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AN ADAPTIVE SOFT HANDOVER SCHEME USING FUZZY LOAD BALANCING FOR WCDMA SYSTEMS

Kemeng Yang, Bin Qiu and Laurence S. Dooley
Faculty of Information Technology, Monash University
Melbourne, Australia
{kemeng.yang, bq, laurence.dooley}@infotech.monash.edu.au

ABSTRACT

In cellular systems, user distribution variations can cause load imbalance between cells. Embedding a load balancing strategy within the handover scheme means that ensuing traffic congestion can be alleviated by dynamically reallocating load between neighbouring cells. An adaptive soft handover scheme for multimedia cellular communication systems is proposed in this paper, that considers both the cell load factors as well as the pilot channel signal-to-interference-and-noise-ratio (SINR) for soft handovers. By using fuzzy principles, the soft handover thresholds and time hysteresis are adapted dependent upon the loads of the neighbouring cells. Simulation results show that the new algorithm provides improved system performance in terms of a more evenly distributed load, lower blocking probabilities and higher throughput.

KEY WORDS

Soft handover, adaptive load balancing, WCDMA

1. Introduction

Handover is an essential operation in cellular networks, to ensure continuous coverage for user equipment (UE) by switching existing connections between different base stations (BSs), with soft handover being used in both Code Division Multiple Access (CDMA) and Wideband-CDMA (WCDMA) systems. A UE can have more than one connection with different BS during soft handover. There is a trade-off between the user quality of service (QoS) and the system capacity. Multi-connections used during soft handover makes the process smoother, but also consume more downlink radio resources, a problem which becomes particularly severe when a cell is overloaded and radio resources scarce.

In CDMA based networks, users operate over a common frequency band and are differentiated by code sequences, so the signal from one user will always cause some interference with other user signals. The cell capacity depends on the level of interference within the cell as well as those from surrounding cells, which is known as *soft capacity*. The soft capacity of CDMA systems makes load balancing between cells more complicated, as simply readjusting UE ownership to BSs cannot achieve the same load balancing results as in GSM (global system for mobile communications) networks, which only consider the available reusable frequency channels instead of the remaining radio resources limited by the maximum transmitting powers of the BS and UEs.

Since the handover decision is based on the received power or SINR of a UE at the pilot channel, changing the BS pilot channel power can reshape the cell boundary. The overloaded BS decreases the pilot channel power to force UEs to make an earlier handoff to neighbouring BSs, which is referred to as *pilot power adjustment* [1-3]. The disadvantage of this approach is that the channel power adjustment cannot be performed independently at a single BS, so co-operation between neighbouring BSs is needed to maintain continuous coverage, which makes it difficult to react to rapid load variations.

An alternative load balancing strategy is to use variable thresholds during handover, which can quickly respond to load variations without adjusting BS transmitting power. A *variable thresholds soft handoff (VTSH)* algorithm is presented in [4], where different sets of add and drop thresholds are broadcast from the overloaded BS to UEs. Simulation results show that *VTSH* leads to lower outage probabilities than the conventional IS-95 [5] soft handover. Meanwhile, [6] proposed a *fuzzy inference system-based soft handoff (FIS SHO)* for IS-95B [7]/CDMA2000 [8], where the drop threshold is adapted to the BS remaining channels and the active set size of each mobile station. Analysis revealed that using *FIS SHO*, the system could support more traffic than IS-95A and IS-95B/CDMA2000. A full performance analysis model for *FIS SHO* is given in [9].

Both *VTSH* and *FIS SHO* are based on IS-95A and IS-95B/CDMA2000, and so are not directly applicable to WCDMA systems because different soft handover algorithms and threshold ranges are employed. Based on the standard WCDMA soft handover algorithm in the 3rd Generation Partnership Project [10], a framework of variable thresholds soft handover for WCDMA called *adaptive soft handover algorithm (ASHA)* has been proposed in [11]. In *ASHA*, the overloaded BS requests mobile users to change the hysteresis parameters for handover, which then makes the handover from the overloaded to neighbouring cells occur earlier.

