An Interworking Architecture for Heterogeneous IP Wireless Networks

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Abstract— **A major trend in next generation or 4G wireless networks (NGWN/4G) is the coexistence of diverse but complementary architectures and wireless access technologies. In this context, an appropriate integration and interworking of existing wireless systems are crucial. Interworking architectures have been proposed for 3G cellular networks and wireless local area networks (WLAN) by both third generation wireless initiatives, 3GPP and 3GPP2. However, proposed interworking architectures still to be hindered by some drawbacks, the most significant being the absence of quality of service (QoS) guarantee and seamless roaming. This paper proposes a novel architecture, called *Integrated InterSystem Architecture* (IISA), based on 3GPP/3GPP2 proposal, which enables the integration and interworking of various wireless networks and hide their heterogeneities from each other. The IISA architecture aims at providing guaranteed seamless roaming and service continuity across different access networks. Numerical results show that IISA with its supported handoff management scheme provides better performance than existing interworking architectures when they use traditional IPv6-based handoff management schemes.**

Index Terms— **Next generation wireless networks, interworking architecture, seamless roaming, mobility management.**

I. Introduction

Next generation or 4G wireless networks (NGWN/4G) are expected to exhibit heterogeneity in terms of wireless access technologies and services. The advantages of 3G cellular networks such as UMTS and CDMA2000, consist of their global coverage while their weaknesses lie in their bandwidth capacity and operational costs. On the other hand, WLAN technology such as IEEE 802.11 offers higher bandwidth with low operational costs, although it covers relatively short range. Moreover, technological advances in evolution of portable devices have made possible the support of different radio access technologies (RATs). This has raised much interest in the integration and interworking of 3G wireless networks and WLAN capable of providing integrated authentication, billing and global roaming.

The integration of these systems seems unavoidable due to potential benefits of their complementarity and will be a major step toward the design of NGWN instead of putting efforts into developing new radio interfaces and technologies [1]. The purpose of the integration of different networks is to unify the advantages of these systems and at the same time to minimize the disadvantages. This allows a great market opportunity. Conceptually, NGWN architecture can be viewed as many overlapping wireless access domains, as shown in Fig. 1. Furthermore, heterogeneity in terms of RATs and network protocols in NGWN asks for common interconnection element. Since IP technology enables the support of applications in a cost-effective and scalable way, it is expected to become the core backbone network of NGWN [2]. Thus, current trends in communication networks evolution are directed towards an *all-IP* principles in order to hide heterogeneities and to achieve convergence of different access networks.

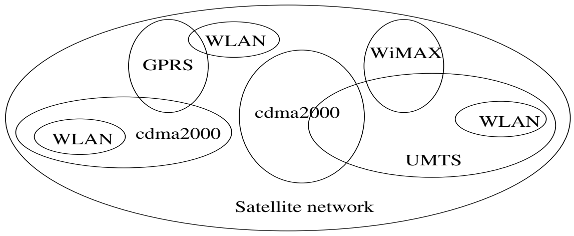

Fig. 1. Overview of 4G/NGWN network architecture.

The integration of 3G cellular networks and WLAN may be done at several point. Two major architectures (*loose* and *tight coupling*) for 3G/WLAN interworking have been proposed by both 3G wireless network initiatives, 3GPP and 3GPP2, for their respective system [3], [4]. However, this integration brings new challenges such as selection of integration point, mobility management, interworking, QoS guarantees and security issues. These challenges are key issues in order to support global roaming and service continuity of mobile nodes (MNs) across various networks in an efficient way.

This paper proposes a novel architecture, called *Integrated InterSystem Architecture* (IISA), based on 3GPP/3GPP2-WLAN interworking models, to integrate the existing wireless systems and hide their heterogeneities from each other. The main objective of the IISA is to enable QoS guarantee, seamless roaming and service continuity for real-time applications in heterogeneous IPv6-based wireless environments. The remainder of this paper is organized as follows. Section II offers an overview of the basic concepts and inherent challenges of designing an integrated architecture are described. After that, related work on the interworking and the integration in heterogeneous wireless networks are presented in Section III. The proposed interworking architecture, IISA, is presented in Section IV followed by performance evaluation in Section V before concluding remarks drawn in last section.

