Wireless LAN Access Network Architecture for Mobile Operators

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ABSTRACT

The evolution of IP-based office applications has created a strong demand for public wireless broadband access technology offering capacity far beyond current cellular systems. Wireless LAN access technology provides a perfect broadband complement for the operators' existing GSM and GPRS services in an indoor environment. Most commercial public wireless LAN solutions have only modest authentication and roaming capability compared to traditional cellular networks. This article describes a new wireless LAN system architecture that combines the WLAN radio access technology with mobile operators' SIM-based subscriber management functions and roaming infrastructure. In the defined system the WLAN access is authenticated and charged using GSM SIM. This solution supports roaming between cellular and WLAN access networks and is the first step toward an all-IP network architecture. The prototype has been implemented and publicly verified in a real mobile operator network.

INTRODUCTION

Seamless access to modern office tools is one of the most valuable assets for mobile business professionals today. Most corporate information systems and databases can be accessed remotely through the Internet (IP) backbone, but the high bandwidth demand of typical office applications, such as large e-mail attachment downloading, often exceeds the transmission capacity of cellular networks. Mobile professionals are looking for a public wireless access solution that could cover the demand for data-intensive applications and enable smooth online access to corporate data services.

Wireless local area networking (WLAN) radio technology provides superior bandwidth compared to any cellular technology. The state-of-the-art Wi-Fi™ wireless LAN standard (IEEE 802.11b) offers a maximum throughput of 11 Mb/s over a license exempt 2.4 GHz frequency band [1, 2]. The maximum data rate of a single user in a public WLAN radio network is 11 Mb/s (typical 6.5 Mb/s), while a General Packet Radio Service (GPRS) handset offers a data rate up to 172 kb/s (typically 42 kb/s) and the third-generation terminal up to 2 Mb/s (typically 144 kb/s). From the end users' perspective the performance difference is huge, which makes WLAN a competitive option to cellular data indoors.

Most WLAN terminals are laptops or PDAs with separate WLAN network adapters. The market analysts forecast a major growth of WLAN PC card market in 2001. The WLAN terminal business is gradually moving toward more integrated devices; the leading high-end laptop models shall have integrated wireless LAN interfaces during 2001. Furthermore, the terminal category is expanding with WLAN PDA phones and integrated PDA devices.

The business professionals' desire for broadband public data access and the rapidly growing WLAN terminal penetration create a fascinating business opportunity for mobile operators to extend their services to cover WLAN access. Today, there are about 50 million mobile laptop users, of which 30 million also have GSM subscription [3]. WLAN can complement mobile operators' traditional wide-area GPRS and GSM service portfolio by offering a cost-efficient wireless broadband data solution indoors. Target places for WLAN access services are airports, railway stations, hotels, business parks, and office buildings where most mobile laptop users typically work.

The key question is how to utilize mobile operator strengths: large GSM customer base, cellular infrastructure investments, and well established roaming agreements in operator WLAN networks. The authors have been involved in the development of a new WLAN system architecture which is targeted to mobile operators. The defined solution, called an *operator WLAN* (OWLAN) system, combines GSM subscriber management and billing mechanisms with WLAN access technology. The OWLAN enables IP roaming between different operator access networks. The operator WLAN solution is available for

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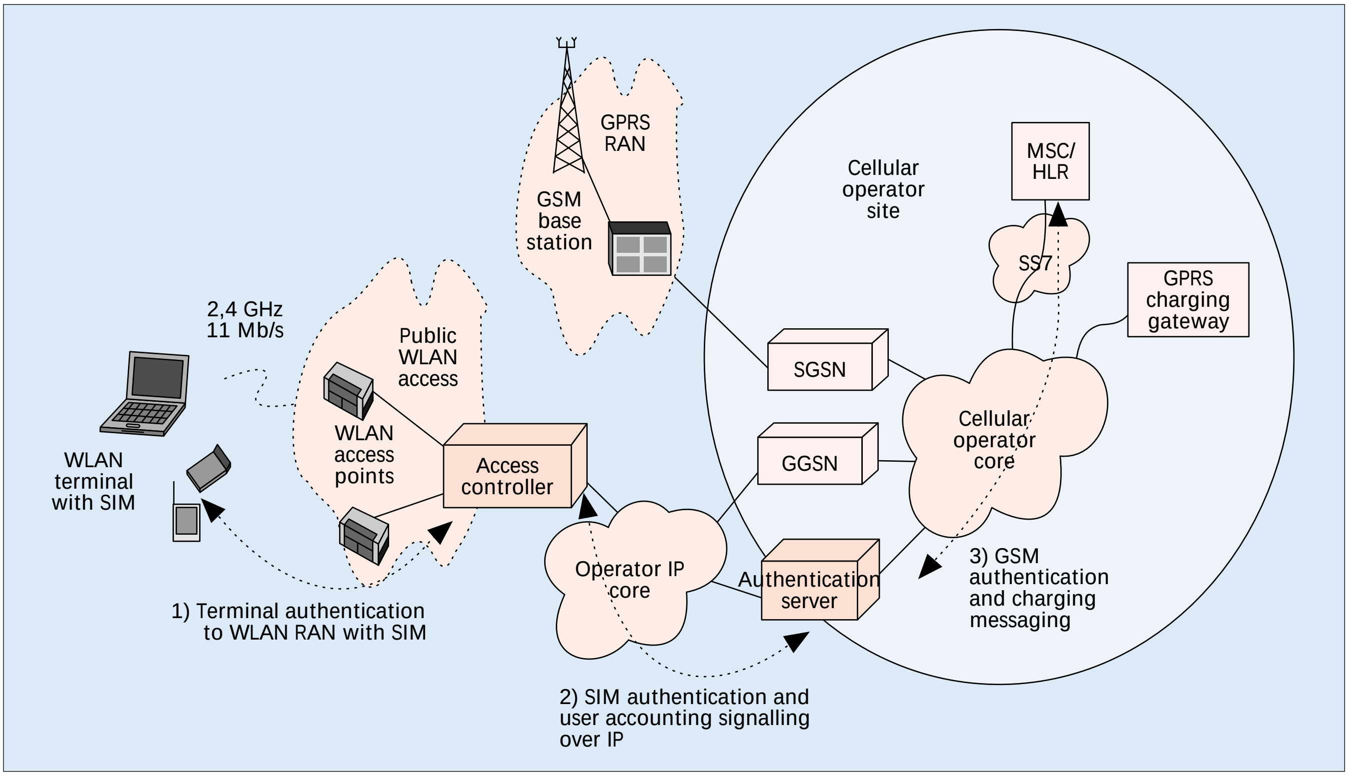


