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Performance analysis of a novel architecture to integrate heterogeneous wireless systems

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Abstract

Current wireless world witnesses multiple heterogeneous systems such as Bluetooth, IEEE 802.11, UMTS, and satellite networks. These systems are envisioned to coordinate with each other to provide ubiquitous communications to mobile users. A novel architecture, Architecture for ubiquitous Mobile Communications (AMC), is introduced in this paper that integrates these heterogeneous wireless systems. AMC eliminates the need for direct Service Level Agreements (SLAs) among service providers by using a third party, Network Inter-operating Agent (NIA). Instead of developing a new architecture, AMC extends the existing infrastructure to integrate heterogeneous wireless systems. It uses IP as the interconnection protocol to provide transparency to the heterogeneities of individual systems. Third-party-based authentication and billing algorithms are designed for AMC. New handoff management protocols are also designed to support seamless vertical handoffs between different wireless systems in AMC. Performance analysis is carried out to determine the latency associated with vertical handoffs and the load on the NIA that arises because of these vertical handoffs. Toward this, a network deployment scenario that consists of three types of wireless systems: WLAN, 3G, and satellite networks is considered. Moreover, the number of SLAs required in AMC is also determined for a given number of network operators. It is also shown that by using hierarchical structure, AMC can realize the integration of heterogeneous wireless systems around the globe.

Keywords: Architecture; Heterogeneous wireless systems; Authentication; Vertical handoff

1. Introduction

Various heterogeneous systems exist in the current wireless world. They adopt different radio technologies and have different network architectures and protocols, such as Bluetooth for personal areas, IEEE 802.11 for local areas, Universal Mobile Telecommunication System (UMTS) for wide areas, and satellite networks for global area. These systems are designed for specific service needs and vary widely in terms of bandwidth, area of coverage, cost, and Quality of Service (QoS) provisioning [2]. However,

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none of them can simultaneously satisfy the low-latency, high-bandwidth, and ubiquitous-coverage needs of mobile users at low cost. Since different wireless systems, each of which is optimized for some specific service demands and coverage area, are complementary to each other, they can co-operate to provide ubiquitous "always best connection" [3] to mobile users. This necessitates the design of intelligently integrating the existing wireless systems so that the users may receive their services via the best available wireless network anytime anywhere.

The integrated wireless system must keep the best features of individual networks, while at the same time, eliminates their weaknesses and drawbacks. It must be able to support for the best network selection based on users' service needs so that each user is always connected to the best available network or networks; must have mechanisms to ensure high quality security and privacy; and must have protocols to guarantee seamless inter-system mobility. Moreover, the architecture should be scalable, i.e., able to integrate any number of wireless systems of different service providers who may not have direct service level agreements (SLAs) among them.

The concept of integrating two or more systems to get better performance is already in use and has been proven to be highly efficient. The existing integrated architectures address the following issues: integration of two specific systems, integration of any two systems, integration of networks of multiple operators but of the same technology, and integration of networks of different operators employing different technologies. These architectures are described below.

In [4,5], specific pairs of different systems are integrated through an additional gateway, such as interworking of Digital Enhanced Cordless Telephone (DECT) with Global System for Mobile Communications (GSM) and interworking of IS-41 with GSM. The additional gateway proposed between a pair of systems takes care of interworking and inter-operating issues such as transformation of signaling formats, authentication, and retrieval of user profiles. In addition, different architectures are proposed to integrate WLAN and 3G wireless networks [6,7]. All the above architectures are limited to the integration of a specific pair of systems and hence are not scalable to integrate multiple systems.

The Boundary Location Register (BLR) approach [8] is proposed to integrate any two adjacent networks with partially overlapping areas. In [9] a handoff algorithm is proposed to carry out seamless inter-system roaming under this architecture. However, this approach is not scalable in the sense that one BLR gateway is needed for each pair of adjacent networks when integrating multiple networks. Moreover, the above architecture assumes the existence of SLAs between the networks, which is not desirable.

GSM association has proposed an inter-PLMN (public land mobile network) backbone using GPRS Roaming eXchange (GRX) [12] to globally integrate the GPRS networks deployed by various providers who may not necessarily have direct SLAs among them. This architecture uses multiple peer GRX nodes for connecting several GPRS networks. This architecture is limited to only one technology, i.e., GPRS networks.

In SMART project [13], a new architecture is proposed to integrate heterogeneous networks. The architecture uses two distinct networks: *basic access network* and *common core network* for signaling and data traffic, respectively. This architecture is scalable, but requires the development and deployment of the new basic access and common core networks. Hence, it is not cost-efficient.

