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PERFORMANCE ANALYSIS OF CDMA POWER CONTROL ALGORTHIMS

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ABSTRACT
It is well known that power control plays a very important role in CDMA cellular system when mobile subscriber moves in the cell, especially when very close to the border; the realization of power control is practically based on the result of the detection of signal power. So different techniques are analyzed in details such as distributed balancing, distance based and constrained power control. Also Stepwise Optimal Removal Algorithm (SORA) is introduced and evaluated to enhance Carrier to Interference Ratio (CIR) and capacity compared with previous techniques where the outage probability remains relatively low at higher users.

تحليل اداء خوارزميات سيطرة القدرة لأنظمة CDMA

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الموجز
من المعروف ان (power control) يلعب دور مهم جدا في الأنظمة الخلوية بأستخدام تكنولوجيا (CDMA)أثناء حركة المحطة المتنقلة (mobile) في داخل الخلية، خصوصا عندما تكون قريبة جدا من حدود الخلية؛ يعتمد power) control) عمليا على تحسس قوة الأشارة. تم في هذا البحث دراسة وتحليل تقنيات مختلفة مثل balancing) (distributed و (distance based) و (constrained power) control. بالأضافة الى تقديم وتقييم خوارزمية (Stepwise Optimal Removal Algorithm) SORA لتقليل التشويش وزيادة السعة مقارنة بالتقنيات السابقة حيث يبقى (outage probability) منخفض نسبيا مع زيادة عدد المستخدمين.

ABBREVIATIONS
g_{mb}: Link gain between mobile m and its home base station b
P_j: Total power
$\emptyset_{bm}$: Total power received at mobile m
BER: Bit Error Rate
CDMA: Code Division Multiple Access
CIR: Carrier to Interference Ratio
E_b/N_o: Energy per bit over the total Noise spectral density
FDMA: Frequency Division Multiple Access

I_b: Index of the mobiles assigned to base station b.
IS-95: Interim Standard - 95
n_m: noise power of mobile m
p_{bm}: power allocated to mobile m from base station b
p_{max}: maximum power per mobile.
P_T: Total power transmitted by each base station
R: Bit Rate
r: Distance from base station b
SIR: Signal to Interference Ratio
SORA: Stepwise Optimal Removal Algorithm
TDMA: Time Division Multiple Access
W: Channel band width
Z: Normalized downlink gain matrix
λ: Path loss exponent of the system

INTRODUCTION

CDMA technology has many features such as higher user capacity compared to traditional technologies such as FDMA and TDMA, universal frequency reuse, multipath rejection, interference rejection, and communication security (**M. Zorzi, 1994**). Power control is one of the most important issues in a CDMA system because it has a significant impact on both performance and capacity it is the most effective way to avoid the near-far problem and to increase capacity (**W.Tam and F. Lau., 1997**). Power control refers to the strategies or techniques required in order to adjust, correct and manage the power from the base station and the mobile station in an efficient manner. In the IS-95 system (**TIA/EIA Interim Standard-95, 1993**), downlink power control was far less sophisticated than uplink power control, resulting in the downlink capacity being more constrained than uplink (**Lei Song and Jack Holtzman, 1998**), and (**Tatcha Chulajata and Hyuck Kwon, 2000**). Downlink power control serves the following important functions (**Andrew Viterbi, 1995**), and (**Kaveh Pahlavan and Allen Levesque, 1995**)

1. Equalizes the system performance over the service area (good quality signal coverage of worst-case areas).
2. 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.

CAPACITY OF A CDMA SYSTEM

The main parameters that affect the capacity of CDMA system are:

