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SHARE: seamless handover architecture for 3G-WLAN roaming environment

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Abstract For the transition from 3G communication systems to 4G communication systems, 3G-WLAN interworking systems can be a reference model for 4G communication systems. In this paper, we identify challenging problems in 3G-WLAN interworking systems and propose a loosely coupled architecture called *SHARE*. In SHARE, each WLAN hotspot access point (AP) is equipped with a 3G radio transmission module to generate radio signals for control channels of 3G networks in addition to a WLAN radio module. Consequently, base stations of the 3G networks *share* their control channels with hotspot APs. By monitoring these channels, mobile nodes can easily detect available WLAN hotspots without probe delay for handovers.

Keywords Network architecture design · 3G-WLAN interworking · Seamless handover

1 Introduction

In recent years, the demand for high data rate service in nomadic environment of 3G networks has rapidly increased. In order to meet such demand, many cellular network service providers have deployed the 3G networks such as Universal Mobile Telecommunication System (UMTS) and Code Division Multiple Access 2000 (CDMA2000).

However, 3G service providers have not been very successful in attracting customers to use 3G data services. This is attributed to the high cost and limited data rate, which can only go up to 2 Mb/s, due to the sharing of radio resources among users. It is, therefore, essential to reduce cost and to increase throughput for data service in order to attract more users. For these purposes, two different systems have been studied, i.e., the cellular data network system and the 3G-WLAN interworking system. Although the cellular data network could provide high-rate data communication environment, large investment is required for setting up a totally new infrastructure. On the other hand, the 3G networks and WLAN hotspots have already been deployed in many countries, i.e., the infrastructure for the 3G-WLAN interworking system is ready to be used. However, we still need to develop an efficient and practical interworking mechanism.

In the 3G-WLAN interworking system, two types of handovers are considered; vertical and horizontal handovers. A vertical handover is a handover between heterogeneous networks, i.e., the handover between a base station (BS) in 3G and an access point (AP) in WLAN. A horizontal handover is a handover in the same networks, i.e., the handover between BSs or between APs. For the effectiveness of the 3G-WLAN interworking system, a mobile node (MN) should quickly detect available hotspots and the handover must be completed as quickly as possible because delays can lower the quality of real-time applications. In addition, the horizontal handover between hotspot APs that belong to different service providers should be taken care of.

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In this paper, we propose SHARE (*Seamless Handover Architecture for 3G-WLAN Roaming Environment*) which can satisfy the above requirements. In SHARE, BSs of the UMTS network *share* their control channels with the hotspot APs. By monitoring these channels, MNs can avoid probing channels of APs. As a result, MNs save power that is normally consumed for hotspot detection and eliminate the probe delay for handovers.

The remainder of this paper is organized as follows. We first review the technologies related to 3G-WLAN interworking. Then we describe a typical scenario in the interworking system and identify challenging problems that must be resolved for efficient interworking. For a new 3G-WLAN interworking architecture, we propose SHARE which can resolve these problems and further discuss issues related to implementation of SHARE. Finally the conclusion follows.

2 Overview of related technologies

In this paper, we define a handover delay as the period beginning from the time when an MN receives the last data from its old point of attachment to the time when it receives the first data from its new point of attachment. If a handover takes place without a user's knowledge, it is called a *seamless handover*. Note that the seamless handover is very important for real-time applications such as voice/audio conference and video/audio on demand. In order to conceal the handover from a user, the handover must be completed in a short time.

The handover delays can be classified as the layer 2 (L2) and layer 3 (L3) handover delays as well as Authentication/Authorization delays. The overall handover delay can take much longer under transmission control protocol (TCP) [4]. Although these delays are all important in actual implementation, in this paper, we will focus on the delays related to movement management of MNs, which are the L2 and L3 handover delays.

2.1 Assumptions

Throughout this paper, the following assumptions apply.

Dual mode devices: We assume that all MNs are dual mode devices which can communicate with a BS and a hotspot AP simultaneously. It is not difficult to add this function in today's cellular phones at a reasonable price.

UMTS-802.11 interworking: We consider an interworking system between a UMTS network and an IEEE 802.11 network [9, 10], which are the most widely used technologies at present. However, we do not restrict the scope of interworking systems. For instance, the proposed system in this paper can also be applied to the CDMA2000 system and other WLANs.

Loosely coupled architecture: We consider a loosely coupled architecture for 3G-WLAN interworking as shown in Fig. 1. An MN can access the Internet through the UMTS network at any time and at any place as well as through the 802.11 network in hotspot areas.

Hotspots preference: We assume that MNs prefer the hotspot service to the 3G service due to its lower cost and wider bandwidth. Thus, when an MN being served by a BS enters a hotspot service area, it will always try to perform a vertical handover to the hotspot AP. The MN will performs a vertical handover to a BS only if there is no hotspot available.

