Personal Networks – An Architecture for 4G Mobile Communications Networks

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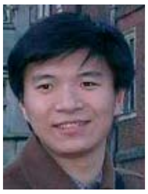

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A personal network is a network architecture which builds on various wireless networking technologies. It is responsible for glueing these wireless networking technologies to serve users. This paper considers the co-operation of several key technologies to realize a personal network; namely Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN) and Universal Mobile Telecommunications System (UMTS). This co-operation poses a new set of problems as these technologies were not designed to interwork with each other. In this paper, we present an architectural framework on which one can build a personal network using these wireless technologies. We also discuss each of these problems and propose solutions toward building a personal network demonstrator.

1 Introduction

The next generation of wireless communications systems, commonly known as fourth-generation (4G) network [1], is envisaged to encompass a multitude of cellular and wireless networking technologies which include Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN) and third-generation (3G) cellular network. These wireless networking technologies are seamlessly interconnected by the Internet Protocol (IP) backbone network. In essence, 4G aims to transform communications architectures from traditional vertical stovepiped to horizontal integrated systems [1]. *Personal Networks* [2] are one such network architecture that can fulfill the aim of 4G with user-centric perspectives. It is a dynamic network building on the above mentioned wireless networking technologies, to facilitate personalized ubiquitous communications anywhere at anytime. Figure 1 shows the network architecture of a personal network which begins from a WPAN bubble that can be expanded or shrunk depending on the user's demands and environment. The WPAN expansion can physically be made via interconnecting structures, e.g. Universal Mobile Telecommunications System (UMTS) [3-4] and the Internet, to remote networks such as home area networks, corporate area networks or vehicular area networks. A WPAN is a network of devices which could consist of a mobile phone, a PDA, a notebook PC, a digital camera, etc. All or a parts of these devices are carried around by a person in everyday life for both work and pleasure.

This paper considers the first step toward building a personal network by enabling the co-operation between the UMTS, and WPAN and WLAN technologies. This co-operation poses a new set of problems. Current cellular and wireless networking technologies consider terminals only in isolation. In personal networks, we no longer have single terminals, but a very dynamic WPAN wanting to establish co-operation with UMTS so that it can connect with remote devices or remote WPANs. That means, current technologies are insufficient or have to be enhanced to accommodate new requirements. The major issues that need to be addressed are self-organization, establishing and maintaining quality of service for particular applications, routing and mobility management. The work presented in this paper will address all of these issues. Firstly, the state-of-the-art technologies are evaluated in view of building a personal network. We will point out the limitations with the current state-of-the-art technologies. Then, we propose solutions to these limitations within the realm of an interconnecting architecture for personal network. Finally, we present a number of ongoing key projects related to personal networks.

2 State-of-the-art Wireless Technologies

In this section, we briefly describe the state-of-the-art wireless technologies that are suitable for building personal networks, namely, WPANs, WLANs and UMTS.

2.1 Wireless Personal Area Networks

A WPAN is a short-range (typically, transmission range is limited to 10 m), low-cost and low-power consumption technology. Unlike UMTS, WPAN operates in the unlicensed Industrial, Scientific and Medical (ISM) frequency band at 2.4 GHz. The IEEE 802.15 working group is standardizing different versions of WPAN:

- IEEE 802.15.1 (Bluetooth) [5]
- IEEE 802.15.3 [6]

2.1.1 IEEE 802.15.1 (Bluetooth)

The Bluetooth specification has been made the IEEE 802.15.1 standard [5]. Hence, Bluetooth and IEEE 802.15.1 are synonymous. Throughout this paper, we use the term Bluetooth. Two or more Bluetooth

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devices sharing the same frequency-hopping sequence form a piconet, which is a star topology. The smallest unit of a WPAN is known as piconet. Within a piconet, a Bluetooth device can play either one of the two roles: master or slave. Each piconet may only contain one master device and up to seven slave devices. Communication in a piconet is organized in such a way that the master device polls each slave according to a certain polling algorithm. A slave device is only allowed to transmit after being polled by the master device as depicted in Figure 2. Different piconets employ different frequency-hopping sequences to prevent mutual interferences. Bluetooth offers gross bit rates of up to 3 Mb/s.

Bluetooth defines not only a radio interface, but a whole communications stack that allows devices to find each other and advertise the services they offer. The core Bluetooth protocol stack, which consists of Layer 1 and 2, is illustrated in Figure 5. Bluetooth Network Encapsulation Protocol (BNEP) provides an Ethernet-like interface to the upper layer. Communications at the Logical Link Control and Adaptation Protocol (L2CAP) layer in a piconet can only be