1. **Carrier to Interference Ratio (CIR) / Signal to Interference Ratio (SIR):**

The CIR and SIR terms are often used interchangeably even though there is a slight difference between the two, if power control is not implemented many problems such as the near-far effect will start to dominate and consequently will lower the capacity of the CDMA system. However, when the power control in CDMA systems is applied, it allows users to share resources of the system equally between themselves, leading to increased capacity. Gain in CIR can be utilized for increasing the number of users per cell in CDMA, and thus, improvements in system capacity can be achieved. The definition of the CIR will be defined as the ratio of the unmodulated desired signal power over the unmodulated interference power. This can be written mathematically as (**Nuaymi, Godlewski, 2001**), and (**Abdurazak Mudesir, 2004**):

$$CIR_m = \frac{g_{mb}\, p_{bm}}{\sum_{j=1}^{B} g_{mj}\, P_j - g_{mb}\, p_{bm} + n_m} \quad (1)$$

which describes the CIR of mobile m as a ratio, where the numerator is the link gain between mobile m and its home base station b (g_{mb}), multiplied by the power allocated to mobile m (p_{bm}). The denominator is the sum of all the link gains from mobile *m* to the *B* base stations in the system multiplied by their total transmitted power ($\sum_{j=1}^{B} g_{mj}\, P_j$), subtracted by the desired carrier power which corresponds to the numerator($g_{mb}\, p_{bm}$), and adding the receiver noise power of mobile m (n_m). However the receiver noise power is usually neglected. Link gain is the magnitude change of a signal travelling along a link expressed as a factor. In CDMA, because the information is spread across a large bandwidth, it is able to have a large processing gain so that it can operate with a CIR less than 1, meaning that the interference power is larger than the carrier power. Practically, CDMA system requires typically a CIR of around -17dB to operate.

2. **Eb/No:**

The energy per bit over the total noise spectral density E_b/N_o, is often used as the real quality indicator for adequate performance and is sometimes called the despread SIR. It is related to the CIR (**Nuaymi, Godlewski, 2001**):

$$CIR = \frac{E_b}{N_o}\,\frac{R}{W} \quad (2)$$

Where R is bit rate, and W is channel band width.

3. **Outage Probability:**

It is usually referred as the probability that the CIR of a mobile falls below a required threshold, outage probability is often used to evaluate the performance and capacity of a CDMA system. In some papers, it is defined as the ratio of the number of disconnected or handed over users to that of the total users in the system (**Nuaymi, Godlewski, 2001**). Therefore, a mobile is considered in outage in simulation if its CIR is below the minimum required CIR (-17dB) or if the mobile is disconnected from the system.

4. **BER**

As the name implies, a bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. If the medium between the transmitter and receiver is good and the signal to noise ratio is high, then the bit error rate will be very small - possibly insignificant and having no noticeable effect on the overall system.

However if noise can be detected, then there is chance that the bit error rate will need to be considered. BER is often used as the quality measurement of a system because in practical system, CIR will be time-variant therefore the average CIR will not be related to the average BER (**D. Novakovic and M. Dukic, 2000**), and (**L. William, 1991**).

POWER CONTROL ALGORITHM

With appropriate power control, the CDMA offers high capacity in comparison to FDMA and TDMA. Since CDMA systems do not explicitly schedule time or frequency slots among users, the central mechanism for resource allocation and interference management is power

control. Each use changes its access to the resources by adapting its transmitting power to the changing channel and interference conditions. Therefore power control is a significant design problem in CDMA systems. Power control encompasses the techniques and algorithms used to manage the transmitted power of base stations and mobiles. Power control helps to reduce co-channel interference, increasing the cell capacity by decreasing interference and prolonging the battery life by using a minimum transmitter power.
In CDMA systems power control insures distribution of resources among users. When power control is not implemented, all mobiles transmit their signal with the same power without taking into consideration the fading and the distance from the base station, in this case mobiles close to the base station will cause a high level of interference to the mobiles that are far away from the base station (**Abdurazak Mudesir, 2004**).
Generally there are two possible groups of power control schemes, distance driven and CIR driven. Distance driven schemes are open-loop schemes that try to estimate the distance between the base station and the mobile based on the received signal strength at the mobile. From this estimate, which it receives from the mobile, the base station will increase signal power or decrease signal power depending if the mobile is close or far away. These types of schemes are best suited for non-shadowed environments as signal strength will be a more accurate estimate of distance. The CIR driven schemes uses a closed loop mechanism to balance the CIR of each mobile so that the cell or system has the maximum common CIR possible. In these schemes, each mobile will send its CIR to the base station, and the base station will then decide whether to increase or decrease signal power to the mobile based on the CIR ratio (**R. Prasad, 1996**).