Heterogeneous network integration using Mobile IP [15] and Session Initiation Protocol (SIP) [22] are proposed in [14,22], respectively. In these architectures, Mobile IP and SIP use Authentication, Authorization, and Accounting (AAA) agents to carry out authentication and accounting during inter-network roaming. However, these architectures do not have any mechanism to decide the best available network. Moreover, although Mobile IP and SIP protocols are used to carry out inter-system handoff, seamless support of inter-system handoff is not always guaranteed [1].

None of these existing architectures satisfy all the previously specified requirements of the integrated heterogeneous systems. This is our motivation behind the design of a new architecture for heterogeneous wireless systems with all the desired characteristics.

In this paper, we present the design of a novel architecture for ubiquitous mobile communications, AMC. AMC integrates heterogeneous wireless systems using a third-party, Network Inter-operating Agent (NIA), thereby eliminates the need for direct SLAs among different network operators. We design the protocols for authentication and billing in AMC. We also design the mobility management protocols to support best network selection and inter-system handoff. AMC achieves transparency to the heterogeneities of individual systems by using Internet Protocol (IP) as the inter-connection protocol. We conduct performance analysis to investigate the number of required SLAs, inter-system handoff delay, and the load on NIA in AMC. Performance results show that using hierarchical structure, AMC can realize the integration of heterogeneous wireless systems around the globe.

The remainder of this paper is organized as follows. We present our proposed architecture, AMC, in Section 2. We describe the security and billing mechanisms in Section 3, followed by mobility management in Section 4. In Section 5, we carry out the performance evaluation, followed by conclusions in Section 6.

2. The proposed architecture

2.1. IP-based inter-connection

The heterogeneities of access technologies and network protocols adopted by different wireless networks ask for a common infrastructure to inter-connect different networks. Since IP provides a globally successful infrastructure for supporting applications in a scalable and cost effective way, it is recognized to become the core backbone network of next-generation wireless systems.

By using IP as the common inter-connection protocol, mobile users may roam among multiple wireless networks in a manner that is completely transparent to different radio technologies. This IP-based inter-connection solution hides the heterogeneities of the lower layer technologies from higher layers in the TCP/IP protocol stack. Under this solution, IP-based mobile devices with multiple radio interfaces may roam from one radio system to another without worrying about the communication issues at the IP layer and above. Therefore, this approach requires no modifications to the existing heterogeneous radio technologies and provides the greatest transparency to ubiquitous communications in the heterogeneous environment. In addition, many existing solutions on providing QoS guarantees in the Internet, such as Resource Reservation Protocol (RSVP) [10] and Multi-Protocol Label Switching (MPLS) [11], can be extended to wireless environments or combined with wireless mobility management solutions. These solutions can provide notable benefits through traffic engineering and the support of advanced IP services such as multimedia communications and virtual private networks.

2.2. AMC

Architectures requiring direct SLAs between different wireless service providers are not feasible because of the following reasons.

- Operators have reservations to open their network databases (which is required for authentication, billing, and service provisioning when SLA is established between operators) to all other operators.
- Each time a new operator deploys a wireless network, it has to setup SLAs with every other operator separately. Given the large number of operators, it is almost impractical for network operators to create bilateral agreement with every other operator. Note that to overcome this problem, in GPRS global roaming support, GSM association has proposed to use GPRS roaming networks [12] instead of direct SLAs among GPRS operators.

Therefore, we propose the use of a third-party to integrate wireless systems of different service providers. In this case, individual network operators need to establish direct SLAs only with the proposed third-party.

Our proposed architecture, AMC, is shown in Fig. 1, which consists of a cdma2000, a GPRS, a satellite network, and a WLAN of service providers A, B, C, and D, respectively. These systems are connected to the Internet through gateways, e.g., cdma2000 is connected to the Internet via Packet data serving node (PDSN), GPRS through gateway GPRS support node (GGSN), satellite network through gateway stations (GS) and WLAN through access router (AR). Note that this architecture can integrate any number of systems of different service providers. In Fig. 1, HLR is the home location register and HAAA is the home AAA server.

We define two new entities *Network Inter-operating Agent* (NIA) and *Interworking Gateway* (IG) for our proposed architecture. The NIA functions as the third-party and the IG as the gateway between a particular system and the NIA. The NIA resides in the Internet, whereas IG resides in each system as shown in Fig. 1. Instead of getting connected to every other system, the IG is connected to only one entity, NIA. It can be implemented as a separate entity or can be

