Wireless Multi-Access for Personal Area Networks
The Always Best Connected PAN Service

Per Johansson1
University of California, San Diego
pjohansson@ucsd.edu

Abstract

The ongoing deployment of the 3rd generation (3G) cellular networks and, in parallel, the rapid spread of wireless local area networks (WLANs) open up an opportunity to combine the two technologies in a complementary service. The always best connected (ABC) service offers a seamless combination of 3G and WLAN networks. With the ABC service, users can remain connected to IP based network services with one single subscription as they move between WLAN hotspots and 3G coverage. This paper introduces an extended ABC service, which includes personal area networks (PANs), i.e. an ABC PAN service. The ABC PAN service allows users to connect their personal electronic devices, (PDAs, mobile phones, notebook PCs, etc.) to WLAN and 3G networks. The ABC PAN uses Bluetooth to interconnect the PAN devices, but also to connect to external networks via devices with external network interfaces. The necessary functional building blocks involved in the design of an ABC PAN service is defined and described herein. The ABC PAN service is also placed into the context of a user scenario to illustrate how the different functions interact. Due to the ad-hoc nature of the ABC PAN, the Zero Configuration Networking model (Zeroconf) from the IETF is proposed for IP address configuration of an ABC PAN service. The Bluetooth PAN profile provides a suitable infrastructure to base the ABC PAN on in terms of ad-hoc IP network functionality. The discussion and the functional description presented in this paper, indicates that it is fully possible to design an ABC PAN service composed mainly out of existing or drafted standards/specifications from the IEFT, the Bluetooth SIG, the IEEE 802.11, and the 3G standardization bodies.

Introduction

Wireless networking for the vast public is currently undergoing a dramatic change in terms of services and applications offered to the end user. Higher data rates and multimedia based Internet services and applications will be available to a growing set of wireless end user devices. This is the case for both the wireless wide area networking (WWAN) technologies as well as for the wireless local area networking (WLAN) technologies. In both cases, the aim is to provide Internet access over IP networks to able to offer a richer set of applications to the end users. New end-user devices also fuel this development by becoming more and more capable (processing, memory, etc.) and often host several different wireless interface technologies. For instance, a modern notebook PC has both WLAN and Bluetooth built in and may have cellular access via a GPRS or CDMA2000 PC card. In addition, PDAs and mobile phones both come with phone capabilities and high definition color displays. Moreover, a user may have a set of devices organized in a Bluetooth based personal area network (PAN), where each device may offer one or more interfaces to external networks to the user. The challenge in this multi-access network environment is to offer an access service for the user that is secure, efficient, understandable, and most importantly, easy to use.

This paper presents a network architecture that composes one single (IP) network access service for the end customer based on multiple access network services: the Always Best Connected (ABC) service. The ABC service supports the user in the selection of available networks for connectivity and also provides seamless mobility between different access networks for uninterrupted service during mobility. In addition, the service provider is given

1 On assignment to conduct research at UCSD.

the capability to show one face to the customer in terms of authentication services, and applications; i.e. personalized services are maintained across different access networks. The ABC concept was first presented in 0, and this paper takes a starting point from 0, but will expand the notion of multi-access networking to the personal area networking space. That is, we introduce an ABC PAN service, which offers the ABC services to a PAN user. Moreover, we will focus on the case where the PAN ABC service operates in a combined 3G (UMTS/GPRS, CDMA2000) and WLAN (IEEE 802.11b) environment (see Figure 1).

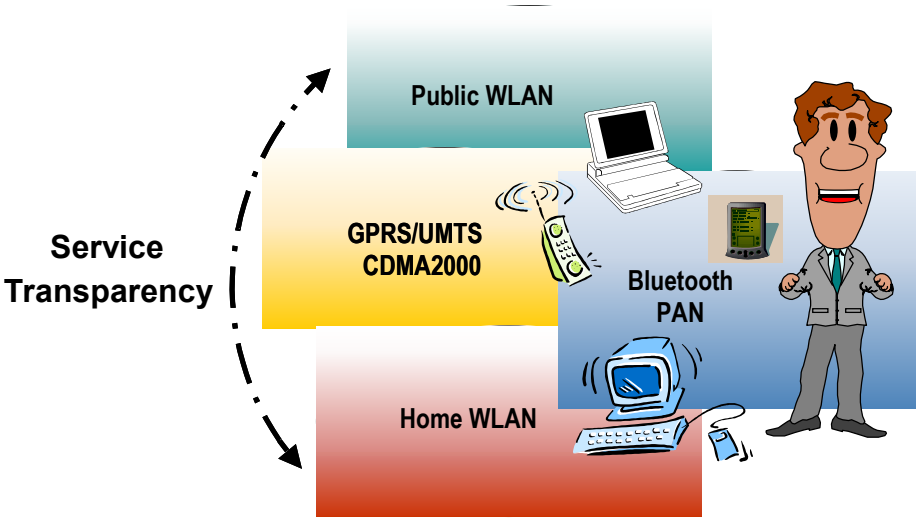

Figure 1. The ABC PAN user can connect his PAN devices to 3G and WLAN networks.

The paper is organized as follows. Section two gives a background to 3G and WLAN and point out some inherent differences and similarities. Section three describes the ABC concept and business case related to an ABC service. An ABC PAN user scenario is given in Section four. Section five outlines the necessary functional building blocks in an ABC PAN service and Section six is dedicated to describe the ABC PAN functionality in more detail.

WLAN and 3G Services

From being basically a wireless extension for telecom voice services only, e.g. TDMA, IS-95, and GSM, the next generation of cellular networks promises to provide data communication services to the end user. This next generation of cellular networks is often referred to as the 3rd Generation cellular networks, or 3G, and is today comprised of two major systems: *Universal Mobile Telephony System* (UMTS) and CDMA2000. The standardization efforts for these systems reside in two standardization collaboration organizations2 namely the *3G Partnership Project* (3GPP 0) for UMTS and the parallel 3GPP2 0 for CDMA2000. Both standards have, to a large extent, adopted protocols that also are used in the Internet to offer data communication services, i.e. the 3G standards are based on the Internet Protocol (IP) standards developed within the *Internet Engineering Task Force*, (IETF 0).

2 3GPP is a collaboration project between ARIB, CWTS, ETSI, T1, TTA, and TTC. It produces specifications for a 3rd Generation mobile system based on evolved GSM core networks and the radio access technologies that they support (i.e. WCDMA). It also includes maintenance and further development of the GSM specifications including evolved radio access technologies i.e.GPRS and EDGE. 3GPP2 is a collaboration project between ARIB, CWTS, TIA,TTA, TTC and is an effort between North America and Asia to develop specifications for ANSI/TIA/EIA-41 towards a mobile system network evolution to 3G based on the CDMA2000 radio access technology.