2.2 Interworking architecture

When designing a 3G-WLAN interworking system, the architecture of the system must be determined first. There are basically two kinds of architectures for 3G-WLAN interworking: tightly coupled and loosely coupled. In a tightly coupled architecture, the 3G networks consider WLANs as their access networks, while WLANs are deployed as separate access networks in a loosely coupled architecture. Figure 1 shows a typical example of tightly coupled and loosely coupled architectures.

A tightly coupled architecture is preferred because it can reuse components of the 3G networks and support seamless vertical handovers easily [18]. On the other hand, a loosely coupled architecture is preferred because hotspots can be deployed independently and hotspot service areas can be expanded simply by establishing roaming service agreements [3]. The Third Generation Partnership Project

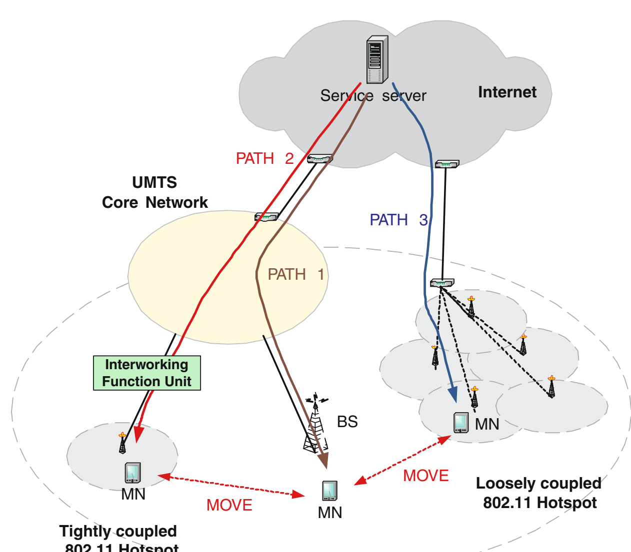


Fig. 1 3G-WLAN interworking architectures

(3GPP) has been developing a 3G-WLAN interworking architecture [2] based on a loosely coupled architecture. However there is another effort to standardize for a tightly coupled architecture such as the recently emerging unlicensed mobile access (UMA) technology [5].

2.3 L2 and L3 handovers

In order to realize a 3G-WLAN interworking system, the data flows must be re-routed from an old point of attachment to a new point of attachment (either an AP or a BS) by appropriate mobility management technologies.

The L2 handover occurs inside the same subnet while the L3 handover occurs between different subnets. If an MN performs a horizontal handover to another AP in the same subnet, this is an L2 handover. In case of a loosely coupled interworking system, when an MN performs a vertical handover from a BS to a hotspot AP, this is an L3 handover. In the latter case, the data packets sent to the MN must be delivered to the AP instead of the BS in order to maintain the present sessions. In the followings, we elaborate on the UMTS and IEEE 802.11 handovers which are related to the L2 handover and the Mobile IP handover related to the L3 handover. We assume that MNs perform a soft handover in the UMTS network.

2.4 UMTS handover

In the UMTS network, each BS has its own unique scramble code and uses three physical channels for synchronization and identification: the primary synchronization channel (P-SCH), the secondary synchronization channel (S-SCH), and the common pilot channel (CPICH). A BS uses the P-SCH and S-SCH to inform MNs of the current cell timing and uses the CPICH to identify the scramble code of the cell. The CPICH also provides the phase reference for coherent demodulation and provides a means to compare signal strengths between BSs, which is used to determine when to initiate a handover. Each BS sends its cell and system information on the Broadcast Channel (BCH) in the transport layer, and then broadcasts it via the Primary Common Control Physical Channel (PCCPCH) in the physical layer.

An MN in the UMTS network initiates a handover from the current BS to a new BS whenever the quality of the current link becomes poor. It maintains a list of neighboring cells (the monitored set) broadcasted by its BS and continuously searches for the cells on the list by monitoring the P-SCH, S-SCH, and CPICH [6]. It also maintains an active set of all the cells whose CPICH signal strength is strong enough for communication. Note that an MN must decode the system information on BCH before attaching itself to a BS [1].

2.5 IEEE 802.11 handover

In IEEE 802.11 network, an AP and its associated MNs form a basic service set (BSS) and two or more BSSs can be interconnected through a distribution system (DS). In this case, a set of interconnected BSSs appears as a single BSS to their associate MNs, and we say that an extended service set (ESS) is formed. BSSs and ESSs are identified using BSSID (BSS identification) and SSID (Service Set identification), respectively.

