Wireless telephony opportunities

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1. Abstract

Introducing both voice and video transmission on Internet Protocol (IP) based networks has been considered as a new alternative to conventional PSTN telephony and GSM/UMTS cellular technology. While PSTN conventional telephony is known for its reliability, GSM/UMTS owes its success to the geographic mobility and the enhanced terminal functions offered to users. With the spreading of WiFi handheld devices (using IEEE 802.11 a/b/g technology), combined with the proliferation of Wireless IP based networks, new telephony opportunities are enabled. Can we consider WiFi as a new wireless technology for telephony?

Many equipment providers already promote their VoWLAN (Voice over Wireless LAN) technology. Within centralized, supervised wireless network, mobile users with WiFi handheld phone can get similar services as using their cellular phone. Otherwise, generalizing and deploying such WiFi telephony mobility in public Wireless IP networks might be less obvious and many constraints limit a seamless usage of VoWLAN technology. One major consideration for such telephony services is the time required to roam between access points. Many aspects of the network configuration, deployment and protocols rule the provided quality of service (QoS).

Solutions to public VoWLAN would be to provide "Universal Access" among Internet Service Providers (ISPs). As an example, there could be exchanges of Credentials of mobile users between home ISP and visited ISP. The aim is to established available seamless services, priorities and billing information for the mobile user. Moreover, networks configuration and management need to be redefined and normalized among all ISPs to offer equivalent QoS among various Access Points.

Also to be considered are the new VoWLAN capable phones that can also hook on other wireless networking technologies like GSM. These multimode wireless phones push the concept of Universal Access to the limit by requiring not only standardization among ISPs but also among service providers that administrate networks based on different technologies.

In this work, the status of various wireless networking technologies is presented. Typical use cases are employed to explain the concept of Universal Access and to put emphasis on its advantages. A discussion on the challenges behind operation, administration, maintenance and provisioning concludes the work.

2. Introduction

Over the past decade, telephony services underwent a somewhat substantial evolution with the advent of Voice over Internet Protocol (VoIP) telephony. The conventional public switched telephony network (PSTN) is no longer the only mean by which a user can place a phone call.

On one hand, the technology on which is based conventional telephony is called circuit-switched technology and possesses very interesting qualities for operation, administration, maintenance and provisioning. Quality of service (QoS) can be naturally assured as the communication channel is reserved for the whole duration of a phone call even when both speakers remain silent or hold the call. Circuit-switched technology also provides direct connection between the delivered telephony service and the dedicated physical link used to provide the service. Consequently, such technology enforces easing maintenance tasks, ensuring phone call confidentiality and making billing activities straightforward. This direct relation between the telephony service and the dedicated physical link also makes 911 emergency services relatively easy to implement. In the paradigm of circuit-switched networks, the task of a network is to transport information from point A to point B with a given level of performance.

On the other hand, packet-based data networks are now seen as the ultimate communication network over which all communication services, including telephony services, will converge. In packet-based data networks, also called packet-switched networks, voice telephony signals are no longer transported through a dedicated communication channel. Instead, voice telephony signals are digitized and then processed according to some standardized or proprietary coders/decoders (a.k.a. codecs) resulting into a time constraint stream of packets. These packets contain both the telephony payload and the destination address where the packets should be delivered. Packets get to their destination hopping over multiple routers that rely on the packet destination address to complete their task. Communication links and router resources used to transmit packets are no longer dedicated but shared with other users over the network, enabling support to other communication services. This complete process of using a packet-based data network for telephony services is called Voice over Internet Protocol (VoIP). In the paradigm of packet-switched networks, the task of a network is to make particular information available to whoever has the right to access that information and at the exact moment it is required.

The main advantage of packet-switched networks used to deliver telephony services is that the communication infrastructure can now be shared among multiple services, consequently lowering the cost of implementation and maintenance of such a network. The main drawback is that direct connection between the delivered telephony service and the dedicated physical link used to provide the service is lost. As a result, ensuring a given QoS level become a much more difficult task since sharing resources among multiple resources may induce network congestion and then affect packet delivery rate. Specialized applications like 911 emergency services are also not trivial to implement because of the weakened relationship between the telephony service and the physical links. Nevertheless, contemporary network engineering practices and sophisticated codecs that can compensate packet drops and packet delivery rate variations (a.k.a. jitter) now make VoIP a reality.