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II. Background

With heterogeneity in NGWN, it is crucial to provide seamless mobility and service continuity (i.e., minimum service disruption during roaming) support based on intelligent and efficient mechanisms.

A. Basic Concepts Overview

Maintaining uninterrupted session while the physical interface is changing constitutes a complex task in NGWN. Handover is defined as a capability for managing the mobility for a mobile node (MN) in active state. An evident way to achieve roaming among networks of different service providers or network operators is by using bilateral service level agreements (SLAs). However, this approach is not feasible due to several reasons such as the increasing number of wireless networks which renders almost impractical for network operators to have direct SLAs with every other operators. Furthermore, another drawbacks to this approach is the reticence of network operators to open their databases to other operators.

An integrated and interworking architecture for NGWN should handle specific requirements and have the following main characteristics [2]:

- *economical*: to ensure economical and rapid deployment, the architecture should use the existing infrastructures as much as possible and minimize the use of new infrastructures;
- *scalable* and *reliable*: integration of any number of wireless systems of both existing and future service providers should be supported by the architecture and be able to provide fault tolerance;
- *seamless mobility*: to eliminate connection interruptions and the QoS degradation during intersystem or intrasystem roaming, the architecture should support seamless mobility;
- *security*: the architecture should provide a level of security and privacy which is equivalent or better than the existing wireless and wired networks.

The above challenges and requirements show that it is very hard to have a single integrated architecture which is appropriate for all interworking scenarios and satisfy both cellular operators and wireless internet service providers. It is very difficult to forecast which interworking architecture will dominate in the market, since selection of model is not based only on performance criterion, but on its cost and its respective profits as well. Hence, until an ideal solution will be designed and deployed, mobile users will still require a practical solution. This could be achieved by a certain tradeoff of the above requirements.

B. 3G/WLAN Interworking Models

Six 3G/WLAN interworking scenarios and their requirements have been defined in [3], [4] in order to provide a proper background for interworking architecture design. These scenarios are described by an incremental set of services and operational capabilities:

1- common billing and customer care;
2- 3G system-based access control and charging;
3- access to 3G system packet-switched based services;
4- service continuity;
5- seamless services provision;
6- access to 3G system circuit-switched based services.

With the particular characteristics of 3G cellular networks and WLAN, scenarios 5 and 6 present significant technical challenges and raise low-layer consideration. Scenario 4 is an extension of scenario 3 with more enhanced mobility management.

III. Related Work

Several 3G wireless networks and WLAN interworking architectures are available in the literature. Two major interworking architectures have been proposed by 3GPP, called *loose coupling* and *tight coupling* [3]. With the tight coupling approach, WLAN appears to the 3G wireless core network as one of the 3G wireless radio access network (RAN). MNs must implement both 3G wireless networks and WLAN interfaces at lower layer. The 3G wireless networks protocol stack should be implemented on top of WLAN technology in MNs' devices. Although, the tight coupling allows easy control of QoS for time-sensitive application, it leads to several drawbacks such as high cost and complexity. Both technologies should be owned by the same wireless operators, MNs' devices and configurations should be modified. Moreover, with tight coupling, traffic from WLAN flows into 3G wireless core network and leads to capacity problems. In fact, 3G wireless core network nodes cannot accommodate the bulk data traffic from WLAN.

On the other hand, with loose coupling, different networks are deployed independently and the data paths are completely separated between WLAN and 3G wireless networks. Hence, the loose coupling enables several advantages in terms of low cost and less complexity: independent traffic engineering, deployment and ownership of both technologies, fewer networks and mobile devices modifications, etc. However, the loose coupling may not guarantee service continuity to other access networks during handover, because it has higher handover latency and packet loss. In fact, the QoS provision with loose coupling depends on the Internet QoS status. The hybrid coupling integration is also proposed in the literature and differentiates the data path according to the type of traffic [5], [6]. With the hybrid coupling, the real-time traffic uses the path based on the tight coupling while non-real time traffic uses the path based on the loose coupling. By combining advantages of 3G wireless networks and WLAN, the hybrid coupling may provide seamless handover in terms of low packet loss and low delay. However, some drawbacks of the tight and loose coupling still exist in the hybrid coupling.