Distributed Balancing Power Control

The aim of this algorithm is to determine the transmitted power to each mobile to ensure that the received CIR is the same for all mobiles within the cell. This is achieved by balancing the link quality for all the users within each cell, i,e. calculates the optimal transmit power assignment for each mobile within the cell, taking into consideration all the neighboring cells. This algorithm is distributed in the sense that each cell operates independently of other cells only the received powers and an estimate of the link gain between the mobile and base station is needed. To achieve this, feedback is needed to report the received power at each mobile, and the base station needs to estimate the link gain between the base station and mobile (**Andrew Viterbi, 1995**), (**Kaveh Pahlavan and Allen Levesque, 1995**), and (**D. Kim, 1999**)

$$\overline{\mathrm{CIR}}_b = \max, \min\left(\frac{g_{mb}\, p_{bm}}{\sum_{j=1}^{B} g_{mj}\, p_j - g_{mb}\, p_{bm} + n_m}, \quad m \in I_b \right) \tag{3}$$

The above link quality balancing problem is solved by maximizing the minimum CIR for all users in the cell. If we assume n_m is negligible, this can be solved by the following steps:

$$\emptyset_{bm} = \frac{\sum_{j=1}^{B} g_{mj}\, p_j}{g_{mb}} \tag{4}$$

$$\Phi_b = \sum_{m \in I_b} \emptyset_{bm} \tag{5}$$

Where I_b is the index of the mobiles assigned to base station b.

Essentially $(\emptyset_{bm})$ represents the total power received at mobile m, normalized to the link gain to its home base station B. This value can then be used to calculate the weighting or fraction of the total base station power mobile m should receive. The power allocated to mobile m by its home base station b, therefore it's calculated by:

$$p_{bm} = \frac{\emptyset_{bm}}{\Phi_b} P_b \qquad (6)$$

The result of this power control algorithm is that all mobiles of base station b will have a common CIR:

$$\overline{CIR}_b = \frac{P_b}{\Phi_b} \qquad (7)$$

Distance Based Power Control

It is an open loop power control algorithm as there is no feedback involved. Assuming that the base station can estimate the distance of a mobile based on the received signal strength, then it allocates power to users based solely on their distance from their home base station. Therefore it tries to improve the system's performance by giving mobiles far away from the base station more power to increase their CIR, and reducing the power to the close in mobiles which already experience a high level of CIR. The power allocation to any mobile m throughout the cell serviced by base station b is based on the following formula (**Andrew Viterbi, 1995**), (**L. William, 1991**), and (**R. Gejji, 1992**):

$$P_{bm} = F_m \; p_{max} \qquad (8)$$

Where F_m is a fraction represented by:

$$F_m = \begin{cases} \left(\frac{r}{R}\right)^n & \text{if } d_{min} \le r \le R \\ \left(\frac{d_{min}}{R}\right)^n & \text{if } 0 \le r \le d_{min} \end{cases} \qquad (9)$$

Where n is the power control factor, r is the distance from base station b to the corresponding mobile m which has been assigned to it, R is the radius of the cell, and d_{min} is a value that represents the distance at which the power allocation stays constant. The purpose of d_{min} is that if a mobile is very close to the base station, according to the power allocation formula, it will receive very little power that it might now have a lower CIR than the far users. Therefore, a value called d_{min} is set so that there is a minimum on how much power can decrease by. L. William (**L. William, 1991**) concluded that the best choice for n is 2, with a corresponding d_{min} of 0.55R. The choice of n=2 however is best for a system where no fading has been considered as in L. William's case. If a system is analyzed with fading, then the choice of n=4 would be more appropriate.

