A Traffic Shedding Algorithm for Soft-Handoff in MC-CDMA Systems

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Abstract

In mobile communication environment, an abrupt increase of mobile users in a specific cell will make traffic overloaded and become a so-called hot-spot cell, which causes an unbalanced traffic load condition because the traffic load in the neighboring cells may be light. In order to utilize a limited bandwidth efficiently, it is necessary to use a good mobile handoff strategy to alleviate the unbalanced traffic condition. This paper proposes a complete traffic shedding algorithm (CTSA) for soft handoff efficiently to alleviate the overloaded traffic in the hot-spot cell by adjusting handoff parameters, which virtually reduces the service coverage of the heavy loaded cell without adjusting the transmission power. The mobile users located in the outer area of the hot-spot cell will early handoff to the neighboring cells with light traffic load; and the mobile users in the neighboring cells postpone to handoff to the hot-spot cell, so that the traffic load of the hot-spot cell can be decreased. The proposed algorithm is analyzed and evaluated by simulation; CTSA algorithm shows better performance than the others; it obviously increases system throughput and decreases soft handoff call dropping ratio, and new call blocking ratio.
Keyword: mobile communication, hot-spot cell, traffic shedding, soft handoff.

1. Introduction

Wireless communication techniques have rapidly been developing recently. In order efficiently to utilize the limited bandwidth, a variety of handoff methods are proposed to achieve steady communication during handoff procedure. In the handoff procedure of traditional CDMA, pilot signal is compared with the fixed threshold parameters, which are defined at the beginning of system startup and cannot be dynamically adjusted for the appropriate values according to the traffic load [1]. For instance, a huge traffic may be aggregated into a cell to form a hot-spot cell when many people suddenly enter the cell at the same time for a specific activity. It may cause an unbalanced traffic compared with the other neighboring cells, which may also increase the burden of base station (BS) and cause the failures of connecting new calls or on-going calls due to the lack of bandwidth [2].

In order to resolve the above-mentioned problems, some related researches have been proposed, such as dynamical channel allocation [3], changing service region by adjusting pilot signal power [4]–[5], dynamical adjustment handoff threshold parameters [2], [6]–[8] etc.. The method of changing service region by adjusting pilot signal power is to use the characteristics of power control and the soft handoff procedure in CDMA system. It shrinks the service region of hot-spot cell by reducing the power of BS's pilot signal, hence it is also called cell shrinking scheme. However, this method easily leads to service holes and increases the probability of handoff failure, because BS cannot independently operate with another BS and rapidly react for the change of traffic load.

For the method of dynamical adjustment handoff parameters, it is simpler and feasible for BS to perform this operation independently, which mainly includes the variable threshold soft handoff (VTSH) and enhanced soft handoff (ESH) methods [7]–[8]. VTSH cannot perform very well especially for the heavy traffic load because it adjusts the handoff parameters only once. ESH frequently changes handoff parameters as hot-spot phenomenon occurs, because it does not define the hysteresis parameter, which easily causes the ping-pong effect of handoff procedure and increases the system burden.

This paper proposes a complete traffic shedding algorithm (CTSA) to solve the unbalanced traffic load problem without adjusting the transmission power of BS's pilot signal. CTSA can effectively adjust handoff parameters dynamically depending on the traffic load variation. The mobile users located in the hot-spot cell boundary will early handoff to a neighboring cell having light traffic load; conversely, the mobile users

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located in the neighboring cells are postponed to handoff to the hot-spot cell. BS can independently accomplish the traffic balancing without adjusting the pilot signal power of the neighboring cells.

2. Soft handoff in MC-CDMA systems

This section briefly explains the traditional code division multiple access (CDMA) handoff mechanism. CDMA uses direct sequence spreading spectrum (DSSS) technique to transmit data. In order to satisfy the bandwidth requirements for different transmission rates, multi-carrier CDMA (MC-CDMA) can be used [9]–[10]. The advantages of MC-CDMA technique are to increase throughput, resist noise and interference, and decrease bit error rate, so it is suitable to be used in wireless environment with the limited bandwidth.

