Journal of Institute of Control, Robotics and Systems (2011) 17(7):714-719
DOI:10.5302/J.ICROS.2011.17.7.714 ISSN:1976-5622 eISSN:2233-4335

셀룰러 망에서 관리 제어를 이용한 분산적 부하 균등 방법

Distributed Load Balancing with Handovers over Mobile Cellular Networks Using Supervisory Control

변희정, 양윤기*
(Heejung Byun[1] and Yoongi Yang[1])
[1]Suwon University

Abstract: This paper proposes a scheme for distributed load balancing in mobile communication networks based on supervisory control framework. Using load information exchanged with neighboring cells, the “supervisors” that reside in the base stations distribute load among cells by controlling handover parameters in a distributed manner. The supervisors are designed so that the load difference among neighboring cells are kept under a pre-defined value. Results from systematic analysis and simulation indicate that our scheme effectively balances traffic load among cells and reduces call blocking rate of the overloaded cells.

Keywords: load balancing, congestion, handover, supervisory control

I. INTRODUCTION

In a mobile communication network, a sudden increase in traffic within a cell can cause a spatial traffic load distribution across the network. Some cells in the network can become more heavily overloaded than their neighbors. When an increased traffic load exceeds the system capacity in a cell, it significantly degrades the grade of service (GoS) because incoming users or services in the congested cell suffer high blocking and dropping rates. Therefore, load balancing is required in order to transfer traffic from heavily loaded cells to lightly loaded cells.

There are several proposals to resolve load imbalance in mobile communication networks [1-12]. In [1-4], mobile stations (MSs) at the cell edge were handed over to neighbor base station (BS) with the strongest signal by reducing the pilot power of BS. However, one of the problems associated with adjusting the pilot power is the occurrence of coverage holes and neighboring BSs may then fail to provide services to some handover users. In [5,6], they proposed inter-frequency assignment (FA) handover for load balancing. To do this, BS should have multiple FAs to facilitate load sharing among FAs and MSs should collect all the BS identifications of co-located FA. In [7,8], they proposed the load balancing scheme within an overlaid multicell environment. In [9], a hard-load-balancing algorithm in heterogeneous wireless systems was simulated as a function of the number of users, channel conditions, and the quality of service (QoS). In [10], a network controlled handover based load balancing algorithm was proposed. In [11], BS-initiated load balancing with directed handovers in mobile WiMAX was proposed. In [12], a directed handover based load balancing scheme for a WLAN access point (AP) cluster was proposed. However, these methods are heuristic in nature and the mathematical model and the formal method used in their works made it difficult to directly utilize their results.

This paper presents a formal method to develop the distributed load balancing mechanism in mobile communication networks based on the supervisory control framework [13,14]. We introduce a discrete event model of the mobile communication networks and propose a supervisor in order to resolve the load imbalance and congestion by stabilizing the load difference below a pre-defined value.

The rest of the paper is organized as follows. In the next section, the supervisory control scheme for load balancing is introduced. Then, based on the proposed scheme, the simulation study follows in section III. Finally, we conclude the paper in section IV.

II. SUPERVISORY CONTROL FOR LOAD BALANCING

1. Preliminaries

In this section, we briefly describe the supervisory control framework developed by Ramadge and Wonham [13,14]. In the supervisory control framework for discrete event dynamic systems [13], the plant to be controlled is modeled by an automaton $G=(\Sigma,Q,\delta,q_0,Q_m)$ where Σ is the set of events, Q is the set of states, $q_0 \in Q$ is the initial state, $Q_m \subseteq Q$ is the set of marker states, and $\delta:\Sigma\times Q \mapsto Q$, the transition function, is a partial function defined at each state in Q for a subset of Σ. Let Σ^* denote the set of all finite strings (sequences) over Σ, including the empty string ε. A subset of Σ^* is called a language over Σ.

To impose supervision on the system, we identify some of its events as controllable and the others as uncontrollable. The event set Σ is partitioned into controllable and uncontrollable

---

* 책임저자(Corresponding Author)

논문접수: 2010. 12. 16., 수정: 2011. 4. 28., 채택확정: 2011. 4. 30.

