IP Services over Bluetooth: Leading the Way to a New Mobility

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Abstract

In our paper, we present protocol concepts for an extension of IP for mobility issues in Bluetooth networks. The protocol is called BLUEPAC IP*, where* BLUEPAC *stands for "**BLUE**tooth **P**ublic **AC**cess". "Public access" means access to various kinds of information in public areas, e.g. airplane, train, hotel room, department store, museum. Bluetooth will reside in low-cost chips that provide wireless communication up to OSI Layer 2. By the end of this year, many mobile devices, e.g. notebooks, PDAs, cell phones, will contain Bluetooth chips as a cable replacement. But Bluetooth is more powerful: With a suitable network protocol that inherits all aspects of IP, it will be possible to provide IP services over Bluetooth. BLUEPAC IP takes IP as a basis and additionally includes functionalities of Mobile IP and Cellular IP for local IP address assignment, routing issues and handoff support.*

Keywords: Bluetooth, IP services, Mobile IP, Cellular IP, wireless networks, network protocol design

1. Introduction

With the dawn of the new millenium, the need for a new mobility arises. Many people would like to have access to information services and/or to the Internet while they are travelling on a plane or a train or while they are in a department store or in a museum. New technologies like Bluetooth [1] lead the way to this new mobility. Bluetooth chips will be available at the end of 1999 and will be installed in a variety of devices like notebooks, Personal Digital Assistants (PDA), cell phones, Web pads etc. This cheap but yet powerful technology will make it possible to install a LAN that includes wireless Bluetooth cells. Thus, users can get wireless access to information provided locally or even access to the Internet if the LAN provides for this service. Those LANs can be used in home, office or public environments. In this paper, we address public Bluetooth environments. We call these public environments "BLUEPAC areas" (**BLUE**tooth **P**ublic **AC**cess). Bluetooth devices enter a BLUEPAC area, stay in one Bluetooth cell or move from one cell to another in possibly short periods of time that might be less than two seconds. The standard IP protocol has been designed with stationary computers in mind and cannot cope with the demands of the moving Bluetooth devices. Thus, IP must be extended by dedicated mechanisms to make it work in BLUEPAC areas. [2] stated: "Defining TCP/IP over Bluetooth requires that bridging, address resolution, MTU definition, and multicast/broadcast mappings be solved." In this paper, we present protocol concepts for the new "BLUEPAC IP" which is based on ideas from Mobile IP (see section 3.1) and Cellular IP (see section 3.2). BLUEPAC IP contains mechanisms for local IP address assignment, support of Mobile IP and handoff support. With the use of BLUEPAC IP instead of standard IP in a BLUEPAC area, TCP and UDP may be used without any modifications.

The paper is structured as follows: Section 2 introduces the Bluetooth technology and section 3 gives an overview of IP mobility concepts, namely Mobile IP and Cellular IP. In section 4, BLUEPAC scenarios will be described and section 5 presents the protocol concepts for BLUEPAC IP. Finally, section 6 presents our conclusions and specifies future work.

2. Bluetooth Overview

The problem of having too many wires and connectors to connect portable devices that do not work well together anyway led to the foundation of the Bluetooth consortium formed in February 1998 by mobile telephony and computing leaders Ericsson, IBM, Intel, Nokia and Toshiba. Bluetooth is a new technology for wireless communication following the vision of a "*truly low-cost, low-power radio-based cable replacement*" (see [2]). Bluetooth defines and specifies the chip-based solution of this vision to be integrated in portable devices of various kinds. All portable Bluetooth devices will be able to set up wireless ad-hoc connections in order to interchange all kinds of information in nearly every situation.

The main properties of the Bluetooth wireless communication technology are (as summarised in [2]):

- low-cost, low-power radio transceiver chip (0.5 square inches)
- price of Bluetooth module will be approx. 15-20 US$ in the near future and the goal for year 2001 is approx. 5 US$
- a low nominal range of Bluetooth radio (10 meters) for saving battery power
- extended range with external power amplifier (100 meters)
- operation in the globally available and unlicensed 2.4 GHz ISM frequency band (ISM – Industrial, Scientific and Medical band)

The Bluetooth radio transmission uses a packet-switching protocol with a hybrid approach of FHSS (Frequency Hopping Spread Spectrum) and DSSS (Direct Sequence Spread Spectrum) to combine advantages of both approaches. The hop frequency is 1600 hops per second, the frequency spectrum is divided into 79 hops of 1 MHz bandwidth each. This definition is similar to the IEEE 802.11 standard for Wireless LAN (see [3]). The frequency hopping scheme is combined with fast ARQ (Automatic Repeat Request), CRC (Cyclic Redundancy Check) and FEC (Forward Error Correction). A binary radio frequency modulation and simple link layer protocols reduce the complexity and the costs of the radio chip.

Bluetooth provides a nominal data rate of 1 Mbit/s for a so-called "piconet". One piconet consists of 1 master and up to 7 slaves where the master-slave principle is used to initiate and control the traffic between devices in a piconet. The master is responsible for defining and synchronising the frequency hop pattern in his piconet. A single Bluetooth unit may send/receive at a maximum data rate of 721 kbit/s or a maximum of 3 voice channels (of 64 kbit/s each with CVSD – Continuous Variable Slope Delta Modulation). Both a Synchronous Connection Oriented (SCO) link and an Asynchronous Connectionless (ACL) link for each master-slave pair are supported. Within the same Bluetooth radio range, separate and independent piconets may be formed. These may build up so-called scatternets to allow for a higher number of Bluetooth devices being active and/or for a higher aggregate bandwidth.