Because of VoIP, telephony market is no longer monopolized and restricted to companies that hold a circuit-switch network. Implementation of packet-switched technology enables cable companies, for example, to enter the telephony market. Even companies without network infrastructure (e.g. Vonage, Skype) can now offer VoIP telephony services, as long as users benefit from Internet connectivity. In a deeper sense, VoIP technology not only breaks the relationship between the telephony service and the dedicated physical link used to provide the service but completely decouples the notion of delivering a telephony service and the notion of transporting information.

Similar to the evolution from circuit-switched technology to packet-switched technology for wired telephony services, wireless telephony services are now at an interesting point where conventional wireless telephony technologies are more and more in competition (or in cooperation) with newer wireless data communication technologies. This is the case when wireless local area network (WLAN) technologies like WiFi, standardized by the Institute of Electrical and Electronics Engineers (IEEE) as a suite of standards in the IEEE 802.11 family, are seen as the vehicle to provide wireless telephony services, also known as voice over wireless local area network (VoWLAN).

The present paper provides an overview of the main elements that have to be taken into account when considering using WLAN technology for wireless telephony services instead of conventional wireless telephony technologies. First, we describe the motivation behind the use of WLAN technology for wireless telephony services. Second, we review the multiple technical challenges that have to be undertaken. Third, we generalize the concept of wireless telephony services over WLAN with the concept of Universal Access, where not only telephony services are offered but also seamless continuous connectivity services are provided. We conclude on a discussion of the challenges behind operation, administration, maintenance and provisioning for such Universal Access services.

3. Motivation

Conventional wireless telephony technologies open the door to communication anywhere at any time. They can be seen as a sophisticated PSTN technologies where the portion of the physical link connecting the user to the network infrastructure is wireless. A dedicated communication channel is used to carry telephony services in the radio cell where the user is located. In that sense, conventional wireless cellular telephony technologies are circuit-switched technologies just like PSTN technologies. In addition to being circuit-switched technologies, additional capabilities are required to manage the wireless aspects and mobility aspects of the telephony service: power and frequency of the radio link, network access rights, terminal authentication, cellular handoff, QoS, etc.

Even at higher cost than wireline telephony, people are increasingly using cellular telephony technologies because of the mobility they allow. A question then arises: why would someone want to use VoWLAN instead of cellular telephony? The answer possesses multiple aspects which are detailed in the following paragraphs.

A first aspect is radio coverage. WLAN technologies are more and more deployed in the environments where people work with computers. These environments are usually located inside buildings where cellular radio coverage may be poor, consequently ending with QoS degradation. Even outdoors, in communities for instance, it can be seen that individuals having a WLAN access point at home contribute to providing short reach access (less than 100 m), which is more than enough to ensure decent radio coverage in many cases. Some municipalities or community organizations (e.g. ZAP in Sherbrooke city or "Île sans fil" in Montreal city) even offer WLAN coverage in dense urban areas. Ubiquity of WLAN coverage is constantly increasing as it is now normally offered in hotels, café hotspots, airports, etc.

A second aspect is the communication bandwidth. The communication bandwidth that can be provided with WLAN technologies is much larger than what can be obtained with nowadays cellular technology. As an example, IEEE 802.11b technology, theoretically allows bandwidth up to 54 Mb/s while actual 3 G cellular technologies like W-CDMA or CDMA2000 provide bandwidth communication in the order of 2 Mb/s. Of course, we are now expanding outside the only field of telephony as less than 10 kb/s is needed for carrying voice with contemporary codec technology (e.g. ITU G.729). But this is how personal communication is evolving: starting with telephony, more and more bandwidth hungry video capabilities or multimedia features are included in communication applications which require Internet connectivity. WLAN represents an important trend for “last-mile” Internet access [1].

This second aspect of communication bandwidth is closely linked to the third aspect which concerns harmonious integration of VoWLAN technologies and computer technologies. This is not solely the case with VoWLAN technology: computer/telephony integration (CTI) was also a major factor in the growing popularity of VoIP technology with respect to PSTN telephony. CTI allows VoIP and VoWLAN services to provide the same basic services as conventional telephony (redial, speed dial, call waiting, call forwarding, caller ID, caller ID blocking, three way calling, etc.) but also makes possible innovative solutions and services like :

- Enhanced Voicemail – access voicemail online or via e-mail and forward voice messages as e-mail attachments;
- "Find Me/Follow Me" – inbound calls automatically ring multiple phones, sequentially or simultaneously based on a personal ring list ;

- Virtual Phone Numbers – set up phone numbers that automatically ring your main VoIP or VoWLAN number, regardless of its area code;
- Click-to-Dial – access or create on the fly call lists stored in your online call logs, in electronic address books or even in web content and "dial" each number simply by clicking on the number;
- Virtual Phone – turn any PC or laptop computer into a phone simply by downloading the VoIP or VoWLAN software to that device, giving you access to your full contact database (e.g. Microsoft Outlook).

