This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2008 proceedings.

A Novel Dynamic Directional Cell Breathing Mechanism with Rate Adaptation for Congestion Control in WCDMA Networks

Khaled A. Ali
ECE Department
Queen's University
Kingston, ON, K7L 3N6
7kama@qlink.queensu.ca

Hossam S. Hassanein
School of Computing
Queen's University
Kingston, ON, K7L 3N6
hossam@cs.queensu.ca

Hussein T. Mouftah
School of Info. Tech. & Eng.
Ottawa University
Ottawa, ON, K1N 6N5
mouftah@site.uottawa.ca

Abstract— **In future cellular networks, random users' mobility as well as time-varying multimedia traffic activity make cellular networks design a challenging task. To efficiently utilize the limited wireless spectrum, it is crucial to enable cellular systems to reactively and dynamically reconfigure cells' service area and capacity. This paper proposes an effective dynamic directional cell coverage adaptation scheme combined with a rate adaptation scheme that together are aimed maximizing radio resource utilization of Wideband Code Division Multiple Access (WCDMA) systems. This approach has the capability of reconfiguring the cell coverage area online by being aware of the system conditions. It takes into account the load on the uplink direction and the pilot power allocation on the downlink direction. Simulation results show the effectiveness of the proposed scheme in increasing WCDMA system efficiency.**

Keywords- WCDMA networks; congestion; radio resource management; smart antennas.

I. INTRODUCTION

The current deployment of WCDMA wireless cellular networks is based on a static design that 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, 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 [5][6]. This interdependence results in underutilizing the limited 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.

In WCDMA systems, unlike 2G, resources cannot be borrowed from one cell to another in case of congestion [2]. Alternatively, the NodeB downlink power can be allocated by exploiting the tradeoff between cell coverage and capacity for better system resource utilization. Since the coverage and capacity of WCDMA systems are directly related to the powers allocated to pilot channel and traffic channels, respectively, system efficiency can be maximized by carefully managing NodeB finite downlink power. In the conventional WCDMA systems, about 10-15% of the NodeB power is statically allocated for pilot channel [8]. Despite its simplicity, fixed pilot power allocation degrades the overall system performance. Therefore, dynamic cell configuration that takes into consideration network traffic fluctuation becomes a necessity in WCDMA network.

In [2], we outlined the principle of cell configuration scheme called Directional Cell Breathing (DCB) module. It capitalizes on recent advances of smart directional antennas of reshaping the coverage area of a cell sector based on system coverage and capacity needs [12]. In DCB, the coverage area of a cell sector is controlled by dynamically varying the Common Pilot Channel (CPCH) power. The proposed module has been evaluated using a static simulation in [3] for single service of single transmission rate. The results have shown a performance improvement of WCDMA resource utilization.

In this paper, a Dynamic DCB (DDCB) mechanism for large scale real WCDMA network has been implemented to operate in a proactive manner. A single service of multiple transmission rates is used for modeling mobile users' traffic. The DDCB changes the coverage area of a loaded cell sector to alleviate its congestion and minimize inter-cell interference on nearby supporting cell sectors. Moreover, a rate adaptation scheme is proposed that reactively adapt transmission rates of active users to accommodate handoff calls arriving at a loaded cell. The link level Quality of Service (QoS) parameters of blocking and dropping rates are evaluated to assess the DDCB performance. These results are compared to the results of a Fixed Pilot Power (FPP) allocation scheme.

The remainder of the paper is organized as follows. An overview of motivated and related work is offered in Section II. In Section III, the underlying system model is outlined. The architectural design of DDCB and the rate adaptation scheme is detailed in Section IV. The performance evaluation and the results analysis are introduced in Sections V and VI, respectively. Concluding remarks and hints at future work are made in Section VII.

