A QoS-Guaranteed Cell Selection Strategy for Heterogeneous Cellular Systems

Qiang Guo, Xianghua Xu, Jie Zhu, and Haibin Zhang

In order to improve the accuracy of cell selection in heterogeneous cellular systems, this paper proposes a fuzzy multiple-objective decision-based cell selection (FMDCS) strategy. Since heterogeneous cellular systems have different access technologies and multiple traffic classes, the strategy adopts cell type, data rate, coverage, transmission delay, and call arrival rate as evaluation indices, and uses different weight vectors according to the traffic classes of the mobile host. Then, a fuzzy multiple-objective decision algorithm is applied to select the optimal cell from all candidates. This paper also gives an instance analysis and simulation. The instance analysis shows FMDCS makes different selections for different traffic classes. Simulation results of the after-handoff quality-of-service (QoS) show the selected cell can provide MH optimal service.

Keywords: Heterogeneous cellular systems, QoS, cell selection, fuzzy multiple-objective decision.

I. Introduction

Current mobile networks are homogeneous cellular systems, which adopt only one radio access technology. For example, Global System for Mobile Communications uses TDMA while the Universal Mobile Telecommunications System (UMTS) uses CDMA. The next generation mobile networks will be heterogeneous cellular systems (HCS) that apply several access technologies. Moreover, the future mobile host (MH) will be a multi-mode terminal [1]. How to implement a handoff in HCS becomes a significant issue [2]. A handoff is a process where an MH is transmitted from one cell to another during a call [3]. A handoff consists of three steps, handoff initiation, cell selection, and handoff execution. Here, handoff initiation handles a setup service such as measuring the received signal strength (RSS), signal interference ratio (SIR), and so on. Cell selection recognizes the handoff demand and selects the optimum cell to hand over. The handoff execution establishes the connection with a new cell. Obviously, cell selection is the most important since it determines the after-handoff quality-of-service (QoS).

In homogeneous networks, handoffs only occur among cells of the same type, and the cell with the maximum signal noise rate (SNR) is usually selected. However, cell selection in HCS may be executed within heterogeneous cells [4]. Conventional cell selection methods are not suitable for HCS. Unlike the situation in a homogeneous network, there are few references related to the cell selection of HCS. Anpalagan and Katzela [5] discuss cell selection in an overlay network and pay more attention to the velocity of the MH and the coverage of a cell. However, they do not notice the traffic type or bandwidth requirement [5]. Majlesi and Khalaj [6] propose an algorithm based on adaptive fuzzy logic. This algorithm takes the

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velocity and bandwidth as the inputs of a fuzzy logic system, and makes its decision according to a defined fuzzy reference rule base. But the input information of the algorithm is too simple to express the features of HCS. Moreover, [6] lacks necessary consideration of the after-handoff QoS. Therefore, this paper presents a fuzzy multiple-objective decision-based cell selection (FMDCS) strategy. The strategy is evaluated through instance analysis and simulation. Simulation results show the selected cell can provide an optimal after-handoff QoS, which proves FMDCS is efficient for cell selection.

II. FMDCS Strategy

After handoff initiation, an MH will execute the proposed FMDCS strategy as shown in Fig. 1. Different traffic types require different QoS [7]; for example, real-time traffics are severely affected by transmission delay, whereas non-real-time traffics pay more attention to the service duration. Therefore, FMDCS first classifies current traffics into real-time and non-real-time types. Second, since the same types of traffics with different bandwidth (for example, voice and videophone) still require different QoS, the strategy further differentiates the bandwidth requirement. In this way, traffics can be classified into real-time & high-bandwidth (R&H), real-time & low-bandwidth (R&L), non-real-time & high-bandwidth (NR&H), and non-real-time & low-bandwidth (NR&L). Different weight vectors, w_{rh}, w_{rl}, w_{nh}, *and* w_{nl} will be assigned to these four classes, respectively. Finally, such essential factors as cell type, data rate, and so on are considered, and according to the set of factors and their correlations, the fuzzy multiple-objective decision algorithm [8]-[9] is applied to make the cell selection. The algorithm includes four steps: 1) Define the evaluation matrix, 2) define the weight vector, 3) do a consistency check, and 4) make a fuzzy integrated decision. These steps will be discussed in the following subsections.