변희정, 양윤기: 수원대학교 IT대학 정보통신공학과
(heejungbyun@suwon.ac.kr/ygyang@suwon.ac.kr)

※ This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (grant number 20100022654) and also supported by the GRRC SUWON 2011-B5 program of Gyeonggi province.

events, i.e., $\Sigma = \Sigma_c \cup \Sigma_{uc}$. The controllable events in Σ_c can be disabled by a supervisor, while the uncontrollable events in Σ_{uc} cannot be prevented from occurring and are therefore considered to be permanently enabled. The behavior of G is characterized by a language $L(G):=\{s \in \Sigma^* | \delta(s, q0) \text{ is defined}\}$, which is the set of event sequences generated in G. A supervisor is then an agent which observes a sequence of events as it generated by G and enables or disables any of the controllable events at any point in time throughout its observation. By performing such a manipulation of controllable events, the supervisor ensures that only a subset of $L(G)$ is permitted to be generated.

To develop the existence of the supervisor, the following notion is necessary: Let us define K as the specification. Then, a language $K \subset \Sigma^*$ is called *controllable* with respect to $L(G)$ if the following condition is satisfied [13]:

$$\bar{K}\Sigma_{uc} \cap L(G) \subseteq \bar{K}$$

where $\bar{K}$ is a prefix of K, i.e.,

$$\bar{K} := \{s \in \Sigma^* \mid (\exists t \in \Sigma^*) st \in K\}.$$

This condition requires that extension of any prefix of K by an uncontrollable event that is feasible in the system should also be a prefix of K. This is because the occurrence of uncontrollable events cannot be prevented.

2. Supervisor design

The mobile measures and reports the received signal power from its serving cell and from the neighboring cells. Serving cell s decides a handover of the mobile to a new cell t if the following condition is satisfied:

$$S_t - S_s \geq h_{st} + Hysteresis \tag{1}$$

where S_t is the received signal power from cell t, h_{st} is the handover offset between cell s and cell t, *Hysteresis* is a constant independent of the cells. We propose the distributed supervisor regulating the handover offset to resolve the problems of cell overload and load imbalance. To do this, the supervisor makes the decision to initiate load balancing automatically and selects the target cell to be reconfigured based on the load information received from neighbors. Then, the load balancing is achieved by controlling the handover offsets and handing over mobiles served from the heavily loaded cell to the lightly loaded cell.

Consider a cellular network where each cell exchanges the load information with neighboring cells, i.e., resource utilization ratio $\rho\,(0 \leq \rho \leq 1)$. We introduce load metric φ_n $(|\varphi_n| \leq 1)$ of cell n :

$$\varphi_n = \rho_n - \hat{\rho}_n \tag{2}$$

where

$$\hat{\rho}_n = \begin{cases} \min\limits_{\forall m \in N_n} \rho_m & \mathit{if}\,((n = \arg\max\limits_{\forall m \in N_n} \rho_m)\,\&\,(\rho_n > \rho_{th})) \\ \max\limits_{\forall m \in N_n} \rho_m & \mathit{if}\,((n = \arg\min\limits_{\forall m \in N_n} \rho_m)\,\&\,(\rho_n < \rho_{th})) \\ \rho_n & \mathit{otherwise}. \end{cases}$$

N_n is the set of neighboring cells of cell n including cell n and ρ_{th} is the threshold to determine the overload state. The value of φ_n is used as an indicator of load imbalance and updated based on the load information received from neighboring cells. We partition the range of load metric φ_n into $(\Gamma+1)$ distinct elements:

$$\Lambda = \{\lambda_0, \lambda_1, \cdots, \lambda_\Gamma\} \tag{3}$$

where $\Gamma = \lceil 2/T \rceil$, T is the quantization level, and $\lceil x \rceil$ is the smallest integer larger than x. Therefore, the value of λ_i $(0 \leq i \leq \Gamma)$ equals to $(i \cdot T - 1)$. The value of T determines the number of states in the supervisor. The size of the total states does not affect the system performance as long as the step size of the sampled load metric is smaller than u, where $\{u : u \times i = \delta, i = \mathit{integer}\}$.