II. MOTIVATION AND RELATED WORK

Several approaches in minimizing congestion and maximizing capacity of WCDMA are proposed in the literature [7][8][9]. In [7], a Case Based Reasoning (CBR) approach is proposed for releasing hotspot congestion and minimizing system call blocking probability. This approach recalls a solution from a database which has previously been used to resolve similar congestion scenarios. It requires database maintainability and its complexity increases as the database size increases. Another approach for dynamic cell configuration is described in [8]. It is based on the concept of reinforcement Q-learning. It is a distributed algorithm but it might be inefficient because of the possible formation of coverage gaps since there is no coordination between neighboring cells. A hybrid network architecture for a network controlled cell breathing mechanism is proposed in [9]. In this architecture, CDMA and TDMA networks cooperate in balancing there load. The complexity lies in managing two different technologies and necessitates the co-allocation of these systems as well as their single ownership.

The multi-hop concept in cellular networks has been studied intensively, e.g. see [10] and the references therein. Multi-hop relay is used for load balancing and congestion control in WCDMA networks in which either mobile users or fixed relaying stations are used to relay traffic of other users towards a base station. This requires the availability of routes and efficient routing algorithms, in addition to mobile users' willingness to be part of a relaying path of others traffic.

Our proposed DDCB scheme overcomes the above mentioned shortcomings by implementing cell breathing directionally to minimize inter-cell interference because of Omni-cell expansion on normally loaded cells while helping loaded one. Also, it does not require the maintainability of large system state; only the cell average interference is required for the system to function properly. Moreover, the current WCDMA implementation requires slight changes to accommodate the proposed signaling messages between the RNC and NodeB as well be shown in subsequent section.

III. System Model

In this section, the underlying network model and the user signal model for WCDMA uplink direction are described.

A. WCDMA Network Model

M-Cell system model is used in evaluating the performance of the proposed scheme. Each cell is divided into N sectors (Fig.1); each is served by a controllable directional smart antenna. Sectors are virtually divided into L concentric supporting levels where each supporting level corresponds to a pilot channel transmission power level. These cells are connected to a single Radio Network Controller (RNC) which governors the radio resource management functionalities of WCDMA systems.

B. Mobile User Signal Model

The path loss calculation of the transmitted signals from users in the network has been modeled based on an outdoor pedestrian radio propagation model as defined in [13]:

$$PL_{Max} = (40log_{10}d) + (30log_{10}freq) + 49 \qquad (1)$$

where PL_{Max} is the maximum allowed path loss for a transmitted signal, d is the distance between transmitter and receiver, and *freq* is the system center frequency. Accordingly, the received power of a signal transmitted from a transmitter at distance d is expressed as:

$$P_r = P_t * 10^{tx\_g} * 10^{rx\_g} * (1/PL) * x \qquad (2)$$

where P_r is the received power, P_t is the transmitted power, tx_g and rx_g are transmitting and receiving antenna gains, respectively, PL is the path loss between the transmitter and the receiver and x is the compensation term for orthogonality factor which computed as:

$$x = (1 - (1/PG) \qquad (3)$$

where PG is the spread spectrum processing gain.

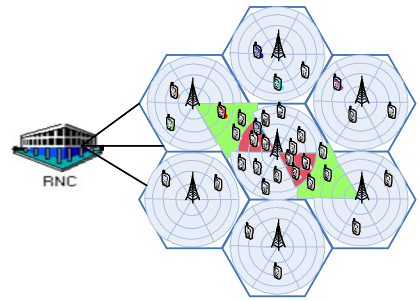

Fig. 1 WCDMA Cellular Network

In WCDMA cellular systems, the received power of a mobile station m of service rate R_m must exceed a predefined signal quality level, denoted by $\omega_{th}(R_m)$ for a proper decoding at the base station [5]. Hence for WCDMA system of bandwidth W, the $\omega_{m,b}(R_m)$ can be defined as:

$$\omega_{m,b}(R_m) = \frac{W}{R_m} * \frac{P_r}{I_{total} - P_r + \eta_o} \geq \omega_{th}(R_m) \qquad (4)$$

where I_{total} is the sum of intra- and inter-cell interferences and η_o is thermal noise.

