JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 23, 1087-1101 (2007)

Seamless Handover in WLAN and Cellular Networks through Intelligent Agents*

LI-DER CHOU, WEI-CHENG LAI, CHEN-HAU LIN+, YEN-CHENG LIN
AND CHIN-MIN HUANG
Department of Computer Science and Information Engineering
National Central University
Chungli, 320 Taiwan
E-mail: cld@csie.ncu.edu.tw
+*Information and Communications Research Laboratories*
Industrial Technology Research Institute
Hsinchu, 310 Taiwan
E-mail: chenhlin@itri.org.tw

With the increasing demand of the mobility of mobile users, seamless handover is a critical issue for heterogeneous network accesses. Improving the blocking probability of SIP calls resulting from the handoff delay is a key issue for achieving seamless handovers across WLAN and cellular networks. This paper presents an efficient scheme, based on intelligent agents, to support pre-authentication for seamless handover, where the intelligent agents are able to cooperate with each other adaptively. Besides, intelligent agents offer the applicability of key distribution with EAP-SIM based AAA protocols to enable fast authentication for inter-domain handovers. The paper proposes a number of possible changes to these solutions for inter-domain operation. In addition, simulation results show that the proposed intelligent-agent-based handoff scheme is capable of improving the performance of the existing handover in call blocking ratio, packet loss ratio and call interruption ratio, so as to reduce the signaling traffic in wireless networks.

Keywords: intelligent agent, seamless handover, handoff delay, EAP-SIM, AAA

1. INTRODUCTION

Today, people can access the Internet easily through wireless LAN (WLAN) and cellular networks such as General Packet Radio Service (GPRS) and Universal Mobile Telecommunications System (UMTS). To provide Quality of Services (QoS) in these wireless networks, many modern traffic schemes have been developed, such as channel allocation [1], admission control [2], traffic scheduling [3] and QoS routing [4]. Dual-mode handsets and multimode terminals are generating demand for solutions that enable convergence and seamless handover across heterogeneous access networks. In the environment of heterogeneous mobile networks, vertical handoffs will deeply affect QoS. Thus how to provide continuous services in the heterogeneous mobile networking environment has become an important issue [5, 6]. In this paper, we study the problem of having continuous access to multimedia services while moving from one hotspot to another.

Received September 15, 2006; accepted February 6, 2007.
Communicated by Ten H. Lai, Chung-Ta King and Jehn-Ruey Jiang.

* This work was supported in part by the Information and Communications Research Laboratory, Industrial Technology Research Institute (ICL/ITRI), Taiwan, under project ID T1-94081-12.

The period from when the mobile node (MN) last receives data traffic via its old IP subnet and when it receives data from the new IP subnet is often referred to as the handover delay. Essentially, the handover delay can be divided into four parts: Layer 1/Layer 2 radio link switching delay, Layer 2 access re-authentication delay, IP layer binding delay, and application layer authentication and registration delay. When MNs change subnets due to mobility, it is necessary to re-authenticate the Authentication, Authorization and Accounting (AAA) servers. The delay in the path from the AP to the AAA server is a critical factor in overall handover delay. These components of handoff delay may cause packet losses, call blockings and service interruptions. To reduce the application layer authentication and registration delay, it is necessary to perform authentications and registrations even before the handover actually occurs. An agent-based pre-authentication mechanism was proposed to reduce the Layer 2/Layer 3 delay in the handover [7], where the approach will impose an additional traffic load. This paper addresses these problems so as to provide a means of seamless handover between subnets or heterogeneous networks.

The rest of the paper is organized as follows. In the following section, we review the existing research. Then we describe the intelligent agent system in section 3, and the methodologies in section 4. Numerical results are simulated and compared in section 5. Finally, conclusions are given in the last section.

2. RELATED WORK

There have been numerous approaches for seamless handover. In this section, we describe the previous works related to fast handover, vertical handoff, and mobility supporting for Session Initiation Protocol (SIP) [8] services. Then, we present an overview of Mobile Intelligent Agent (MIA) technology and MIA based pre-authentication.

2.1 Fast/Vertical Handover

The technology of Mobile IP provides the key to facilitate the seamless handover between the WLAN and cellular networks. As a result, the handover latency for these schemes is in the scale of seconds. A fast handover scheme based on the Mobile IPv6 mechanisms was proposed to reduce the connectivity delay and packet losses [9]. Because soft handover provides same data receiving from multiple access routers, it allows MN's session to progress without interruption when a MN moves from one network to another. Fast handover enables data duplication through old and new access routers.

The multihoming feature enables the MN to support seamless handover by simultaneous binding of two different addresses while staying the overlapping region. The packets are multicast to MN and MIP agents, and thus the packet loss is reduced during the vertical handover. With the consideration of QoS, multicast in heterogeneous wireless networks was studied in [10]. The characteristic of multihoming is capable of providing seamless streaming media in heterogeneous mobile networks [6].