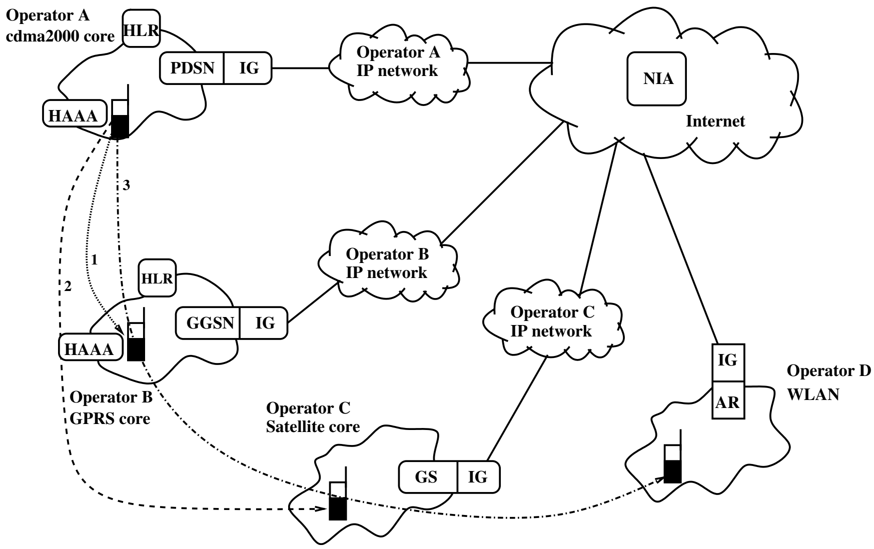

Fig. 1. NIA-based integrated architecture for heterogeneous wireless systems.

integrated with the gateways through which individual systems are connected to the Internet, e.g., PDSN, GGSN, GS, AR, in case of cdma2000, GPRS, satellite network, and WLAN, respectively. We advocate the latter choice because in this case, the IG can be plugged into the existing infrastructure and thus, it is easy to implement and manage.

The NIA handles the authentication, billing, and mobility management issues of inter-system roaming. Currently, the AAA broker networks support authentication and billing for users belonging to different service providers. However, they cannot handle the mobility management issues, and hence, cannot be used as the third-party.

2.3. Components of the NIA and the IG

The sub-systems of the NIA are shown in Fig. 2(a).

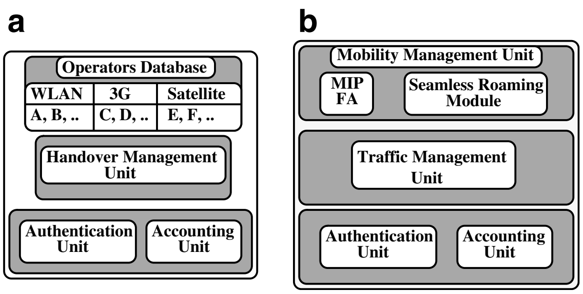

Fig. 2. Logical diagram showing the subsystems of the NIA and IG.

- The *authentication unit* is used to authenticate users moving between two systems belonging to two different service providers as discussed in Section 3.1.
- The *accounting unit* handles the billing issues related to inter-system roaming as discussed in Section 3.2.
- The *operators database* stores information about the network operators who have SLAs with the NIA.
- The *handover management unit* decides if the inter-system handover (ISHO) request should be granted. It derives the *Network Access Identifier* (NAI) from the Mobile IP *Registration Request* [15] message and verifies with the *operators database* for the existence of the SLA with the home operator of the mobile terminal (MT). When applicable, it also acts as the mediator between different networks, e.g., for transferring user service profiles between them. The handover management unit also decide about the best available network as discussed in Section 4.1.

The components of the IG are shown in Fig. 2(b).

- The *mobility management unit* implements Mobile IP [15] (MIP) functionalities using the MIP foreign agent (FA). Note that when a particular wireless system already implements Mobile IP, e.g., cdma2000, there is no need to implement the FA in the IG. In this case, the FA in the

IG refers to the FA already implemented in the system. The *seamless roaming module* implements mobility management algorithm for seamless inter-system roaming as discussed in Section 4.
- The IG implements traffic monitoring function in its *traffic management unit* by discarding the packets coming from unauthorized users.
- The *authentication unit* and *accounting unit* provide authentication service and billing support, respectively, as described in Section 3.

3. Authentication and billing support in AMC

3.1. Authentication

Our proposed security architecture is shown in Fig. 3, where the Foreign Network (FN) is the network where the MT is currently visiting. This architecture glues the security architectures of the FN and the Home Network (HN) through *Authentication Unit* (AU) of the NIA (AU_NIA). The use of AU_NIA eliminates the need for any direct security association/agreement between the FN and HN. Both the FN and HN have separate security association/agreement with AU_NIA. Thus, AU_NIA functions, in essence, as a trusted third party for authentication dialogs between the FN and HN. The working principle of this third party based security architecture is as follows. When a mobile user requests services from an FN and the FN determines that it has no service level agreement (SLA) with the user's HN provider, it forwards the request to AU_NIA to authenticate the user. Then, AU_NIA talks to the user's HN provider and mediates between the FN and HN for authentication message exchanges. Once the user is authenticated, AU_NIA also creates security associations/keys required between different network entities. At the end of the proposed security procedures, the HN and FN will be mutually authenticated, and will have session keys for secured data transfer.