There are four handoff parameters related to the measurement of pilot signal for the basic handoff procedure in CDMA [1], [7], which are T_ADD, T_COMP, and T_DROP and T_TDROP. T_ADD is to indicate pilot detection threshold; a mobile terminal (MT) may send a pilot strength measurement message (PSMM) to BS if MT detects that the pilot strength is greater than T_ADD. The PSMM contains the following information for each of the pilot signals: estimated E_c/I_t, arrival time, and handoff drop timer. T_COMP is to indicate comparison threshold; BS may send a handoff direction message (HDM) to MT when BS receives the pilot strength of PSMM to be greater than the sum of T_ADD and T_COMP. T_DROP and T_TDROP are to indicate pilot drop threshold and drop timer threshold, respectively; MT starts the T_TDROP timer if the pilot strength falls below the T_DROP value; and MT must leave the BS's service region if the timer expires. Figure 1 shows the basic handoff procedure in CDMA that an MT moves from base station A (BS_A) toward base station B (BS_B) [1].

For traditional soft handoff (CSH) method, the handoff region is always fixed, so the handoff parameters cannot be changed to follow the traffic load variation. Mobile is subject to higher refusing ratio because of the insufficient resources, when the hot-spot problem occurs.

3. Traffic shedding procedure

In order to resolve the hot-spot problem, the concept of traffic shedding can be applied that the mobiles in hot-spot cell should early handoff to the neighboring cells having light traffic load; and the mobiles in the neighboring cells should postpone to handoff into the hot-spot cell. Figure 2 shows the concept of changing handoff parameters when traffic shedding starts. We assume that BS_A is a hot-spot cell and an MT is leaving

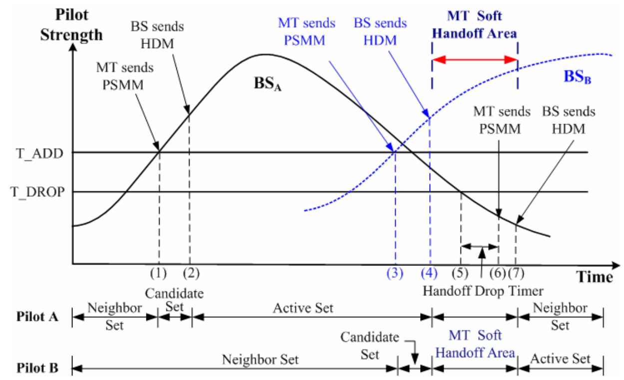

Figure 1 The basic handoff procedure in CDMA

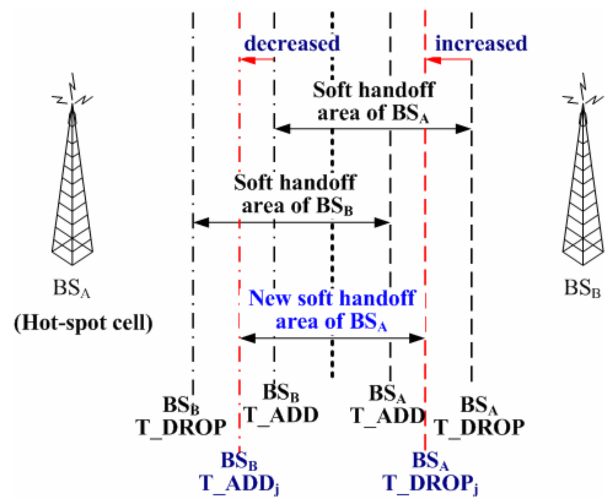

Figure 2 The concept of changing handoff parameters on traffic shedding

BS_A for BS_B. The soft-handoff region can be shifted closer to the hard-handoff boundary of BS_A, if the T_ADD value of the entering BS_B decreases and the T_DROP value of the leaving BS_A increases [11]–[12]. When shedding mechanism starts to execute, BS must adjust the handoff parameters, e.g., T_ADD_j and T_DROP_j are the T_ADD and T_DROP values after the j^{th} traffic shedding, respectively. Therefore the mobile can early handoff to the neighboring cell and release the occupied resource from BS_A.

It is necessary for a recovery mechanism after performing the traffic shedding if the traffic load of the hot-spot cell becomes lighter later, i.e., T_ADD and T_DROP should be resumed to the previous values. The recovery mechanism makes the mobile go back the normal handoff procedure, prevent from causing unnecessary early handoff to the neighboring hot-spot cell, and alleviate the congestion status in the neighboring hot-spot cell.

