Power-Controlled Rate and Coverage Adaptation for WCDMA Cellular Networks

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***Abstract*—To efficiently utilize the limited spectrum of interference limited Wide-band Code-Division Multiple-Access (WCDMA) cellular networks, transmission rates allocation and base station association for mobile users need to be optimal. In this paper, *Power-Controlled Rate and Coverage Adaptation (PCRCA)* module is proposed to balance network load, maximize number of users admitted to the system while assuring their Quality of Service (QoS) requirements. It is a cooperative scheme which allows nearby sectors of two adjacent cells to dynamically change their coverage to meet the optimal transmission rates allocation for their mobile users. A heuristic algorithm is implemented to solve an optimization model of the proposed scheme. The obtained power and capacity gains as well as outage probability of the proposed algorithm is compared to the obtained results of a system with only power-controlled rate adaptation mechanism.**

I. Introduction

Since it is interference limited, Wide-band Code-Division Multiple-Access (WCDMA) cellular networks' capacity is greatly affected by the number of users simultaneously granted access to the system. Therefore, an approach for maximizing the number of users in the system while maintaining their Quality of Service (QoS) requirements is desirable. For this approach to be successful, it has to consider users' transmission rates and dynamic network coverage jointly with a power control mechanism. For code-division multiple-access (CDMA) systems, power control is employed to maintain the received power of the users nearly equal to a desired level which minimizes interference and controls near-far problem [1][4]. This level is maintained by the signal to interference ratio (SIR) parameter which defines the acceptable received signal level for a modem to be able to decode the received signal correctly [4]. Mobile users transmission powers and their assigned transmission rates as well as user's processing gain are key factors in determining the user received SIR level [4][5].

The current static deployment of WCDMA wireless cellular networks is based on predefined traffic patterns. Practically, however, traffic patterns change dynamically and temporally users' mobility and heterogonous service activities. Accordingly, traffic load distribution may become unbalanced between network cells[1], negatively affecting system efficiency. Moreover, in interference limited wireless systems such as Universal Mobile Telecommunication Systems (UMTS), there is a direct interdependence between coverage and capacity [4][7]. Therefore, static system design results in wastage of possibly utilized wireless spectrum when traffic intensity varies over a network service area. Therefore, it is essential for such systems to reactively configure coverage and capacity to maximize network utilization and, hence, operator revenue.

Recently, we introduced a coverage adaptation module called Directional Cell Breathing (DCB) and mathematically analyzed [2]. The DCB dynamically and jointly adjusts the serving area of nearby sectors of two neighboring cells whose load is unbalanced. The proposed module has been evaluated using a static simulation for a single transmission rate traffic [3]. The results have shown a considerable performance improvement in WCDMA resource utilization.

In this paper, a framework is proposed to study the effect of integrating the DCB approach with power-controlled rate adaptation for large scale WCDMA systems. When a hotspot is formed, the scheme is invoked to evaluate the optimal coverage combination of nearby cell sectors for balancing their load. The activated coverage has to guarantee the maximum possible rate allocation for the users of both sectors given that their transmission powers are maintained at a minimum level, network throughput is maximized and outage probability is minimized.The link level QoS parameters are evaluated to assess the performance of the proposed scheme. These results are compared to the results of a Fixed Pilot Power (FPP) allocation scheme of a power-controlled multirate adaptation scheme.

The remainder of the paper is organized as follows. The related work is outlined in Section II. The *PCRCA* module is presented in Section III. The simulation setup and results analysis are provided in Section IV. Concluding remarks and directions for future work are made in Section V.

II. Motivation and Related Work

Several approaches in minimizing congestion, balancing load and maximizing capacity of WCDMA systems are proposed in the literature. These are typically transmission power, transmission rate, and coverage control adaptation algorithms, which has been either proposed individually or in combination. In this section, we highlight some of these algorithms, which is related to our work herein.

[1] In this paper, cells and sectors are used interchangeably.

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A. Power and Rate Control in WCDMA Cellular Networks

In interference limited systems, such as WCDMA networks, for a mobile received signal to be decoded properly its received signal-to-interference-noise ratio *(SIR)* needs to be above a certain threshold. For such systems, every mobile user received signal is degraded by other mobiles received signals[2]. Therefore, given *M* mobile users simultaneously accessing the system, the received *SIR* of mobile user *m* can be stated as:

$$SIR_m = \frac{g_{mb} p_m}{\sum_{l \neq m}^{M} g_{lb} p_l + I_{inter} + N_o} \qquad (1 \leq m, l \leq M) \tag{1}$$

where g_{mb} and p_m are the channel gain to the base station *b* and the transmission power of mobile user *m* respectively, g_{lb} and p_l are the channel gain and the transmission power of other mobile users *l* in the same cell respectively, I_{inter} is the inter-cell interference and N_o is the background noise power at the base station.

