Adaptive Power Control Algorithm for 3G Cellular CDMA Networks

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***Abstract*— In this paper, we study adaptive power control algorithms for the Universal Mobile Telecommunications System (UMTS) and we propose an evolution for these algorithms. The proposed algorithm can be used in both link directions of the Frequency Division Duplex (FDD) mode and in the downlink of the Time Division Duplex (TDD) mode of UMTS, where the same closed-loop power control is used. Unlike the standardized closed-loop power control algorithm of UMTS, adaptive power control algorithms have a dynamic transmitted power update step. For these algorithms, power control steps depend on the instantaneous mobile command and the command history. Our proposed algorithm adds some intelligence to mobiles and base stations in order to limit oscillations around the target signal-to-interference ratio (SIR). When the received SIR is close to the target SIR, the receiver sends alternative up and down commands. These alternatives commands are interpreted by the transmitter. In this case, the transmitter stabilizes its transmitted power. Simulations are performed in order to evaluate the proposed algorithm performance. Simulations have shown that the proposed algorithm decreases the outage probability and dramatically reduces the transmitted power, which are the main objectives of power control algorithms.**

***Index Terms*— Adaptive power control, UMTS, TDD, FDD.**

I. BACKGROUND

The UMTS air interface uses the Code-Division Multiple Access (CDMA) technique to increase the spectral efficiency. The capacity of CDMA systems is interference-limited [1]. Therefore, power control is an essential function of the air interface and it was widely studied in the literature [2][3][4][5][6][7][8][9]. The UMTS power control was specified in the 3rd Generation Partnership Project (3GPP) standardization forum [10][11] for FDD and TDD modes.

Power control algorithms in the downlink of the TDD mode and in both link directions of the FDD mode are based on a closed-loop control. This closed-loop power control is used after an initial phase that uses an open-loop power control. An outer-loop is also used in both modes [12]. The main objective of the outer-loop is to dynamically adjust the target Signal-to-Interference Ratio, denoted SIR_{target}, according to a fixed Block-Error Rate (BLER) or Bit-Error Rate (BER) depending on multipath and shadowing effects. The SIR_{target} of a given radio channel is achieved by the inner loop power control. The downlink inner-loop of the TDD mode is the same as the inner-loop of the FDD mode. The only difference is that in the TDD mode, power control is executed at the Coded Composite Transport Channel (CCTrCH) level to allow flexibility in the up and down allocation and to optimize the transmission in the uplink. The drawback of the TDD variant is that the rate of the feedback command in slow rate applications is reduced to 100 Hz compared to 1500 Hz of the FDD mode [9]. In the following, we will study only the downlink closed-loop power control of the FDD mode.

The transmission unit in the UMTS-WCDMA interface is a 10 ms frame. Each frame is divided into 15 time slots and each slot contains one power control command (up or down). Two algorithms were proposed in the 3GPP specification [10]. In the first algorithm, the transmitted power is updated each time slot while it may be updated once each 5 time slots in the second algorithm. Only the first algorithm is studied in this paper. Each time slot, the mobile estimates the received SIR and compare it to SIR_{target}. When the estimated SIR, denoted SIR_{est}, is higher than SIR_{target}, the transmitted power command (TPC) is set to "0" and the transmitted power is decreased of Δ_{step} dB. Otherwise, the TPC is set to "1" and the transmitted power is increased of Δ_{step} dB. In most UMTS formats, the TPC command is repeated on two bits as an error-protection redundancy. The power control step is fixed by higher layers and it depends on radio and service parameters. Several values of the order of 1 dB are proposed in the specification [10].

In a wireless telecommunications system, frequent variations occur in the radio interface. Hence, the received SIR may change dramatically and very fast. In many cases, the presently-proposed 3GPP power control cannot carry out with this variation. This leads to the degradation of the quality of service; therefore, some channels may be dropped. One of the main problem in the 3GPP power control algorithm is that the power update step is fixed and thus the power will change even if the received SIR is close to SIR_{target}. Therefore, the received SIR may oscillate around SIR_{target} with a high variance. Some methods were proposed to increase the adaptation of the PC by using asymmetric power control steps to increase and decrease power [9]. Other methods suggest an adaptive power variation step in order to decrease oscillations around SIR_{target} and to increase the speed of the power control when the difference between the received SIR and SIR_{target} is very high [13][14]. The authors of [15][16][17] propose a self-tuning predictor algorithm where the TPC is coded on 2, 3 or 4 bits instead of one. In these latter papers, the parameters of the power control change according to the quality measurements of the system level, which can be deduced from the command and the SIR error history.