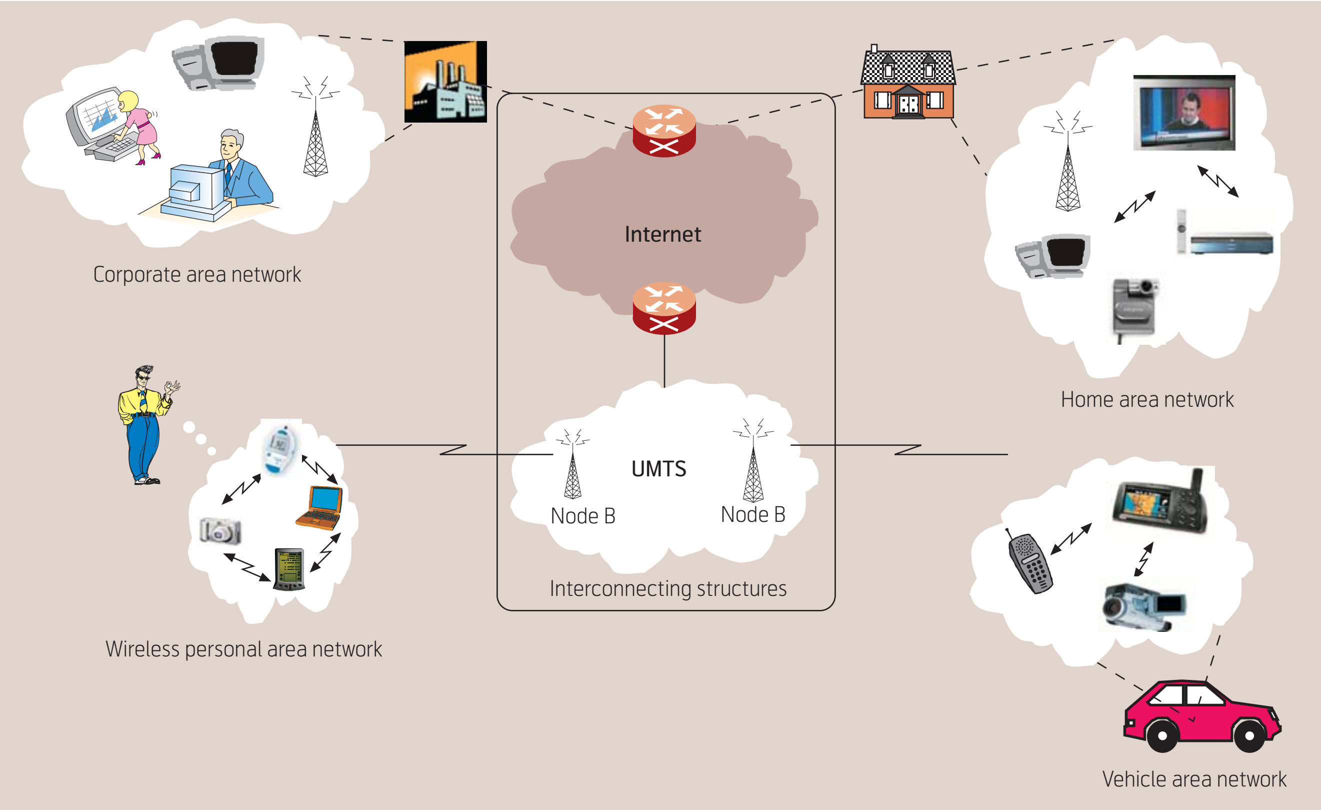

Figure 1 Personal Network

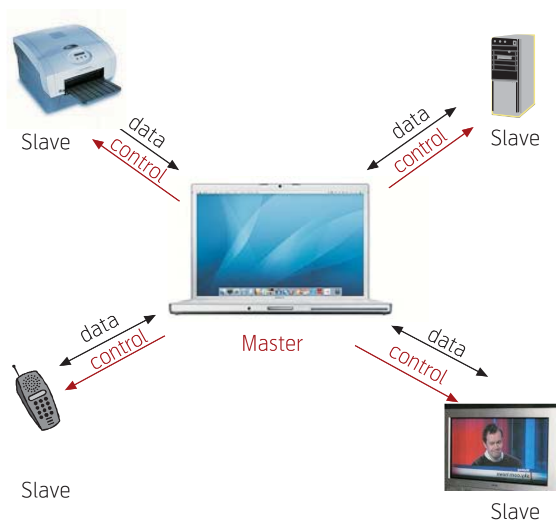

Figure 2 Bluetooth Piconet Architecture

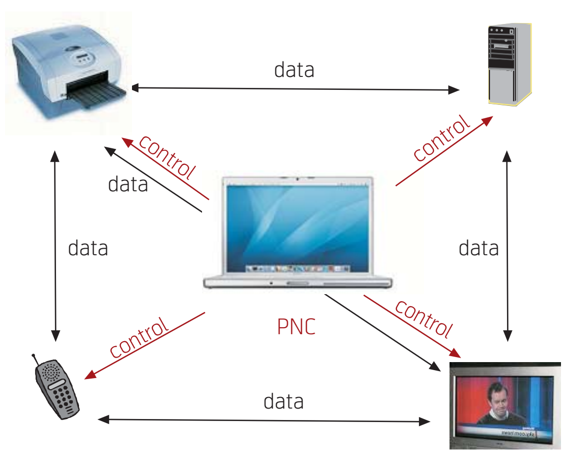

Figure 3 IEEE 802.15.3 Piconet Architecture

between the master device and a slave device. The master device acts as an Ethernet bridge at the BNEP layer forwarding packets that are not destined for itself.

2.1.2 IEEE 802.15.3 High Data Rate WPAN

Unlike Bluetooth, IEEE 802.15.3 [6] offers high gross bit rates of up to 55 Mb/s. An IEEE 802.15.3 piconet is a distributed topology with a central controller known as Piconet Controller (PNC). The PNC differs from the Bluetooth master in that it is responsible for scheduling the communication between the devices but the data traffic may not pass through the PNC. That means, the devices in the piconet can communicate on a peer-to-peer basis as shown in Figure 3. Each piconet may only contain one PNC device and up to 255 slave devices.

The IEEE 802.15.3 standard only defines Layers 1 and 2, namely, the Physical layer and the Medium Access Control layer as depicted by the center block diagram in Figure 5.

2.2 Wireless Local Area Networks

Currently, IEEE 802.11 [7] is the most mature and widely deployed WLAN technology. It also operates in the unlicensed frequency band of 2.4 GHz. The IEEE 802.11 standard defines two modes, namely, infrastructure and ad hoc. In the former mode, the IEEE 802.11 devices form a star topology with an access point as the central controller. For non-real-time services, the devices communicate with the access point through a random access technique while a polling scheme is used for real-time services. In the ad hoc mode, the devices communicate with each other directly on a peer-to-peer basis as shown in Figure 4. The IEEE 802.11 standard only defines Layers 1 and 2 as shown in the right block diagram of Figure 5.

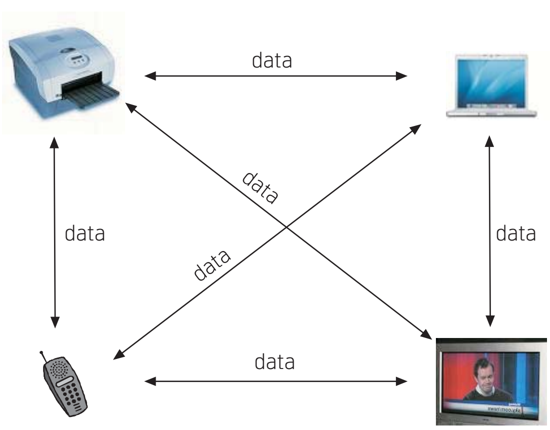

Figure 4 IEEE 802.11 Ad Hoc Mode Network Architecture

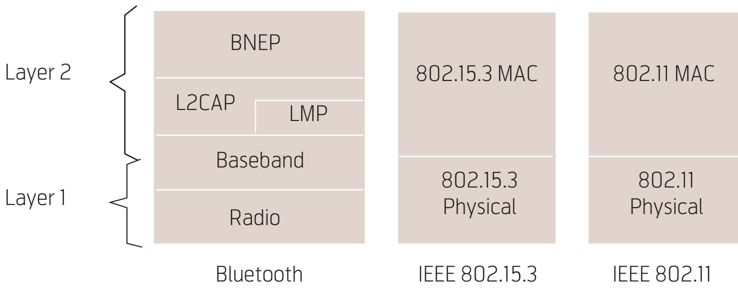

Figure 5 Protocol Architecture of Bluetooth, IEEE 802.15.3 and IEEE 802.11

Each of the above-mentioned state-of-the-art wireless technologies provides its own mechanism for WPAN formation or self-organization. In personal networks, a WPAN consists of heterogeneous devices. In this case, the WPAN formation mechanism defined in each wireless technology is insufficient. However, in the next section, we will describe the design of a personal network gateway architecture which can be used in the formation of such a heterogeneous WPAN.

2.3 UMTS

The UMTS network architecture [3-4] is depicted in Figure 6 which consists of a User Equipment (UE) (the UMTS term for mobile station) and two independent land-based network segments: the UMTS Terrestrial Radio Access Network (UTRAN) and the core network. The latter is composed of the Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) which are interconnected via an IP network. The SGSN keeps track of the location of individual mobile stations and performs security functions and access control. The GGSN encapsulates packets received from external IP networks and routes them toward the SGSN. The UTRAN consists of the Radio Network Controller (RNC) and Node B (i.e. the base station) connected by an asynchronous transfer mode network. The RNC is in charge of the overall control of the logical resources provided by Node Bs. A UE communicates with the Node B through a radio interface based on Wideband Code Division Multiple access (WCDMA) technology. The

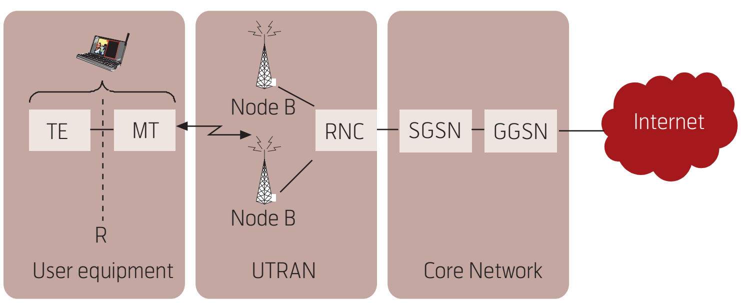

Figure 6 UMTS Network Architecture

UE in turn consists of two disjoint entities, namely, the Terminal Equipment (TE) and the Mobile Terminal (MT). The TE and MT entities can reside in different physical modules interconnected by the *R-reference* point. The TE hosts the application and user-interaction, while the MT is in charge of all the UMTS communications-related tasks. Figure 7 shows the protocol stacks of UMTS, which comprise the user plane and the control plane. The user plane consists of a layered protocol structure providing user information transfer, along with associated information transfer control procedures. The control plane consists of protocols for control and support of user plane functions.

