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# BlueMobile – A mobile IP based Handoff system for Bluetooth, 802.11 and GPRS links.

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***Abstract*—Ad-Hoc networks using Bluetooth technology has gained immense popularity among the networking community. Nowadays electronic devices like cell phones come shipped with Bluetooth. Whereas Bluetooth technology has certain obvious advantages like low power consumption and reliable connection but it suffers some inherent problems including low area of operation, limit of 7 slave devices per master device. 802.11 technology on the other hand, has a wider area of operation and therefore very useful as Access points and higher bandwidth to the order of 11 Mbps in 802.11b. But 802.11 has a higher power consumption than Bluetooth. Cellular networks have a much wider coverage in geographical area than 802.11. Complementing Bluetooth with 802.11 and cellular network technology like GPRS would solve the shortcomings of these three technologies. With this idea we designed a handoff system called BlueMobile to integrate Bluetooth, 802.11 and GPRS technologies, by introduction of a simple extension to the already existing Mobile IP implementation.**

***Keywords-Mobile IP; Handoff; Bluetooth; 802.11; GPRS; GSM***

## I. Introduction

In recent times Ad-Hoc networks using Bluetooth technology [19], [20], [24] has become popular in networking community as a market leader for short range wireless networks. For example, modern cell phones come shipped with Bluetooth. The IEEE 802.11 standard [11], [21], [22], [23] for WLANs is the most widely used WLAN standard today. The standard uses the carrier sense multiple access (CSMA), medium access control (MAC) protocol with collision avoidance (CA). On the other hand, GPRS (General Packet Radio System) [17], [18] is the packet mode extension of GSM and is a prevalent cellular technology.

Bluetooth, IEEE 802.11 and cellular network technology like GPRS have properties complementing one another in different amplitudes of power consumption, area of operation and data rate. While Bluetooth comes with low power consumption, reliable connectivity, low bandwidth (in the order of 721 kbps) and a small area of operation (about 10 meters) with only a maximum of 7 slaves per master device, 802.11 provides wider area of operation, bandwidth to the order of 11 Mbps, coupled with higher power consumption. On the other hand, while 802.11 supports data rate from 1 to 54 Mbps and can cover upto a few thousand square meters, GPRS technology offers limited data rates from 64 kbps to 2 Mbps [3] but a much wider area of coverage with all-over connectivity. Thus these three technologies if converged, can actualize a system which will enable roaming users to smoothly switch between technologies and thus to exploit all the advantages bestowed by these 3 types of network. With this idea in mind, we designed a handover system called BlueMobile. BlueMobile integrates Bluetooth, 802.11 and GPRS technologies, by introducing a simple extension to the already existing Mobile IP implementation [10], [15].

The task of designing the network architecture for a handoff system [12], [13], [14], [16] switching between 3 different technologies is challenging since the aim is smooth interaction both from the end user and network operator's viewpoint.

### *A. Research Contributions*

In this paper we describe an approach to the design of an integrated Bluetooth/802.11/GPRS network architecture. We introduce Mobile IP elements to various networks and using a simple extension to the Mobile IP, we integrate the three networks. We also present algorithms for handoff between the networks in various situations. Finally we analyze the performance and delay of our Handoff algorithms.

### *B. Outline*

The rest of the paper is organized as follows. In section II we mention the related works in this field. Section III describes the GPRS technology. In section IV we describe the mobile IP technology followed by the Mobile IP adaptation between Bluetooth, 802.11 and GPRS in section V. Section VI describes the Handoff algorithm between the networks followed by and the analysis of the algorithm in section VII. Finally, in section VIII we give a conclusion and describe future work in this field.

## II. RELATED WORK

In [6] we proposed a Bluetooth algorithm for fast scatternet formation with the ability to be controlled remotely. In [7] we proposed an architecture for co-existance of Bluetooth and other wireless networks. In [25] we presented a novel convergence protocol between Bluetooth and 802.11 through the introduction of a Software Layer (LSC) in the protocol stack of Bluetooth and 802.11. The present work is in continuation of the previous works.