Figure 1. *An overview of the operator WLAN system architecture.*

any wireless LAN terminal device that provides GSM SIM card reader and defined operator WLAN signaling module. The reference system was implemented as part of the company research project and was successfully piloted in a real mobile operator network in 2000. The observations and learnings from the trial proved the usability of the concept, and the first commercial system was launched in July 2001 and has been successfully piloted by several mobile operators.

This article describes the OWLAN architecture, main system components and their functionality. The focus is on the SIM based authentication, roaming and billing mechanisms.

OWLAN	GPRS	Function
Authentication server (AS)	SGSN	User authentication, access billing
Access controller (AC)	GGSN	End point of IP packet network, IP address allocation
Access point (AP)	BTS	Radio coverage
Mobile terminal (MT)	Mobile phone	End-user device

Table 1. *OWLAN vs. GPRS network elements.*

Operator WLAN Solution Overview

Design Objectives

The future mobile operator network shall be a combination of several radio communication technologies, such as GSM/GPRS, the third generation radio access and wireless LAN. A single subscriber identity should be used in all access networks to enable smooth roaming and seamless service availability. The operator WLAN system should maintain compatibility with the existing GSM/GPRS core network roaming and billing functions [4, 5], which minimizes the number of modifications in the GSM core equipment and the standardization effort needed. A GSM Subscriber Identity Module (SIM) is a natural choice for WLAN subscriber management since it is widely deployed and enables roaming to existing GSM/GPRS handsets and networks.

In the first phase the focus of WLAN business is on data applications. Thus, the OWLAN system should be optimized for terminal initiated IP data services, which reduces system complexity. The evolution to all-IP services in the wireless LAN shall follow in the next step as mobile operator all-IP service infrastructure is available.

To minimize the installation costs and complexity, the OWLAN should utilize the existing GPRS charging system. GPRS operators have defined a mechanism for exchanging billing data between operators' networks [6]. The same mechanism should be used for transmitting WLAN charging records.

Operator WLAN System Architecture

The OWLAN system architecture, depicted in Fig. 1, consists of the public LAN access network and the cellular operator site, which communicate over the IP backbone. The main design challenge was to transport standard GSM subscriber authentication signaling [4] from the terminal to the cellular site using the IP protocol framework. One could call the resulting operator WLAN architecture the first instance of a mobile operator all-IP network.