If cell 1 is the home cell, then x_1= r. therefore the power received from the home base station and the power received from the other base stations are:

$$P_{home} = P_T \; x_1^{-\lambda} \qquad (10)$$

$$P_{other} = \sum_{i=1}^{18} P_T \; x_1^{-\lambda} \qquad (11)$$

Where P_T is the total power transmitted by each base station and is assumed to the same for all the base stations, and λ is the path loss exponent of the system.
The total interference factor is defined as

$$x_I = \left(\sum_{i=1}^{18} x_i^{-\lambda}\right) r^{\lambda} \tag{12}$$

The total power received is:

$$P_{rec} = P_{home} + P_{other} \tag{13}$$

$$P_{rec} = P_T \,.\, r^{-\lambda} .\, x_I \tag{14}$$

$$P_{bm} = F_m \, p_{max} \tag{15}$$

Where:

$$F_m = \begin{cases} \left(\frac{r}{R}\right)^n & \text{if } d_{min} \le r \le R \\ \left(\frac{d_{min}}{R}\right)^n & \text{if } 0 \le r \le d_{min} \end{cases} \tag{16}$$

p_{bm} is the power allocated to mobile m in base station b, and p_{max} is the maximum power per mobile.
If the hexagonal cells can be approximated by circular cells with radius R, then the density will be:

$$\rho = \frac{N}{\pi R^2} \tag{17}$$

Then the total transmitted power is P_T:

$$P_T = \frac{N}{\pi R^2} \int_0^{2\pi} \int_0^{R} p_{bm} .\, r dr d\theta \tag{18}$$

$$P_T = N p_{max} \left[\frac{2}{n+2} + \frac{n}{n+2} \left(\frac{d_{min}}{R}\right)^{n+2}\right] \tag{19}$$

$$f(d_{min}) = \left[\frac{2}{n+2} + \frac{n}{n+2} \left(\frac{d_{min}}{R}\right)^{n+2}\right] \tag{20}$$

$$P_T = N .\, p_{max} \,.\, f\,(d_{min}) \tag{21}$$

$$CIR = \frac{p_{bm} \; r^{-\lambda}}{P_T \; x_I \; r^{-\lambda} - p_{bm} \, r^{-\lambda}} \tag{22}$$

Constrained Power Control:
This algorithm is based on the same concept as the distributed balancing algorithm except there is a constraint on the maximum base station transmitter power, with the aim to

minimize this power. This algorithm can be operated distributedly with no centralized control of the cells. Each cell in the system balances the link gains in its cell so that all the mobiles have the largest common CIR. Following this, the base station of each cell adjusts its total transmitting power by reducing its total power by a calculated factor, if the common CIR of a particular cell is above the minimum required CIR. If the common CIR is below the minimum required CIR, no adjustment is made. The power adjustment factor is equal to $CIR_{common}/CIR_{required}$. The result of this base station power adjustment process is that it will try and balance the common CIR of each cell throughout the system (**Q. Wu, 1999**), and (**D. Kim, 1999**).

$$\overline{CIR}_b = \max, \min\left(\frac{g_{mb}\, p_{bm}}{\sum_{j=1}^{B} g_{mj}\, P_j - g_{mb}\, p_{bm} + n_m},\quad m \in I_b \right) \tag{23}$$

$$\emptyset_{bm} = \frac{\sum_{j=1}^{B} g_{mj}\, P_j}{g_{mb}} \tag{24}$$

$$\Phi_b = \sum_{m \in I_b} \emptyset_{bm} \tag{25}$$

Where I_b is the index of the mobiles assigned to base station b.
The power allocated by base station b to mobile m is:

$$p_{bm} = \frac{\emptyset_{bm}}{\Phi_b}\; P_b \tag{26}$$

The result of this power control algorithm is that all mobiles of base station b will have a common CIR of:

$$\overline{CIR} = \frac{P_b}{\Phi_b} \tag{27}$$

STEPWISE OPTIMAL REMOVAL ALGORITHM (SORA):

It is possible that if there are too many mobiles per cell, the common CIR of some cells or all cells is below the required CIR. Therefore, some mobiles will need to be disconnected from the system to improve the CIR of the other mobiles. A simple strategy that is introduced is that after L iterations, if the common CIR of a cell is below the required CIR, then the mobile that requires the most power from the base station is disconnected. This continues until the CIR of all mobiles in that cell is at or above the required CIR, where all the link gains of every mobile to every base station of a cellular system are known to a central computer, and from which the power allocation to every mobile is calculated has been explored by a number of people.