When the signal strength, which is represented by the received signal strength indicator (RSSI), of an associated AP is below a predetermined level or consecutive transmission failures occur, the MN initiates the handover procedure. The IEEE 802.11 working group recommended a practice for multi-vendor access point interoperability at handover via the Inter-Access Point Protocol which is called IEEE 802.11f [11]. According to the IEEE 802.11 and IEEE 802.11f, the handover procedure can be divided into three parts as shown in Fig. 2: probe, authentication, and association.

The probe procedure is to find out the neighboring APs and their channels. During the probe procedure, an MN scans all the channels on the ChannelList first [10]. If it fails to find an AP, it continues to probe the rest of the channels. After the probing is completed, the MN chooses the best AP (target AP). After the authentication, the MN

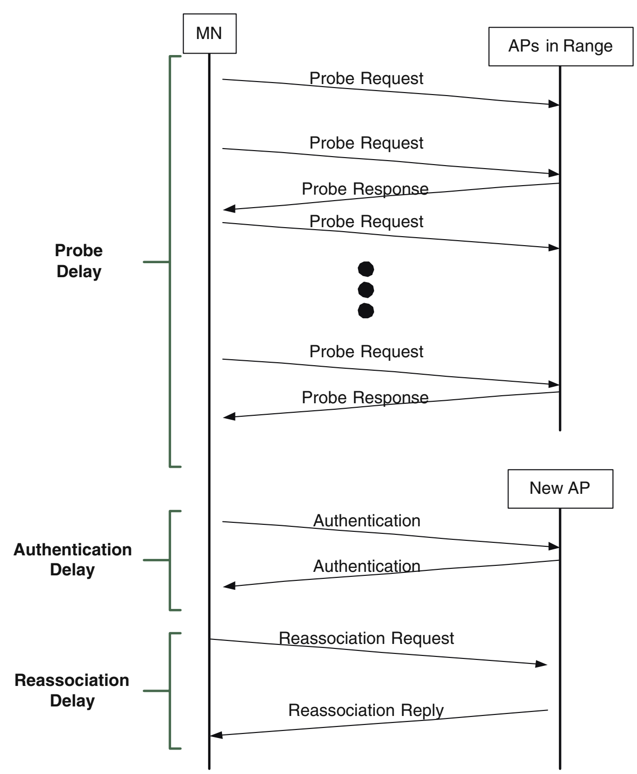


Fig. 2 Handover procedure of IEEE 802.11

requests for a reassociation to the target AP. Then, the AP fetches the MN's context information from the old AP.

2.6 Mobile IP

Mobile IP (MIP) [16] was introduced to conceal the movement of an MN from corresponding nodes (CNs). In MIP protocol, four components are involved, i.e., Home Agent (HA), Foreign Agent (FA), MNs, and CNs. In the case of MIP for IPv6, FA is not required [12]. An MN has two IP address: Home Address (HoA), which remains unchanged regardless of the point of attachment, and Care-of-Address (CoA), which indicates the current point of attachment of the MN. In order to conceal the movement of the MN, the HA maintains the association of a HoA with a CoA. When the HA sees a packet that is destined to the MN, it encapsulates and forwards the packet to the MN. This is the re-routing mechanism of MIP.

The handover delays of MIP can be divided into two parts: network detection delay and registration delay. The network detection delay is the time taken for an MN to detect changes in its points of attachment, while the registration delay is the time taken to refresh the HA's associations of the HoA and a new CoA. The packets to the MN are lost for these handover delays.

3 Motivation and problems

In this paper, we propose a new 3G-WLAN interworking architecture, SHARE, which can reduce the L2 handover delay. In this section, we describe the reason for the need to reduce the L2 handover delay, present a typical scenario in interworking, and identify challenging problems that need to be resolved.

3.1 Motivation

In order to achieve a seamless handover in a 3G-WLAN interworking system, we must take into account the L3 handover delay as well as the L2 handover delay, i.e., the MIP handover delay and the WLAN handover delay must be considered together.

Since the original MIP does not seriously take the delay into consideration, several extensions [8, 13, 14, 20] have been proposed to improve handover delays. The handover delay of the original MIP reported in the literature lasts for several 100 milliseconds (ms) to several seconds [7, 17, 19]. Hsieh et al. showed that by combining the extensions, the handover delay can be reduced to around 300 ms [7]. Furthermore, Hsieh et al. [8] and Sharma et al. [19] were successful in reducing the delay to 100 ms by introducing a new seamless MIP architecture or caching agents.

In order to reduce the L2 handover delay, it is essential to make the probe delay as small as possible, because this delay is the primary contributor to the overall handover delay as shown by Mishra et al. [15]. They showed that the probe delay accounts for 90% of the overall handover delay of WLAN at layer 2, which ranges from 10s of milliseconds to two or three hundred milliseconds with large variations depending on manufacturers of MNs. Velayos and Karlsson [21] showed that the probe delay can be reduced by setting MinChannelTime and MaxChannelTime properly. However, they also found that the probe delay increases as the number of MNs and the offered load increase.