The state machine for establishing Bluetooth connections is presented in Figure 1. When not in use, the Bluetooth unit stays in a sleep state (Standby) with a Low Power Oscillator (LPO) still running. One unit (the master) then initiates the connect procedure by sending either a PAGE or an INQUIRY message. If the address is already known (e.g. most addresses in an office environment are already known for daily use) the PAGE message is sent. If the address is unknown (e.g. a Bluetooth unit tries to find a public printer with an unknown address) the unit changes to the "Inquiry" state trying to get response by possibly active units within radio distance.

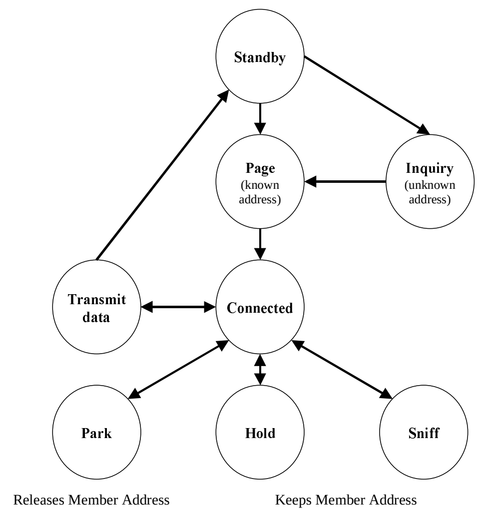

Figure 1. Connection state machine

Once connected the unit is able to transmit and receive data. For saving battery power, three low power modes are available: Sniff, Hold, and Park (in increasing order of power efficiency): In the **"Sniff" mode**, both master and slave periodically sleep and "sniff" for certain time intervals which have been previously negotiated. The **"Hold" mode** can be used when no data needs to be transmitted for long time intervals (e.g. several minutes). An internal timer determines when the unit will be reactivated. The **"Park" mode** releases the 3 bit member address of the piconet. This mode can be chosen when the unit does not participate in data transmission but still wants to stay synchronised to the frequency hopping pattern.

For a more detailed description of the state machine and the state transitions refer to [4] or [2].

There are several user situations or networking scenarios of the Bluetooth technology:

1. **"The Cordless Desktop" = Wire replacement:** In this usage model the Bluetooth radio provides a simple way to connect all peripherals to the desktop PC without the need of using cables interwoven like spaghetti.
2. **"The Internet Bridge" = Access to public networks:** In this usage model the Bluetooth radio bridges the gap between portable devices and a public network (PSTN, ISDN, GSM, xDSL, LAN, ...) via an access point or gateway. E.g. a cellular phone may be the gateway between Bluetooth devices and the cellular phone network to access the Internet or the telephone network. Connecting a notebook to the Internet or the "Instant Postcard" by connecting a camera to the mobile phone and sending photos or video clips to remote places are possible applications.
3. **"The Three-in-one Phone":** A mobile phone with Bluetooth device may work in three modes: (1) at home it works as a portable phone with PSTN connection (and charging), (2) in the office it works as an intercom (without charge to the phone owner), (3) elsewhere it works as a cellular phone.
4. **"The Interactive Conference" = Personal ad-hoc Networking:** This usage model allows a set of mobile hosts to form a wireless network without any additional networking hardware or cable support.

In a broad or abstract sense, the scenarios for the use of Bluetooth may be categorised as follows:

- Use in the office environment: Bluetooth devices and technology are used to help in professional networking and communication services, e.g. to bridge the gap between portable devices and a sophisticated (possibly wired) backbone of additional equipment and services.
- Use in the home environment: Bluetooth technology is used to connect a variety of different devices without cable, e.g. cordless desktop, portable phone, remote control, ...
- Use in public environment: Bluetooth capable user devices (e.g. a PDA – Personal Digital Assistant) establish access to local information services in public areas (e.g. an airport, railway station, ...).
- Location independent use, ad hoc networks: Use of Bluetooth technology to connect devices independently and out of range of any fixed networking equipment (see IEEE 802.11 Study Group on WPAN - Wireless Personal Area Networks [5] and Wearable Computers [6], or [7]).

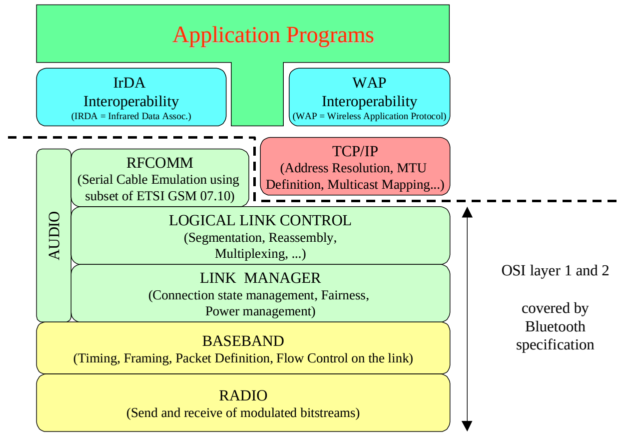

Figure 2. Application framework for Bluetooth

The Bluetooth standard [4] defines among other things the physical requirements and Link Layer functions (OSI layers 1 and 2) to be implemented in hardware on small chips. Together with a networking and application framework (see Figure 2), the Bluetooth technology provides wireless access to communication services between Bluetooth devices or with access to network services with different technology (e.g. GSM, PSTN, Internet, ...).