2.2 SIP Mobility

Although the original SIP protocol did not take the mobility of the MNs into consideration, there have been ongoing research efforts to support mobility in current SIP protocol. Wedlund and Schulzrinne proposed mobility support in the application layer protocol SIP where applicable, in order to support real-time communication in a more efficient way [11, 12]. The SIP networks provide handover process via the Correspondent Nodes (CNs). If the MN moves during an active session, first it obtains a new IP address from a DHCP server, and then sends a new session invitation to the CN. With this new invitation, it tells its new IP address so as to forward packets properly. While the SIP- based approach offers several advantages over a corresponding MIP-based solution, it continues to suffer from several drawbacks.

It can cause call disruption if the new SIP session is not created completely while a MN is in the overlapped area and loses its old radio link. As opposed to an MN using MIP (when the MN detect movements, it can obtain CoA from a FA), a MN using SIP-mobility always needs to acquire an IP address via DHCP, which can be a major part of the overall handover delay.

2.3 MIA-Based Pre-Authentication

In recent years MIA has been the focus of much speculation. The Mobile Agent (MA) is a software component including data and executable code, which can be transferred from a network element to another while carrying on its status of execution. The MA is a quite alluring technology which can walk everywhere in Internet to search for application relative information [13]. It can find us a great deal of goods and services, and interact with other MA within the same network or remain bound to a particular host. Also, the MA technology can diminish network traffic compared to the traditional client-server model and maintain load balancing, thus is successfully applied to network monitoring [14], network diagnoses [15] and wireless Internet telephony [16]. So we take advantage of the MA technology to assist the SIM-based pre-authentication for decreasing the handoff delay of inter-WLAN domain. The MA technology not only reduces control packets to process the SIM-based authentication but also build a VPN tunnel at the new location of attachment for secured packet transmissions in advance [17]. The method comprises a SIM-based pre-authentication with a MIA of the mobile device. The use of MIAs not only reduces the number of control packets to process the authentication but also reserve the necessary bandwidth prior to handover. Based on the multi-homing technique, the agents will collect bi-cast or multicast data at new location of attachment in advance, which reduces the possibility of packet loss.

3. INTELLIGENT AGENT SYSTEMS

For seamless handover, the design of the adaptive IA system is a critical part of the paper. To accommodate the exponentially growing mobile wireless data service subscribers, also to improve the service reliability and scalability, a distributed server/proxy architecture is used and responsibilities and functions are delegated to intelligent agents (IAs) [18]. The adaptive IA based approach we proposed comprises use of the various IAs according to the users' and servers' requirements. For local caching, it improves the handover delay. For load balancing, it further improves performance and scalability.

3.1 Use of Intelligent Agents

User Intelligent Agents (UIA) may be configured to authenticate on behalf of users and load balance. The benefit of UIAs performing authentication is to not only reduce handover delay in the wireless network and allocate the bandwidth to avoid call blocking, but also interact with other UIAs within the same network or remain bound to a particular host.

Server Intelligent Agent (SIA) may be configured to authenticate UIAs locally or act as a proxy to forward a request to the AAA server. SIA uses a typical trick to avoid the re-authentication overhead; it caches the user profile of frequently visited UIAs so that they can be directly authenticated in the future. Once UIAs do not access SIA again within a certain period of time, their user profile will be discarded from the cache memory.

SIAs leverage the authentication and authentication information between the MN and the Extensible Authentication Protocol Method for GSM Subscriber Identity Modules (EAP-SIM) based AAAF server, *i.e.* the EAP-SIM based AAA server in the foreign network of the MN. The AAA server may spawn authentication processes to handle incoming authentication requests of UIAs and enable SIAs to provide dynamic, scalable, and authentication traffic load distribution between multiple geographically dispersed UIAs. The benefit of SIAs improving the performance of network traffic involving UIAs is to alleviate congestion in densely populated areas with heavy traffic.

Initially an AAA server dispatches SIAs to a visited registrar proxy (VRP) in its domain to handle the authentication requests of UIAs. The SIA acts as a server and its memory is also capable of carrying the user profiles for UIAs visited most, which in turns reduces their authentication delay. Once users do not access again within a certain period of time, their user profile will be discarded from the cache memory. The AAA server and SIAs are assumed to share a trust relationship setup via a shared secret or other credential. AAA attributes are needed to transmit the key from the AAA server to SIAs. SIAs also contain support for exchanging the AAA credential with the AAA server. The benefit of SIAs improving the performance of authentication is to reserve the necessary bandwidth in advance for UIAs.

The drawback of a UIA is its user traffic is not shared among a group of users trying to authenticate with a common AAA server. For users trying to authenticate with an AAA server, it's desirable that UIAs have shared secrets if they exist. The alternative is to provide a single point of authentication with a Group User Intelligent Agent (GUIA). In this scenario it is assumed that UIA first ever dispatched to target AP could potentially become a GUIA. The GUIA monitors its own traffic load and performs load balancing by evenly spread its tasks over its peers based on its real-time traffic conditions. The benefit of GUIA is to provide the flexibility to leverage multiple authentications to reduce signaling overhead and resource consumption.

