

Research Article

A Cost-Based Adaptive Handover Hysteresis Scheme to Minimize the Handover Failure Rate in 3GPP LTE System

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We deal with a cost-based adaptive handover hysteresis scheme for the horizontal handover decision strategies, as one of the self-optimization techniques that can minimize the handover failure rate (HFR) in the 3rd generation partnership project (3GPP) long-term evolution (LTE) system based on the network-controlled hard handover. Especially, for real-time operation, we propose an adaptive hysteresis scheme with a simplified cost function considering some dominant factors closely related to HFR performance such as the load difference between the target and serving cells, the velocity of user equipment (UE), and the service type. With the proposed scheme, a proper hysteresis value based on the dominant factors is easily obtained, so that the handover parameter optimization for minimizing the HFR can be effectively achieved. Simulation results show that the proposed scheme can support better HFR performance than the conventional schemes.

1. Introduction

The evolved universal mobile telecommunication system (UMTS) terrestrial radio access network (E-UTRAN), which is also known as the 3GPP LTE mobile communication system, aims at lowering the cost of providing mobile broadband connectivity, reduction of end-user monthly fees, and delivery of new improved services and applications [1–3]. In the 3GPP LTE system, there is a tendency to simplify and to enhance the network management inherited from the UMTS with the advanced self-organizing network (SON) solution focused on self-configuration and self-optimization techniques. The SON is one of the hopeful areas for an operator to reduce operational expenses [3–5]. The self-configuration provides the automated initial configuration of cells and network nodes before entering operational mode. Also, the self-optimization performs the optimization and adaptation to changing environmental conditions during operational mode. With this self-optimization, we can achieve several optimization results such as load balancing, handover parameter optimization, and capacity and coverage optimization. Here, we focus on the handover parameter optimization. For the handover parameter optimization, we

can consider two types of the handover schemes: vertical and horizontal handover. The type of handover that takes place in a heterogeneous network is called vertical handover whereas the type of handover that happens in a homogeneous network is called horizontal handover. There are quite a lot of research results on the cost function for the vertical handover decision strategies in heterogeneous networks [6, 7, 12, 13], but not on the cost function for the adaptive hysteresis strategies of horizontal handover in homogeneous networks.

Thus, in this paper, we research on a cost-based adaptive handover hysteresis scheme that can realize the handover parameter optimization for self-optimization in 3GPP LTE system based on the network-controlled hard handover. In order to realize the handover parameter optimization by a cost function for adaptive handover hysteresis in the horizontal handover as well as the cost function for the vertical handover decision strategies, we propose a cost-based adaptive handover hysteresis scheme which is based on the dominant factors closely related to HFR performance, such as the load difference between the target and serving cells, the velocity of user equipment (UE), and the service type, which affect the decision of the handover trigger time. The minimization of the HFR, which is the objective of the

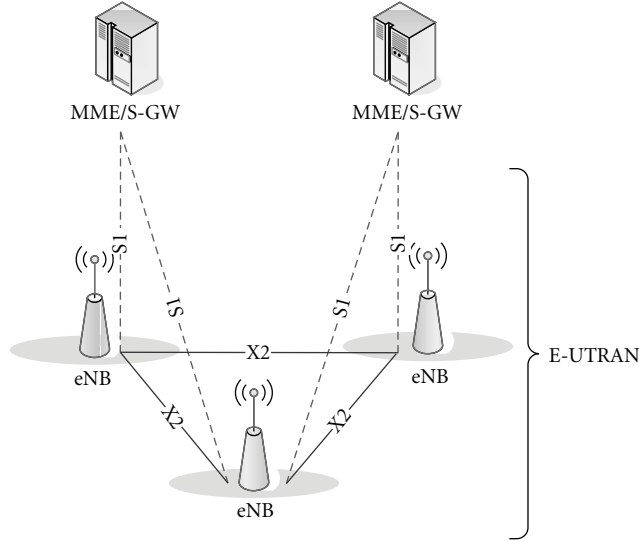


FIGURE 1: Overall E-UTRAN architecture.

proposed scheme, is one of the most important performance indicator related to the self-optimization technique in 3GPP LTE system.