Let us define the event set Σ, the uncontrollable event set Σ_{uc}, and the set of states Q as

$$\begin{aligned} &\Sigma = \{e_{\delta^-}, e_{\delta^+}, e_{\delta^0}, e_{h^-}, e_{h^+}, e_{h^0}\} \\ &\Sigma_{uc} = \{e_{\delta^-}, e_{\delta^+}, e_{\delta^0}\} \\ &Q = \{S_0, \cdots, S_\Gamma, S_0^{\delta^-}, \cdots, S_\Gamma^{\delta^-}, S_0^{\delta^+}, \cdots, S_\Gamma^{\delta^+}, S_0^{\delta^0}, \cdots, S_\Gamma^{\delta^0}\} \end{aligned} \tag{4}$$

where e_{δ^-}, e_{δ^+}, e_{δ^0} are the events representing that the value of φ_n is updated and $\varphi_n < -\delta, \varphi_n > \delta, |\varphi_n| \leq \delta$, respectively. The value of δ is a constant to be chosen. Event e_{h^-}, e_{h^+}, e_{h^0} represent the decrement of handover offset $h_{n\hat{n}}$ by the pre-defined step size Δ, the increment of $h_{n\hat{n}}$ by Δ, and the maintenance of $h_{n\hat{n}}$, respectively, where

$$\hat{n} = \begin{cases} \arg\min\limits_{\forall m \in N_n} \rho_m & \mathit{if}\,(n = \arg\max\limits_{\forall m \in N_n} \rho_m) \\ \arg\max\limits_{\forall m \in N_n} \rho_m & \mathit{if}\,(n = \arg\min\limits_{\forall m \in N_n} \rho_m) \\ 0 & \mathit{otherwise}. \end{cases}$$

State S_i represents that the value of the load metric after handover parameter reconfiguration corresponds to i-th elements of Λ. State $S_i^{\delta^-}$, $S_i^{\delta^+}$, $S_i^{\delta^0}$ represent that load metric φ_n is updated, and $(\rho_n - \hat{\rho}_n) < -\delta, (\rho_n - \hat{\rho}_n) > \delta$, $|\rho_n - \hat{\rho}_n| \leq \delta$, respectively. Hence, an active event set at state $S_i^{\delta^-}$, $S_i^{\delta^+}$, $S_i^{\delta^0}$ $(\forall i)$ is:

$$Act(S_i^{\delta^-}) = Act(S_i^{\delta^+}) = Act(S_i^{\delta^0}) = \{e_{h^-}, e_{h^+}, e_{h^0}\}. \tag{5}$$

The objective of the proposed algorithm is to alleviate cell overload and load imbalance by stabilizing the difference of the resource utilization ratio at a value smaller than δ, i.e., $|\varphi_n| \leq \delta, \forall n.$ Therefore the marked states are S_p and $S_p^{\delta^0}$ where

$$\begin{aligned} &p = \{i : -\delta \leq \lambda_i \leq \delta\} \\ &\Rightarrow \left\lceil \frac{(1-\delta)}{T} \right\rceil \leq p \leq \left\lfloor \frac{(1+\delta)}{T} \right\rfloor \end{aligned} \tag{6}$$

and $\lfloor x \rfloor$ is the largest integer smaller than x. The transition

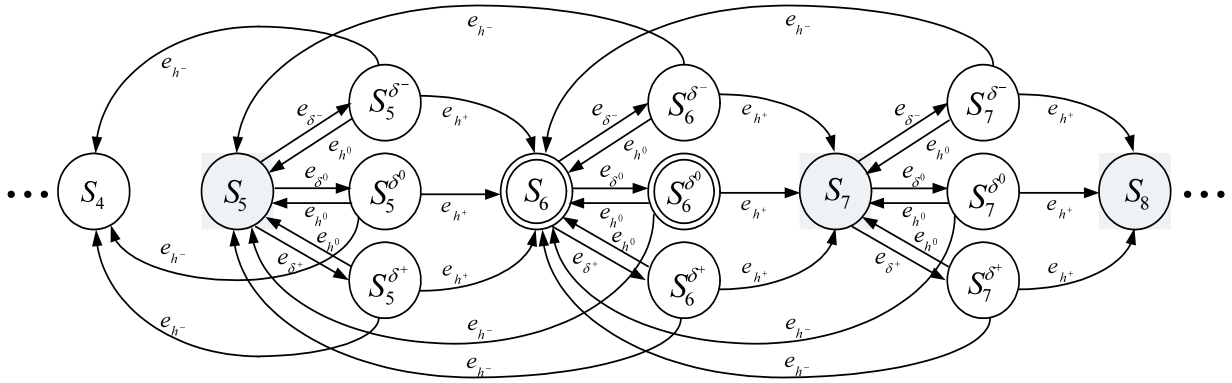

그림 1. 플랜트 G: 이산 사건 모델.