Currently, the notion of WPAN, which comprises a group of TEs associated with a single MT, does not exist in the UMTS standards. What has been defined in the standard is a protocol for point-to-point communication between an MT and a TE over a serial physical link which can be a cable. Point-to-Point Protocol (PPP) is used to establish such communications between MT and TE, where the MT serves as a modem. However, in our context, we have a number of TEs which are grouped into a Bluetooth or an IEEE 802.15.3 WPAN, and the MT functions as a personal network gateway which will be described in the next section. Instead of using PPP for communication, the group of TEs and the MT are networked using Bluetooth or IEEE 802.15.3.

3 Personal Network Architecture

A key component in the WPAN is the *Personal Network Gateway* (PNG) which seamlessly connects a WPAN or a WLAN to UMTS as shown in Figure 8. Unlike other devices in the WPAN, the PNG is multi-modal, i.e. it contains different protocol stacks. On the WPAN/WLAN side, it houses the Layer 1 and Layer 2 of Bluetooth, IEEE 802.15.3, and IEEE 802.11, and on the other side it is the UMTS user plane and control plane radio access protocol stack as depicted in Figure 9. The UMTS user plane is connected to the Bluetooth, the IEEE 802.15.3 and the IEEE 802.11 at the IP layer. The PNG can also assume the role of master or PNC in Bluetooth or 802.15.3, respectively.

In addition to providing UMTS connectivity, the PNG also facilitates communication between devices which are equipped with different technologies. For example, a Bluetooth-enabled device can communicate with an 802.11-enabled device via the PNG. In this paper, we assume that there is only one PNG in

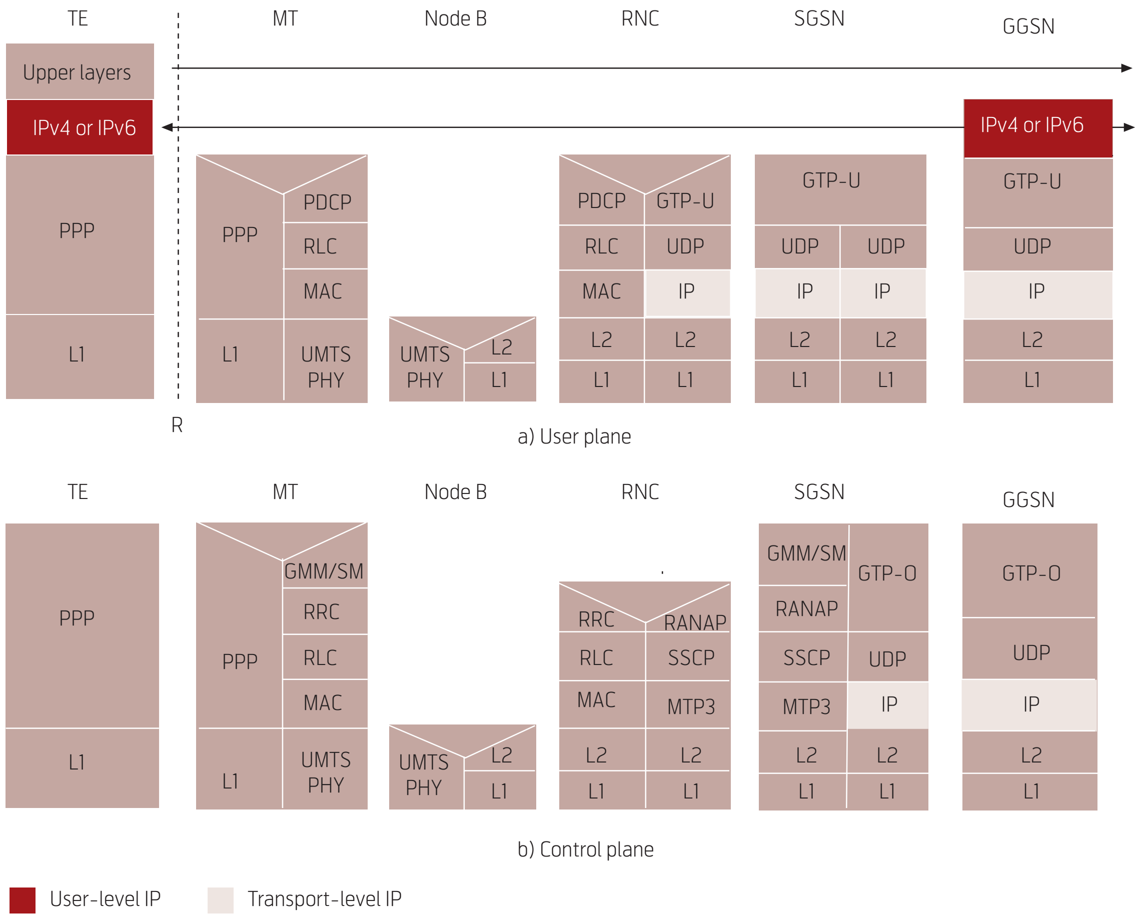

Figure 7 UMTS Protocol Architecture

a WPAN or WLAN and the rest of the devices in the WPAN or WLAN are single-mode, i.e. either Bluetooth, 802.15.3 or 802.11. In the scope of this paper, a user's WPAN is not limited to Bluetooth- and 802.15.3-enabled devices but may also include 802.11-enabled devices due to the popularity of the WLAN technology. The PNG operates as a bridge in order to link Bluetooth-, 802.15.3- and 802.11-enabled devices together. Using a bridge, the different devices appear to be connected on the same subnetwork. Bridging is recommended because it provides efficient communication in a small sized network such as WPAN. If two communicating devices are more than one hop away, then multi-hop communication is utilized. This will be described in subsection 3.3.1.