In [3] Buddhikot et al. present integration of 802.11 and GPRS on seamless connectivity. Ye Min-hua et al. [2] introduce a mobile IP handoff scheme between 802.11 and GPRS. In [4] Shrikant Sharma et al. bring forward a vertical handoff system between GPRS and WLAN by using extended mobile IP. Markus Albrecht et al. [1] present protocol concepts for an extension of IP for mobility issues in Bluetooth networks. In [9] H. Velayos et al. propose techniques to reduce 802.11b handoff time.

## III. TECHNOLOGY PRELIMINARIES

### *A. GPRS Technology*

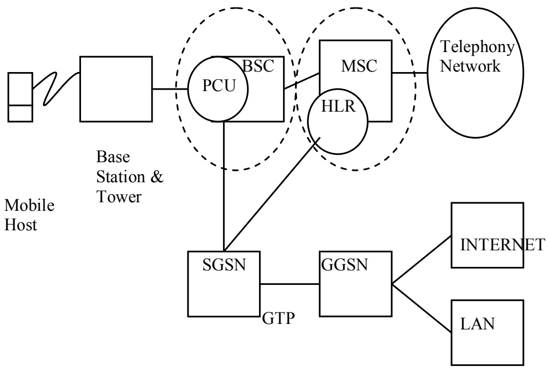


Figure 1: GPRS Network Architecture.

GPRS (General Packet Radio System) uses the bursty nature of voice traffic to make use of the physical channels of GSM for its packet traffic. Although it uses the same physical channels, GPRS uses new logical radio channels for its packet data traffic. It uses GSM network for operation. The Mobile Host (MH) access the GPRS network via the Base Station. The Packet Control Unit (PCU) is a hardware upgrade for the GPRS to be used in the GSM. Two service nodes are defined in GPRS – serving GPRS support node (SGSN) and gateway GPRS support node (GGSN). The GGSN acts as an interface to public networks like the Internet and contains the routing information to be used to tunnel packets from the Mobile Host through the SGSN. The SGSN are in charge of one or more Base station and they do location management through the HLR and VLR and are responsible for the delivery of packets. The GGSN determines which Mobile Host the packet belongs to and the packet is forwarded to the SGSN to be delivered to the Mobile Host (MH).

## IV. MOBILE IP

Traditional IP technology can't support mobility in IP layer. IETF defines Mobile IP. Mobile IP introduces two network entities: home agent (HA) and foreign agent (FA) to manage mobility. When MH is in its home subnet (its initial subnet), it uses normal IP protocol to communicate. While it enters the foreign subnet (other subnets except home subnet), it acquires an IP address, called care of address (COA). It then sends registration message to HA to inform HA its current location, COA. The data packets sent by correspondent host (CH) to MH arrive at MH's home subnet by normal IP routing. HA captures these packets on behalf of MH, and encapsulates them with new IP header, whose destination address is COA, source address is HA (it is tunneling). Then the encapsulated packets are forwarded to MH's COA. FA or MH restores the original IP packets. Data packets from MH to CH are routed normally. The flow of data transmission is illustrated as Figure 2.

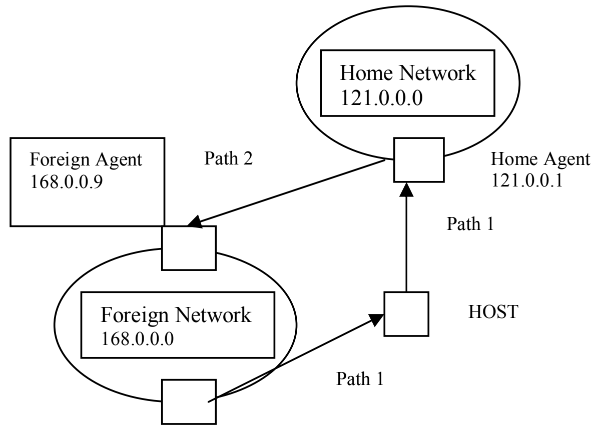


Figure 2. IP datagram flow to and from a Mobile Host Using Mobile IP.