Fig. 1. Plant G: DEM of transition with p = 6.

diagram between the states modeled by discrete event model (DEM) with $p = 6$ is shown in Fig. 1, where the marked states are marked by double circles. For the purpose of simplicity, Fig. 1 shows the case of the sequential state transition after reconfiguration. However, the state transition diagram and the results of this paper can be generalized to the arbitrary state transition cases.

Let us define K_d as the specification to meet our objectives. We define $\Theta = \{e_{\delta^-}e_{h^+}, e_{\delta^+}e_{h^-}\}$. Then the specification K_d is described as

$$K_d = \Theta^*\{e_{\delta^0}e_{h^0}\}^+ \tag{7}$$

with $\{x\}^+ = \{x\}\{x\}^*$ where $\{x\}^*$ is the Kleene closure of $\{x\}$. Note that we ignore the saturation nonlinearity of handover offset. The specification K_d means that load metric $|\varphi_n|$ should be smaller than δ after the transient behavior represented by Θ^*.

To find out the existence of the supervisor, we define $K_1 := \{st \in \bar{K}_d \mid s \in \bar{K}_d, t \in \Sigma_{uc}\}$, $s_1 \in \bar{K}_d - K_1$ and $s_2 \in K_1$. Then obviously, $s_1 t \in \bar{K}_d$ and $s_2 t \notin \bar{K}_d$ for $t \in \Sigma_{uc}$. Moreover, if the absolute value of the load metric becomes smaller than δ, event e_{δ^-} or event e_{δ^+} cannot occur as long as the network conditions do not change. As it follows from the above, since $\bar{K}_d \Sigma_{uc} \cap L(G) \subseteq \bar{K}_d$, K_d is controllable with respect to $L(G)$.

Since K_d is controllable, we design a distributed supervisor of cell n to achieve K_d by controlling event. At cell n, state $S_i^{\delta^-}$ means that cell n is most lightly loaded, thus the supervisor should increase handover offset $h_{n\hat{n}}$ by Δ over the current handover offset where $\hat{n} = argmax_{\forall m \in N_n} \rho_m$. Therefore, the supervisor should enable event e_{h^+} and disable events e_{h^-}, e_{h^0} to delay handover to cell $\hat{n}$. On the contrary, state $S_i^{\delta^+}$ means that cell n is most heavily loaded, thus the supervisor should decrease handover offset $h_{n\hat{n}}$ by Δ where $\hat{n} = argmin_{\forall m \in N_n} \rho_m$. Therefore, the supervisor should enable event e_{h^-} and disable events e_{h^+}, e_{h^0} to handover users close to cell border to cell $\hat{n}$. At state $S_i^{\delta^0}$, the supervisor should enable e_{h^0} to keep the present state of handover offset because the load metric already lies within the range of $[-\delta, \delta]$. In this way, the supervisor adapts the handover offset according to the load metric so that the load difference converges to a value smaller than δ. The value δ affects both the transient response and the control overhead. Specifically, as the value of δ becomes larger, the load balancing function reacts to network change more slowly and the load difference among cells converges to a lager value. On the contrary, as the value of δ becomes small, the transient period becomes long. In addition, the load balancing function is triggered more frequently and the system wastes the resource due to the unnecessary overhead processing. The control action of the supervisor is demonstrated in Table 1 where Σ_e is defined as a set of enabled events and Σ_d is defined as a set of disabled events.

When the specification K_d of each cell is achieved, the load difference between the most heavily loaded cell and the most lightly loaded cell in the network is smaller than δ. Therefore, the proposed supervisor with local view and peer-to-peer interaction can drive the overall systems to reach the marked states and the controlled network resolves overload and load imbalance problem.

3. Recongifuration

When handover offset $h_{n\hat{n}}$ is adapted by the supervisor of cell n, cell n initiates the load balancing by requesting cell $\hat{n}$

표 1. 관리제어기 S.

Table 1. Supervisor S.