IV. Dynamic Directional Cell Breathing Network Architecture

DDCB is implemented in two entities, the NodeB and Radio Network Controller (RNC). At the NodeB part, there are four components, namely: Interference Measurement (IM), reactive HandOff (rHO), proactive HandOff (pHO), and Rate Adaptation (RA). The components at the RNC comprise Interference Evaluation (IE) and Dynamic Directional Cell Breathing (DDCB). The implementation architecture is schematized in Fig.2. These components interact through predefined messages exchanged between NodeB's and the RNC. The utility of each unit is explained below.

A. Components at the NodeB

1) Interference Measurement (IM): The total received power at WCDMA NodeBs consists of intra- and inter-cell interferences [5], both of which can be used to characterize a cell's load. Interference is sampled periodically and averaged every T samples. The intra-cell interference of M mobile users on cell i can be defined as:

$$I_{intra,i} = \sum_{m=1}^{M} p_{m,recev} \qquad (5)$$

while the inter-cell interference on cell i from users located in other cells J can be expressed as:

$$I_{inter,i} = \sum_{j=1 \& j \neq i}^{J} \sum_{m=1}^{M} P_{recev,(m,j)} \qquad (6)$$

where M is the total number of mobile users in a cell.

For stability, the ratio of inter-cell to intra-cell interference of cell i has to be within a certain range between 0 and 1. This ratio is computed by:

$$I_{ratio,i} = \frac{I_{inter,i}}{I_{intra,i}} \quad (7)$$

To control congestion, a mechanism is required to act upon this measured ratio, that we call the *interference ratio*. The basis of this scheme will be detailed in section IV.*B*.

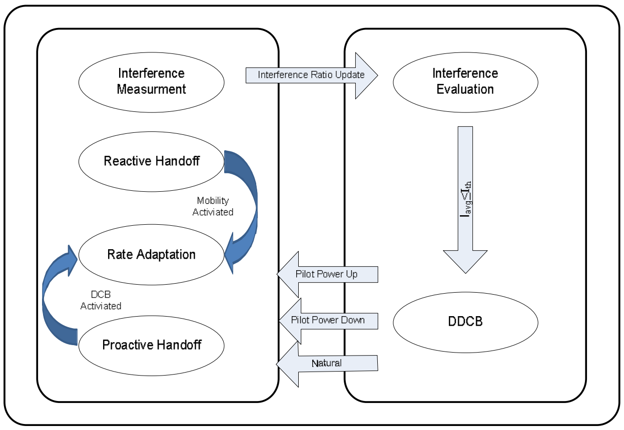

Fig.2: Dynamic Directional Cell Breathing Architecture

2) Reactive HandOff: The *Reactive HandOff* unit interacts with IM and RA units in fulfilling its functionality managing handoff requests.

3) Proactive HandOff: Upon congestion, the activation of DDCB algorithm may change the service area of two neighboring sectors through reducing the loaded cell's coverage while expanding lightly loaded cell coverage [2]. The proactive handoff unit hence oversees the handoff users near the loaded cell border need towards the expanded sector.

4) Rate Adaptation: Rate adaptation is concerned with increasing and decreasing users transmission rates based on network conditions and demand magnitude. In WCDMA networks, as the users' transmission rates increase, their contribution to intra- and inter-cell interference becomes significant. A Minimum Bandwidth Adaptation scheme is borrowed and adapted as a Minimum Rate Adaptation (MRA) scheme [13]. In this scheme, a cell state can be represented by an X vector of S states; each corresponding to the number of class s ongoing calls.