The OWLAN system contains four key physi-

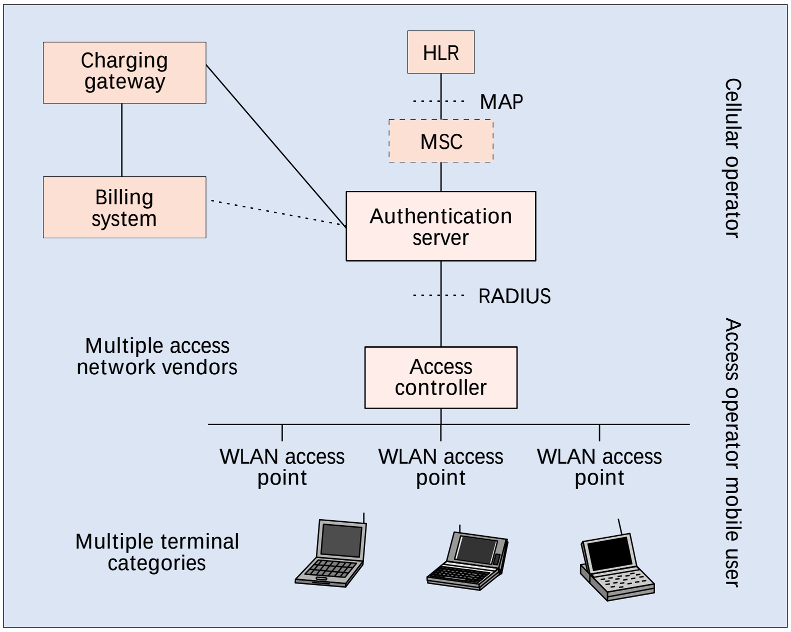


Figure 2. *The elements of the OWLAN system.*

cal entities: authentication server, access controller, access point, and mobile terminal (Fig. 1). The system architecture resembles a GPRS network. Each system component has a counterpart in the GPRS network, as illustrated in Table 1.

The significant difference compared to the GPRS architecture is that in the OWLAN system only the control signaling data is transported to the cellular core. The access controller routes user data packets directly to the IP backbone, which is used for accessing the public and private services. This architecture avoids the GPRS kind of roaming complexity since the user's IP traffic does not have to be carried via the cellular core to the home network. Consequently, the operator WLAN approach decreases the load of the cellular core.

The subscriber authentication works as follows. First a WLAN terminal associates with a WLAN access point, gets an IP address from the access controller, and initiates the network authentication by sending a dedicated authentication request to the access controller (1). The access controller relays the authentication request to the authentication server (2), which implements the gateway between the access network and the GSM signaling network. The authentication server queries the GSM home location register (HLR) for the authentication data and performs user authentication using this information (3).

System Elements

Figure 2 depicts the main operator WLAN system elements and interfaces in more detail.

The Authentication Server

The authentication server is the main control point of the OWLAN subscriber management. A single entity may support several access controllers and provide authentication and billing services for thousands of roaming users in different access zones. The authentication server communicates with the access controller using RADIUS authentication protocol [7], which is a de facto authentication, authorization, and accounting (AAA) protocol in the IP industry. When the user disconnects, the authentication server receives the accounting data from the access controller, converts it into GPRS billing format [6], and issues the ticket to the cellular billing system.

The authentication server hides the cellular infrastructure from the access network. It provides a gateway to the cellular core network elements, namely the GSM home location register (HLR) and GPRS charging gateway. The authentication server sends standard GSM authentication signaling to the HLR using the SS7 signaling network that connects various operator networks together. The cellular network identifies the user with GSM International Mobile Subscriber Identity (IMSI) code stored in the SIM card.

In the prototype system the authentication server has been implemented using a Windows NT server platform that has been connected directly to the Nokia Mobile Switching Centre (MSC). An IP-compliant vendor-specific protocol carries the authentication requests from the AS to the MSC. Figure 2 shows the applied configuration in which the MSC offers a redundant high-performance MAP interface and allows us to balance the signaling traffic from the WLAN with normal GSM signaling. In this setup WLAN requests can never block GSM signaling. Alternatively, the authentication server could be implemented with a native MAP interface.

A predefined bit pattern in the HLR subscriber service profile indicates the WLAN service subscription. The authentication server always checks if the roaming user has subscribed to the WLAN service. In the future the service profile could be extended to include, for example, the quality of service class of a WLAN subscriber. The current GSM standard does not define a WLAN service bit pattern, and the service profile bit interpretation rules are operator-dependent.

Access Controller

The access controller provides an Internet gateway between the radio access network and the fixed IP core. It allocates IP addresses to the mobile terminals and maintains a list of the authenticated terminals' IP addresses. The AC acts as a traffic filter monitoring the address of each incoming or outgoing IP packet and discarding the packets that come from a nonauthenticated terminal. The access controller separates the mobile terminals using a terminal IP address and a unique WLAN link-layer-specific MAC address. The MAC address verification ensures that a duplicate IP address cannot simultaneously be used by a hostile user. The access controller gathers accounting information for billing purposes. The access controller prototype has been implemented using an IP router platform, more precisely, Nokia IPSO IP330 series router.

The Wireless LAN Access Point

The access point offers a wireless Ethernet link between the mobile terminal and the fixed LAN. Access points are connected to the same LAN with the access controller. The access points are Wi-Fi compliant and support the data rates of 1,