Transmission power control mechanism is a key factor in maintaining users' received signal levels above a certain threshold. The literature is rich with such power control algorithms [8][9][11][12][13][14]. In such algorithms, a power vector $P = [p_1, p_2, \ldots, p_M]^T$ is defined which tries to maintain the *M* mobile users' *SIR* levels above a predefined target γ_m^{tar}. This value is achievable by a power control algorithm if there exists a power vector $\mathbf{P} > 0$ (i.e. $(p_m > 0)$ for all *M*), such that $\gamma_m \geq \gamma_m^{tar}$. Therefore, the system can be characterized by $M \times M$ gain matrix *G* whose entries are determined by mobile users' link gains to their base station,

$$G = \begin{pmatrix} 1 & \frac{g_{21}}{g_{11}} & \frac{g_{31}}{g_{11}} & \cdots & \frac{g_{M1}}{g_{11}} \\ \frac{g_{12}}{g_{22}} & 1 & \frac{g_{32}}{g_{22}} & \cdots & \frac{g_{M2}}{g_{22}} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \frac{g_{1M}}{g_{MM}} & \frac{g_{2M}}{g_{MM}} & \cdots & \frac{g_{(M-1)M}}{g_{MM}} & 1 \end{pmatrix} \tag{2}$$

the solution of such system has been mathematical proved in [8][9][10]. Based on such matrix, a number of iterative solutions has been developed in[11][12][13][14]. In these algorithms, the network is modelled as a system of linear algebraic equations in which:

$$AP = b \qquad \mathbf{P} = [p_1, p_2, \ldots, p_m]^T \tag{3}$$

where the elements of *A* and *b* are given by $a_{mm} = 1$, $a_{ml} = \gamma_m^{tar} \cdot g_{ml}/g_{mm}$, $m \neq l$, and $b_m = N_o \cdot \gamma_m^{tar}/g_{mm}$. Therefore, with the knowledge of current $\gamma_m(n)$; where *n* is the iteration number, and γ_m^{tar}, the above system of linear equations can be solved using numerical linear algebra iterative methods. Therefore, the transmission power for mobile user *m* in iteration *(n+1)* is defined as following:

$$p_m(n+1) = \frac{\gamma_m^{tar}(n)}{\gamma_m(n)} \cdot p_m(n), \quad m = 1, 2, \ldots, M. \tag{4}$$

this algorithm is called the distributed power control (DPC) algorithm [12].

In [14], a power-controlled multirate iterative algorithm; Selective Power Control (SPC), has been proposed. It determines the next transmission power used by mobile user *m* based on the power vector *P(n)*, γ^k target; where *k* is the transmission rate level utilized by mobile user *m* , and $\gamma_m(P(n))$ is the current $SIR_m(P(n))$ given that the user's transmission power is constrained by upper and lower values:

$$p_m(n+1) = \max_k \left(\frac{p_m(n) \cdot \gamma^k}{\gamma_m(P(n))} \cdot I_{\left(0 < \frac{p_m(n) \cdot \gamma^k}{\gamma_m(P(n))} \leq p_{max}\right)} \right) \tag{5}$$

where $I_{(E)}$ is the indicator function of the event *E*.

[2]Without loss of generality, the uplink is considered throughout this paper

B. Coverage Control Algorithms

In a static WCDMA system design, the power and rate adaptation algorithms are developed to alter the state of mobile users in a cell. *In case of congestion, what if the optimal power vector P can not achieve the* SIR *target value for such users?* In such scenarios, mobile users dropping will be inevitable. Recently, quite a few papers addressed the concept of dynamic network coverage as a solution to the problem of congestion and load balancing in WCDMA systems [2][15][16][17][18]. These approaches take advantage of the interdependence between coverage and capacity in such systems, *capacity increases as coverage decreases*.