The performance of *ASHA* is analysed in a two BS model with the assumption that only the overloaded cell is in the UEs active set [11]. The limitation of *ASHA* is that the overloaded cell is always assumed to have the worst pilot SINR and will be removed from the active set first. While in radio link removal and radio link replacement event of

WCDMA soft handover [10], any BS meeting the trigger will be removed or replaced. This could be the overloaded BS, but equally also a BS we might wish to retain in the active set. Decreasing the drop thresholds does not always achieve the effect of congestion relief, and indeed there exists the risk of actually making the congestion worse.

An adaptive load balancing strategy based on soft handover would assist in providing the macrodiversity gain brought by multi-radiolink connections during soft handover. The load release should only affect the overloaded cell, without unnecessary service quality being sacrificed in neighbouring cells. Moreover, the load balancing algorithm should be scalable and applicable for multi-cells and various UE distribution and movement.

In this paper, an adaptive soft handover scheme is proposed using a fuzzy approach in which both the handover thresholds and time hysteresis are adaptively adjusted depending on the load of neighbouring cells. The performance of the proposed algorithm is evaluated by simulations, with results confirming the new algorithm consistently provides a lower blocking probability and improved system throughput.

The paper is organized as follows. An analysis of the impact of soft handover on the load factor is presented in Section 2, while Section 3 discusses the proposed adaptive soft handover algorithm, with the simulation model and results described in Sections 4 and 5. Finally, some conclusions are given in Section 6.

2. Impact of Soft Handover on Load Factor

In WCDMA systems, the load factor η is commonly used to predict the cell load from the physical layer measurements [12]. A brief introduction of the interference and load factor measurements used in WCDMA system is firstly presented, before the soft handover impact on link and system level performance is analysed.

2.1 Interference and Load Factor

As uplink and downlink use separate frequency bands, their respective load factors are measured separately. There are two approaches for measuring η: load estimation based on either power or throughput.

For the uplink, load estimated from wideband received power is calculated as [12]:

$$\eta_{UL} = 1 - \frac{P_n}{I_{total}} = \frac{I_{own} + I_{oth}}{I_{own} + I_{oth} + P_n} \quad (1)$$

where I_{total} is the total received wideband power consisting of the power of own cell users I_{own}, power of other cell users I_{other}, and background and receiver noise P_n. Load estimated from throughput is defined as [12]:

$$\eta_{UL} = (1+i)\sum_{j=1}^{N} L_j = (1+i)\sum_{j=1}^{N} \frac{1}{1+\dfrac{w}{(E_b/N_o)_j \cdot R_j}} \quad (2)$$

where N is the number of users in the own cell, L_j is the load factor of connection j, w is the chip rate, R_j is the bit rate of user j, i is the other-to-own cell interference ratio, and $(E_b/N_o)_j$ is the energy per user bit divided by the noise spectral density for user j, which is a combination of user bit rate and SINR measurements:

$$(E_b / N_o)_j = \frac{w}{R_j} \cdot \frac{P_j}{I_{total} - P_j} \quad (3)$$

where P_j is the BS received signal power from user j.

The downlink E_b/N_o has a similar expression to (3):

$$(E_b / N_o)_j = \frac{w}{R_j} \cdot \frac{P_j}{I_{j\_total} - P_j} \quad (4)$$

except P_j is the received power from downlink channel j, and I_{j_total} is the total received power of user j.

For the downlink, the load estimated by power is [13]:

$$\eta_{DL} = \frac{P_{total} - P_{pilot}}{P_{total}} \quad (5)$$

where P_{total} is the total downlink transmitting power, and P_{pilot} is the transmitting power of the pilot channel. Load estimated based on throughput is:

$$\eta_{DL} = \frac{\sum_{j=1}^{N} R_j}{R_{\max}} \quad (6)$$

where R_j is the bit rate of the P_j user and R_{max} is the maximum allowed throughput of the cell.

