A Novel Load Control Strategy For TD-SCDMA Enhanced Uplink

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Abstract—In this paper, we propose a novel load control strategy for TD-SCDMA Enhanced Uplink, called as system-based load control strategy. We compare its performance with the cell-based load control strategy, which was widely accepted in TD-SCDMA Release 4/5. It is concluded that system-based load control outperforms cell-based load control in the Rise over Thermal (RoT) control and the system throughput.

Keywords—load control; RoT; TD-SCDMA; Enhanced uplink

I. INTRODUCTION

A series of specifications are released by 3GPP during the evolution of TD-SCDMA to address the demand for increasing the system coverage and throughput while reducing the packet delay. The downlink of TD-SCDMA was improved significantly for the introduction of High Speed Downlink Packet Access (HSDPA) in release 5. The next logical step in the evolution of TD-SCDMA is to improve the uplink performance. This was done with the introduction of the Enhanced Dedicated Channel (E-DCH) in release 6, which is also referred to High Speed Uplink Packet Access (HSUPA). Compared to earlier releases of TD-SCDMA, the end-user experiences significantly improved services through higher offered data rates and reduced delays, whereas the operator benefits from an increased system capacity, by introducing several technologies, such as Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeat Request (HARQ), Node-B controlled scheduling, fast signaling, and shorter TTI [1].

As an important function of radio resource management (RRM), tight load control is desired. Because over-usage of uplink load makes system unstable, and under-usage brings a lower throughput. For CDMA communication systems, the uplink load in a cell is defined as [2]:

\[ \eta = \frac{P_{r_{\text{own}}} + P_{r_{\text{other}}}}{P_{r_{\text{own}}} + P_{r_{\text{other}}} + P_{r_{\text{noise}}}} \]  

(1)

Where \( P_{r_{\text{own}}} \) is the received power from the users in the own cell, \( P_{r_{\text{other}}} \) is the received power from the users in the other cells and \( P_{r_{\text{noise}}} \) denotes the thermal noise power. Another parameter, Noise Rise which is named as RoT [3], also indicates the uplink load. The relationship between Noise Rise and uplink load can be described as:

\[ RoT_{\text{cell}} = \frac{1}{1-\eta} = \frac{P_{r_{\text{own}}} + P_{r_{\text{other}}} + P_{r_{\text{noise}}}}{P_{r_{\text{noise}}}} \]  

(2)

Cell-based load control is proposed in the existing TD-SCDMA Release 4/5 [4], since the uplink scheduling and rate control module resides in the Radio Network Controller (RNC) which has the knowledge of the throughputs of all the Node-Bs that connected to it. Whereas in the case of TD-SCDMA HSUPA, the MAC entity related to the scheduling and RoT control is placed at the Node-B [1]. On one hand, this kind of the Node-B controlled scheduling can reduce the delay of signalling transmission, thus it will provide a better control of RoT variance and utilize the uplink resource more efficiently. On the other hand, this scheduling scheme has its own limitation. As it is a kind of “decentralized scheduling”, which means that the schedulers of all the cells are independent, there is no information sharing between the Node-Bs, the inter-cell interference cannot be directly considered in the cell-based load control strategy.

Considering that cell-based load control might not be suitable for TD-SCDMA HSUPA, we propose a more efficient system-based load control strategy in this paper. This strategy takes the inter-cell interference into account, and it is also in line with current structure in release 6.

The paper is organized as follows. Section II provides enhanced uplink features on the inter-cell interference control mechanism in the specifications, and section III presents theoretical background information of load control strategies, including cell-based and system-based load control strategy. The procedure of the mechanism is shown in the next section. The simulation assumptions and results are presented and discussed in section V. At last, we give the conclusion in section VI.

II. ENHANCED UPLINK FEATURES IN RELEASE 6

For TD-SCDMA HSUPA, most of the intra-cell interference is removed by the receiver due to the adoption of the technologies, such as smart antenna and joint detection, thus the dominant interference comes from the neighbouring cells. Unlike WCDMA HSUPA, support for uplink soft handover is not mandatory in TD-SCDMA system. Moreover, there is no corresponding support in the UE for active reception of downlink control signals (such as E-DCH Relative Grant Channel (E-RGCH)) from multiple cells [5]. Thus, the TD-SCDMA enhanced uplink solution to manage inter-cell interference via E-RGCH cannot be applied to TD-SCDMA.

In order to manage inter-cell interference for TD-SCDMA HSUPA, an improvement has been made on UE side. Metrics based upon the serving cell and the neighbouring cell path...
losses are signalled on the uplink from the UE and fed back to the serving cell scheduler in the Node-B MAC-e [6]. Path losses are calculated by the UE via measurement of the serving cell and the neighbouring cell P-CCPCH Received Signal Code Power (RSCP) and via the knowledge of the associated P-CCPCH reference powers provided by system information, thus the Node B can estimate the inter-cell interference when allocating a specific power to a UE.

