Optimal implementation of novel WCDMA uplink outer loop power control algorithm

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ABSTRACT
Wideband code division multiple access (WCDMA) uplink outer loop power control has been responsible for changing the signal to interference ratio (SIR) target value according to the SIR target control algorithms. Thus maintains the desired block error rate (BLER) for voice connections and transmission to target error rate (TTE) for data connections. During a call, the SIR target varies between implemented lower (sirMin) and upper boundaries (sirMax), which are fixed values on radio network control station (RNC). As possible solution for WCDMA uplink overload problems, a novel uplink outer loop power control algorithm with dynamic change of sirMax has been proposed. In this paper optimal implementation for dynamic change of sirMax has been investigated. Performance management statistic and general performance event handling (GPEH) data, for current uplink received signal strength indicator (UL RSSI) and required SIR target, have been obtained. Based on analysis from obtained data optimal implementation for dynamic change of sirMax has been proposed.

1. Introduction

Power control is essential in WCDMA systems to provide satisfactory quality of service (QoS) [1] and to combat several problems:

- To mitigate the fading effect.
- To adjust the radiated power of mobile stations in a way that all received signals at the base station have the same SIR for the same bit rate [2].
- To reduce co-channel interference by concurrent users.

SIR in the WCDMA system corresponds to the ratio of the received useful signal at the base station receiver over a frequency range of 5 MHz width compared to interfering co-channel sources. In the uplink, received useful signal at the base station receiver is signal from the mobile station. Sources of interfering signals are all other mobile stations in the cell, as well as other mobile stations in neighboring WCDMA cells that transmit on the same channel [3]. There are three types of algorithm for power control, investigated in [4–10], which are implemented in WCDMA system: open loop power control, inner loop power control and outer loop power control. Based on analysis of uplink air interface overload problems, it has been concluded that existing uplink outer loop power control has difficulty to combat uplink overload in real networks. Thus self-optimizing uplink outer loop power control with dynamic change of sirMax, based on current uplink load, has been proposed [11]:

\[
sirMax[dB] = \text{MaxULRSSI[dBm]} - \text{ULRSSI[dBm]} + C[dB]
\]

where \(sirMax\) is value used by uplink outer loop power control, \(\text{MaxULRSSI}\) is maximum allowed UL RSSI of the cell, \(\text{ULRSSI}\) is measured UL RSSI of the cell and \(C\) is constant that is used by operator to modify dependency of \(sirMax\) to measured UL RSSI. During a call, the SIR target varies between implemented lower (sirMin) and upper boundaries (sirMax), which are fixed values on RNC in existing uplink outer loop power control. On the other hand, in self-optimizing uplink outer loop power control upper boundary (sirMax) has been load dependent. The comparison of two outer loop power control algorithms has been presented in next section.

2. Comparison of uplink outer loop power control algorithms

Cooperation between three types of uplink power control algorithms has been presented at Fig. 1.
Open loop power control is used to calculate the required radiated power by the mobile station for access preamble, the random access channel (RACH) and the initial power for dedicated channels (DCH). Once dedicated channels have been established outer and inner loop power control shall cooperate in order to maintain the necessary block error rate (BLER) for voice or transmission target error rate (TTE) for data calls. This is done in a way that outer loop power control sets and adjusts the SIR target value used by inner loop power control. Outer loop power control monitors the cyclic redundancy check (CRC) of transport blocks after diversity combining at the control station and change the SIR target value according to the SIR target control algorithms for the uplink. Thus maintains the desired BLER and TTE in the uplink, regardless of user’s radio conditions, and whether user is stationary or mobile. The upper boundary for SIR target value is determined by $sirMax$ parameter on RNC, which is load dependent value in self-optimizing uplink outer loop power control algorithm presented at Fig. 2.