An architecture for the next generation all-IP-based wireless systems is proposed in [2] and called Architecture for Ubiquitous Mobile Communications (AMC). Two new entities, Network Interworking Agent (NIA) and Interworking Gateway (IG) are introduced. The QoS guarantee is not taken into account in AMC and deployment of NIA and IG require extra cost. Other works have been done for interworking of heterogeneous wireless networks [7], [8]. Often these integration

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schemes are based on deployment of a gateway, which takes care of interworking issues, between each pair of networks. Adding a gateway at each boundary between two systems will increase deployment costs. Moreover, these works seem to integrate only cellular networks.

The choice of an optimal interworking architecture is determined by some number of factors. For example, if the wireless network is composed by a large number of WLAN and 3G wireless operators, the loosely coupled architecture would be the best choice. On the other hand, if the WLAN network is exclusively owned and operated by a 3G wireless operator, the tightly or hybrid coupled architecture might become a more attractive option. The loose coupling approach offers more advantages than tight coupling, with virtually no drawbacks and it is the most advocated interworking scheme in the literature [9]. Although most proposed schemes offer several advantages, they continue to be hindered by certain drawbacks, the most significant being the absence of the QoS guarantee and seamless roaming.

IV. Proposed Architecture for NGWN

As stated in [3], no use cases have been identified for scenario 6. Thus, for further development, it is not considered worthwhile. Then, we focus on scenarios 4 and 5, and propose an interworking architecture, called *Integrated InterSystem Architecture* (IISA), that allows seamless service continuity across various RATs. Instead of developing new infrastructures, IISA extends existing infrastructure to tackle the integration issues and provide mobile users with ubiquity (*always best connected*) [10]. For the sake of simplicity, only UMTS, CDMA2000 and WLAN networks are illustrated in the IISA architecture. However, IISA may integrate any number of RATs and mobile devices may be equipped with any number of interfaces.

A. Interworking Architecture IISA

The proposed IISA architecture is shown in Fig. 2 and is based on adaptive loose coupling model. With the IISA architecture, various integrated networks appear as peer network. The IISA uses hierarchical architecture and is IPv6-based, i.e., it implements Mobile IPv6 (MIPv6) [11] and Hierarchical MIPv6 (HMIPv6) [12] functionalities. A novel entity, *Interworking Decision Engine* (IDE), is introduced to enable interworking between different networks. The IDE may be under the responsibility of the third-party service provider (owned by one or multiple operators with SLAs among them) like it is the case for GPRS Roaming eXchange (GRX) in GPRS networks [13]. Then, the network operator needs to establish only one direct SLA with the IDE service provider instead of establishing individual SLAs with all other operators. The usage of the IDE could be seen as a value-added services that operators offer to their subscribers to allow global roaming. If necessary, an IDE operator will be responsible for making additional agreements with other IDE operators.

To enable the support of IPv6-based mobility management protocols, some functional entities of UMTS/CDMA2000 networks are extended. Hence, SGSN/PCF is enhanced with the functionalities of an access router (AR) and is called AEN (*Access Edge Node*). Similarly, GGSN/PDSN is extended with MAP (Mobility Anchor Point) and interworking functionalities (to enable message formats conversion, QoS requirements mapping, etc.) and is called BEN (*Border Edge Node*). The BEN has the information for ARs such as IP address, subnet prefix, link address within its domain. The WLAN interworking gateway (WIG) acts as a route policy element, ensuring message format conversion. Extended functionalities can be integrated into existing network entities or implemented separately. We advocate for the first choice because it is easy to implement and to manage.