3.2 Adaptive Intelligent Agents

The IA system is adaptive in that the bandwidth allocated to the IAs can vary with current network condition. As an IA is generated to represent a specific user, it can reserve the required bandwidth of the user between the node and server in advance to support the delivery of data exchanges. The IAs evenly distribute the traffic load among them by constantly monitoring the traffic flows from the nodes. The load balancing of server transmissions assures that all users enjoy the same bandwidth from the server. It offers a simpler and better way to move more data faster via the server. The solution is to utilize a set of threshold levels activated according to the congestion level of the node, wherein the congestion threshold is set to provide a tolerable delay in combination with a tolerable packet loss rate. With adaptive load balancing, all traffic traveling from the server is automatically balanced between all links. If the links of an IA become a bottleneck, some additional IAs forked by the IA can eliminate the bottleneck and achieve the load balancing. The adaptive IAs manage their own execution logic and life cycle model with a finite state machine. These features will be implemented in the adaptive IA system.

3.3 State Machines

The IA may manage its own execution logic and life cycle model, but often a better choice is for it to delegate these responsibilities to a finite state machine. A finite state machine provides a simple and effective mean to control the life cycle and overall behavior. The life cycle model defines the different execution states and the events that cause the movement from one state to another. It also provides a common framework for the IAs from start to finish. The definitions of IA terminology may help to describe the concept of load balancing.

IA_{ii}: the *i*th IA
IA_{ji}: the *j*th IA forked by the *i*th IA
IA_{ii}^{Load}: the signaling load on the *i*th IA
IA_{ji}^{Load}: the signaling load on the *j*th IA forked by the *i*th IA
IA_{ii}^{N}: the number of the active links on the *i*th IA
IA_{ji}^{N}: the number of the active links on the *j*th IA forked by the *i*th IA
$Threshold_{Load}$: the threshold of the maximum signaling load allowed on an IA
$Threshold_{N}$: the threshold of the maximum number of the active links allowed on an IA

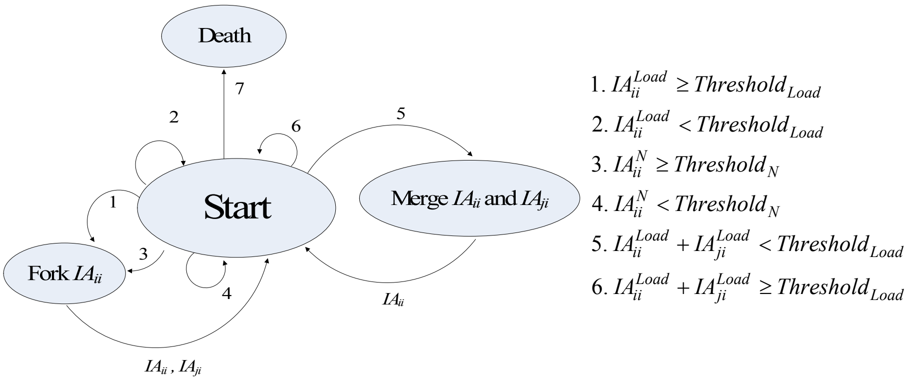


Fig. 1. State transition diagram of intelligent agents.

The state machine depicted in Fig. 1 sketches the overall behavior of the IAs. The machine contains the states Start, Fork, Merge and Death. Transitions are shown as directed arcs that interconnect the states. The state machine provides the mechanism of load balancing (*e.g*. Fork and Merge) to alleviate congestion in densely populated areas with heavy traffic.

In state charts, states are connected via transitions with conditions and actions annotated. The conditions are in sequence indexed by numbers as above. The Start state is the creation of IAs denoted as IA_{ii}. The Start state permits a transition to Fork, if the load of IAs is greater than its threshold $Threshold_{Load}$ (condition 1) or if the number of IAs reaches its threshold $Threshold_N$ (condition 3), whichever comes first. Otherwise, it loops back to itself (conditions 2 and 4). In this case, the IA is forked and enters the Fork state afterwards. The Start state also permits a transition to Merge, if the loads of an IA_{ji} and its clone IA_{ii} generated in Fork is less than the threshold $Threshold_{Load}$ (condition 5). In this case, the IA and its clone are merged together and enter the Merge state afterwards. Otherwise, it loops back to itself (condition 6). Furthermore, there are transitions from Fork and Join back to Start without actions. Finally, the Start state permits a transition to Death without actions. In this case, the IAs are terminated and enter the Death state afterwards.

3.4 Load Balancing

The load balancing between IAs is an important issue since it provides a tolerable delay in combination with a tolerable packet loss rate. In particular, SIAs and GUIAs provide a mean for multi-agent communication by enabling IAs to maintain their load balancing via Merge and Fork. The load balancing leads to the movement of nodes covered by the fully loaded GUIA to other lightly loaded one. As results, the whole system will then experience better link quality (higher data rate and less delay). The probability of packet collisions will increase dramatically when the number of nodes crosses a certain threshold and as the time to authenticate other AAA servers grows. Hence, a need for adaptive IAs to have a load-balancing scheme has been recognized. Ideally, IAs should dynamically adapt to the network condition. In the rest of the paper we present a solution that has this property.