In [15], a Case Based Reasoning (CBR) approach is proposed for releasing congestion and minimizing call blocking probability. It recalls a solution from a database which has previously been used to resolve similar congestion scenarios. Such scheme requires database maintainability and its complexity increases as the database size increases. Another approach has been proposed recently and is based on the concept of reinforcement Q-learning [16] . The shortcomings of such scheme is the possible formation of coverage gaps, since there is no coordination between neighboring cells, and the infinite search space. A hybrid network architecture is proposed in [17]. In this architecture, *CDMA* and *TDMA* networks cooperate to balance their load. The management of two different platforms and the co-allocation of cell sites are needed though.

A different approach, the multi-hop concept, has been studied intensively, e.g., see [18] and the references therein. In multi-hop *CDMA*, mobile users or fixed relaying stations are used to relay traffic of other users towards a base station. This requires the availability of routes, routing algorithms and mobile users' willingness to be part of a relaying path of others traffic.

The previously mentioned coverage adaptation mechanisms are designed for Omni-directional antenna and some require an additional hardware which adds to the cost of the network. In a hotspot scenario, for such schemes, the coverage reduction of a loaded cell results in a coverage expansion of all neighboring cells in Omni-directional manner for which some stable neighboring cells might be negatively affected. Therefore, it would be optimal if the coverage expansion is done only towards the needed cell.

Directional Cell Breathing (DCB) is a recently proposed congestion and load balancing scheme [2]. DCB utilizes the concept of WCDMA cell breathing in a directional manner. In DCB, the coverage area of each cell sector is partitioned into *L* concentric supporting levels where each supporting level corresponds to a transmission power level of Common Pilot Channel *(CPICH)* . DCB is facilitated by recent advances in smart directional antennas [19]. When hotspots are formed, the coverage areas of nearby sectors of two adjacent cells are allowed to be self-configured to force near boarder users of the loaded sector to

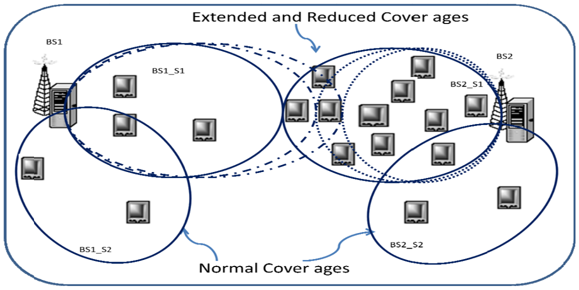

Fig. 1. Directional Cell Breathing Mechanism

change their association to the nearby lightly loaded sector (Fig. 1). Hence, the load can be evenly distributed among these nearby sectors.

III. Power-Controlled Rate and Coverage Adaptation (PCRCA) Module

The Power-Controlled Rate and Coverage Adaptation *(PCRCA)* module is an adaptation mechanism which searches for optimized coverage of nearby sectors of two adjacent cells for which mobile users transmission powers are minimized, their transmission rates are optimally allocated, and network congestion is released in both sectors. Although, it can be easily extended to be for a general coverage adaptation scheme, herein the module utilizes the DCB coverage adaptation scheme [2] and is not limited to any power or rate adaptation schemes. The proposed module and its optimization model are detailed in Subsection *A*. A heuristic algorithm for solving the model is provided in Subsection *B*. Subsection *C* gives illustration examples to demonstrate such algorithm.

A. PCRCA Optimization Model

Given the traffic of two adjacent sectors, the *PCRCA* module optimally and dynamically allocates sectors coverage and their mobile users transmission rates in a joint manner to balance such traffic and release congestion. These allocations are performed in two steps; namely: *Local* and *Global*, as explained below.

1) PCRCA Local (PCRCA-L) Module: In the *PCRCA-L* module, given *M* mobile users distributed over a given sector *j* of service area A_j , we define a function w_{A_j} which optimally allocates transmission powers and rates for such users as:

$$w_{A_j} = \max_{k} \sum_{m=1}^{M_{A_j}} f\left(p_m, \gamma^k\right) \tag{6}$$

s.t.

$$0 \le p_m \le P_{max}$$
$$\gamma^1 \le \gamma^k \le \gamma^K \qquad k \in (1, 2 \dots K)$$

where M_{A_j} is the number of mobile nodes in sector *j* given that its serving area is A_j, and $f(.,.)$ is the used power controlled rate adaptation scheme which is a function of mobile user *m* transmission power and its target *SIR*; γ^k. The outcomes of $f(.,.)$ are the optimal power and rate vectors to mobile users of sector *j*. Herein, since A_j is dynamic and depends on the load of sector *j* as well as nearby supporting sector load, the values of M_{A_j} vary and so do their power and rate allocations. This approach is only performed locally for every cell sector in the network.