The IISA is based on existing infrastructures and just adds the AAA (authentication, authorization and accounting) linkage and supports of IPv6-based mobility management scheme when it is not available. Interworking of different access networks is required for an efficient integration. The mapping between home location register or home subscriber server (HLR/HSS) in 3G wireless networks and AAA server in WLAN is required to allow execution of authentication and billing when user roams across both technologies. In the IISA architecture, authentication is done by combining AAA protocol and context transfer or token-based approach. We make distinction between home AAA server (AAAH) located in the MN's home network and local AAA server (AAAL) located in the foreign network.

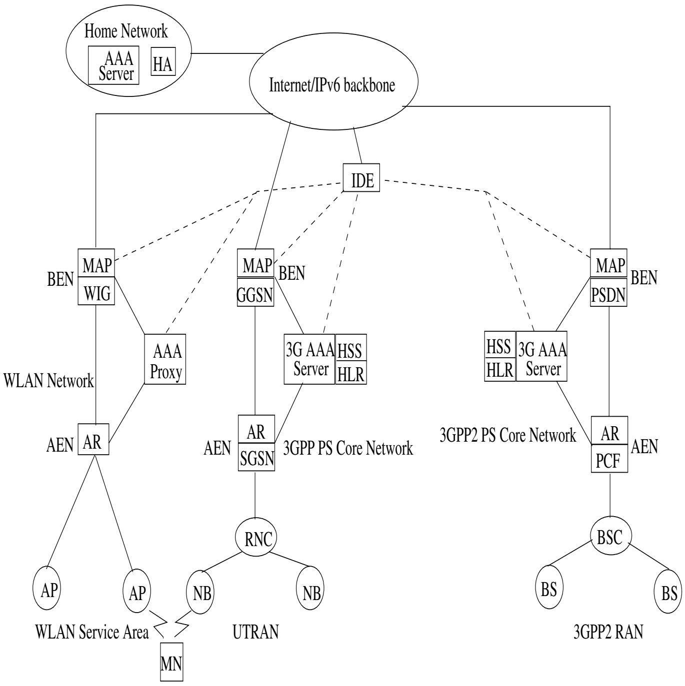

Fig. 2. Interworking IISA architecture for NGWN/4G.

B. Interworking Decision Engine

The Interworking Decision Engine (IDE) is introduced to enable handoff regardless of wireless access technologies, operators and wireless service providers. It is designed for the purpose of exchanging required information between heterogeneous wireless systems in order to reduce signaling traffic

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and services disruption during handover. Specifically, the IDE handles AAA and mobility management for intersystem and/or inter-domain roaming. The IDE makes policy decisions and provides mediation between different service providers or network providers. To reduce IDE's load, the IDE is involved only for intersystem and/or inter-domain handover process and it manages only control signaling traffic; users' data packet traffic does not go through the IDE. In fact, the IDE is in a control plane while the MAP/BEN handles the actual traffic, thus it is in the transport plane. By separating the control and transport plane, the IISA architecture becomes flexible for adding new services, and offers easy interworking with legacy networks.

Furthermore, to enable the scalability of the IISA architecture, if the number of mobile users that requires intersystem and/or inter-domain handoff increases or if the number of heterogeneous wireless systems increases, the IDE can be deployed in hierarchical or distributed framework. For roaming user with ongoing session, the IDE allows the reduction of association and authentication delays. Since the IDE is closer to foreign network than home network to foreign network; then, handover process execution is speed up. To allow easy deployment of the IDE, it may be placed at a control point within a signaling network or core network, for example in the Internet.

Logical components of the IDE are illustrated in Fig. 3. *Authentication Module* (AuM) is used to authenticate users moving across different wireless networks and it avoids the need for direct security agreement or association between foreign network (FN) and home network (HN). When an MN enters into a new domain for the first time, authentication and authorization procedures are performed between FN and HN through the IDE. The credential information is then stocked in the IDE and a token is provided to MN for further authentication and authorization needs. Thus, when an MN moves to another FN, an end-to-end re-authentication is not necessary. The MN will just use its token and send it to the IDE for validation. The AuM emulates HSS/HLR functionalities for WLAN's subscribers to enable usage of 3G wireless network legacy authentication and location update procedures when WLAN subscriber roams into 3G wireless network. The AuM maintains an entry list until lifetime is expired. If the lifetime expires, the entry is removed. However, the lifetime may be refreshed by a request to AAAH server. The WLAN AAA server/proxy routes the AAA messages to appropriate 3G AAA server through AuM/IDE and vice versa.