4. METHODOLOGIES

This section exploits a novel agent-based architecture providing means for pre-authentication and optimization for seamless handover, which is based on an extension of the IA scheme.

4.1 Seamless Handover

We consider two different scenarios, *i.e*. the break-before-make and make-before-break handovers. Break-before-make (hard handover) is a term to describe the discontinuity in connectivity between MNs and access networks during a handover, while make-before-break (soft handover) implies the seamless handover. In the seamless 'make-before-break' handover, the MN is allowed to pre-authenticate and prepare for handover at any time. The handover consists of layer 2 and layer 3 handovers that are physical and logical handovers, respectively. In the seamless handover, two handovers are interleaved to reduce the handover latency. Prior to the handover, a MN can thus maintain a list of possible alternative APs by scanning for APs between the deliveries of voice packets. It can also receive information from the current AP about other APs in the vicinity. Once the MN detects that a handover has started either because it initiates the request or because the signal strength in the current subnet is lower than a certain threshold, it forks the IAs to the predictive AP. The IAs then authenticate and register to the AAA server via this AP for the application server access. Since new AP receives the authentication information in advance, further message exchanges are not needed when the MN actually hands off to new AP. The migrated MN can obtain all the information from the IA within the new AP and it is not necessary to send an access request message to the AAA server. It thus reduces the Layer 2/Layer 3 delay in the handover.

4.2 Pre-Authentication and Registration

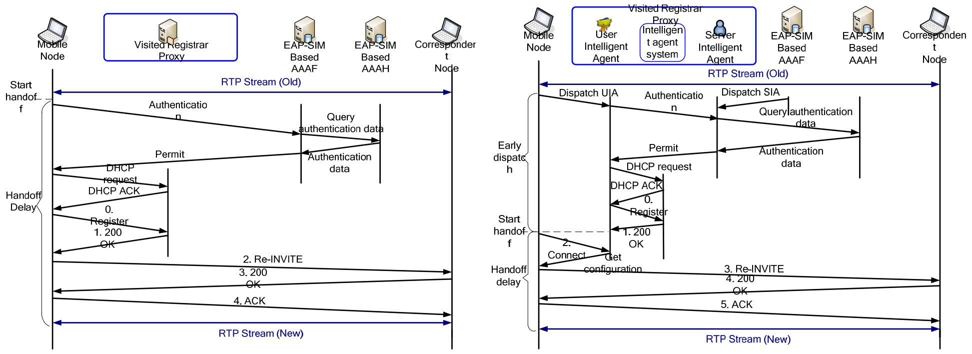
Generally, since the AAA server is often located in a remote domain for more scalable service, the delay in the path from the AP to the AAA server is a critical factor in overall handover delay. To reduce re-authentication and registration delay, we proposed the idea of performing the authentication and registration even before the handover actually occurs. Initially a MN communicates with a CN in a RTP stream session. Prior to handover, it dispatches a UIA to a foreign network. The UIA acts like a spirit of the MN carrying user's SIM information and migrating to a predictive AP to process EAP-SIM based authentication before handover occurred. Once certificated by a VRP, it will obtain a new IP address from a DHCP server to perform the SIP registration, and forward the network configuration data to the MN for future connection. After the registration is completed, the MN sends the SIP re-INVITE message to the CN to update the session.

Adaptive IA system requires SIAs and GUIAs to have significant advance knowledge of what users are handover, which may complicate pre-dispatching decisions. Further enhancement by creating additional signaling flows burdens the existing traffic. Initially an AAA server dispatches SIAs to a VRP in its domain to authenticate UIAs. SIA acts as a server and its memory is capable of carrying the user profiles for UIAs visited most, which in turns reduces their authentication delay. On the user side, the MN has the mobility information of authentication server.

In order that MN dispatches UIAs in time before MN arrived, we consider to early estimate one possible visited network for MN itself. A comparison between handovers performed by non-agent system and handovers initiated by IA system is made. The conventional handover, shown in Fig. 2 (a), requires an exchange of 9 messages between the MN and AP, and handover with IAs, shown in Fig. 2 (b), requires 5 messages.

4.3 SIM Based Authentication

This session describes the authentication processes in the integrated authentication for WLAN and GPRS/UMTS. The SIM-Based AAA provides a single authentication mechanism for the users of WLAN and GSM/GPRS integrated networks. We adopted the EAP-SIM protocol [19] to integrate the authentication of WLAN and GSM/GPRS networks, which integrates EAP in 802.1X [20] and SIM authentication. The EAP-SIM



(a) (b)

Fig. 2. Message flows of (a) conventional handover and (b) handover with intelligent agents.

