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A Fuzzy Logic-Based Adaptive Handoff Management Protocol for Next-Generation Wireless Systems

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***Abstract*— In the integrated next-generation wireless systems (NGWS), users are always connected to the best available networks and used to switch between different networks based on their service needs. It is an important and challenging issue to support seamless handoff management in NGWS. The objective of this paper is to develop a seamless handoff management protocol for NGWS. In this paper, a fuzzy logic-based adaptive handoff (FLAH) management protocol is developed which is then integrated with an existing cross layer handoff protocol. Afterward, the handoff performance comparison of the existing protocol and our proposed protocol is carried out. The simulation results exhibit that, proposed fuzzy logic-based handoff management protocol has much better performance than conventional protocols for both intra and intersystem handoffs.**

***Index Terms*— Call Admission Control, Fuzzy Logic, Handoff Management, Intelligent Systems, Mobility Management, Wireless Networks.**

I. INTRODUCTION

In the integrated NGWS, users are always connected to the best available networks and switch between different networks based on their service needs, each of which is optimized for some specific services and coverage area to provide ubiquitous communications to the mobile users. In NGWS, mobile user can roam between a diverse set of wireless architectures like wireless local area network (WLAN), cellular, and satellite network [1]. Call admission control or handoff management of a mobile user while roaming through different wireless network architectures of NGWS is one of the important issues that needed to be solved. Mobility management contains two components: location management and handoff management [2]. Location management enables the system to track the locations of mobile users between consecutive communications. On the other hand, handoff management is the process by which users keep their connections active when they move from one Base Station (BS) to another. In NGWS, two types of handoff scenarios may arise:

- Horizontal Handoff: Handoff between two BSs of the same system. Horizontal handoff can be further classified into
  - Link-Layer Handoff: Horizontal handoff between two BSs that are under the same Foreign Agent (FA).
  - Intrasystem Handoff: Horizontal handoff between two BSs that belong to two different FAs and both the FAs belong to the same system and hence, to same Gateway Foreign Agent (GFA).
- Vertical Handoff (Intersystem Handoff): Handoff between two BSs that belong to two different systems and, hence, to two different GFAs.

However, seamless support of handoff management in NGWS is still an open research issue. The existing handoff management protocols are not sufficient to guarantee handoff support that is transparent to the applications in NGWS. Mobility management protocols operating from different layers of the network protocol stack (e.g., application layer [3], transport layer [4], network layer and link layer [5]) are proposed to provide seamless services. However, none of them alone are capable of supporting seamless mobility in NGWS. Therefore, recently the design of cross-layer mobility management protocols has gained significant attention [2]. Recently, new handoff algorithm are emerging based on advanced techniques like pattern recognition [8], neural networks and fuzzy logic system (FLS) [9]. These complicated algorithms are necessitated by the complexity of the handoff problem and dynamic conditions of wireless networks. In this paper, a fuzzy logic based handoff management protocol is introduced which is integrated with an existing Cross-Layer Handoff Management Protocol (CHMP) [2]. The simulation results reveal that, fuzzy logic based handoff management protocol has much better performance than conventional algorithms as well as CHMP for both intra and intersystem handoffs.

The remainder of the paper is organized as follows: we discuss analysis of handoff process in terms of handoff signaling delay and handoff failure probability in Section II. In Section III, we introduce our proposed fuzzy logic-based adaptive handoff management protocol and carry out its performance evaluation in Section IV. Finally, we summarize performance of FLAH management protocol in Section V.

II. An Overview of Handoff

When a Mobile Terminal (MT) is moving from its serving Old Base Station (OBS) to New Base Station (NBS) with a speed v, the MT may learn about the possibility of moving into another cell when the Received Signal Strength (RSS) of OBS decreases continuously. When the MT discovers that it may enter into the coverage area of the NBS, the next challenge is to decide the right time to initiate Hierarchical Mobile IP (HMIP) registration procedures with the New Foreign Agent (NFA). The existing link-layer-assisted HMIP protocols [6] propose to initiate the HMIP registration when the RSS from the serving BS, e.g., OBS in Fig.1, drops below a fixed threshold value S_{th}.