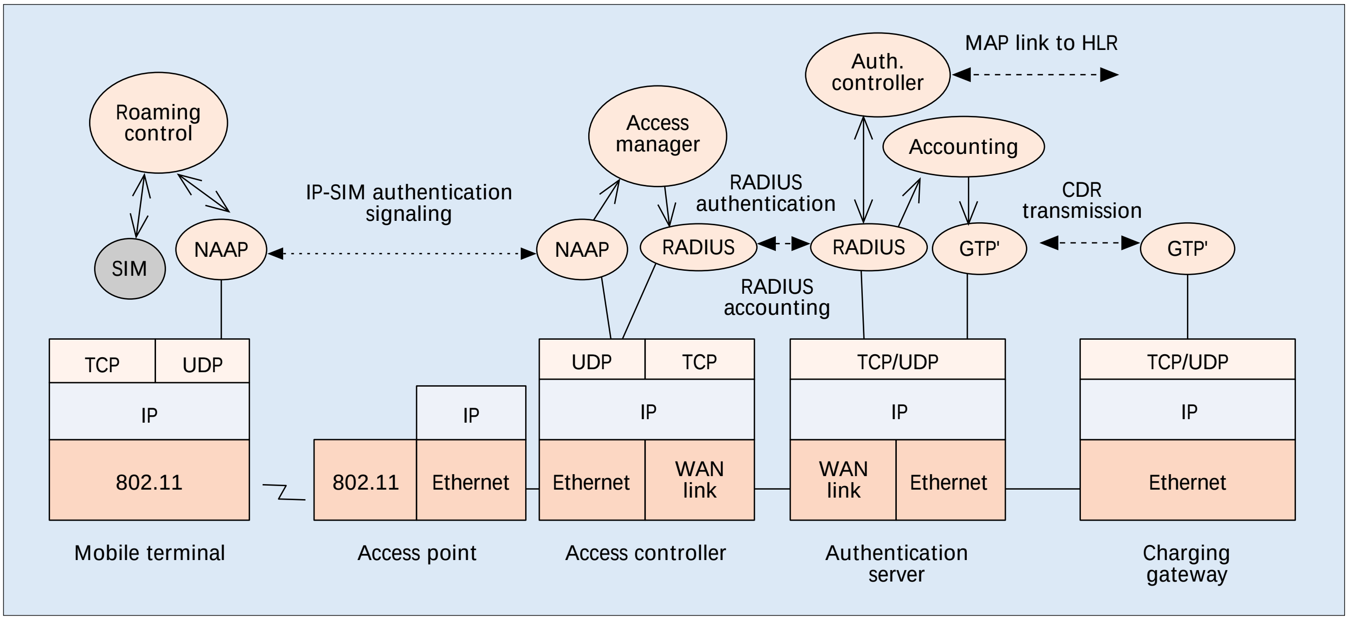


Figure 3. *OWLAN control plane architecture.*

2, 5.5, and 11 Mb/s [1, 2]. The typical coverage range of a single Wi-Fi access point is 50–100 m indoors. The coverage can be extended using directional antennas and radio network planning tools. The access point offers a shared radio interface. Consequently, the amount of active terminals affects the perceived user data rate. If there are no other terminals in the same access point, a single user may use the complete 11 Mb/s radio link. This is one significant difference from GPRS radio access [5].

MOBILE TERMINAL

OWLAN service is available for any terminal with WLAN radio access capability, a SIM reader, and a SIM authentication software module. The end user may deploy either a WLAN card with an integrated SIM reader or a WLAN card and an external smart card reader. Laptop vendors have also indicated that some laptop models shall have integrated smart card readers in the future.

The OWLAN terminal may detect the correct roaming WLAN network by using predefined network profiles that contain the list of the roaming partners' radio network identifiers. When entering a new location the terminal compares the names of available WLAN networks with the roaming profile and associates to the correct WLAN. The operator may distribute the profiles, say, in a SIM card or using a Web server.

SYSTEM OPERATION

The requirement to maintain compatibility with existing WLAN devices and the cellular core implicitly lead to an architecture in which the necessary SIM specific signaling messages are transported using the IP protocol. The IP approach makes an OWLAN system independent of the WLAN standard and allows us to deploy the same concept for future 5 GHz WLAN systems, such as IEEE 802.11 and HIPERLAN/2.

The functional division between the access controller and the authentication server keeps the complexity of the core network low. The computing-intensive IP packet filtering and routing functions reside on the access network side where the processing load can be distributed among a number of access controllers. This improves system scalability and robustness. Figure 3 illustrates the resulting control plane architecture.

The core component of the mobile terminal software is the Roaming Control module, which offers a graphical control user interface to roaming services. This module communicates with the SIM card. The operator WLAN-specific Network Access Authentication and Accounting Protocol (NAAP) protocol encapsulates GSM authentication messages inside IP packets. The NAAP utilizes a connectionless User Datagram Protocol (UDP) transport layer but includes a retransmission mechanism that ensures reliable relay of the control messages.

The key component of the access controller is the Access Manager which controls IP routing and collects accounting statistics. The RADIUS protocol [7] carries SIM specific authentication parameters inside vendor specific attributes while the accounting data is submitted using standard RADIUS accounting attributes [8].

The most important module in the authentication server is the Authentication Controller which handles the RADIUS authentication messages and communicates with the GSM core. The Accounting module receives and stores the accounting information from the access network. The Accounting module interfaces with the GPRS charging gateway using GTP' billing protocol [6]. There is no uniquely defined open GTP' interface available, but rather there exists a combination of several GTP' versions and various billing data formats. The authentication server offers an open FTP interface which can be used for transferring the accounting data directly to various billing systems. The following paragraphs describe the key system procedures, such as authentication, billing and secure access to the corporate network in detail.