… and many more. With these new capabilities, VoIP and VoWLAN technologies not only entered the personal sphere but also the enterprise sphere as IP technologies are being widely adopted as PBX replacement in many enterprises [2].

The final aspect, which is a major one for consumer services, is the cost of the communication service. In principle, with the appropriate software application running on a computer and decent wireless Internet connectivity, a given user can benefit from VoWLAN technology for free. A new question then arises, which is very similar to the previous one: why would someone want to use cellular telephony instead of VoWLAN? The main answer is that QoS is not yet at the same level with VoWLAN than with cellular technology. Users are still willing to pay a small monthly amount in order to get a decent QoS level.

Also, and this is probably where lies the most difficult challenges for VoWLAN, WLAN connectivity is not automatically offered even though WLAN coverage is present in an area. Unless the WLAN connectivity service is an open service offered by a hotel, a municipality, a community organization etc., a VoWLAN user will not be able to use the free telephony service made possible by WLAN access technology. In addition, mobility during the call is a huge advantage of cellular telephony. Cellular telephony relies on a central controller to manage the moment where the cellular phone of a given user needs to proceed to a cell handoff, consequently avoiding dropping the call when moving. Doing the same thing with VoWLAN technology is still a significant technical challenge. These technical challenges are addressed closer in the next section.

4. Technical challenges

As radio coverage offered by an access point is limited by a reach in the order of 100 m, it becomes necessary to use multiple access points to properly cover areas where users want to benefit from VoWLAN. In contrast, a single cellular telephony base station can cover an area at least two order of magnitude larger as the reach is on the order of 1 km. Arjona and Takala [3] evaluated to 30 the number of WiFi access points required to cover one square mile (2.59 square kilometers). One square mile can be walked through in less than 15 minutes causing up to six handoffs (or change of access points). Evidently, the handoff frequency becomes larger as the user speed increases e.g. when the user is using public transportation. As any of these handoff operations is prone to communication disruption or severe QoS degradation, the real technical challenge in VoWLAN mobility is then to maintain connectivity and QoS level when proceeding to the handoff operation.

Conventional cellular technology takes care of the handoff operation by design. In addition to being able to cover a larger area with a single base station, consequently reducing the handoff frequency, the decision to proceed with a handoff from one cell to another is made by a central controller residing in a complex and dedicated network infrastructure. This centralized operation allows phones to be efficiently relayed from one base station to another, keeping ongoing phone calls from being dropped. During this handoff process, all customer and ongoing call information is transferred to the new cellular base station. This operation also performs all required authentication, authorization, billing and network traffic rerouting automatically, without any end user assistance.

In VoWLAN networks, the decision to proceed with a handoff operation belongs to the VoWLAN software application itself, with very limited knowledge about the network state information. The handoff decision is generally triggered by the weakness of the radio signal received from the access point where the mobile unit is connected. Following the handoff decision, all operations like authentication, authorization, network traffic rerouting, etc. need to be performed before pursuing the communication. This process is very similar to the one performed when a wired user reconnects in a new network port. There is no guarantee that the handoff operation will be successful and, consequently, there is no guarantee that an ongoing call won't be dropped. Even if successful the VoWLAN handoff operation can be as long as few 100 ms or even seconds, this delay surely impacts severely user experience.

The VoWLAN handoff operation can be considered in two different cases. The WLAN network on which the VoWLAN service is provided can be either a supervised or an unsupervised network. Let's detail each case.

4.1 VoWLAN handoff in the supervised WLAN case

Many WLAN equipment manufacturers are now offering proprietary solutions where a centralized management system monitors all connected mobile units and available access points [4]. These solutions are usually dedicated to specific geographic areas like campuses that represent a single network domain where the complete network infrastructure is accessible and properly configured.

When a mobile unit needs to proceed to a handoff operation, the decision still remains the responsibility of the mobile unit. However, the handoff process is facilitated as operations like registration, authorization and so on, are performed by the central management system. As a consequence, the handoff latency is kept under a reasonable amount of time (few 100 ms) and is acceptable for VoWLAN applications. This handoff technique is very much inspired from cellular telephony technology.