The remainder of this paper is organized as follows. Section 2 introduces the handover preparation procedure in 3GPP LTE system. Section 3 presents the proposed cost-based adaptive hysteresis scheme. Section 4 provides the simulation environment and simulation results. Finally, Section 5 concludes our work.

2. Handover Preparation Procedure in 3GPP LTE System

As shown in Figure 1, the LTE architecture consists of evolved NodeBs (eNBs), mobility management entity (MME), and system architecture evolution gateways (S-GW) [3]. The eNBs are connected to the MME/S-GW by the S1 interface, and they are interconnected by the X2 interface. The handover preparation information on the load status between the eNBs can be directly exchanged by using the X2 interface, while the preparation information on the velocity and the service type of the UEs can be periodically reported back to the serving eNB through uplink by using radio resource control (RRC) signaling [8]. The intra-MME/serving gateway handover procedure in a 3GPP LTE system has three phases of handover preparation, handover execution, and handover completion. The handover preparation procedure is mainly made up for a handover decision stage in serving eNB and for an admission control stage in target eNB as shown in Figure 2.

In an LTE system, the handover decision in the handover preparation procedure is made by the radio resource management function based on the measurement report from the UE. For this, the three parameters of threshold, hysteresis, and time to trigger (ΔT) can be properly combined to build the hard handover criterion. First of all, the need for the handover arises when the received signal strength

(RSS) of the serving eNB is less than a given threshold value. In the case of a usual hard handover decision scheme, if the candidate target eNB holds higher RSS than that of the serving eNB during a period of ΔT , a hysteresis operation for the detected situation should be considered. A well-established hysteresis and time to trigger can provide exact and efficient decisions based on the measurement informations in the handover preparation procedure.

3. Proposed Cost-Based Adaptive Hysteresis Scheme

In homogeneous networks, since the adaptive hysteresis scheme provides better HFR performance than the fixed hysteresis scheme, many adaptive hysteresis schemes have been introduced. However, most of the previously studied adaptive schemes focused on single factor consideration among many influential factors as follows: the load-based adaptive hysteresis scheme in [9] considered only the load difference between the target and serving cells based on load information by the X2 interface; the velocity-based adaptive hysteresis scheme in [10] used the RRC measurement report message containing the velocity of the UE which can be estimated by Doppler spread or global positioning system (GPS) in 3GPP LTE system; a service-based adaptive hysteresis scheme was also studied in [11].

In order to minimize the HFR in adaptive hysteresis scheme, we need to consider many factors affecting the HFR performance, simultaneously. These factors can be used to constitute the cost function for the adaptive hysteresis strategies of horizontal handover in homogeneous networks with similar approach to the concept of the cost function for the vertical handover decision strategies in heterogeneous networks [6, 12]. The cost function for the vertical handover in heterogeneous network is provided as a weighted sum of normalized functions by many factors. The cost function can be summarized as

$$f = \sum_{i=1}^{i=K} w_i \cdot N_i, \quad (1)$$

where w_i is a weight for the i th normalized function N_i and the sum of all weights is 1. K is the maximum number of the normalized functions to be considered. The value of f is between -1 and 1 because the sum of all weights is 1 and N_i ranges from -1 to 1 . The most important process in calculating the cost function is how to determine the weights of different metrics for heterogeneous network systems. Recently, various vertical handover decision algorithms have been proposed, such as multiplicative exponent weighting (MEW), simple additive weighting (SAW), technique for order preference by similarity to ideal solution (TOPSIS), grey relational analysis (GRA), and fuzzy multiple attribute decision making (MADM) algorithms [7, 13, 14]. In (1), as the number of the normalized functions increases, we come to face with the complex multiple criteria decision making problem of finding the optimum combinatorial value of the corresponding weights [15–17]. Furthermore, the performance improvement is not as satisfactory as expected in