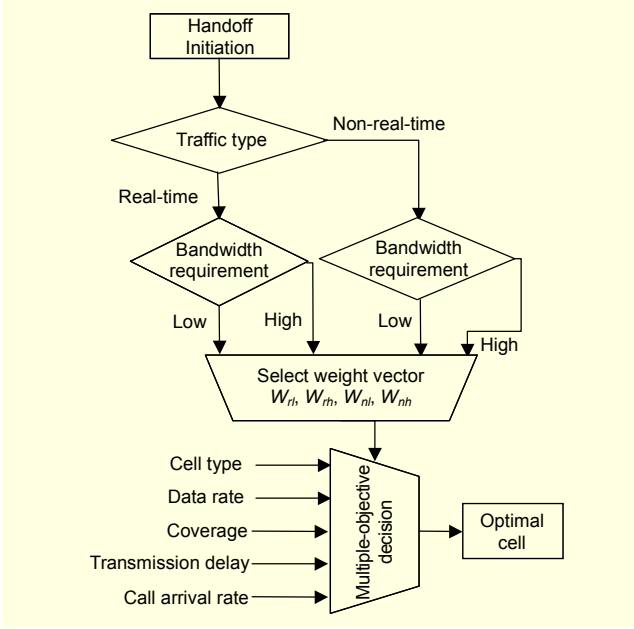

Fig. 1. Flow diagram of FMDCS strategy.

1. Define Evaluation Matrix

Suppose there are n candidate cells that support the current traffic of an MH. As shown in Fig. 1, cell type, data rate, coverage, transmission delay, and call arrival rate are selected as evaluation indices. The reasons for using these indices are as follows.

- Cell type (t) is used to distinguish the type of candidate cells. If a candidate cell has the same type as the current one, set t=1; otherwise set $0<t<1$ according to the traffic carrying capacity of the cell. For example, the traffic carrying capacity of UMTS is higher than that of GPRS, so t of the former should be higher than that of the latter. The aim of adopting cell type is to encourage the handoff to occur between homogeneous or similar cells, which can improve the reliability of the handoff.
- Data rate (r) can directly affect the after-handoff QoS of the MH. Usually, a high value of r means the cell supports high transmission performance.
- Coverage (c) affects the handoff frequency. A smaller value of c corresponds to a higher probability of handoff occurrence.
- Transmission delay (l) is a key factor that affects the transmission performance of real-time traffics, and it also affects the QoS of non-real-time traffics, for example, through a dropped packet and retransmission.
- Call arrival rate (a) has a significant impact on the after-handoff QoS. A cell having a high value of a means there will be many new calls in the cell, thus the service performance and quality of the cell will decline rapidly.

Based on these five evaluation indices, we define the evaluation matrix X for the n candidate cells as

$$X = (x_{ij})_{5\times n} = \begin{bmatrix} x_{t1} & x_{t2} & \cdots & x_{tn} \\ x_{r1} & x_{r2} & \cdots & x_{rn} \\ x_{c1} & x_{c2} & \cdots & x_{cn} \\ x_{l1} & x_{l2} & \cdots & x_{ln} \\ x_{a1} & x_{a2} & \cdots & x_{an} \end{bmatrix},$$

where element x_{ij} presents the evaluation value of cell j for index i (i=t, r, c, l, a). Matrix X should be standardized because its elements have no uniform criterion and cannot be compared directly. Set $x_{i\_\max} = \max(x_{i1},\ldots,x_{in})$ and $x_{i\_\min} = \min(x_{i1},\ldots,x_{in})$,

and denote r_{ij} as the standardized value of x_{ij}. Then,

$$r_{ij} = \frac{x_{ij}}{x_{i\_\max}}. \quad (1)$$

Here i (i=t, r, c) presents the favorable evaluation indices for the after-handoff QoS.

$$r_{ij} = \frac{x_{ij}}{x_{i\_\min}}. \quad (2)$$

Here i (i=l, a) presents the adverse evaluation indices for the after-handoff QoS. Then, we get the standardized evaluation matrix R from X as

$$R = (r_{ij})_{5\times n} = \begin{bmatrix} r_{t1} & r_{t2} & \cdots & r_{tn} \\ r_{r1} & r_{r2} & \cdots & r_{rn} \\ r_{c1} & r_{c2} & \cdots & r_{cn} \\ r_{l1} & r_{l2} & \cdots & r_{ln} \\ r_{a1} & r_{a2} & \cdots & r_{an} \end{bmatrix}.$$