2) PCRCA Global (PCRCA-G) Module: The global module of *PCRCA* searches the optimal coverage of nearby sectors which gives the optimal joint allocation for transmission powers and rates for mobile users in nearby sectors of the *WCDMA* network. For ease of management, the serving area of each cell sector is partitioned into *L* concentring coverage levels; each corresponds to a certain *CPICH* transmission power [2]. These *L* coverage levels define *L* serving areas of such sector (see Fig. 1). Therefore, the number of users in each sector depends on the activated coverage level. When traffic is unevenly distributed between two nearby sectors, activating certain coverage levels at both sectors may balance the load and prevent users dropping. Such activation forces near boarder users of the loaded sector to handoff towards the nearby lightly loaded expanded sector. Also, for such activation to be acceptable, it has to prevent coverage gaps between these sectors.

For given loaded and supporting sectors; *j* and $\hat{j}$, the objective of *PCRCA-G* is to maximize the support given to the loaded sector *j* by the supporting sector $\hat{j}$. Therefore, the *PCRCA-G* proposes coverage levels combination for sectors *j* and $\hat{j}$. Then, the *PCRCA-L* locally searches for optimal resource allocation to mobile users of such sectors. After evaluating all possible combinations, the optimal coverage combination which maintains a predefined system objectives can be activated.Such module is represented mathematically in (7):

$$F = \max_{k,sl} \sum_{j,\hat{j}} \left\{ \sum_{sl=0}^{L} \left(w_{A_j} + w_{A_{\hat{j}}} \right) \cdot f(sl) \right\} \tag{7}$$

s.t.

$$0 \le L \le SL_{max}$$
$$f(sl) \le 1$$

where $f(sl) = sl_0 * b_0 + sl_1 * b_1 + \ldots + sl_L * b_L$ and $b_i = 1$ only for the supporting level which is currently activated. In cases when no possible support can be provided, all b_i will be assigned a binary value of ”0”. The optimal solution of such scheme is *NP-complete* and hence can not be found in realtime. Therefore, a heuristic solution has been devised in this paper, which is detailed below.

B. PCRCA Heuristic Algorithm

An iterative algorithm is proposed in which for every possible coverage of two nearby sectors, mobile users transmission powers and their transmission rates are allocated efficiently. This heuristic algorithm is composed of three procedures; namely: *Initialization()*, *PCRCA-L()*, and *PCRCA-G()*, which are explained below:

1) Initialization(): For every load scenario, the *Initialization* procedure overseas the initial settings of mobile users parameters. Such settings are mobile users locations, initial transmission and receiving powers and initial transmission rates. Also, the active and inactive mobile users are defined in the initialization stage.

2) PCRCA-L(): After the initialization of users and network parameters, for every possible coverage combination of two nearby sectors an iterative power controlled rate adaptation algorithm is invoked locally to seek the mobile users’ optimal power and rate allocations in such sectors. If no such feasible allocation exists, the user will be turned off and an outage will be reported. Finally, the allocated transmission powers and rates, and the *SIR* values for active users, as well as the number of outages will be reported with respect to the given coverage.

3) PCRCA-G(): The execution of *PCRCA-L()* is based on the coverage allocation of nearby sectors defined by *PCRCA-G()* procedure. Therefore, whenever the *PCRCA* is invoked, after the initialization process, the *PCRCA-G()* procedure evaluates all possible coverage scenarios of the loaded and supporting sectors. For every coverage combination, the *PCRCA-L()* is invoked locally for such sectors. The obtained results are combined and the activated coverage is based on the optimal combined results for such sectors. The pseudocode of the *PCRCA* algorithm is sketched in Algorithm III.1. j and $\hat{j}$ are the loaded and supporting sectors, respectively, M_{A_j} and $M_{A_{\hat{j}}}$ are the number of active mobile users in j and $\hat{j}$ given their coverage areas A_j and $A_{\hat{j}}$, respectively, and SL_{Max} is the maximum support level $\hat{j}$ can give to j.