When MH enters new subnet, it needs handoff. It acquires a new COA and registers it to HA again, so that HA can correctly forward IP packets to it. During the time between MH leaving its old foreign subnet and HA receiving MH's new registration request message, because HA doesn't know MH's current COA, it still forwards those packets whose destination address is MH to the old FA, and these packets will be dropped by the old FA. It is possible that the connection will be disrupted. If the distance between the MH and HA is a bit long, the disruption time will be large. In this case, decreasing handoff delay and packet loss is the crucial issue for Mobile IP handoff. Mobile IP is proposed to support mobility in computer network. But because of its characteristic of easy realization, Mobile IP can be used in many wireless networks to support mobility.

Figure 2 shows the IP datagram flow between a mobile host connected to a foreign network and its communicating element in the internet. Datagrams from the mobile host to the communicating element are routed via path 1 through the Host to its home network. But Datagrams from the Internet are tunneled by the Home Agent to the Care-of-Address of the Mobile Host through Path 2 via the Foreign Agent.

## V. MOBILE IP ADAPTATION FOR BLUETOOTH, 802.11 AND GPRS

In order to support mobility between the two networks, we use a peer network structure. That is, GPRS and Bluetooth access Internet as peer networks, and implement the function of

Mobile IP respectively. In the Bluetooth network, we assume that the existing architecture is enhanced by network elements using the concepts from the BLUEPAC IP [1], which is based on ideas from mobile IP. Also, the GPRS network has Mobile IP components for supporting handoffs. In GPRS network, we propose to implement the HA function at GGSN. When MH whose home network is GPRS moves to a foreign network (it is possibly not GPRS, such as Bluetooth), it registers to HA (GGSN) its current COA through the FA at the foreign network. GGSN checks all the IP packets that came from outside Internet. Once there are some packets whose destination is MH, it acts as HA, that is, it re-encapsulates these IP packets and forwards them to MH by tunnel.

We can also implement the FA function at GGSN, but we propose to implement it at SGSN. Then the FA function can be distributed to the SGSNs, but not centralized at GGSN, which can alleviate the burden of GGSN.

When MH moves to GPRS network, which is a foreign network to it, GGSN will assign an IP address to it (assuming IPG). IPG can be a private IP address, but also can be a public one. At this time, SGSN acts as the FA of MH, so it broadcasts the Agent Advertisement messages to MH [5]. MH registers the IP address of SGSN (assuming as IPS) as its COA to the HA. SGSN relays this registration message, and records a mapping: <MH, IPG> in its database.

When HA receives the registration message, it forwards the data packets belonging to MH to SGSN. When SGSN receives these packets, it looks up in the database and finds the mapping of MH. It de-encapsulates these packets, and re-encapsulates them to new IP packets, whose destination address is IPG and source address is IPS. SGSN forwards the new packets to MH using GPRS routing mechanisms. At last, MH de-encapsulates the IP packets and restores the original IP packets. The packets from MH to CH are sent to SGSN firstly, and then are tunneled to GGSN. They are forwarded to Internet by the GGSN at last.

When MH moves in the service area of a SGSN, it only considers handoff between different BSSs (This is a problem of link layer handoff.); when it moves between different SGSNs, it should take the Mobile IP handoff. It should register the new SGSN to its HA.

The mobility support in Bluetooth is comparatively simple. Bluetooth itself defines OSI layer 1(baseband radio) and OSI layer 2 (connection setup, link management), so it only need add the layer 3—Mobile IP function to Bluetooth network: adding the HA and FA module using hardware or software in the fixed network it connects. The HA and FA function can be implemented in a router or a host or an access point. Simlarly, in a 802.11 network, the HA and the FA module are implemented in an Access point, router or a Host.