The application framework of Bluetooth is intended to achieve interoperability with IrDA (Infrared Data Association, [8]) and WAP (Wireless Application Protocol) as well as allowing several other application programs to use Bluetooth technology and protocols. Addressing the upper layers of the OSI model, the WAP Forum specifies the "Wireless Application Protocol" to bring Internet content and advanced services to mobile phones and other wireless devices. The goal is to "*create a global wireless protocol specification to work across differing wireless network technologies*" [9]. For example, the "wireless browsing" shall be made possible by using WML (Wireless Markup Language), a language that inherits XML's concepts. The connection between WAP and Bluetooth is not fixed yet. Especially the transport and network layers require additional work.

A comprehensive overview and more information on Bluetooth may be found in [2] or [1].

3. IP and Mobility

Standard IP has not been designed for mobility issues. IP assumes a computer to stay in the same IP-subnetwork. If the computer moves to another IP-subnetwork, a new IP address that is valid in that particular section of the Internet has to be assigned. In the past few years, the need for mobility has led to Mobile IP, which is described in section 3.1. Recently, Cellular IP (see section 3.2) was proposed to solve the problems encountered in scenarios where IP-hosts change their network connection rapidly. Our protocol concepts that are presented in section 5 use mechanism from both Mobile IP and Cellular IP, therefore, this section discusses the basics of the two protocols.

3.1. Mobile IP

The Internet Protocol is based on the assumption, that each host is assigned a hierarchical IP address: a netid followed by a hostid. Consequently, IP datagrams to a host are routed to the network given by the netid first, which then takes care of the delivery to the actual host.

As portable computers are becoming widespread nowadays, people wish to be connected to the Internet not only at their home networks (which may be the office intranet), but also via foreign networks, where Internet access is granted (e.g. Conference Center network, hotel network, train compartment, ...). In addition to that, local services provided by the home network (NFS, E-Mail, access to Intranet data) should be present, when connected through a foreign network, too. Due to the fact that these services and many other configuration items on the mobile computer are depending on the usage of the home IP address, it is desirable to provide a solution for being reachable at foreign networks by the home IP address. Additionally, location hiding is highly desirable in many scenarios. To overcome this situation, IP mobility support has been defined in RFC 2002 (see [10]) by the mobile IP working group of the IETF. A network providing Mobile IP support for its roaming portable devices has to establish an entity called “home agent”, whereas networks providing access to the Internet for portables using their home network address have to establish an entity called “foreign agent”. On arrival at a new network, a mobile host contacts the local foreign agent, which supplies it a “care-of-address” which may be an address of the foreign agent itself. After that, the mobile’s home agent is informed that all IP datagrams destined to the mobile host must be forwarded (tunnelled) to the new care-of-address in order to reach it.

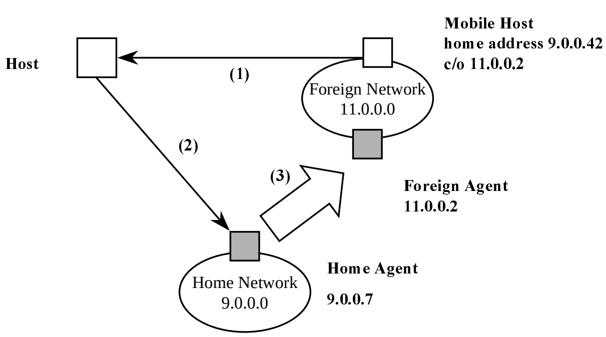

Figure 3. IP datagram flow between a mobile host and its peer, using Mobile IP

Figure 3 shows the datagram flow between a mobile host connected to a foreign network and its communication partner on the Internet. Datagrams from the mobile host are routed to the peer via standard routing (1). Datagrams to the mobile host are routed to its home network first (2). The home agent, aware that the mobile is currently not attached to its network, tunnels the incoming datagrams to the mobile’s care-of-address (3), where they are received by the foreign agent and delivered to the mobile.

3.2. Cellular IP

Cellular IP specifies a protocol that makes routing of regular IP datagrams to moving mobile hosts in a local network possible (see [11], [12], [13]). It provides local mobility and handoff support for frequently moving hosts, which means that mobile hosts can migrate inside a Cellular IP Network with little disturbance to active dataflows. It is only intended for local area networks and metropolitan area networks. For mobility between different Cellular IP Networks, it works with Mobile IP.

Mobile hosts connecting to a Cellular IP Network are able to retain their IP address. Cellular IP makes it possible to route IP packets to that IP address regardless of the location in the Cellular IP Network and without being bothered by a device’s foreign IP address. Thus, hosts inside the Cellular IP Network are identified by their home IP address, but these IP addresses have no location significance. Hosts outside the Cellular IP Network do not need any changes and they are unaware of the mobile host’s location.