Algorithm III.1: PCRCA()

procedure INITIALIZATION()
for $i \leftarrow 1$ **to** $numOfCells$
for $j \leftarrow 1$ **to** $numOfSectors$
for $m \leftarrow 1$ **to** M_{A_j}
do $\{InitializeMobileUserParameters(m)$
return (0)

procedure PCRCA-L$(j, \hat{j})$
for $n \leftarrow 1$ **to** $numOfIteration$
do $\begin{cases} \textbf{for } m \leftarrow 1 \textbf{ to } M_{A_j} \\ \quad \textbf{do } \{w_{A_j}() \\ \textbf{for } m \leftarrow 1 \textbf{ to } M_{A_{\hat{j}}} \\ \quad \textbf{do } \{w_{A_{\hat{j}}}() \end{cases}$
return (0)

procedure PCRCA-G$(j, \hat{j})$
for $sl \leftarrow 1$ **to** SL_{Max}
do $\begin{cases} PCRCA - L(j, \hat{j}) \\ \max_{k,sl} \sum_{j,\hat{j}} \left\{ \sum_{sl=0}^{SL_{Max}} \left(w_{A_j} + w_{A_{\hat{j}}} \right) \cdot f(sl) \right\} \end{cases}$
return (0)

procedure MAIN()
$Initialization()$
for $i \leftarrow 1$ **to** $numOfCells$
for $j \leftarrow 1$ **to** $numOfSectors$
$PCRCA - G(j, \hat{j})$
return (0)

C. Scheme Illustration

Two examples are briefly illustrated bellow to show where the *PCRCA* scheme can be beneficial:

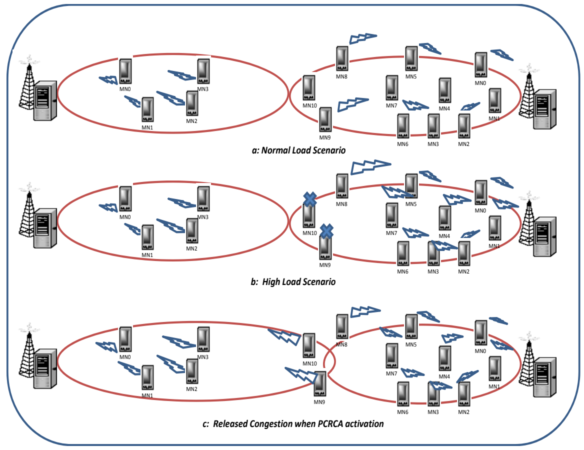

Fig. 2. Delay Based Hotspot Scenario

Example 1: Delay Based Hotspot– Occasionally, the load of the *WCDMA* system will be localized in a certain coverage area (Fig. 2-a). In such scenarios, viz. the end of a game in a football stadium, call arrival rate suddenly increases which makes such load not possible to be accommodated by the base station serving that area (Fig. 2-b). One possible solution for such problem would be degrading the ongoing calls transmission rates, which results in reducing mobile users transmission powers, to allow new initiated calls accessing the system. Although transmission rates are degraded, which might not be preferable for mobile users and service providers, there are cases where even the minimum provisioned transmission rates can not be assured. Therefore, dropping calls will be inevitable to maintain the *SIR* of other calls above a target value (see Fig. 2-b).

Herein, whenever the loaded sector gets saturated where the received *SIR* of its mobile users exceeds the provisioned value, the *PCRCA* is triggered to maintain such values above such target[3](see Fig. 2-c). Instead of severally degrading transmission rates or dropping calls, the *PCRCA* adapts the coverage areas of saturated sector and its nearby lightly loaded supporting sector to balance traffic, suppress interference given that mobile users' transmission rates are maximized as possible. As can be inferred from (Fig. 2-c), changing the association of near edge mobile users of the loaded sector towards the expanded sector may prevent call dropping, lower average transmission power with the cost of a possible increase in mobile users transmission powers of the supporting sector.

Example 2: Preference Based Hotspot– Mobile users' daily activity creates hotspots over wireless network coverage area. Such hotspots depends on the time of the day, viz. downtown areas during the morning, residential areas at evenings, and shopping malls and recreational activities on weekends. While in the move, mobile users handoff from one cell to another which may increase the handoff rate towards such concentrated areas (Fig. 3-a). In the classic *WCDMA* system, if there is congestion, calls will be dropped or if it is possible their transmission rates will be degraded (Fig. 3-b).