By implementation of load dependent $sirMax$ value, maximum allowed radiated power per mobile station has been dynamically adapted to current uplink load, which could bring improvement in provided QoS during uplink overload. On the other hand, during normal uplink load $sirMax$ would be increased, thus allowing higher radiated power from mobile station and better uplink throughput. Dynamic changes of $sirMax$ have been strongly dependent of $MaxULRSSI$ setting that defines targeted maximum allowed UL RSSI of the cell, set by operator. For measured UL RSSI of empty cell and if cell has not been interfered by transmitting mobile stations from neighboring base stations, the measured signal strength at the base station receiver ($UL RSSI_0$) correspond to thermal noise[13]. Thermal noise level at the base station receiver can be estimated by techniques described in [14], which gives $UL RSSI_0$ equal to:

$$UL RSSI_0 = C \log_{10} (1 + S/N) \text{dBm}$$  \(\text{(4)}\)

where $C$ is the capacity in bits per second, $B$ is the bandwidth of the channel in Hertz, and $S/N$ is the signal to noise ratio (SNR). In this paper the focus is on uplink interference limited scenario, thus SNR would be the most relevant measure to determine WCDMA uplink overload threshold. On the other hand, uplink air interface utilization measurement techniques on RNC are based on UL RSSI measurements. Thus UL RSSI has been used, instead of SNR, to determine WCDMA uplink overload threshold. Maximum allowed UL RSSI of the cell has been defined as maximum allowed noise rise over thermal noise due to interference at which it is still possible to distinguish users [12].

$$UL RSSI_{\text{max}} = UL RSSI_0 + NR_{\text{max}}$$  \(\text{(3)}\)

where $UL RSSI_{\text{max}}$ is maximum allowed UL RSSI of the cell, $UL RSSI_0$ is measured UL RSSI of empty cell and $NR_{\text{max}}$ is maximum allowed noise rise. If there are no users in the cell, and if cell has not been interfered by transmitting mobile stations from neighboring base stations, the measured signal strength at the base station receiver ($UL RSSI_0$) correspond to thermal noise [13]. Thermal noise level at the base station receiver can be estimated by techniques described in [14], which gives $UL RSSI_0$ equal to:

$$UL RSSI_0 = -105 \text{ dBm}$$  \(\text{(4)}\)

Eq. (5) from [15] has been used to calculate noise rise, which is equal to:

$$NR = -10 \times \log(1 - \eta_{UL}) \text{ dB}$$  \(\text{(5)}\)

where $\eta_{UL}$ is the uplink load factor. Statistical analysis from live network gives result that satisfying call setup success rate (CSSR) can be achieved with $\eta_{UL} = 0.98$, due to admission and congestion procedures specified in [16]. From (5), calculated maximum noise rise ($NR_{\text{max}}$) is then 16.99 dB. From (3), $UL RSSI_{\text{max}}$ value is then $-88.01 \text{ dBm}$. Thus WCDMA cells with measured $UL RSSI$ above $-88.01 \text{ dBm}$ have been considered as cells in state of uplink overload.

### 3. WCDMA uplink overload threshold

The Shannon–Hartley theorem states that the channel capacity is given by:

$$C = B \log_2 (1 + S/N)$$  \(\text{(2)}\)
Conditions from live network that could produce uplink overload are divided in 3 groups:

- Uplink air interface overload due to large number of simultaneous users, like concerts, sport events, traffic jams on highway etc., [17].
- Uplink air interface overload caused from outer source of interference [18]. Sources of outer interference could be malfunctioning radio devices (TV antenna amplifier, DECT systems, FAX devices etc.) or mobile operators from neighboring countries that use same frequency spectrum.
- Uplink air interface overload caused by passive inter modulation products created by own system, which has become a significant factor with increased spectrum bandwidth acquired by operators [19].

Optimal implementation for dynamic change of \( \text{sirMax} \) has been investigated based on statistical data from performance management statistic and GPEH measurements specified in [20], which has been presented in Sections 4 and 5.

### 4. Performance management statistic

Performance management statistic has been obtained by RNC performance management counters, \( \text{pmSumULRssi} \) and \( \text{pmSamplesULRssi} \) that exist for every cell controlled by RNC:

- \( \text{pmSumULRssi} \) is counter that records the value of received total wideband power (RTWP) measured on cell and sent to the RNC via nodeB application part (NBAP) common measurement reporting [21], over lub interface which is specified in [22], where RTWP refers to UL RSSI measurement.
- \( \text{pmSamplesULRssi} \) is a counter that records how often sample has been recorded and it is actually captured every 10 s. That means that RNC is notified every 10 s of measured UL RSSI at each cell on RNC.