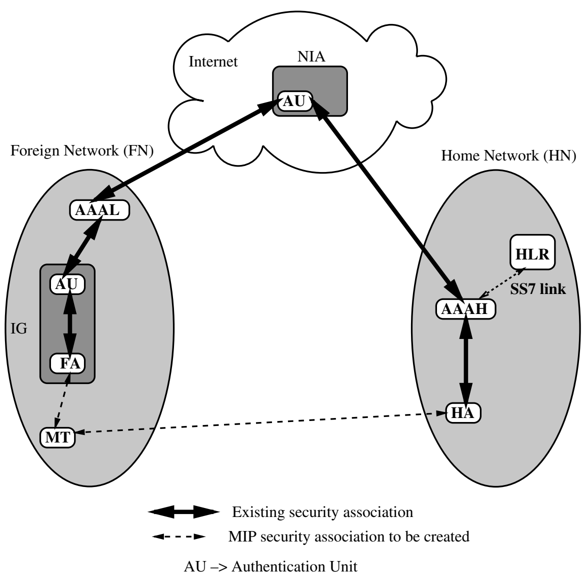

Fig. 3. The proposed security architecture for AMC.

We integrate the authentication and Mobile IP registration processes as defined in [14]. The architecture in Fig. 3 shows the existing security associations along with the required MIP security associations so that the FN will be able to deliver services to the roaming MT. We use Extensible Authentication Protocol (EAP) [16] over Diameter [17] for end-to-end mutual authentication between an MT and its home AAA server (AAAH). The authentication and MIP registration are carried out when the MT roams into the FN's domain. We use EAP-SIM [18] as the authentication algorithm in AMC. It may be noted that any other authentication schemes, e.g. EAP-AKA, EAP-SKE, EAP-TLS etc., can also be used.

3.2. Billing

Once the MT is authorized by the FN, *Accounting Unit* of the IG (ACU_IG) maintains a per user accounting record based on the charging policy of the FN provider (e.g., connection duration, amount of data transferred, etc.). It transfers the accounting information either on per session basis or in real-time to the local AAA server (AAAL) of the FN domain. The AAAL server collects and consolidates the accounting information for the MT and forwards it as the FN access call detail records (CDRs) to the *Accounting Unit* of the NIA (ACU_NIA), which converts it to the CDR format supported by the MTs home network and forwards the final CDRs to the AAAH for billing the user.

4. Mobility management in AMC

In AMC, two types of handoff scenarios may arise: (1) *horizontal handoff*, i.e., handoff between two base stations (BSs) of the same system and (2) *vertical handoff*, i.e., handoff between two different systems, e.g., movement from the cdma2000 network to the WLAN in Fig. 1. Vertical handoff is also referred as inter-system handoff. It is essential that the applications running on a user's terminal remain unaware of user's movement to ensure uninterrupted services with minimum QoS degradation. This can be achieved by reducing the handoff failure probability and handoff latency to the values that are tolerable by the applications.

Out of several mobility management protocols, Mobile IP [15] based mobility management for horizontal and vertical handoffs is gaining more acceptance [1]. The standard Mobile IP is not sufficient to carry out seamless horizontal and vertical handoffs [1]. Micro-mobility protocols are proposed to support seamless horizontal handoff [1]. However, the support of seamless vertical handoff is still an open issue. There are several issues that has to be addressed during the vertical handoff. First, based on the service needs of a user, the best available network should be determined. Then, the authentication, authorization, and accounting procedures are to be carried out before the Mobile IP registration process. In AMC, the existing micro-mobility protocols are used to carry out seamless horizontal handoff. We develop algorithms for best network selection and seamless vertical handoff support as described next.

In AMC, when the need for vertical handoff arises, first the best available network is selected. Then, the handoff initiation instance is estimated in such a way that Mobile IP procedures are carried out successfully before the user moves out of the coverage area of the serving network. This handoff instance estimation guarantees a successful inter-system handoff.

4.1. Best network selection

Several factors influence the design of policies on the best network selection for vertical handoff. Monetary cost, network conditions, power consumption, network performance, and user activity history are considered as the decision metrics. In addition, the required QoS from applications is also an input parameter for the policy design. Moreover, the best network selection also affects the distribution of the overall system load.

We develop a hybrid network selection scheme that combines terminal-based and network-based selection mechanisms. Terminal-based mechanism allows MTs to periodically collect dynamic network conditions and determine the best reachable network for handoff by themselves. Network-based mechanism makes globally optimized selection and achieve load balancing for the whole system. The objective of the proposed scheme is to provide satisfactory overall performance of the whole system as well as take into account the user preferences. It is a two-level decision-making scheme. At the first level, each MT monitors and collects the dynamically varying network conditions for decision-making at the terminal side. At the second level, the *handover management unit* inside the NIA finds the optimal user distribution for each individual network based on global observations. The decision made by this central controller is the feedback to the first level decision as adjustments. The details of the proposed best network selection scheme is in [25].