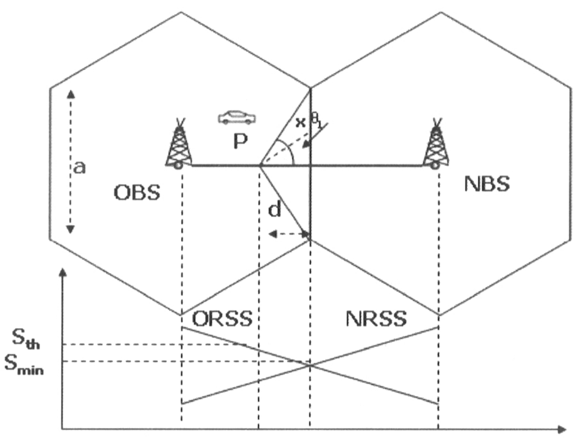

Fig. 1. Analysis of handoff process.

During the course of its movement, when the MT reaches the point P (the distance of P from the cell boundary is d) as shown in Fig. 1, the RSS from the OBS drops below S_{th}. Therefore, when the MT reaches P, it initiates the HMIP registration with the NFA. At this point, the RSS received by the MT from NBS shown as NRSS in Fig. 1 may not be sufficient for the MT to send the HMIP registration messages to NFA through NBS. Hence, the MT may send the HMIP registration messages to NFA through OBS. This is called pre-registration. For a smooth and successful handoff from OBS to NBS, MT's HMIP registration with NFA and link and MAC layer associations with NBS must be completed before the RSS of OBS drops below S_{min}, i.e., before the MT moves beyond the coverage area of OBS [2].

The need for handoff to NBS arises only if MT's direction of motion from P is in the range $[\theta \in (-\theta_1, \theta_1)]$, where $\theta_1 = \arctan(\frac{a}{2d})$. Otherwise, the handoff initiation is a false one. Therefore, the probability of false handoff initiation is

$$\begin{aligned} p_a &= 1 - \int_{-\theta_1}^{\theta_1} f_\theta(\theta)d\theta \\ &= 1 - \frac{2\theta_1}{2\pi} = 1 - \frac{1}{\pi}\tan^{-1}\left(\frac{a}{2d}\right) \end{aligned} \quad (1)$$

The probability of handoff failure [2] is given by

$$P_f = \begin{cases} 1, & \tau > \frac{\sqrt{\frac{a^2}{4}+d^2}}{v} \\ \frac{1}{\theta_1}\cos^{-1}\left(\frac{d}{v\tau}\right), & \frac{d}{v} < \tau < \frac{\sqrt{\frac{a^2}{4}+d^2}}{v} \\ 0, & \frac{d}{v} \geq \tau \end{cases} \quad (2)$$

III. Proposed Fuzzy Logic Based Adaptive Handoff Algorithm

The proposed fuzzy logic based system initiates handoff using fuzzy logic; it uses mobiles speed and distance as input and received signal strength as output. The proposed algorithm is adaptive to velocity interference and distances, resulting in fewer dropped calls, better communication quality, potentially lower MT transmit power requirements, gives good performance at different MT speeds, and decreases handoff failure probability.

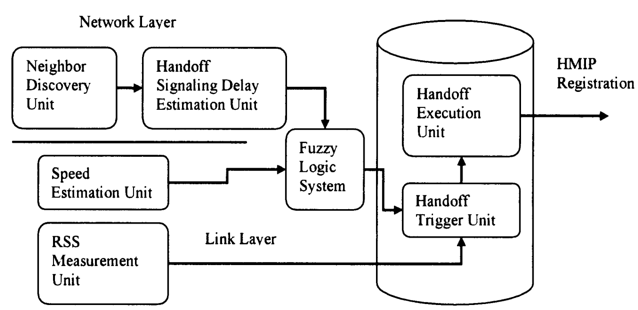

Fig. 2. Proposed fuzzy logic based handoff architecture.