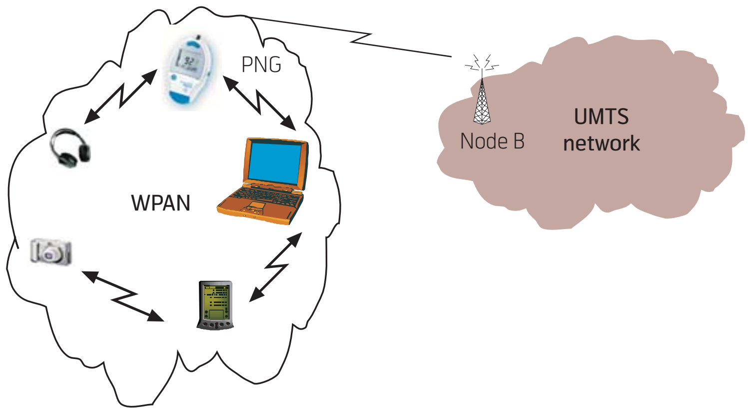

Figure 8 Personal Network Gateway

3.1 Self-Organization

WPAN is a self-organized ad hoc network which is automatically formed with little or no user intervention. The WPAN formation mechanism is provided by Layer 1 and Layer 2 of the WPAN. The WPAN formation mechanism of Bluetooth and IEEE 802.15.3 is provided by the Inquiry and the Association procedures, respectively. For the IEEE 802.11 ad hoc mode, any device within radio range can be directly addressed without forming a subnetwork by using the Scan procedure. The formation of a WPAN, which comprises devices of different wireless technologies, will be coordinated by the PNG using the WPAN formation mechanism of its wireless technology because it has multiple interfaces. The procedure is described in subsection 3.1.1.

Once the WPAN is formed, it can operate either as a stand-alone ad hoc network or as a subnetwork of the interconnecting structure. In the latter, the PNG acts as the gateway and provides seamless connectivity to the UMTS network which is in turn connected to the Internet. Before any device in the WPAN can send and receive traffic from the interconnecting structure, it must be able to obtain a valid IP address and configure the PNG as the default router.

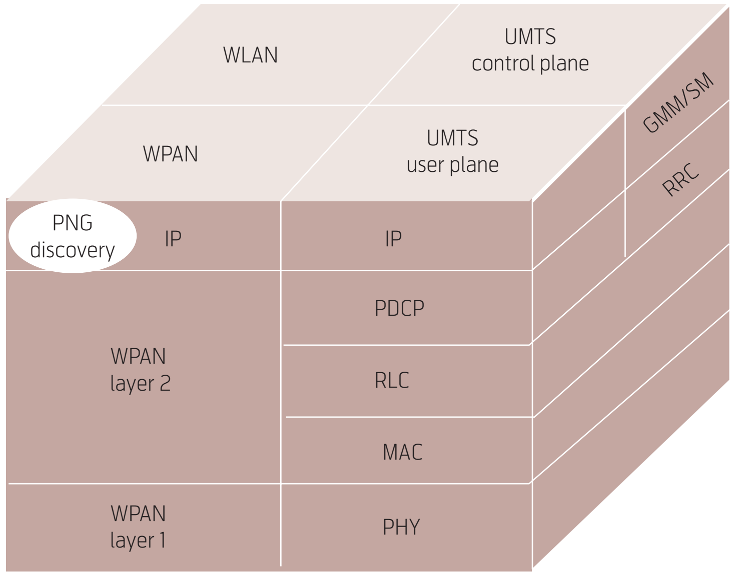

Figure 9 Personal Network Gateway Protocol Architecture

3.1.1 Personal Network Gateway Discovery

The PNG provides connectivity to the interconnecting structure, and therefore also needs to acquire unique IPv4 or IPv6 addresses for the WPAN devices. In order to use the PNG, devices in a WPAN must be able to find it even if the PNG is several hops away from the devices. Hence, the PNG discovery mechanism must also facilitate route construction between the device and the PNG in the event of a multi-hop scenario. The PNG discovery can be realized proactively or reactively. In the latter approach, the PNG discovery is triggered by a WPAN device, while the former is initiated by the PNG. To leverage the advantages of the two approaches, a hybrid approach is appropriate for PNG discovery. The PNG discovery protocol comprises two messages: `PNG Advertisement` and `PNG Solicitation`. PNG Advertisements are periodically broadcast into the WPAN by the PNG. The period between two consecutive PNG advertisements must be set to an optimum value so that the WPAN is not flooded to avoid wasting WPAN radio resources. If a device in a WPAN wants to learn about the PNG immediately, it can broadcast a PNG Solicitation which triggers immediate PNG Advertisements. These two messages could be defined as new Internet Control Message Protocol (ICMP) message types.

3.1.2 Address Auto-configuration

Two addressing schemes can be envisaged here considering both IPv4 and IPv6. We call the first of these two schemes "Private Address Auto-configuration" and the second one "Global Address Auto-configuration".

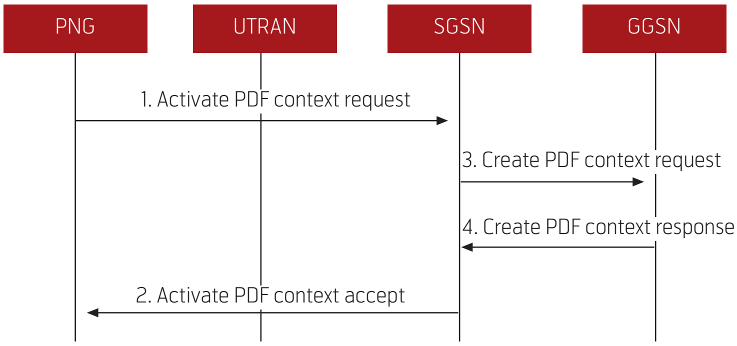

Figure 10 PDP Context Activation Procedure

Private Address Auto-configuration

In this scheme, the WPAN is assigned a single globally unique IP address. That means, the WPAN appears as a single point of presence on the Internet. The globally unique IP address is allocated to the PNG and the rest of the devices in the WPAN are assigned with private IP addresses which are not globally unique. Hence, a Network Address Translator (NAT) [8], which is located in the PNG, is employed to translate private IP addresses to the global routable IP address for packets emanating from any device in the WPAN, and vice versa. Both IPv4 and IPv6 support auto-generation of private addresses, viz. RFC 3927 [9] and RFC 2462 [10], respectively. The PNG can obtain a globally unique IP address through the UMTS *Packet Data Protocol* (PDP) context activation which is defined in the Session Management (SM) layer of the UMTS control plane. The PDP context can be viewed as a record that holds parameters that characterize a certain connection. In other words, it is a virtual connection between the PNG and the GGSN, which is characterized by the IP address and the quality of service profile. The PDP context is stored in the PNG, the SGSN and the GGSN. With an active PDP context, the PNG is visible to the GGSN and it can send and receive data packets. Figure 10 illustrates the steps involved in the PDP context activation.

Step 1: The PNG generates the `Activate PDP Context Request` message and sends it to SGSN.

Step 2: The SGSN checks the `Activate PDP Context Request` message and generates the `Create PDP Context Request` message which is sent to the GGSN to establish a GTP tunnel between the SGSN and the GGSN. The tunnel is used as the packet routing path between the GGSN and the SGSN.

Step 3: The GGSN allocates an IP address for the PNG, which is carried by the `Create PDP Context Response` message.

Step 4: Finally, the SGSN informs the PNG of the allocated IP address through the `Activate PDP Context Accept` message.

Global Address Auto-configuration

In this scheme, each device in the WPAN is allocated a globally unique IP address. Therefore, each WPAN device is visible to external nodes on the Internet. In this case, the PNG does not need to perform address translation for the WPAN devices. This addressing scheme does not favor IPv4 because of limited IPv4 address space. For allocating globally unique IP addresses, IPv4 supports only stateful address allocation technique, while IPv6 defines two techniques, namely *stateless* address allocation and *stateful* address allocation.