Up to now, several methods of the location information feedback have been investigated in [7], including full feedback based on full speed, full feedback based on slower speed, partial feedback based on poorest-cell and partial feedback based on geometry. Since full feedback consumes excessive uplink signalling bandwidth and partial feedback based on poorest-cell only reports the worst-case cell, which might reduce the accuracy of interference control, we recommend the partial feedback based on geometry in the paper.

The Geometry of user \( i \) is defined as

\[
G_i = \frac{1}{\sum_{j \neq i} \Lambda_{i,j}}
\]

(3)

Where location information \( \Lambda_{i,j} \) is the ratio of the pathloss between the user \( i \) and the neighboring cell \( j, L_{i,j} \), to the pathloss between the user \( i \) and the serving cell \( j, L_{i,J} \), as shown in (4).

\[
\Lambda_{i,j} = \frac{L_{i,j}}{L_{i,J}}
\]

(4)

Substituting (4) into (3) yields to

\[
G_i = \frac{1}{\sum_{j \neq i} \frac{1}{L_{i,j}}} = \frac{1}{\sum_{j \neq i} \frac{P_j}{L_{i,j}}} = \frac{P_{Ri,J}}{\sum_{j \neq i} P_{Ri,j}}
\]

(5)

Where \( P_i \) is the transmission power of the user \( i \), \( P_{Ri,J} \) is the received power from the user \( i \) in the serving cell \( J \), \( \sum_{j \neq i} P_{Ri,j} \) is the sum of the received power from the user \( i \) in the neighbouring cell \( j \).

III. LOAD CONTROL STRATEGY

A. cell-based load control strategy

In order to control the system load level efficiently, the RNC allocates load thresholds to the Node-Bs respectively, and the Node-Bs are responsible to report their loading conditions back, then the RNC could adjust the thresholds to balance the loading according to the feedbacks [8].

The uplink load factor of a Node-B is calculated as the sum of the load factors of all the UEs that connected to it. When allocating the resources to the users, Node-B must guarantee the uplink load factor not to exceed the cell threshold.

However, there may be some problems with this strategy in HSUPA. On one hand, since the MAC entity related to the scheduling and load control is placed at Node-B as mentioned in previous section, no information is shared among the Node-Bs, and the geometry information of the UEs will not be used for scheduling and load control, thus the UEs, that have the same contribution to the serving cell, may cause much different interference to the neighbouring cells due to different geometries. On the other hand, the delay between Node-B and RNC might weaken inter-cell load balancing, since it cannot follow the variation of channel.

B. System-based load control strategy

To improve the validity of the resource allocation and load control, we propose the system-based load control strategy. In this strategy, we define the system RoT as a load control factor, which represents the total system interference caused by the UEs. It has a little difference from the cell RoT. The system RoT is defined as:

\[
RoT_{sys,i} = \frac{P_{r,own} + P_{r,neighbour} + P_{r,noise}}{P_{r,noise}}
\]

(6)

Where \( P_{r,own} \) is the received power from the users in the serving cell, \( P_{r,neighbour} \) is the received power of the neighbouring cells from the users in the serving cells.

In TD-SCDMA, the contribution of a scheduled UE to the system RoT is

\[
RoT_{sys,i} = \alpha \cdot ((1 - \beta) P_{Ri,J} + \sum_{j \neq i} P_{Ri,j}) + P_{N0}
\]

(7)

Where \( \alpha \) is the statistical gain of the smart antenna [9], \( \beta \) is the joint detection factor, which represents the influence of joint detection, \( P_{N0} \) is the thermal noise power.

The system RoT of the cell \( J \) is the sum of the system RoT of the UEs that are connected to the cell. It is defined as:

\[
RoT_{sys,J} = \sum_{i \in cell J} RoT_{sys,i}
\]

\[
= \alpha \cdot \left( \sum_{i \in cell J} ((1 - \beta) P_{Ri,J} + \sum_{j \neq i} P_{Ri,j}) \right) + P_{N0} / P_{N0}
\]

(8)

Substituting \( G_i \) from (5) in (8), we can get:
According to (9), we can see that under the same Quality of Service (QoS) requirement, the cell-edge users, whose geometries are lower than the central ones, lead to more interference to the neighboring cells and more contribution to the system RoT.

Since the system RoT has considered the impact of user’s geometry, the system-based load control strategy could give a more precise control to the inter-cell interference, when compared to the cell RoT.

Further, if the UEs are evenly distributed in the cell and the system operates at full load, we can get:

$$\sum_{k \in \text{Serv}} \text{RoT}_{\text{sys},k} = \sum_{k \in \text{Serv}} \text{RoT}_{\text{cell},k}$$

(10)

Where the symbol Serv denotes the serving cell set, $\text{RoT}_{\text{sys},k}$ and $\text{RoT}_{\text{cell},k}$ are considered as random variables with the same distribution.