Note that compared to the L3 handover delay, the L2 handover delay is not negligible. Moreover, the L2 handover delay can increase according to the number of MNs and the offered load. Consequently, it is clear that in order to achieve a seamless handover, we need to find a better way of reducing the L2 handover delay.

In addition to delays, the data loss rate should be low in a seamless handover, because high loss rate may degrade the quality of service to irritate users. Fortunately, some MIP variants like FMIP [13] provide little data loss so we exclude this issue in this paper.

3.2 Scenario

In this paper, we consider a case in which there are three hotspot APs in one UMTS cell (Fig. 3). We assume that a UMTS service provider has made a contract with two hotspot service providers for the provision of roaming services. One of the hotspot service providers has two APs and the other has one AP and these three APs are located in a row. The handover procedure will follow as an MN moves through three hotspots. This handover scenario includes basic elements of possible handovers that should be considered in general scenarios.

At first, the MN communicates with the BS of UMTS. After moving into the service area of WLAN1, the MN performs a vertical handover from the BS to AP1. Then, the MN performs a horizontal handover to AP2 as it moves along the MOVEMENT line. When the MN gets into the hotspot service area of WLAN2, it performs a horizontal handover from WLAN1 to WLAN2 instead of a vertical handover to the UMTS network. Finally, when the MN reaches the edge of the service area of WLAN2 and realizes that there is no available hotspot AP, it performs a vertical handover to the UMTS network.

In this paper, we classify available APs into two different types depending on their SSID. For MNs, the hotspot APs in the same ESS are available APs. In this case, the MN can perform a horizontal handover to any other available APs by changing the point of attachment. The

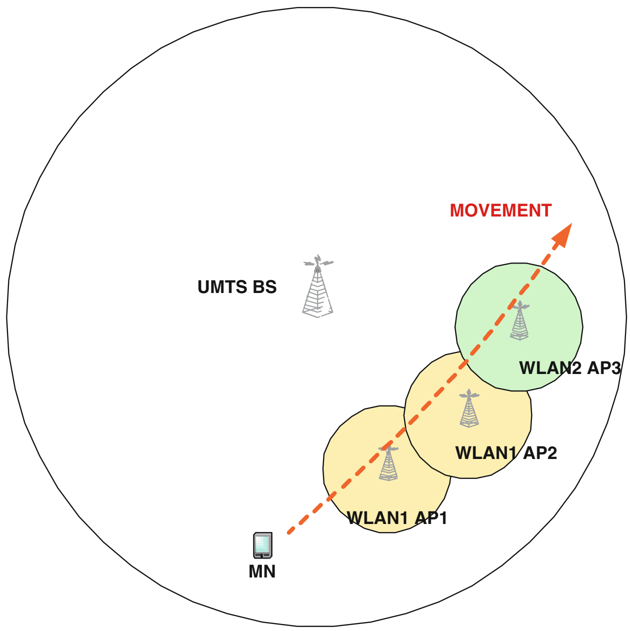


Fig. 3 Handover scenario

hotspot APs in other ESS can also be available APs, if there is a roaming service agreement between their hotspot service providers and the UMTS service provider. It should be noted, however, that in this case, the L3 handover is required to re-route flows to a new AP. Figure 4 shows the flowchart for an MN which performs a handover.

3.3 Problems

In order to realize the handover scenario for 3G-WLAN interworking described above, the following questions should be answered first.

– How can an MN detect a hotspot area more efficiently?
– How can an MN distinguish available hotspot APs from the others?
– How can an MN know whether there exists any available hotspot AP?
– How can an MN perform handovers with an AP as quickly as possible?