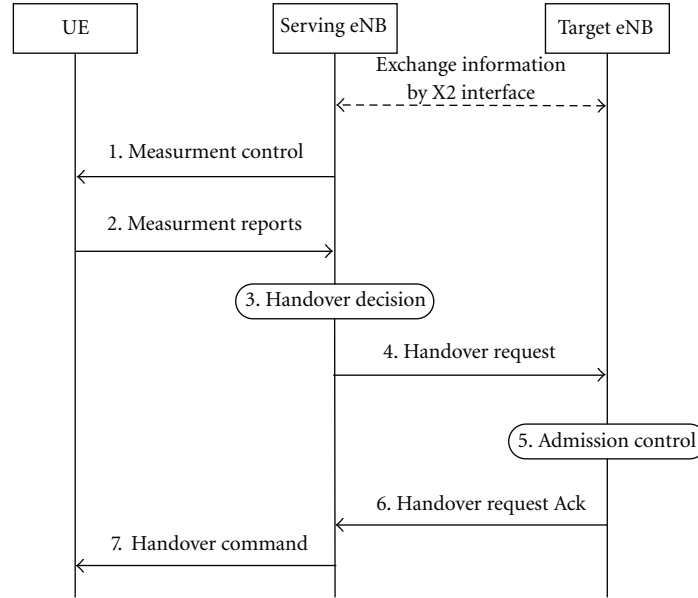


FIGURE 2: The handover preparation procedure.

spite of the rapid increase of the optimization complexity because the performance improvement is not proportional to the complexity increase. Therefore, in this paper, since the cost function is necessitated for a new adaptive handover hysteresis scheme with aim for minimizing the HFR in 3GPP LTE system, we apply the cost function of the vertical handover decision strategies given in (1). Also, in order to make it possible to solve the problem in real-time in practical systems, we propose a simplified cost function, $f_{l,v,s}$, consisting of the normalized functions by the dominant factors in the handover procedure as given by

$$f_{l,v,s} = w_l \cdot N_l + w_v \cdot N_v + w_s \cdot N_s, \quad (2)$$

where N is the normalized function by the respective handover preparation information, and w is the weight for the respective normalized function. The sum of the weights must be 1. The subscripts l , v , and s are the handover preparation information corresponding to the load difference between the target and serving cells, the velocity of UE, and the service type, respectively. The handover preparation informations can be obtained through the X2 interface from the RRC measurement report.

Figure 3 shows an example calculation of the hysteresis values when a UE moves from its serving eNB to an adjacent target eNB. In the figure, H_{default} is the default hysteresis value, and ΔH denotes the handover margin between the serving and target eNBs; H_{min} and H_{max} are the minimum and maximum hysteresis values, respectively. In the proposed scheme, the hysteresis value, H , is adaptively calculated by

$$H = H_{\text{default}} + \Delta H \quad (3)$$

and a UE connected to the serving eNB enters the handover procedure to the target eNB when

$$\text{RSS}_{it} - \text{RSS}_{is} \geq H, \quad (4)$$

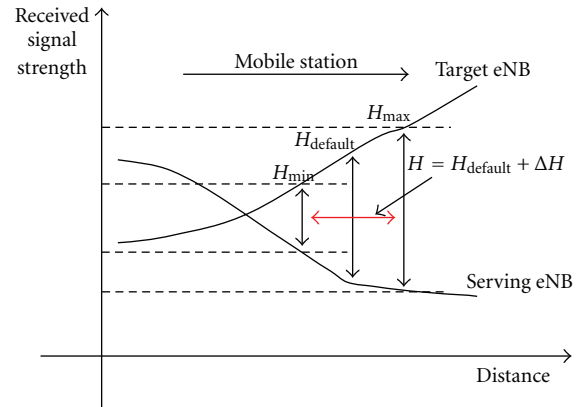


FIGURE 3: An example of the hysteresis values in the proposed cost-based adaptive hysteresis scheme.