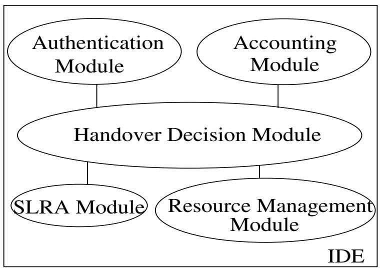

Fig. 3. Logical components of the Interworking Decision Engine (IDE).

Accounting Module (AcM) enables billing between different wireless networks. It acts as common billing/charging system between various network operators. The AcM collects accounting information received from AAA server of FN per-user based on the charging policy of FN operator. It converts if necessary call detail records of FN before to forward this information to AAAH server for billing purposes. Charging information associated to resource usage is stored in AcM. Usually, different administrative domains have different QoS policies for resource allocation. Then, when an MN moves between two different administrative domains, the QoS re-negotiation may be required. This re-negotiation will be based on SLAs between both domains through the IDE. Hence, *Resource Management Module* (RmM) enables QoS mapping, fast transfer of user profile and QoS parameters between different domains during handover. The RmM handles also operations for bandwidth management that offers resource allocation, policy enforcement and call admission control. The *SLRA Module* stores information about service providers or network operators who have SLAs and roaming agreements (RAs) with the IDE operator.

The *Handover Decision Module* (HdM) is used when intersystem and/or inter-domain handover should be granted or no. In other words, it enables support of roaming and handover for mobile users. The HdM module verifies with SLRA module the existence of agreements with MN's home network. Moreover, the HdM decides the best available network in case of network-controlled handoff and enables efficient load balancing. The HdM includes also the MAP functionalities for mobility management of users who perform inter-domain/system handover. If some lawful operations such as legal intercept are required, a decision module to handle them may be included as MAP functionalities of the HdM.

C. Registration and Roaming

To avoid the additional signaling overhead due to the execution of great amount of AAA procedure each time an MN performs handoff and request registration, we propose a token-based approach. During roaming within the MAP/BEN domain of access networks having agreements with the IDE, an MN presents a token, which it obtains from the IDE after its first successful registration in FN, to the MAP/BEN or AR. The token includes security association parameters for secure tunnel set up and context transfer. This yield a lower registration latency than performing authentication and authorization check with the AAAH server. If the MAP/BEN or AR verifies the token successfully, it initiates the authorization process. The home agent (HA) functionalities related to MN authentication, distributing keying materials, security association, context transfer and mobility management are delegated to the IDE during MN roaming. Subsequent movements are handled either by the MAP/BEN and AAAL server or by the IDE whether movement is intrasystem or intersystem.

When an MN detects it is moving out of its residence area, for example from L2 trigger [14], the MN select the best target network from relevant information received through network entities. The handoff decision function proposed in [15] may be used since it is more appropriate for heterogeneous networks. After the subnet selection, the MN initiates authentication and authorization procedures which are combined with MIPv6 registration procedure. The request sent by an MN to the MAP/BEN, allows the latter to know that the MN is a roaming user. The MAP/BEN can then start handoff procedure execution by determining if an intersystem or inter-domain is required for the MN. In case of intersystem or inter-domain handoff, the MAP/BEN forwards registration request to the IDE. The latter determines if the MN may be granted the permission to access FN according to SLAs its HN operator has established with the IDE operator. If SLAs exist, the IDE performs registration request along to authentication and authorization. After a successful registration, the MN can start communication through the new subnet. The handoff process is illustrated in Fig. 4.

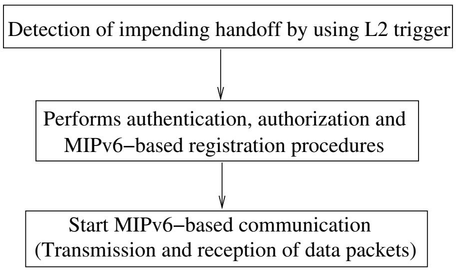

Fig. 4. Handoff process associated to the IISA architecture.