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3.1. Relationship between handoff region and shedding ratio (SR)

Shedding ratio (SR) concerns the adjusted variation of the threshold values and the related service region when traffic shedding occurs. Figure 3 shows the relationship between handoff region and shedding ratio. Before explaining the relationship between handoff region and shedding ratio, we assume that mobiles are uniformly dispersed in each service region, the traffic density in hot-spot cell is greater than the other neighboring cells, and the original cell radius and hard-handoff boundaries are R_0 and R_h, respectively, as shown in Fig. 3. In order to analyze the proposed algorithm, several system parameters are defined as follows. ρ is the bandwidth utilization of BS, which is defined as the used bandwidth divided by the total bandwidth of BS. α and γ are the threshold values of traffic loads for traffic shedding and recovery mechanisms, respectively, where the shedding and recovery mechanisms start when $\rho > \alpha$ and $\rho < \gamma$, respectively. β is the upper limit value of traffic load after adjusting and set between α and γ; ρ is adjusted from α to β when shedding mechanism starts. η is a flag to indicate if the shedding or recovery mechanism starts, e.g., it is set to 1 for starting the shedding or recovery mechanism and 0 for ending the recovery mechanism. r_j is the cell service radius after the j[th] shedding. T_{dur} is the duration that BS checks the traffic load if the recovery mechanism should start.

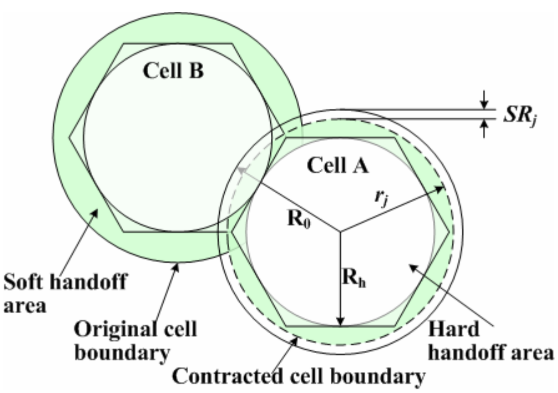

Figure 3 The relationship between handoff region and shedding ratio

The shedding ratio after the j[th] shedding, SR_j, can be derived as shown in Eqs. (1)–(2):

$$SR_1 = R_0 - r_1 \tag{1}$$

...

$$SR_j = r_{j-1} - r_j \tag{2}$$

Let us further denote ρ_m to be the mobile density in each service region; α_i, β_i and ρ_{mi} (for $i = 1, 2, \ldots, j$) are the values of α, β and ρ_m at the i[th] shedding, obtained step-by-step until the j[th] shedding. According to the previous mentioned assumptions, the relations among α_i, β_i and r_i can be shown as in Eqs. (3)–(4).

$$\frac{\beta_1}{\alpha_1} = \frac{\rho_{m1}\pi r_1^2}{\rho_{m1}\pi R_0^2} = \left(\frac{r_1}{R_0}\right)^2 \tag{3}$$

….

$$\frac{\beta_j}{\alpha_j} = \frac{\rho_{mj}\pi r_j^2}{\rho_{mj}\pi r_{j-1}^2} = \left(\frac{r_j}{r_{j-1}}\right)^2 \tag{4}$$

Let us further assume that α_i and β_i (for $i = 1, 2, \ldots, j$) have the same values and are equal to α and β, respectively, as shown in Eqs. (5)–(6). Finally, r_j and SR_j can be obtained by simplifying Eqs. (3)–(4) as shown in Eqs. (7)–(8), respectively.

$$\alpha_1 = \alpha_2 = \cdots = \alpha_j = \alpha \tag{5}$$

$$\beta_1 = \beta_2 = \cdots = \beta_j = \beta \tag{6}$$

$$r_j = \left(\frac{\beta}{\alpha}\right)^{\frac{1}{2}} r_{j-1} = \left(\frac{\beta}{\alpha}\right)^{\frac{j}{2}} R_0 \tag{7}$$

$$SR_j = \left(\frac{\beta}{\alpha}\right)^{\frac{(j-1)}{2}} \times \left[1 - \left(\frac{\beta}{\alpha}\right)^{\frac{1}{2}}\right] \times R_0 \tag{8}$$

3.2. CTSA algorithm

This subsection explains the main processes of CTSA, including traffic shedding, recovery, and postponing algorithms.

