Otherwise, if the curves are changing with other radio parameters, for example the spreading factor, the uncoded BER is estimated on the control-channel. In the network under investigation the uncoded BER is estimated on the control-channel, see Fig. 4. The figure reveals that coding rate (R_c), the spreading factor (L_s), as well as the gain factor (β) have an influence on the measurement curves.

If the QE is used to estimate the actual BLER, it is unhandy that every set of radio parameters bears a different curve. Instead, if every measurement curve is shifted for a value which is related to the energy per coded bit, they overlap. In consequence, one reference BLER over QE curve can be identified. The shifting is performed by transforming the QE values according to

$$\text{QE}_{\text{corr}} = \text{QE} + \alpha \log_{10}\left(\frac{\beta^2 L_s}{R_c L_{s,c}}\right). \tag{3}$$

Here the term $\beta^2 L_s / R_c$ is proportional to the energy per coded bit and $L_{s,c}$ denotes the spreading factor of the control channel, which is used as reference. The factor α influences the residual spread of the curves. A numerical minimization showed that if α equals 165, the residual spread is reduced to 40 in terms of QE (80% in terms of BER). We performed a regression analysis of the corrected measurement curves, deploying a generalized linear model. It yields that the optimum (least squared error) reference BLER over BER curve is well approximated by

$$1 - \text{BLER} = \frac{1}{1 + e^{-15 + 0.117 \cdot \text{QE}_{\text{corr}}}}. \tag{4}$$

Note that the radio parameters may change every Radio Frame (RF), corresponding to 10 ms. An allowed combination of radio parameters forms a Transport Format Combination (TFC). All allowed combinations for a given connection are collected in the Transport Format Combination Set (TFCS). Depending on the actual desired throughput an adequate TFC is chosen instantly from the TFCS. If the QE parameter is used to determine the actual BLER, it is reasonable to consider only that TFC which yield the worst

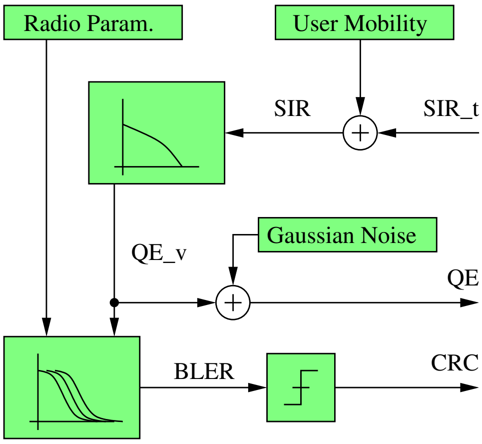

Fig. 5. Model of the control path of the OLPC

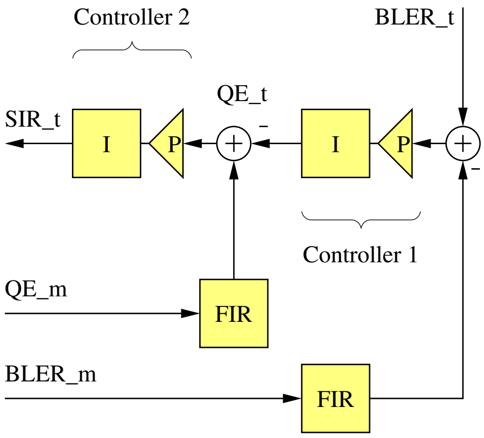

Fig. 6. New OLPC alg. using *uncoded BER* information

BLER over QE relation of the whole TFCS (leftmost curve). In such a case the estimation of the uncoded BER on the control-channel is an advantage; the BLER can be estimated from the uncoded BER for the worst TFC, independent from the actually used TFC.

The conclusions from the measurements where that the QE parameter bears more information about the actual BLER than the CRC. Consequently, it allows faster and more accurate determination of the BLER, although the values are disturbed by strong noise.

IV. Modeling and simulations

A. Control path

Figure 5 shows the model of the control path (ILPC, data transmission, reception) we developed for simulations. The only input is the target SIR parameter, whereas the outputs are the CRC and the QE parameter. One iteration is performed per Transmission Time Interval (TTI). Furthermore the model assumes that the amount of transmitted data is only one TB per TTI, however, with variable size and different radio parameters.

The model is explained in the following. The target SIR signal is added to a term called *User Mobility*. This is a level which defines the SIR demands for a desired BLER. It is either set to be constant (static user) or changing with variable dynamics (moving user). In our measurements we had no direct access to this parameter. Consequently, we did not accurate by model it, but assumed a random walk. Measurements have shown that most of the target SIR values are concentrated within a region of 5 dB, therefore, it was assumed that this value is an upper bound on the dynamic variations of the SIR demands. The resulting value can be interpreted as actual SIR. It is transformed by means of a measurement curve (see Fig. 3) to a virtual QE value (QE_v). The virtual QE is on the one hand added to Gaussian noise, resulting in the real QE, on the other hand it is transformed to a BLER value by means of a measurement curve (see Fig. 4). Thereby different radio parameters can be chosen, which influence this transformation. The BLER is converted randomly to the outcome of a CRC-check.