V. Performance Evaluation

We analyze the handoff procedure by considering authentication and binding update delay in order to show the effectiveness of our proposal over existing schemes. In other words, we define total cost (C_T) as the sum of authentication cost (C_A) and registration cost (C_R): $C_T = C_A + C_R$. Note that, authentication cost is the same with traditional approaches at the first movement to the new MAP/BEN domain. However, the rest of processing is more effective since the authentication is performed by the IDE. Let T_{AC} be the sum of L2 handover latency, router discovery delay and duplicate address detection (DAD) delay; $T_{X,Y}$ be the one-way transmission delay between nodes X and Y. We compare cases when IPv6-based mobility schemes such as MIPv6 and HMIPv6 are used in traditional interworking architectures with our handoff management in the IISA architecture.

A. Numerical Results

With MIPv6, whenever the MN across subnet boundary, it must register and authenticate with the HA/AAAH in home network first. After that, a return routability procedure is performed with all active correspondent nodes (CNs) followed eventually by binding update to CNs. Hence, the handover latency for any movement, when MIPv6 is used, is given as follows:

$$D_{MIPv6} = T_{AC} + 2T_{MN,HA} + T_{RR} + 2T_{MN,CN} \qquad (1)$$

where $T_{RR} = 2\max[(T_{MN,HA} + T_{HA,CN}), T_{MN,CN}]$ is the delay of return routability procedure. We assume that processing delay and routing table lookup delay are negligible compared to access and to transmission delay.

An MN performs two types of binding update with HMIPv6: local and global. Global binding update occurs when an MN moves out of its MAP domain while local binding update is performed when an MN changes its current IP address within a MAP domain. Hence, for global binding update, the MN first registers with a local MAP and thereby obtains a regional care-of address (RCoA) on the MAP's link, then registers this RCoA to HA and CNs. Hence, the handover latency for local and global binding update, when HMIPv6 is used, is given as follows:

$$\begin{aligned} D^{l}_{HMIPv6} &= T_{AC} + 2T_{MN,MAP} \\ D^{g}_{HMIPv6} &= 2T_{MN,MAP} + D_{MIPv6}. \end{aligned} \qquad (2)$$

Our proposed roaming management scheme is based on HMIPv6. Hence, we obtain same handover latency. However, the main difference is with authentication process. In fact authentication procedure for MIPv6 and HMIPv6 is similar while the authentication in IISA is delegated to the IDE. The authentication delay associated are given as follows:

$$\begin{aligned} D^{A}_{MIPv6} = D^{A}_{HMIPv6} &= 2T_{MN,HA} \\ D^{A}_{IISA} &= 2T_{MN,IDE}. \end{aligned} \qquad (3)$$

For numerical analysis, we consider random-walk mobility model and the following system parameters: $T_{MN,HA} = 30$, $T_{MN,CN} = 20$, $T_{MN,IDE} = 8$, $T_{CN,HA} = 10$ and $T_{MN,MAP} = 6$. Let μ be the subnet crossing rate; we assume that average subnet residence time is $1/\mu = 10$ seconds and boundary crossing probability $p = 0.65$, when they are not considered as variable parameters.

Average subnet residence time is the expected duration that an MN stay in a subnet. Hence, as the average residence time increases, the MN performs less movement; then, the average handoff latency cost decreases for all schemes as shown in Fig. 5. However, our proposal outperforms both MIPv6 and HMIPv6. The handoff latency cost gain of IISA over MIPv6 and HMIPv6 are 40% and 27%, respectively. Fig. 6 shows the