The Foreign Agent (FA) in the GPRS and Bluetooth network have the functionality of a DHCP-server [8] to assign Care-Of-Addresses (COA) from a pool of locally available IP addresses. The COA's are assigned for a period only, after that they are reclaimed by the FA for reuse. The Mobile Host has to renew subscription to a particular COA if it wants to keep it for a longer time.

## VI. MOBILE IP HANDOFF ALGORITHM BETWEEN BLUETOOTH, 802.11 & GPRS

Let us take two specific cases of voluntary handoff & a case of forced handoff due to disconnection.

### A. User is in the radio range of both GPRS & BT and wants to voluntarily switch from his currently running BT-BT communication to GPRS, possibly because he needs a wider area of connection (Figure 1):

We introduce a polling scheme whereby the Bluetooth Access Point (AP) constantly polls the client when the client is using the Bluetooth network. The clients also must respond to these poll packets, even when they have no data to transfer. Though the *Link Supervision timer* is present on the link layer in Bluetooth protocol stack that detects broken links, we do not depend on this timer. This is because, the default timeout value specified in the *Link Supervision Timer* is 20 seconds, which introduces a very large handoff latency when considering a handoff between GPRS and Bluetooth When the MH wants to switch over to GPRS, it must inform its old Bluetooth FA that it intends to switch over. It does this by sending some special control bits along with these poll acknowledgements. Immediately, the FA in Bluetooth sends a control packet to the HA in WLAN giving the current address of the client that wishes to switch over to GPRS and acknowledges the switchover to the mobile node using another control packet. This sending of acknowledgement and transmission of control packets to $HA_{802.1}$ takes place simultaneously or within negligible time interval so that for all practical purposes, we may safely neglect this latency. When the Host Agent receives this message, it begins to put all the unsent packets intended for this MH in a FIFO buffer. The size of the buffer depends on the maximum latency of the GPRS-Bluetooth handoff and also on the transmission datarate.

Once MH decides to enter the GPRS network, it changes interface to GPRS and sends Host Agent in the WLAN network the formal registration message through the GPRS Foreign Agent to confirm the Handoff. After receiving the final registration message, the HA tunnels the IP packets to the GPRS Foreign Agent from the FIFO buffer to the Mobile Host. The FA of GPRS then tunnels these packets back to MH. Similarly, all packets that are sent by the mobile node are first received by the FA of the GPRS network and is then tunneled over to the HA which then sends these packets to its true destination.

### B. User is in the radio range of both GPRS and BT and he wants to voluntarily switch from his currently running GPRS communication to Bluetooth-Bluetooth communication, possibly because he needs to save power or GSM airtime (Figure 2):

When the MH wants to switch over to GPRS, it must inform its old GPRS FA that it intends to switch over before activating its Bluetooth interface. The GPRS FA immediately informs this to the node's HA along with its address information. The HA immediately stops sending packets to the old GPRS FA and creates a buffer for all unsent packets destined for this Bluetooth mobile node. The size of the buffer as usual depends on the maximum latency of the GPRS-Bluetooth handoff and also on the transmission datarate. The 802 HA informs all Bluetooth FA in range that a device with that address wants to register itself with the Bluetooth network. The Bluetooth FA sends control packets to the Bluetooth AP's in the network which in turn starts paging for a device using that address. This saves precious time on enquiry procedure. The paging attempt is tried four times and if the device is not found, it is assumed that some other AP must have discovered the Bluetooth device.