(1) Traffic shedding algorithm

- Step 1: If the traffic load exceeds the threshold value α, BS starts the shedding mechanism.
- Step 2: BS decides the shrunk service radius of handoff region and sets flag η to be 1.
- Step 3: The service radius is set to be the hard handoff boundary R_h if the shrunk service radius is less than R_h.
- Step 4: BS broadcasts the corresponding handoff threshold parameters to mobiles for updating.

(2) Recovery algorithm

- Step 1: BS periodically checks the traffic load in the duration T_{dur}. Recovery mechanism starts if flag η is set to 1 and the traffic load is less than the threshold γ.
- Step 2: BS resumes the service region according to the previous shedding ratio.
- Step 3: Flag η is set to 0 if the service radius of BS reaches the original cell boundary R_0 after adjustment.
- Step 4: BS broadcasts the corresponding handoff

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parameters to mobiles for updating after adjustment.

(3) Postponing algorithm

A mobile sends a PSMM to a new neighboring BS if the mobile detects that the pilot strength of the new BS is greater than the threshold T_ADD+ T_COMP. The PSMM message includes the information of handoff drop timer to indicate how much time the mobile will be dropped by the original BS [1], therefore, the new BS can use this information to control when the mobile should be admitted to prevent on-going mobiles from being dropped. Figure 4 shows the timing sequence on the threshold when BS_B is a hot-spot cell and a mobile is in the service region of BS_A and goes toward the service region of BS_B. A mobile normally sends a PSMM to BS_B again at timestamp (4), when the pilot strength of BS_B is greater than T_ADD+T_COMP. BS_B then admits the mobile if BS_B has enough resource. If BS_B is in the hot-spot status, we can control the timing of sending HDM to postpone the mobile entering the service region of BS_B by cooperating the handoff drop timer of PSMM and the resource of BS_B, where the postponed interval is between timestamps (5) and (7). That is, at the timestamp (5), the mobile sends a PSMM to BS_B with the value of handoff drop timer to be greater than zero. BS_B admits the mobile if BS_B has enough resource for the mobile request. Otherwise, BS_B keeps postponing the mobile entering until the handoff drop timer expires at timestamp (7). Therefore, BS_B does not temporarily admit the mobile to save resource if the pilot strength is between timestamps (4) and (5).

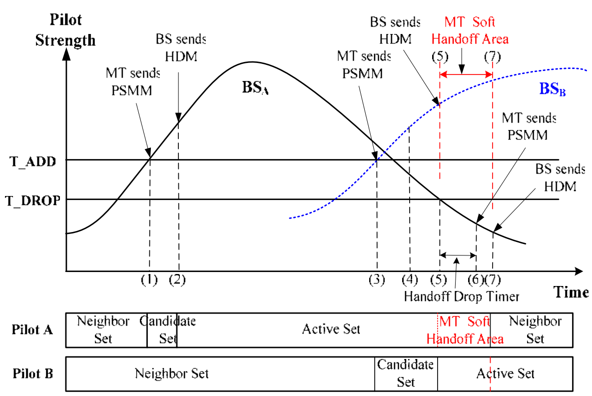

Figure 4 The timing sequence on the threshold when BS_B is a hot-spot cell

3.3. Relationship between service radius and handoff parameters

The process of mobile handoff is either to leave or enter the service regions of the original BS or another BS, respectively. Generally, a mobile may receive a pilot signal from BS; $L_i(d_i,\zeta_i)$ denote the strength of the pilot signal sent by BS_i, where d_i and ζ_i are the distance and the shadowing fading effect between the mobile and BS_i, respectively. $L_i(d_i,\zeta_i)$ can be obtained by propagation model and shown as Eq. (9) [6], [13]:

$$L_i(d_i,\zeta_i) = p\, d_i^{\,m}\, 10^{\frac{\zeta_i}{10}}\,, \qquad (9)$$

where p is the transmitter signal power of BS_i which is a constant value; m consists of path loss component and the effect of multi-path fading. Let us further assume that ζ_i is Gaussian distribution with zero mean and standard deviation σ. The log-normal form of Eq. (9) can be expressed as Eq. (10):

$$L_i(d_i,\zeta_i)_{(dB)} = 10\log p + 10m\log d_i + \zeta_i \qquad (10)$$

We assume that BS_B is a general cell but BS_A is a hot-spot cell and runs the shedding algorithm to change the handoff threshold. A mobile will be postponed to enter the service region of BS_A if it is moving from BS_B to BS_A. Conversely, in the opposite direction, the mobile will handoff to BS_B earlier to alleviate the congestion situation. Let us denote that $L_A(r_j,\zeta_A)$ and $L_B(r_j,\zeta_B)$ are the strengths of pilot signals sent by BS_A and BS_B, respectively, which satisfy the conditions of Eqs. (11)–(12) according to the shedding algorithm if the mobile in the service region of BS_A is approaching the service region of BS_B.

