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# An Analysis of Prioritized Hybrid Interworking Requirements in Next-Generation Wireless Networks

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## Abstract

*The growing demands for ubiquitous high-speed data services require hybrid interworking in Next-Generation (NG) wireless networks. Handover management is important in providing seamless roaming when User Equipments (UE) are moving across boundaries of radio coverage areas provided by different networking technologies. Handover mechanisms have been well studied in homogeneous circuit-switched networks, such as GSM and IS-41, and have also began to be implemented in NG wireless data networks, e.g. UMTS and 802.11 Wireless LAN (WLAN). Hybrid interworking of NG wireless data networks has to address more issues, such as user context, signaling process, traffic routing and Quality of Service (QoS) so as to perform the challenging tasks in dealing with the heterogeneities of networking technologies. In this paper, we investigate handover mechanisms in current homogeneous data networks, and present four roaming scenarios for hybrid interworking, in which handover is assigned different levels of weight. The prioritized requirements for hybrid interworking scenarios will be analyzed, and compared.*

## 1. Introduction

The emerging IEEE 802.11 Wireless LAN (WLAN) technology provides satisfactory supplements to 3rd generation (3G) cellular networks with its high-speed data access capability. For worldwide coverage communications, 3G cellular systems and WLAN are expected to combine to enable ubiquitous computing [1] in Next-Generation (NG) wireless data networks. Handover management in hybrid interworking is important in maintaining communication sessions when UE is moving across boundaries of both homogeneous and heterogeneous wireless networks.

Core networks of 3G cellular systems are composed of circuit-switched domains and packet-switched domains. Handover mechanisms in circuit-switched networks [2], such as GSM and IS-41 have been well studied, and thus provided a model for implementing handover in packet-switched networks. Handover process in wireless data networks, e.g. General Packet Radio Service (GPRS) networks is entangled with handover of telephony voice in circuit-switched domains. For handover of data services, routing area update procedures have to be performed to deal with mobility registration, addresses assignment and location updates. 3G cellular systems, like Universal Mobile Telecommunications System (UMTS) can provide wide areas of coverage and support data services up to 2Mbit/s. In comparison, 802.11 WLAN systems can support bandwidth up to 54Mbit/s with relatively simple network architectures. Although handover mechanisms have been well addressed in either 3G cellular systems or WLAN networks, dynamic cooperation between them is still left unresolved.

Hybrid interworking of wireless data networks calls for a number of requirements (listed in Table 1) to be satisfied in terms of integrating architecture, handover signaling, identity management [3] and Quality of Service (QoS). In the evolution towards NG wireless data networks, ubiquitous seamless roaming is expected to be put into practice gradually with prioritized phase goals. Four roaming scenarios (shown in Sec. III), ranging from non-roaming interworking to ubiquitous seamless roaming are abstracted to describe the likelihood that NG wireless networks will be deployed in the near future.

The rest of this paper is organized as follows. In the next section, we describe handover mechanisms in homogeneous wireless data networks. We first review 3G UMTS technology, especially handover procedures in its packet-switched domains. Then, we investigate the latest handover methods in IEEE 802.11f WLAN. In Sec. III, we take the integration of UMTS and WLAN networks as an example to introduce four typical roaming scenarios in the evolution towards NG wireless



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data networks. Finally, we describe specific interworking requirements for each scenario, followed by the conclusion in Sec. V.

## 2. Handover in homogeneous networks

The packet-switched domains of 3G cellular networks will be an evolution of GPRS networks. Hence, 3G UMTS networks share many similarities with GPRS networks. After presenting handover in UMTS networks, we describe the latest handover mechanism proposed for 802.11 WLAN, which is emerging as an effective supplement for offering high-speed data services, but still lacks sufficient mobility support.