In order to balance the huge number of link gains in a cellular system, an eigenvalue problem needs to be formulated. The problem is that in CDMA systems, because all users in a cell share the same frequency bandwidth, this will result in three dimensional link gain matrices. CDMA downlink power control problem was successfully formulated into an eigenvalue problem by assuming that the CIR within a cell is balanced, therefore he was able to simplify the link gain matrix into two dimensional (**Q. Wu, 1999**).

It is possible that after solving the link quality balancing problem of the system (and hence balance the CIR of the system) that the value of the CIR for all the mobiles might be inadequate, therefore there needs to be some sort of strategy to disconnect mobiles to improve the overall quality of the system. This includes the Stepwise Optimal Removal Algorithm (SORA) which gives a good approximation to the upper performance bounds of a power control algorithm, this is as following:

1. Determine CIR^* corresponding to the Z matrix. If $CIR^* \geq$ CIR required, then use corresponding eigenvector $P^*$and stop, else set M'=M.
2. Remove mobile k, where the CIR^* of the remaining system is the largest. This forms a new matrix Z' with a size of (M'-1) x (M'-1). Determine CIR^* corresponding to Z' and if $CIR^* \geq$ CIR required, then use corresponding eigenvector $P^*$and stop, else set M'=M-1 and repeat step2.

SYSTEM MODEL:

This CDMA cellular system consists of N cells with M active mobiles. The total interference experienced by a mobile consists of the sum of the powers of the other M-1 active mobiles. Each of the m mobiles in cell k is mapped to i, where 1> i > M. Using these notations, we can write the CIR of mobile i as:

$$CIR_i = \frac{G_{ik} p_i}{\sum_{j \neq i}^{M} G_{il} p_j} \tag{28}$$

Where k and i are the cells which mobile i and j belong to G_{ik} is the link gain between mobile i and its home base station in cell k. p_i is the power allocated to mobile i in cell k. p_i is the power allocated to mobile j in cell l. G_{il} is the link gain between i and the interfering base station in cell l.

By normalizing the link gain:

$$CIR_i = \frac{p_i}{\sum_{j \neq i}^{M} p_j \ Z_{ij}} \tag{29}$$

Where,

$$Z_{ij} = \begin{cases} \frac{G_{il}}{G_{ik}}, & i \neq j \\ 0, & i = j \end{cases} \tag{30}$$

The normalized downlink gain matrix Z = $\{Z_{ij}\}$

$(CIR)_{maximum}$ is denoted by CIR^* is equal to:

$$CIR^* = \frac{1}{\lambda^*} \tag{31}$$

Where λ^* is the largest real eigenvalue of the Z matrix, and P^*, the vector of the power allocations to achieve CIR^*, is the corresponding eigenvector.

SIMULATION RESULTS:

DISTRIBUTED BALANCING POWER CONTROL:

Figure 1 shows the results for the system-level analysis of the distributed balancing power control. The distributed balancing power control is able to achieve a maximum capacity of 26 users/cell at 0% outage probability.

DISTANCE BASED POWER CONTROL:

Figure 2 shows the results for the system-level analysis of the distance based power control. The distance based power control is able to achieve a maximum capacity of 26 users/cell at 0% outage probability

CONSTRAINED POWER CONTROL:

Figure 3 shows the results for the system-level analysis of the constrained power control. The constrained power control is able to achieve a maximum capacity of 35 users/cell at 0% outage probability. A simple disconnection strategy was used which was the mobile that requires the most power (and hence would improve the cell's common CIR the most) would be disconnected. Essentially, the only outage that occurs in this algorithm is the number of users disconnected as the algorithm continues to disconnect users until the system's CIR is greater or equal to the minimum required CIR. Therefore the outage probability in this algorithm is the number of disconnections over the total number of users in the system.

STEPWISE OPTIMAL REMOVAL ALGORITHM (SORA):

Figure 4 shows the results for the system-level analysis of Stepwise Optimal Removal Algorithm power control. It is able to achieve a maximum capacity of 37 users/cell at 0% outage probability. **Figure 5** shows the results of all the power control algorithms.