**C. A client running BT connection, moving away from the BT AP so that it no longer lies in its radio range. Our design allows seamlessly switching to the GPRS network so the client does not feel any break in connection.**

This will be similar to case A. Only difference here will be that the MH will discover that it is out of the Bluetooth range only when it no longer receives the poll packets from the Bluetooth AP. The Bluetooth AP will also discover that MH has moved away from its range when it does not receive the acknowledgement packets in response to its poll packets. Immediately, the FA in Bluetooth sends a control packet to the HA in WLAN giving the current address of the client that is missing. When the Host Agent receives this message, it begins to put all the unsent packets intended for this MH in a FIFO buffer until HA receives the registration message from MH through FA of GPRS that it has successfully registered itself with GPRS network.

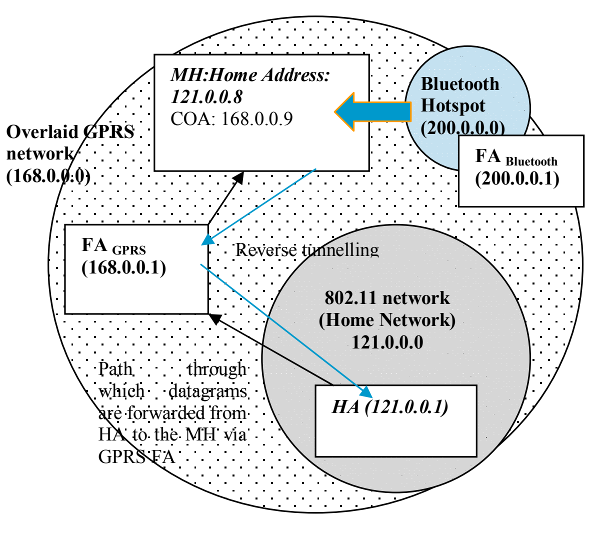


***Figure 3: Shows he overall network architectural plans. Figure shows that MH moves from its Bluetooth connectivity to GPRS connectivity as shown by thick blue arrowhead.***

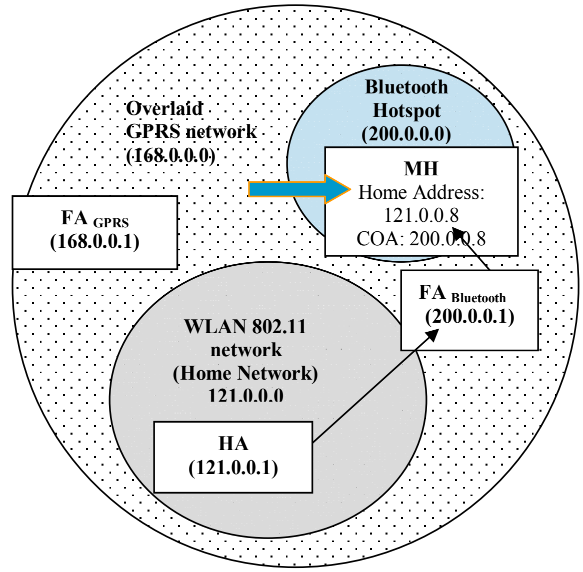


***Figure 4: Shows he overall network architectural plans. Figure shows that MH moves from its GPRS connectivity to Bluetooth connectivity as shown by thick blue arrowhead.***

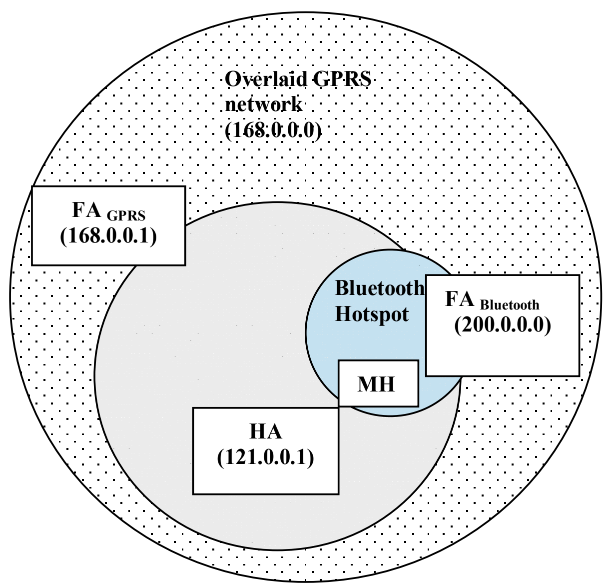


***Figure 5: Diagram shows an overlapped Bluetooth and 802.11 network region and MH is residing in the overlapped zone.***