In parallel with the cellular evolution from 2G to 3G, the local area networks (LANs) have seen a very rapid deployment of wireless LANs (WLANs). A WLAN provides wireless broadband extensions to the fixed Internet, or to a corporate intranet, and has recently also become very popular as a wireless extension to a residential broadband access (e.g. DSL or cable). In addition, several public spaces, such as airports, city centers, and university campuses have also deployed WLANs and now offer Internet access to the public and to campus communities. The most widely spread WLAN standard has been developed within the IEEE 802.11b standards group 0, and it specifies an Ethernet-like wireless link layer that operates in the license free 2.4GHz IMS band. In contrast to the 3G development, the IEEE 802.11b standard only specifies functionality from the physical layer up to the link layer. For functionality above these layers, legacy IP networking is used and thus relies on standards developed within the IETF.

Even thought there is a certain overlap between the services offered over the 3G and WLAN networks, the two network technologies address inherently different application requirements. The 3G networks will offers a mix of datacom and telecom services globally available for mobile users. This is basically an extension of the behavior of today's 2G cellular networks in terms of user reachability and uninterrupted operation of applications during mobility. Several of these applications will still be interactive user-to-user voice communication, but amended with datacom oriented content, for instance interactive multimedia aaplications. Typically, high data rates will be sacrificed for the sake of larger coverage and user mobility, and the user will in, most cases, be offered data rates in the order of a few hundred kilobits per second. Still, the key application for the 3G network is to offer user-to-user communication that is independent of user location and user mobility.

The WLAN networks, on the other hand, are wireless extensions of legacy IP networking where the basic end user device typically is a mobile computer such as a notebook PC. The main driver for WLAN based Internet access is the convenience of un-tethered Internet and/or Intranet with basically maintained LAN data rates within a limited coverage area (radius typically less than fifty meters). WLAN users will, in most cases, continue to use the same set of applications used when they were attached to a fixed network access, i.e. client-server based applications where macro mobility support is of limited importance. However, mobility within a building or a campus is still within the scope of interest since that allows the user to easily move between offices and meeting rooms with uninterrupted applications. Thus, a larger coverage area is sacrificed for higher data rates in a limited, and many times, access controlled area. The key application for the WLAN is to offer high speed client-server based applications such as Internet web browsing and media streaming to the user.

Even though wide area and local area wireless technologies have aimed at supporting different communication needs, a service that combines the two would seem to have the potential to offer the best of the two "worlds". The challenge is how to make this combination easy to use, affordable, and flexible enough to attract a wide user group. The next section describes one approach to offer such a service: the *always best connected* (ABC) concept, which combines the services offered by the WLAN and 3G networks together into one integrated service, the ABC service.

The Always Best Connected Concept

In a future, IP based, common core network, we still expect to see a heterogeneous wireless access network environment composed of various access technologies, for instance IEEE 802.11(a,b,g etc.), UMTS (WCDMA, EDGE, GPRS/GSM), CDMA2000 (1X,

EV-DO, EV-DV), and in some cases Bluetooth. Within each family of these access networks, interworking is normally a part of the product evolution strategies where multimode and/or integrated user terminal equipment is a way to offer seamless multi-access solutions as the networks evolve to new technologies. However, across these technologies, only a few examples of interworking solutions exist. Cross technology interworking is a key functionality, which must be present in order to offer seamless services in a common IP based network with heterogeneous access networks. This ubiquitous multi-access interworking functionality should give the user the option to always be connected to the services offered by the network independently of the current (available) connectivity environment.

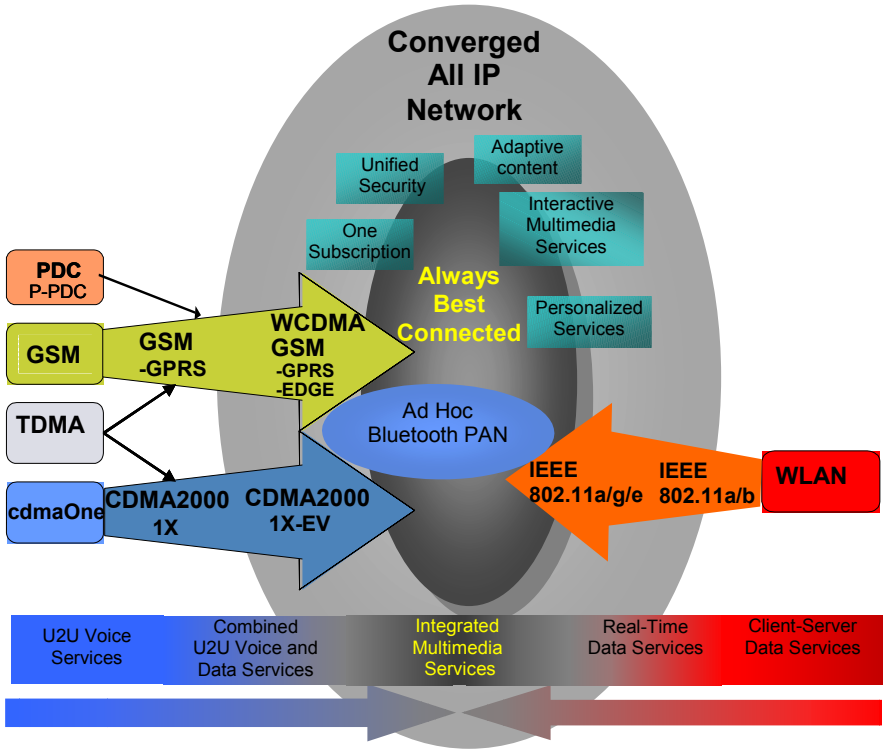

Figure 2. Schematic view over wireless telecom and wireless datacom convergence an all IP framework. The ABC service plays a central role in this stepwise evolution.

Depending on personal preference, a user may opt to make decisions regarding which access network to connect to, or let it be handled entirely by the multi-access interworking function, so the option to be always best connected should be given to the user. This notion of an always best connected (ABC) service is outlined in this paper and comprises the functional components to offer a seamless connectivity support to a wireless network user. The ABC concept refers to being not only always connected, but also being connected in the best possible way, combining in this case the world-wide coverage of cellular systems with the high bandwidth of WLAN hot-spots.

On a longer term, the ABC service could be seen as a step towards an all IP3 network that will support converged multimedia services over one commonly shared IP network.

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3 The term “All IP” network is often used to describe a future shared, common, core IP network that is capable to support converged telecom and datacom

However, the wireless access network technologies will still be heterogeneous where new technologies are added and older technologies slowly fade away. Hence, the ABC service plays a central role to tie different wireless networking services together into a useful service (Figure 2). Nevertheless, a fully converged all IP network is still several years ahead and in this paper, we will focus on how the ABC service can be realized with network components that all are available today.

A number of different aspects need to be considered when designing the ABC service:

- the business relationships between the different actors in the system, i.e. the network access operators, network service providers, network content providers, and the end user,
- the required user experience of ABC, and
- the actual technical solutions in the network and in the end user terminal(s).