For the stateful address allocation technique, the operation is similar to the first scheme except that the PNG needs to perform the PDP context activation for each device in the WPAN in order to get a globally unique IP address. The PNG also needs to perform PDP context activation to obtain an IP address for the UMTS interface. In IP-based networks, the stateful address allocation can be accomplished by means of Dynamic Host Configuration Protocol (DHCP). However, DHCP has been designed with the assumption that the DHCP client and server is one hop away.

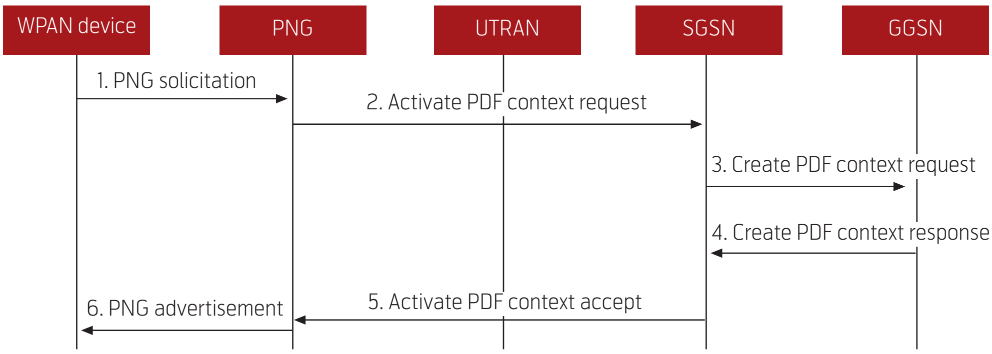

Figure 11 IPv6 Stateful Address Allocation

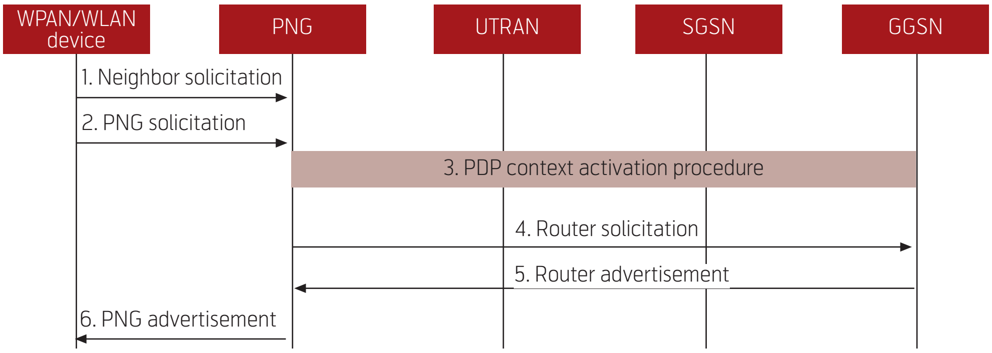

Figure 12 IPv6 Stateless Address Allocation

In WPAN, the DHCP client and the server may be multiple hops away. Hence, DHCP is not suitable for providing stateful address configuration in a multi-hop network. The PNG messages should be designed to support the stateful address configuration option. Figure 11 illustrates the operation of stateful address configuration. As shown in step 1 of the figure, the `PNG Solicitation` is used by the device in the WPAN to request for an IP address, which in turn triggers the PNG to perform PDP context activation (step 2 to step 5). Finally, the IP address allocated during PDP context activation is conveyed to the WPAN device via the `PNG Advertisement` message.

As mentioned, the stateless address allocation technique is only applicable to IPv6 since no equivalent technique exists in IPv4 for generating globally unique IP addresses. For this technique, each device in the WPAN is able to generate its own IPv6 address by concatenating a subnet prefix with an interface identifier. In IP-based networks, such a subnet prefix is contained in the IPv6 Router Advertisement messages which are transmitted by an IPv6 router. Similarly to DHCP, IPv6 Router Advertisement is not designed for multi-hop networks. The PNG messages should also support stateless address configuration in addition to stateful address configuration. The PNG can be configured to support either the stateful or the stateless address configuration. The interface identifier can be a Bluetooth, an IEEE 802.15.3 or an IEEE 802.11 MAC address. The stateless address allocation is depicted in Figure 12. The WPAN device is responsible for ensuring that the interface identifier is unique by broadcasting an IPv6 `neighbor solicitation` message to perform duplicate address detection (step 1 of Figure 12). However, the duplicate address detection cannot be used unchanged in a multi-hop scenario because the message can only reach devices one hop away. The duplicate address detection in multi-hop scenario is also present in mobile ad hoc networks. Several mechanisms have been proposed [11]. Therefore, these proposed mechanisms can be used by personal networks. If no address duplication is detected, then the WPAN device will use the interface identifier and issue a PNG `Solicitation` message (step 2). In order to get the IPv6 subnet prefix for the entire WPAN, the PNG performs the PDP context activation (step 3). Once the PDP context activation is completed, the GGSN can send an IPv6 `router advertisement` message (step 5) on the newly established PDP context. Alternatively, the PNG may issue an IPv6 `router Solicitation` message to GGSN (step 4). After the PNG receives the router advertisement message, it broadcasts the PNG `Advertisement` message to the devices in the WPAN (step 6). At the same time, the PNG constructs its IPv6 address by concatenating a randomly generated interface identifier and the subnet prefix. The interface identifier is randomly generated because the UMTS network interface does not have an equivalent IEEE MAC address. The WPAN device also generates its IPv6 address by concatenating its interface identifier and the subnet prefix.

3.2 Quality of Service

Quality of Service (QoS) is defined as a set of service characteristics that the network is requested to meet when transporting a sequence of data packets. The service characteristics can be expressed in terms of throughput, delay, loss, bit error rate, or as a relative priority of access to the network. End-to-end QoS in personal network spans across different domains: WPAN, UMTS and IP QoS-enabled interconnecting structures such as the future Internet. In such a heterogeneous environment, the end-to-end QoS will rely on the coordination of QoS mechanisms in different domains along the end-to-end communication path. Each of these domains (Bluetooth, IEEE 802.15.3 or UMTS) has its own QoS provisioning mechanisms. The challenge in QoS provisioning in personal network is to seamlessly interwork the QoS mechanism in each domain. The QoS provisioning functionality of each domain is identified and interworked as