CONCLUSION:

The Stepwise Optimal Removal Algorithm power control and constrained power control are clearly have a better performance at 0% outage probability, with the Stepwise Optimal Removal Algorithm power control edging out the constrained power control by two users/cell. Their outage probabilities also remain relatively low at higher users per cell as it increases steadily unlike the distance based and distributed balancing which increases rapidly soon after exceeding 0% outage. The distance based power control clearly appears to be very similar to the distributed balancing power control in terms of performance with a very similar outage curve.

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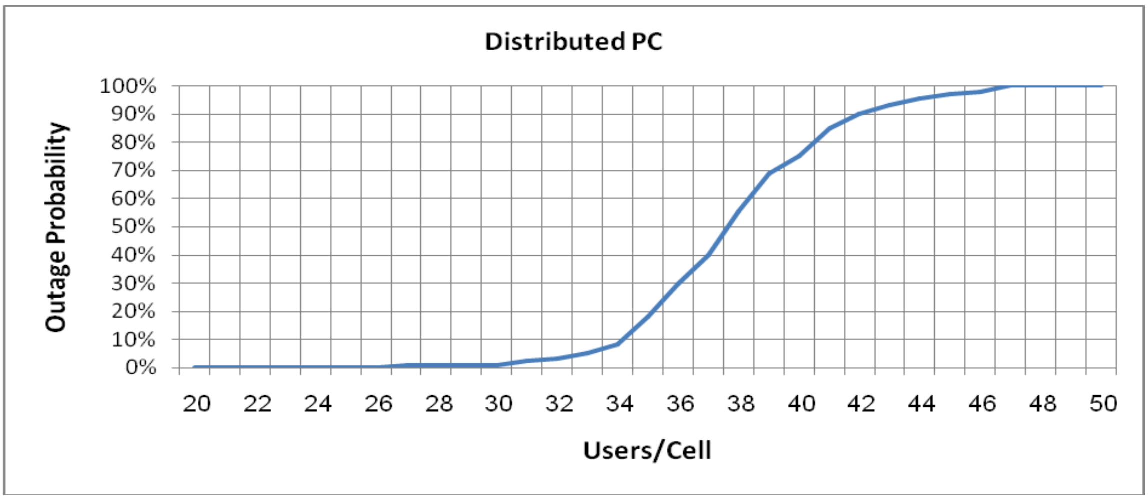

Figure 1 distributed balancing power control.

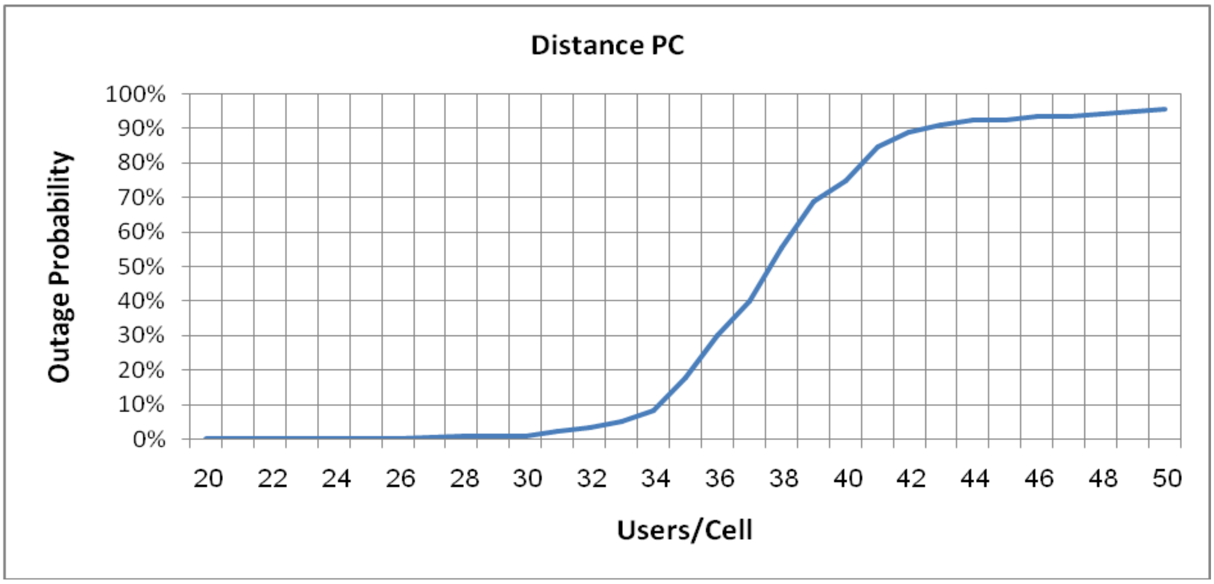

Figure 2 distance based power control.