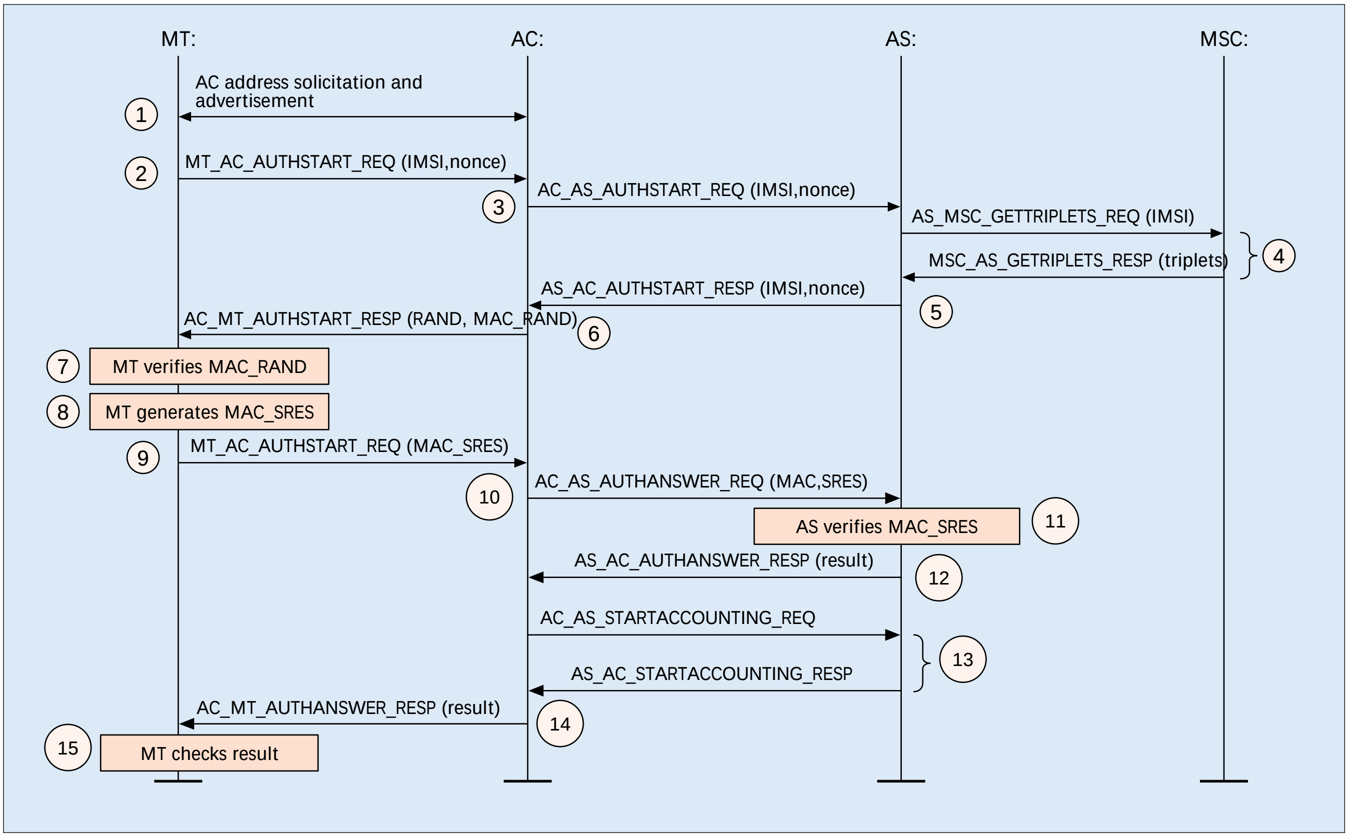


Figure 4. *The SIM-based authentication sequence.*

AUTHENTICATION

The core part of the operator wireless LAN system is the SIM-based authentication. The access controller acts as a relay between the terminal and the authentication server. The authentication sequence is as follows:

The first step is to activate the user terminal with the personal identity number (PIN). The SIM card and user identity are secured with PIN code protection. When the authentication phase is started, the software prompts the user for the PIN code. This functionality is equivalent to GSM, and makes it impossible to use a stolen SIM card that has PIN query enabled without knowledge of the correct PIN code.

The phases of the SIM-based authentication are illustrated in Fig. 4. The steps are numbered both in the figure and in the text below. Initially, the terminal locates the access controller in the network by sending a NAAP solicitation message to which the access controller replies (1). After receiving the IP address of the access controller, the terminal sends the initial authentication request to the access controller, where the IMSI is encapsulated into the Network Access Identifier (NAI) (2). NAI is a well-known part of the standard IETF AAA framework [9]. The domain part of the NAI identifies the home operator domains, e.g. IMSI@operator.com. The access controller and RADIUS infrastructure use the domain part for relaying the authentication request to the correct authentication server (3).