where RSS_{it} and RSS_{is} denote the received signal strengths (RSSs) of UE i from the target eNB t and the serving eNB s , respectively. In (3), ΔH is expressed by

$$\Delta H = \alpha \cdot f_{l,v,s}, \quad (5)$$

where α is less than $H_{\text{max}} - H_{\text{default}}$ (or $H_{\text{default}} - H_{\text{min}}$). As α increases, the range of ΔH is extended. Since the rapid and dynamic change of H due to the extended range of ΔH makes it possible to find the best hysteresis value, it is clear that the HFR can be effectively minimized when α is set as $H_{\text{max}} - H_{\text{default}}$ (or $H_{\text{default}} - H_{\text{min}}$).

The parameters N_l , N_v , and N_s in (2) comprising $f_{l,v,s}$ are calculated as follows.

3.1. Normalized Function by the Load Difference between the Target and Serving Cells. If the load of the target cell is higher

than the load of the serving cell, the hysteresis value should be increased so as not to let the UEs near the cell boundary switch over to the target cell; otherwise, the hysteresis value should be decreased so as to avoid the bandwidth shortage of the current serving cell, forcing the UEs near the cell boundary to switch over to the target cell. As a result, if the load of target cell is high, the increased hysteresis tries to prevent the UEs from joining the target cell in order to reduce the HFR. Thus, we define the normalized function N_j as the load difference between the target and serving cells, that is,

$$N_l = L_{tc} - L_{sc}, \quad (6)$$

where L_{tc} and L_{sc} are the load information of the target and the serving cells, respectively. (The load information is expressed as the ratio of the occupied bandwidth to the total bandwidth in each cell.)

3.2. Normalized Function by the Velocity of UE. Recall that a fast moving UE experiences lower handover trial as it moves a longer distance per unit time than slow moving UEs, which means that the HFR can be affected more by the slow moving UE than the fast moving one. Thus, to suppress the handover trial of the slow moving UE at the cell boundary, it is necessary to increase the hysteresis value. Therefore, the normalized function by the velocity of UE is formulated as

$$N_v = -2 \cdot \frac{V_j}{V_{\max}} + 1, \quad (7)$$

where V_j and V_{\max} are the velocity of the UE j and the maximum velocity among the UEs, respectively.

3.3. Normalized Function by the Service Type. The service types with different QoSs in 3GPP LTE system supporting integrated services can be a factor for the calculation of the hysteresis value. The integrated services can be largely classified into real-time (RT) service and nonreal-time (NRT) service. RT and NRT services have different QoS requirements. Generally, an RT service has higher priority than an NRT service since it is delay-sensitive, and so it is desired to have smaller hysteresis value. On the other hand, an NRT service has lower priority than an RT service since it is not delay-sensitive, and thus it needs to have higher hysteresis value. Using this property, we introduce a normalized function expressed by

$$N_s = \frac{N_{\text{non-real}} - N_{\text{real}}}{2}, \quad (8)$$

where N_{real} and $N_{\text{non-real}}$ are the number of RT services and the number of NRT services in a handovering UE with maximum four service types, respectively.

4. Simulation Results

Computer simulation was performed to verify the effectiveness of the proposed scheme. For the simulation, we

TABLE 1: The bandwidth allocation and the service usage ratio per service type.

	VoIP	Music streaming	Web browsing	P2P
The bandwidth allocation	64 Kbps	128 Kbps	512 Kbps	512 Kbps
The usage ratio	40%	15%	30%	15%

TABLE 2: Simulation parameters.