4.2. Seamless vertical handoff

Once the network that a user is going to move is determined, the next challenge is to determine right time to start the Mobile IP handoff procedures. Currently, there are several proposals using the physical and MAC layer sensing to determine the appropriate time for vertical handoff initiation. In these algorithms, the implicit assumption is that the signaling delay associated with vertical handoff is constant. Based on this assumption, these algorithms initiate the vertical handoff when the received signal strength (RSS) of the serving BS of the current network goes below a certain fixed threshold value, S_{th}. However, in a real scenario, the vertical handoff signaling delay varies from few seconds to several tens of seconds depending on several factors, e.g., traffic level in the backbone network, the wireless link quality, and the distance between the user and its home network. In these approaches as the handoff procedures are started when the RSS of the serving BS drops below S_{th}, these procedures must be completed before the RSS goes from S_{th} to S_{min}, i.e., the minimum RSS required by an MT for successful communication with the serving BS. Else the handoff process becomes unsuccessful and the MT looses its connections. Therefore, the probability of successful handoff depends on the time required for the RSS to drop from S_{th} to S_{min}. This depends on the time that the MT requires to travel the distance over which the RSS drops from S_{th} to S_{min}. If we assume that the distance over which the RSS drops from S_{th} to S_{min} is d. Then, the time taken by the MT to cross this distance d is equal to $\frac{d}{v}$, where v is the speed of the MT. For successful handoff completion this time should be greater than or equal to the handoff signaling delay, i.e., $\frac{d}{v} \geqslant \tau$, where τ is the vertical handoff signaling delay. Therefore, for a fixed value of τ, the value of d and the corresponding value of S_{th} should be higher for higher values value of v. Moreover, for a fixed value of v, S_{th} should be higher for higher value of τ. In summary, S_{th} should be adaptive to both speed and vertical handoff signaling delay.

The RSS of the serving BS is averaged over an averaging window. An adaptive fuzzy logic based handoff algorithm is proposed in [19] to select the size of averaging window based on users' speed. Therefore, in this algorithm when the speed of the user is higher less latency is introduced in handoff decision process. However, this algorithm does not address the above issue of variable vertical handoff signaling delay and time taken by the MT to travel the distance d. Numerical value of MTs speed is used for handoff decisions in overlay cellular systems in [23,24]. This decision making is limited to whether a handoff to macro or micro cellular system should be carried out or not. However, they do not address the issues related to adverse effects of MTs speed and vertical handoff signaling delay on the handoff performance. Therefore, the existing handoff algorithms can not be used for seamless vertical handoff support in AMC.

As pointed out earlier, the numerical value of S_{th} should be adaptive to both τ and v to support handoff performance independent of network load and users' speed. Toward this, we propose the use of dynamic RSS threshold, S_{dth}, to initiate the handoff procedures. The operation of this dynamic RSS threshold based handoff support can be summarized as follows.

- Using the existing physical and MAC layer sensing algorithms the need for a vertical handoff is determined. Then, the best available network is selected.
- The handoff latency, τ, in the event of MTs handoff to this selected network is estimated using the technique proposed in [21]. Moreover, MTs speed, v, is estimated using our own speed estimation algorithm proposed in [20].
- Then, using the estimated values of τ and v, the dynamic value of RSS threshold is determined using our algorithm proposed in [21]. The numerical value of S_{dth} is determined such that if the vertical handoff procedures are initiated when the RSS of the serving network goes below S_{dth}, they are completed before the user moves out the coverage area of the serving network. The *seamless roaming module* implements the algorithm for the estimation of S_{dth}.

More details about handoff signaling delay estimation and determination of dynamic RSS threshold can be found in [21]. Moreover, the details about the speed estimation algorithm can be found in [20].

The operation of the vertical handoff is summarized in Fig. 4. First the MT learns about a possible vertical handoff when the RSS of its serving BS belonging to the current network decreases continuously. Then, the best available network for the MT is selected. The MT estimates the handoff signaling delay in the event of its movement to the selected network. The MT also estimates its speed. Using the handoff signaling delay and speed information,