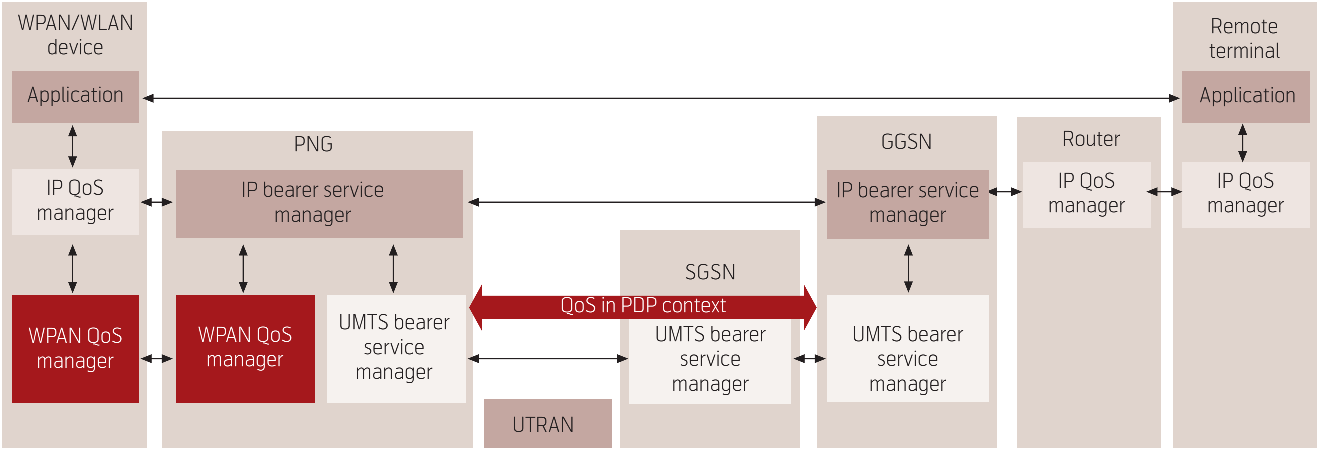

Figure 13 Personal Network QoS Management

shown in Figure 13. The interworking between QoS functionality takes place at the PNG and the UMTS GGSN. The PNG provides interworking between the WPAN QoS functionality and the UMTS QoS functionality while the GGSN deals with interworking between the UMTS QoS functionality and the QoS functionality in external IP networks.

The QoS management modules for UMTS are specified in [12-13]. UMTS achieves QoS management using a layered architecture with bearer services established at different layers between UMTS QoS management modules. The QoS management in WPAN is responsible for setting up a bearer (or connection) according to the requested QoS parameters.

The application in a WPAN device triggers the request for network service with particular QoS requirements. The application QoS requirements are sent to the IP QoS manager of the WPAN device for an IP level service. The IP QoS manager translates the QoS parameters for the WPAN QoS manager, which sets up the bearer with the required QoS between the device and the PNG. The WPAN QoS manager comprises admission control and scheduling algorithms. The admission control takes care of the radio resource allocation based on the availability while the scheduling algorithm schedules data transmission according to the QoS requirements. The same application QoS requirements, which are received by the WPAN QoS manager at PNG, are signaled to the IP bearer service manager. This in turn sets up the UMTS bearer service by initiating the PDP context activation with the required QoS. The PDP context which contains the application QoS requirements is translated for the IP bearer service manager by the UMTS bearer service manager at the GGSN. The IP bearer service manager uses the requirements for controlling the QoS with external IP networks.

For QoS control with an external IP network, UMTS specifies the use of DiffServ at the IP bearer service manager in the GGSN. For the QoS signaling between WPAN and UMTS, a number of QoS signaling protocols, e.g. Resource reSerVation Protocol (RSVP) can be used at the IP QoS manager and the IP bearer service manager in the WPAN device and the PNG, respectively. For illustration purposes, we have chosen RSVP because it can provide accurate and complete description of application QoS requirements. The basic idea is to employ RSVP as a local resource reservation protocol between a WPAN device and the PNG, and to use the QoS description contained in the RSVP messages for interworking with the QoS functionality in other networks.

The application in a WPAN device sets its QoS requirements in an RSVP PATH which is processed by the WPAN QoS manager in the WPAN device and conveyed to the PNG. Upon receiving the RSVP message, the PNG performs the following tasks: translates RSVP parameters into PDP context parameters; initiates PDP context activation procedures if RSVP PATH message is received; and negotiates the PDP context characteristics with the UMTS network. Conversely, if the QoS requirements are initiated by the external IP network, the PNG performs the following tasks: translates PDP context into RSVP parameters, constructs and sends an RSVP PATH to the recipient; and completes the PDP context modification when the RSVP RESV is received.

Figure 14 shows the signaling flows. We assume that a PDP context already exists, which is set up during the IP address allocation. The existing PDP context is referred to as the primary PDP context and supports best-effort data only. The QoS request is initiated by the external IP network. The IP bearer service manager of GGSN maps the requested QoS into PDP context parameters and triggers the GGSN-initiated PDP

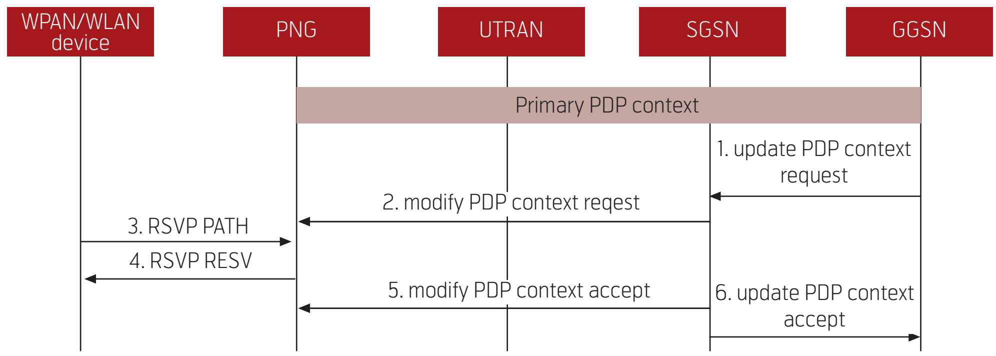

Figure 14 QoS Signalling with RSVP

context modification (steps 1 and 2 in Figure 14). Upon receiving the `Modify PDP Context Request` message, the requested QoS requirements are translated into an RSVP PATH message which is sent by the PNG. Once the PNG receives the RSVP RESV message, it triggers the `Modify PDP Context Accept` message (steps 4 to 6 in the figure).

3.3 Routing

Routing in personal networks can be categorized into two levels: intra WPAN routing, and WPAN and remote area network routing as shown in Figure 15.

3.3.1 Intra WPAN Routing

Intra WPAN routing deals with the communication between two devices in the same WPAN. That is, the communication does not involve the interconnecting structures. In a WPAN, if direct communication is not feasible due to out of radio range, then multi-hop forwarding is utilized. Multi-hop communication is an issue that belongs to the area of Mobile Ad hoc NETwork (MANET) routing which has been an active area of research for the last decade. The MANET research efforts are mostly concerted by the MANET Working Group [14] of the Internet Engineering Task Force (IETF). However, MANET mostly deals with large-scale, military-typed ad hoc networks. Furthermore, MANET assumes that the wireless technology is homogeneous, i.e. all the devices use the same radio access technology, e.g. IEEE 802.11. Conversely, multi-hop communication in a WPAN could be over different wireless technologies. For instance, a WPAN is composed of a Bluetooth-enabled device, an IEEE 802.11-enabled device and a PNG which has multiple interface including Bluetooth and IEEE 802.11. When the Bluetooth-enabled device and the 802.11-enabled device want to communicate with each other, the communication is only possible via the PNG. In addition, the multi-hop communication is over different network topologies. The size of WPAN/WLAN is relatively small as compared with the scenarios considered in MANET. Instead of designing new routing protocols, which is not the scope of this paper, state-of-the-art routing protocols can be adopted and customized to suit the need of personal networking. The idea of PNG-assisted routing seems appealing. As mentioned in subsection 3.1, the PNG co-ordinates the formation of WPAN and naturally, it becomes the central controller of the WPAN. Hence, it is fully aware of the devices in the WPAN. During the PNG discovery phase, routes are constructed between the PNG and any device that wants to join the WPAN. Therefore, the PNG can be used as a default router. For instance, if device *A* wants to send packets to device *B* in the WPAN, then device *A* sends the packets to the PNG which in turn forwards to device *B* using the route constructed during the PNG discovery phase. With PNG-assisted routing, the ad hoc routing protocol is energy-efficient and simple since the device does not need to build and maintain routing table to other devices in the WPAN. An energy-efficient ad hoc routing protocol is needed because WPAN devices are usually battery-powered. The PNG-assisted routing can result in non-optimum routes and high traffic load at the PNG. However, the performance will not be critical since the network size of WPAN is small.