### A. 3G UMTS

UMTS is a key 3G cellular technology identified by ITU. It reuses GPRS technology in its core networks, but is equipped with fresh radio access domain - UMTS Terrestrial Radio Access Network (UTRAN). 3G UMTS provides packet-switched services by connecting user equipments (UE) to Public Data Network (PDN), such as Internet and X.25. In UMTS, Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) are employed for mobility management and packets routing respectively. The SGSN is regarded as the UMTS equivalent to the Mobile Switching Centre (MSC). The GGSN performs functions, such as mapping addresses, tunneling packets and gateway etc. Other components in UMTS include some legacy elements in GSM, including Home Location Register (HLR), Visitor Location Register (VLR) and MSC.

Mobility management (MM) in UMTS is more complex than that in traditional circuit-switched cellular networks [2], e.g. GSM, due to the two major reasons: 1) additional MM context, Packet Data Protocol (PDP) context (which characterizes the session with PDP type, PDP address and QoS etc.) are required for dealing with the issues such as data transmission speed, priorities and delay; 2) a set of routing area update operations have to be performed in both SGSN and GGSN for directing ongoing data packets to new areas. All of these changes contribute to the complexities of UE handover procedures in UMTS networks. In comparison to handover process in circuit-switched cellular networks, we show UMTS handover procedures in Figure 1. Basically, the handover procedures for UMTS can be divided into three key phases. In the UE attach phase (see Step 1-3), the new SGSN authenticates the UE by obtaining its identity from the old SGSN upon receiving the UE attach request. And then, in the followed routing area update phase (shown in Step 4-10), the new SGSN queries the context information of the UE with the old SGSN, and updates the corresponding records in the GGSN. In the last phase, the standard GSM location update procedures are executed to update location information in the old VLR and the new VLR.

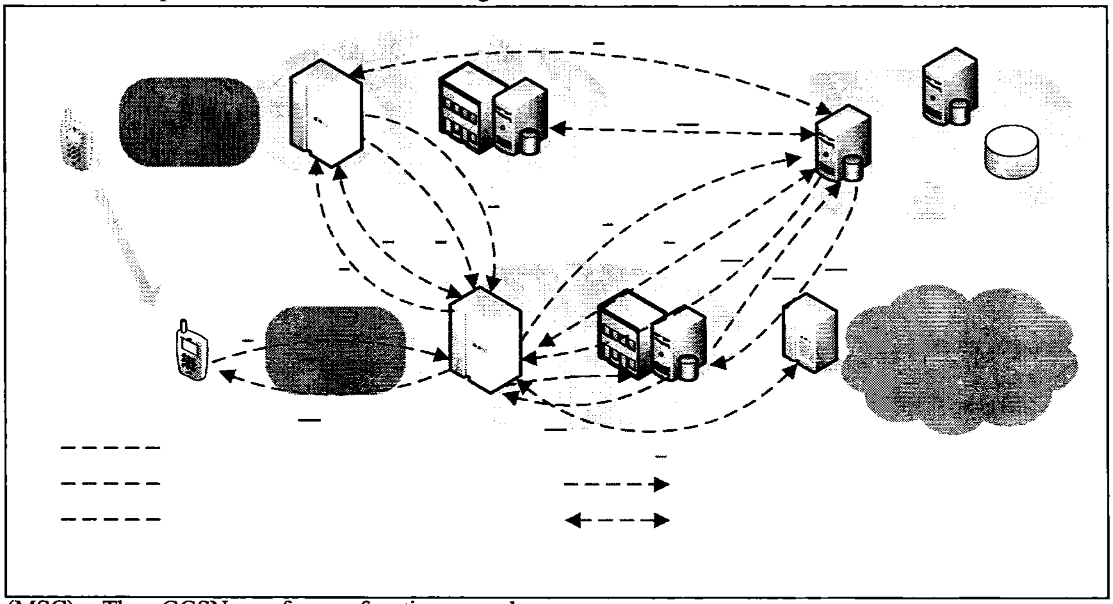

**Figure 1: Handover Procedures in 3G UMTS Networks**

- **Attach Procedures:**

**Step 1**: The UE sends an attach request message to the new SGSN.

**Step 2-3**: The new SGSN queries the old SGSN for the IMSI of the UE by providing its old P-TMSI. Afterwards, the UE authentication procedures may be performed by the new SGSN.