We design an architecture to initiate handoff procedure that is adaptive to the link layer (Layer 2) and network layer (Layer 3) parameters. Then, we develop a handoff management protocol based on the architecture. As the proposed handoff management protocol uses information derived from different layers of TCP/IP protocol stack (e.g., speed information from link layer and handoff signaling delay information from network layer), we call it cross-layer handoff management protocol. The architecture of our proposed FLAH is shown in Fig. 2. Some of these modules collect the link and network layer information useful for handoff management and other modules use this information to decide the appropriate time to initiate and execute the handoff procedures using fuzzy logic system. The functionalities of these units are as follows:

- **The neighbor discovery unit** assists the MT to learn about the neighboring BSs.
- **The handoff signaling delay estimation unit** estimates the delay associated with intra and intersystem handoffs.
- **The speed estimation unit** estimates mobile's speed using VEPSD [7].
- **Fuzzy logic system unit** uses speed and handoff signaling delay information to estimate adaptive RSS threshold (S_{ath}) as discussed in Section IV.
- **Handoff trigger unit** collects information from RSS measurement unit and when the RSS of the serving BS drops below S_{ath}, the handoff trigger unit sends a trigger to the handoff execution unit to start the HMIP handoff procedures.

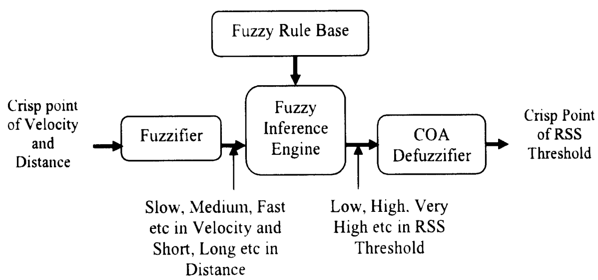

Fig. 3. Fuzzy logic system unit in details.

Finally, the handoff execution unit starts the HMIP registration process at the handoff initiation time calculated by the handoff trigger unit.

A. Proposed Fuzzy Logic System

A fuzzy logic rule base is created based on the known sensitivity of handoff algorithm parameters (e.g., RSS threshold, signal to interference, traffic, etc). Fig. 3 shows the fuzzy logic system in details. The task of the fuzzifier is to map crisp value of $distance$ and $velocity$ to the fuzzy variables. The input fuzzy variable $speed$ is assigned to one of the five fuzzy sets, "Slowest", *"Slow"*, *"Medium"*, *"Fast"* or *"Fastest"*. This research utilizes the Mamdani FLS. Figure 4 illustrates the membership functions of the input fuzzy variable $velocity$ for microcellular system. We used triangular and trapezoidal membership functions and considered 50% overlap of assigned fuzzy sets. Table I shows the rules used in the FLS for microcellular system. Similarly, we defined such rules for macrocellular system. The nonsingleton fuzzifier and the center of area defuzzification method is used.

For example, when the value of $velocity$ is *"fastest"* and the value of $distance$ is *"short"*, this condition indicates that handoff should be encouraged immediately. Hence, output threshold RSS is *"very high"*.

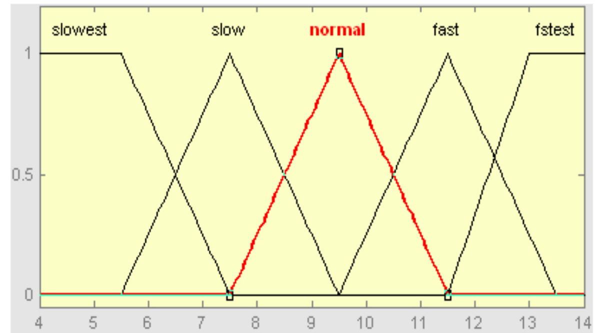

Fig. 4. Membership function of fuzzy variable velocity(microcellular system).

IV. Simulation

A. Simulation Criteria

Fuzzy logic system determines the value of adaptive RSS threshold (S_{ath}) to initiate the HMIP handoff procedures using speed and handoff signaling delay information. Then performance is evaluated as follows: first, value of d is calculated for a desired value of probability of handoff failure P_f using (2) where v is MT's speed, d is MT's distance from the boundary of the serving BS, and τ is the handoff signaling delay [2]. Then an approximate value of d can be calculated using

$$p_f = \frac{\cos^{-1}\frac{d}{v\tau}}{\tan^{-1}\frac{a}{2d}} = \frac{\frac{\pi}{2} - \frac{d}{v\tau}}{\frac{\pi}{2} - \frac{2d}{\sqrt{4d^2+a^2}}}. \tag{3}$$

And the value of false handoff initiation probability can be calculated using (1).