A Cellular IP Network consists of a gateway, routers, base stations and mobile hosts. The gateway connects the Cellular IP Network to a regular IP network such as the Internet. Nodes inside the Cellular IP network are routers with at least two interfaces. One interface leading towards the gateway and one or more interfaces leading towards base stations. Cellular IP base stations are nodes which have an interface to a wireless network and an interface to a wired network. Base stations periodically send beacon signals. Mobile hosts use these beacon signals for locating the nearest base station and for detecting a handoff when receiving a different beacon signal.

Packets transmitted from mobile hosts are always routed from the base station to the gateway by a hop-by-hop shortest path routing. So, even when the destination host is within the Cellular IP Network, the packets are routed to the gateway before being routed to the destination host. Each Cellular IP Node has a routing cache which maps a mobile host’s IP address to the interface leading to the mobile host. Therefore, each packet coming from the mobile host and going to the gateway updates this cache by mapping the mobile host’s IP address to the interface through which the packet entered. IP packets addressed to a mobile host can then be routed by the chain of mappings in the routing caches.

The mapping in a cache is only valid for a specific time. To prevent these mappings from timing out the mobile host has to transmit control packets regularly during periods with no data to send. These control packets are ordinary IP packets with an empty payload field and directed to the gateway.

A handoff occurs, when a moving mobile host leaves the range of a base station and approaches a new base station. When coming within range of the new base station the mobile host sends its packets through the new base station. The first of these packets, going from the new base station through the nodes and towards the Cellular IP gateway, reconfigures the routing caches of the nodes. The new path along the way from the gateway to the new base station may overlap with the old path leading to the old base station. For the time up to the timeout value the route to the old base station coexists with the new route and the packets are sent along both paths. Upon timeout the old route is deleted from the routing caches and all packets are sent only to the new location of the mobile host.

Cellular IP was specifically developed for supporting frequently moving hosts, but can also support rarely moving hosts and even static hosts. Thus, Cellular IP contains some concepts, which are promising for BLUEPAC local area networks. In scenarios, such as the supermarket scenario, hosts are often in motion and connections should not be lost while migrating from one base station to the next. Even in public access scenarios where connected devices are static, concepts from Cellular IP may be useful. Mobile IP makes these connected devices reachable, but only in networks where the device is directly connected to a Foreign Agent. Cellular IP makes routing possible, even if there are several routers between the Foreign Agent and the connected device.

4. Bluetooth in Public Areas: Scenarios

In this section, we describe several application scenarios in public areas. As mentioned above, these areas shall be called BLUEPAC areas (**BLUE**tooth **P**ublic **AC**cess). We distinguish between scenarios with low user mobility and high user mobility. These scenarios will be merged into a reference network architecture, which is described in section 5.1.

4.1. Scenarios with Low User Mobility

Many people are looking for comfortable ways to get their notebook etc. connected to the Internet to get urgent work done, for email exchange, IP-telephony or surfing the Internet while they are travelling. The network provider might also offer enhanced services like Video- or Music-on-Demand. Examples are connectivity in an airplane, in a train or in a hotel room.

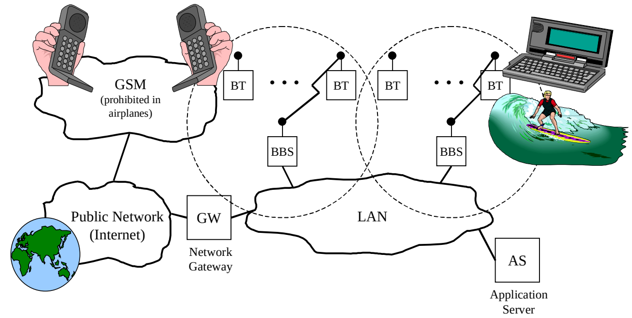

Figure 4. Scenario with low user mobility

The usage of Bluetooth (BT) devices in airplanes is of very high interest since a lot of business people do their work during flight. That is especially important for telephoning with the home company or customers etc. since the use of cellular phones is prohibited during flight. In the future, a person may be allowed to use the Bluetooth capable phone to establish a connection to the airplane's LAN and can make a call using the public network attached to the airplane's LAN through a gateway. However, the approval of the FAA is still pending.

Compared to the airplane scenario, the main difference of using Bluetooth devices in a train or in a hotel room is that cellular phone calls are basically possible (see Figure 4). That means that making people do their phone calls via the internal LAN devices the Bluetooth network provider must either offer better quality of service or lower costs when using BT devices instead of a cellular phone. For example, the costs could be decreased by audio advertisements to be transmitted before setting up the phone connection. QoS improvement obviously also would be appreciated by everybody who ever used his cellular phone on a moving train. Calls may be made by direct cellular phone connection or (possibly with better QoS) by an IP connection via the LAN and Network Gateway. Furthermore, there may be local information services provided by an application server: individual information (e.g. city map) and broadcast information (e.g. train delays at next station).

In these scenarios, the user enters the BLUEPAC LAN, stays in one place most of the time. Entering a BLUEPAC area, he needs connectivity that has to be provided by the BLUEPAC LAN. This issue is addressed in section 5.2 and 5.3.