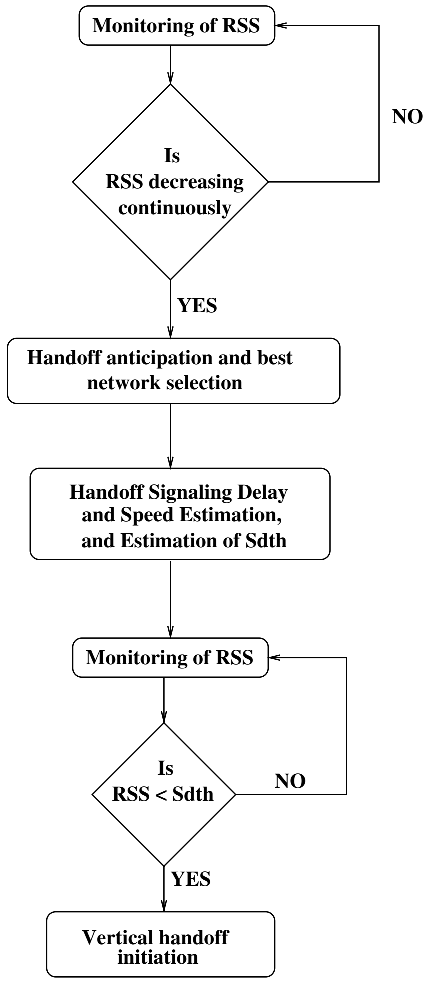

Fig. 4. Flow diagram of vertical handoff operation in AMC.

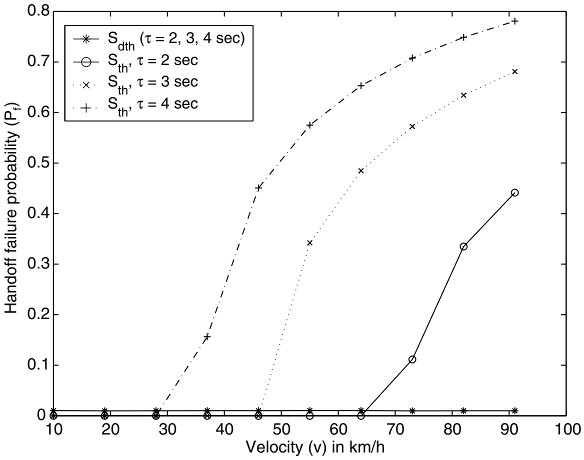

Fig. 5. Inter-system handoff failure probability in AMC.

the MT determines the numerical value of S_{dth} and starts to monitor the RSS of its serving BS. When, the RSS of the serving BS drops below S_{dth}, the MT initiates the vertical handoff procedures. Fig. 5 shows the comparison handoff failure probability of the existing fixed RSS threshold based vertical handoff algorithms vs. the proposed dynamic RSS threshold based vertical handoff algorithm. The results show that by using S_{dth} instead of S_{th} the performance of the vertical handoff algorithms can be significantly improved. For Fig. 5, we use $S_{th} = -63$ dB and different values of τ. The results are similar for other values of S_{th} and τ. It may be noted that the proposed dynamic RSS threshold based vertical handoff algorithm can also be used for the existing architectures that use bilateral SLAs to integrate heterogeneous wireless systems. Moreover, when the proposed vertical handoff algorithm is used for the existing architectures, the handoff failure probability will be similar to that of the AMC. This is because the handoff algorithm takes into account the vertical handoff delay to determine the RSS threshold that it uses for vertical handoff initiation.

5. Performance analysis of AMC

Here, we analyze the number of required SLAs, inter-system handoff delay, and load on NIA in AMC.

5.1. Required number of SLAs

To compare the number of required SLAs in AMC and the existing bilateral SLA based architectures, we assume that the number of network operators is M. To realize roaming among the networks deployed by these operators, the number of SLAs required in case of existing bilateral SLA based architecture, N_1, is given by

$$N_1 = 1 + 2 + 3 + \cdots + M = \frac{M(M+1)}{2}. \quad (1)$$

On the other hand, the number of SLAs required in AMC, N_2, is given by

$$N_2 = M. \quad (2)$$

This is because in AMC each operator needs to create only one SLA with the NIA. Therefore, when bilateral SLA based architecture is used, the number of SLAs required is proportional to the square of the number of operators. Whereas, in AMC this is linearly proportional to the number of operators. This is a significant reduction in the number of SLAs especially when the number of operators, M, is large.

5.2. Inter-system handoff delay

We first study the relationship between the inter-system handoff delay and the distance of the NIA from an IG. Under AMC, inter-system handoff delay consists of two components: message signaling time over wireless links $M_{wireless}$ and message signaling time over the Internet M_{wire}. According to [9], the time to send a message is the sum of the transmission time α, the propagation time β, and the processing time for the signaling message γ. $\alpha = \frac{b}{B}$, where b is the size of the signaling message in bits and B is the bit rate of the link on which the message is sent. Based on the model in [26], for wireless links,

$$M_{wireless} = (\alpha + \beta + \gamma) \cdot \frac{1+p}{1-p}, \quad (3)$$

where p is the probability of wireless link failure. For wireline links,

$$M_{wire} = (\alpha + \beta + \gamma) + t_q, \quad (4)$$

where t_q is the queuing delay at each router in the Internet. When a signaling message arrives at a router, the router may be busy processing other higher priority messages and queue the signaling message for deferred processing. Queuing delay at each router depends on the packet arrival rate and processing rate. Hence, it is not a function of the distance between the NIA and an IG.