Regarding the end terminal(s), a user may carry several devices that all have or require external connectivity. A natural extension of the ABC concept is to allow a user to easily connect more than one device to an external network and at the same time interconnect his/her devices together in a local personal area network (PAN). The PAN devices could be notebook computers, PDAs and cell phones interconnected via Bluetooth to synchronize calendars, exchange smaller files etc. We will discuss the implications a PAN will have on the ABC service later in the paper.

Finally, the scope of the ABC service described herein will focus on how to realize the seamless traffic connectivity and unified user authentication component of the ABC service. This will enable smooth interworking between client-server based applications over both WWAN and WLAN for the end user, which is probably the most useful ABC capability for the user today. The user will benefit from a unified “always on” way to access applications such as e-mail, web browsing, messaging (with pictures), streaming video/audio, and corporate network access. Thus, interactive user-to-user multimedia services over the ABC service is not described in this paper, but could still be considered as part of the overall ABC concept.

An ABC Business Scenario

The ABC service inherently needs to deal with the business relations between different access network operators and network service providers. In the case of a cellular network operator, these roles are in most cases combined; the network service provider is also the access network operator. However, in the case of mobile virtual network operator (MVNO), the network service provider does not operate the network access, e.g. does not own radio spectrum. One example of an MVNO is Virgin Mobile in the UK, who is marketing to its customers based on a well-recognized brand name.

For the WLAN access, the business models are more scattered, which is mainly due to the fact that WLANs operate in an unlicensed spectrum. This leaves the field open to wide variety of residential, corporate/campus and public WLAN initiatives to provide wireless Internet access. A public WLAN access, or hotspot, may be run by a wireless ISP (WISP), such as Wayport, Boingo, or by a cellular network operator such as T-mobile.

(multimedia) services by means of end-to-end QoS support functionality (e.g. Diffserv plus RSVP).

Thus, a number of business combinations exist of the three roles: access network operator, network service provider, and the ABC service provider. However, we will make the assumption that a traditional cellular network operator (i.e. a combined access network operator and network service provider) also provides the ABC service. Furthermore, we will assume that the WLAN access is offered by a public WISP that has a fairly large subscriber base, and that there is an agreement between the cellular operator and the WISP to provide WLAN access for the cellular subscribers. A more general discussion about ABC business combinations is given in 0.

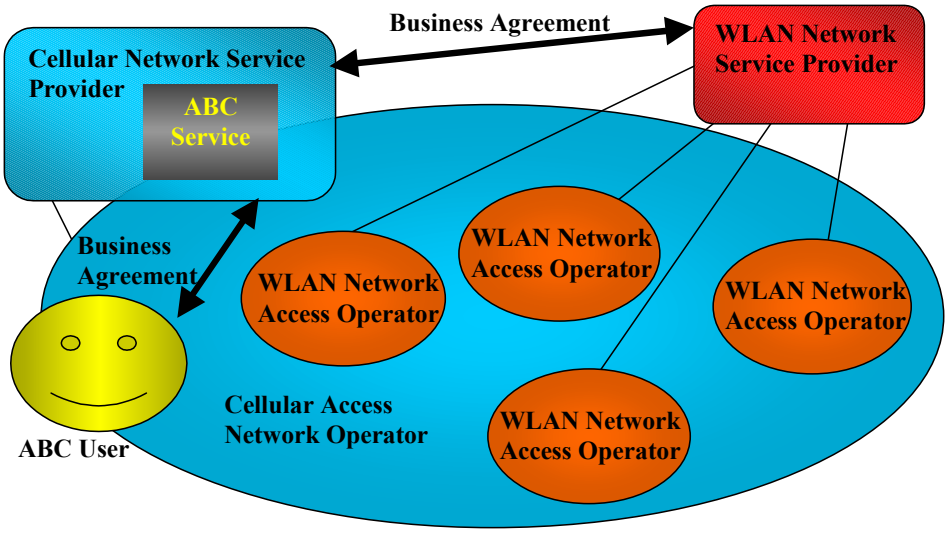

Figure 3. ABC business relationships.

The example given in Figure 3 depicts the case where the ABC user has a business relation to the cellular operator, who hosts the ABC service. Access to the WLAN services is provided through the cellular subscription, which means that the user authentication is executed in the background between the WISP and the cellular operator.

The ABC PAN — An Ad-hoc ABC extension

The ABC solutions have so far mostly been focused on providing multi-access to one terminal that moves between different network contexts, basically with or without WLAN coverage. In most cases the user has more than one device that is capable to connect to the network or has the potential to do so. This may be cellular phone, notebook computer PDAs, cameras, DVD players, mp3 players, game devices etc. A collection of such personal user devices may form personal area networks (PANs) based on a short range ad-hoc wireless technology such as Bluetooth 0 0 0 0. Now the multi-access functionality becomes a distributed functionality where one or more of the PAN devices may play the role of access gateway to an external network – either a WLAN access or a cellular network access. In principle, the same type of functionality as in a single device case must be satisfied in the PAN case as well, but in a distributed environment.

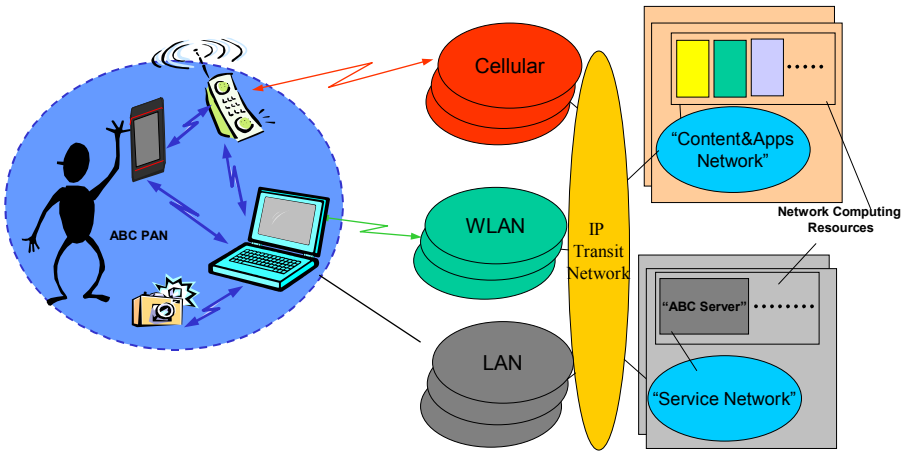

Figure 4. A Bluetooth based ABC PAN offers an aggregate of network access networks to the user.

Seen from the viewpoint of the traditional mobile network, a Bluetooth based PAN opens up a new way to extend the mobile network services into the user domain and to other devices further out in the PAN. In terms of traffic load offered to the network, the aggregate traffic of the PAN would typically exceed that of the single mobile phone.

Figure 4 illustrates the case discussed above with a scenario of a Bluetooth ABC PAN consisting of a notebook computer, a cellular phone, a digital camera, and a PDA. In case the mobile operator offers an ABC service, the ABC PAN could make simultaneous and coordinated use of both the 3G access and the WLAN access to achieve an efficient utilization of all the available network resources. Thus, the ABC PAN would benefit from the total aggregate of all access technologies residing in the devices of the ABC PAN.