	Σ_e	Σ_d	Condition
$S_i^{\delta-}$	$\{e_{h^+}\}$	Act $(S_i^{\delta-})$ - $\{e_{h^+}\}$	$i < \Gamma$
	$\{e_{h^0}\}$	Act $(S_i^{\delta-})$ - $\{e_{h^0}\}$	$i = \Gamma$
$S_i^{\delta^+}$	$\{e_{h^-}\}$	Act $(S_i^{\delta+})$ - $\{e_{h^-}\}$	$i > 0$
	$\{e_{h^0}\}$	Act $(S_i^{\delta+})$ - $\{e_{h^0}\}$	$i = 0$
$S_i^{\delta 0}$	$\{e_{h^0}\}$	Act $(S_i^{\delta 0})$ - $\{e_{h^0}\}$	-

to reconfigure the handover offset. We assume that cell *k*, corresponding to $argmin_{\forall m \in N_k} \rho_m$, receives the reconfiguration request message from cell *n*. If cell *n* equals to cell $\hat{k}$ where $\hat{k} = argmax_{\forall m \in N_k} \rho_m$, cell *k* determines its handover offset according to its supervisor, and notifies cell $\hat{k}$ of a successful reconfiguration. Otherwise, cell *k* responds with failure message. If cell *n* receives a failure message for the reconfiguration request from cell $\hat{n}$, the reconfiguration does not carried out and the value of handover offset is restored. This method guarantees that the parameter reconfiguration is carried out between only two cells every iteration and these two cells correspond to the most heavily loaded cell and the most lightly loaded cell each other.

III. SIMULATION RESULTS

First, we use a simple system model with two cells and vary the traffic load of cell 1 and cell 2 over time. We use macrocell model for all system level simulations. Each cell covers a circular region with radius 0.5 km. The initial handover offset is 2 dB and Hysteresis is fixed at zero. The values of $h_{\min}$ and $h_{\max}$ are 0 dB and 8 dB, respectively, with $M = 2$, $= 0.04$, and $\rho_{th} = 0.5$.

Fig. 2(a) shows the change in resource utilization ratio for cell 1 and cell 2 with a fixed handover offset. After 2000 seconds and again at 5500 seconds, the load difference between cell 1 and cell 2 is a maximum. Around 2000 seconds, if additional traffic is suddenly introduced into cell 1, call drop and call blocking is likely to occur, and the GoS will be degraded. As shown in Fig. 2(b), the proposed load balancing scheme successfully balances the resource utilizations of cell 1 and cell 2. In addition, the proposed scheme distributes the load by controlling the handover offset nonlinearly, which results in the fast response and the high convergence speed.

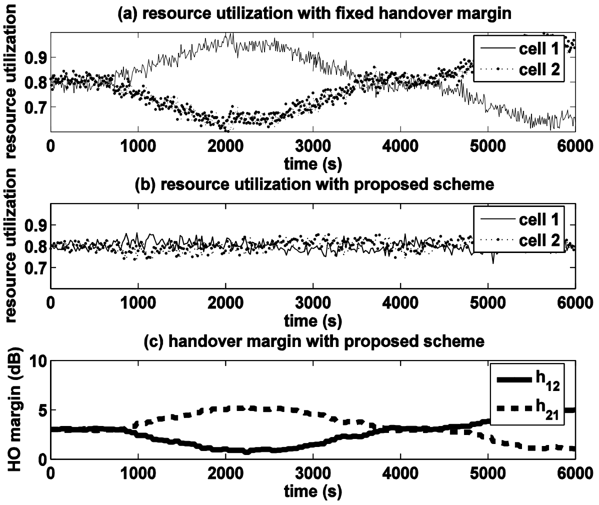

그림 2. (a) 고정 핸드오버 옵셋 방식의 자원 효율 (b) 제안한 방식의 자원 효율 (c) 제안한 방식의 핸드오버 옵셋.

Fig. 2. (a) Resource utilization with fixed handover offset (b) Resource utilization with proposed supervisor (c) Handover offset with proposed supervisor.

Fig. 2(c) shows the change in the handover offset between cell 1 and cell 2 as a function of time using the proposed scheme. As the traffic load of cell 1 increases, the handover offset h_{12} decreases in order to hand over users to cell 2. Conversely, cell 2 delays handover to cell 1 by increasing h_{21}, resulting in the automatic load balancing.