$$L_B(r_j,\zeta_B) > T\_ADD_j + T\_COMP = T\_ADD - \Delta T\_ADD_j + T\_COMP \qquad (11)$$

$$L_A(r_j,\zeta_A) > T\_DROP_j = T\_DROP + \Delta T\_DROP_j \qquad (12)$$

ΔT_ADD_j and ΔT_DROP_j are the adjustment ranges of handoff threshold after the j^{th} shedding. From Eqs. (8) and (11), ΔT_DROP_j can be obtained as follows.

$$\Delta T\_DROP_j = T\_DROP_j - T\_DROP$$
$$= L_A(r_j,\zeta_A) - L_A(R_0,\zeta_A)$$
$$= 10m\log\left(\frac{r_j}{R_0}\right) = 10m\log\left(\frac{\beta}{\alpha}\right)^{\frac{j}{2}} = 5jm\log\left(\frac{\beta}{\alpha}\right) \qquad (13)$$

Similarly, ΔT_ADD_j can be obtained by Eq. (14).

$$\Delta T\_ADD_j = 5\omega jm\log\left(\frac{\beta}{\alpha}\right) \qquad (14)$$

4. Simulation experiments

This section analyzes and compares the performance measurements obtained by simulation experiments for CSH, VTSH, ESH and CTSA algorithms, such as system throughput, handoff call dropping ratio, and

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new call blocking ratio. We assume that two adjacent base stations are the hot-spot cells having higher mobile density, while the other surrounding cells, eight BSs, are the general cells having lower average mobile density. Table 1 shows the related parameters for system shedding and recovery used in the simulation.

Table 1 Parameters for shedding and recovery

Parameters		Values
Base station service radius		1000 m
Base station transmission bandwidth		9 Mbps
Call arrival process		Poisson
Guard channel for soft-handoff call		2%
Traffic load shedding parameters	α	0.95
	β	0.9
	γ	0.85
	ω	0.5

Figure 5 shows system throughput against call arrival rate according to the sending or receiving data by a mobile. The hot-spot situation begins at the traffic load 500 calls/min and CTSA performs best, but CSH is worst. CSH has the most quantity of handoff calls and the least system throughput, because it does not have shedding function. VTSH cannot effectively keep shedding traffic when traffic load increases such that its improvement is restricted, because the handoff region is adjusted only once when traffic load is getting heavier. ESH dynamically begins adjusting the handoff region at the traffic load over 70% of the hot-spot traffic (i.e., 350 calls/min); it cannot adjusts the service region to the optimal status after having the hot-spot situation, because ESH occasionally adjust the handoff region according to the traffic load variation. When the hot-spot situation occurs, CTSA first adjust handoff threshold parameters and then adjust handoff region after waiting for a period depending on the traffic load