As the ABC PAN concept matures, it will allow new devices and new access technologies to be incorporated into the ABC PAN framework. It may also eliminate the need to create hybrid devices, such as a combined PDA-mobile phone, since the PAN network will instead allow for wireless integration. In other words, it will not be necessary to trade off form for function.

ABC PAN user scenario

In order to illustrate the ABC business case and the ABC PAN capabilities outlined in the previous section, we will describe an example scenario of an ABC PAN user, Leah, who has subscribed to the ABC service offered by her cellular mobile operator. Leah works as a sales manager for a larger corporation and spends a fair amount of time traveling between customer meetings and her corporation's offices, both by car and by air. This means that her office environment changes between her residence, her car, the visited customer offices, and her own corporate office. Thus, a mobile office that keeps up with her mobile work schedule is a requirement in order to coordinate meetings with short notice and, for instance, to always be able to access the latest sale information requested by her customers. Below, we will follow Leah in a typical, mobile, day.

At home 07:00 AM (PST):

Leah takes part in an internal corporate meeting to prepare the customer meeting later today. Five people take part in a video conference. In her home, Leah uses her residential WLAN connected via a DSL ISP access and takes part in the meeting using her desktop PC (which has a high quality video/audio system). A secure corporate IP tunnel is used to connect to her home office. During the meeting, she downloads a new customer presentation to her notebook PC controlled remotely from the desktop PC over the Bluetooth ABC PAN. Likewise, her PDA, mobile phone, and notebook calendars and e-mail clients are automatically synchronized with the new agenda items and new e-mails over the ABC PAN.

Drives to customer meeting, 08:00 AM

On the way out to her car Leah selects to continue the conference over the mobile phone (voice only via her Bluetooth headset) and the ABC PAN initiates the move of the voice session over to the mobile phone over the 3G network. Pictures of the voice conference participants now show up on the mobile phone display. Inside the car, the in-car Bluetooth network automatically interacts with the mobile phone and the session is moved over to the car hands free audio/video system and the 3G access now goes via an ABC capable mobile access router in the car (the mobile access router also has a WLAN interface to be used in cases when the car is within WLAN coverage). During her commute, Leah receives the customer's office location from one of the conference members. These coordinates are automatically given to the navigation system in the car as a mobile feature of the conference application. A last minute update to the customer presentation is automatically sent to the notebook PC (via the mobile access router over the ABC PAN).

Arrives at customer office, 09:30 AM

The customer office has an open WLAN service as a courtesy to visitors so Leah's ABC PAN gives her the option to access her company's corporate network (through an IPSec tunnel) via the WLAN (alternatively, she connects via the 3G access). One part of the sales presentation is given by one of the technical experts from Leah's corporate office via her notebook computer. The presentation application connects to the audio/video system in the customer's office via an A/V Bluetooth network in the conference room. Leah receives comments on her product proposal (documents and presentations) directly from the customers via their interconnected Bluetooth PANs; she then feeds the comments back directly into the corporate product development system via the WLAN access. Some of the urgent issues brought up by the customer can thus be dealt with immediately based on a precise customer feedback.

Drives to corporate office, 02:00 PM

On the way back to the car, Leah's ABC PAN connects to the 3G network via her mobile phone to maintain the connectivity. Inside the car, the in-car Bluetooth network (mobile access router) takes over the access connectivity via a WLAN public access in the plaza outside the customers office. Before she drives to her corporate office, Leah reads and replies to some e-mails that have been left unanswered. When Leah drives away and out of the WLAN hotspot coverage, the ABC mobile access router in the car automatically switches over to the 3G network. On the way to the office, Leah enters an internal customer debriefing conference via her in-car audio/video system (no video is activated since she's driving) to give a first report about the meeting.

In corporate office, 03:00 PM

When Leah enters the office building, her ABC PAN switches from the 3G mobile phone access to the corporate network WLAN via her notebook PC in her briefcase. She continues the conference on her PDA, connected via the notebook PC over the ABC PAN, now with the video component enabled. The power level in the PDA was low, so the ABC PAN service automatically selected the WLAN connection via the notebook PC (in her briefcase) over Bluetooth instead of directly using the more power consuming internal WLAN interface in the PDA. When Leah enters her office, her ABC PAN moves the videoconference session over to her desktop PC. The ABC PAN maintains calendars and email clients synchronized in all the devices as Leah is scheduling new meetings for the days to follow.

Driving home, 05:00 PM

Leah finishes her last report just before 5:00 PM and plans to go home. To relax a bit after a hectic day, she connects her Bluetooth stereo headset to her 3G phone that has a built in mp3 player. As part of her 3G subscription, she has a music service that constantly, but in the background, downloads her preferred music. This service is opportunistic when connected in an ABC PAN in the sense that it downloads more songs if the PAN is within WLAN coverage. When entering the car the mp3 player in the ABC PAN connects to the car's A/V system and Leah can enjoy her favorite music on her drive back home.

The scenario above shows that the ABC service and the ABC PAN can maintain a user connected to various business applications while on the road. It also helps to identify a number of requirements for the ABC service and the ABC PAN in terms of agility to detect, select, and adapt to new access networks in a dynamic network environment. In the following section we list necessary functional components to build an ABC service and to further extend it with an ABC PAN capability.

ABC Functional Building Blocks

The ABC service described in the previous sections will require a number of functional building blocks in order to provide the necessary service. We have organized these into the following entities (Figure 5): access discovery, access selection, AAA4 support, mobility management, profile handling content adaptation, and ABC PAN functionality.

Parts of the functionality need to be implemented in the ABC PAN devices, and other parts need to be implemented in the network. The following describes each functional block in further detail.

4 Authentication, Authorization, and Accounting

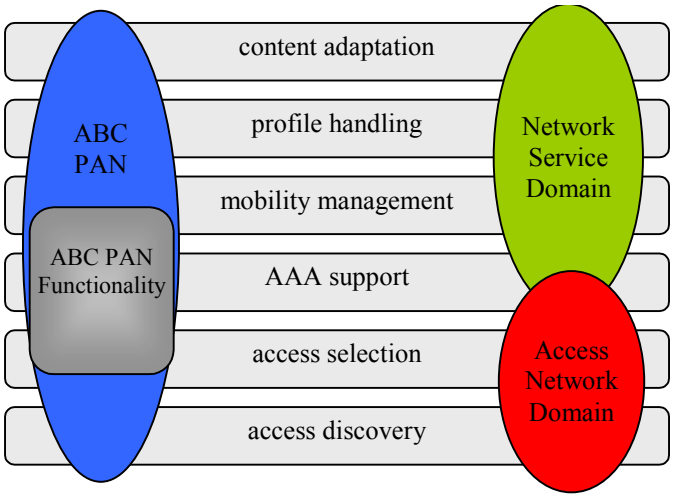

Figure 5. The functional building blocks of an ABC PAN solution.