2. Define Weight Vector

The multiple-objective decision algorithm gives a decision according to weighted factors. We define the weight vector for the previously described evaluation indices as $w = [w_t, w_r, w_c, w_l, w_a]$. The analytic hierarchy process [10] is used to derive vector w. Denote quantization value $c_{i,j}$ as the relative importance of index i to j. Table 1 lists its typical values [10].

Table 1. Importance contrast between evaluation indices.

Importance contrast between i and j	$c_{i,j}$
Equally important	1
Weakly more important than	3
Strongly more important than	5
Very strongly more important than	7
Absolutely more important than	9

Comparing the evaluation indices with each other, we get the following contrast matrix C:

$$C = (c_{i,j})_{5\times 5} = \begin{bmatrix} c_{t,t} & c_{t,r} & c_{t,c} & c_{t,l} & c_{t,a} \\ c_{r,t} & c_{r,r} & c_{r,c} & c_{r,l} & c_{r,a} \\ c_{c,t} & c_{c,r} & c_{c,c} & c_{c,l} & c_{c,a} \\ c_{l,t} & c_{l,r} & c_{l,c} & c_{l,l} & c_{l,a} \\ c_{a,t} & c_{a,r} & c_{a,c} & c_{a,l} & c_{a,a} \end{bmatrix}.$$

Calculate each weight using the geometrical average as

$$w_i' = \sqrt[5]{\prod_{j=t,r,c,l,a} c_{i,j}} \quad (i = t,r,c,l,a). \quad (3)$$

Normalize the above weight as

$$w_i = \frac{w_i'}{\sum_{i=1}^{5} w_i'} \quad (i = t,r,c,l,a). \quad (4)$$

Referring to (4), we can obtain the final weight vector w.

Different traffic classes need different QoS. For example, R&H traffic is sensitive to transmission delay, while NR&L traffic always needs the coverage to be large enough to avoid frequent handoffs. Thus the contrast matrix C should be adjusted according to traffic classes. For instance, set $c_{l,c}$ to be 5 for R&H traffic, and set $c_{l,c}$ to be 1/5 for NR&L traffic. Consequently, FMDCS adopts different weight vectors for different traffic classes. As shown in Fig.1, these weight vectors are w_{rl} for R&L traffic, w_{rh} for NR&H traffic, w_{nl} for NR&L traffic, and w_{nh} for NR&H traffic.

3. Consistency Check

The analytic hierarchy process algorithm requires the contrast matrix C to satisfy consistency. A consistency check should be executed to decide whether to accept matrix C or not. The consistency check includes the following steps.

a) Compute the maximum eigenvalue $\lambda_{\max}$ of matrix C.
b) Compute the consistency index $CI=(\lambda_{\max}-m)/(m-1)$, where m is the number of indices. In an FMDCS strategy, m=5.
c) Find the corresponding average random consistency index RI. Table 2 [10] gives the values of RI for m= 1,…,9.
d) Compute the consistency ratio $CR = CI/RI$. If CR<0.1, matrix C can be accepted; otherwise, adjust matrix C and go to step a).

Table 2. Average random consistency index RI.

m	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

4. Fuzzy Integrated Decision

Based on the standardized evaluation matrix and weight vectors, a fuzzy integrated decision algorithm is used to select the optimum cell, $cell\_best$, as

$$cell_{\_best} = \arg\max_{1\le j\le n}\left\{ \bigvee_{i=t,r,c,l,a} (w_i \cdot r_{ij}) \right\}, \quad (5)$$

where w_i is the weight vector derived from (4), r_{ij} is the standardized value of evaluation matrix element, $\vee$ denotes the maximum in fuzzy operation, and the "arg" operator denotes the ordinal of the "max" operation.

III. Instance Analysis and Simulation

In the instance analysis, we assume there are four candidate cells during system handoff. Table 3 gives the values of their evaluation indices. Here transmission delay is measured during handoff initiation.