$$X = (x_0, x_2, x_3 ...., \; x_S) \quad (8)$$

where x_s represents the number of class s calls. The number of users in each state is a random variable and their assigned transmission rates are also random values from the predetermined R_s rates. In MRA, two quantitative values are defined for each call; namely: degrading value *(DV)* and upgrading value *(UV)*. The DV_i^s is the value of transmission rate call i of class s can release in case of congestion by lowering its transmission rate one level without being dropped:

$$DV_i^s = r_{j,s} - r_{(j-1),s} \;\; \forall j = 1,..., n_s \quad (9)$$

while the UV_i^s is a one level up transmission rate increase would be acquired by call i of class s to improve its call quality when cell resources permit that:

$$UV_i^s = r_{(j+1),s} - r_{j,s} \;\; \forall j = 1,..., n_s \quad (10)$$

To minimize signaling and interference in WCDMA systems, only minimum number of users is degraded or upgraded. Therefore, users with large *DV* and *UV* values are selected for rate adaptation. In this paper, the RA unit implements the MRA scheme to meet the above mentioned requirements.

B. Components at the RNC

1) Interference Evaluation: The cell i measured interference ratio, $I_{ratio,i}$, is periodically updated to the *IE* unit. The average of these measurements, $I_{avgRatio,i}$, is periodically computed by *IE* unit every T evenly timed samples. If the computed average is below a certain limit of $DDCB_{th}$, the *DDCB* algorithm is activated as explained after to adapt the coverage and capacity of the loaded sector and its nearby supporting sector.

2) DDCB: The *DDCB* component is the core of our architecture. The sector's smart antenna has the capability of adapting coverage by varying the pilot power strength to meet sector's coverage and capacity demands (Fig.3). For ease of implementation, the cell sectors are partitioned into L concentric supporting levels each corresponding to a pilot power transmission level.

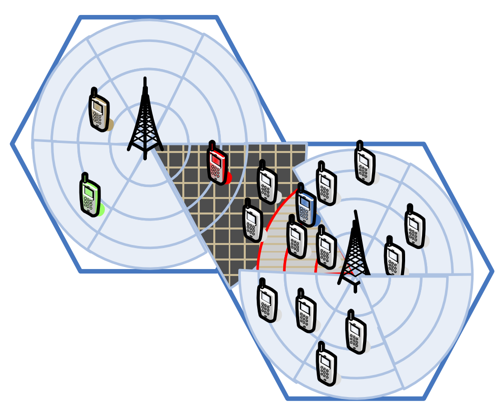

Fig.3: Dynamic DCB Concept

The pseudo code of the *DDCB* algorithm is given in Fig.4. (Due to lack of space we have used variables that are

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2008 proceedings.

self-explanatory and hence not explicitly defined.) The average cell interference ratio can be obtained from *IE* unit. In this architecture, the average interference ratio of each sector is used as an indication of sector's load level and if possible *DDCB* is engaged. Therefore, if the interference ratio of a sector is below $DDCB_{th}$ the sector is considered loaded and its coverage is shrunk to permit proactive handoff while the support sector is extended to prevent coverage gapes given that the supporting sector is not loaded.

```
1) WCDMA Network Initialization:
M users uniformly distributed over the network coverage area. Poisson call
arrival and exponential call service time are assumed. Random Walk with
reflection mobility model is used.
Calculate interference values from every mobile to every cell sector and use it
for computing interference ratio
2)For every cell 'i' and i < numberOfCells
3)For every sector 'j'and j <numberOfSectors
4)If(j's interference ratio samples == T samples)
    Compute Sector j average interference ratio (I_avgRatio,j)
5)   If( I_avgRatio,j <DDCB_th){
        Decrease Sector j coverage one level
        Increase Sector j_neigh coverage one level
 6)    For every Mobile user MU of cell i sector j
 7)       If MU_Distnace_to_BS > Sector_j_Radius
             Change MU association to Sector j_neigh BS
             If Active user{
                Compute MU Tx power and Rx Powers on every cell
                Compute sector j and j_neigh Loads
                If(Loads < Load_th)
                     Call Pro_Active HandOff method
                     Go to 9
                Elseif RateAdaptation Enabled
                     Triger Rate Adaptation for sector j_neigh BS
                     If (RateAdpation Succesfful)
                        Call Pro_Active HandOff method
                        Go to 9
             Else
(8)                  Terminate DDCB because it is not successful
(9)     }         Activate sectors' coverage by:
        Sending PilotPowerUp message to supporting sector
        Sending PilotPowerDown message to loaded sector
        Reset Sector j interference counters
        j = j+1
        Go to 3
10)    }else{// I_avgRatio,i >DDCB_th)
           Reset Sector j interference ratio values
           Neutral message to both sectors
           j = j+1
           Go to 3
     }
       i = i+1
}
```