In the example of Figure 1, all data traffic between A and B goes through the WLAN manager (WM). As B point of view, A is always at the same location. For A, WM is the virtual access point and also the Authentication, Authorization and Accounting (AAA) server of this network. All traffic coming from A always go through WN using tunnels created with access points. When A move between wireless zone 1 to 2, nothing seems to change on the network infrastructure for A and B. As WN is the AAA server, A will not need to re-associate to the new access point, and routing table, kept locally into the WN, allows traffic from B to be delivered correctly.

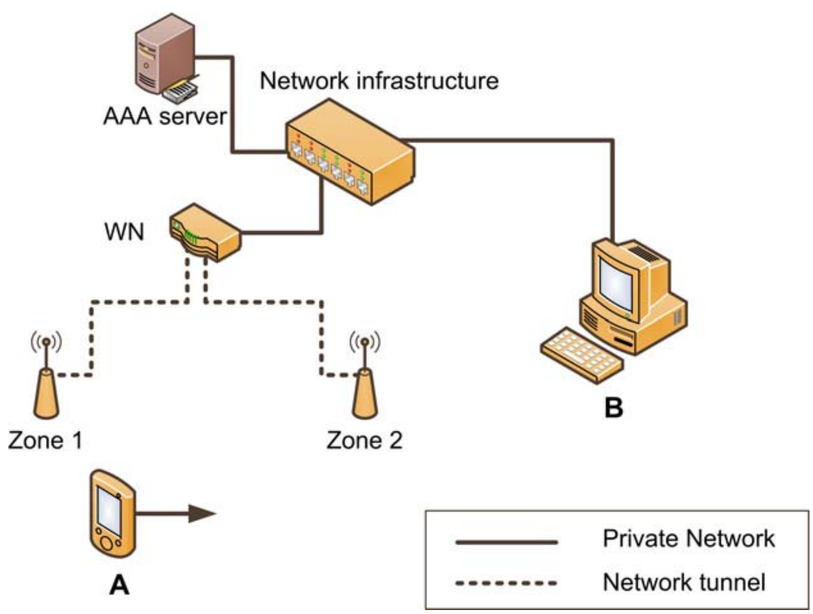

Figure 1   Example of supervised WLAN

4.2 VoWLAN handoff in the unsupervised WLAN case

In the more general case, it is not given that the WLAN infrastructure is totally accessible and configurable to enable centralized management system. An example of such a general case is illustrated by mobile user walking in his neighborhood. This user may successively enter the WLAN radio coverage provided by his neighbors' access points. However, maintaining a VoWLAN while walking will be impossible: in the majority of handoff decisions, if not all, the VoWLAN call will be dropped because of the inefficiency of the unsupervised handoff process where all operations like registration, authorization and so on, have to be undertaken by the mobile unit. Moreover, security features of his neighbors' WLAN access point will most probably prohibit the use of WLAN bandwidth, nailing the VoWLAN communication for good. In fact, major reasons for the handoff failure are:

- Different accounts (user and password) required for access on multiple access points;
- Different login mechanisms or user intervention required;
- Different Internet Service Providers;
- IP address modification;
- Inconsistent available bandwidth and QoS;
- Different radio channels from one access point to another;
- Encryption mechanisms and encryption keys varying from access point to access point.

There is actually no efficient solution for VoWLAN handoff in the unsupervised WLAN case. That topic currently represents state-of-the-art research. As an example of damaging situation, we can look at two techniques currently implemented for general Internet access connectivity [5].

The first technique, largely in use, allows users to access the network through a login web page. As shown on Figure 2, after authentication with a centralized AAA server, the user can access freely to the Internet. Figure 3, show an example of required sequence of messages to authorize a mobile user to access Internet through the newly discovered access point. Possible new IP address, HTTP and HTTPS redirection (with suspended IP communication with internet), user interaction with the Web page, delay to contact the centralized AAA server, are only basics issues to resolve. This mechanism requires user intervention and is not perfectly adapted to seamless handoff between networks.