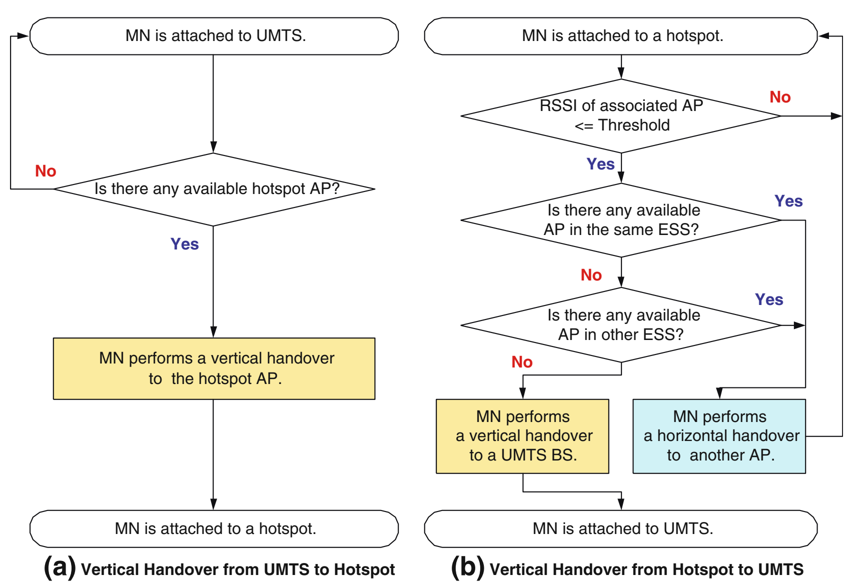
First, although detecting a hotspot area can be achieved simply by periodic scanning all the possible channels of WLAN, this is not a good solution because it is not power efficient and the MN must take some time to detect a hotspot. Thus, we need to find a solution that is simpler and consumes less power.

Second, note that an AP, which has not agreed on the roaming service with the 3G service provider, may respond to a probe request frame of an MN. In this case, the MN is likely to perform a vertical handover to the AP, because a probe response frame has no information on the roaming service agreement. However, this attempt will end in vain, therefore, we have to provide the MN with a mechanism to avoid such a case.

Third, since MNs prefer hotspot APs to BSs, they first try to find available APs at the time of a handover. If there is no AP available in the same ESS, they move on to find other available APs in a different ESS. In this case, MNs will waste time of no use, if there is no available AP. So, if there is no available AP, the MN must perform a vertical handover to a BS without spending time for finding APs.

Finally, as mentioned before, the probing of the channels in WLAN takes up a lot of time with the handovers to an AP. Therefore, if there is a way to inform an MN of the channel of the target AP, the handover delay to the AP can be significantly reduced.

Fig. 4 Flowchart for an MN



4 SHARE

In this section, we propose SHARE (*Seamless Handover Architecture for 3G-WLAN Roaming Environment*) which can solve the problems discussed in the previous section. Then, we describe how SHARE works in the handover scenario in Fig. 3.

In SHARE, BSs of the UMTS network *share* their SCHs, CPICH, and BCH with the hotspot APs within their communication ranges. The hotspot AP is equipped with a UMTS transmission module and performs some of the functions of a BS. By monitoring these channels, MNs need not probe channels of APs. Consequently, MNs can save power that is normally consumed for hotspot detection and eliminate the probe delay for handovers. In addition, SHARE uses the signal strength of the CPICH (P_{CPICH}) instead of RSSI in making more reliable handover decision. SHARE does not require any modification in the operations of deployed BSs and does not affect the operations of legacy MNs. Note that because SHARE only deals with the L2 handover, we assume that the mobile IP [16] deals with the L3 handover.

4.1 Architecture description

In SHARE, in addition to WLAN radio signal, hotspot APs are made for generating radio signals for the P-SCH, S-SCH, CPICH, and BCH as BSs. Each AP has its own scramble code and can be identified by MNs with the code.

4.1.1 Operation of a hotspot AP

Figure 5 briefly shows the structure of an AP in SHARE. Each hotspot AP is equipped with a UMTS radio transmission module in order to generate UMTS radio signals. The AP in SHARE announces its presence via the CPICH, and informs its system information on the BCH, which is broadcasted via the PCCPCH, to MNs. Consequently, APs in SHARE generate radio signals only for the P-SCH, S-SCH, CPICH, and PCCPCH. However, the system information block of the PCCPCH is different from that of a BS. This system information block includes the name of the UMTS service provider, i.e., Public Land Mobile Network (PLMN) name, SSID for ESS identification, BSSID for BSS identification, supported WLAN types, and the channel number of the AP (see Table 1). When the configuration of the WLAN module in the AP is changed, the broadcasted system information should also be changed. In this study, we made the coverage of the SCHs, CPICH, and PCCPCH to be equal to that of the hotspot AP and a hotspot service provider distributes scramble codes to its APs without overlapping area of the same scramble code.

4.1.2 Scramble code distribution

Similarly to a BS, each AP in SHARE must have a scramble code for identification. This code is used for scrambling the CPICH and PCCPCH signals. Recall that an MN searches for the cells only in the monitored set which is broadcasted by its current cell. Therefore, in order to detect an AP in SHARE, MNs must know the scramble code of the AP. In this work, we assume that a 3G service provider assigns scramble codes, which are different from the scramble codes used by BSs, to hotspot service providers. When hotspot service providers build a new hotspot, they assign a suitable scramble code to each AP in the new hotspot. Each MN participating in SHARE must know these scramble codes in advance.