Parameter	Value
Network layout	2-Tier 19 cells
Cell radius	1 Km
Cell bandwidth	5 MHz
Peak data rate	20 Mbps
Antenna type	Omnidirection
Transmit power of eNB	46 dBm
Distance-dependent path loss	$128.1 + 37.6 \log_{10}^R$, R in Km [18]
Shadowing standard deviation	6.5 dB [19]
Measurement report period	100 msec
Time to trigger (ΔT)	300 msec
Minimum hysteresis (H_{\max})	2 dB
Maximum hysteresis (H_{\max})	5 dB
Default hysteresis (H_{default})	3.5 dB
α in adaptive hysteresis schemes	1.5 dB

used a mixed target cell selection (TCS) scheme considering both RSS-based TCS [20] and load-based TCS schemes [21], and a simple hard QoS-based call admission control scheme which blocks a new call into a cell when there is no available bandwidth. The bandwidth allocation and usage ratio per service type are shown in Table 1. It was assumed that each UE originating a call supports maximum four service types at the same time [22, 23]. For the mobility mode of the UEs, we adopted the random direction model (RDM) [24]. In this model, each UE was generated according to the Poisson arrival process, and the lifetime of a UE was assumed to be a random variable with the exponential distribution and with the average lifetime of 2 minutes. Each UE was assumed to move in its own direction with a velocity uniformly distributed from 0 km/h to 140 km/h. The simulation duration was 120 sec.

Table 2 shows the parameters used in the simulation. For the simulation, we assumed a 19-cell system with wrap-around based on the 3GPP LTE downlink specifications defined in [25]. We used the pathloss model in [18] and the shadowing model in [19]. The shadowing model, which is an updated model for the moving UEs, is represented by

$$S(t) = W_a \cdot S(t-1) + W_b \cdot C + W_c \cdot V, \quad (9)$$

where W_a , W_b , and W_c are the weighting factors that should be calculated accordingly to statistical properties of autocorrelation and cross-correlation, for $S(t-1)$, C , and V , respectively. The weight W_a is given by $W_a = e^{-1 \times (d/d_{\text{corr}}) \ln 2}$

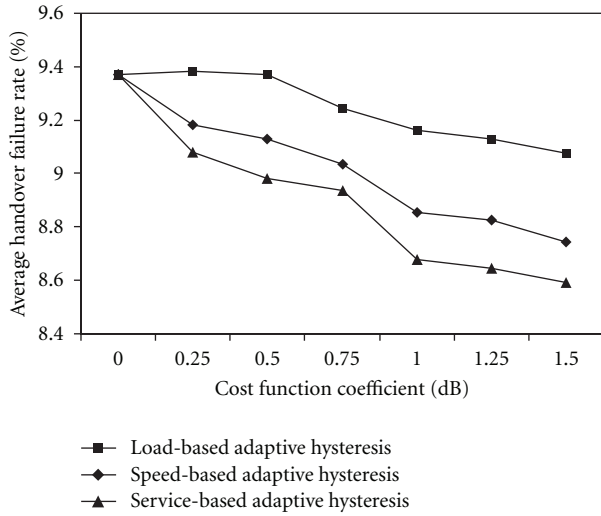


FIGURE 4: AHFR by the proposed cost-based adaptive hysteresis scheme under a variety of the cost function coefficient (α) when call arrival rate is fixed at 0.03.

where d is the migration distance of a vehicle with the speed of 70 km/h for 100 ms and d_{corr} is the decorrelation distance between adjacent eNBs. We used $d = 1.944$ m ($= 70$ km/h \times 100 ms) and d_{corr} was set to 33 m. The weights W_b and W_c are given by $\sqrt{R_L S_d^2 (1 - W_a^2)}$ and $\sqrt{S_d^2 (1 - W_a^2) - W_b^2}$, respectively. Here, the cross-correlation of shadow fading between links (R_L) and shadowing standard deviation (S_d) were set to 0.7 and 6.5 dB. In (9), C is the common value for the wireless links and V is the zero-mean standard Gaussian random variable with the variance of 1 [19].