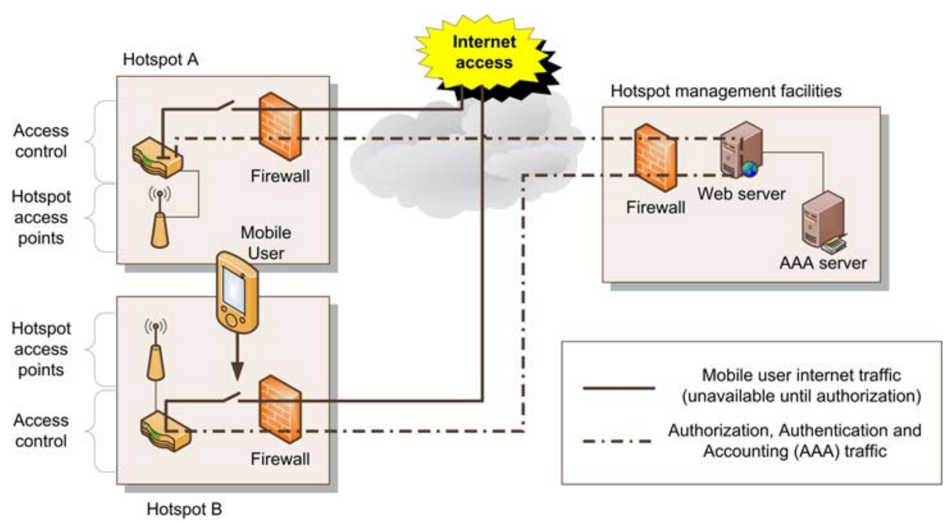

Figure 2 Simplified security mechanisms using a login page for user authentication

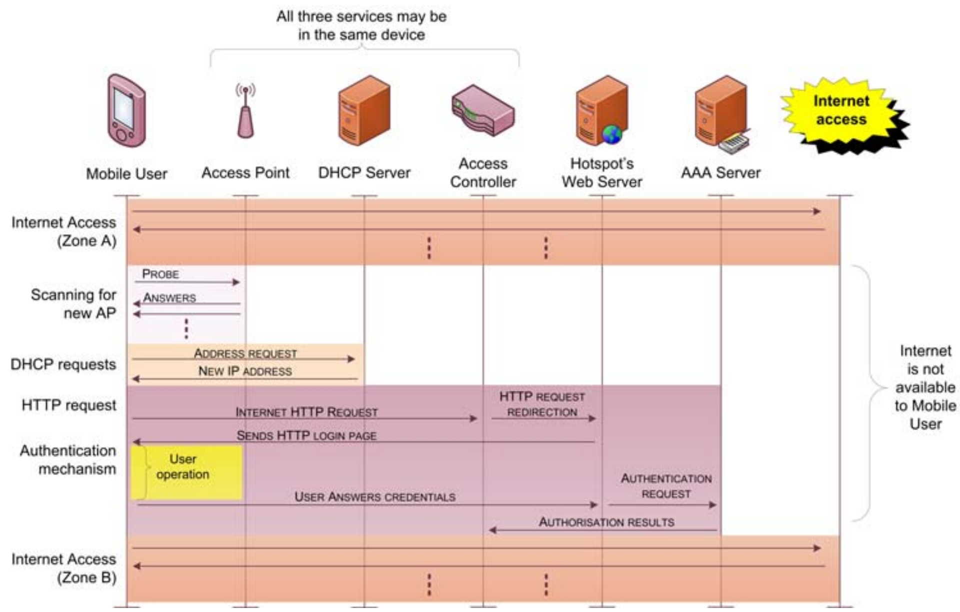

Figure 3 Sequence of messages required to authorize a mobile user

The second technique, offered by some hotspots, allows direct connection using mechanisms based on IEEE standard 802.1X (Figure 4 and Figure 5). This assumes preregistration with all possible hotspots. Again, there are significant negative handoff impacts but, at least, the delay caused by user intervention is removed.

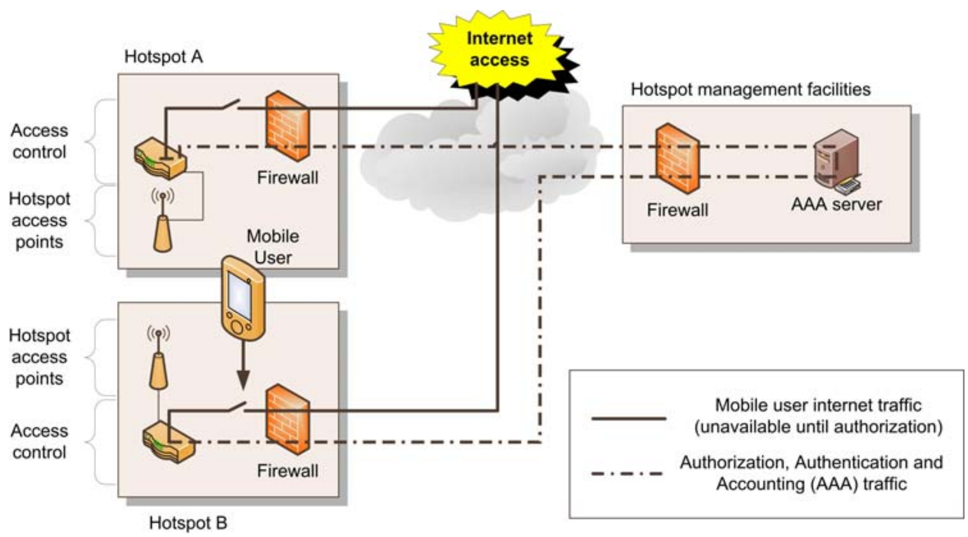

Figure 4 Simplified security mechanisms using an AAA Server without user intervention