4.1.3 Operation of an MN in SHARE

MNs in SHARE maintain two additional lists, the SHARE list and the list of available APs, which we will refer to as the AP list. The SHARE list contains the scramble codes for hotspot APs in SHARE. By monitoring the SCHs and CPICH, an MN can find the cells in the monitored set and also know whether there are any scramble codes in the SHARE list. If the MN knows that there is an AP in SHARE and wants to access a hotspot, it decodes the system information block on the BCH according to Table 1. If the AP is available, the MN adds it to the AP list.

When an MN accessing the Internet through the UMTS system moves into a hotspot area, it knows the existence of a hotspot AP by looking into the scramble codes in the SHARE list. Then, the MN examines the PCCPCH and obtains the system information on the BCH of the AP. After examining the PLMN name in the system information block, the MN decides whether to perform a vertical handover or not. When the MN decides to perform a vertical handover, the MN sends an authentication request frame to the AP. Note that the information for authentication request such as SSID, the channel number, and supported WLAN device types is already provided through the system information block. After performing the vertical handover, the MN continuously monitors the SCHs and CPICH to search for the cells in the monitored set and to detect the scramble codes on the SHARE list, and maintains the active set for BSs and the AP list.

When P_{CPICH} of the associated AP drops below a predetermined level, the MN looks through the AP list and performs a horizontal handover to the target AP. In this case, if the AP list is empty, the MN performs a vertical handover to a BS in the UMTS network. The flowchart of this procedure for an MN is shown in Fig. 6. We believe that P_{CPICH} is a better indicator than RSSI in making

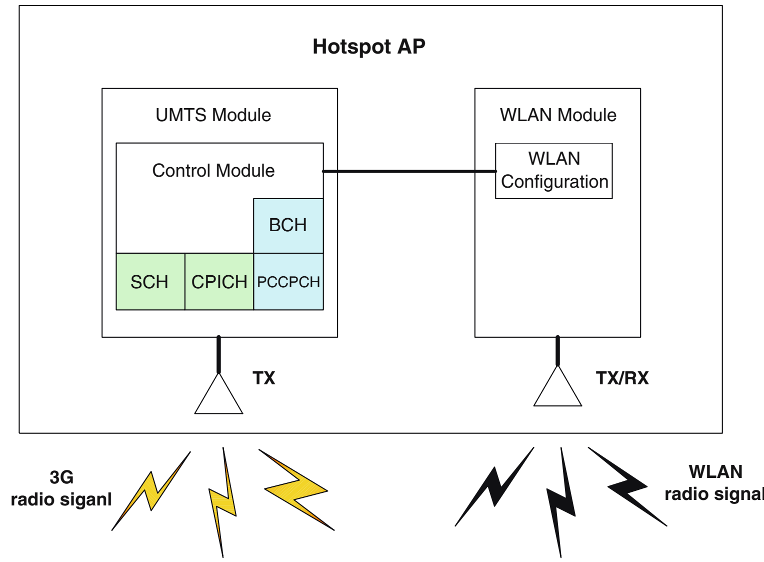


Fig. 5 Structure of a hotspot AP in SHARE

Table 1 System information block for APs in SHARE

Item	Description
PLMN name	Names of UMTS service providers who have established a roaming service agreement with the hotspot service provider. Other MNs which are not served by these PLMNs cannot perform a vertical handover to this hotspot AP
SSID	ID of a hotspot. In most cases, hotspot APs form a WLAN ESS owned by the same hotspot service provider. In order to access an AP, each MN must know the SSID of the target AP. In conventional WLANs, an MN obtains the SSID by the probing
BSSID	ID of a BSS. Each AP is identified by this value
TYPE	WLAN types which can be supported by an AP in SHARE. For example, IEEE 802.11b, 802.11a, and 802.11g etc.
Channel	Channel number used by an AP in SHARE. In order to access a WLAN AP, MNs must know the channel used by the AP

handover decisions for several reasons, which will be discussed in more detail in the next section.

In SHARE, no modification is made in BSs. In addition, SHARE does not influence the behaviors of legacy MNs which do not support SHARE. When a legacy MN moves into the service area of a hotspot AP under SHARE, the MN can not detect the CPICH of the AP, because the scramble code of the AP is not on the monitored set. When a legacy MN is turned on to operate in a hotspot area, it can detect the CPICH of the AP but can not read a system information block on the BCH. In this case, the MN will try to find another cell in order to attach itself to a BS. Consequently, it does not make any difference to the behavior of the legacy MN, even when it encounters APs in SHARE. It is worth noting that when an MN is outside of a hotspot service area, the WLAN module of the MN in SHARE is turned off, while that of a legacy MN should be turned on to find a hotspot.