4.2. Scenarios with High User Mobility

In contrast to the scenarios presented in the previous section there are scenarios in which the user does not stay

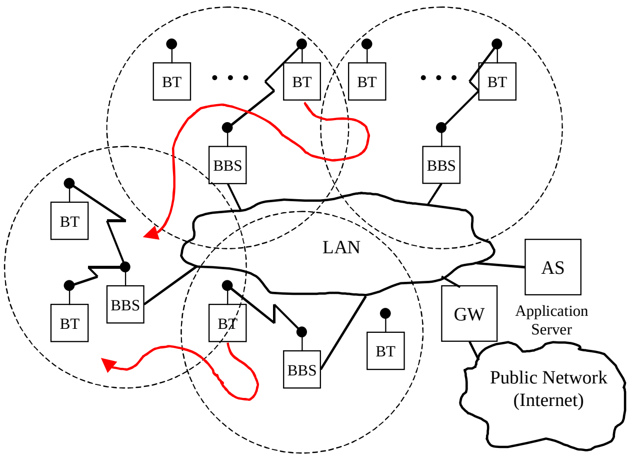

Figure 5. Scenario with high user mobility

put in one place but moves around, e.g. on a railway platform or in a department store (see Figure 5).

Consider a railway station: The waiting passengers and those who have just arrived are often very interested in the arrival/departure times of trains and which platform to go to so the application server has to provide this information. Furthermore, there may be a lot of people who want to use the information services, so there have to be enough basestations for providing wireless access. Additionally, people want to get connected to the Internet, so the LAN might offer this service as well. Similar scenarios may be found at bus stations and airport terminals, theatres, cinemas and opera houses: Once inside the entrance-hall the visitor can browse the current program and even book and pay the tickets. In a department store, customers may be guided through the department store towards the products of interest. Furthermore, by keeping track of the customers' way through the store special offer products can be placed strategically. Store managers may gain profit if they know the behaviors of their customers. Similar scenarios are digital tours through museums, zoos or botanic gardens where visitors are guided to the places of interest. Shopping malls with several stores may be realized with interconnected LANs, each LAN owned and operated by a different store.

Thus, the Bluetooth Base Stations (BBS's) have to be arranged such that a complete coverage of the corresponding area is achieved. The connection between each BT device and the application server is set up when the customer enters the area and is torn down when the customer leaves it. This requires the protocol mechanisms to keep track of the BT device (see section 5.4).

5. Protocol Concepts for BLUEPAC IP

This section describes the reference network architecture for BLUEPAC scenarios and the protocol concepts for BLUEPAC IP. BLUEPAC networks have to take into account that a BT device connecting to the network may or may not have its own IP address. Furthermore, BLUEPAC networks have to support moving devices as well as static devices.

All devices in a BLUEPAC LAN (e.g. BT devices, BLUEPAC Base Stations, routers, application servers) have to use BLUEPAC IP, but communication with IP hosts outside is possible without modification to any device outside the BLUEPAC LAN.

5.1. Reference Network Architecture

The identification and examination of potential Bluetooth scenarios with public access (see section 4) leads to a reference network architecture that is valid for all BLUEPAC scenarios.

The reference network architecture is depicted in Figure 6 and contains the following elements:

- **BLUEPAC Local Area Network:** The main element is a (wired) LAN to which the BT devices should gain access, see Figure 6. In a more detailed view, the BLUEPAC Local Area Network may consist of several interconnected heterogeneous LANs.
- **Gateway (GW):** The network gateway connects the BLUEPAC LAN in the BLUEPAC area (typically owned by the BLUEPAC service provider) to a public network (e.g. Internet, PSTN) providing access to global information and communication services.
- **BT device:** BT devices are the end devices of Bluetooth users (e.g. Notebook, PDA – Personal Digital Assistant, ...).
- **BLUEPAC Base Station (BBS):** The BBS acts as

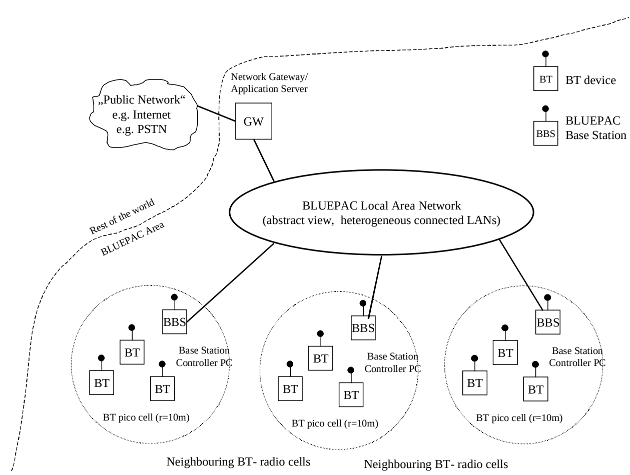

Figure 6. BLUEPAC reference network architecture

a LAN access point. The BBS is directly attached to the BLUEPAC LAN and typically owned by the BLUEPAC service provider. A BBS marks the edge of the BT radio cloud. Each BBS may serve one or more BT pico cells.

- **BLUEPAC area/Rest of the world:** The BLUEPAC area where the BLUEPAC services are available to customers/users with BT devices can easily be separated from the "Rest of the world" where the protocols using our concepts need not to be installed.

The basic scenario of connecting BT devices is the following: within radio range to one of the BBSs a connection may be set up between the BBS and a user's BT device. This connection enables access to the BLUEPAC LAN services, and, in some cases, access to the public network.