Figure 4 shows the average handover failure rate (AHFR) with the value of the cost function coefficient, α . In the simulation, H_{\min} , H_{default} , and H_{\max} were 2 dB, 3.5 dB, and 5 dB, respectively, which means that the operating range of α was from 0 dB to 1.5 dB since we have $H_{\max} - H_{\text{default}} = H_{\text{default}} - H_{\min} = 1.5$. The AHFR was obtained by taking an average of the HFR values for the call arrival rates in [0.03, 0.04], that is,

$$\text{AHFR} = \sum_{n=0}^{n=5} \text{HFR}(0.03 + 0.002 \times n) / 6. \quad (10)$$

From the figure, we find that the AHFR is the least when α is 1.5 dB. It is because the largest α causes the hysteresis value H to be fully autotuned to the proposed cost function between H_{\min} and H_{\max} as shown in (3) and (5). As a result, the adaptive hysteresis scheme results in a lower AHFR as α increases. On the other hand, the fixed hysteresis scheme corresponds to the case with $\alpha = 0$ dB. As α of 1.5 dB provides the least AHFR among all the adaptive hysteresis schemes, all the adaptive hysteresis schemes in the following figures adopted this value. It is also found that the performances of the adaptive hysteresis schemes are worse in the order of the load-based scheme with the weight of ($w_l=1, w_v = w_s = 0$), the velocity-based scheme with the weight of ($w_v = 1, w_l =$

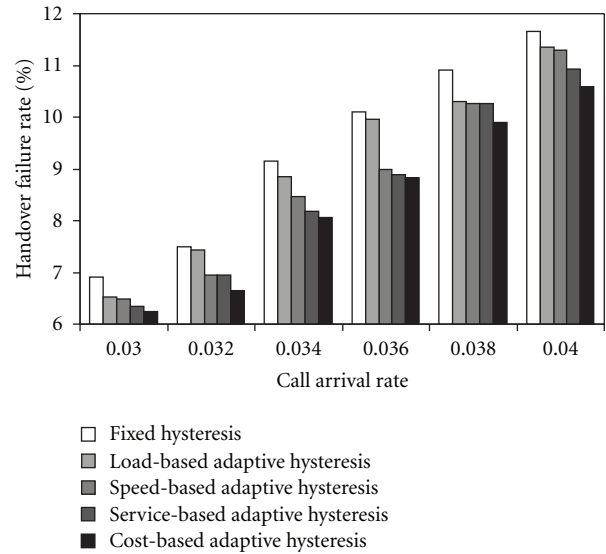


FIGURE 5: HFR by the five hysteresis schemes under a variety of call arrival rate.

$w_s = 0$), and the service-based scheme with the weight of ($w_s = 1, w_l = w_v = 0$). Thus, to reflect the performance difference with the different weight value for the three factors such as the load difference between the target and serving cells, the velocity of the UEs, and the service type, we used the cost-based adaptive hysteresis scheme with the weight of ($w_l = 0.1, w_v = 0.4, w_s = 0.5$) confirming the sum of weights was equal to 1. It is noted that an optimum weight decision scheme needs a more efficient optimization technique, but this is left for further research.

Figure 5 shows the HFR obtained by the fixed hysteresis scheme with $\alpha = 0$ dB and the adaptive hysteresis schemes with $\alpha = 1.5$ dB. From the figure, we find that the proposed cost-based adaptive hysteresis scheme with the weight of ($w_l = 0.1, w_v = 0.4, w_s = 0.5$) provided the least HFR since it considered all three dominant factors such as the load difference between the target and serving cells, the velocity of the UEs, and the service type. Since the load-based scheme, velocity-based scheme, and service-based scheme considered only a single factor for each scheme, the load difference between the target and serving cells, the velocity of UE, and the service type, respectively, they showed better HFR performance than the fixed hysteresis but worse than the proposed cost-based adaptive hysteresis scheme.

Figures 6 and 7 show the performances for different service types when the call arrival rate was 0.03 and 0.04, respectively. The fixed hysteresis scheme used $\alpha = 0$ dB, and all the adaptive hysteresis schemes used $\alpha = 1.5$ dB. The proposed cost-based adaptive hysteresis scheme adopted the weight of ($w_l = 0.1, w_v = 0.4, w_s = 0.5$). From the figures, it is observed that an RT service such as VoIP and Music streaming provided lower HFR compared to the NRT services such as Web and P2P service. This is because the RT services requested less bandwidth allocation than the NRT services as described in Table 1. It is also observed that