Fig.4: Dynamic Directional Cell Breathing

V. Performance Evaluation

The proposed architecture has been evaluated by means of system level simulation that takes into account WCDMA link level characteristics (values shown in Table I). A 7-cell model is considered where each cell is 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 40 supporting levels. Each support level corresponds to a certain pilot power level. For each simulation scenario, 100 mobile users are distributed over each cell sector and remain in the system until the end of the simulation. The initial distribution of these mobile users is uniform. However, during simulation the users distribution varies based on average Sector Residence Time (*SRT*) of each individual sector.

In this paper, users' mobility is controlled by each sector's *SRT* parameter which is inversely related to the users' handoff rate. *SRT* is an exponentially distributed parameter. In the simulation scenarios, we vary *SRT* to vary sectors' loads. Only a single class of service is considered in this paper and the presented results are for multi rate voice traffic of 8, 9.6 and 12.2 kbps. Calls are generated according to a Poisson process with an average call arrival rate of 10 calls/h/user and exponentially distributed call holding time of an average of 180 s. Upon its arrival, a call is assigned a predetermined transmission rate, $r_{s,requetsed}$, where $r_{s,Min} < r_{s,requested} \leq r_{s,Max}$. In this paper, $r_{s,requested}$ is assigned the maximum transmission rate of 12.2kbps. The rate adaptation is only considered for handoff calls to minimize call dropping rates.

TABLE I: System Simulation Parameters

Cell parameters	Parameters values
Number of Sectors	6
Antenna Gain	18 dB
Thermal noise	-104 dBm
UE parameters	**Parameters values**
Maximum transmitted power	21 dBm
Minimum transmitted power	-50 dBm
Thermal noise	-100 dBm
Eb/No	5 dB
DDCB Parameters	**Parameters values**
Number of Supporting Levels	40
Measurement Interval (t)	2s
Number of Samples (T)	10
$DDCB_{th}$	0.2

VI. Simulation Scenarios and Numerical Results

A delay based hotspot [4] is modeled to evaluate the performance of the proposed dynamic directional cell breathing algorithm. The center cell of the 7-cell network model is the hotspot cell while the surrounding cells are the supporting cells. Different approaches have been used to assist the proposed algorithm; namely:

- **A.** *Single Sector Delay based Hotspot*
- **B.** *Single Sector Delay Based Hotspot and Nearby Loaded Supporting Sector*

A. *Single Sector Delay based Hotspot*

In this scenario, a single 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 FPP and DDCB schemes. The rate adaptation scheme is applied for both. In this scenario, the average *SRT* of all network sectors but the loaded one is set and fixed to 5s. For creating a hotspot at the selected sector, the average *SRT* is varied from 10s-30s in steps of 5s. The average of 10 runs for call blocking and dropping probabilities at the loaded sector (LS) and supporting sector (SS) with and without rate adaptation (RA) are depicted in Fig.5-Fig8. Each run last one simulation hour.

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2008 proceedings.