For CHMP, the value of S_{ath}, when the MT is at a d distance from the cell boundary is given by

$$S_{ath} = 10\log_{10}[P_r(a-d)]. \tag{4}$$

where $P_r(a-d)$ is the received power at a known distance $(a-d)$, given by

$$P_r(x) = P_r(d_0)(\frac{d_0}{x})^{\alpha} + \epsilon. \tag{5}$$

The typical value of d_0 is 1 km for macrocells and 100 m for microcells.The numerical value of $P_r(d_0)$ depends on different factors, such as frequency, antenna heights, and antenna gains. α is the path loss exponent and its typical value ranges from 3 to 4 and 2 to 8 for a typical macrocellular and microcellular environment, respectively. ϵ is a zero-mean Gaussian random variable that represents the statistical variation in $P_r(x)$ caused by shadowing. Typical standard deviation of ϵ is 8 dB. We simulate and analyze the relationship among RSS threshold value, mobile's speed and handoff signaling delay. Then we make comparison between FLAH and CHMP with respect to these relationships.

TABLE I
FUZZY RULE BASE

Intrasystem			Intersystem		
Input		Output	Input		Output
Velocity	**Distance**	**$RSS_{threshold}$**	**Velocity**	**Distance**	**$RSS_{threshold}$**
Slowest	Very-short	Near Medium	Slowest	Very-short	Low
Slowest	Short	Low	Slowest	Short	Low
Slowest	Medium	Low	Slowest	Medium	Low
Slowest	Long	Very Low	Slowest	Long	Very Low
Slowest	Very-long	Very Very Low	Slowest	Very-long	Very Very Low
Slow	Very-short	Medium	Slow	Very-short	Medium
Slow	Short	Near Medium	Slow	Short	Near Medium
Slow	Medium	Near Medium	Slow	Medium	Near Medium
Slow	Long	Low	Slow	Long	Low
Slow	Very-long	Low	Slow	Very-long	Low
Medium	Very-short	Far Medium	Medium	Very-short	Far Medium
Medium	Short	Far Medium	Medium	Short	Far Medium
Medium	Medium	Medium	Medium	Medium	Medium
Medium	Long	Medium	Medium	Long	Medium
Medium	Very-long	Near Medium	Medium	Very-long	Near Medium
Fast	Very-short	Very High	Fast	Very-short	Very High
Fast	Short	Very High	Fast	Short	Very High
Fast	Medium	High	Fast	Medium	High
Fast	Long	High	Fast	Long	High
Fast	Very-long	Far Medium	Fast	Very-long	Far Medium
Fastest	Very-short	Very Very High	Fastest	Very-short	Very Very High
Fastest	Short	Very Very High	Fastest	Short	Very Very High
Fastest	Medium	Very High	Fastest	Medium	Very High
Fastest	Long	Very High	Fastest	Long	Very High
Fastest	Very-long	Very High	Fastest	Very-long	Very High

B. Simulation Model

For simulation the following scenarios and parameters are considered: a macro-cellular system with cell size, a, of 1 km, a micro-cellular system with cell size, a, of 30m, macro-cell reference distance, d_0, of 100m, micro-cell reference distance, d_0, of 1 m were chosen. We assume that the target handoff failure probability, P_f, is 0.02. We consider that the maximum values of users' speed in micro-cellular and macro-cellular system are 14 km/h and 140 km/h, respectively. Moreover, we assume that the value of S_{min} is -64 dBm.

C. Simulation Results

1) Relationship between S_{ath} and Speed: The relationship between S_{ath} and MT's speed (v) for different values of handoff signaling delay (τ) is analyzed. Fig. 5 shows the relationship between S_{ath} and v for different values of τ when the serving BS (OBS) belongs to a micro-cellular system. For Macro-cellular system we got similar result.

- Fig. 5 shows that for particular value of τ , the value of S_{ath} increases as MT's speed increases. This implies that for a MT with high speed, the handoff initiation should start earlier compared to a slow moving MT to guarantee the desired handoff failure probability to users independent of their speed.
- Fig. 5 also shows that S_{ath} increases as τ increases. This is because when τ is high the handoff must start earlier compared to when τ is small. The lower and higher values of τ correspond to intra and inter-system handoff, respectively. Therefore, FLS calculates S_{ath} that is adaptive to both v and τ.