2.2 Performance Analysis

When the maximal ratio combining [14] is used during soft handover, UE_j received $(E_b / N_o)_j$ can be expressed as:

$$(E_b / N_o)_j = \sum_{k=0}^{N_{AS}} (E_b / N_o)_{jk} \quad (7)$$

where $(E_b / N_o)_{jk}$ is the received E_b/N_o from the connection with the *kth* BS in UE_j active set, and N_{AS} is the total number of BSs in UE_i active set. (7) can be written as:

$$(E_b / N_o)_j = \sum_{k=0}^{N_{AS}} (E_b / N_o)_{jk} = \sum_{k=0}^{N_{AS}} \frac{w}{R_j} \cdot \frac{P_{jk}}{I'_{j\_total} - P_{jk}} \quad (8)$$

where, P_{jk} is user j received power from connection k, and I'_{j_total} is UE_j total received power during soft handover. Using balanced power control, under ideal conditions $P_{j1} = P_{j2} = \ldots\ldots = P_{jk}$, so

$$(E_b / N_o)_j = \frac{w}{R_j} \cdot \frac{N_{AS} P_{jk}}{I'_{j\_total} - P_{jk}} \quad (9)$$

Assuming the interference from common channels and other users downlink channels remain the same:

$$I'_{j\_total} - N_{AS} P_{jk} = I_{j\_total} - P_j \quad (10)$$

From (4), (9) and (10), P_j can be derived as

$$P_j = \frac{N_{AS}(I'_{j\_total} - N_{AS} P_{jk})}{I'_{j\_total} - P_{jk}} P_{jk} \quad (11)$$

The I'_{j_total} can be expressed as

$$I'_{j\_total} = \sum_{i=0}^{N_{BS}} P_{i\_total} L_{ij} = \sum_{i=0}^{N_{BS}} (P_{i\_common} + \sum_{x=0}^{N_{DCH}} P_{i\_DCHx}) L_{ij} \quad (12)$$

where P_{i_total} is the total transmitting power of BS_i, L_{ij} is the pathloss from BS_i to UE_j, P_{i_common} is the total transmitting power of common channels (including the pilot channel) of BS_i, and P_{i_DCHx} is the transmitting power of dedicated channel (DCH) from BS_i to user x.

Since the maximum transmitting power of downlink DCH is generally equal to the constant transmitting power of pilot channel[12], we have $P_{i\_common} \geq P_{i\_DCHx}$, then

$$I'_{j\_total} > 2N_{AS}P_{jk} \tag{13}$$

Thus, from (11)

$$P_{jk} < P_j < N_{AS}P_{jk} \tag{14}$$

which shows that the soft handover splits the user required receiving power P_j between several BSs, so the required power for each connection $P_{jk} < P_j$. From a system perspective, the soft handover introduces more downlink power consumption, which increases the interference level and degrades the whole system capacity. If the user in an overloaded cell is allowed to enter the soft handover state earlier than normal, by splitting the user's downlink power, the total downlink power consumption for this BS can be reduced. So more radio resources are released for centre users, thereby decrease the new call blocking probability for the BS.

3. The Fuzzy Soft Handover Algorithm

From the analysis in Section 2.2, the BS transmitting power is affected by the number of downlink connections, transmitting power of each downlink channels, and the downlink interference level in the cell. The aim of soft handover optimization for load balancing is to minimize the total transmitting power required for the overloaded BS. The following approaches can be adopted to achieve load balancing:

1) For those UEs only connected with the overloaded cell: allow them to add neighbouring BSs into the active set earlier.

2) For those UEs during soft handover which have the overloaded BS in their active set: remove or replace the overloaded BS from the active set sooner and keep the non-overloaded BS in the active set longer.

3) For those UEs only connected with the neighbouring BSs of the overloaded BS: add the overloaded BS later.

These load balancing approaches cannot be fully achieved by solely adjusting soft handover thresholds as described in Section 1. To overcome the limitation of adaptive threshold algorithms, time hysteresis adjustment is introduced into the proposed algorithm, together with threshold value adjustment. The proposed algorithm comprises the following functions:

1) Threshold value adjustment function: the radio network controller (RNC) will send a threshold update command to the UE according to the congestion states of BSs in its active set, as shown in Figure 1.

