Performance Analysis of Downlink Power Control in CDMA Systems

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***Abstract*— In this paper, we analyze three existing downlink power control algorithms and adapt an uplink power control algorithm for downlink. In addition, based on the concept of hysteresis, we propose an enhancement to this adapted algorithm in order to mitigate oscillations observed at low outage probabilities. Using simulation results, we show that the behavior of outage with number of iterations in our adapted algorithm converges as rapidly as the original algorithm; however the oscillations at low outage percentages have been reduced using our algorithms.**

Keywords: Adaptive multiple step, CDMA, downlink power control.

I. Introduction

Spread spectrum multiple access communication, in the form of Code Division Multiple Access (CDMA), is fast emerging as the driving technology behind the rapidly advancing personal communications industry. Power control refers to the strategies or techniques required to adjust, correct and manage the power from the base station *and* the mobile station in an efficient manner.

Downlink power control serves the following important functions [1], [2], [3], [4]:

- It equalizes the system performance over the service area (good quality signal coverage of worst–case areas).
- It provides load shedding between unequally loaded cells in the service areas by controlling the inter-cell interference to the heavily loaded cells.
- It minimizes the necessary transmission power level to achieve good quality of service. This reduces the co-channel interference in other cells, which increases the system capacity.

Power control is needed in CDMA systems to compensate for the interference caused by high-powered mobiles against weak ones within a cell. In a time-varying channel, the propagation environment is modeled as d^{-4} and the path loss range is of the order of 80 dB. Power control is also a solution to the near–far problem [5] which is caused by near-orthogonal codes that make other users appear as interference at the receiver. Hence, the use of power control reduces the average transmit power of interfering mobiles, thus conserving battery power at the affected mobile and offering a better quality of service.

In this paper, we propose two downlink power control algorithms and compare their performance with three existing algorithms using MATLAB simulations. Our algorithms achieve better performance in terms of faster convergence and fewer oscillations at low outages. Section II analyzes these five downlink power control schemes while Section III provides simulation results to compare their performances. Finally, Section IV concludes with future areas of research.

II. Downlink Power Control Algorithms

A. Distance Based Power Allocation Algorithm

The distance-based power allocation algorithm (DBPA) [6] uses the distance between base station and each mobile station to allocate transmitted power to each each of its served mobiles. No correction or feedback is provided; hence it is an open–loop power control mechanism.

If power control is not employed (*i.e.*, the transmitted power is same for all users), the most constrained value of the signal-to-interference ratio (SIR) will be for a user at the boundary of the cell. Thus, more transmitted power should be allocated to mobiles that have poor channel conditions.

The DBPA algorithm computes the transmitted power of mobile m according to the following equation:

$$p_m = kx^n_{a_m m} \tag{1}$$

$$\text{where, } x_{a_m m} = \begin{cases} \frac{d_{a_m m}}{R}, & \text{if } d_{a_m m} > d_{min} \\ \frac{d_{min}}{R}, & \text{if } d_{a_m m} \leq d_{min} \end{cases} \tag{2}$$

$k =$	positive constant
$n =$	real positive value
$R =$	maximum base-to-mobile distance
$d_{a_m m} =$	distance between mobile m and its assigned base station

In order to avoid having very small transmitted powers for mobiles close to the base stations, the same transmit power is assigned to all mobiles whose distance $d_{a_m m}$ is less than a certain threshold value d_{min}.

B. Distributed Balancing Algorithm

The distributed balancing (DB) algorithm [7] is an adaptive approach that uses the received SIR at the mobiles to adjust the transmit power of the base station in order to achieve better global transmission quality, *i.e.*, for the entire network.

The algorithm calculates the optimal transmit power assignment for each mobile within the cell, taking into consideration all the neighboring cells. The optimal trasmit power assignment for a mobile is proportional to the ratio of the total received power of the mobile to the link gain between its base station and itself.