Due to large amount of data, the obtained results have been aggregated by RNC. Aggregated UL RSSI value over 15 min has been stored on performance management statistic database, for every WCDMA cell on RNC. The obtained result by performance management statistic, for one real WCDMA cell with typical data traffic, has been presented at Fig. 3.

As it can be concluded from Fig. 3, there are exactly 96 measurement results during monitoring period of one day, thus highest frequency for \( \text{sirMax} \) change could be every 15 min. From (1), self-optimizing uplink outer loop power control, based on performance management statistic, would use 96 \( \text{sirMax} \) values during one day.

As it has been presented in this section, RNC is notified every 10 s of measured UL RSSI at each cell on RNC, which is system limit and highest possible frequency for obtaining UL RSSI data. The information of measured UL RSSI in 10 s resolution can be obtained by GPEH measurements, which has been presented in next section.

### 5. GPEH measurements

The purpose of GPEH measurements has been providing real-time performance monitoring capabilities instead of aggregating delay introduced by performance management statistic. The collection and recording of GPEH measurements has been instrumented by monitoring tasks which are accessed through management interfaces supporting the CORBA (Common Object Request Broker Architecture) set of the performance and notification integration reference points. GPEH measurements for WCDMA can monitor:

- Control functions.
- Mobility functions.
- Capacity functions.
- Bearer functions.
- Measurement reports.
- Configuration management functions.
- Inter-node communication.
The main drawback of using GPEH compared to performance management statistic is large amount of data that has been collected and stored on database. The result of measured UL RSSI obtained by GPEH measurements, for same real WCDMA cell from previous section, in same time period, has been presented at Fig. 4.

As it can be concluded from Fig. 4, there are exactly 8640 measurement results during monitoring period of one day, thus highest frequency for sirMax change could be every 10 s. From (1), self-optimizing uplink outer loop power control, based on GPEH measurements, would use 8640 sirMax values during one day.

Furthermore, required uplink SIR target has been obtained by GPEH measurements for all data connections on same real WCDMA cell in same time period. The obtained results have been presented at Fig. 5.

Presented results for measured UL RSSI and required uplink SIR target have been used to investigate optimal implementation for dynamic change of sirMax, which has been presented in next section.

6. Optimal implementation for dynamic change of sirMax

As it can be concluded from previous sections live data have been used for evaluation purpose. Live data can be obtained by GPEH measurements on 10 s resolution or by performance
management statistic with highest resolution of 15 min (other resolutions are hour, day, week and month). Analysis has been made to determine would it be good enough to implement changes based on UL RSSI from performance management statistic (which is simpler), or there is actual need to use highest possible resolution and GPEH measurements which is more complicated.
To determine optimal implementation of proposed algorithm it has been compared to existing uplink outer loop power control with fixed \( \text{sirMax} \) implementation of 12 dB, which is optimized value by network operator for normal cell load, presented at Fig. 6. As it can be concluded from Fig. 6, there have been data connections with required SIR target above implemented \( \text{sirMax} \) value. Thus, uplink throughput has been limited for those data connections, which has been presented at Fig. 7.

As it can be concluded from Fig. 7, there have been 22\% data connections with limited uplink throughput.

To determine optimal implementation for dynamic change of \( \text{sirMax} \), variable \( \text{sirMax} \) has been obtained from (1). Used Max- \( \text{ULRSSI} \) for self-optimizing uplink outer loop power control has been determined from (2) and set to \(-88\) dBm, while \( C \) has been \(-2\) dB. The result for variable \( \text{sirMax} \), with \( \text{ULRSSI} \) from Fig. 3, has been presented at Fig. 8.

Self-optimizing uplink outer loop power control, based on UL RSSI from performance management statistic, has produced 96 \( \text{sirMax} \) values. Compared to fixed \( \text{sirMax} \) value of 12 dB all 96 variable \( \text{sirMax} \) values have been above 12 dB. Thus number of data connections with limited uplink throughput has changed, which has been presented at Fig. 9.

As it can be concluded from Fig. 9, number of data connections with limited uplink throughput has decreased from 22\% to 8\%. On the other hand, there has been no additional throughput limitation due to that all 96 variable \( \text{sirMax} \) values have been above fixed \( \text{sirMax} \) value. Thus it can be concluded that uplink overload, during monitored period, has not been detected by self-optimizing uplink.
outer loop power control based on UL RSSI from performance management statistic.