Table 3. Evaluation indices of candidate cells.

Evaluation indices	Cell 1	Cell 2	Cell 3	Cell 4
Cell type	0.3	1	1	0.5
Data rate (Mbps)	1	11	5.5	2
Coverage (m)	1200	200	300	1000
Transmission delay (s)	0.52	0.02	0.033	0.24
Call arrival rate	0.10	0.05	0.08	0.125

According to Table 3, we get the evaluation matrix X for the four candidate cells as

$$X = (x_{ij})_{5\times 4} = \begin{bmatrix} 0.3000 & 1.0000 & 1.0000 & 0.5000 \\ 1.0000 & 11.000 & 5.5000 & 2.0000 \\ 1200.0 & 200.00 & 300.00 & 1000.0 \\ 0.5200 & 0.0200 & 0.0330 & 0.2400 \\ 0.1000 & 0.0500 & 0.0800 & 0.1250 \end{bmatrix}.$$

By standardizing matrix X, we get the standardized evaluation matrix R as

$$R = (r_{ij})_{5\times 4} = \begin{bmatrix} 0.3000 & 1.0000 & 1.0000 & 0.5000 \\ 0.0909 & 1.0000 & 0.5000 & 0.1818 \\ 1.0000 & 0.1667 & 0.2500 & 0.8333 \\ 0.0385 & 1.0000 & 0.6061 & 0.0833 \\ 0.5000 & 1.0000 & 0.6250 & 0.4000 \end{bmatrix}.$$

Suppose the instance includes two types of traffics: 1) Traffic A, an R&H videophone, which demands the transmission of 128 pixel × 120 pixel images at 10 frames/second, and 2) Traffic B, an NR&L FTP, which demands the download of a total of 30 files (100 kbyte each). Tables 4 and 5 show importance contrast c_{ij} $(i,j=t,r,c,l,a)$ in traffics A and B.

Table 4. Important contrast of evaluation indices in traffic A.

$c_{i,j}$	t	r	c	l	a
t	1	1/3	3	1/7	1/5
r	3	1	5	1/3	1/3
c	1/3	1/5	1	1/7	1/7
l	7	3	7	1	3
a	5	3	7	1/3	1

Table 5. Important contrast of evaluation indices in traffic B.

$c_{i,j}$	t	r	c	l	a
t	1	1/3	1/7	3	3
r	3	1	1/5	5	5
c	7	5	1	9	9
l	1/3	1/5	1/9	1	1
a	1/3	1/5	1/9	1	1

Denote contrast matrices C_A and C_B for traffics A and B, respectively. We get

$$C_A = \begin{bmatrix} 1 & 1/3 & 3 & 1/7 & 1/5 \\ 3 & 1 & 5 & 1/3 & 1/3 \\ 1/3 & 1/5 & 1 & 1/7 & 1/7 \\ 7 & 3 & 7 & 1 & 3 \\ 5 & 3 & 7 & 1/3 & 1 \end{bmatrix}, \quad C_B = \begin{bmatrix} 1 & 1/3 & 1/7 & 3 & 3 \\ 3 & 1 & 1/5 & 5 & 5 \\ 7 & 5 & 1 & 9 & 9 \\ 1/3 & 1/5 & 1/9 & 1 & 1 \\ 1/3 & 1/5 & 1/9 & 1 & 1 \end{bmatrix}.$$

According to (3) and (4), we get their weight vectors w_A and w_B as

$$w_A = [0.0674 \quad 0.1521 \quad 0.0367 \quad 0.4641 \quad 0.2796],$$
$$w_B = [0.1027 \quad 0.2092 \quad 0.5968 \quad 0.0456 \quad 0.0456].$$

Compute the consistency ratios CR_A=0.0614 and CR_B=0.0437. They both satisfy the consistency check. According to (5), for traffic A, we get $cell_{\_best}$=2, and for traffic B, we get $cell_{\_best}$=1. That is, the FMDCS strategy selects cell 2 as the optimum cell for traffic A, and selects cell 1 as the optimum one for traffic B.

To study the correctness of the above selection, we simulate the after-handoff QoS in the four cells. The simulation results are illustrated in Figs. 2 through 9.

Figures 2 through 5 are the simulation results for traffic A. Here, the simulation parameters are set according to Table 3.