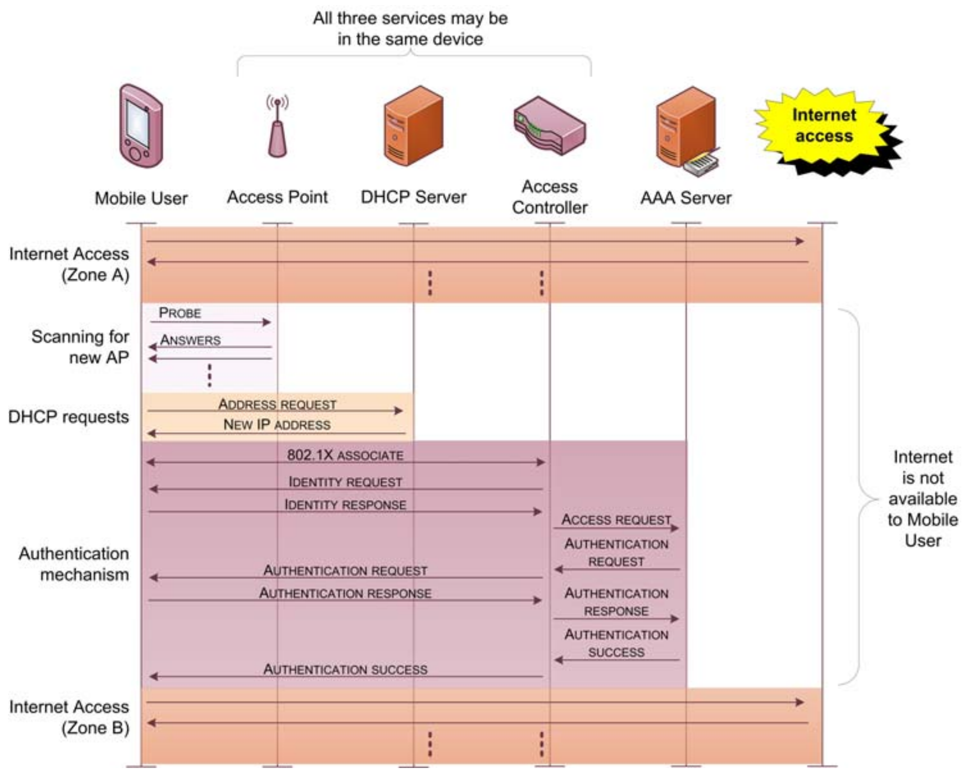

Figure 5 Sequence of messages required to authorize a mobile user using IEEE 802.1X

However, it quickly becomes clear that these techniques are not effective for the VoWLAN case that has stringent requirements on handoff performance. Only situations where users do not move when using VoWLAN (nomadic mobility) can be satisfied with these techniques.

Obviously, the VoWLAN handoff problems in the unsupervised WLAN case come from a lack of standardization of network access procedures and also from a lack of standardization in the sharing of mobile user credentials information among Internet service providers. These aspects are much more advanced in conventional cellular telephony as it is quite usual to be able to roam among networks operated by different network operators. Possible solutions are:

1- Create a centralized database for all mobile users
2- Access already established user information using cellular SIM cards (RFC 4186)[6]
3- Enable a collaboration system to share mobile user information
4- Allow other networks to query mobile user's home network

Some research efforts also try to develop techniques by which the behavior of a mobile user can be learned by its VoWLAN device, allowing advance preparation of the handoff operation before reaching the next access point.

Starting from the motivation behind the desire to use VoWLAN instead of conventional cellular technology, we have been discussing so far the technical challenges, which are related to the handoff procedure needed to go from access point to access point in both supervised and unsupervised WLAN cases. That type of handoff, where the ongoing call is supported by the same technology before and after the handoff operation, is called the horizontal handoff. Next section introduces the concept of vertical handoff. That type of handoff is very important for the general case that we call the Universal Access.