Same analysis has been performed for self-optimizing uplink outer loop power control based on UL RSSI from GPEH measurements. Variable $\text{sirMax}$ has been obtained from (1), with $\text{MaxULRSSI}$ set to $-88$ dBm, while $C$ has been $-2$ dB and ULRSSI has been obtained from Fig. 4. The result for variable $\text{sirMax}$, based on UL RSSI from GPEH measurements, has been presented at Fig. 10.

Self-optimizing uplink outer loop power control, based on UL RSSI from GPEH measurements, has produced 8640 different $\text{sirMax}$ values. Compared to fixed $\text{sirMax}$ value of 12 dB, 8350 variable $\text{sirMax}$ values have been above, while 290 variable $\text{sirMax}$ values have been below 12 dB. Thus number of data connections with limited uplink throughput has changed, which has been presented at Fig. 11.

As it can be concluded from Fig. 11, number of data connections with limited uplink throughput has decreased from 22% to 8%, which is same improvement as in case of self-optimizing uplink outer loop power control based on UL RSSI from performance management statistic. On the other hand, there has been additional throughput limitation due to 290 variable $\text{sirMax}$ values that have been below fixed $\text{sirMax}$ value of 12 dB. From obtained result it can
be concluded that uplink overload, during monitored period, has been detected, which has been presented at Fig. 12.

As it can be concluded from Fig. 12, uplink overload have been detected in 3.36% of times monitored period which corresponded to 290 short bursts of uplink overload with duration of 10 s each.

6.1. Analysis of recorded results

Improvement by self-optimizing uplink outer loop power control compared to legacy uplink outer loop power control, based on source of data for UL RSSI measurement, has been presented at Table 1.

As it can be concluded from Table 1, the main difference has been in cases of uplink overload during short time periods, which has not been detected by performance management statistic. Thus self-optimizing uplink outer loop power control based on UL RSSI from performance management statistic could set to high value for sirMax, which could lead to uplink instability. On the other hand, self-optimizing uplink outer loop power control based on UL RSSI from GPEH measurements has successfully detected uplink overload during short time periods. Thus sirMax has been adjusted to appropriate value and possible uplink instability has been avoided. For rapid changes of sirMax value, RNC signaling and processor load must be taken into the consideration. By implementation of self-optimizing outer loop power control, sirMax would be calculated from (1) and it would not be any more RNC parameter. New parameters on RNC would be MaxULRSSI and C which are fixed values in a same way as it was sirMax in legacy implementation. In this case additional RNC signaling and processor load has not been expected. Thus highest possible frequency for sirMax change would be recommended, which is equal to every 10 s.

Self-optimizing uplink outer loop power control with changes of sirMax value for every available UL RSSI measurement on WCDMA cell would be adapted to dynamic conditions on uplink air interface. Thus in cases of low uplink load, higher value of sirMax would be used, allowing higher radiated power per mobile station and higher uplink throughput. On the other hand, in cases of high uplink load, lower value of sirMax would be used, thus limiting radiated power per mobile station and uplink throughput. The changes of sirMax in cases of high uplink load would be fast enough to adapt to short bursts of uplink overload.

7. Conclusion

Self-optimizing uplink outer loop power control has been introduced to combat problems with uplink air interface overload in WCDMA networks. Dynamic change of sirMax based on current uplink load has been introduced by new algorithm. Thus maximum allowed radiated power per mobile stations has been dynamically adapted to current uplink load. In this paper optimal implementation for dynamic change of sirMax has been investigated. Performance management statistic and GPEH measurements have been used to obtain UL RSSI and required SIR target on monitored WCDMA cell. Based on obtained results it has been concluded that improvement in percentage of data connections that would achieve higher uplink throughput is same for changing sirMax every 15 min or every 10 s. The main difference has been in fact that short periods of uplink overload have been detected and resolved by changing sirMax every 10 s, which has not been detected by changing sirMax every 15 min. High setting of sirMax during short periods of uplink overload could lead to uplink instability of WCDMA cell. Thus it has been proposed, for novel WCDMA uplink outer loop power control algorithm, to change sirMax every 10 s.

References

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