- Access discovery and Access Selection

When an ABC PAN device is turned on, it performs access discovery to find the available access networks and/or access devices that can offer IP connectivity. The entire PAN is within the scope of the access discovery, which means that some access networks are reached directly in the devices and some will be reached via a PAN gateway device. The access discovery may be using an ABC PAN internal service discovery function to find the available access networks in the PAN.

Access selection refers to the process of deciding which access network to connect over at any point in time. We identify three important parts of this: device-based selection, network-based selection, and user intervention. When selecting access, a number of different aspects need to be considered:

- ABC PAN user profile, which contains the user's personal preferences for choice of access;
- preferences from the network service provider or a corporation;
- network characteristics, for instance available bandwidth, cost, and operator;
- device capabilities and application requirements.

At start time, or if the connectivity is lost, an ABC PAN device needs a stored profile, a priority list, a default setting, or prompt for the user to choose access network based on the access discovery.

A benefit of network-based support for access selection is that a network service provider could offer network-specific information, such as performance measurement data, that may be hard for the device to acquire itself. Network-based access selection also allows for radio resource efficient selection and load balancing in order to maximize the total system throughput.

- Authentication, Authorization, and Accounting (AAA) support

A key component in any ABC scenario is the AAA infrastructure. The purpose of an AAA solution is to verify the ABC user identity (authentication), to verify what service the ABC user is entitled to (authorization), and to collect and present data to bill the ABC user for the service (accounting). The AAA functionality is needed for the ABC PAN to access the network and the ABC service, but also for applications and services, such as corporate network access. These solutions may be incorporated into one solution enabling a single logon for the user.

Let us visit Leah again. Leah has a subscription with a cellular operator Cellular (UMTS or CDMA2000). Cellular has a service agreement with a WLAN operator (called WLANspot), who provides WLAN coverage in hotels nationwide, to offer WLAN access to Cellular's customers. On a business trip, Leah stays in one of the hotels where WLANspot offers network access. When she enters the hotel, her ABC PAN devices with WLAN interfaces (a notebook computer and a PDA) automatically discovers the WLANspot's access point(s). Since she has her hotel reservation information stored in her PDA she initiates an office application on the PDA, which automatically connects to one of the discovered WLAN access points. During the connection procedure, Leah's PDA is asked to provide credentials for authentication. These credentials are sent to the WLANspot AAA server (Figure 6 (2)). Now, the WLANspot AAA server realizes that Leah does not have a subscription with WLANspot, but has one with Cellular, and the request goes from the WLANspot AAA server to the Cellular AAA server (Figure 6 (3)). The Cellular AAA server verifies that this is indeed Leah and that Leah's PDA shall be allowed to use the WLAN network, so this information is sent to the WLANspot AAA server. The WLANspot AAA server can now grant Leah access.

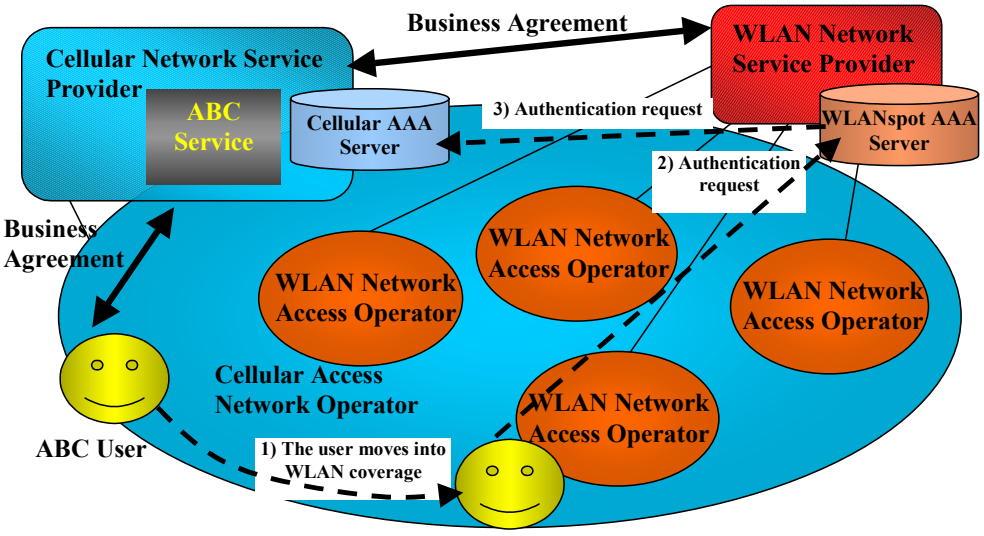

Figure 6. Example of AAA support for the ABC service. The user moves from a cellular network to a WLAN and gets authenticated by the Cellular AAA server through the WLANspot AAA server.

This scenario requires an authentication interface between the two operators. The next generation AAA protocol, which is currently being standardized by IETF is called Diameter. Diameter, which consists of a base protocol 0 and Diameter applications such as the

Diameter NASREQ and Mobile IPv4 applications, provides a number of enhancements compared to the existing protocol for remote authentication dial-in user service (RADIUS). The solution for radio access network authentication in GPRS/UMTS and in CDMA2000 is based on MAP/SS7 signaling to the home location register (HLR), while both systems also support RADIUS/Diameter for IP-based services. Also, 3GPP is currently defining the home subscriber server (HSS), which is a combined HLR-AAA/Diameter entity, for future releases of GPRS/UMTS.

- Mobility management

There are different aspects of mobility that may be provided as part of the PAN ABC service. We distinguish three enhancements from a mobility management point of view:

1. session continuity – to maintain a session when the PAN ABC terminal moves between different access networks and technologies;
2. session transfer – to maintain a session when the user or applications move between different devices in the ABC PAN;
3. reachability or presence – which refers to the ability to reach an PAN ABC user at his or her current access network and device.

There are different solutions available to provide this functionality. One solution for session continuity is Mobile IP 0; an IP layer solution aimed at making movements on the IP layer transparent to higher protocol layers. Solutions for session transfer are typically based on higher layers, for instance session layer mobility 0. The session initiation protocol (SIP) 0 is a solution for reachability/presence of ABC PAN users.

- Profile Handling and Content Adaptation

When a user subscribes to an ABC service, a user profile is set up containing the user's personal preferences for choice of access, application adaptation, and virtual private network (VPN) solutions. The user profile is stored by the ABC service provider and can be updated either by the user directly or through the ABC service provider. The ABC service provider also keeps a profile for the user containing information regarding what the user's subscription allows him or her to do (for authorization), user credentials (for authentication), and accounting data.

It is essential for applications to adapt to current conditions. One approach for adaptation is for the application to detect changes in network characteristics and/or device capabilities and request the application server to adapt the contents accordingly. Another approach is for the terminal to provide information about the access network and device either to the application, to the application server or to databases and servers in the ABC service provider network. A third approach is to let the access network provide information to the application server and/or the device regarding network characteristics, for instance notification of quality of service (QoS) changes.