In this paper, we study adaptive power control algorithms for UMTS systems and we propose a new adaptive algorithm. In Section 2, the proposed method is presented and justified. The system model is described in Section 3 and results are discussed in Section 4. Conclusions and useful comments are highlighted in the last section.

II. MODIFIED ADAPTIVE POWER CONTROL

The aim of the power control procedure is to provide an adequate SIR to all mobiles by the mean of a simple algorithm. The 3GPP power control algorithm uses a fixed power control step; The fixed step leads to oscillations with high variance around the SIR_{target}. Moreover, the fixed step restrains the capability of the power control algorithm to follow radio interface variations.

A. Adaptive-step power control

In order to increase the speed of power control, an adaptive transmitted power control step may be used. The Adaptive-Step Power control (ASPC) algorithm has been proposed in [13]; if the base station detects the same TPC from a mobile in a set of consecutive slots, the step dedicated to this mobile is increased. On the contrary, if an alternative sequence of up and down TPCs of a mobile are received by a base station, the step dedicated to this mobile is reduced.

The adaptive power control step reduces oscillations around the SIR_{target}. However, the limited amplifier precision prevents transmitters from using very low power control steps; therefore, oscillations are not totally eliminated.

B. Stabilization zone

One solution to the oscillation problem is to use an SIR margin M and to define $SIR_{target} + M$ as the new power control target. The new SIR_{target} is denoted SIR^{M}_{target}.

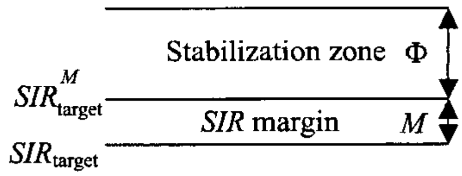

Fig. 1. The SIR margin M and the stabilization zone Φ define the new SIR target and the zone where the transmitted power is kept stable.

When the estimated SIR of a mobile station is close to SIR^{M}_{target}, a power decrease may degrade the SIR of the mobile in the next slot if the margin is not high enough. Therefore, a high margin must be used to minimize the outage probability for a given traffic. However, increasing M will decrease the system maximum capacity due to the high value of SIR^{M}_{target}. Moreover, the power consumption is an increasing function of SIR^{M}_{target}. Hence, a trade-off must be taken between the maximum capacity, power consumption and the outage probability.

The Modified Adaptive Power Control (MAPC) algorithm combines adaptive-step power control algorithm with the new concept of stabilization zone to completely eliminate oscillations. In the MAPC algorithm, the SIR margin is divided into two parts: a margin M and a stabilization zone Φ. The stabilization zone is defined as the zone where the estimated SIR is in the interval $[SIR_{target}+M;$ $SIR_{target} + M + \Phi]$ (figure 1). When the received SIR of a mobile is in the stabilization zone, the mobile generates an alternative TPC sequence (ups and downs). Consequently, the transmitter reduces its power control step and stabilizes its transmitted power. This scheme allows the stabilization of the received SIR above the desired value with the same signalization load as the 3GPP power control algorithm. Furthermore, the use of a stabilization zone decreases the needed margin value, which can be omitted also; therefore, the system maximum capacity is increased and the power consumption is reduced.

C. Mobile station algorithm

Each mobile station compares the estimated SIR (SIR_{est}) with SIR^{M}_{target} and generates the TPC according to the following algorithm:

- if $SIR_{est} > SIR^{M}_{target} + \Phi$, then the transmitted TPC is set to "0" requesting a transmit power decrease.
- if $SIR^{M}_{target} \leq SIR_{est} \leq SIR^{M}_{target} + \Phi$, then the transmitted TPC is the complementary of the previous TPC (saved in the command register) requesting an unchanged transmitted power. In this interval, mobiles generate alternative up and down power control commands.
- if $SIR_{est} < SIR^{M}_{target}$, then the transmitted TPC is set to "1" requesting a transmit power increase.
- The TPC is saved in a command register of one bit.