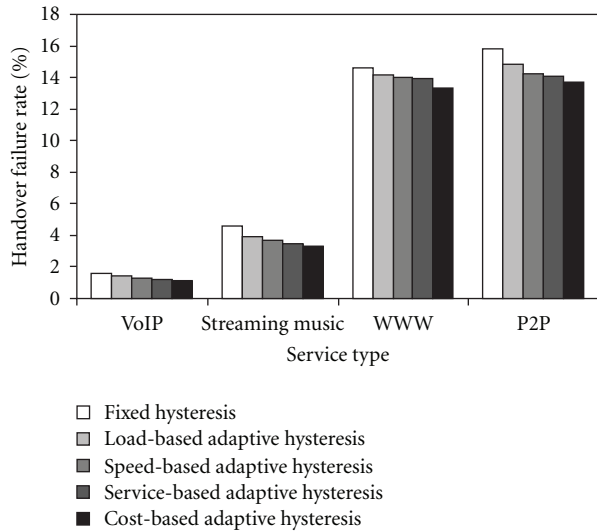


FIGURE 6: HFR per service type by the five hysteresis schemes when call arrival rate is fixed at 0.03.

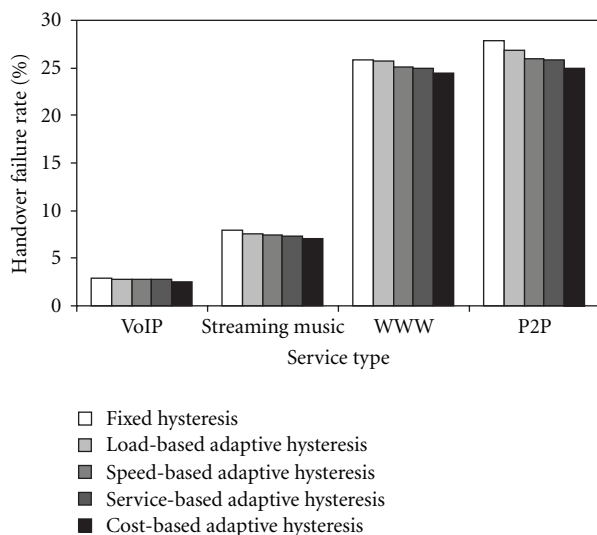


FIGURE 7: HFR per service type by the five hysteresis schemes when call arrival rate is fixed at 0.04.

the proposed scheme with the dominant factor such as the service type contributed to the reduction of the HFR of the proposed scheme unlike the existing schemes. This is because in the proposed scheme the UEs with RT service required smaller hysteresis value than the UEs with NRT service.

5. Conclusion

In this paper, we proposed a novel cost-based adaptive hysteresis scheme which is a kind of the handover parameter optimization for self-optimization in 3GPP LTE system. The proposed adaptive hysteresis scheme for horizontal handover operates on the control plane between the eNBs with the

X2 interface protocol in the 3GPP LTE network architecture. Using the proposed scheme, we can calculate the optimum hysteresis with the cost function focusing on performance improvement in terms of the HFR in real time. The dominant factors of the cost function are the load different between the target and serving cells, the velocity of UE, and the service type. Simulation results showed that the proposed scheme can exhibit better HFR performance than the other existing algorithms.