If N_i denotes the number of communicating mobiles in cell i, B_j denotes the base j, M_{ik} denotes the mobile k in cell i, Z_{ikj} denotes the link gain from B_i to M_{ik}, and P_{ik} denotes the downlink power transmitted from B_j to M_{ik}, then the signal-to-interference ratio (SIR) at the kth mobile in the ith cell may be written as:

$$SIR_{ik} = \frac{P_{ik}Z_{iki}}{\Sigma_j \Sigma_{m=1}^{N_j} P_{jm}Z_{ikj} - P_{ik}Z_{iki}} \tag{3}$$

where it is assumed that self–jamming is more dominant on the SIR compared to the background noise and thus the latter may be neglected. If the SIR at any mobile station is balanced by the DB algorithm, the SIR_{ik} is independent of mobile k in cell i, *i.e.*, $SIR_{ik} = SIR_i$.

Rearranging (3) leads to:

$$P_{ik} = \frac{SIR_i}{1 + SIR_i} \frac{\Sigma_j \Sigma_{m=1}^{N_J} P_{jm}Z_{ikj}}{Z_{iki}} \tag{4}$$

Eq. (4) implies that the optimal transmitted power assignment for M_{ik} is proportional to the ratio of the total received power of this mobile to the link–gain between its home base and itself. By expressing $\Sigma_m P_{jm} = Q_j$, this may be written as:

$$(P_{ik})_{opt} \propto \frac{\Sigma_j Q_j Z_{ikj}}{Z_{iki}} \tag{5}$$

A new parameter C_{ik} may be defined as:

$$C_{ik} \cong \frac{\Sigma_j Q_j Z_{ikj}}{Z_{iki}} \tag{6}$$

The optimal power allocation is consequently obtained as:

$$P_{ik} = Q_i \frac{C_{ik}}{\Sigma_m C_{im}} \tag{7}$$

The operation of the DB algorithm may be summarized as follows:

1) The power allocation for each mobile station is calculated at the base station in a centralized manner (typically every 1.25 ms, or 800 times per second).
2) Each mobile estimates the SIR and the link–gain between its home-base and itself at the beginning of every control period, and transmits the measurements to its base station.
3) The base station assigns a certain downlink power based on this feedback.
4) As the base station updates its transmission power to each mobile based on their feedback, this affects the received power at each mobile, and the corresponding SIR.

The method arguably gives the best achievable performance, but is relatively difficult to implement and has additional overheads. It has been suggested [7] that if the cost of a separate high–bandwidth control channel were acceptable, then the DB algorithm is a suitable downlink power control method to guarantee high capacity and good quality of service.

C. Multiple Step SIR-based Power Control Method

Multiple step power control (MSPC) [7] is a closed–loop power control algorithm in which feedback from the mobile is used to adjust the transmitted power of the base station. The update is based on the average SIR received at the mobile, and the adjustments usually occur in multiple steps, which explains the name.

The steps involved in the operation of the MSPC algorithm are:

1) The mobile stations measure the SIR over time and compare them with a pre-determined threshold.
2) If the observed SIR is larger than the threshold, then the mobile sends a power–down command to the base station. Otherwise, it sends a power–up comand.
3) The base station interprets the command from step 2 and updates the transmit power accordingly.
4) The power control updates usually take place in multiple fixed-size steps. This distinction is important in the light of Adaptive Step Power Control (ASPC) [8], discussed in the next subsection.

D. Adaptive Step Power Control

The Adaptive Step Power Control (ASPC) [8] is a closed–loop power control mechanism that was originally proposed for uplink transmission using adaptive step sizes as opposed to fixed step sizes, in order to achieve faster convergence towards the target SIR. In our study, we have adapted this algorithm for downlink transmission using the following steps:

1) The mobile stations measure the observed value of the SIR at each iteration and compare them with a preset threshold value.
2) If the observed SIR is larger than the threshold, then the mobile sends a power–down command to the base station. Otherwise, it sends a power–up comand.
3) The first power update command is interpreted as a fixed step modification, as suggested in [7]. However, we adapt the step size dynamically if successive feedback commands request additional change in the power level in the same direction, to ensure faster convergence.
4) The base station interprets the power control command from each mobile station and updates the transmit power accordingly.
5) The power control updates take place in multiple steps of different sizes.