- **Routing Area Update Procedures:**

**Step 4-5**: The new SGSN requests the mobility management (MM) and packet data protocol (PDP) contexts of the UE from the old SGSN. The cached packets may be forwarded from the old SGSN to the new SGSN.

**Step 6**: The new SGSN updates the routing area information and PDP context in the GGSN through GPRS tunneling protocol (GTP) tunnel management.

**Step 7**: The location update request is sent from the new SGSN to trigger the related location update process.

**Step 8-10**: The HLR first cancels the stale contexts of the UE in the old SGSN, and then notifies the new SGSN to insert the subscriber data of the UE.

- **Location Update Procedures:** (*following circuit-switched domain location update process*)

**Step 11-15**: The new SGSN initiates a location update request to delete the obsolete record of the UE in the old VLR, as well create a new one in the new VLR. The detailed process can be found in [4].

As an extension to GPRS-based 2.5G systems, UMTS allows combined GPRS/IMSI attach procedures. The disconnection from UMTS can be initiated by either UE or SGSN. Routing area update process is quite unique, compared with handover procedures for telephony voice. It is important for the packets in a session to be correctly routed to the target network right after a handover. There are other types of UMTS handovers that have not been described due to space limitations.

## B. 802.11 Wireless LAN (WLAN)

The IEEE 802.11 WLAN can offer high bandwidth user access, and is envisioned to interwork with 3G cellular networks to provide ubiquitous data services to mobile clients. In 802.11 WLAN, several mobile stations (STAs) are connected to an Access Point (AP) to form the Basic Service Set (BSS), which is the basic building block of a 802.11 network. Multiple BSSs are interconnected via the Distributed System (DS), which is known as the Extended Service Set (ESS). The interoperability between different APs within the same DS is recommended by the Inter-Access Point Protocol (IAPP) in IEEE 802.11F [5]. The IAPP can be implemented to support user mobility on a common DS.

The IAPP handoff procedure is illustrated in Figure 2. In this case, we assume that no context information of the moving STA has been proactively cached in the new AP. In addition, the handoff procedure is performed only between the BSSs that belong to the same ESS. With the support of the RADIUS registry, the new AP gets the DSM IP address of the old BSSID that the STA was associated with, and invokes the STA context transfer by exchanging MOVE-notify and MOVE-response messages with the old AP. The detailed procedure can be found in Step 1 to Step 6.

**Step 1**: The STA sends out a reassociation request to associate with the new AP when moving from the BSS 1 to the BSS 2.

**Step 2**: To discover the DSM IP address of the old AP and verify the identity of it, the new AP sends a RADIUS access request to the RADIUS server of the DS with the old BSSID.

**Step 3**: The RADIUS server responds to the new AP with the old AP's IP address and necessary security information.

**Step 4**: The new AP issues a MOVE-notify packet to the old AP for the context information of the STA.

**Step 5**: The MOVE-response packet indicating the status upon receiving the MOVE-notify is sent by the old AP. If successful, the context block of the STA will be included.

**Step 6**: The STA reassociation with the new AP is approved or denied according to the results of the previous procedures.