4.2 Handover scenario in SHARE

In this section, we describe how an MN maintains its connectivity under SHARE by elaborating the handover scenario mentioned in the previous section. As shown in Fig. 3, there is one MN which moves across several hotspots belonging to two different ESSs, WLAN1 and WLAN2. Table 2 shows the attributes of APs.

4.2.1 Vertical handover from UMTS to WLAN

At first, the MN accesses the Internet through a BS, and then starts to follow the MOVEMENT line in Fig. 3. When the MN enters the hotspot area of AP1, it detects $Code_{HS1}$ by examining the SCHs and CPICH. After it realizes that $Code_{HS1}$ is one of the scramble codes on the SHARE list, the MN continues to check P_{CPICH} of the newly detected CPICH. When the P_{CPICH} exceeds a predetermined level, the MN decodes the system information block on the BCH of AP1.

When the MN decides to perform a vertical handover, it sends an authentication request frame to AP1 without probing. This is because it already has the necessary information for the authentication by decoding the system information block on the BCH. After the authentication, the MN requests an association to AP1. When the association is granted, it can transfer data through AP1.

After these operations, the MN sends a connection detachment request message to the BS and concludes the vertical handover. In this case, the L3 handover procedure should be conducted to re-route data packets to AP1 from the BS.

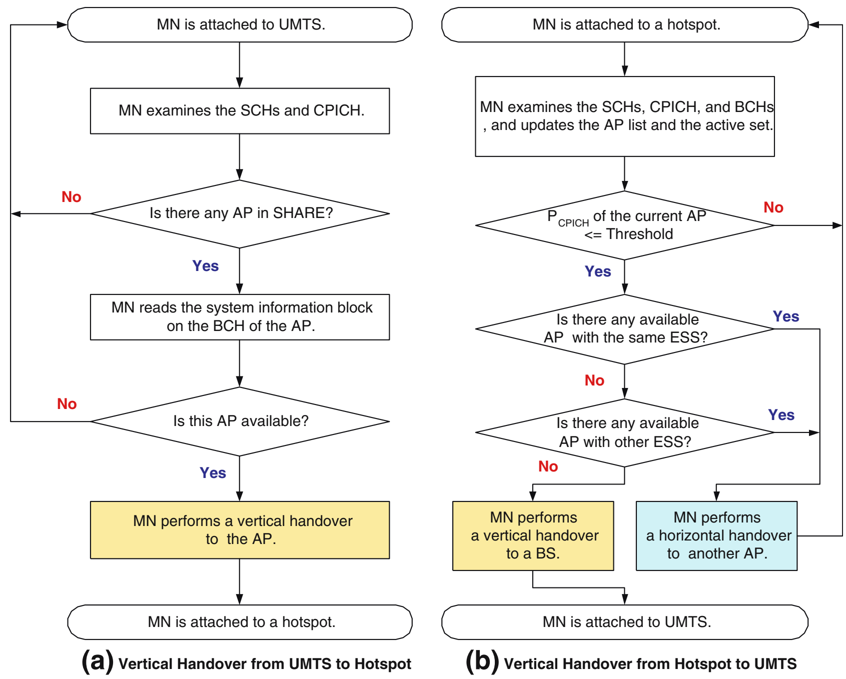


Fig. 6 Flowchart of a SHARE MN

Table 2 Attributes in handover scenario

	WLAN1 AP1	WLAN1 AP2	WLAN2 AP3
PLMN name	UMTS.3G	UMTS.3G	UMTS.3G
SSID	WLAN1	WLAN1	WLAN2
BSSID	MAC1	MAC2	MAC3
Type	802.11b	802.11b	802.11b
Channel	Ch 6	Ch 11	Ch 7
Scramble code	$Code_{HS1}$	$Code_{HS2}$	$Code_{HS1}$

4.2.2 Horizontal handover in the same ESS

Being attached to AP1, the MN continuously checks the SCHs and CPICH, and keeps updating the AP list. Moving across the service area of AP1, the MN detects $Code_{HS2}$ and decodes the system information block on the BCH, and then registers AP2 onto the AP list. When the P_{CPICH} of AP1 drops below the predetermined level, the MN performs a horizontal handover from AP1 to AP2. In this case, the L3 handover is not necessary, because AP1 and AP2 are inside the same ESS.

4.2.3 Horizontal handover between different ESSs

As the MN moves to the overlapping service area of AP2 and AP3, it detects $Code_{HS1}$ originated from AP3 and notices that the P_{CPICH} of AP2 is weakening. When the P_{CPICH} of AP2 falls below the predetermined level, the MN decides to perform a handover from AP2 to AP3. It sends an authentication request frame to AP3 even though AP3 does not belong to the same subnet of AP2. After the horizontal handover is completed, the L3 handover procedure is followed.