E. Modified Adaptive Step Power Control (with buffer)

The modified adaptive step power control algorithm (M-ASPC) is our enhancement to the adaptive step power control algorithm proposed in [8]. In the ASPC algorithm, we observed that while the outage plot had a faster convergence rate than MSPC [7], there was significant instability even at low outage percentages. This can be attributed to a single threshold value separating the outage and non-outage regions.

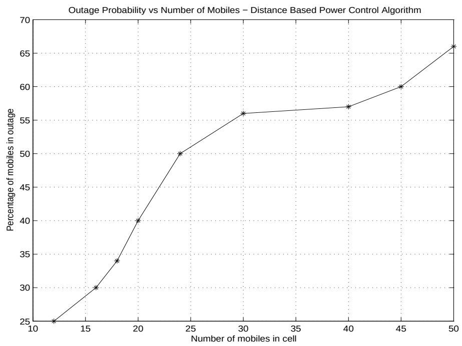

Fig. 1. Outage percentage versus number of mobiles for the Distance–Based Power Allocation algorithm.

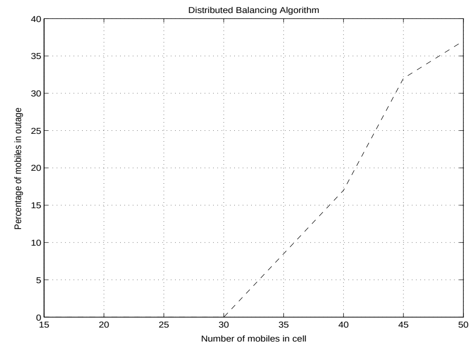

Fig. 2. Outage percentage versus number of mobiles for the Distributed Balancing Power Control algorithm.

As a result, the mobiles toggled between the two regions whenever they were near the threshold. In order to mitigate this effect, we introduced a buffer region that resulted in two threshold levels– the *lower critical threshold* and the *upper critical threshold*. We observed an increase in stability due to the buffer, which provided a memory–based damping effect similar to hysteresis.

The steps of operation in the M-ASPC algorithm are as follows:

1) The mobile stations measure the observed value of the SIR at each iteration and compare them with the preset lower and upper critical threshold values.
2) If the observed SIR is smaller than the lower critical threshold, then the mobile sends a power–up command to the base station. The first power update command is interpreted as a fixed step modification; however, we dynamically adjust the step size if successive feedback commands request additional change in the power level in the same direction.
3) If the observed threshold is between the lower and the upper critical threshold values, then the mobile does *not* send any control signal to the base station. Thus, we eliminate the oscillations observed at low outage percentages in MSPC.
4) The increment size is chosen larger than the decrement size. This ensures that mobiles in outage can quickly come out of outage.
5) Once the mobiles are out of outage and not in the buffer region, the smaller decrement size brings the mobile back into the buffer region.

III. Simulation and Results

We carried out the performance analysis and comparison of the power control algorithm using MATLAB. The following assumptions were made:

1) Characteristics of each forward link are independent and identical.
2) There are a fixed number (M) of mobile stations per cell.
3) The mobiles are located uniformly within the cell.

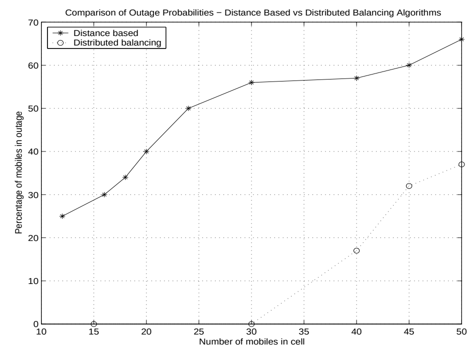

Fig. 3. Comparison of outage percentages versus number of mobiles in the cell for distance-based and distributed balancing algorithms.

4) All mobiles are listening at all times.
5) Outage is defined as the condition when the observed value of the SIR is below the threshold value ($\text{SIR}_{\text{threshold}} = -14$ dB [7]).

A. Non–Iterative Algorithms

Both the DBPA and DB algorithms are non–iterative since the power assignments are decided on the basis of the initial SIR values. Consequently, our simulation results in Figs. 1 and 2 show that the percentage of nodes in outage increases with the number of mobiles in the cell. Furthermore, Fig. 3 shows that the performance of DBPA is worse than DB since it uses only the individual distance of the mobile from the base station as the metric for power allocation.