To prevent a base station from reaching a saturation point

[3]For clarity, SIR values, transmission power and transmission rate adaptations are not shown in the figures

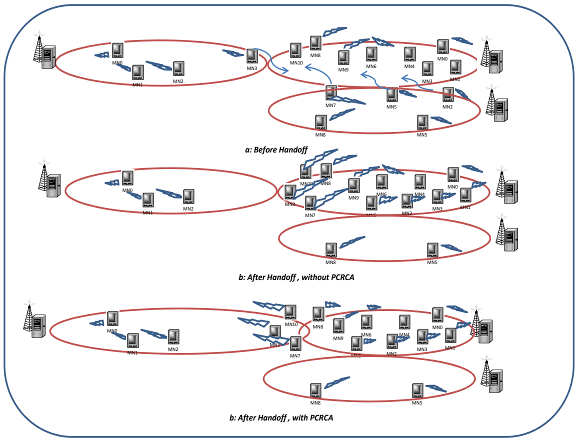

Fig. 3. Preference Based Hotspot Scenario

or to release its congestion, adjacent sectors can be expanded towards such base station to ease its load and balance network traffic. Therefore, the system load is monitored. Whenever there is a handoff, the possible new *SIR* values of mobile users are evaluated to assess the possibility of admitting the handed in call. If there is a violation of such values, the *PCRCA* is triggered to adapt sectors coverage area and mobile users transmission powers and rates (Fig. 3-c). Such scheme activation results in utilizing the unused resources of the nearby sector to ease congestion of the loaded sector.

Because of space limitations, in this paper we are evaluating the performance of *PCRCA* scheme using the concept of a delay based hotspot.

IV. Simulation Setup and Results Analysis

We simulated a system composed of a *7-cell* model that takes into account the *WCDMA* link level characteristics shown in TABLE I. The *WCDMA* network cells are divided into 6 sectors each served by a smart directional antenna. In our architecture, micro cells each of 1km radius are considered. The coverage area of each sector is divided into 20 supporting levels, each corresponds to a certain pilot transmission power level. Initially, the coverage areas of network sectors are equal and users are associated with their nearest base station. Each mobile user *m* utilizes transmission rate r_m^k where $k \in \{1, 2, 3, 4\}$. For each utilized r_m^k the mobile user received signal has to fulfill $SIR_m \geq \gamma_m^k$ constraint to be decoded properly. We utilize the *SPC* power controlled rate adaptation scheme, Eq. (5), with the *DCB* coverage adaptation module to assure the above stated requirement and evaluate the performance of the proposed *PCRCA* module.

To evaluate the performance of the *PCRCA* module, different scenarios are proposed. In each scenario, 100 mobile users are distributed over each cell sector while the number of active users in each sector varies depending on the required testing load. The distribution of these mobile users is uniform and the users' mobility is not considered herein. In the simulation scenarios, we vary the number of active mobile users in the loaded and supporting sectors while maintaining the number

TABLE I
WCDMA Network Simulator Parameters

Network Parameters	**Parameters Values**
number of Cell sectors	6
Antenna gains	18dB
Thermal noise	-104 dBm
Maximum Supporting Levels (SL_{max})	10
Number of iterations/secnrio (N)	500
UE Parameters	**Parameters Values**
Maximum transmitted power	27 dBm
Minimum transmitted power	-50 dBm
Thermal noise	-100 dBm
Eb/No (Γ)	5 dB
Number of transmission rate levels (K)	4
Max transmission rate (R_{Max})	25 kb/s
mobile user Tx rate (r_m^k)	$(R_{Max} \cdot \frac{1}{2^{k-1}})$
mobile user target SIR (γ_m^k)	$\frac{(r_m^k \cdot \Gamma)}{W}$

of active users in other sectors fixed. Only a single class of service is considered in this paper and the presented results are for multi rate traffic of maximum transmission rate of 25 kb/s which corresponds to $k = 4$. Each mobile user *m* is initially allocated the maximum transmission rate R_{Max} and its initial transmission power is a randomly selected value within the range of $P_{Min} \leq p_m \leq P_{Max}$. For each combination of mobile users in the loaded and supporting sectors, the transmission powers and rates of the mobile users and their received *SNR* are iteratively evaluated for every possible coverage combination using the *PCRCA* and *FPP* modules. If no such feasible values exist for a mobile user, its state is toggled to inactive and an outage is reported. The number of iterations, *N*, used herein is 500 iterations and the presented results are the average of 100 runs of *PCRCA* and *FPP* heuristic algorithms.