We now provide the performance results in terms of load difference and call blocking rate. We use a system model with a cluster of 7 cells ($cell_1 \sim cell_7$). There is $cell_1$ in the middle of a cluster and adjacent BSs reside around $cell_1$. Then, N_k $(1 \le k \le 7)$ for each cell is as follows: $N_1=\{cell_k, \forall k\}$, $N_2=\{cell_1, cell_2, cell_3, cell_7\}$, $N_3=\{cell_1, cell_2, cell_3, cell_4\}$, $N_4=\{cell_1, cell_3, cell_4, cell_5\}$, $N_5=\{cell_1, cell_4, cell_5, cell_6\}$, $N_6=\{cell_1, cell_5, cell_6, cell_7\}$, $N_7=\{cell_1, cell_2, cell_6, cell_7\}$. We assume an unequal load distribution to the system so that (8-i) times as many users connect to $cell_i$ $(2 \le i \le 6)$ than $cell_7$ and nine times as many users connect to $cell_1$ than $cell_7$. For each cell, all of the users are uniformly distributed in the coverage area. We consider the FTP service for non real time traffic type and files of random sizes are sent at each iteration. We use the following parameters: $\delta = 0.25$, $T = 0.01$, $\rho_{th} = 0.5$, $\Delta = 0.5$, and initial handover offset is 2.

Fig. 3 shows the trajectories of load difference for each cell and the maximum load difference in a cluster with the proposed supervisor. As shown in Fig. 3, the load difference of all cells are converged to a value smaller than 0.25 after the 10-th iteration. In addition, the maximum load difference in the cluster is also less than 0.25. This is because that the proposed supervisor identifies the need of load balancing automatically and reacts to the load imbalance in a timely manner.

Fig. 4 illustrates the average load difference for cell 1-cell 7 by varying the value of δ. The proposed scheme controls the average load difference below the value of δ at all different values. Moreover, the maximum load difference in a cluster is also less than the value of δ. This is because the proposed scheme resolves the load imbalance until the load difference

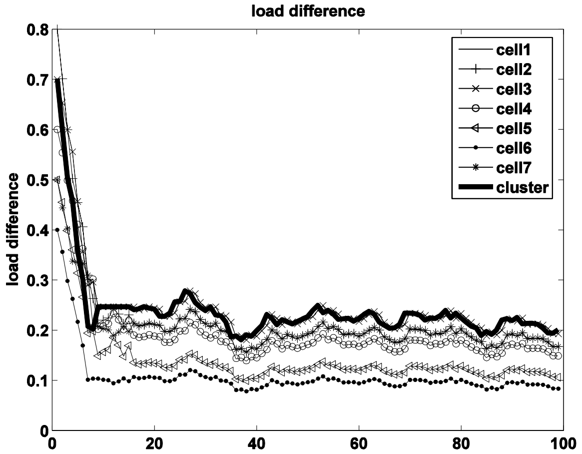

그림 3. 셀1~셀7에 대한 부하 차이 변화와 셀 클러스터 내 최대 부하 차이.

Fig. 3. Variation of load difference for $cell_1 \sim cell_7$ and maximum load difference in the cluster.

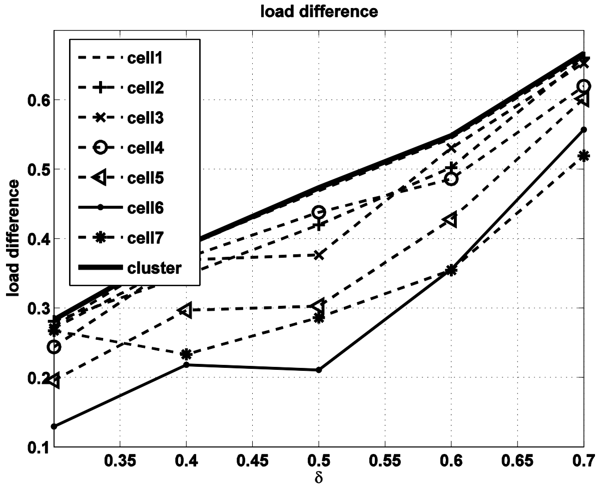

그림 4. Δ 변화에 따른 평균 부하 차이.

Fig. 4. The average load difference varying the value of δ.