Figure 6 shows how BLUEPAC services can be provided in an area that exceeds the range of a single Bluetooth pico cell: Several BBSs may be attached to the LAN in order to cover a larger area. In certain scenarios this may be useful/necessary to reach a complete coverage of the public area (see section 4).

The general requirements that have to be met for establishing BLUEPAC scenarios are:

- **Connectivity of devices via Bluetooth technology, OSI layer 2:** This is given by the BT standard, since [4] specifies OSI layers 1 (baseband radio) and 2 (connection set-up, link management).
- **Connectivity of (foreign) BT devices in BLUEPAC area, OSI layer 3:** BLUEPAC IP covers this issue. Based on the Internet protocol family in the BLUEPAC LAN (i.e. TCP/IP, UDP/IP) the necessary steps and concepts to connect the conventional protocols with the new Bluetooth technology in public environments will be presented in the following sections.

Figure 7 shows some elements that have been added to the reference network architecture. Furthermore, these new elements are necessary/useful to define and explain specific options of this general architecture to cover specific properties or requirements of the BLUEPAC scenarios as described in section 4.

First of all, an application server provides location-based information services. A BT device communicates with this application server via its LAN access point, the BBS. Here, Bluetooth only has to establish the connection on OSI layer 2. The task of how to reach the application server (OSI layer 3) is covered by BLUEPAC IP.

Referring to the arriving user with the "foreign" BT device in the bottom right corner of Figure 7, BLUEPAC IP must include specific mechanisms and elements to

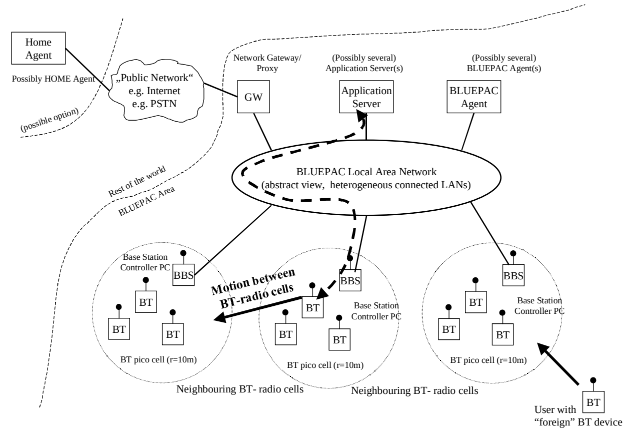

Figure 7. BLUEPAC reference network architecture with functional elements

register new customers: The BLUEPAC Agent coordinates the communication with the arriving BT device. If the BT device has got its own IP address the BLUEPAC Agent will accept this address. For reasons of authentication and home connectivity the BLUEPAC Agent may contact the HOME Agent of the BT device. For example, if somebody in the Internet wants to send an e-mail to the BT device, he directs the e-mail to the home IP address. The HOME Agent (i.e. similar IP address) intercepts this e-mail and forwards it towards the BLUEPAC Agent that previously signaled that it has got connection to the BT device.

Furthermore, the BLUEPAC Agent can assign local IP addresses to mobile devices chosen from a free address space dedicated to this purpose (DHCP, see [14]). Once registered by and connected to the BLUEPAC Agent the BT device is offered various services from the BLUEPAC Agent. These services may reach from local information (e.g. location-based information services, WWW browsing, WAP/WML) to global connectivity (IP telephony, PSTN telephony, connection to HOME Agent).

There is another specific option of the general reference network architecture that is covered by BLUEPAC IP: "Fast" motion of foreign BT devices in BLUEPAC area with continuous service. Referring to Figure 7, the BT device in the middle pico cell has established a connection to the application server. As described in section 4, some scenarios require the tracking of moving BT devices. Leaving the middle and entering the left pico cell, the BLUEPAC Agent might tear down the current connection and set up a new connection with the same BT device. The challenge in this situation is not to interrupt or even loose the service. In many scenarios the user will appreciate the ability to walk to neighboring pico cells without losing the (virtual) connection to the application server.

Changing to a different pico cell results in connection to a different base station. In this case, the complete status/information about the current connection kept by the "old" BBS must be forwarded to the "new" BBS.

5.2. Local IP Address Assignment

For BT devices that do not bring their own IP address and want to connect to a Bluetooth Public Access Network a mechanism is needed to assign IP addresses and to provide the device with the relevant information for connecting to that network (DNS server, proxy server, etc.). Figure 8 shows this case. The typical BLUEPAC Local Area Network consists of several BLUEPAC Base Stations, a BLUEPAC Agent, an application server, possibly a proxy server and possibly several routers between the servers and the base stations (refer to the reference network architecture given in Figure 7).

The BLUEPAC Base Station is the edge device between the Bluetooth Radio and the wired network. It routes the packets from the wired network to the connected BT devices and vice versa.