A delay based hotspot [20] is modeled to evaluate the performance of the proposed *PCRCA* module. The center cell of the 7-cell network model is the hotspot cell while the surrounding cells are the supporting cells. Different scenarios have been used to asses the proposed module; namely:

A.Hotspot Sector and Lightly Loaded Supporting Sector
B.Hotspot Sector and Near-Loaded Supporting Sector

A. *Hotspot Sector and Lightly Loaded Supporting Sector*

In this scenario, a delay based hotspot sector is formed. This sector is supported by a nearby lightly loaded sector of an adjacent cell. The scenario is implemented for the *PCRCA* and *FPP* modules. The number of active users in the loaded sector is varied from 40-80 users in steps of 10 users while the number of mobile users in the supporting sector is maintained fixed at 10 mobile users. The average combined results of such values of every possible coverage combination of the loaded and supporting sectors are shown in Figures 4-6. As can be inferred from Fig. 4, the average combined transmission power of mobile users of the loaded and supporting sectors varies from coverage level to another [4]. As the *PCRCA* algorithm is invoked, the average combined transmission power is decreased for the first supporting

[4] In this figure and subsequent ones, supporting level "0" results are with respect to *FPP* algorithm

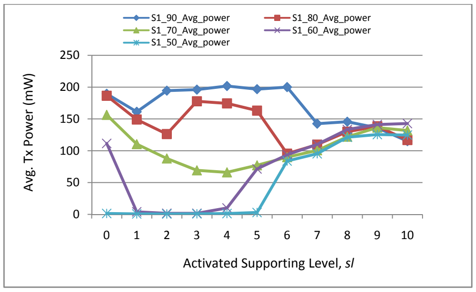

Fig. 4. Scenario 1: Combined Average Transmission Power

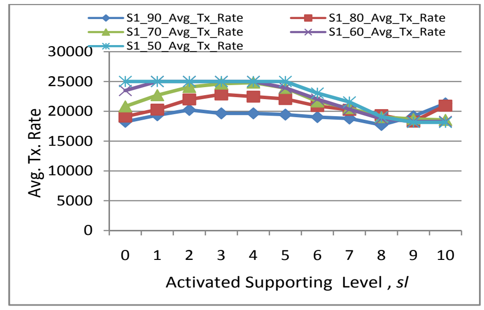

Fig. 5. Scenario 1: Combined Average Transmission Rate

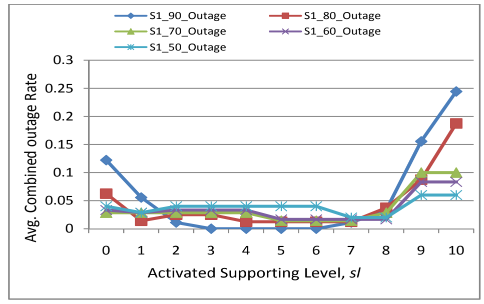

Fig. 6. Scenario 1: Combined Average Outage Rate

level. As the support level is increased, the average combined transmission power of each load scenario either increased or decreased. The increase scenario is because of the handed off mobile users towards the supporting sector given that the loaded sector load is still high. Such handed off users transmit with more power to communicate with their new base station. As the support level is further increased, the average combined transmission power is decreased significantly. The reason behind this decrease is the increased combined outage ratio shown in Fig. 6 below. Such outages come from the increased number of mobile users whose transmission powers exceed their maximum.

For the decreased case, as the support given to the loaded sector is increased, the number of mobile users handed off towards the supporting sector is increased and the loaded sector load is released. The lower the load of loaded sector is the more decrease in combined average transmission power will be. As the supporting level is further increased, the average path loss of the handed off mobile users to their new base station is increased too. Therefore, such mobile users averaged transmission powers are increased which also negatively affects the combined average transmission powers of both sectors.

The average combined transmission rate of loaded and supporting sectors varies from one supporting level to another (Fig. 5). Initially, As the support level is increased, the average transmission rate is increased too. The reason behind this increase is that, the handed off mobile users towards the supporting sector provide an opportunity to the mobile users, specially to the ones in the loaded sector, to increase their transmission rates. This opportunity is granted by decreasing the loaded sector load, which results in decreasing transmission powers of its users. As the activated supporting level is further increased, the average combined transmission rate is decreased because mobile users need to use more power to transmit with higher rates, but such transmission powers are limited by the the maximum value of R_{Max}.

For such load scenarios, the average combined outage ratio is shown in Fig. 6. It can be seen from the figure that the average combined outage ratio is kept at a lower value for most supporting levels. But, as the supporting level is increased, the average combined outage ratio is increased because some mobile users can not maintain their transmission power below the maximum provisioned value .Therefore, such mobile users are turned off to give the opportunity to other mobile users to transmit with better rates.