ABC PAN functionality

The ABC PAN needs a set of functions in order to form and maintain the PAN device connectivity and to offer the ABC service to an ABC PAN user in an understandable way. In particular, the ad-hoc operation of the PAN poses a challenge in terms of IP networking

functionality. IP address configuration, name resolution, IP mobility, and IP security are all affected by the dynamics of the ABC PAN.

The next section will describe the ABC PAN functionality in more detail and also outline some possible solutions.

ABC PAN functionality

The ABC PAN gives the ability to select an access network indirectly via one or more PAN devices. Potentially, any of the devices in the PAN may be able to offer an external network access to any other node in the PAN; thus, an ABC PAN device could act as both an end host and/or a packet forwarding node. In fact, the ABC PAN will form a wireless ad-hoc network extension to the 3G and WLAN access networks. We will take a closer look into what type of functions that are necessary parts of the ABC PAN.

We will assume that the PAN is based on Bluetooth since it provides the necessary features in terms of security, ad-hoc operation, low power, low cost, and recently, it also defines a PAN profile 0. The PAN profile enables the devices in a Bluetooth piconet5 to be interconnected in an Ethernet-like fashion (packet format defined by IEEE 802.3), which enables a straightforward IP sub-networking between the nodes in the ABC PAN. Therefore, the underlying piconet topology is abstracted into a broadcast segment where all PAN devices are only one virtual hop away from each other (see Figure 7). The Bluetooth PAN profile uses the Bluetooth network encapsulation protocol (BNEP) 0 to implement the Ethernet-like interface and the bridging of packets between Bluetooth slave nodes, i.e. between devices that has more than one Bluetooth hop between them.

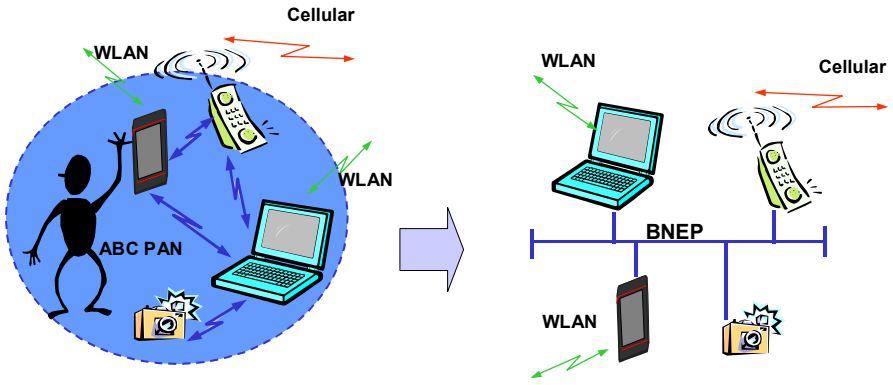

Figure 7. The Bluetooth PAN uses BNEP to create an Ethernet-like broadcast environment.

5 A Bluetooth network is based on the piconet, which is a star topology where the piconet master is the central node and the piconet slaves are the peripheral nodes. A piconet is formed in an ad-hoc manner where any node may select to be master or slave depending on which Bluetooth profile the devices select to use. Each piconet is using its unique random frequency hop channel, which is determined based on the masters unique device address (a 48-bit MAC address).

Since the Bluetooth PAN offers an ad-hoc Ethernet equivalent, there are basically two main options on how to access an external network for a node within the PAN:

- The PAN access device acts as an Ethernet bridge towards the external access networks and the “first” IP router a packet meets will be located inside an access network, e.g., in the 3G operator’s IP network or on the LAN.
- The PAN access device acts an IP router towards the external access networks and is an IP gateway for the nodes in the PAN.

The two cases result in two fundamentally different ways to configure the ABC PAN devices from an IP networking point of view. In both cases, we assume that the ABC PAN devices needs to be dynamically configured with an IP address. In the bridging case, the bridging unit can be kept fairly simple, but it requires all devices to be on the same IP sub-network provided by the access network. The latter also has to issue one IP address for each unit in the PAN.

For the routed case, on the other hand, the access device needs to act as a router, possibly also as a network address translator (NAT), and may also offer a dynamic host configuration protocol (DHCP) service for the devices in the ABC PAN. Offering this functionality may be heavy-weight for a “thin”, low-power device such as a 3G phone. However, we expect these types of devices to gain more processor capacity and power efficiency and, thereby, be capable of handling the routing case. Moreover, a router will make a clear distinction between the access network and the PAN that will help to limit the scope of functions and access according to legacy IP (sub) networking principles. In the description that follows, we will make the assumption that external network access is provided via an ABC PAN gateway device that acts as an IP router.

ABC PAN cases

We will outline a few topological cases that the ABC PAN functionality needs to handle, primarily in terms of the selection on which gateway device to select. We will look at the following cases:

1. The ABC PAN has one device that can act as the gateway to a number of different access networks.
2. The ABC PAN has more than one device that can act as gateways to different access networks.
3. The ABC PAN has more than once device that can act as gateways to different access networks. In addition, the host device can also be a gateway.

The first case is depicted in Figure 8, where three ABC PAN devices use their Bluetooth connectivity to connect to any of the external networks offered through the ABC PAN Gateway device. The three devices may either have other external interfaces residing in them that they choose not to use (e.g. due to power reasons) or simply be a Bluetooth-only device (e.g. mp3 player, or a digital camera). This ABC PAN case would be typical in a car scenario, where the ABC PAN gateway device would be an in-car ABC mobile access router that relieves the ABC PAN devices from a power consuming external access. The ABC PAN connectivity function may present the ABC PAN devices with options on which external network to connect to. Therefore, the gateway node needs to route the packets dependent on the choice the source ABC PAN device selects.

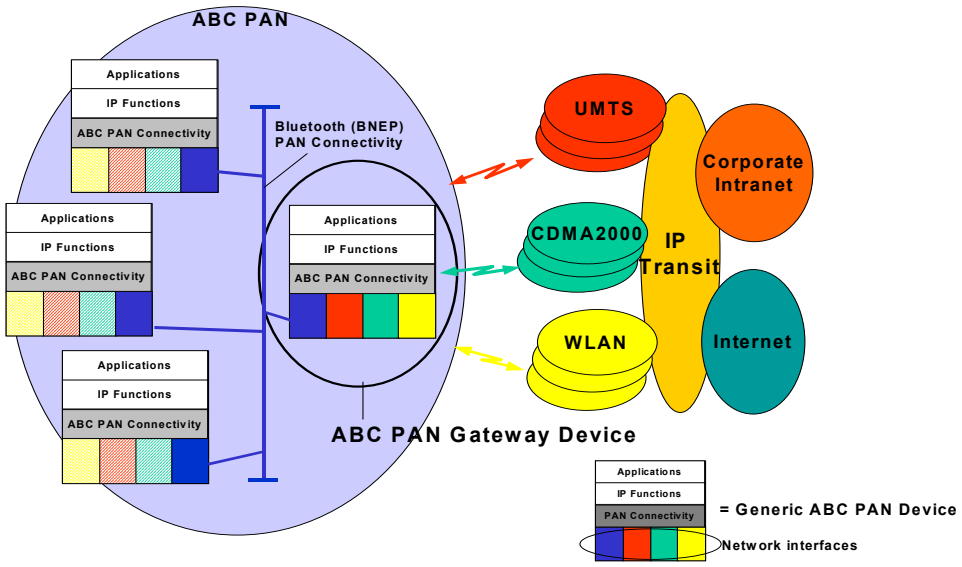

Figure 8. The ABC PAN has only one external gateway device for external network access.