For each mobile, the Radio Resource Control (RRC) layer in the core network sets the parameters SIR_{target}, M and Φ based on the system load, the service type and radio interface characteristics. These parameters are sent to mobile stations via signalization channels.

D. Network algorithm

The proposed method adds some intelligence to base stations in order to increase the speed of power control. In consequence, the MAPC algorithm is executed by the base station in the network side. The base station receives the TPCs from mobile stations and analyzes the command of each mobile station independently. After each power control iteration, these commands are saved in a command register, where only one bit is dedicated for each mobile station.

To set the power of a mobile, the base station uses the bit dedicated to the mobile in the command register with the instantaneous TPC and execute the following algorithm:

- if the TPC and the saved command are the same, the power control step Δ_{step} is multiplied by μ and the transmitted power is updated by the mean of the new step.
- if the TPC is different from the saved command, the power control step Δ_{step} is divided by λ and the transmitted power is maintained stable.
- the TPC is saved in the command register.

Parameters λ, μ and the initial value of Δ_{step}, are fixed by the RRC layer in the core network. Furthermore, the power control step margin is limited by the precision of the used amplifier and is always in the interval $[\Delta_{\min}; \Delta_{\max}]$.

III. System model

The MAPC scheme is evaluated by simulation using Matlab. It is compared to the 3GPP closed-loop power control and to the adaptive-step power control algorithm [13]. An outdoor Manhattan scenario with 5×5 blocks is used to evaluate power control algorithms. The block size is 200×200 meters. Mobiles are uniformly distributed and each mobile is served by the best-received base station. A wrap-around technique is used in order to overcome cell boundary effects. Common channels, call dropping, error detection and correction, and TPC errors are not considered in simulations.

The assumed propagation model is an Okumura-Hata-Cost231 model with shadowing; the path gain between mobile i and base station j is modeled as $G_{i,j} = a_{i,j}/d_{i,j}^{3.5}$, where $d_{i,j}$ is the mobile-to-base distance expressed in meters and the coefficient $a_{i,j}$ models the shadowing effect. The shadow fading coefficient $a_{i,j}$ is a Log-Normal random variable with zero mean and 10 dB variance [18]. A correlation coefficient of 0.5 is considered between the shadow fading coefficients of a mobile and neighboring base stations. When mobility is considered, an exponential autocorrelation function $R(\Delta x)$ is used with a decorrelation distance of 5 m:

TABLE I
POWER LIMITS AND RECEIVER THERMAL NOISE

	MS channel	BS
Max Tx Power [dBm]	33	20
Power cntrl range [dB]	30	25
Receiver thermal noise [dBm]	-98	-

TABLE II
POWER CONTROL PARAMETERS

Δ_{step}	λ	μ	$\Delta_{\max}$	$\Delta_{\min}$
1 dB	2	4	4 dB	0.25 dB

$$R(\Delta x) = e^{-\frac{\Delta x}{d_{cor}} \ln 2},$$

where Δx is the path length and d_{cor} is the decorrelation distance [19].

The simulated service is 8 kbps circuit-switched service with 100% activity factor. The SIR_{target} for all mobiles is $w_0 = -17$ dB and a perfect SIR estimation is considered. Class 3 mobile stations are used. The transmitted power limits and the receiver thermal noise are presented in table I [20]. The initial transmitted powers have random values between the minimum value and 10% of the maximum transmitted power. The adaptive power control parameters are presented in table II.

Algorithm performance is evaluated using frame-outage probability, which is the probability that the average received SIR over one Transmission Time Interval (TTI, e.g. 20 ms) falls below SIR_{target}. The average value of the frame-outage probability is evaluated by Monte Carlo simulations for 100 independent mobile configurations. In each configuration, mobiles are active in the downlink during the N slots of the simulation. The mean frame-outage probability is averaged over the simulation period. The capacity of the system is considered as the load for which the mean frame-outage probability is less than 0.02.