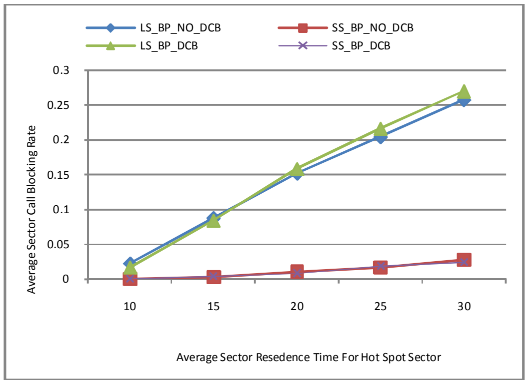

Fig. 5: Call Blocking Rate for Loaded and Supporting Sectors

As can be inferred from Fig.5, the call blocking probability for both loaded and supporting sectors remains the same for FPP and DDCB schemes up to 20s of *SRT*. When the *SRT* of a loaded sector exceeds 20s, the blocking rate for DDCB becomes slightly larger than the one of FPP scheme. This is because as the level of support is increased because of high load at the hotspot sector, proactive handoff towards the supporting sector is triggered. Hence the inter-cell interference on the hotspot sector increases since further users use high transmission power to reach further NodeB then their previous one. Therefore, the blocking probability increases at the hotspot sector because of both intra- and inter-cell interferences.

With respect to call dropping rate, it is significantly improved under the DDCB scheme (Fig.6). For the FPP scheme, the increase in dropping probability is related to high intra-cell interference at the loaded sector. When DDCB is activated, the dropping rate is lowered significantly. The reason behind this behavior is the load distribution among the loaded and supporting sectors become balanced and the interference level and handoff rate at both sectors become comparable.

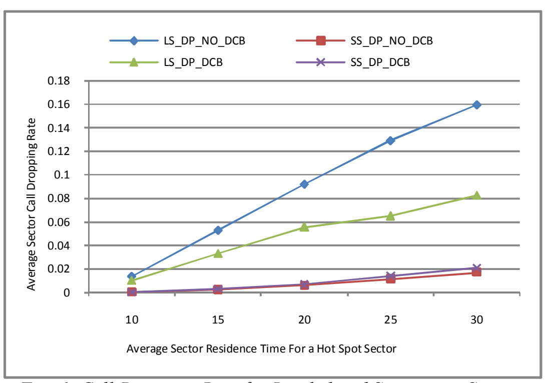

Fig. 6: Call Dropping Rate for Loaded and Supporting Sectors

Fig.7 and Fig.8 show the call blocking and dropping rates when the MRA scheme is enabled. As can be seen in the figures, the call blocking and dropping rates are maintained at lower values comparing to the values in Fig5 and Fig. 6. This lower blocking and dropping rates comes at the cost of low users' transmission rates. To control users' rate degradation levels and to maximize system throughput, a threshold on rate adaptations DDCB must be exercised.