B. Control algorithm

We propose a new OLPC algorithm (*integral-algorithm*) shown in Fig. 6. This controller is organized in two stages, both integral elements. The first one, *Controller 1*, maps the difference between desired and measured BLER to a *target BER* (target QE). It has low dynamics, in order to guarantee a satisfactory accuracy of the measurement of the BLER by means of the CRC. The second stage, *Controller 2*, maps the difference between the target BER (target QE), determined by the first stage, and the measured BER (QE) to a target SIR value. This output is the target value for the ILPC. This stage is faster than the former, significant changes may occur after some few TTIs. The dynamic behavior is determined by the FIR filters, which are low-pass filters deployed to suppress noise components of the measured signals. Summarizing, the controller satisfies the equations

$$\mathrm{QE}_{t,k} = P_1(-\mathrm{BLER}_{t,k} + \sum_{i=1}^{L} \alpha_i \mathrm{BLER}_{m,k-i}) + \mathrm{QE}_{t,k-1}$$

$$\mathrm{SIR}_{t,k} = P_2(-\mathrm{QE}_{t,k} + \sum_{j=1}^{N} \beta_j \mathrm{QE}_{m,k-j}) + \mathrm{SIR}_{t,k-1}, \quad (5)$$

where α_i and β_i denote the coefficients of the FIR filters, the factors P_1 and P_2 denote the gains in both sub-controllers, the subscripts m and t stand for *measured* and *target* and the subscript k denotes the time-index.

The stability of the OLPC algorithm cannot be evaluated on the basis of a single connection. This issue can only be addressed by taking resource management procedures into account. In a multi-cell, multi-user environment the stability is coupled with the *feasibility of power control* problem, what has been addressed in [15], [16]. If the power control is not feasible, admission control must take place.

C. Numerical results

We performed simulations for two different scenarios. In one the receiver needs a constant SIR to maintain the desired BLER (static user). In the second scenario the demanded

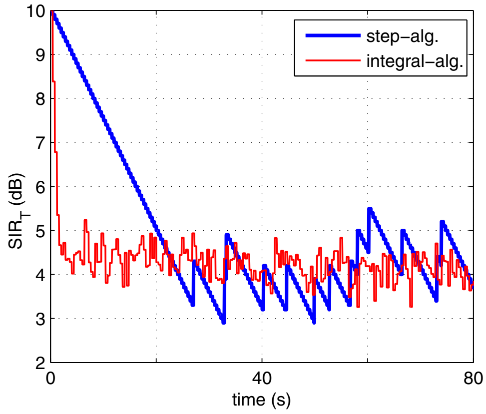

Fig. 7. Simulation of the OLPC, both algorithms

SIR to maintain a constant BLER is changing dynamically, (moving user).

The output SIR of both controllers for the static case is shown in Fig. 7. The biggest difference is observed in the start-up phase of the connection, where the step-algorithm shows the typical slow convergence, already known from the measurements. In contrary, the integral-algorithm shows a very fast convergence to the desired SIR value, this is due to the fast tracking of the uncoded BER. A small residual error is eliminated by the second integral stage. The overall gain of the integral-algorithm in comparison to the step-algorithm in this scenario is 0.2 dB less mean SIR target. Furthermore, the call-duration has an influence on this gain, for example, if it is fixed to 30 s the gain exceeds 1 dB, see [17].

The effect of fast convergence due to the tracking of the uncoded BER can also be used to improve the performance of the step-algorithm, without changing the actual controller. If the step-algorithm estimates its initial value by use of the uncoded BER of the first few received TBs, its convergence time can be reduced dramatically.

In the case of dynamic SIR demands the integral-algorithm has the advantage to be able to follow those demands, whereas the step-algorithm is not able to follow. The step-algorithm can follow only raising demands, for decreasing demands the convergence is too slow due to the small step-size. Hence, the resulting mean target SIR is higher for the step-algorithm. The gain of the integral-algorithm in comparison to the step-algorithm is roughly 1 dB in this case, see [17].

Again note that the integral-algorithm is preliminary. It was designed only to reveal possible improvements of the OLPC by the use of the uncoded BER as additional input parameter. Its robustness in worst-case scenarios has not been evaluated. This issue could raise the necessity for slight modifications of the algorithm.

V. Conclusion

Large-scale measurements have shown that the uplink OLPC algorithm in UMTS networks, has a convergence time in the order of a short call duration, hence, it cannot follow quickly changing SIR demands of a moving user.

We provided a detailed analysis of the relations between target SIR, BLER, and uncoded BER for static and moving users, respectively. It revealed that the uncoded BER can be used to multiply the OLPC convergence speed. In consequence we proposed a new OLPC algorithm which makes use of this parameter.

Simulations showed that the algorithm reduces the mean target SIR. The reduction ranges from 0.2 dB for static users up to 1 dB for users with high mobility. Furthermore, reductions of more than 1 dB can be achieved for connections with a duration of less than 30 s, independent of the user mobility.

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