IV. Simulations and results

We first consider a simulation with fixed-position mobiles. In each configuration, 600 time slots are simulated (i.e. 400 ms). In figure 2, we present the effect of the SIR margin (without stabilization zone) on the mean frame-outage probability when the 3GPP power control algorithm is used in a system with 24 mobiles/cell. System maximum capacity is reached with a 0.6 dB SIR margin. For a cell load of 24 mobiles/cell, the mean frame-outage percentage is drastically reduced when the optimal SIR margin is used (from 15% to 0.3%).

The impact of the stabilization zone size combined with an SIR margin is shown in figure 3 for a cell load of 26 mobiles/cell. This figure shows that the optimal value of Φ is 0.3 dB with no SIR margin. For these parameters, the

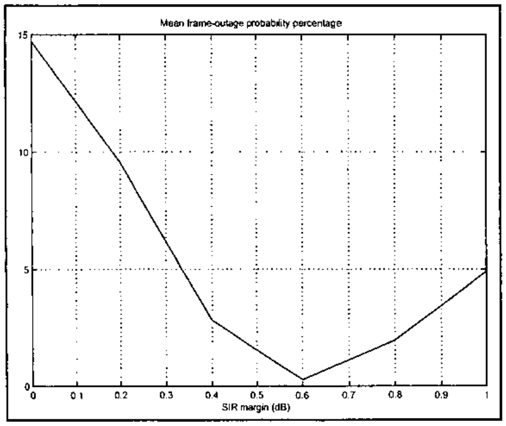

Fig. 2. The mean frame-outage probability percentage for different values of the margin M when the 3GPP power control algorithm is used in a system with 24 mobiles/cell.

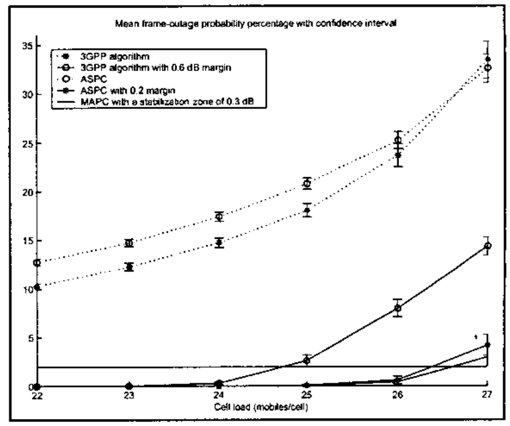

Fig. 4. The mean frame-outage probability percentage for different cell loads for a fixed mobile configuration. The horizontal line represents the 0.02 outage probability.

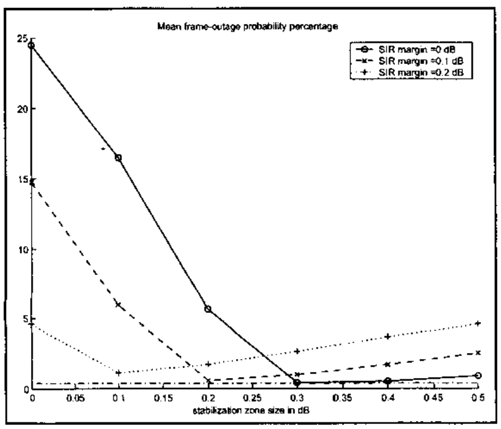

Fig. 3. The mean frame-outage probability percentage as a function of Φ for different values of M and with a cell load of 26 mobiles/cell.

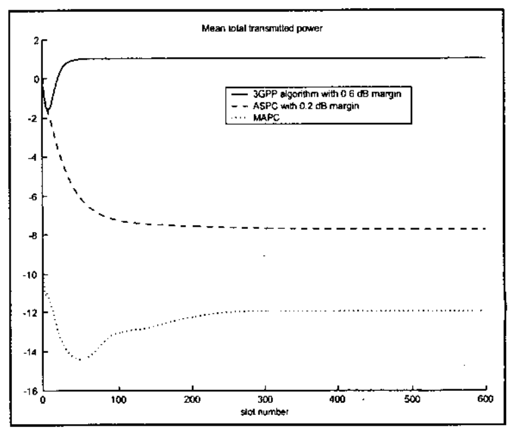

Fig. 5. The mean total transmitted power as a function of the slot number

mean frame-outage probability is 0.4%. Furthermore, the optimal value of Φ as a function of the SIR margin is a decreased function. We notice that the stabilization zone size changes slightly the mean frame-outage probability when no SIR margin is used and Φ is greater than 0.3 dB.