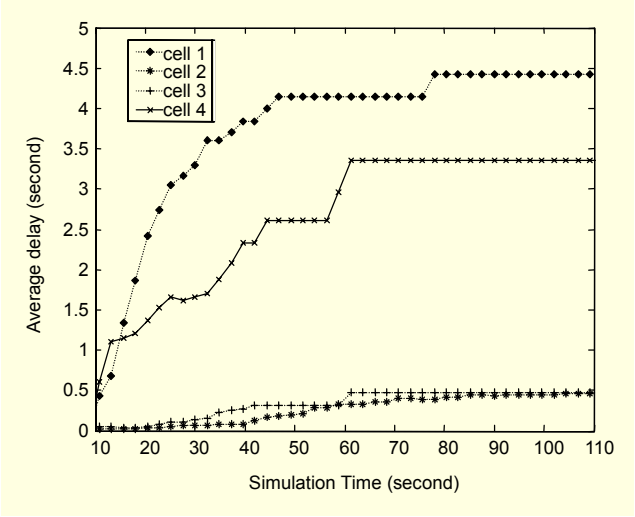

Fig. 2. Comparison of average delay in traffic A.

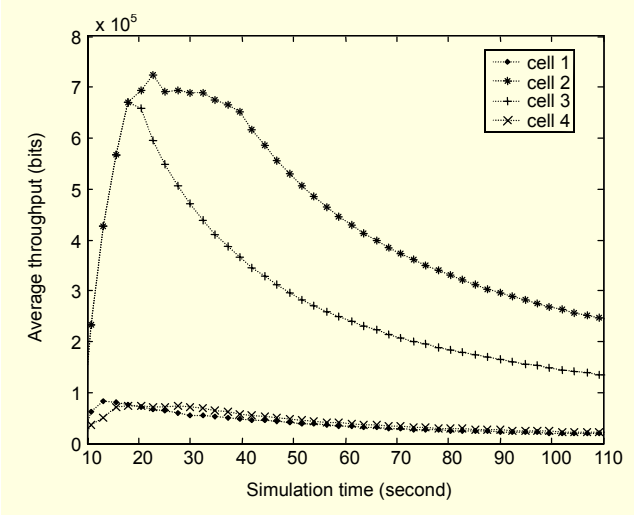

Fig. 3. Comparison of average throughput in traffic A.

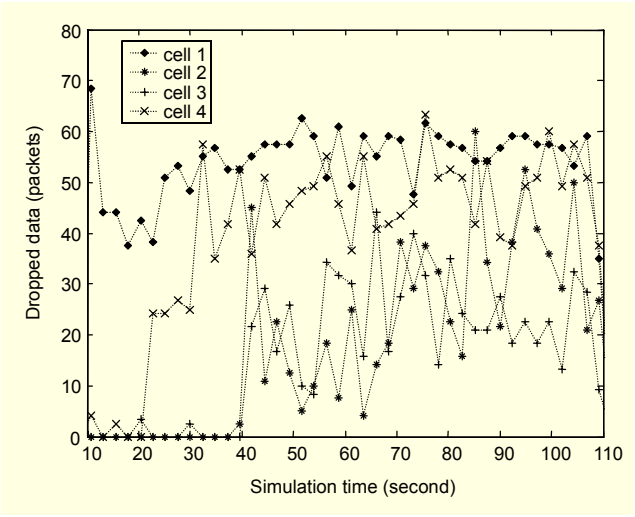

Fig. 4. Comparison of dropped data in traffic A.

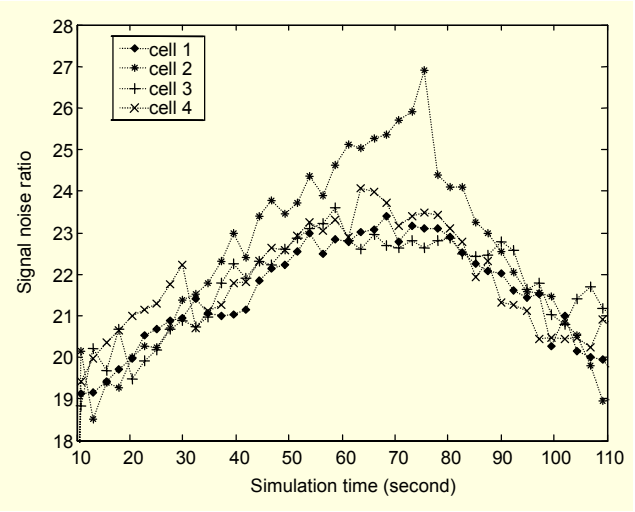

Fig. 5. Comparison of SNR in traffic A.