IV. THE PROCEDURE OF THE STRATEGY

To explain the system-based load control strategy further, we give the implementation of the strategy in the system simulation. The steps can be summarized as follows:

1. UE sends scheduling request via E-DCH Random Access Uplink Control Channel (E-RUCCH), which includes the geometry, power headroom, buffer information, et al.

2. Node-B prioritizes the UEs according to their requests and certain scheduling algorithm, such as round-robin and proportional fair.

3. Calculate the maximal transmission power $P_{\text{max}}$ that allowed for the UE on the top of the priority list by (11). If the value exceeds the power headroom of the UE $P_{\text{e,max}}$, set $P_{\text{max}} = P_{\text{e,max}}$.

$$P_{\text{max}} = \begin{cases} (\text{RoT}_{\text{sys}} - 1) \cdot \frac{\text{P}_{\text{e,avg}}}{\text{RoT}_{\text{sys}}} & \text{if } P_{\text{max}} < P_{\text{e,max}} \\ \alpha(1 - \beta + \frac{1}{G_i}) \cdot \frac{\text{P}_{\text{e,avg}}}{\text{RoT}_{\text{sys}}} & \text{if } P_{\text{max}} \geq P_{\text{e,max}} \end{cases}$$

(11)

Where $\text{RoT}_{\text{sys}}$ is the system load threshold, which is appointed by the higher layer.

4. Estimate the maximal Carrier-to-Interference ratio (C/I) that the UE can reach using (12).

$$P_{\text{max}} = \frac{\frac{C}{I}}{\frac{\text{RoT}_{\text{sys}} \cdot \text{P}_{\text{e,avg}} \cdot \text{PL}_{\text{serving}}}{\alpha - (1 - \beta) \cdot P_{\text{e,max}}}}$$

(12)

5. The actual target C/I that the Node-B allocates to the UE can be given by (13), where the set of the C/I thresholds of different Modulation Coding Schemes (MCS) is denoted $\{ \frac{C}{I_1}, \frac{C}{I_2}, \ldots, \frac{C}{I_N} \}$, $N$ is the number of MCS levels.

Then we can get the contribution to the system RoT by this UE from (7). If the target C/I cannot be found, the UE will not be scheduled.

$$k = \arg \left( \frac{C}{I_k} \right), \quad 1 \leq i \leq N - 1$$

(13)

6. Update the system RoT according to (14).

$$\text{RoT}_{\text{sys}} = \text{RoT}_{\text{sys}} - \text{RoT}_{\text{sys},i}$$

(14)

Where $\text{RoT}_{\text{sys},i}$ denotes the contribution to the system RoT by the user $i$.

7. Remove the scheduled UE from the list and go back to 2. If the list is empty, the procedure is over.

V. SIMULATION ASSUMPTIONS AND RESULTS

We use dynamic simulator for system-level simulations of UMTS. The system has a hexagonal wrap-around topology with 19 cells. The 25.942/Xia propagation model [10] and a mixed channel model (PB3 50%, and VA30 50%) are used. Non-ideal channel estimation is modeled whereas the SIR estimation is assumed to be perfect. Inner loop power control step size is 1dB with no feedback error and the outer loop power step size is 0.5dB with 10% target frame error rate (FER). Both the TFC selection and TFC control are considered with a Round Robin scheduler. The details of system parameters are summarized in Table I.

Figure 2 plots the Cumulative Distribution Function (CDF) of the cell RoT based on the two different load control strategy at the same RoT threshold (7dB). We can see that the variety of the cell RoT with the cell-based approach is more fluctuant than that with the system-based approach. The variation range of the cell RoT with system-based approach is only 1.5dB, and the mean value reaches about 6.5dB, closer to the threshold. Moreover, the RoT overshoot of the cell-based approach, which is defined as the percentage of the time that RoT is over the threshold, reached as much as 9%, owing to its poor ability of controlling the inter-cell interference.
Figure 3 compares the cell throughput based on the two different strategies at the different RoT thresholds. The cell throughput gain of the system-based approach is found around 33% higher than that of the cell-based approach, since it controls the RoT more tightly as shown in figure 2.

VI. CONCLUSION

In this paper we present the system-based load control strategy on the TD-SCDMA enhanced uplink. After introducing the enhanced uplink features in Release 6, we give a description of cell-based load control strategy, which has been widely accepted in Release 4/5, and the system-based load control strategy, which is proposed to be utilized under the structure of Release 6. The performances of the two strategies are compared via the dynamic simulations. The system simulation results show that the RoT with system-based approach is controlled more tightly, and the cell throughput has a gain around 33% over the cell-based approach.

VII. REFERENCES


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<td>Shadow Fading Standard Deviation</td>
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![Figure 1. Smart antenna beamforming gain](image1)

![Figure 2. RoT CDF with cell-based and system-based load control strategies](image2)

![Figure 3. Cell throughput vs. RoT with cell-based and system-based load control strategies](image3)