5. Generalizing: the concept of Universal Access

From user perspective in mobile telephony context, the major aspect to consider is to provide ubiquitous service experience to user, with an expected level of QoS and at the lowest possible cost. The underlying technology (ie. VoWLAN or conventional cellular telephony) has no relevance for user. In some areas, where only conventional cellular telephony coverage is available, user has no choice to use it even though the cost of that service might be higher than VoWLAN. In other areas, where both technologies, with acceptable QoS, are available, user will opt for less expansive technology. When such a scenarios is enabled, the concept of Universal Access becomes a reality.

The concept of Universal Access requires many substantial technical challenges to become a reality. We have already explored the horizontal handoff problem in the previous section. In the case of the Universal Access, not only horizontal handoff is needed but also vertical handoff, where the ongoing call is supported by a different technology before and after the handoff procedure. The fact that vertical handoff involves various radio access technologies simultaneously brings an additional degree of complexity to the handoff problem.

The impact of Universal Access on the mobile device is very much significant as the mobile device now needs to be able to access network resources with various technologies. This is why we now see mobile phones that, while being able to access conventional cellular networks, can also access WLANs. The way this is implemented can simply be through the use of a dedicated radio interface for each technology. Such a mobile phone is called a multimode phone. Also, software defined radio (SDR) technology can be implemented instead of relying on a dedicated radio interface for each technology. With SDR, a single radio interface is simply reprogrammed depending on the radio technology that is required at a given moment. As an example, Attala *et al*. [7] recently showed a GSM transmitter that can be reprogrammed to implement a P25 radio interface. GSM is one of the most popular cellular phone technologies while P25 is an emerging standard in the area of public safety communication. Substantial amount of work still needs to be done in the area of SDR before it can be widely applied to solve the problem of Universal Access.

Universal Access becomes a significant challenge for network operators. Through competition, network operators are pushed to get together and find ways to share information making it possible for mobile users to hop from one network to another while being on a call. A significant challenge for operators is to maintain their profit margins while always improving their offering and lowering the cost for the end user. This can only be achieved by converging the network infrastructure to a packet-based infrastructure as much as possible. In fact, that convergence to a packet-based infrastructure is at the center of the actual standardization effort of the 3GPP consortium, where fourth generation (4G) cellular telephony systems are being defined. The only part that remains a differentiating factor is then the performance of the deployed radio access technology.