The MH moves at a speed of 2 m/s and the simulation time is 100 seconds. Figure 2 shows that the average transmission delay of cell 2 is within 0.5 seconds, and such values of cell 1 and cell 4 are over 3 seconds, which will lead to severe video delay and directly affect transmission quality. Although the average transmission delay of cell 3 is low, its throughput, shown in Fig. 3, is obviously less than that of cell 2. Figure 4 shows cell 2 has the least number of dropped packets, and Fig. 5 shows cell 2 has the highest SNR. All the simulation results show cell 2 is superior to other cells and can effectively guarantee the after-handoff QoS of the MH. Thus, cell 2 is optimum for traffic A.

Figures 6 to 9 are simulation results for traffic B. Here, simulation parameters are also set according to Table 3. The MH moves at a speed of 5 m/s and its travel-distance in one cell is the radius of the cell. The simulation time is 130 seconds. From simulation results, we can see as the coverage of each cell is different, the travel-time of the MH in each cell is also different. Figure 6 shows cell 1 can download 2.5 Mb files. This is obviously greater than other cells. Figure 7 shows cell 1 has the largest transmission delay l since the data rate of cells 2, 3 and 4 is higher than cell 1. As l<0.14 s for cell 1, such transmission delay is still allowable. Figure 8 shows that the average throughput of cell 1 is higher than other cells, and Fig. 9 shows cell 1 has a similar performance of package retransmission as other cells. Synthetically, compared to other cells, cell 1 owns the largest size of downloaded files and highest average throughput, and its delay and retransmission are allowable. Moreover, since the coverage of cell 1 is the largest, the probability of frequent handoffs is the lowest. Accordingly, cell 1 is most suitable for traffic B.

Consequently, we can conclude the selections of FMDCS for traffics A and B are correct.

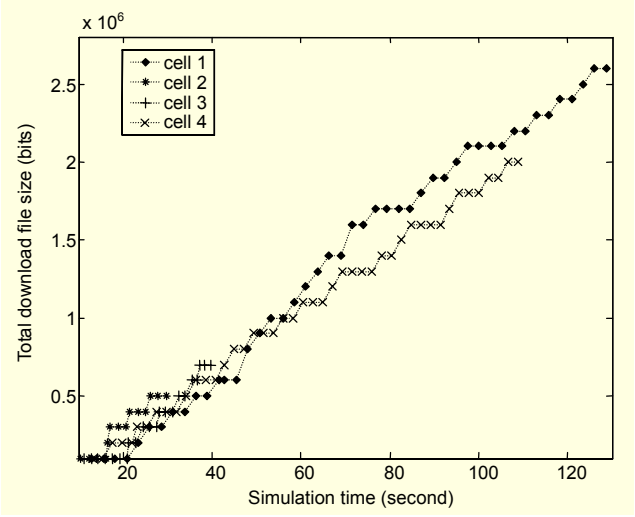

Fig. 6. Comparison of total download files size in traffic B.

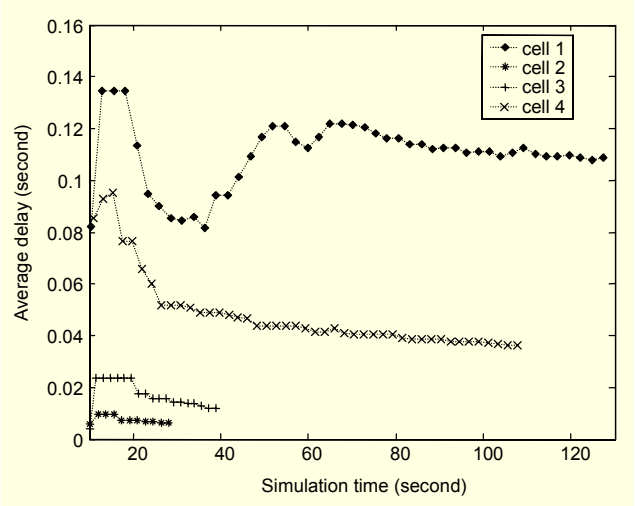

Fig. 7. Comparison of average delay in traffic B.