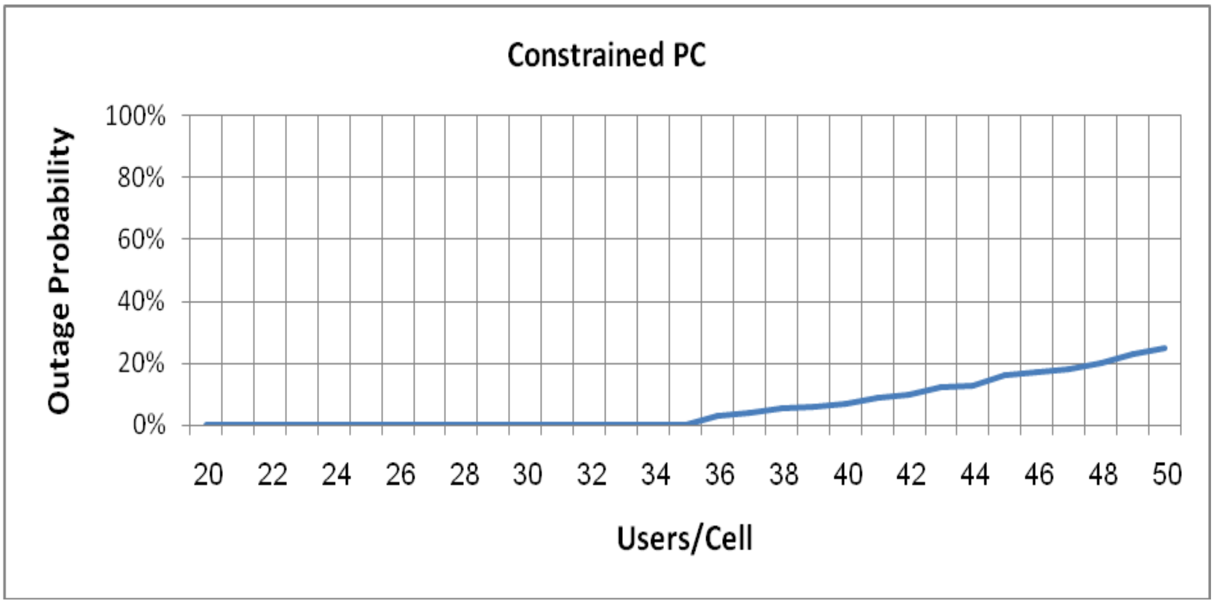

Figure 3 constrained power control.