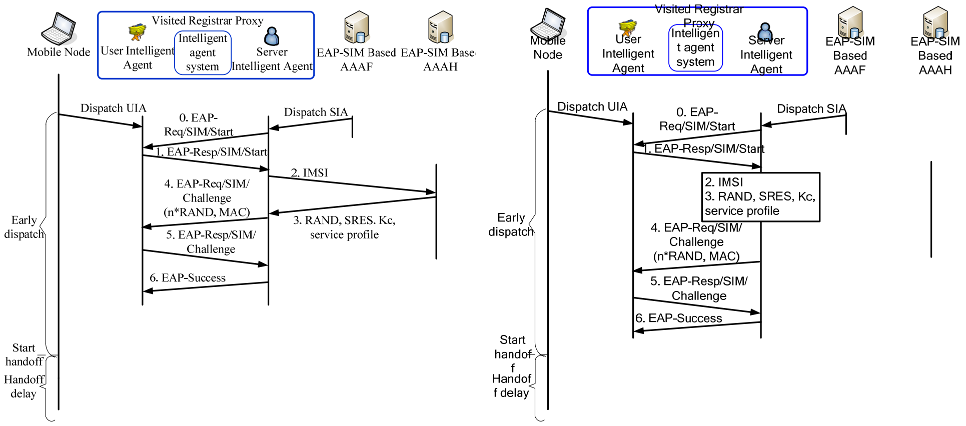
protocol, resident on the client, specifies the EAP mechanism for authentication and session key distribution using GSM SIM. The AAA infrastructure is based on a network of AAA servers, which includes the EAP-SIM based AAAH, *i.e.* the EAP-SIM based AAA server in the home network, and the EAP-SIM based AAAF, *i.e.* the EAP-SIM based AAA server in the foreign network of the MN. The EAP-SIM based AAA server provides the authentication and key distribution via the Internet. The mutual authentication between the user and home domain is required. It is assumed that the user and AAA server share a common set of algorithms and keys. These algorithms and keys will be used to authenticate the user to the home domain and the home domain to the user.

4.4 Authentication Key Distribution

An authentication key distribution to IAs provides an efficient alternative to reduce packet loss due to collision at the physical layer for a CSMA/CA based wireless network. To shorten the certification latency the authentication centre transfers a set of authentication triplets to the VRP that, in turns, can authenticate IAs directly with the connection configuration information. SIAs can play a role in key distribution and reduce signaling load between the users and AAA server. They retrieve the keys from the EAP-SIM based AAAH to reduce the re-authentication delay and collision occurrence. The authentication takes place when the keys of UIAs are matched with those of SIAs in VRP. For a hit-and-miss policy, only when authentication keys are found will be a hit, otherwise it would be a miss. The signaling flows of the authentication process for the miss is shown in Fig. 3 (a), and those for the hit in Fig. 3 (b).

5. PERFORMANCE EVALUATIONS

The simulation provides the performance metrics to quantify packet loss, call interruption, handoff call blocking, and new call blocking and bandwidth overhead associated with the handover. The simulations involve plotting the performance metrics of the number of mobile nodes to find statistically probable outcome. We specifically compare the above performance metrics built by the adaptive IA to that built by the MA.



(a) (b)

Fig. 3. Message flows of authentication in case of (a) a miss and (b) a hit.

5.1 Simulation Model

The simulations based on Network Simulator 2 (NS2) involve monitoring several VoIP performance indices, *e.g.* packet loss rate, call interruption ratio, handoff call blocking ratio, new call blocking ratio and bandwidth overhead, to find statistically probable outcome. The simulation uses Wi-Fi in the infrastructure mode. The scenarios consist of nine APs placed onto a rectangular grid with different number of nomadic users or MNs. These are chosen to show the effect of increased nodes for network performance. Table 1 summarizes the simulation parameters in the simulation.

Table 1. Simulation parameters.

Parameters	Values
Simulation Area (meter^2)	380
Number of APs	9
X-dimension of Distance between 2 APs (meter)	140
Y-dimension of Distance between 2 APs (meter)	140
Number of Nodes (Random Scenario)	100 ~ 550
Packet Size (Kbytes)	64
Intelligent Agent Packet Size (Kbytes)	16
Simulation Time (sec)	21600
Transmission Range (meter)	100
Bandwidth (Mbps)	11
AP Placement	Grid
Node Placement	Random
Call Duration (sec)	180
Poisson Arrival Rate (calls/sec)	0.001
MAC Protocol	IEEE 802.11