The BLUEPAC Agent's job is the assignment of IP addresses and the authentication of the connecting devices. The assignment of IP addresses can be realized in analogy to a DHCP-Server [14]. If the assignment of globally unique IP addresses from the Internet Registry is to be avoided then local IP addresses may be used. Since these addresses are valid within a local network only, a proxy server is needed when connection to the Internet is required. The proxy then forwards the data to hosts in the Internet and back again. So the BLUEPAC Agent's job of assigning IP addresses and giving the address of a domain name server may also include the allocation of a proxy

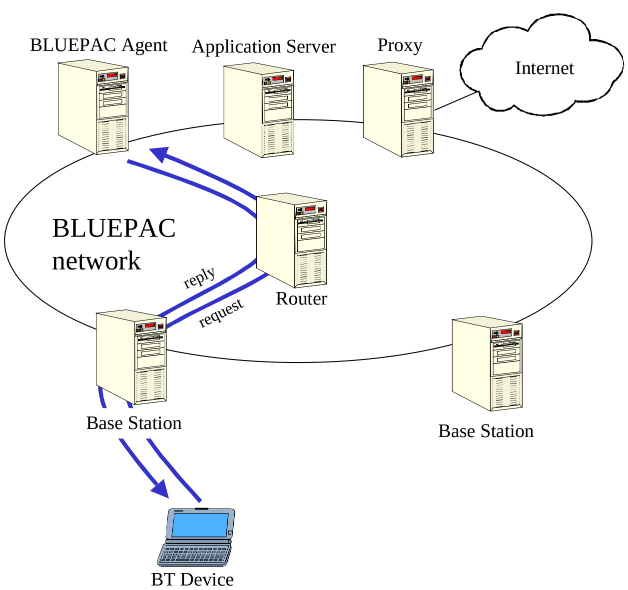

Figure 8. Local IP address assignment

server. It also has to handle disconnection and timeout of connected devices to revoke allocations and reuse the IP addresses for additional devices. If globally unique IP addresses are used then a router is needed instead of the proxy.

In the BLUEPAC local area network it must be possible to route data to the connected BT devices. The devices' allocated IP addresses do not necessarily have location significance and the devices may even be in motion. Here the concepts of Cellular IP are beneficial, as it allows for routing to IP addresses regardless of the current location of the device.

With the properties presented above, a BT device is able to connect to a BLUEPAC network without having an own IP address. When the device is within range of a Bluetooth Base Station, it connects to the base station, sends a registration request to the BLUEPAC Agent and receives a reply with an allocated IP address and possibly an address and port of a proxy server. Now the device is able to communicate with application servers, with other connected BT devices anywhere in the BLUEPAC network and even with hosts in the Internet.

5.3. Support of Mobile IP

Mobile IP offers two addressing schemes for mobile hosts connected to a foreign network:

Providing each mobile host with its own foreign network IP address

Here, the network's foreign agent assigns each mobile host a unique and globally valid IP address, which is referred to as a co-located care-of-address. Using the co-located care-of-address, the mobile host becomes a fully qualified participant of the foreign network. IP datagrams from the home agent to the mobile host are directly received and unwrapped by the mobile host itself. Unfortunately this addressing policy requires the network administrators to maintain a (possibly) large pool of real IP addresses, depending on the maximum number of mobile devices, that may be given access to the Internet simultaneously. Another problem arises when a mobile host changes the local access point to the foreign network which seems to be likely when considering a user moving his mobile BT device out of reach of the BBS, that currently connects it to the BLUEPAC LAN. Standard routing techniques assume that all hosts of a network share the same network address part. Routing between several LANs is often accomplished by subnetting the host part of the IP address and thus creating an additional hierarchy for the LAN routers to determine to which LAN a datagram must be forwarded to reach its destination. In that case, the BT device has to share the subnet address with its current BBS. In cases where the new BBS the user connects to is a member of a different subnet, a new IP

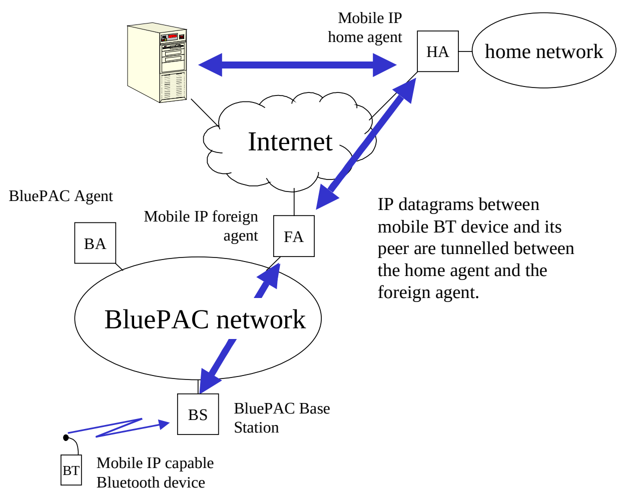

Figure 9. Mobile IP support

address would have to be assigned to the BT device reflecting its new location in the LAN topology. This does not appear to be very efficient.

Assigning a foreign agent care-of-address and using the home address in the foreign network

The second addressing scheme supports only one care-of-address for all mobile computers in the foreign network: an address of the foreign agent. This address-saving scheme still has an unresolved issue – the distribution of incoming tunnelled IP datagrams from the mobile host's home agents to the mobile host. Assuming that foreign agent and mobile host are just one hop apart, incoming datagrams can be sent directly from the foreign agent to the mobile host. This assumption does not hold here: BT devices are connected to the BLUEPAC LAN by a BBS, resulting in at least two hops. In a large BLUEPAC area, it is feasible to introduce a more complicated routing hierarchy with several LANs connected by routers, increasing the number of hops between the BT device and the foreign agent. The problem of having several routing hops from the foreign agent to the BT devices, where the BT devices are addressed by their home address may be solved with the Cellular IP routing scheme which does not care about subnetting and network address parts.