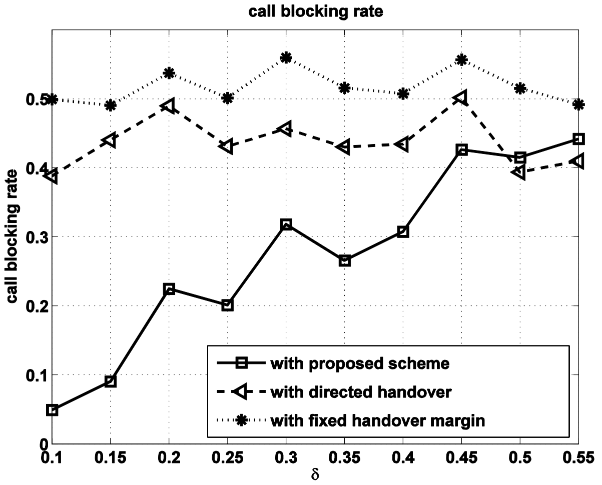

그림 6. Δ 변화에 따른 호 차단율.

Fig. 6. Call blocking rate varying δ.

for each cell lies within the value of δ. Therefore, we can conclude that local supervisor of each individual cell achieves the global properties, such that the load difference in a cluster is stabilized globally within the predefined value of δ.

In order to evaluate the performance of the proposed scheme in terms of call blocking rate, the following simulations are carried out. The system is first loaded in a unbalanced way, described by above configuration, and increases the traffic intensity level by dropping more users to all cells, i.e., the user increment at *i*-th traffic intensity level is $(i-1)\cdot 10$.

Fig. 5 shows the call blocking rate by varying the traffic intensity level using the proposed scheme, the fixed handover offset scheme, and the directed handover scheme [11]. We observe that the call blocking rate of the fixed handover offset scheme increases linearly with an increase in the traffic intensity level. The call blocking rates of both the directed handover scheme and the proposed scheme are negligible when the traffic intensity level is below 5. This is because the traffic load is distributed efficiently between the overloaded cell and the underloaded cell. When the traffic intensity is larger than level 8, the call blocking rates of all methods increase rapidly. After level 9, there is little difference in the call blocking rates. This is because when all the systems are overloaded, the load difference decreases considerably, and thus the load balancing function may not be trigged. Therefore, the load difference of each base station becomes too small to gain benefits from load balancing. According to the proposed scheme, the load balancing function is not triggered when all the systems are lightly loaded or overloaded. The reason is that the proposed scheme does not intend to equalize load exactly among systems, but rather to avoid overload in one system whilist other systems are less loaded. In the case of the directed handover scheme, the call blocking rate increases rapidly after traffic intensity level 6. The reason is that when the traffic is highly loaded across the network, the average load of the system increases and the triggering threshold of the directed handover scheme increases to a significantly high value, which causes incoming call blocking before the initiation of the load balancing.

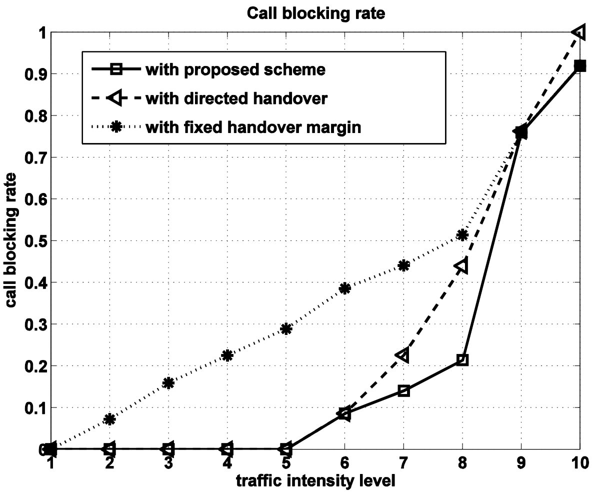

그림 5. 부하 수준에 따른 호 차단율.

Fig. 5. Call blocking rate varying traffic intensity level.

Fig. 6 shows the call blocking rate by varying the value of δ. Traffic intensity level is 8. When δ is small, the proposed scheme triggers the load balancing more frequently. This leads to congestion avoidance in advance, resulting in a negligible call blocking rate. However, as the value of δ increases, the call drop rate of the proposed scheme also increases. Specifically, when δ = 0.55, there is little difference compared with the call drop rates of the directed handover and the fixed handover offset scheme. This is because as the value of δ increases, the proposed scheme recognizes that the load is balanced even though the load difference is rather high. To avoid this problem, the value of δ should not be chosen to be large.