References

- [1] 3GPP TS 25.913, Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN), December 2009.
- [2] 3GPP TS 36.423, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP), March 2010.
- [3] 3GPP TS 36.300, Evolved Universal Terrestrial Radio Access Network (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2, January 2010.
- [4] 3GPP TR 36.902, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network (SON) use cases and solutions, April 2010.
- [5] S. Feng and E. Seidel, *Self-Organizing Networks (SON) in 3GPP Long Term Evolution*, Novel Mobile Radio Research, München, Germany, 2008.
- [6] J. McNair and F. Zhu, "Vertical handoffs in fourth-generation multinet environments," *IEEE Wireless Communications*, vol. 11, no. 3, pp. 8–15, 2004.
- [7] E. Stevens-Navarro and V. W. S. Wong, "Comparison between vertical handoff decision algorithms for heterogeneous wireless networks," in *Proceedings of the 63rd IEEE Vehicular Technology Conference (VTC '06)*, vol. 6, pp. 947–951, May 2006.
- [8] 3GPP TS 36.331, Evolved Universal Terrestrial Radio Access Network (E-UTRA); Radio Resource Control (RRC); Protocol specification, April 2010.
- [9] R. Nasri and Z. Altman, "Handover adaptation for dynamic load balancing in 3GPP long term evolution systems," in *Proceedings of the International Conference on Advances in Mobile Computing & Multimedia (MoMM '07)*, pp. 145–153, 2007.
- [10] H. Zhang, X. Wen, B. Wang, W. Zheng, and Z. Lu, "A novel self-optimizing handover mechanism for multi-service provisioning in LTE-advanced," in *Proceedings of the International Conference on Research Challenges in Computer Science (ICRCCS '09)*, pp. 221–224, 2009.
- [11] H. Zhang, X. Wen, B. Wang, W. Zheng, and Y. Sun, "A novel handover mechanism between femtocell and macrocell for LTE based networks," in *Proceedings of the 2nd International Conference on Communication Software and Networks (ICCSN '10)*, pp. 228–231, February 2010.
- [12] M. Kassar, B. Kervella, and G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Computer Communications*, vol. 31, no. 10, pp. 2607–2620, 2008.
- [13] Q. Song and A. Jamalipour, "A network selection mechanism for next generation networks," in *Proceedings of the IEEE International Conference on Communications (ICC '05)*, vol. 2, pp. 1418–1422, March 2005.

- [14] W. Zhang, "Handover decision using fuzzy MADM in heterogeneous networks," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC '04)*, vol. 2, pp. 653–658, Atlanta, Ga, USA, March 2004.
- [15] A. Singhrova and N. Prakash, "Multi parameter based vertical handoff decision in next generation networks," in *Proceedings of the Communications of Systemics and Informatics World Network (SIWN '08)*, vol. 4, pp. 82–87, June 2008.
- [16] V. Gazis, V. N. Houssos, N. Alonistioti, and L. Merakos, "On the complexity of 'Always Best Connected' in 4G mobile networks," in *Proceedings of the 58th IEEE Vehicular Technology Conference (VTC '03)*, pp. 2312–2316, October 2003.
- [17] Q. Song and A. Jamalipour, "Network selection in an integrated wireless lan and UMTS environment using mathematical modeling and computing techniques," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 42–48, 2005.
- [18] 3GPP TS 25.848, Physical Layer Aspects of UTRA High Speed Downlink Packet Access, March 2001.
- [19] H. Kim and Y. Han, "Enhanced correlated shadowing generation in channel simulation," *IEEE Communications Letters*, vol. 6, no. 7, pp. 279–281, 2002.
- [20] M. Anas, F. D. Calabrese, P. E. Mogensen, C. Rosa, and K. I. Pedersen, "Performance evaluation of received signal strength based hard handover for UTRAN LTE," in *Proceedings of the 65th IEEE Vehicular Technology Conference (VTC '07)*, pp. 1046–1050, April 2007.
- [21] A. Tolli and P. Hakalin, "Adaptive load balancing between multiple cell layers," in *Proceedings of the 56th Vehicular Technology Conference (VTC '02)*, vol. 3, pp. 1691–1695, September 2002.
- [22] WiMAX Forum, Can WiMAX Address Your Applications?, October 2005.
- [23] Final Report for UMTS Forum, Global Mobile Broadband: Market potential for 3G LTE, January 2008.
- [24] D. H. Kim and K. Jun, "The effect of the QoS satisfaction on the handoff for real-time traffic in cellular network," in *Proceedings of the High Performance Computing and Communications*, vol. 3726 of *Lecture Notes in Computer Science*, pp. 1106–1111, September 2005.
- [25] 3GPP TS 36.201, Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description, March 2010.