4.2.4 Vertical handover from WLAN to UMTS

So far the MN has maintained its connectivity to the Internet by performing several handovers. As it keeps moving, the MN notices the P_{CPICH} of AP3 is weakening and the AP list is becoming empty. At this time, the MN can conclude that the only way to maintain its connectivity is performing a vertical handover to the BS. So, instead of wasting time for probing, the MN sends a connection attachment message to the BS. After receiving a permission message from the BS, it sends a disassociation frame to AP3. After attaching to the BS, the L3 handover procedure is commenced.

5 Implementation issues of SHARE

In this section, we discuss issues related to the implementation of SHARE. Although SHARE has several advantages, the following issues should be studied further in order to be a feasible solution.

5.1 UMTS channel interference

In SHARE, hotspot APs generate UMTS radio signals which may increase the interference level of the UMTS network. So, it is important to study the relationship between the interference level and the number of hotspot APs in an overlapping service area. In this paper, we assume that a hotspot service provider chooses a scramble code for an AP, which induces minimal interference.

5.2 Power consumption

When an MN in SHARE is served by a BS, the UMTS module of the MN may consume more power due to the additional detecting process for finding the codes on the SHARE list. However, we think that this additional power consumption is negligible because the UMTS module in the MN is always powered on during data transmission and the additional process requires only simple comparison operations.

In the legacy UMTS system, an MN is basically in the power saving mode when it has no active session. When the MN performs a vertical handover from a BS to a hotspot AP, active sessions are maintained with the WLAN module and the UMTS module may not be used any more. However in SHARE, after performing a vertical handover from a BS to a hotspot AP, the UMTS module in the MN needs to be active in order to obtain information from 3G channels of hotspot APs.

Consequently, an MN in SHARE turns on a UMTS module when it is outside of a hotspot, and turns on a UMTS module and a WLAN module when it is inside a hotspot. On the other hand, a legacy MN turns on a UMTS module for transmissions and a WLAN module for finding hotspots when it is outside of a hotspot, and turns on a WLAN module when it is inside a hotspot. Though the power consumption of an MN varies depending on environment and its movement behavior, we guess that an MN in SHARE will consume less power than a legacy MN, because the service area of a hotspot is smaller than that of a BS.

5.3 CPICH versus RSSI

In SHARE, we use P_{CPICH} in making handover decisions instead of RSSI. There are several advantages of using P_{CPICH} compared with using RSSI.

First of all, there is no recommended value for RSSI in the IEEE 802.11 specification [10]. As a result, the radio signals generated by APs differ in their strengths depending on the manufacturers, which confuses MNs when making handover decisions. However, there are values recommended for P_{CPICH} in the specification [1], which makes handover decision more reliable.

Second, the RSSI of the associated AP is available to MNs only when the AP transmits a frame. Therefore, unless the AP transmits a frame, an MN can not determine whether to perform a handover to another AP or not, which in turn raises the possibility of missing the right time for the MN to initiate the handover. Moreover the MN can not monitor its neighbor APs because these APs use other channels in order to avoid interference. This explains why it takes up a long time in probing. On the other hand, P_{CPICH} is always available because the neighboring APs in SHARE send the CPICH signal on the same frequency.

5.4 QoS-aware handover

In this paper, we assume that MNs always prefer to be attached to hotspots under the assumption that APs provide better service than BSs. However this assumption may not hold in some cases. If an MN performs a vertical handover to a busy AP without considering the expected service quality, it may be given a worse service from the AP. In this case, the handover is not recommended.

From this point of view, another mechanism is needed to inform MNs of the status of APs including parameters related to quality of service (QoS). An AP may convey this information through its beacon frames or, in the case of SHARE, through its BCH. Then, an MN decides whether to perform a handover or not based on the QoS related information. Determining the QoS parameters and making a good handover policy based on the parameters need further study.

6 Conclusions

In this paper, we have reviewed the technologies related to 3G-WLAN interworking and proposed SHARE, a loosely coupled architecture for 3G-WLAN interworking.

In SHARE, a hotspot AP is equipped with a UMTS radio transmission module and generates radio signals for some of the control channels of the UMTS network, so that a BS of the UMTS network *shares* its SCH, CPICH, and BCH with hotspot APs. By monitoring these channels, MNs can detect available hotspots without delay and can perform either vertical or horizontal handovers without spending time on probing. Moreover, by using P_{CPICH} in making handover decisions instead of RSSI, MNs can make handover more reliable.

In this paper, we assumed that the mobile IP takes care of the L3 handover. However, we believe that it is possible to further reduce the L3 handover delay in SHARE, which remains as future work. Although we considered the UMTS system and the IEEE 802.11b system, SHARE can be applied to the design of an interworking system between other 3G networks and WLANs.

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