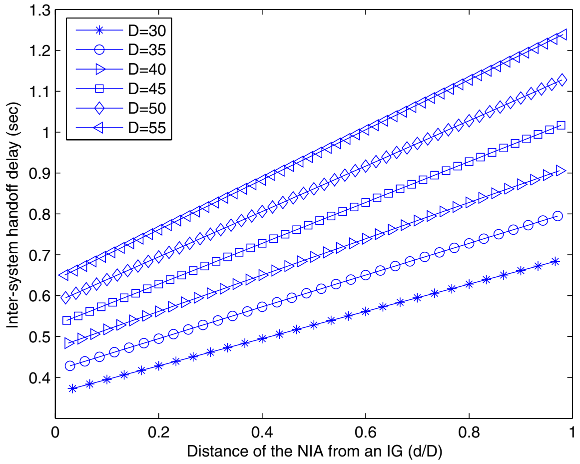

Fig. 6. Inter-system handoff delay in AMC.

Assume that the total number of hops between the HA and an IG is D and the total number of hops between the NIA and the IG is d. Then, the distance between the NIA and the HA is $D - d$. Based on the signaling procedure of inter-system handoff, the inter-system handoff delay is given by

$$T = 4 \cdot M_{\text{wireless}} + 4 \cdot M_{\text{wire}} \cdot d + 2 \cdot M_{\text{wire}} \cdot (D - d). \tag{5}$$

The relationship of the inter-system handoff delay vs. the ratio of the distance between the NIA and an IG to the total distance between the HA and the IG, i.e., $\frac{d}{D}$, is shown in Fig. 6. System parameters are obtained from [9] [26]. Fig. 6 shows that the farther the NIA from the IG, the higher the inter-system handoff delay.

5.3. Load on the NIA

To analyze the load on the NIA, we consider that in a particular geographic region, e.g., a city like New York, the number of satellite networks, 3G networks, and WLAN networks are, N_s, N_g, and N_w, respectively. We assume that the satellite network has global coverage and the 3G and WLAN have coverage area of A_g and A_w, respectively. We consider that a mobile user's preference for networks follows the order WLAN then 3G and then the satellite network. We also assume that the WLANs are overlaid with 3G networks and the 3G networks are overlaid with satellite networks. Hence, the possible types of inter-system handoff in the above scenario are between WLAN $\leftrightarrow$ 3G and 3G $\leftrightarrow$ satellite networks. We assume that the user density in satellite networks, 3G networks, and WLANs are, ρ_s, ρ_g, and ρ_w, respectively. We assume that the cell radius of a 3G network and WLAN are r_c and r_w, respectively. If we denote the number of cells that belong to one subnet of the 3G network as R, the subnet crossing rate in the 3G networks is given by [27]

$$R_{sg} = \frac{\rho_g v L_s}{\pi}, \tag{6}$$

where v is the average user velocity and L_s is the perimeter of one subnet in 3G networks. As each subnet crossing results in an MIP [15] handoff, the number of MIP handoffs in a 3G is given by (6). Similarly, the number of WLAN to 3G and 3G to satellite inter-system handoffs is given, respectively, by

$$R_{dwg} = N_w \frac{\rho_w v_1 L_w}{\pi}, \tag{7}$$

$$R_{dgs} = N_g \frac{\frac{\rho_g}{N_g} v L_g}{\pi} = \frac{\rho_g v L_g}{\pi}, \tag{8}$$

where v_1 is the average user velocity in a WLAN. L_g and L_w are the perimeter of a 3G and WLAN network. For simplicity, we assume that 3G networks have coverage over the same region and have uniform user density. Therefore, if the density of 3G users is ρ_g, the user density of each 3G network is ρ_g/N_g. Using (6)–(8), the ratio between the total number of vertical handoffs to that of total number of MIP handoffs is given by

$$\frac{H_v}{H_h} = \frac{\rho_g v L_g + N_w \rho_w v_1 L_w}{G_s \rho_g v L_s}, \tag{9}$$

where G_s is the total number of subnets in a 3G network. Fig. 7(a) shows the plot of (9) vs. N_w for different values of v using the parameters shown in Table 1. The results show the number of vertical handoffs is insignificant compared to the number of MIP handoffs. Hence, the load on the NIA arising from inter-system handoffs is limited. In the current implementation, one HA is used to handle the MIP handoffs of a particular 3G network.