2*) Active set update delay function:* when receiving the UE's active set update request, the RNC may request the UE to increase the trigger time ΔT according to the congestion state of target BS, as shown in Figure 2.

The proposed load balancing algorithm can be implemented within the RNC, which is usually capable of controlling between 100 and 250 BSs [15], with Lucent Flexent® RNC [16] able to support up to 750 BSs. The RNC controls all users' active updating and also directly knows the congestion stage of all the BSs connected to it.

The following two sections describe the above two functions in detail.

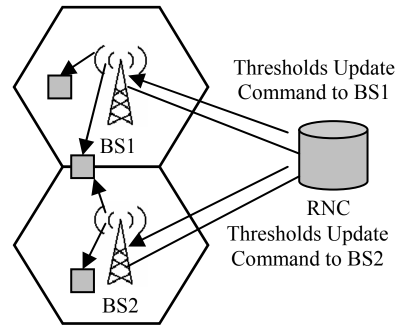

Figure 1. Thresholds Value Adjustment Function

3.1 Threshold value adjustment function

BS_i uses two different sets of soft handover thresholds for non-congested and congested states as shown in Table I.

TABLE I: ADAPTIVE THRESHOLDS

	Non-congested	Congested
add_threshold$_i$	α_1	α_2
drop_threshold$_i$	β_1	β_2
replace_threshold$_i$	γ_1	γ_2

The relationships between the three thresholds in each state are: $\alpha_1 < \alpha_2$, $\beta_1 > \beta_2$, and $\gamma_1 > \gamma_2$, with $\alpha_2 < \beta_2$ being upheld to avoid the ping-pong phenomenon. During soft handover, a UE may receive several threshold values, so it will always choose the maximum *add_threshold*, minimal *drop_threshold* and minimal *replace_threshold*.

During soft handover [14], BS_i will be added to UE active set provided the difference between the UE received pilot SINR from BS_i and the highest received pilot SINR from other BSs in the active set is less than *add_threshold* for ΔT. A larger *add_threshold* therefore allows the UE to add the BS earlier. Conversely, to remove BS_i from the UE active set, the difference should be greater than *drop_threshold* for ΔT, thus a smaller *drop_threshold* enables the UE drop the BS earlier. To replace BS_1 with BS_2, the received pilot SINR from BS_2 should be larger than the received pilot SINR for BS_1 plus *replace_threshold,* so a smaller *drop_threshold* triggers an earlier BS replacement.

The typical ranges for addition, removal and replacement thresholds are described in [12]. These are: 2dB≤*add_threshold*≤4dB, 4dB≤*drop_threshold*≤6dB and 0dB<*replace_threshold*≤2dB. To achieve the best load balancing effect from the adaptive thresholds adjustment, critical values were chosen from these typical ranges and according to the rules discussed above as: α_1 = 2dB, α_2 = 4dB, β_1 = 6dB, β_2 = 4.1dB, γ_1 =2dB and γ_2 =0.1dB.

3.2 Active set update delay function

In the active set update delay function, we need to consider the load factor of the BS being added, removed or replaced as well as the load factor of the other BSs in the UEs active set. Different delay control functions should be applied for different request types: add, remove and replace.

For example, if a UE which already has BS_1 in its active set then adds BS_2, the RNC will make different responses depending on the respective load factors η_1 and η_2 of BS_1 and BS_2. If $\eta_1 > \eta_2$, then UE add BS_2 immediately while if $\eta_2 > \eta_1$, then a delay is applied, which should be further adjusted depending on the relative value of η_1 and η_2.

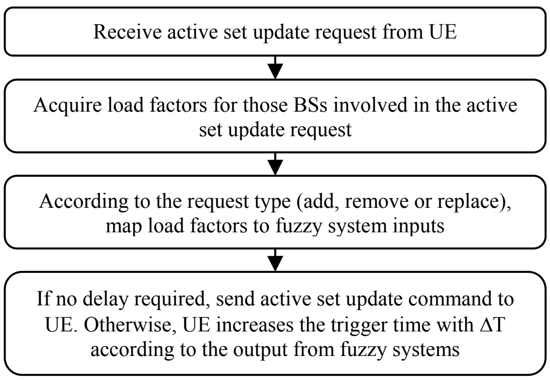

Figure 2. Active Set Update Delay Operations in RNC

Fuzzy systems are useful in the control and decision making of cellular networks, with applications in handover [6] [17] and call admissions control algorithms [18]. Considering the complexity of the active set update delay function and the uncertainty of user movements and traffic distributions, the fuzzy system can be used to control the active set delay process.