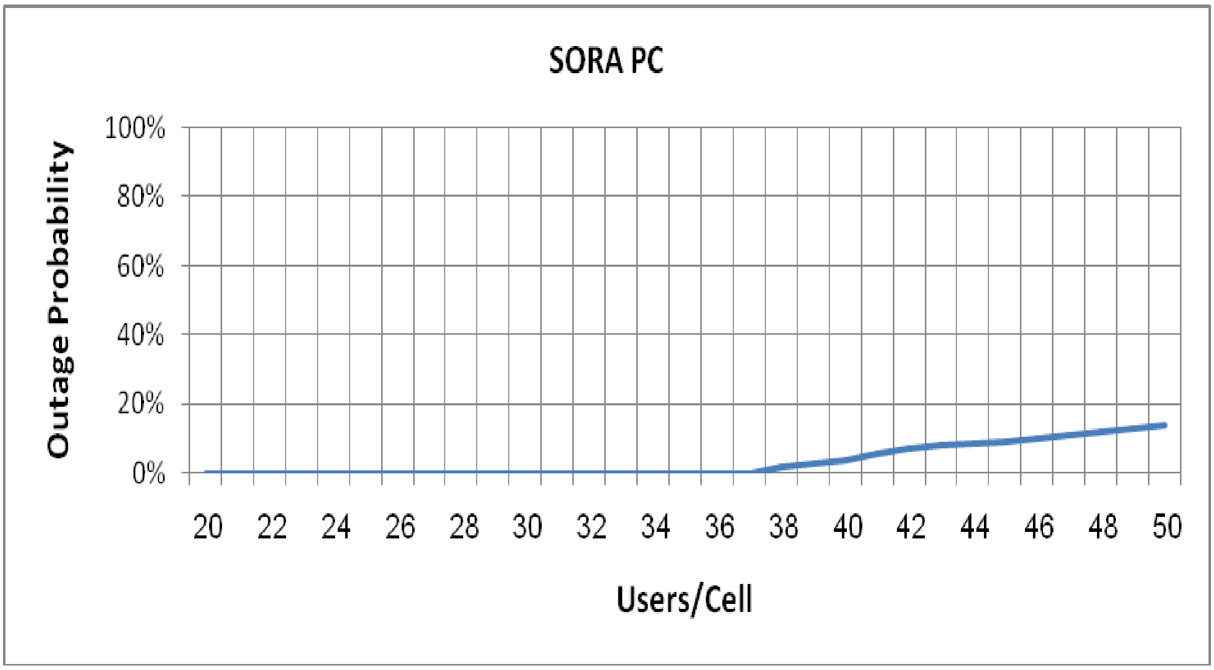

Figure 4 Stepwise Optimal Removal Algorithm.

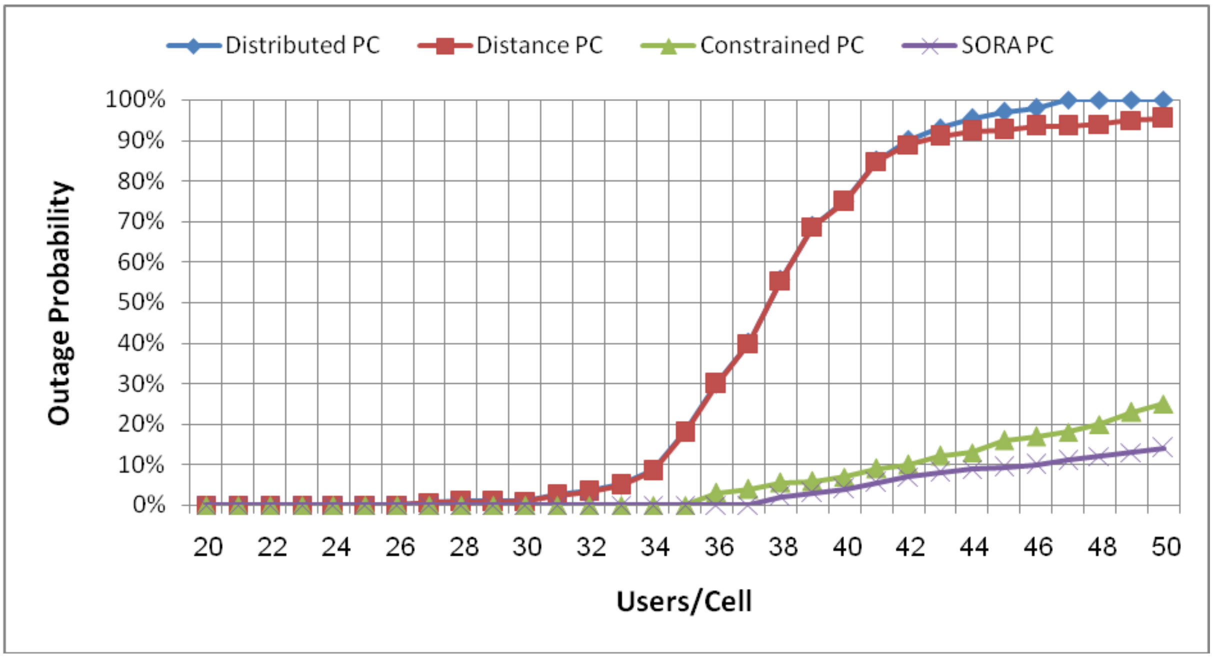

Figure 5 distributed, distance, constrained, and SORA PC.