B. Iterative Algorithms

In MSPC, because of the feedback mechanism, the percentage of nodes in outage decreases with the number of iterations as seen in Fig. 4. However, since MSPC uses fixed step sizes, the outage percentage falls off at a slower rate. This is remedied by using adaptive step sizes in the ASPC algorithm. This results in a faster reduction of the outage percentage as seen in Fig. 5. However, we notice oscilations due to the single threshold separating the outage and non–outage regions. We introduce a buffer zone based on hysteresis in M-ASPC and eliminate the oscillations completely while maintaining a

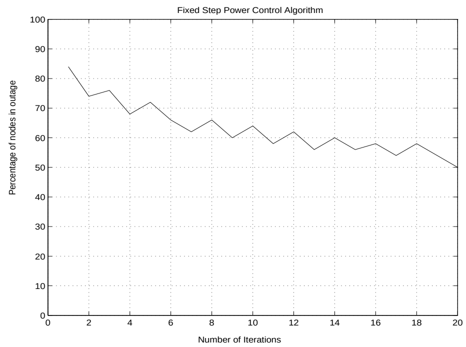

Fig. 4. Outage percentage versus number of iterations for the Multiple–Step SIR-based Power Control algorithm.

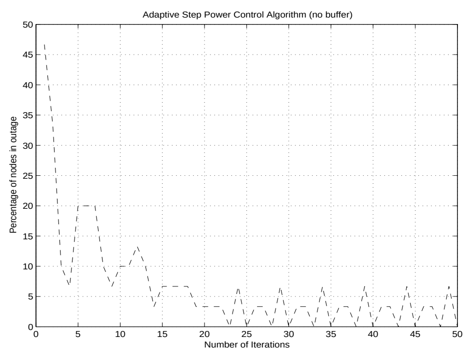

Fig. 5. Outage percentage versus number of iterations for the Adaptive Step Power Control algorithm.

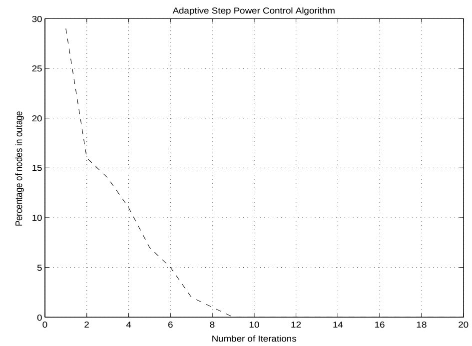

Fig. 6. Outage percentage versus number of iterations for the Modified Adaptive Step Power Control algorithm.

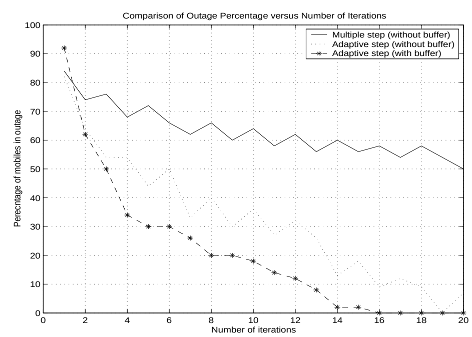

Fig. 7. Comparison of outage percentage versus number of iterations for different adaptive step power control algorithms.

comparable rate of reduction of outage percentage, as seen in Fig. 6.

Fig. 7 provides an instructive comparison of the three iterative algorithms in terms of outage percentage versus the number of iterations and confirms that the M-ASPC algorithm performs better than the existing algorithms.

IV. Conclusion

We have analyzed the performance of both iterative and non–iterative power control techniques using MATLAB. Amongst the non–iterative algorithms, DB power control performed better than the DBPA algorithm. On the other hand, our M-ASPC algorithm outperformed both ASPC and MSPC in terms of rate of reduction of outage probability and convergence.

Future work in this area includes extending the idea of hysteresis for multiple cell scenarios and consideration of power limitations at the base station. Also, the performance with mobility models could be studied for situations where a mobile moves from one base station to another (*i.e.*, handoff control).

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