For an active set size of two, there will be two inputs for the fuzzy system:

⇒ L_1: load factor of cell1

⇒ L_1-L_2: difference between load factors of cell1 and cell2

If $L_1 < L_2$, then cell2 is more congested than cell1 so no delay is needed. Otherwise, a delay is applied according to the output of fuzzy system. There are three membership functions for input L_1: low, medium and high, as shown in Figure 3, while there are two membership functions for inputs L_1-L_2: small and large (Figure 4). For the output, three membership functions: small, medium and large are used, as shown in Figure 5. For simplicity and efficiency of operation, triangular and trapezoidal membership functions with maximum support are used for all fuzzy inputs and outputs. Assuming the call admission control threshold is 0.75 [13], a cell is considered as congested when the load factor reaches 0.75, therefore the triangular membership function of medium in input L_1 peaks at 0.75 and the degree of membership for large in L_1-L_2 reaches 1 after 0.25.

Since there are three membership functions for input L_1 and two for input L_1-L_2, there are a total of six rules for the fuzzy system as shown in Table II. The mapping rules between load factors of BSs involved in active set update request and fuzzy system inputs are as following:

1) For active set addition request from UE_j, L_1 is the η of the BS being added, and L_2 is the η of the BS already in active set of UE_j.

2) For active set removal request from UE_j, L_1 is the η of the BS remaining in the active set, and L_2 is the η of the BS being removed.

3) For active set replacement request from UE_j, L_1 is the η of the BS being introduced into the active set, and L_2 is the η of the BS with the worst pilot SINR in the active set of UE_j.

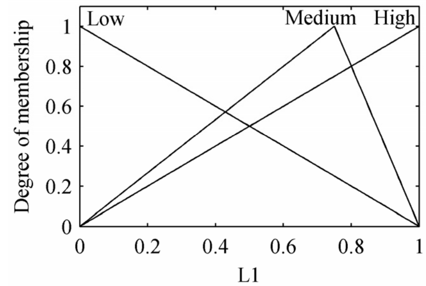

Figure 3. Fuzzy Membership Functions for L1

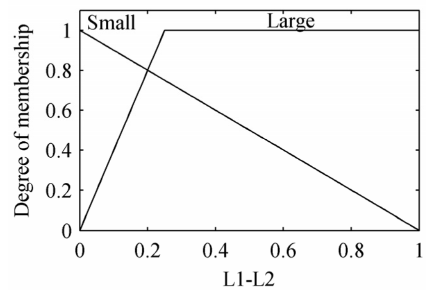

Figure 4. Fuzzy Membership Functions for L1-L2

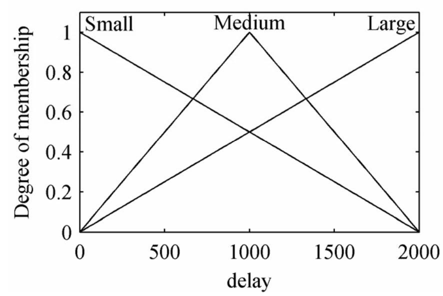

Figure 5. Fuzzy Membership Functions for Delay

TABLE II: FUZZY RULES

Rules	L1	L1-L2	Delay
1	High	Large	Large
2	High	Small	Zero
3	Medium	Large	Medium
4	Medium	Small	Small
5	Low	Large	Zero
6	Low	Small	Zero

4. Simulation Environment

A Matlab-based WCDMA simulator has been developed, which is used for investigating the network performance under different radio resource management strategies. The simulator consists of four basic modules: network scenes generator, user traffic generator, dynamic simulator and post processing.