The authentication server requests GSM triplets from the home location register using an MSC connection (4). Then the authentication server sends the GSM RAND to the mobile terminal along with a message authentication code calculated over the RAND (5, 6). The message authentication code authenticates the cellular network to the terminal, enabling mutual authentication. The terminal calculates the message authentication code and compares it to the one it received from the network (7). If the calculated message authentication code does not match with the received one, the terminal can suspect a fraudulent service and stop answering the authentication request. This mechanism makes it impossible for an attacker to gather RAND and SRES pairs from the IMSI, and thus makes it impossible to find out the secret key Ki stored on the SIM card. The message authentication procedure utilizes the HMAC mechanism presented in [10]. Next the terminal calculates the signed response (SRES) using the algorithms stored on the SIM card and also calculates a message authentication code over the SRES (8).

The terminal sends the response to the access controller which relays it to the authentication server (9, 10). The authentication server verifies the response by calculating the similar message authentication code over the SRES (11). The authentication server sends the result code of the authentication to the access controller (12). If the authentication was successful, the access controller sends the authentication server an indication that a new accounting session has been started (13). Finally, the access controller enables routing for the terminal data packets, and sends the acknowledgment to the terminal (14, 15).

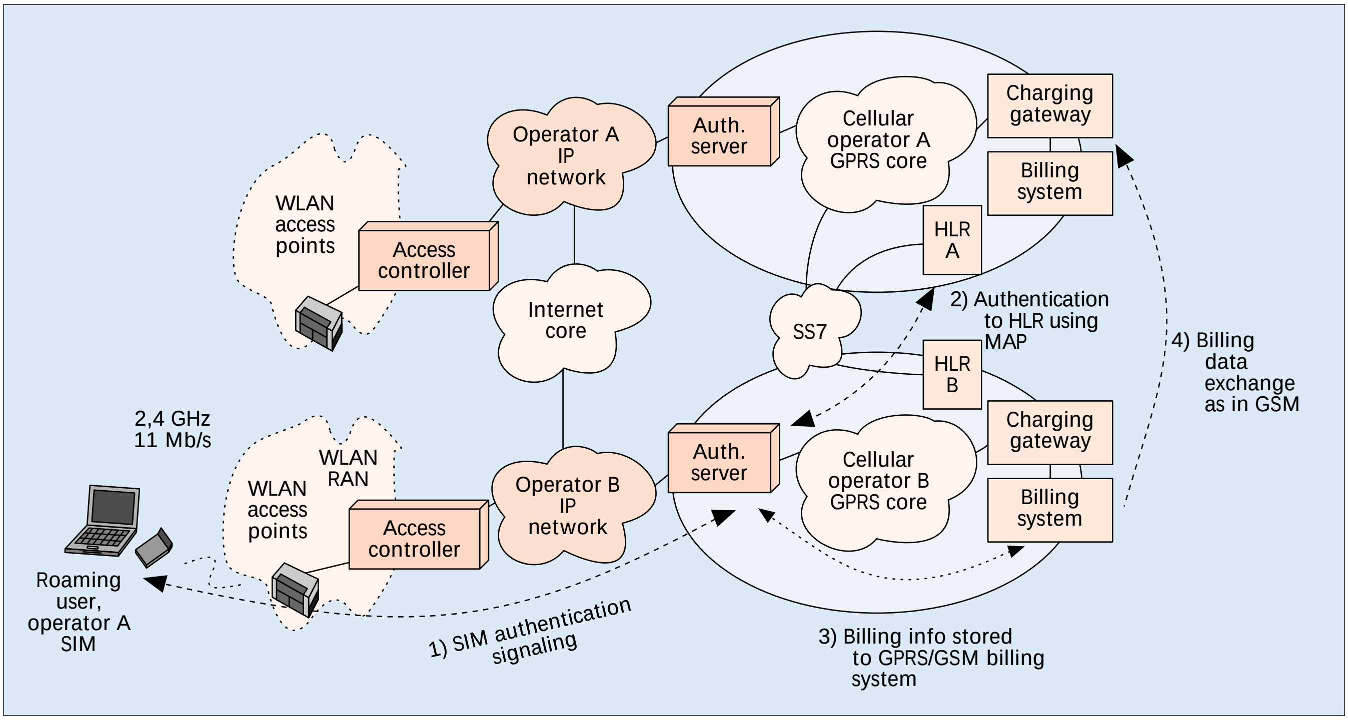


Figure 5. *WLAN roaming to a foreign operator network.*

The authentication procedure may be aborted due to the following reasons: the IMSI is not known in HLR, the WLAN service has not been subscribed, the access operator does not support roaming of the specific IMSI, or the authentication server does not receive the triplets from the HLR. In these cases, the terminal remains nonauthenticated and the access controller does not route the IP traffic of the terminal.

During the authentication sequence the authentication server sends the terminal and the access controller a session lifetime value, which indicates how long the authenticated session is valid. When the session lifetime expires in the access controller or the terminal disconnects, the access controller closes the terminal's connection. It also notifies the authentication server, which closes the accounting session for the terminal. The terminal must initiate a reauthentication sequence before the session lifetime expires, if it wishes to continue the session. The reauthentication procedure allows the operator to grant an access that is valid only for a certain period. This is a useful feature for prepaid systems as well as for environments where charging could be bound to certain access times. This also allows the operator to authenticate the terminal periodically during an active session just like in the GSM system.