B. *Hotspot Sector and Near-Loaded Supporting Sector*

In this scenario, the number of mobile users of the loaded sector is maintained at a fixed value of 60 mobile users while the number of mobile users of the supporting sector varies from 10-30 mobile users. For each combination of such mobile users, the performance of *PCRCA* and *FPP* algorithms are evaluated to test the ability of a nearly loaded sector in giving support to a loaded sector. The performance results of the *PCRCA* and *FPP* algorithms in such setting are shown in Figures 7-9.

As can be inferred from the first and second results points in Fig. 7, as the load of the supporting sector is increased, the average combined mobile users transmission power is decreased. This can be argued as follows: When the first supporting levels are activated, outages take place at the loaded sector because its load is high and the supporting sector is nearly loaded. Such case drives some mobile users in the loaded and supporting sectors to exceed their maximum allowed transmission power, hence turned off. Such action will benefit the still active mobile users

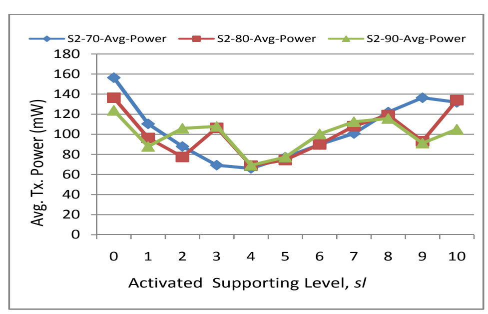

Fig. 7. Scenario 2: Combined Average Transmission Power

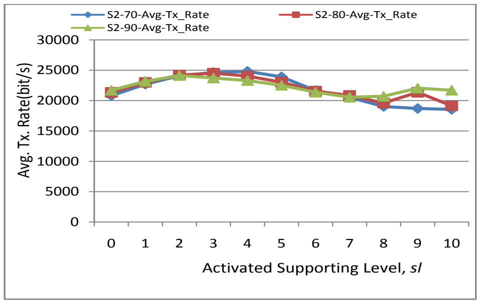

Fig. 8. Scenario 2: Combined Average Transmission Rate

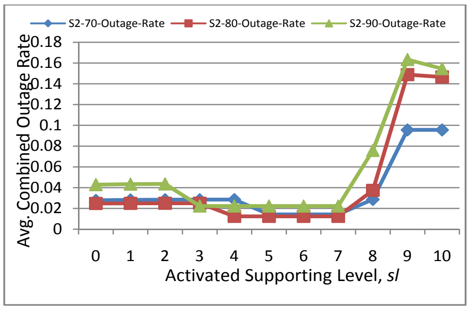

Fig. 9. Scenario 2: Combined Average Outage Ratio

to transmit with lower powers. As the support level is increased, the load of the loaded and supporting sectors is balanced and the outages will be minimized. As the given support level is further increased, the average transmission power is further increased because of an increase in the number of handed off mobile users towards the supporting sector. Such users use higher transmission powers to compensate their higher path loss.

The average combined transmission rate of each load scenario is depicted in Fig. 8. As the supporting level is increased, the combined average transmission rates is decreased. The reason behind this decrease is that, mobile users increase their transmission power to compensate the increase in interference level in the network. This results in transmitting with lower rates to maintain their transmission powers within the limit of the maximum transmission power value.

The average combined outage ratio of the loaded and supporting sectors is depicted in Fig. 9. As can be inferred from the figure, the outage ratio of the more loaded scenario is higher than other scenarios. As the activated supporting level is increased, such ratio is decreased and become comparable to the ratio of other load scenarios. As the given supporting level exceeds supporting level 9, the outage ratio is increased because of the higher transmission power used by the handed off mobile users.

V. Conclusion

In this paper, a congestion control and load balancing module is proposed for *WCDMA* wireless systems. In such module, rate and coverage adaptation mechanisms are combined to evenly distribute traffic and increase the allocated transmission rates for mobile users while maintaining their transmission powers at a minimum value. An optimization model for such scheme has been introduced herein. Since it is NP-complete problem, such model has been evaluated heuristically. The obtained results have shown a significant improvement over the static coverage design of such systems. Such results can be used by system designers to decide which best coverage can be used based on their desired *QoS* parameters. For example, for cases in which users transmission powers are of most concern, we can activate the optimal coverage level of which the companied average transmission power is minimum. This module will be integrated in a class-based dynamic *WCDMA* simulator to evaluate its performance in a large scale systems.

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