Figure xx2 depicts the second topology case, where the ABC PAN has several devices that offer access to external networks (two in the figure). In this case, the ABC PAN connectivity function may also present the ABC PAN devices with choices of external networks, which indirectly gives the selection of the connecting gateway. In addition, the same external access network may be offered by more than one external device. The decision will be based on a combination of best gateway device and best access network for the application(s) in question.

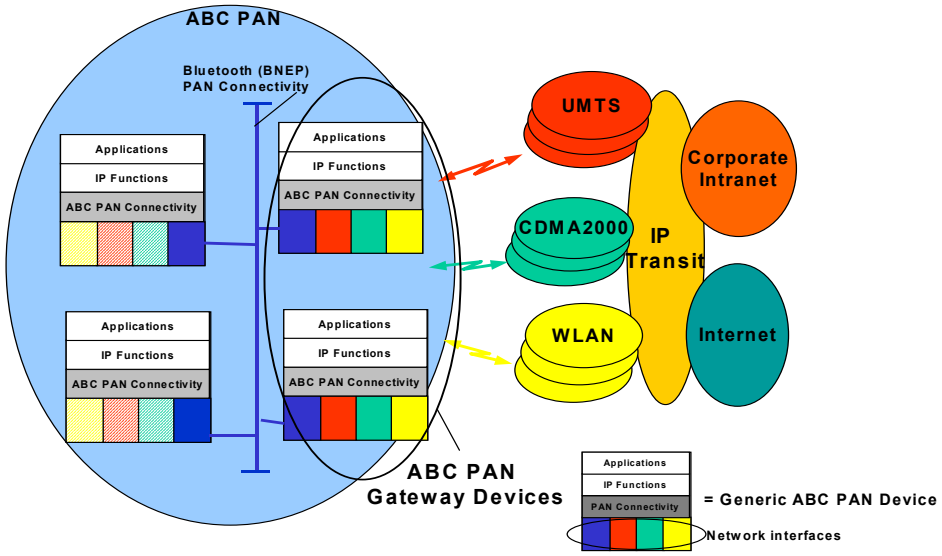

Figure 9. The ABC PAN has several external gateway devices for the devices to choose from

Figure 9 can also represent the third topology case since one of the gateway nodes may host applications that have the option to either connect directly to an external network through one of its own interfaces, or to use the other gateway node as an gateway device. The choice depends, again, on the combination on best gateway and best access network for the application.

PAN topology implications

Even though the BNEP protocol in the PAN abstracts the underlying Bluetooth piconet it cannot hide the fact that all the packets sent between any two nodes in the ABC PAN need to pass through the Bluetooth master node. This may have performance implications if the majority of the traffic is sent between two slave nodes in the network 0. For instance, an ABC PAN gateway node may be a slave device in the Bluetooth PAN and the only other active device is also a slave node. Moreover, if the master device suddenly leaves the ABC PAN network, all traffic will immediately stop.

In order to counter some of these effects, the Bluetooth PAN should have functions for PAN forming and re-organization. One such objective could be to initially form the PAN so that the master is the most likely ABC PAN gateway node. However, as the ABC PAN adapts to different network contexts and thereby the ABC PAN gateway role(s) is (are) shifting, the master role may follow along with the ABC PAN gateway role. In the case of multiple PAN gateways, a more elaborate decision needs to be made. Another more advanced approach is to adapt the piconet roles to the current traffic conditions and optimize the master assignment to the node that gives the best performance. The Bluetooth devices have built in support to switch master and slave roles between the nodes in a piconet and this could be invoked to re-organize a badly formed piconet. Note that the BNEP bridging function needs to reside in the piconet master node, which means that the BNEP entity also needs to move with the master and updates its (link layer) forwarding table accordingly.

In the event that the master moves away or fails, a new master node needs to be appointed among the slave nodes to recover from the lost node. This newly appointed master node then has to connect to the remaining slave nodes and form a new piconet. Furthermore, the BNEP function needs to restart in the new master node and rebuild the forwarding table. Measures to speed up this recovery procedure may include a list of candidate master nodes prepared during normal operation.

Any ongoing IP based sessions in the ABC PAN devices should only be disrupted temporarily while the underlying Bluetooth is reorganizing or recovering from a lost node.

ABC PAN address configuration

The ABC PAN will inherently exist in a dynamic network environment where external networks may or may not be available and/or may change over time as the PAN user moves in an out of different access network’s coverage areas. This also means that the ABC PAN will move in and out of the network contexts represented by the administrative domains of the different access networks. Clearly, a dynamic address configuration of all the ABC PAN devices per access network context may result in a constant reconfiguration of addresses as the PAN moves. Solutions that avoid frequent address reconfigurations are desirable to give host applications a consistent network view. In addition, when no external network is available, some sort of local ad-hoc address configuration must take place to enable local applications such as calendar synchronization, file transfer, local audio/video streaming, etc.

The Zero Configuration Networking (Zeroconf) working group 0 in the IETF is currently drafting a number of specifications to handle the type of ad-hoc IP address configuration described above. The objective for the Zeroconf work is to allow very simple devices to exist in an IP network, typically for the home environment, with a minimum or no prior configuration. Zeroconf deals with two types of IP addresses: link-local (169.254/16) and routable addresses. The latter may be both private and public IP addresses, where a router may forward packets to and from hosts with either type of these addresses. However, a router shall never forward a link-local IP address, regardless of whether it is a source or destination IP address. The link-local address is randomly chosen (within the 169.254/16 address space) by the host itself and the address uniqueness is checked via an address resolution (ARP) procedure. A host in a Zeroconf network may have one link-local IP addresses and zero or more routable IP addresses per interface. Typically, a very simple device that will only operate locally will only use a link-local IP address. A host with both a link-local and a global IP address has to make a decision on which source address to use based whether the destination address is link-local or not.

The ABC PAN will operate in a network environment well within the scope described by the Zero-configuration draft specifications, so it makes sense to adhere to the Zeroconf IP address configuration mechanisms. In this model, each ABC PAN device will obtain a link-local address to be used locally between devices within the ABC PAN. Since BNEP is providing a broadcast environment between the PAN devices, these are all residing on the same virtual link. For the ABC PAN devices that require external network access, a routable address has to be obtained. The devices with external network access interfaces within the device itself will in most cases obtain a routable address from the external network via DHCP 0. On the other hand, a device that needs to reach an external network via the ABC PAN, i.e. via the Bluetooth interface, has to configure an additional routable IP address for the Bluetooth PAN interface. Alternatively, the link-local IP address can be replaced by a routable IP address. This may however trigger updates to ongoing link-local (TCP) sessions and name-to-address resolution servers; updates that are not desirable in cases where uninterrupted operation is required. The use of private, but routable, IP addresses within the ABC PAN will enable applications in ABC PAN devices to access external networks via network address translation (NAT) functions in the ABC PAN gateway devices. The NAT functionality will not mean drastically increased complexity in the ABC PAN gateway device since it in any case should have firewall functionality to protect the ABC PAN nodes. The firewall functionality can in most cases be utilized by a NAT function.