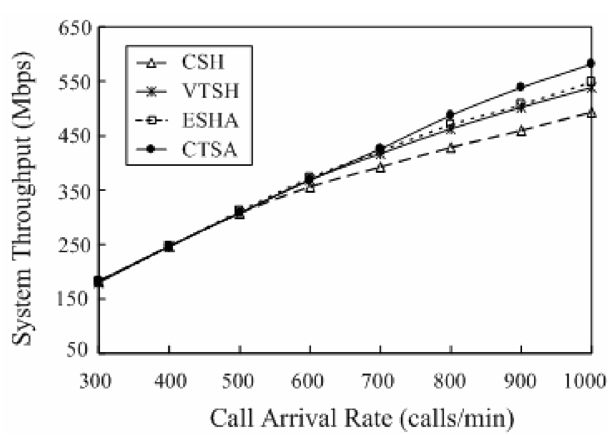

Figure 5 System throughput of user's viewpoint against call arrival rate

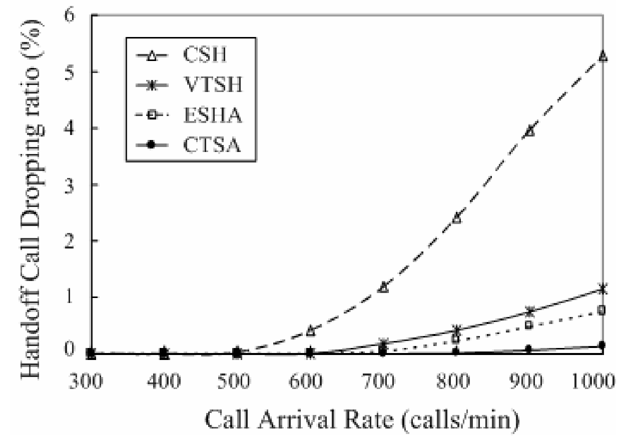

Figure 6 System soft-handoff call dropping ratio against call arrival rate

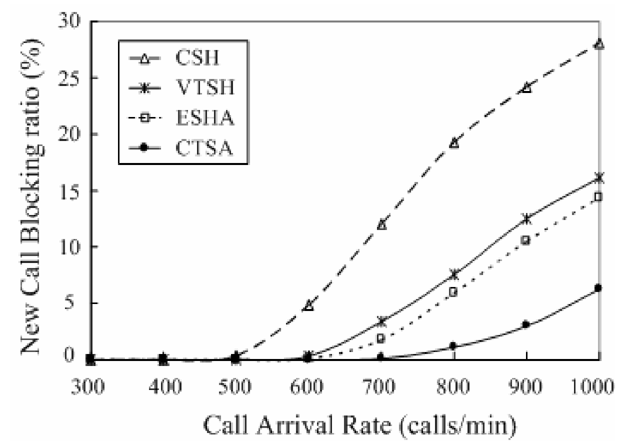

Figure 7 System new call blocking ratio against call arrival rate

situation; CTSA also starts postponing algorithm that the mobile located in the neighboring cells postpones to handoff to the hot-spot cell. In summary, CTSA can effectively alleviate BS's congestion problem.

Figures 6 and 7 show soft-handoff call dropping ratio and new call blocking ratio against call arrival rate, respectively. Obviously, CTSA can effectively execute shedding algorithm and postpones the mobile to handoff to the hot-spot cell according to traffic load variation. CTSA can efficiently reduce the number of handoff calls and soft-handoff call dropping ratio, hence resources can be assigned to new calls to reduce new call blocking ratio. This system reserves 2% of total bandwidth for soft-handoff call so that handoff call has higher priority over new call; therefore the new call blocking ratio is greater than soft-handoff call dropping ratio. CSH performs the worst for both handoff call dropping ratio and new call blocking ratio when traffic load becomes heavier, because CSH

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cannot dynamically adjust handoff threshold parameters according to the traffic load. Bandwidth is doubly used in CSH algorithm, which is getting more serious especially for the lack of resource when the number of soft-handoff call requests increases; therefore the handoff call dropping ratio and new call blocking ratio obviously grow up. VTSH performs worse than ESH, because ESH can adjust the handoff region many times according to the traffic load variety but VTSH adjusts only once.

In summary, CTSA can effectively alleviate BS's congestion problem according to the previous results. It increases system throughput and reduces soft-handoff call dropping ratio, and new call blocking ratio to resolve the hot spot problems.

5. Conclusion

This paper mainly focuses on solving the unbalanced traffic problems for mobile communication system when the number of mobiles rapidly increases in a specific cell. The handoff process of traditional CDMA may make mobiles suffer from serious call blocking and dropping, because BS has no enough resource for the rapid increasing traffic load. CTSA can improve the unbalanced traffic problems by adjusting handoff threshold dynamically according to traffic load variation.

Generally, adjustment range should be moderate; otherwise the service hole problem may be rather serious if it is too large, or the hot-spot traffic cannot effectively be shed if it is too small. System can save additional capacity, which may be occupied during the soft handoff process, to reduce call refusing ratio if the mobiles located in the hot-spot cell can handoff to the neighboring cells earlier. However, ping-pong effect may occur and affect system efficiency if the handoff threshold parameters are adjusted too often. CTSA provides shedding, recovery, and postponing algorithms to prevent the ping-pong effect.

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