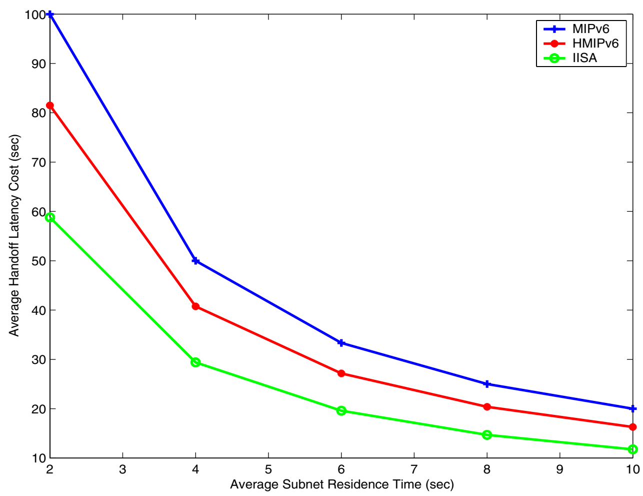

Fig. 5. Handoff latency cost vs. average residence time.

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relation between handoff latency cost and the domain crossing probability (p). We can see that the handoff latency cost of our proposed scheme is always smaller than that of MIPv6 and HMIPv6. The smaller handoff latency cost of our proposed scheme results in less network signaling traffic in comparison with that of both MIPv6 and HMIPv6. In MIPv6, the handoff latency cost remains constant since it does not differentiate intra-domain and inter-domain movement.

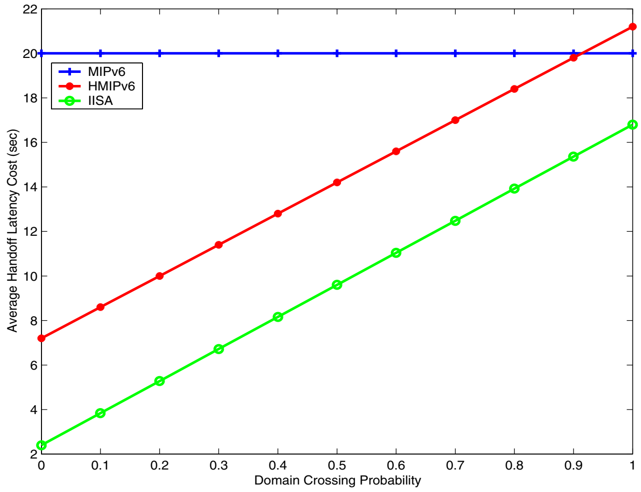

Fig. 6. Handoff latency cost vs. boundary crossing probability.

B. Characteristics of the IISA Architecture

As stated in Section II, a novel network architecture should satisfy some requirements and design goals. The IISA architecture achieves those requirements. In fact, only one new entity is introduced in existing network infrastructures to allow roaming across heterogeneous networks and other logical functionalities may be implemented in existing network nodes. Thus, IISA is economic. Assume that there is O operators. The number of bilateral SLAs required to realize a roaming among all networks deployed with traditional interworking architecture is $\frac{O(O-1)}{2}$. Whereas the number of SLAs required with the IISA architecture is O. When O is very high, the IISA allows a significant reduction of the number of SLAs.

With the IDE, the IISA is an open framework, so it can support any number of networks and service providers. Moreover, the centralized nature of the IDE may arise scalability issue of IISA. However, it is observed that the IISA allows separation of control plane (signaling traffic) from control plane (data traffic) and the IDE is only responsible for handling signaling traffic. The latter is much smaller compared to data traffic. Hence, the IDE should be able to support a huge number of users. Furthermore, centralized controllers have been successfully employed in the literature and it is certainly scalable. Otherwise, as stated above, if needed, the IDE may be deployed hierarchically or in distributed way. The IP technology is used as common interconnection layer for next generation networks to allow transparency of heterogeneous access technologies. With extension performed in different network nodes, mobility may be management by traditional IPv6-based mobility schemes or by our proposed handoff management scheme. This proposed handoff scheme is able to allow seamless mobility and service continuity. An equivalent level of security as provided by existing wireless is achieved in the IISA framework. The IISA architecture is simple enough, thus its deployment will not require strong effort and extensive costs.