In figure 4, the mean frame-outage probability percentage is plotted as a function of the cell load. The 95% confidence interval is also plotted in this figure. As noted before, the 3GPP power control offers the maximum capacity when a 0.6 dB margin is added. The performance of the ASPC algorithm without margin is not satisfying due to amplifier precision ($\Delta_{\min} = 0.25$ dB). However, the ASPC algorithm with an SIR margin of 0.2 dB increases the system capacity from 24 to 26 mobile/cell (i.e. 8% increase from the maximum capacity offered by the 3GPP algorithm). Furthermore, the MAPC algorithm offers the best mean frame-outage probability without an SIR margin.

It should be noted that the mean frame-outage probability is considered without error detection and correction; therefore, the capacity of a real system will be higher when these procedures are used. Moreover, when the mean frame-outage probability reaches 10%, the call admission control blocks new mobile admissions to reduce the outage probability.

In figure 5, the mean total transmitted power is plotted as a function of the slot number. This figure shows that the MAPC algorithm reduces the transmitted power by 6 dB from the best configuration of the ASPC algorithm and 13 dB from the best configuration of the 3GPP algorithm. This power decrease is the result of the power stabilization which allows the elimination of the SIR margin.

We then analyze the performance of the studied algorithms when the terminals are moving in the system. Mobile speed is considered as time-constant. It has a uniform distribution between 0 and 30 km/h. The position of a mobile is updated when the mobiles moves 5 m. Figure

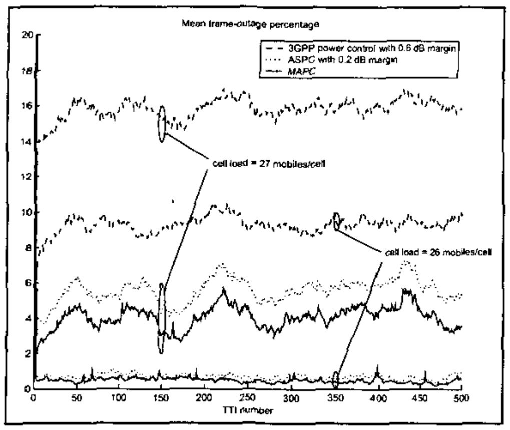

Fig. 6. The frame-outage probability percentage as a function of the TTI number when terminals are moving.

6 shows that the MAPC algorithm gives the least frame-outage probability without the need of an SIR margin. We can see also that the MAPC performance, compared to the ASPC algorithm, is enhanced when the cell load increases.

V. Conclusions

Adaptive power control algorithms have been studied in this paper. Moreover, an evolution of these algorithms has been proposed to limit oscillations around the target signal-to-interference ratio. The proposed algorithm is a simple variant of the 3GPP power control algorithm in which some intelligence is added to mobile and base stations. To limit oscillations, the modified adaptive power control algorithm forces the receiver to transmit an alternate sequence of up and down commands in a stabilization zone above the target SIR. The transmitter responds to this sequence by a power stabilization. An alternate up and down command sequence is also possible outside the stabilization zone. In this case, the transmitter also stabilizes its power. This phenomena may decrease the algorithm performance. However, the power stabilization is kept in one slot only; therefore, the algorithm performance is slightly influenced by this phenomena.

The MAPC algorithm has shown better performance than the 3GPP and the ASPC algorithms; system maximum capacity was increased and the power consumption has been reduced dramatically. This advantage is due to the elimination of the SIR margin. Simulations has shown also that the ASPC and MAPC preserves almost the same outage probability when mobility is considered. This stability is due to the adaptive power control step. Furthermore, the algorithm implementation does not increase the signaling load and slightly increases procedures complexity.

To increase the algorithm performance, a dynamic stabilization zone that depends on radio and services characteristics may be used for each mobile. This is left for future research.

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