5.2 Performance Metrics

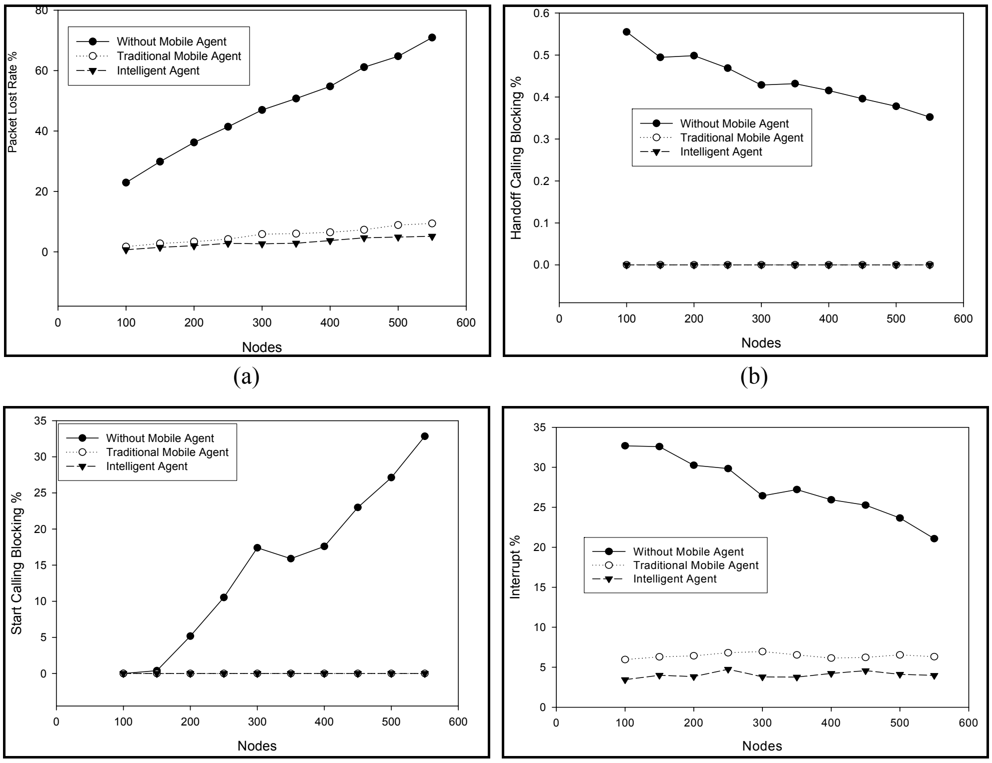
We compare the performance of the conventional, MA and adaptive IA schemes along the following dimensions:

- Packet Loss Ratio: Ratio of the number of lost RTP packets to the total number of RTP packets that should have been received.
- Handoff Blocking Ratio: Ratio of the number of blocked calls to the total number of handover attempts. The handoff blocking occurs when an AP has no bandwidth allocated to the users.
- New Call Blocking Ratio: Ratio of the number of new calls to the total number of handover attempts. Admitting new call always increases the resource consumption in the system.
- Call Interruption Ratio: Ratio of the number of interrupted calls to the total number of handover attempts. If there is no bandwidth available for the duration of a call or the delay in break-before-make handover is greater than 200 milliseconds, the user may experience a brief service interruption.
- Bandwidth overhead: It refers to the multiplication of bandwidth consumed in voice transmission and resource consumption in the duration of the call.

The first four metrics are the most important for evaluating the performance of the real-time voice application. Here, we may note that these metrics are not completely independent. For example, a larger new call blocking may cause a lower call interruption. But, a lower call interruption does not necessarily imply a lower new call blocking because the interruption metric depends on the successful delivery of packets. The motivation for studying the new call and handoff blocking rates is that the Quality of Service (QoS) in the Cellular network is mainly determined by these two quantities. The first determines the fraction of new calls that are blocked, while the second is closely related to the fraction of admitted calls that terminate prematurely due to dropout. Another concern for the handover performance is the delay, *i.e.* the time that is needed to complete the handover procedure. If the handover does not occur fast, the QoS may degenerate below an acceptable level. During the handover there is obviously a brief service interruption. The chances of dropping a call due to factors such as the availability of bandwidth increase with the number of handover attempts.

5.3 Simulation Results and Analyses

We conducted simulation experiments to evaluate the performance of the proposed architecture. The simulation results were then compared against similar results produced by the conventional and MA systems running without load balancing. The input rate of new calls and handover calls is proportional to the expected number of nodes in the range between 100 and 550. We assume these systems running with 100, 150, 200, 250, 300, 350, 400, 450, 500 and 550 nodes to simulate SIP networks with varying levels of node density. The complete set of results is plotted over the number of nodes. As mentioned before, we have to assume the call duration time to be exponentially distributed. The calls provide fair allocation of bandwidth for voice packets. For every simulation run a number of performance metrics were measured for the 21,600 seconds of simulation.



(a) (b)

(c) (d)

Fig. 4. Variation of the (a) packet loss ratio, (b) handoff call blocking ratio, (c) new call blocking ratio and (d) call interruption ratio with varying nodes of the three different schemes.

Fig. 4 (a) shows that the packet loss rate is only slight greater without load balancing than with it. We assume this effect results mainly from a higher hit rate (*i.e.*, probability of user profile in UIA is contained in cache memory of SIA) in those cases that have small number of user profiles. Where a conventional system is used, the number of nodes attempts to transmit simultaneously may vary with time, some mechanism to manage the contention is needed. Where a MA system is used, the time the signaling protocols spend traveling from and to the AAA server is decreased, which in turns decreases in collisions between packets in the MAC layer. Where an adaptive IA system is used, SIA is capable of reserving bandwidth for UIAs, which further reduces in collisions and packet loss.

Fig. 4 (b) shows the handoff call blocking ratio versus the number of nodes for various schemes. For the conventional system, the handoff call blocking rate decreases as the number of nodes increases. In this case the call admission policy is simple: all calls will be accepted only if the number of users at the AP is less than the maximum value. For each dropped call, a new call attempt is reinitiated, which further increases the network congestion levels. Every time a collision occurs, the calls will exponentially back off due to CSMA/CA. The call rejection probability rapidly decreases as we increase the maximum number of admitted users and the overload probability does not increase so rapidly with this maximum number. As the number of nodes increases, the handoff call blocking ratio of conventional system drops quickly, whereas MA and adaptive IA systems achieve consistently low handoff calling blocking.