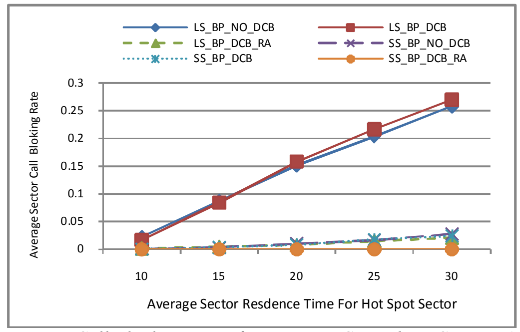

Fig. 7: Call Blocking Rate for FPP, DDCB and DDCB+MRA

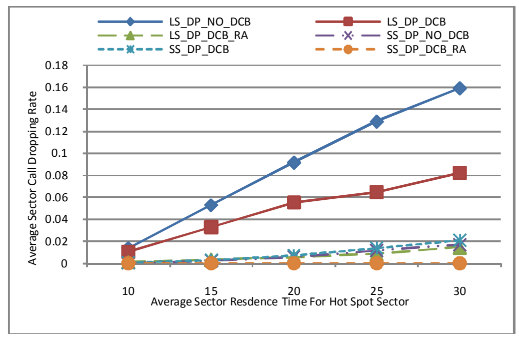

Fig.8: Call Dropping Rate for FPP, DDCB and DDCB+MRA

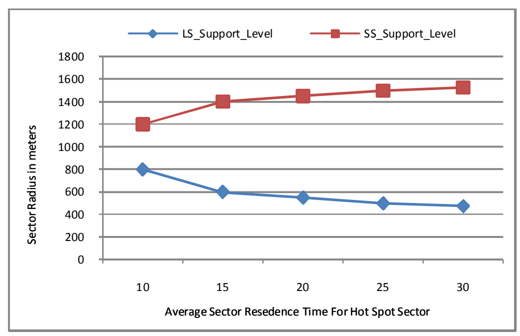

Fig.9: Loaded and Supporting Sectors Coverage Adaptation

The adaptive coverage for loaded and support sectors is shown in Fig.9. As can be seen from the figure, the coverage of the loaded sector is decreased as its load increases while the coverage of the supporting sector is increased. This validates our objective in simultaneously increasing and decreasing sectors coverage area to prevent coverage gaps.

B. *Single Sector Delay based Hotspot and Nearby Loaded Supporting Sector*

In this scenario, the loaded sector load is maintained at a high level while the supporting sector load is gradually increased and the load on all other network sectors is maintained at a lower value. Herein, the loaded sector *SRT* is assigned 30s and other network sectors *SRT* but the supporting sector is assigned 5s for the whole simulation time. On the other hand, the support sector *SRT* is increased from 10s-30s in steps of 5s. The rate adaptation scheme is not applied in this scenario. The obtained results are shown if Fig.10 and Fig.11.

The network behavior shown in Fig.10 explains the effect of increasing support sector load on both loaded and support sectors. As *SRT* value of the support sector increases, the sector tends to be a hotspot and support to the loaded sector will be decreased. The interesting phenomena here is that as the support sector load increases the loaded sector blocking rate for FPP and DDCB decreases while it increases for the support sector. The reason behind that is as the *SRT* of the support sector increases, the load distribution becomes balanced between loaded and support sectors. At the point where the load becomes balanced, the blocking rate becomes comparable for both sectors and the DDCB scheme tends to behave like the FPP scheme because no support can be given by any sector.

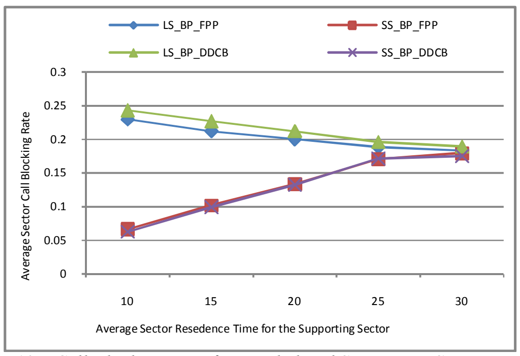

Fig.10: *Call Blocking Rate for Loaded and Supporting Sectors*

The call dropping rate for both schemes is also affected as the support sector load increases (Fig.11). As can be seen in the figure, the call dropping rate for the loaded sector is decreased while it is increased for the supporting sector for the same reason as with the blocking rate in Fig.10. As sectors load become nearly balanced, their dropping rates converge to nearly equal vales.