Table 1
Numerical values of parameters

Parameter	Value	Parameter	Value
N_s	1	A_g	7800 km^2
ρ_s	0.0083 m^{-2}	A_w	0.25 km^2
ρ_g	0.0083 m^{-2}	r_c	2 km
ρ_w	0.0083 m^{-2}	r_w	50 m

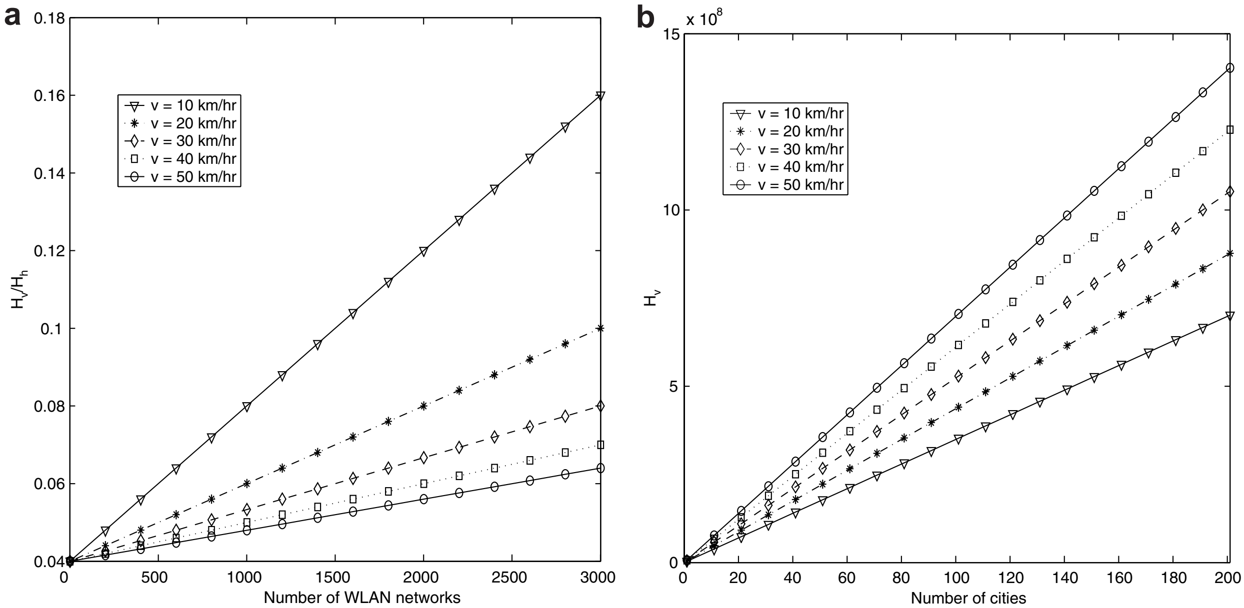

Fig. 7. Total number of vertical handoffs (a) relative to horizontal handoffs, (b) absolute value.

Therefore, we advocate that one NIA will be sufficient to handle the inter-system roaming of a particular geographic region, e.g., a city.

Our previous discussion is for one city. As the number of cities increases, the number of inter-system handoffs also increases. We show the total number of inter-system handoffs for different number of cities in Fig. 7(b). It shows that the load on the NIA increases as the number of cities increases. This implies that as the size of the geographic region increases, the total number of inter-system handoffs increases.

Based on the above results, we propose hierarchical NIA architecture to integrate wireless networks globally to limit the load on the NIA and inter-system handoff delay to desired values. In this hierarchical architecture, wireless networks of various providers are integrated at the regional (e.g., city) level through the first tier of NIAs. These regional NIAs of a particular country or several countries are then integrated through the second tier of NIAs, followed by the third tier of NIAs to realize global integration.

6. Conclusion

In this paper, we presented a third-party-based integrated architecture, AMC, for heterogeneous wireless systems. AMC reduces the cost of architecture deployment by using the access and core network infrastructures of the existing wireless systems. We showed how AMC can integrate heterogeneous wireless systems of different operators who may not necessarily have direct SLAs among them. Furthermore, security equivalent to the existing wireless systems is achieved under AMC. Finally, advanced link layer sensing algorithms and neighbor discovery protocols are implemented in the IG to achieve seamless inter-system handoff by reducing the connection interruption and handoff failure during inter-system handover. We also conducted performance analysis of AMC. Performance results showed a significant reduction in the number of required SLAs in AMC. The results of inter-system handoff delay and load on the NIA can help to design hierarchical NIA architecture which can integrate wireless networks globally.

AMC is a centralized third-party-based architecture. It can afford greater control over heterogeneous networks for providing authentication, service agreement, mobility management, etc. It avoids problems of distributed coordination among individual networks. However, it may create a single point of failure and the third-party may become a bottleneck, reducing performance. Advanced solutions are needed to take care of the reliability and scalability issues of AMC. The hierarchical NIA architecture as discussed in Section 5.3 can resolve the bottleneck problem and still maintain the benefits of centralized control.

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