3.3.2 WPAN and Remote Area Network Routing

This level of routing deals with the communication between a WPAN and another WPAN or a remote area network such as a corporate area network. The communication may involve interconnecting structures or go via ad hoc networks. In either case, the communication entry and exit point of the WPAN is the PNG or the gateway for the remote area network.

3.4 Mobility Management

Mobility management is responsible for tracking the dynamics of the personal network and users. Several types of mobility are identified within personal networks, viz. *terminal* mobility, *network* mobility and *session* mobility. To date, solutions for each type of mobility have been investigated and developed separately. In personal networks, we require a unified mobility solution that is efficient and can support all

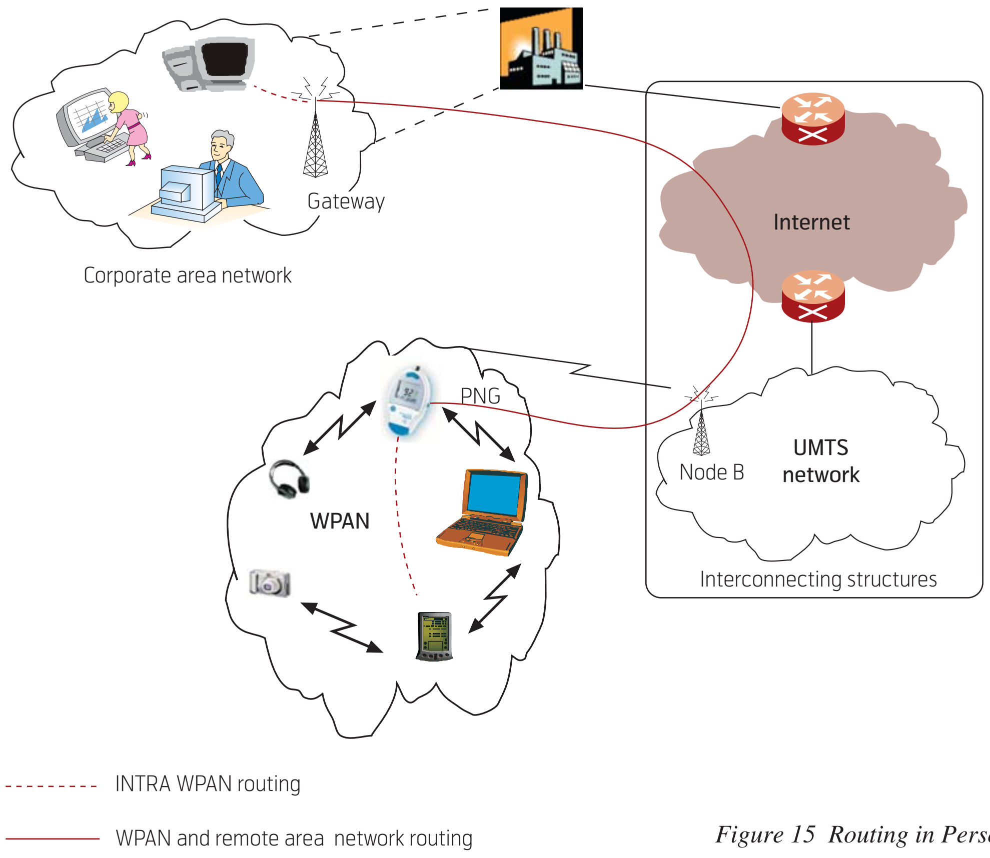

Figure 15 Routing in Personal Networks

three types of mobility simultaneously. In this subsection, we will describe such a solution.

Terminal mobility arises due to devices joining or leaving the WPAN. The WPAN generally resides in the same location as the user who will be mobile. As the user moves around his/her environment, new devices may be encountered and attached to the WPAN, similarly other devices may become detached. The IETF has standardized network-layer solutions to support terminal mobility, namely Mobile IPv4 [15] and Mobile IPv6 [16]. The IETF has also standardized and has been working on different solutions such as the Stream Control Transmission Protocol (SCTP) [17] and the Host Identity Protocol (HIP) [18]. For a comprehensive survey of terminal mobility solutions, we refer to [19].

When the entire WPAN moves as a unit and changes its point of attachment to the interconnecting structure, it is referred to as *network* mobility. For example, a WPAN switches its connection from WLAN to UMTS. The IETF has established a working group called NEtwork MObility (NEMO) [20] to standardize solutions for network mobility. NEMO aims at extending existing solutions to support network mobility in IPv6.

Session mobility concerns the transfer of an ongoing session from one device to another. A session is an active transport connection (i.e. TCP) between two communicating devices. The need for a session transfer arises when a device is detached or a new and more powerful device joins the WPAN. Session mobility is inherent to personal networks. The solutions for terminal mobility and network mobility do not cater for session mobility.

Hence, we propose a session mobility solution which leverages the advantages of Virtual Network Address Translation (VNAT) [21] and Mobile IP. The solution can also deal with terminal mobility and network mobility. Currently, IP addresses are used to identify the end-point of TCP connections. As each device is assigned a different IP address, it is impossible to transfer the TCP connection to another device without breaking and restarting the connection on another device. VNAT decouples the TCP end-point identification from the IP addresses by using virtual addresses. The virtual address is then mapped to a corresponding IP address at the Network layer. VNAT, however, relies on external servers for obtaining IP addresses, which incurs extra overhead. Instead of relying on virtual addresses and external servers, we can achieve a similar decoupling effect by using the home IP address of a device in combination with Mobile IP.

The protocol architecture, which contains the VNAT and Mobile IP layers, is shown in Figure 16. VNAT is composed of the *connection translation layer* and the *session transfer management layer*. The VNAT connection translation is responsible for mapping the IP address used for TCP end-point identification into the IP address of the new device after the session transfer. The VNAT session transfer management facilitates the automatic migration by securing and keeping alive sessions during the migration process. Mobile IP is then used by the new device to inform the home agent of the old device to tunnel packets belonging to this session to the new device.

Figure 17 shows an example of a session transfer from device *A* to device *B* in the WPAN. The session is a TCP connection set up between device *A* and device *C* which resides in the user's WPAN and home area network, respectively. On device *A* and device *C*, the end-point of the TCP connection is identified by the IP address of *A*, IP address of *C* and port numbers as shown in the bottom diagram of the figure. The port numbers are not shown in the figure. Then, session *S* is transferred to device *B*. In order to keep the session alive, the end-point identifier remains the same as on device *A* and device *C*. On device *B* and device *C*, the VNAT Connection Translation module is responsible for mapping IP address *A* into the IP address of *B,* and vice-versa. The figure also illustrates terminal mobility. Device *B* is a foreign device in the WPAN, then it will obtain a care-of IP address. If Mobile IP route optimization is employed, the IP home address of *B*, which is used by the VNAT Connection Translation module is mapped into the care-of address as shown in Figure 17. The advantage of using Mobile IP is that functions for network mobility easily can be incorporated.