Fig. 4 (c) shows the new call blocking ratio versus the number of nodes for various schemes. For the conventional system, the slope of new call blocking ratio is ascending prior to descending with 300 nodes and resumes its uptrend again with 350 nodes. Such a behavior is consistent with that in call interruption ratio as Fig. 4 (d), which provides evidence on a causal relation between new call blocking and call interruption. The time interval between packets decreases due to the increase in collisions as the number of nodes increases, which reduces the available bandwidth for new calls in the networks. As the number of admitted new users below 150, all of them allow direct connection to the APs and there is no advantage to be gained with IA mechanism. As the number of admitted new users above 150, new call blocking will increase steeply as the number of nodes increases. The IA mechanism may prevent it against the node increases. The reason for this is because the admission control mechanism will block new arrivals as the system congests rather than dropping existing one.

Fig. 4 (d) shows that even at high nodes, the adaptive IA system can achieve lower call interruption ratio. This is because IAs reserve bandwidth in advance, which do not suffer from large call interruption. This increases likelihood that the MN can receive calls again. For the conventional system, the call interruption ratio decreases as the number of nodes increases. Bearing in mind, the denominator in the definition is the number of handoff attempts. However, the absolute value of the descending slope is close to that of descending slope in Fig. 4 (b) but significantly less than that of the ascending slope in Fig. 4 (c). The reason for this is because non-blocked existing calls decrease reduces the probability of call interruption. Fig. 4 (d) shows that the call interruption ratio is greater without load balancing than with it. The certification latency improvement is dominated by increasing the hit rate of SIAs. In all of our simulations, for performance metrics, an 80% hit rate was used. As far as the accuracy is concerned, the hit rate should be evaluated based on its real-time performance.

In general, the admission decisions in wireless VoIP networks are made to ensure guaranteed QoS for heterogeneous traffic, while maintaining high resource utilization and low handoff call dropping probability. To achieve this, an access point must maintain a balance between two conflicting requirements: to maximize resource utilization and minimize the forced handoff call dropping probability. In order to maintain the maximum resource utilization, the maximum number of calls should be admitted into a network, which may result in an unacceptably high handoff call dropping probability due to insufficient resources for handoff calls. Therefore, it is very important in wireless VoIP networks to develop a dynamic resource reservation scheme which can estimate future resource demands, reserve the minimum amount of necessary resources to maintain an acceptable handoff call dropping probability, and provide relatively high resource utilization. If there is a very busy AP, namely the resource utilization of this AP is very much bursty in nature. And thus this AP will handoffs all calls served by it to other APs more frequently. This simulation tells us that a good method to predict the bandwidth utilization will result in low handoff frequency and reduce the signaling traffic.

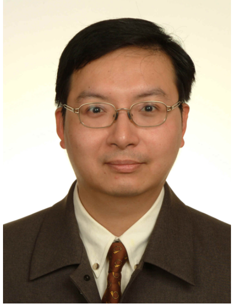
6. CONCLUSIONS

A new IA-based architecture for handoffs in WLAN and Cellular networks has been proposed to achieve low handoff and new call blocking probabilities, low packet loss and low call interruption probabilities. The performance of the conventional system, MA and adaptive IA systems, at handover in WLAN and Cellular networks, is compared quantitatively. In particular, we have shown that although conventional system is better than MA and adaptive IA systems in terms of overhead, MA and adaptive IA systems have smaller delays and transmit fewer packets than the conventional system. The simulation results show that our proposed system outperforms the best previously known schemes in terms of call dropping probability, call blocking probability, and bandwidth utilization.