The private IP addresses in the ABC PAN may be obtained by a local DHCP service, where one of the devices is an assigned DHCP server. The ABC PAN should apply a dynamic election procedure to unambiguously assign only one DHCP server in the PAN. Note that the link-local IP addresses in the ABC PAN can be used by a service discovery protocol, e.g. the service location protocol (SLP) to discover and select a unique DHCP server to be used by the ABC PAN devices. Similarly, a SLP based service discovery mechanism may be used to detect and present the possible external access networks (via their gateway devices) to all the ABC PAN devices.

In addition to the IP address configuration, name resolution services also need to be able to operate in the ABC PAN. The Zeroconf framework identifies multicast DNS (mDNS) as a possible candidate for a name resolution services in a zero-configuration environment when no global DNS server can be reached to resolve names. The Link-local Multicast Name Resolution (LMNR, 0) protocol is a multicast DNS proposal, intended for the link-local, ad-

hoc environment. LMNR uses a link-local multicast IP address to resolve domain names to IP-addresses in a distributed mechanism, i.e. a device responds to requests for its own name(s) only.

Mobility and session continuity

Applications running in ABC PAN devices that require session continuity across external access networks need to be able to quickly select a new interface in the event of lost connectivity over the active interface. In the case Mobile IP (MIP, 0) is used to support session continuity, an ABC PAN device needs to maintain connectivity to a MIP foreign agent (FA) residing in one of the external access networks. We assume the Mobile IP client resides in the ABC PAN host device where the end application resides, which enables the application to maintain an end-to-end relation to the Home Agent (HA) and the corresponding host inline with the Mobile IP specification. If, instead, the MIP client is located in the ABC PAN gateway device, session continuity will be difficult to maintain to an internal ABC PAN device in the event of a changed gateway device. Moreover, the AAA functions for MIP can be applied directly to the end device, which ensures the client-to-HA security association.

The ABC PAN gateway nodes need to operate as proxy-FAs that re-broadcasts FA advertisements, originating from FAs located in the external access networks, to the ABC PAN devices. Since the FA advertisements are link-layer broadcasts, the gateway devices pass them on to the Bluetooth PAN sub-network. Likewise, FA solicitations sent from the devices inside the PAN need to be passed on by the ABC PAN gateways to the external access networks that offer Mobile IP services. Once an ABC PAN device has selected an FA to associate with, the MIP registration procedure is carried out according to the specification. However, the proxy FA function in the ABC PAN needs to forward packets from the FA sent to PAN ABC devices using their home IP address, issued by the MIP home agent (HA). To solve this, the proxy FA function may place a route entry for the ABC PAN device’s home address upon its registration to the HA that associates the home IP address with the link layer address of the PAN device.

If an active ABC PAN MIP client device loses contact with the FA it is associated with, it needs to quickly hand-over to a new FA. The ABC PAN device may have cached a number of candidate FAs, from which the ABC functionality selects (possibly after invoking a user selection option) the next best access network to associate with. Alternatively, the PAN device will broadcast a FA solicitation message to inquire for new FAs. A new FA may be reached through the same ABC PAN gateway device, or through another gateway device. Once the MIP client device has registered with the new FA and the MIP tunnel has switched over to the new FA, the session can continue. The delay involved in this handover, mainly depends on how fast the new FA can be discovered and associate with the MIP client device. The proxy FA function in the ABC PAN gateway devices may also aggregate some of these messages in order to avoid multiple FA solicitations to the same FA from the ABC PAN devices.

ABC PAN inter-communication

Direct communication between users’ ABC PANs over Bluetooth is a functionality that typically would be used by peer-to-peer type applications, such as ad-hoc exchange of documents, presentations, business cards, but also for multiplayer games. The PAN ABC model described earlier will accommodate PAN-to-PAN communication by interconnecting the ABC PAN gateway devices. From a Bluetooth PAN perspective the interconnected gateway nodes need to form their own PAN consisting of two or more gateway devices.

From an IP networking point of view, this inter-connecting PAN will be a new ad-hoc sub-network that interconnects the ABC PAN gateways (routers). The gateway devices should be configured with routable IP addresses, since the main purpose is to interconnect the devices that belong to different ABC PANs. However, the initial configuration could be based on link-local addresses in a similar way as the ABC PAN, e.g. to find a DHCP server and a name resolution server. Note, that the name resolution scope is in this case not limited to one ABC PAN, as destination end-hosts are located in other ABC PANs. The use of mDNS is one possible solution to resolve names in other, adjacent, ABC PANs.

Conclusions

In this paper we have presented the always best connected (ABC) service, which offers a solution for a seamless combination of 3G and WLAN network access services. With the ABC service, users can remain connected to IP based network services with one single subscription as they moves between WLAN hotspots and 3G coverage. The selection of access network may be handled automatically, made by the user, or as a combination thereof, depending on the user preference.

Furthermore, the ABC service was extended to also include personal area networks (PANs) in order to allow the ABC user to connect his/her personal electronic devices, such as a PDA, a mobile phone, and a notebook PC, to wireless networks. The ABC PAN service enables a combination of Bluetooth based PAN-local communication and PAN-external communication through devices with WLAN and/or 3G interfaces.

The necessary functional building blocks involved in the design of an ABC PAN service was defined and described. The ABC PAN service is also put into the context of a user scenario to illustrate how the different functions interact. Clearly, the ABC PAN opens up a wider variety of service options and personal device preferences, but also represents a challenge in terms of service design. Due to its ad-hoc nature, the Zeroconf networking model is a good candidate for IP address configuration of an ABC PAN service. However, MIP based session continuity will require some modifications in order to work in the ABC PAN context. Specifically, the ABC PAN gateway nodes may need to operate as FA-proxies for the MIP clients inside the ABC PAN.

The Bluetooth PAN profile and protocol, BNEP, provides a suitable infrastructure to base the ABC PAN on in terms of ad-hoc network formation, low power consumption, and low price. Further optimization and adaptation of the Bluetooth PAN behavior (e.g. piconet reconstruction) may, however, be desired to give a dynamic ABC PAN good performance.

The discussion and the functional description presented in this paper indicates that it is fully possible to design an ABC PAN service composed mainly out of existing or drafted standards/specifications from the IETF, the Bluetooth Special Interest Group (SIG), IEEE 802.11, and the 3G standardization bodies. However, it still remains to be seen to what extent the consumers will embrace this new technology. Convenience and ease of use will be two key components for a successful ABC PAN service.

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