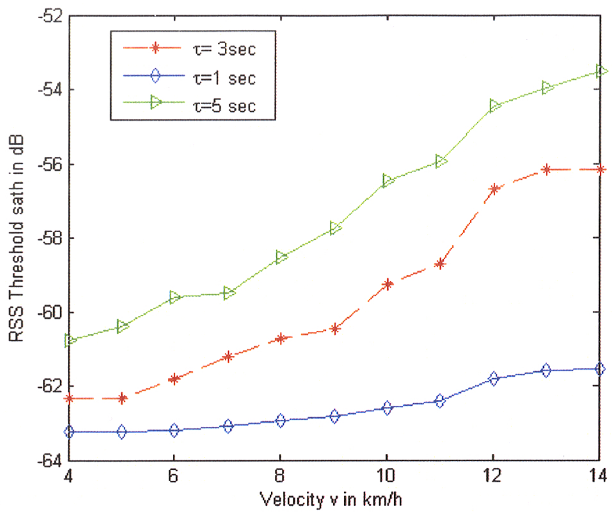

Fig. 5. RSS threshold (S_{ath}) for different speed when the OBS belongs to microcellular system.

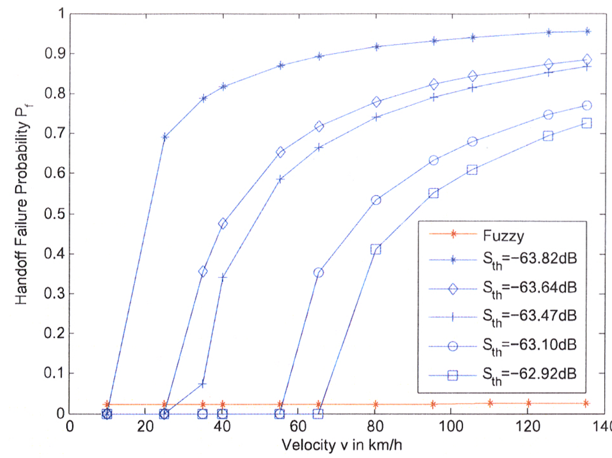

Fig. 7. Relationship between handoff failure probability (Fuzzy) and speed when the OBS belongs to a macrocellular intersystem for fixed RSS.

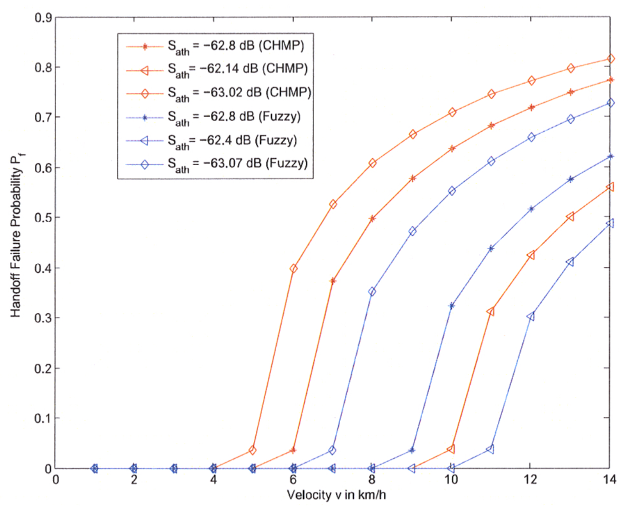

Fig. 6. Relationship between handoff failure probability and speed when OBS belongs to a microcellular intrasystem for fixed RSS.

2) Relationship between the Handoff Failure Probability of FLS and Speed: We calculate S_{ath} using speed and handoff signaling delay information. Then, we use S_{ath} to determine the handoff failure probability.

- Fig. 6 shows the handoff failure probability of FLS and CHMP, for different values of speed when the serving BS belongs to a micro-cellular system.
- It shows that reduction in P_f is achieved in FLS compared to CHMP.
- Fig. 7 shows the results when the serving BS belongs to a macro-cellular intersystem. Similarly we also investigated the results when the serving BS belongs to a macro-cellular intrasystem. Comparison of the results show that when FLS is used and MT's speed is known P_f is almost constant as the calculated RSS is adaptive to velocity and distance. On the other hand, for a particular value of fixed RSS threshold the numerical value of P_f is different and depends on the numerical value of S_{th}. This shows that the handoff protocols need to be adaptive irrespective of the type of handoff.
- Fig. 7 also shows that when the speed of the MT is known, 70% to 80% reduction in handoff failure probability is achieved in FLS compared to fixed RSS based Handoff management system.