The performance of the proposed adaptive soft handover algorithm has been evaluated with the scenario shown in Figure 6, in which there are 7 BSs and 200 randomly generated UEs, whose position changes every time interval, depending on its speed and direction which are randomly chosen with certain mean direction and speed changing rate (i.e., 5 changes/100 seconds). In the traffic generator, according to a given mean call arrival rate and call duration, the user traffic rates are randomly generated following a Poisson arrival.

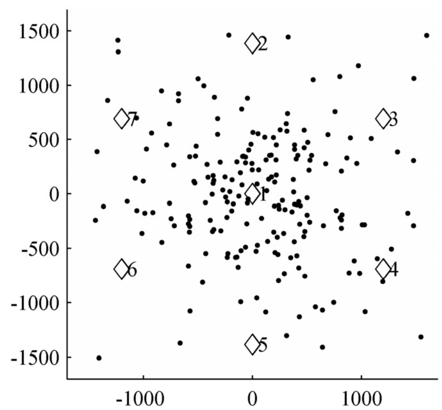

Figure 6. Simulation Scenario of 200 UEs and 7 BSs

The main parameters in the simulation are given in Table III, with the parameter settings using the typical values in [10], [13] and [19].

TABLE III: MAIN SIMULATION PARAMETERS

Cell radius	800m
Max UE moving speed	80km/hour (22.2m/second)
Mean call duration	90s
Data rate	12.2kbps, 64kbps, 144kbps, 384kbps
Chip Rate	3.84Mcps
BS background noise power	4dB
UE background noise power	7dB
Pilot channel power	30dBm (1W)
Other common channels combined power	30dBm (1W)
Maximum DCH power	30dBm (1W)
Maximum BS power	43dBm (20W)
Required E_b/N_o for BLER =10%	5.5dB (uplink) 6.4dB (downlink)
Call admission control threshold	0.75

A macro-cell propagation model for urban and suburban areas [20] is employed, so for a carrier frequency of 2GHz and a BS antenna height of 15 meters, the path loss is:

$$Pathloss\,(dB) = 128.1 + 37.6\log_{10}(R) + \log(F)$$

where R is the distance between the BS and UE in metres and $\log(F)$ is the log-normal distribution shadowing with standard deviation σ=10dB.

Both uplink and downlink power control [12] are performed during the simulations. During soft handover maximal radio combining is used for downlink, and the target E_b/N_o is the sum of the E_b/N_o of each connection. For uplink, UE transmits at the lowest required power from every BS in the active set.

5. Results

Simulations were carried out for various sets of user distribution and call arrival rates. In order to evaluate the load balancing effects of different algorithms, Cell 1 was made to have higher user density than other cells, and the simulated mean arrival rates should be high enough to have Cell 1 always congested. At the mean arrival rate of 1 call/s, the load factor of Cell 1 is 0.68 which is not congested as explained in section 3.2. Therefore, results below 1 call/s are out our interest here. The average load factor of neighbouring cells of Cell 1 for mean call arrival rates from 1-3 calls/s has been measured as shown in Figure 7. As it can be seen, the average load factor of neighbouring cells is higher than 0.75 when the mean call arrival rate is 3 calls/s. The congestion point (with a load factor of 0.75) of the whole system is reached before the value of 3calls/s. Since the aim of load balancing is to spread out load from the congested cell to its non-congested neighbours, mean call arrival rates higher than 3calls/s is not considered in this paper.