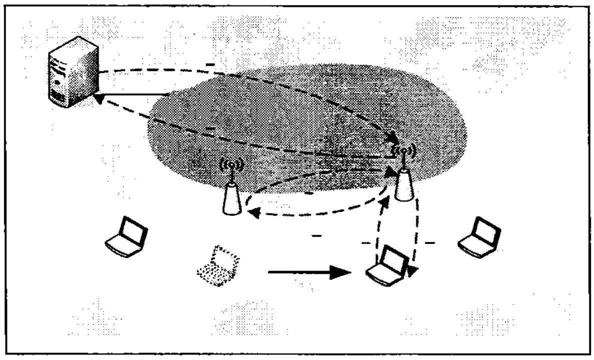

**Figure 2: The Handover Procedures in 802.11 WLAN**

The IAPP does not deal directly with the data frame delivery. Instead, it concentrates on DS and related services, such mapping of BSSID to DS IP addresses, formation of DS, and transfer of STA context information between APs [5]. The handover of STA between different APs of 802.11 WLAN within one DS relies on the communication between the concerned APs. The IAPP handover is generally classified as link layer handover since the handover decision is made by just checking link-layer indications from APs, and no IP conversion is necessary for reassociation procedure. For the cases where multiple DSs are involved, mobile IP [6] can be employed to provide IP layer handoff mechanisms.

## 3. Handover scenarios in Hybrid Interworking

Bearing in mind that the handover mechanisms in 3G UMTS cellular networks and 802.11 WLAN mentioned in Sec. II, there would likely be different handover scenarios in hybrid interworking of those forementioned networks. These scenarios require different levels of roaming support. Depending on integration architecture [7], mobility protocols [8] and handover procedures implemented, a variety of roaming capabilities can be provided in the hybrid interworking, such as UMTS-WLAN networks.

When a common radio interface is used to support the handover between homogeneous networks, it is referred to as *horizontal handover*. While, the handover between heterogeneous wireless networks can be enabled by switching between multiple interfaces using different wireless technologies. The latter is known as *vertical handover*. The vertical handover is expected to be a major challenge for hybrid interworking systems.

For the integration of Public Land Mobile Networks (PLMN), e.g. UMTS, and wireless LAN networks, several interworking scenarios can be envisioned. In Figure 3, we illustrate 4 typical scenarios with different levels of roaming support, and consider them in a multi-technology and multi-operator environment. To simplify the issue, we assume the UE has been subscribed to PLMN, but also equipped with a WLAN interface for network access. The Home PLMN (HPLMN) is the network which the user has subscribed to, and also where the user profile is stored. The Visited PLMN (VPLMN) acts as an intermediate between HPLMN and WLAN in a roaming scenario. It can provide local data access and route AAA messages between UE and HPLMN.