To summarize the results, the proposed load balancing scheme resolves the load imbalance automatically and reduces the call blocking rate effectively by controlling the load difference below the predetermined threshold. These evaluations and considerations are expected to contribute to the auto-tuning of mobility algorithm in the mobile communication systems as a load balancing self-optimization use case.

IV. CONCLUSIONS

In this paper, we propose a discrete event system approach to accommodate the decentralized load balancing scheme and make the supervisory control feasible for the network application. The proposed scheme stabilizes the load difference below the pre- defined threshold by controlling the handover parameter. The analysis and simulation results show that the proposed scheme globally balances the load, while converging in a small number of iterations. The proposed scheme can be used as a means to enhance automatic load balancing scheme taking into reliability and stability.

REFERENCES

[1] H. Kashima and H. Zhu, "Load balancing effect of interfrequency handover with pilot power tuning in UTRAN," *Proc. IEEE Vehicular Technology Conference*, 2004.

[2] X. H. Chen, "Adaptive traffic load shedding and its capacity gain in CDMA cellular system," *IEE Proc-Communication*, vol. 142, no. 3, pp. 186-192, 1995.

[3] D. J. Lee and D. J. Cho, "Cell size adaptation in W-CDMA cellular system," *Proc. IEEE Vehicular Technology Conference*, pp. 444-448, 2002.

[4] H. Zhu et al, "Load balancing in WCDMA common pilot by adjusting pilot power, *Proc. IEEE wireless personal multimedia communications*, vol. 13, pp. 936-940, 2002.

[5] S. H. Lee and Y. Han, "A novel inter-FA handover scheme for load balancing in IEEE 802.16e system," *Proc. IEEE Vehicular Technology Conference*, pp. 763-767, 2007.

[6] K. P. Moon, J. Park, J. Kim, H. Choo, and M. Y. Chung, "Dual handover procedures for FA load balancing in Wibro system," *IEEE International conference on convergence and hybrid information technology*, vol. 2, pp. 54-59, 2008.

[7] E. Yanmaz and O. K. Tonguz, "Dynamic load balancing performance in cellular networks with multiple traffic types," *Proc. IEEE Vehicular Technology Conference*, vol. 5, pp. 3491-3495, 2004.

[8] E. Yanmaz and O. K.Tonguz, "Dynamic load balancing and sharing performance of integrated wireless networks," *IEEE J. Sel. Areas Commun.*, vol. 22, no. 5, pp. 862-872, 2004.

[9] K. Kim, Y. Han, and J.-R. Lee, "Load sharing in heterogeneous wireless systems using dynamic load measures," *Proc. IEEE Vehicular Technology Conference*, vol. 1. pp. 368- 372, 2006.

[10] E. Yanmaz and O. K. Tonguz, "Dynamic load balancing performance in cellular networks with multiple traffic types," *Proc. IEEE Vehicular Technology Conference*, vol. 5, pp. 3491-3495, 2004.

[11] T. Casey, N. Veselinovic, and R. Jantti, "Base station controlled load balancing with handovers in mobile WiMAX," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1-5, 2008.

[12] H. Velayos, V. Aleo, and G. Karlsson, "Load balancing in overlapping wireless LAN cells," *IEEE International Conference on Communications (ICC 2004)*, vol. 7, pp. 3833-3836, 2004.

[13] P. J. Ramadge and W. M. Wonham, "Supervisory control of a class of discrete event processes," *SIAM Journal Control and Optimization*, vol. 25, pp. 206-230, 1987.

[14] P. J. Ramadge and W. M. Wonham, "The control of discrete event systems," *Proc. of the IEEE*, vol. 77, no. 1, pp. 81-98, 1989.

변 희 정

1999년 숭실대학교 정보통신공학과 학사. 2001년 한국과학기술원 전자전산학과 석사. 2005년 한국과학기술원 전자전산학과 박사. 2010년 삼성종합기술원, 삼성전자. 2010년~현재 수원대학교 IT대학. 관심분야는 네트워크 제어.

양 윤 기

1989년 서울대학교 제어계측공학과 학사. 1991년 서울대학교 대학원 제어계측공학과 석사. 1996년 서울대학교 대학원 제어계측공학과 박사. 현재 수원대학교 정보통신공학과 부교수. 관심분야는 디지털 통신, 영상처리, 신호처리.