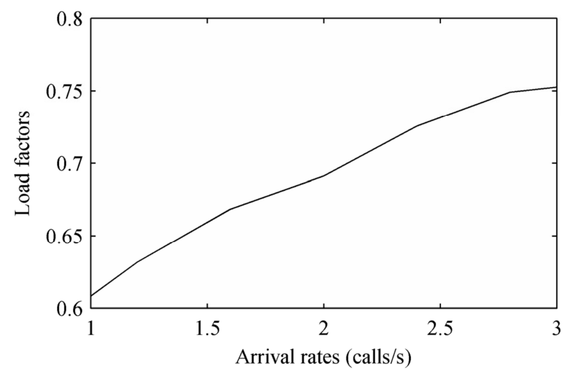

Figure 7. Average Load Factor of Neighbouring Cells

The standard WCDMA soft handover, variable thresholds soft handover, and the proposed fuzzy adaptive soft handover algorithm were evaluated and compared in terms of call blocking probability and throughput. As mentioned in Section 1, [11] only presented the *ASHA* framework and did not show the exact threshold values applied for different congested states during soft handover. Therefore, the threshold settings presented in Section 3.1 are used for the variable thresholds soft handover algorithm involved in the comparison, with the critical values been chosen from available threshold ranges for the maximum possible load balancing gain.

Figure 8 shows the call blocking probabilities for different mean call arrival rates. Both the variable thresholds soft handover and fuzzy adaptive soft handover algorithms can relieve the congestion and decrease the call blocking probabilities of the system compared with the standard WCDMA soft handover. By introducing the active set update delay function, the fuzzy adaptive soft handover algorithm overcomes the limitation of variable thresholds approach, therefore can further relieve the congestion and lead to lower blocking probability. The load balancing effect introduced by using fuzzy adaptive soft handover algorithms becomes more prominent when the call arrival rate increases and the system is more congested.

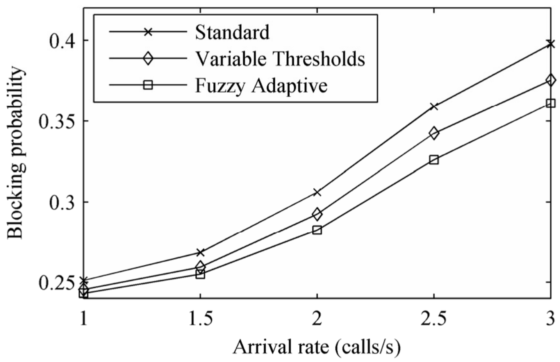

Figure 8. Call Blocking Probability Plots

The average cell throughputs under different traffic loads are plotted in Figure 9. Both the variable thresholds soft handover and fuzzy adaptive soft handover algorithms balance the load between cells, therefore the system can support more traffic. The results reveal that by using the new fuzzy adaptive soft handover algorithm, the system has higher average cell throughput than both variable thresholds soft handover and the standard WCDMA soft handover algorithms at a given call arrival rate within the range of Figure 9. For our simulation scenario, as shown in Section 4, the average cell throughput reaches a peak around the call arrival rate of 2.5calls/s. The average throughput then begins to fall as the call arrival rate increases further because the whole system becomes congested and the interference of more active users degrading the radio resource performance.

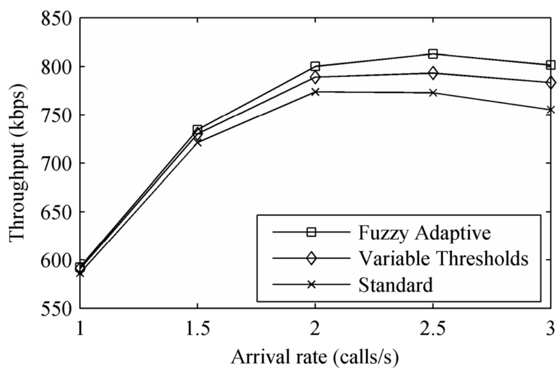

Figure 9. Cell Throughput Plots

6. Conclusion

Soft handover algorithms have two conflicting effects on the performance of WCDMA systems. They can lead to link level macrodiversity gain while consuming additional system level resources. To minimize the resource consumption, soft handover algorithms designed to optimise the link level performance, need also to be dynamically adjusted depending on the system overload state. The proposed adaptive soft handover scheme in this paper employs fuzzy principles to dynamically adjust each UE's addition, removal and replacement thresholds, as well as delaying the active set update, by increasing the trigger time. When cell congestion happens, the proposed scheme can balance the load between neighbouring cells and relieve the congestion, until all cells become congested and the whole system reaches the capacity limit. Simulation results confirm that this novel strategy improved system level performance in terms of a lower blocking probability and higher throughput.

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