5.4. Handoff Support

In certain BLUEPAC scenarios – e.g. in a supermarket – BT devices will be in motion. In these scenarios, the BLUEPAC Network must support handoffs to maintain existing connections while BT devices move from one base station to the next.

Figure 10 illustrates how to solve the handoff support in a BLUEPAC network. Once again the BLUEPAC local area network consists of an application server and possibly a gateway or proxy. The gateway or proxy allows for connections to the Internet. The application server offers services for public access networks, the base stations provide connectivity between the Bluetooth Radio and the wired network. Several BLUEPAC routers may exist between the servers (gateway, application server, etc.) and the base stations.

Obviously, these routers are the main factor to make handoffs possible. Our concepts for these routers are based on Cellular IP. A routing mechanism with routing regardless of the location within the internetwork is required to accommodate devices in motion, changing their position within the network all the time. Furthermore, a routing mechanism is required which keeps a connection alive when changing from one base station to the next. These requirements are met by Cellular IP.

The data transmitted from a BT device connected to a base station possibly passes several routers on the way to the gateway. Each packet received from a router updates the routing cache by mapping the sending device's IP address to the interface the packet was received from, i.e. the interface leading to that device. If the device has not got any data to send, it has to send control packets periodically to the server to update the routing caches. When leaving the range of the old pico cell, the BT device connects to the next BLUEPAC Base Station available and continues sending its information through the new base station. These packets going through the new base station towards the servers update the routing caches to the new route leading to the device. If the device has not got anything to send at the time of the handoff, the routing caches

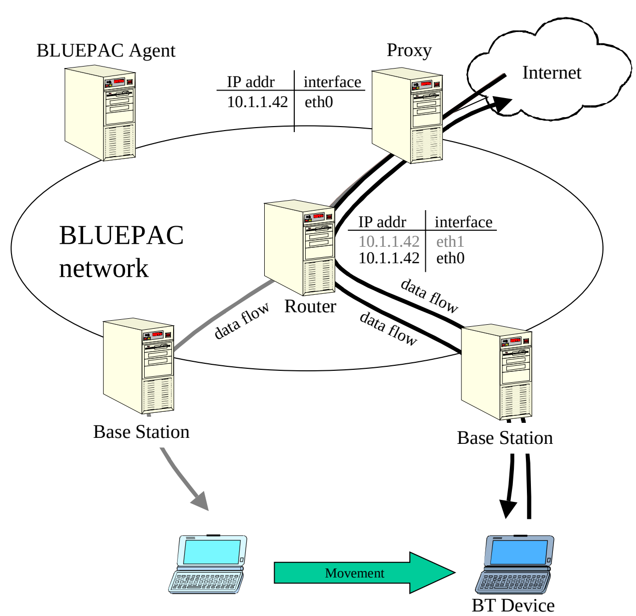

Figure 10. Handoff support for mobile BT devices in BLUEPAC area

are updated with the next control packet sent by the BT device. For the period up to a timeout value, there will be two routes available, until the old route times out after not being used for a short while. All nodes above the gateway or proxy do not notice the handoff.

All in all, the protocol concept presented above allows handoffs in BLUEPAC Local Area Network with little disturbance to active data flows.

6. Conclusions and Further Work

With the availability of Bluetooth chips it will be possible to build medium to large local area cellular networks. To include Internet services in these networks, it is not sufficient to use conventional IP because IP cannot cope with moving hosts due to its addressing scheme. We introduced a reference network architecture for BLUEPAC networks that includes Bluetooth devices, BLUEPAC Base Stations, a BLUEPAC Agent, an Application Server, a Network Gateway/Proxy, and a BLUEPAC LAN. All devices in a BLUEPAC area have to use BLUEPAC IP for which we have presented protocol concepts. These concepts cover the issues of local IP address assignment, support for Mobile IP and handoff support.

If a Bluetooth device does not have its own IP address when entering the BLUEPAC area it gets one assigned from the BLUEPAC agent and gets information when connecting to that network (DNS server, proxy server, etc.). If a Bluetooth device brings its own IP address and has a Mobile IP home agent, the device can ask the BLUEPAC LAN's foreign agent to provide communications in a Mobile IP fashion. To cope with the possibly fast moving Bluetooth devices, it is necessary to have a routing mechanism that allows for routing regardless of an IP address' location within the networks. Furthermore, the routing mechanism has to assure that a connection is kept alive while the Bluetooth device migrates from one base station to the next. This support of handoffs is done by the routing mechanisms of Cellular IP which are also present in BLUEPAC IP.

With all the above, a Bluetooth device using BLUEPAC IP is able to communicate with every other device in a BLUEPAC area and, if the BLUEPAC area provides for it, with every IP host – which uses standard IP – in the Internet.

In our further work, we will specify our protocol concepts for BLUEPAC IP in SDL (**S**pecification and **D**escription **L**anguage, [15]). Furthermore, we will do a prototype implementation and performance evaluations by measurements and by simulations. We will also evaluate our protocol concepts for the applicability over other wireless MAC protocols.

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