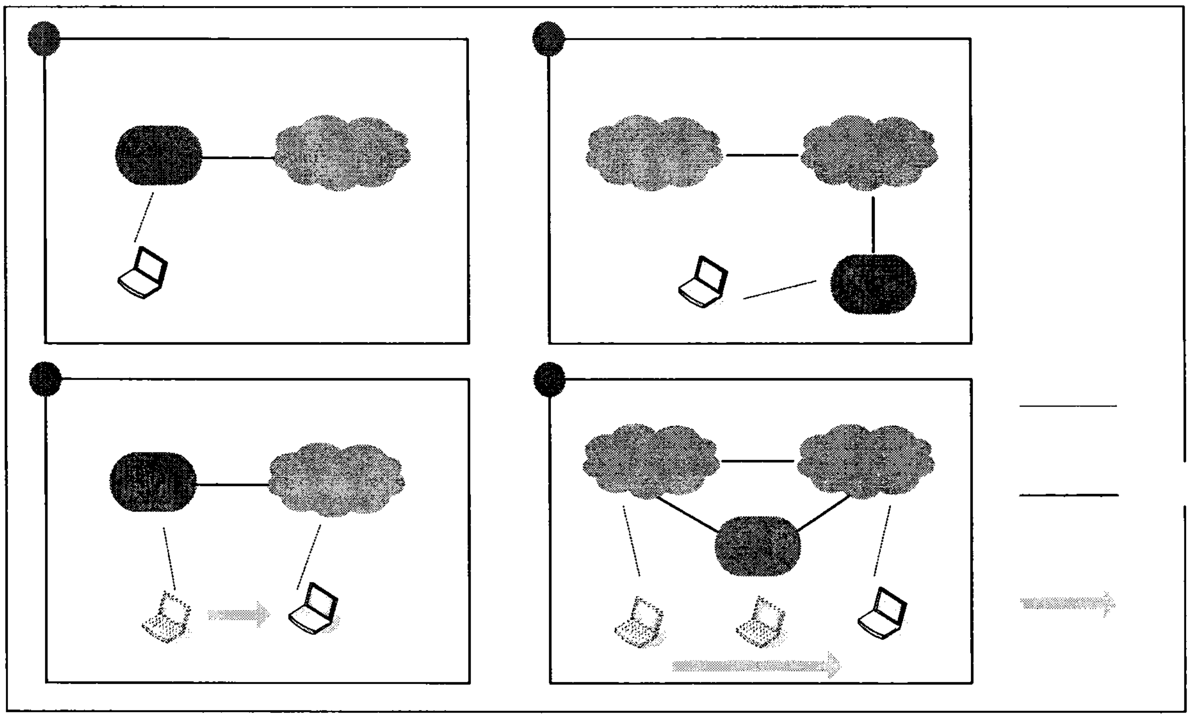

**Figure 3: Handover Scenarios with Different Levels of Roaming Support.**

*Scenario 1 – Non-roaming Interworking*

This is the simplest form of integration, in which WLAN networks are coupled with HPLMN via AAA gateway for user profiles' sharing. For PLMN UEs, the WLAN networks appear as another component of PLMN but with independent data access capabilities. We name this scenario as tightly AAA coupled (TAC). Since no other messages except AAA signaling is exchanged between WLAN and PLMN networks, the cooperation between two networks is still limited to local service access. The PLMN UEs are only allowed to use WLAN services via a few APs of WLAN that have been subscribed to. No central entity is expected for mobility management of UEs in wireless overlap of PLMN-WLAN. The non-roaming interworking would be a typical scenario that would likely happen in the initial phase of NG hybrid integration, because it has the minimum requirements on interworking techniques and investment. When subscribing to PLMN, the users may request the services of some specific APs, where they would visit most frequently, e.g. at office or home location. It can be implemented by adding the AP address or corresponding SSID to the subscriber's user profile which is stored in his HPLMN. In non-roaming interworking, handover of UEs is only available at each homogeneous domain.

*Scenario 2 – Roaming Enabled Interworking*

In this scenario, WLAN may establish indirect AAA association with concerned PLMN via other third-party PLMNs. Each PLMN can act as an AAA server for its subscribers or as an AAA proxy for other PLMNs. To differentiate it from the TAC of Scenario 1, we regard this scenario as loosely AAA coupled (LAC). Because AAA signaling can be routed via many networks, the number of accessible WLAN networks is thus increased greatly. Without relying on a AAA gateway, WLAN networks are no longer bound to a specific PLMN. As a result, the PLMN UE can be authorized to a number of WLAN operators depending on roaming agreements between them. For example, the PLMN UE (in Figure 3) gets authenticated to the WLAN via a VPLMN, which has been integrated with the WLAN and also connects to the HPLMN of that UE. All the AAA requests and responses are sent back and forth via that VPLMN. The WLAN is even unaware of the exact location of the HPLMN. The roaming scope of users largely relies on AAA cooperation among multiple network domains. However, similar to the TAC, keeping ongoing WLAN session of the UE at wireless overlap boundaries is impossible due to lack of necessary mobility mechanisms implemented.

In NG wireless networks, both TAC and LAC are the compromised interworking schemes by considering just accessibility of services but not continuity of service sessions. The motivation of them is to enable both networks (PLMN and WLAN) for the subscribers in either network.