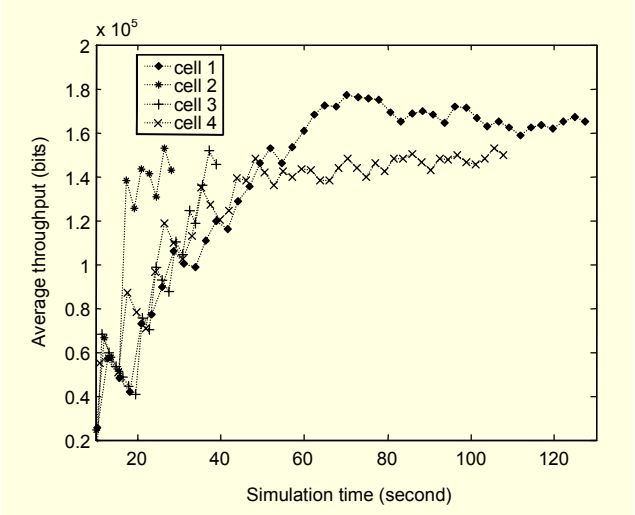

Fig. 8. Comparison of average throughput in traffic B.

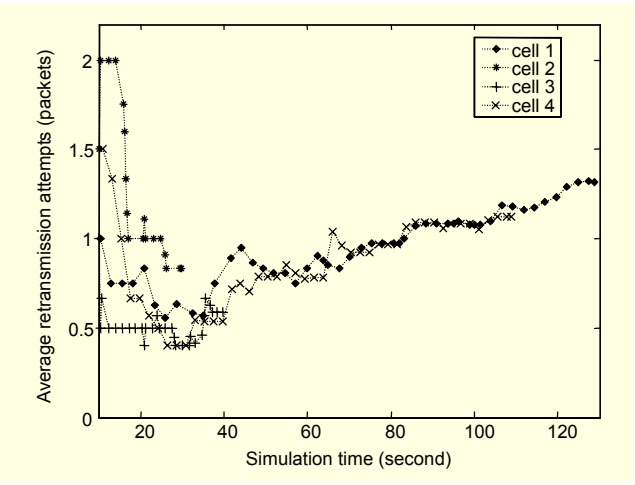

Fig. 9. Comparison of average retransmission in traffic B.

IV. Conclusion

According to the characteristics of multiple access technologies and traffic types in HCS, this paper proposed an FMDCS strategy to make cell selection by synthetically considering the factors of the MH and the attributes of candidate cells. For the MH, traffic types are classified to choose the appropriate weight vector, and for the candidate cells, key attributes that affect the after-handoff QoS are introduced to make the decision. The cell selection algorithm includes the evaluation matrix definition, weight vector calculations, and a consistency check for the contrast matrix. In FMDCS, the appropriate weight vector is selected according to different traffic types, thus improving the accuracy of the decision algorithm. The consistency check for the contrast matrix needs matrix computation and even some value-adjustment of the matrix element. But these computations and adjustments can be preprocessed before the strategy is put in practice. Thus the real-time computation requirement of the MH (or base station) is reduced. Most of the real-time computations are for the evaluation matrices. Nowadays, the hardware performances of the mobile termination and base station are improving very quickly. Therefore, the computational overhead for the evaluation matrices can be under control, and will occupy few resources of the CPU and system buffer. As shown in an instance analysis, FMDCS makes different selections when an MH runs different traffics. And further simulations show its selection is correct and that the selected cells can offer optimal after-handoff QoS.

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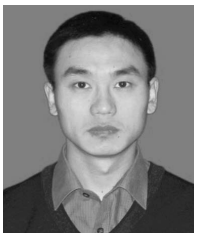

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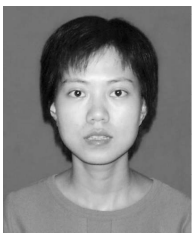

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