Accounting and Billing

The access controller monitors the data traffic and periodically sends the traffic statistics information to the authentication server. The following accounting methods are supported:

- Time-based: connection start time and end time are recorded
- Volume-based: the amount of transferred data is recorded
- Flat rate

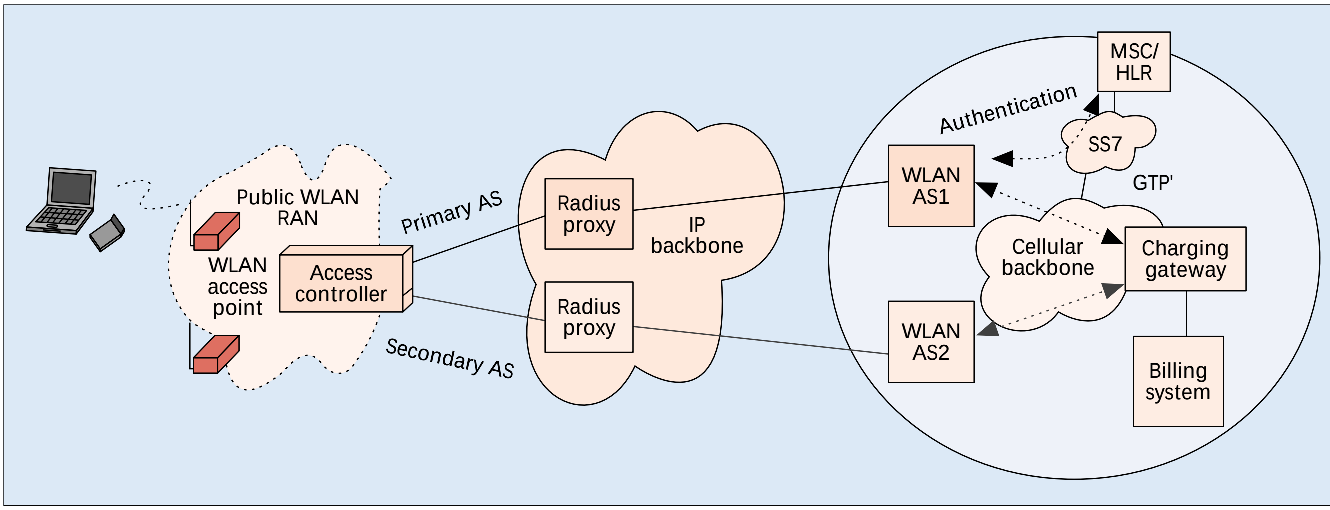
The authentication server converts the accounting data to standard GPRS charging data record (CDR) format. WLAN CDRs are marked with a WLAN-specific identifier code. More details on the CDR format can be found in [6].

The authentication server verifies the received accounting data related to an authenticated terminal (IMSI). This ensures that charging records are not generated for a connection that has not been properly authenticated. Furthermore, accounting data is protected using the shared secret mechanism in RADIUS protocol [7]. This mechanism prevents fraudulent insertion of accounting data in the IP network side since the access controller and authentication server that share the secret key notice if the data has been altered during transmission. The shared secret key is entered in the access controller and authentication server during system configuration. The transferred data can also be encrypted using IP Security (IPSEC) protocol [11] between access controller and authentication server.

Finally, the authentication server delivers the generated CDRs to the charging gateway or billing system. The explicit rules according to which the connection is eventually billed are configured in the back-end process of the operator billing system.

Roaming to Foreign WLAN Networks

Mobile operator consortia have the infrastructure and the culture to support roaming between different access networks as well as between operator networks. Unlike most Internet service providers, mobile operators have the infrastructure and the culture to support roaming between different access networks as well as between operator networks. The mobile operators have agreed on how to exchange the authen-



■ **Figure 6.** *Using RADIUS proxies for system redundancy.*

tication and accounting data between the roaming and the home operatotr. The existing operator billing systems are also capable of exchanging accounting information with each other. Figure 5 illustrates how the operator-to-operator roaming scenario works in the operator WLAN system.

First, the roaming mobile terminal associates to the foreign operator WLAN network and initializes authentication by sending an authentication request to the access controller, which relays it to the authentication server (1). The authentication server analyzes the IMSI and verifies that the operators have a valid roaming agreement for WLAN services. Next, the authentication server sends the authentication query to the correct HLR using the GSM SS7 network (2) [4]. The corresponding HLR responds with user profile and authentication triplets, and the authentication procedure is completed in a normal way. After the terminal disconnects, the authentication server sends the charging record to the foreign operator's billing system (3). The IMSI code indicates that the CDR is generated for a roaming terminal. The operator billing systems regularly communicate with each other, and exchange GSM/GPRS and WLAN-specific billing records generated by roaming users. Using this mechanism the foreign operator's billing system relays the WLAN CDR to the user's home operator billing system, which finally submits the end-user bill (4).