*Scenario 3 – Hybrid Seamless Roaming*

Hybrid seamless roaming refers to the fact that handover from one networking domain to another is transparent to the UE. In other words, the application-level connectivity of the UE is kept during the handover of user session in hybrid interworking. In the example of Figure 3, the connection of the UE is being switched from the WLAN to the PLMN when the UE is moving out of the WLAN coverage. Before triggering handover, a few handover metrics are collected and evaluated for decision making. After the destination network has been selected according to some criteria (e.g. best QoS), the active UE session is switched to the PLMN. Then, the PLMN goes to inform the WLAN of what has happened to the UE. With hybrid seamless roaming, the UE gets a smooth transition experience when moving-in or moving-out transition area. Seamless roaming in hybrid interworking is actually a complex process, and involves Mobility Management (MM) implementations at multiple layers (Physical Layer to Transport Layer). Normally it can be provided by setting up MM-enabled control entities between hybrid networks, e.g. an interworking gateway. In seamless roaming architecture, routing of signaling traffic and data traffic is the biggest concern since active user session has to be maintained in different networking domains in time order. The interworking solutions for seamless roaming have been classified as three categories: tight coupling, loose coupling, and peer networks in [9].

*Scenario 4 -- Ubiquitous Seamless Roaming*

This is the ultimate goal of hybrid interworking in NG wireless networks. The UE can access services irrespective of accessing technologies and visited network operators, at anywhere, anytime. That means that the UE should be able to get authenticated to its home network via any access network. Meanwhile, the handover of active sessions should be conducted in a timely manner so as to keep upper-layer applications alive. In the scenario shown in Figure 3, we assume that three independent operators run the network domains PLMN#1, PLMN#2 and WLAN, which have been connected in a ring. The PLMNs or WLAN can be interconnected with the HPLMN of the UE directly or indirectly, e.g. through other PLMN or third parties. Because seamless roaming has been enabled at the boundaries of each pair, the UE is thus allowed to enjoy the integral and vast coverage jointly provided by three networks. With more networks joined, we can have network coverage extended globally, and provide truly ubiquitous services in the so-call "Mobile next-generation networks"[1]. Ubiquitous seamless roaming can be achieved by applying the concept of federated authentication [10] to establish roaming agreements between large numbers of network operators.

## 4. Hybrid Interworking requirements

To support the four handover scenarios mentioned in Sec. III, hybrid interworking systems need to satisfy a number of requirements to provide different levels of roaming support.

The specific requirements for each scenario have been analyzed and presented in the following paragraphs.

*R1. Non-roaming Interworking Requirements*

In Scenario 1, the UE needs to be equipped with a dual WLAN-PLMN interface for accessing both types of networks. As an independent networking domain, the WLAN provides its local services to the visited PLMN UE, and gets it authenticated via an AAA gateway to the HPLMN. All the external data traffic, e.g. Internet, of PLMN or WLAN is going through their local Packet Data Gateways (PDG) respectively. Both PLMN and WLAN function as a standalone system in terms of data traffic. In non-roaming interworking, the UE can be authorized to several WLAN networks (DS). Thus, mapping of user identifier to his subscribed WLAN ESSs has to be conducted in HPLMN when user is subscribing to PLMN networks. If the interconnected networks have an overlapped coverage area, manual network selection should be prompted to user in those areas so that he can determine which network operator to choose. Charging functions should be integrated into AAA gateway in case PLMN and WLAN are owned by different network operators.

*R2. Roaming Enabled Interworking Requirements*

Roaming enabled interworking allows multiple AAA hops between visited network and HPLMN so as to make more access networks available for roaming UEs. The common solution is to have intermediate PLMN networks transmit AAA messages between WLAN and HPLMN. For any PLMN network, both AAA proxy and AAA server functionalities should be implemented. It acts as an AAA proxy for those roaming users, as well as an AAA server for its own subscribers. Routing of AAA messages is also important in optimizing AAA messages' delivery path. Unlike TAC scenario, roaming enabled interworking has to deal with AAA of roaming UEs in multiple networking domains, the number of which may vary as user changes his location. Traditional authentication methods are likely not enough to cope with such an uncertainty of network conditions. This would call for substituted Identity Management scheme, which is employed to secure access to an expanding set of network resources. As a reference, all the requirements related to R2 are listed in Table 1.