REFERENCES

1. H. Y. Shin, J. L. C. Wu, and H. H. Liu, "Performance analysis of dynamic multichannel scheme with channel de-allocation in integrated wireless networks," *IEICE Transactions on Fundamentals*, Vol. E87-A, 2004, pp. 1681-1691.
2. Y. W. Chen, Y. L. Lee, and I. H. Peng, "Connection control by virtual admission in wireless LAN environment," LNCS 4138, 2006, pp. 14-25.
3. Y. W. Chen and S. H. Hu "Study of the traffic scheduler by using correlation heuristics," *IEICE Transactions on Communications*, Vol. E87-B, 2004, pp. 2273-2280.
4. J. M. Chen, S. P. Ho, Y. C. Lin, and L. D. Chou, "QoS routing with link stability in mobile ad hoc networks," LNCS 3824, 2005, pp. 683-692.
5. M. Shi, X. Shen, and J. W. Mark, "IEEE 802.11 roaming and authentication in wireless LAN/cellular mobile networks," *IEEE Wireless Communications*, Vol. 11, 2004, pp. 66-75.
6. L. D. Chou, J. M. Chen, H. S. Kao, S. F. Wu, and W. Lai, "Seamless streaming media for heterogeneous mobile networks," *ACM Springer Mobile Networks and Applications*, Vol. 11, 2006, pp. 873-887.
7. C. H. Lin, J. S. Yang, and K. C. Wu, "Mobile intelligent agent technologies to support intelligent handover strategy," in *Proceedings of the Workshop on Wireless*, *Ad Hoc*, *and Sensor Networks*, 2005, pp. 521-528.
8. J. Rosenberg, H. Schulzrinne, G. Camarillo, A. Johnston, J. Peterson, R. Sparks, M. Handley, and E. Schooler, "SIP: session initiation protocol," IETF RFC 3261, 2002.
9. R. Koodli, "Fast handovers for mobile IPv6," IETF RFC 4068, 2005.
10. L. D. Chou, H. J. Hsieh, and J. M. Chen, "Multicast with QoS support in heterogeneous wireless networks," LNCS 3207, 2004, pp. 581-590.
11. E. Wedlund and H. Schulzrinne, "Mobility support using SIP," in *Proceedings of the 2nd ACM/IEEE International Conference on Wireless and Mobile Multimedia*, 1999, pp. 76-82.
12. H. Schulzrinne and E. Wedlund, "Application-layer mobility using SIP," *ACM Mobile Computing and Communications Review*, Vol. 4, 2000, pp. 47-57.
13. A. Karmouch and V. A. Pham, "Mobile software agents: an overview," *IEEE Communications Magazine*, Vol. 36, 1998, pp. 26-37.
14. L. D. Chou, K. C. Shen, K. C. Tang, and C. C. Kao, "Implementation of mobile-agent-

based network management systems for national broadband experimental networks in Taiwan," LNCS 2744, 2003, pp. 280-289.
15. L. D. Chou and C. J. Hong, "Multiple mobile agent based network fault diagnoses systems in multihomed networks," *Journal of Internet Technology*, Vol. 6, 2005, pp. 143-148.
16. B. Emako, R. H. Glitho, and S. Pierre, "A mobile agent-based advanced service architecture for wireless Internet telephony: design, implementation, and evaluation," *IEEE Transactions on Computers*, Vol. 52, 2003, pp. 690-705.
17. K. C. Wu, J. S. Yang, and C. H. Lin, "System and method for connection handover in a virtual private network," Patent pending filed in 2005.
18. L. D. Chou, W. C. Lai, and C. H. Lin, "Strategy of a dispatch intelligent agent to deal with wireless handover," Patent pending filed in 2005.
19. H. Haverinen and J. Salowey, "Extensible authentication protocol method for GSM subscriber identity modules (EAP-SIM)," IETF RFC 4186, 2006.
20. IEEE Std 802.1X-2004 – IEEE Standards for Local and Metropolitan Area Networks, Port-based Network Access Control, 2004.



Li-Der Chou (周立德) received a B.S. in Electronic Engineering from National Taiwan Ocean University, Taiwan, R.O.C. in 1988, a M.S. and a Ph.D. in Electronic Engineering from National Taiwan University of Science and Technology, Taiwan, R.O.C. in 1991 and in 1995, respectively. He has worked as an associate professor with Jinwen College of Business and Technology, Chung Hua Polytechnic Institute, and Central Police University, respectively. From 1997 to 1999, he acted as the director of the Multimedia Communications and Services Division, Computer Center, National Central University, Taiwan, R.O.C. From 1997 to 2005, he was an associate professor with the Department of Computer Science and Information Engineering, National Central University, Taiwan, R.O.C. Currently he is a professor with the same department. He has published more than one hundred of journal and conference papers in the area of computer networks. Besides, he won the Award of Excellence in IPv6 International Appli-Contest 2005. His current research interests include network management and planning, broadband wireless networks, sensor networks, and Internet applications and services.

Wei-Cheng Lai (賴韋丞) received his B.S. and M.S. degrees both in Computer Science and Information Engineering from Chung Hua University, Taiwan, R.O.C. in 2000 and 2004, respectively. He is pursuing his Ph.D. degree in Computer Science and Information Engineering from National Central University, Taiwan. His research interests include wireless networks, and mobile computing.

Chen-Hau Lin (林晨浩) received his M.S. degree in Computer Science from San Jose State University, San Jose, California, U.S.A., in 2002, his Ph.D. and M.S. degrees in Physics from University of Massachusetts, Lowell, Massachusetts, U.S.A., in 1989 and 1992, respectively and his B.S. degree in Physics from National Cheng Kung University, Tainan, Taiwan, in 1982. He has been a research engineer of Information and Communications Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan, since 2001. His research interests include computer networks, wireless communication and cellular systems.

Yen-Cheng Lin (林彥丞) received B.S. degree in Industrial Design from National Cheng Kung University, Taiwan, in 2004, a M.S. degree in Computer Science and Infor- mation engineering from National Central University, Taiwan, in 2006. His research interests include wireless networks and mobile computing.

Chin-Min Huang (黃志閔) received his B.S. degree in Mathematics from Tamkang University, Taiwan, R.O.C. in 2002. He is pursuing his M.S. degree in Computer Science and Information Engineering from National Central University, Taiwan. His research interests include wireless network.