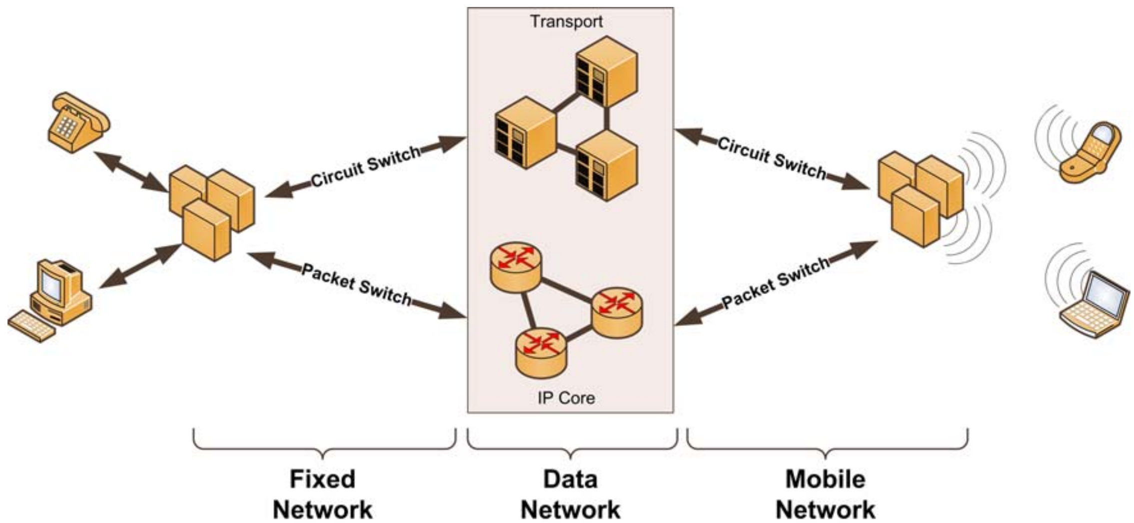

Figure 6 Actual networking architecture

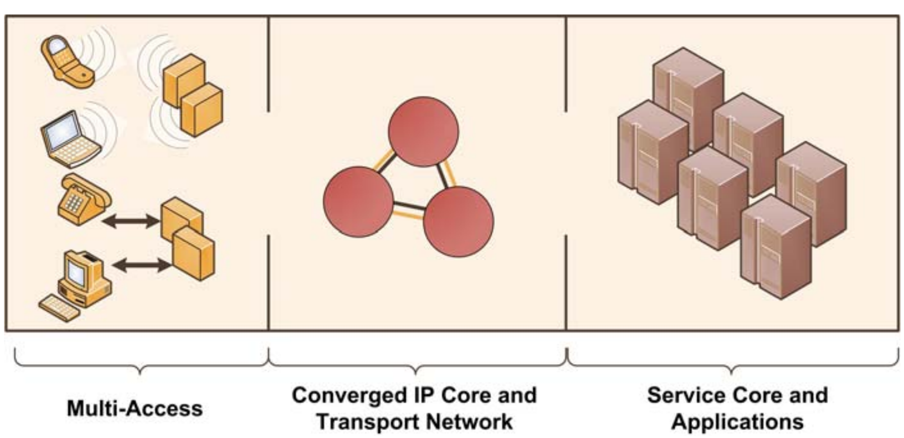

Figure 7 Converged networking architecture

Figure 6 and Figure 7 are inspired from a presentation made in November 2007 by Dr. Klaus-D. Kohrt, head of Industry Marketing at Nokia Siemens [8]. Figure 6 shows actual networks, where the fixed network portion is a totally different entity than the mobile network portion. This is the actual situation. Figure 7 presents the future situation where the fixed and the mobile portions have been converged to a multi-access network and where the packet-based network and transport network are totally integrated. With the exception of access technology, which can be wired or wireless, all information processing and transport are included at packet level, no matter if the information flows is audio, video, control or any other data streams. As a consequence, network operation becomes more and more automated, standardized and simplified. This allows network operators to continue improving their offering to customers while maintaining their profit margin.

Converged network can also be supported at application level. As signalisation for VoIP services is becoming standardized by the IETF SIP protocol, it can be expected to continue using SIP to control multimedia throughout vertical handoff operations. Inherited IP based support network, like GPRS, can convey SIP signalisation messages. Such a solution will enforce network transition transparency for devices.

Converging the network infrastructure to a packet-based infrastructure also opens the door to a new business model where the network operator is not necessarily the service provider. We already mentioned the existence of network-less VoIP telephony service providers in section 2 and we believe this a business model that will be more and more applied.

6. Conclusion

From the networking architecture perspective, we are actually in a very exciting era where networks are converging to packet-based architectures that represent the common denominator for a wide variety of services: telephony, video services, Internet connectivity, etc. Still, because of the physics of things, the network access portion will remain relatively varied as access technologies all have their pros and cons. In some situations, a given technology will be appropriate while it won't be appropriate at all in other situations.

With respect to wireless telephony, the present trend is to enable VoWLAN services whenever possible over conventional cellular telephony. The main motivation to use VoWLAN over conventional cellular telephony is the cost of the communication. However, we have showed that significant technical challenges remain to be solved before radio coverage and QoS level of VoWLAN services get to a level where it can completely annihilate the need to use conventional cellular telephony. Horizontal handoff in VoWLAN networks is now a reality in supervised networks. However, the general case of horizontal handoff in unsupervised networks is much more difficult and is currently investigated by many researchers.

But is it necessary to annihilate the need to use conventional cellular telephony? We don't believe it is. What is really needed is that the proper access technology is applied to the proper situation. To do so, vertical handoff between various technologies has to be transparent to the end user. For the wireless telephony world, this means that mobile devices need to support multiple radio interfaces. That multiple support can be made possible through multiple independent radio interfaces integrated in the same mobile device or by new emerging technologies like SDR which minimizes the quantity of hardware by exploiting software reprogrammability.

From the standardization point of view, many efforts are still needed in order to have mobile users credentials shared among multiple network operators for QoS purposes but also for many other network management aspects (e.g. billing).

As access technologies become transparent to the end user, network operators still have to live with the challenge of maintaining their profit margins while delivering more at a lower cost. This will be achieved by converging the entire network infrastructure to a packet-based infrastructure. The role of network operator and service provider can then be more easily decoupled and this should induce a very interesting competitive offering for end users. Only at this moment will the end user benefit from Universal Access, where the most appropriate access technology will be used at a given situation and where a wide service offering will be possible at anytime, anywhere.

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