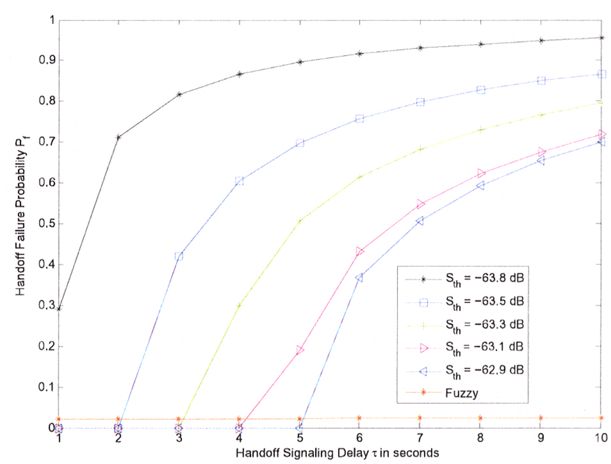

Fig. 8. Relationship between handoff failure probability (Fuzzy) and handoff signaling delay.

3) Relationship between the Handoff Failure Probability and Handoff Signaling Delay: Figure 8 shows the handoff failure probability of FLS for different values of handoff

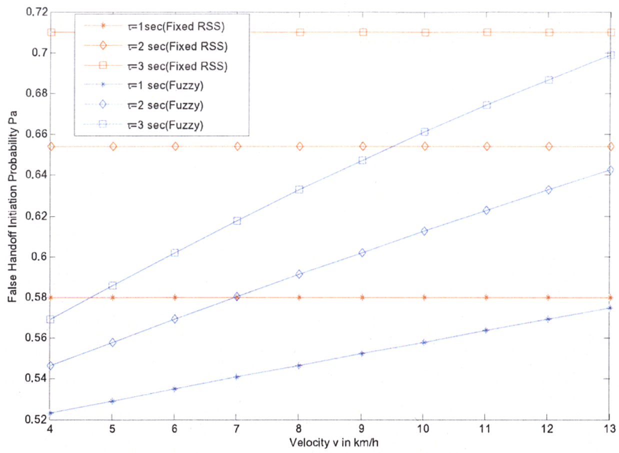

Fig. 9. Relationship between false handoff initiation probability (Fuzzy and Fixed RSS) and speed when the OBS belongs to microcellular system.

signaling delay (τ). The results show that unlike the fixed RSS based handoff protocols; P_f remains independent of τ in case of FLS. This is because FLS considers τ for the tuning membership function of dynamic RSS threshold. Fig. 8 shows that $70\% - 80\%$ reduction in P_f is achieved in case of FLS compared to the fixed RSS based handoff protocols. The lower and higher values of τ correspond to intra and inter-system handoffs, respectively. Therefore, by incorporating the estimated value of τ into dynamic RSS, the P_f is limited to the desired value irrespective of users speed and variation of handoff signaling delay.

4) Relationship between False Handoff Initiation Probability and Speed: Fig. 9 shows the comparison of the false handoff initiation probability of FLS with the fixed RSS threshold based algorithms when the serving BS belong to a micro-cellular system. For macro-cellular system similar result is achieved.

- The figure shows that the false handoff initiation probability of FLS is 5 percent to 15 percent less compared to the fixed RSS threshold based algorithms.
- Thus, FLS achieves up to 15% reduction in the cost associated with false handoff initiation. The use of adaptive RSS threshold initiates the handoff procedures in such a way that just enough time is there for the successful execution of the handoff.
- Therefore, an adaptive value of RSS threshold (S_{ath}) avoids too early or too late initiation of the handoff process. The former limits the value of handoff failure probability. The later ensures that handoff is carried out smoothly. Thus, FLS optimizes the false handoff initiation probability and handoff failure probability.

V. Conclusion

In this paper, a new fuzzy logic based adaptive handoff management algorithm for next generation heterogeneous wireless system is introduced. It uses mobile's speed and handoff signaling delay information to enhances the performance of hierarchical mobile IP (HMIP) handoff significantly. Performance analysis and simulation results show that FLS significantly enhances the performance of both intra and inter-system handoffs. It can estimate the right time to initiate handoff more precisely. It also significantly reduces the cost associated with the false handoff initiation because it achieves lower false handoff initiation probability than existing handoff protocols.

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