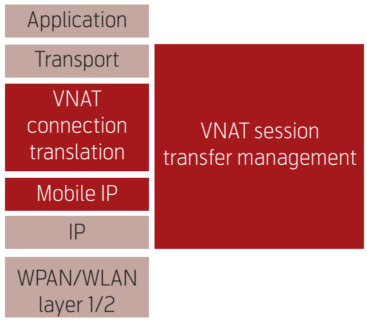

Figure 16 VNAT and Mobile IP Protocol Architecture

5 Personal Network Related Projects

In this section, we present some of the current personal network projects in Europe and around the world. Note, it is not in the scope of this paper to present an exhaustive list.

5.1 IST MAGNET Beyond

My personal Adaptive Global NETwork and Beyond (MAGNET Beyond) [22] is an Information Society Technologies (IST) project, which builds on the achievements and results of its predecessor, i.e. the MAGNET project. The objective of MAGNET Beyond is to design and develop the concept of personal network that supports context-aware resource-efficient, robust, ubiquitous personal services in a secure, heterogeneous networking environment for mobile users.

5.2 Personal Distributed Environment

The concept of personal networking is also being defined and developed by the Mobile Virtual Centre of Excellence (MVCE) at the University of Strathclyde [23]. The personal network concept is known as the Personal Distributed Environment (PDE). The objective of the PDE is to provide virtual personal network connectivity in a dynamic and heterogeneous environment, irrespective of the location of devices included in the personal network.

5.3 IBM Personal Mobile Hub

IBM has built a Personal Mobile Hub (PMH) [24] which serves as a gateway between a WPAN and the Internet. The functionality of PMH is similar to the PNG. The WPAN consists of devices worn by users such as medical sensors, wrist-watch computers, etc.

5.4 MOPED

In [25], the authors presented a networking model that treats a user's set of personal devices as a MOPED, an autonomous set of MObile grouPEd Devices (MOPED), which appears as a single entity to the rest of the Internet. All communication traffic for a MOPED user is delivered to the MOPED, where the final disposition of the traffic is determined.

5.5 MyNet

MyNet project [26] is a collaboration between Nokia and the MIT User Information Architecture group. MyNet aims to study and develop a network architecture, tools and applications for simple, secure, personal overlay networks.

5.6 Freeband PNP 2008

Personal Network Pilot 2008 (PNP 2008) [27] is a project sponsored by the Dutch Research Council under the Freeband Communication program. The project aims at developing the personal networking concept into practical technology and demonstrators.

6 Conclusion

The paper has addressed the major issues of self-organization, establishing and maintaining QoS and mobility management in personal networks. The personal network is built on top of WPANs and UMTS.

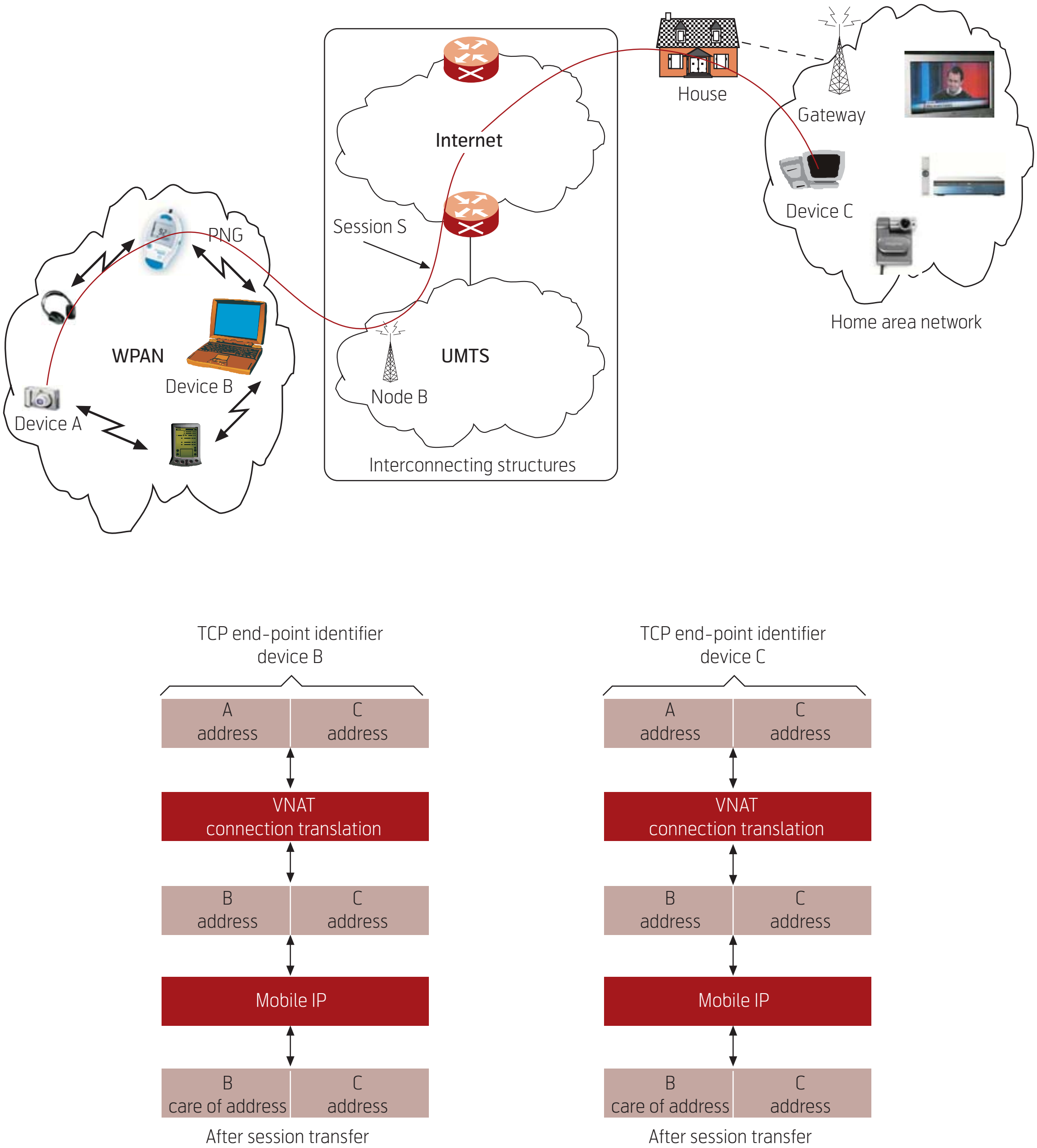

Figure 17 Session Mobility with VNAT and Mobile IP

The WPAN technologies considered are Bluetooth and IEEE 802.15.3. IEEE 802.11, which is a WLAN technology, is also considered due to its popularity. A key component in the WPAN and UMTS co-operation is the PNG which seamlessly connects a WPAN to a UMTS network. The PNG enables the WPAN to dynamically configure globally unique IP addresses and to provide routing information for devices in the WPAN. As for QoS, the QoS provisioning functionality in WPAN and UMTS was identified and interworking QoS management modules were designed to allow seamless QoS establishing by applications. We proposed a unified solution to deal with terminal mobility, network mobility and session mobility in the personal networks.

Acknowledgement

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