VI. Conclusion

Several integration and interworking architectures have been proposed in the literature. However, these interworking architectures are not able to fulfill all requirements for real-time applications. This paper proposes a novel interworking architecture for NGWN/4G, called *Integrated InterSystem Architecture* (IISA), to enable a better network performance in heterogeneous IPv6-based wireless environments. The IISA provides a guarantee for seamless roaming, service continuity and alleviates service disruption during handover as required in NGWN. The IISA has several advantages such as scalability, security, easy deployment and is economic.

From the numerical results, we can argue that the major benefits of our proposal are minimization of handoff latency consequently lower packet loss and limited network signaling traffic. In other words, by combining the IISA with proposed handoff management scheme, it is possible to guarantee seamless roaming and service continuity across various heterogeneous IP-based wireless networks to mobile users.

References

[1] S. Y. Hui and K. H. Yeung, "Challenges in the Migration to 4G Mobile Systems," *IEEE Commun. Mag.*, vol. 41, no. 12, Dec. 2003, pp. 54-59.

[2] I. F. Akyildiz, S. Mohanty and J. Xie, "A Ubiquitous Mobile Communication Architecture for Next-Generation Heterogeneous Wireless Systems," *IEEE Commun. Mag.*, vol. 43, no. 6, June 2005, pp. S29-S36.

[3] 3GPP TS, "3GPP System to WLAN Interworking; System Description (Release 6)," 3GPP TS 23.234 v6.3.0, Mar. 2004.

[4] 3GPP2 TS, "cdma2000-WLAN Interworking; Stage 1 Requirements," 3GPP2 S.R0087-A v1.0, Feb. 2006.

[5] J. Y. Song, S. W. Lee, D. H. Cho, "Hybrid Coupling Scheme for UMTS and Wireless LAN interworkings," *Proc. of IEEE Vehicular Technology Conf.* (VTC'03), vol. 4, pp. 2247-2251, Oct. 2003.

[6] M. Jaseemuddin, "An Architecture for Integrating UMTS and 802.11 WLAN Networks," *Proc. of IEEE Symp. on Comput. and Commun.* (ISCC'03), Antalya, Turkey, pp. 716-723, 2003.

[7] I. F. Akyildiz, J. Xie and S. Mohanty, "A Survey of Mobility Management in Next-Generation All-IP-Based Wireless Systems," *IEEE Wireless Commun.*, vol. 11, no. 4, Aug. 2004, pp. 16-28.

[8] A. D. Assouma, R. Beaubrun and S. Pierre, "Mobility Management in Heterogeneous Wireless Networks," *IEEE Jour. of Select. Areas in Commun.*, vol. 24, no. 3, March 2006, pp. 638-648.

[9] M. Buddhikot, G. Chandranmenon, S. Han, Y. W. Lee, S. Miller and L. Salgarelli, "Integration of 802.11 and Third-Generation Wireless Data Networks", *Proc. of IEEE INFOCOM*, vol. 1, April 2003, pp. 503-512.

[10] E. Gustafsson and A. Jonsson, "Always Best Connected," *IEEE Wireless Commun.*, vol. 10, no. 1, Feb. 2003, pp. 49-55.

[11] D. B. Johnson, C. E. Perkins and J. Arkko, "Mobility Support in IPv6," IEFT RFC 3775, June 2004.

[12] H. Soliman, C. Castelluccia, K. El-Malki and L. Bellier, "Hierarchical Mobile IPv6 Mobility Management (HMIPv6)," IETF RFC 4140, Aug. 2005.

[13] GSM Association, "Inter-PLMN Backbone Guidelines," IR 34, v.3.5.2, Aug. 2004.

[14] V. G. Gupta and D. Johnston, "A Generalized Model for Link Layer Triggers," *IEEE 802.21 Media Independent Handoff Working Group*, http://www.ieee802.org/handoff/march04_meeting_docs/Generalized_triggers-02.pdf, March 2004.

[15] C. Makaya and S. Pierre, "Handoff Protocol for Heterogeneous All-IP-based Wireless Networks," in *Proc. of IEEE Canadian Conf. on Electrical and Computer Engineering* (CCECE'06), Ottawa, Canada, May 2006.

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