*R3. Hybrid Seamless Roaming Requirements*

For hybrid seamless roaming, apart from all the requirements of *R1* and *R2*, smooth transfer of upper-layer user sessions is of most important consideration when wireless links have to be switched between hybrid access networks. To keep ongoing session uninterrupted, close coordination between neighboring hybrid networks is required, while the biggest obstacle in heterogeneous environments is having no central control entity between different parties. To resolve this problem, a series of mechanisms have to be provided. Handover signaling facilitates the interaction in between hybrid network components, as well as between UE and access networks. At UE end, handover decision process determines the best candidate network based on evaluation of handover metrics collected via handover signaling, and also the right time to trigger handover. In addition, flexible registration and binding mechanisms are required as UE needs to synchronize its current status with its home network. Due to nature of packet-oriented transmission, caching and forwarding of user data traffic between old AP/BSS and new AP/BSS is a necessary step in keeping the integrity of transiting connections, since the packets can be confirmed by the old AP before the connection is lost. All the above mechanisms should also aim to reduce handover latency, handover failure probability and packets drop-off so as to get better QoS expectation.

**Table 1 An Overview of Prioritized Hybrid Interworking Requirements**

| Requirements | Non-roaming Scenario | Roaming Enabled Scenario | Hybrid Seamless Roaming Scenario | Ubiquitous Seamless Roaming Scenario |
|---|---|---|---|---|
| Dual Interface (UE) | × | × | × | × |
| AAA Gateway | × | × | × | × |
| Mapping of ESSs | × | × | × | × |
| Manual Network Selection | × | × | × | × |
| Charging | × | × | × | × |
| AAA Proxy | | × | × | × |
| Routing of AAA Message | | × | × | × |
| Identity Management | | × | × | × |
| Handover Signaling | | | × | × |
| Handover Decision | | | × | × |
| Mobility Registration/Binding | | | × | × |
| Caching and Forwarding | | | × | × |
| Quality of Service (QoS) | | | × | × |
| Identity Federation | | | | × |
| Scalability and flexibility | | | | × |
| SLA | | | | × |

*R4. Ubiquitous Seamless Roaming Requirements*

Ubiquitous seamless roaming is actually an implementation of all the basic requirements of three described scenarios in a flexible and scalable manner. For ubiquitous services in NG wireless networks, it is foreseeable that coverage can not be provided by single type of networking technology or any network operator alone. To support multi-technology/multi-operator interworking, identity federation is expected at the network end so that a circle of trust can be established among different networking domains. Identity federation is employed for enabling trust relationship between any pair of network entities by implementing so-called "Federated Authentication" [10]. The basic idea behind identity federation is to use an AAA mesh to reduce the number of physical AAA associations from $N^2$ to $N$ when $N$ networking domains get involved. For consistency of services, e.g. QoS, uniform Service Level Agreement (SLA) is another consideration in support of intersystem movement of UE in different domains. Generally, ubiquitous seamless interworking should have the flexibility and scalability to accommodate new wireless systems economically.

## 5. Conclusion

In this paper we briefly classified and presented hybrid handover requirements with 4 interworking scenarios of NG wireless networks in conjunction with handover management in UMTS and 802.11 WLAN networks. The ultimate goal of hybrid interworking is to enable ubiquitous seamless roaming of users in multi-technology and multi-operator environments. It relies on 4 phases of implementation with different levels of roaming support. Accordingly, we prioritized these interworking requirements so as to clarify some important issues in the evolvement towards NG wireless networks.

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