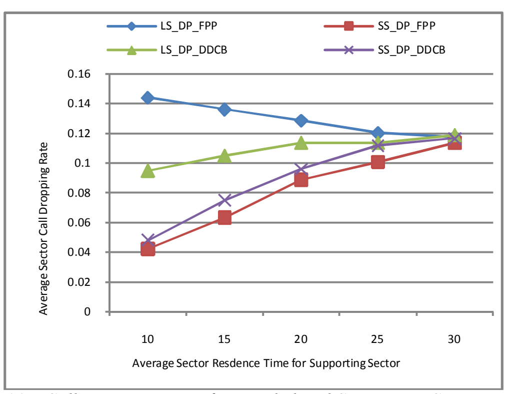

Fig.11: *Call Dropping Rate for Loaded and Supporting Sectors*

VII. CONCLUSION

A novel dynamic cell architecture called Dynamic Directional Cell Breathing (DDCB) for a large scale real WCDMA network has been studied in this paper. It is based on the concept of DCB module sketched in our previous work. A dynamic WCDMA network simulator has been designed and implemented to assess the performance of the proposed architecture. The obtained results are compared to the results of a Fixed Pilot Power (FPP) allocation scheme. In most cases, the DDCB outperforms the FPP in terms of call blocking and dropping probabilities. A Minimum Rate Adaptation (MRA) scheme has been used to adapt users' transmission rates to cope with network congestion. It is shown that DDCB with rate adaptation has lower blocking ratios than DDCB without rate adaptation. We remark, however, that, user transmission rates can be severely degraded, and a degradation ratio threshold is recommended. In the future, this work will be extended to multi-class services with call admission control to support Quality of Service in WCDMA cellular Networks.

REFERENCES

[1] H. Holma and A. Toskala, WCDMA For UMTS, Radio Access For Third Generation Mobile Communication, Jhon Wiley & Sons, Revised Edition, 2001.
[2] K. A. Ali, H. S. Hassanein, A. M. Taha and H. T. Mouftah, "Directional cell breathing: a module for congestion control and load balancing in WCDMA networks," in Proc. International Wireless Communications and Mobile Computing Conf (IWCMC), pp. 317 - 323, July 2006.
[3] K. A. Ali, H. S. Hassanein and H. T. Mouftah, "Directional Cell Breathing Based Reactive Congestion Control in WCDMA Networks", in Proc. IEEE International Symp. On Computers and Communications (ISCC), pp. 685-690, July 2007.
[4] J. Jobin, M. Faloutsos, S. Tripathi and S. Krishnamurthy,"Understanding the Effects of HotSpots in Wireless Cellular Networks", IEEE INFOCOM, pp.660-671, March, 2004.
[5] K. S. Gilhousen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver, Jr., and C. E. Wheatley, "On the Capacity of a Cellular CDMA System", IEEE Trans. Vehicular Technology, vol. 40, no. 2, pp. 303-312, May 1991.
[6] Li-Chun Wang, S. Huang, and Y. Tseng, "Interference Analysis and Resource Allocation for TDD-CDMA Systems to Support Asymmetric Services by Using Directional Antennas," Vehicular Technology, IEEE Transactions on Vol. 54, Issue 3, pp.1056 – 1069, May 2005.
[7] C. Laio, F. Yu, V. Leung, C. Chang, "A Novel Dynamic Cell Configuration Scheme in Next-Generation Situation-Aware CDMA Networks" , IEEE JSAC, Vol. 24, NO. 1, Jan. 2006.
[8] J. Romero, O. Sallent, R. Agusti, N. Garcia, L. Wang, H. Aghvami, "Network Controlled Cell-Breathing for Capacity Improvement in Heterogeneous CDMA/TDAM Scenarios", in Proc. of IEEE WCNC, pp.36-41, April, 2006
[9] N. Yao, L. Cuthbert,"Reducing Congestion over Hotspot Clusters in WCDMA Networks", in Proc. of IEEE WCNC, pp.3734-3738, March,2007.
[10] Z. Dawy, S. Arayssi, I. Abdel Nabi and A. Husseini,"Fixed Relaying with Advanced Antennas for CDMA Cellular Networks", in Proc. of IEEE GLOBECOM, pp. 1-5, Nov. 2006.
[11] A. Talukdar and B. Badrinath,"Rate Adaptation Schemes in Networks with Mobile Hosts", in Proc. of ACM MOBICOM, pp.169-180, October, 1998.
[12] C. Balanis and P. Ioannides, Intorduction to Smart Antennas, Morgan & Claypool, 2007
[13] OPNET: UMTS Model User Guide, Version. 12.1, Release May, 2007.