Secure Remote Access for Corporate Users

The target customers of the operator wireless LAN service are mobile business users who use wireless LAN extension to access the corporate network. In order to guarantee the privacy of business-critical information, an end-to-end encrypted connection needs to be established between the terminal and the corporate network. Typically this is provided using a virtual private networking (VPN) server in the corporate network side and a corresponding VPN client software in the remote terminal [11]. The usability of the remote access may further be improved by storing the VPN authentication certificate in the SIM. This makes it possible to protect the VPN keys and to launch seamless VPN authentication after SIM-based authentication to the access network. In this approach the operator could offer both VPN and access service in close cooperation with the corporate information management department.

A few VPN clients support only the use of routable IP addresses instead of private IP addresses. This is a common constraint for all remote access services as the operator has to allocate a large number of routable IP addresses for roaming users. The operator WLAN architecture requires the usage of modern VPN products with private addressing support, which improves the scalability and usability of the public WLAN access system.

Scalability and System Robustness

The mobile operators have extremely high error tolerance and resilience requirements for the networking infrastructure. To meet these requirements the operation of the access point, the access controller and the authentication server must be reliable and the system has to offer sufficient redundancy characteristics.

The critical part of the operator WLAN system is the fault tolerance of the authentication server since a single AS may serve several radio access networks and tens of thousands of mobile users simultaneously. A minimum installation of the operator WLAN consists of two authentication servers. Fault tolerance of the authentication server is supported using standard RADIUS proxy infrastructure, depicted in Fig. 6. The access controller is connected to both proxies, one being the primary and the other the secondary RADIUS proxy. If the authentication server does not reply to the access controller's messages, the access controller sends the message to the secondary RADIUS proxy, which relays the messages to the secondary authentication server. Consequently, redundant IP routing infrastructure and RADIUS proxies ensure seamless switching between the authentication servers in the case of an error. This approach allows the mobile operator to increase the system capacity by adding more authentication servers to the network. It must be noted that only interoperability-tested proxy servers should be deployed.

The risk of losing accounting data is minimized by updating it periodically to the authentication server. The operator may further improve system robustness by installing a secondary access controller which is used if the primary access controller is broken or under heavy load. The access controller platform also monitors its internal functionality. If the platform is not working correctly it shall send alarms to the network management system and/or automatically reboot.

The redundancy of the access point is not extremely critical. If an access point is not functioning well it shall turn its radio off, after which the terminal automatically roams to a new access point.

Summary and Conclusions

The increasing amount of roaming data users and broadband Internet services has created a strong demand for public high-speed IP access with sufficient roaming capability. Wireless LAN systems offer high bandwidth but only modest IP roaming capability and global user management features.

This article describes a system that efficiently integrates wireless LAN access with the widely deployed GSM/GPRS roaming infrastructure. The designed architecture exploits GSM authentication, SIM-based user management, and billing mechanisms, and combines them with public WLAN access.

With the presented solution cellular operators can rapidly enter the growing broadband access market and utilize their existing subscriber management and roaming agreements. The OWLAN system allows cellular subscribers to use the same SIM and user identity for WLAN access. This gives the cellular operator a major competitive advantage over ISP operators, who have neither a large mobile customer base nor a cellular kind of roaming service.

The designed architecture combines cellular authentication with native IP access. This can be considered the first step toward all-IP networks. The system proposes no changes to existing cellular network elements, which minimizes the standardization effort and enables rapid deployment. The reference system has been commercially implemented and successfully piloted by several mobile operators. The GSM SIM-based WLAN authentication and accounting signaling has proved to be a robust and scalable approach that offers a very attractive opportunity for mobile operators to extend their mobility services to also cover indoor wireless broadband access.

The designed architecture combines cellular authentication with native IP access. This can be considered as the first step toward All-IP networks.

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Biographies

Juha Ala-Laurila (juha.ala-laurila@nokia.com) received his M.Sc. degree in telecommunications from Tampere University of Technology in 1997. He has been with Nokia since 1995. He has been involved in the development of various wireless broadband data services both in the Nokia Mobile Phones and in Nokia Internet Communications. Between September 1995 and October 1998, he worked as the workpackage leader in the Magic WAND (Wireless ATM Network Demonstrator) project, which was the European Union funded activity within the Fourth Framework programme called Advanced Communications Technologies and Services (ACTS). In June 1998 he was nominated technology officer within Nokia. In this position he managed research and development activities related to wireless LAN quality of service, security, and IP mobility. Between 1999 and 2001 he has been responsible for development on the Nokia operator WLAN system.

Jouni Mikkonen received his Ph.D. degree in telecommunications from the Technical University of Tampere in 1999. He has been with Nokia since 1992. He has been involved in the development of GSM network and new data services at both Nokia Telecommunication and Nokia Mobile Phones. Between September 1995 and October 1998 he worked as technical manager of the Magic WAND project, which was the European Union funded activity within the Fourth Framework programme called ACTS. In April 2000 he was nominated senior technology manager of wireless broadband technologies within Nokia.

Jyri Rinnemaa received his M.Sc. degree from the Tampere University of Technology, Finland, in 1999. He joined Nokia in 1997. From 1999 tp 2001 he has been involved in the development of the wireless LAN networking security features and mobile operator wireless LAN system solutions.