## VII. ANALYSIS OF THE ALGORITHM

In our design of BlueMobile, we have considered only standard technology features, like inquiry and paging procedures in Bluetooth. In the following, we analyze the handoff duration and give an estimate of the handoff delay in two cases: of the voluntary switch from Bluetooth to GPRS or 802.11 and vice versa, and in another case of the disconnection from Bluetooth hotspot due to the Mobile Host going away from the region of Bluetooth coverage.

**Case 1: Voluntary Bluetooth to GPRS handoff**

Here, the FA in the Bluetooth Access Point detects that a handoff is requested by using the control frame of the message sent by the Mobile Host Decision module. Once it receives the control frame, it sends its response in the next slot. Assuming the length of the packet to be of 5 slots, the total delay is 10-slot time, which is about 6 milliseconds. Once the Bluetooth AP receives the response, $FA_{BLUETOOTH}$ forwards the Request message along with the Mobile Host address to the $HA_{802.11}$ in the Home network. The $HA_{802.11}$ responds to the request and sends an advertisement to the $FA_{GPRS}$ within 2 ms of notification time [4]. Mobile-IP responds to this advertisement by invalidating previous agent advertisements and sending a registration request within 2 milliseconds. The GPRS foreign agent responds with registration reply after approximately 800 to 1100 milliseconds. The length of the duration corresponds to the round trip time on the GPRS link. The registration reply completes the handoff and further packets are sent over the GPRS network.

Thus total handoff latency is = ( 6 + 2 + 2 + 800/1100)ms = 810 – 1110 milliseconds.

**Case 2: Voluntary GPRS to Bluetooth handoff**

Here, the FA in the GPRS station detects that a handoff is requested by using the control frame of the message sent by the Mobile Host Decision module. Once it receives the control frame, it forwards the request to the $HA_{802.11}$. The $HA_{802.11}$ responds to the notification with 2 milliseconds and sends the address of the Mobile Host to the all available Bluetooth Foreign Agents in range (since the 802.11 HA would not know which Bluetooth FA the current MH is close to and there can be more than one Bluetooth hotspots. The mobile IP responds to this notification within 2 milliseconds. The $FA_{BLUETOOTH}$ in turn instructs the $AP_{BLUTOOTH}$ to PAGE ($T_{AP\_Page}$ ) the Mobile Host using that address; thus saving the time expensive INQUIRY procedure as it already has the Bluetooth Device Address. The round trip time for WLAN is approximately 250 milliseconds. $T_{AP\_Page}$ = 128 slot time = 2.5 milliseconds (min) for mobile in Scan Repition(SR) Mode R0; 1.28 seconds (average) for mobile in SR mode R1 and 2.56 seconds (maximum) for mobile in SR mode R2. The paging procedure completes the handoff and further packets are sent over the Bluetooth Network.

So delay in this case is:

Minimum delay = 2 + 2 + (250 or 2.5) = 254 milliseconds; But latency in the GPRS links is 400 – 700 milliseconds. So the mobile node will keep receiving some out of order packets upto 400 – 700 milliseconds on its GPRS interface. If the notification request is send well in advance then there is no packet loss during the handoff.

Average delay = 2 +2 + (250 or 1280) = 1284 milliseconds

Maximum delay = 2 + 2 + ( 250 or 2560) = 2564 milliseconds.

**Case 3: Voluntary Bluetooth to 802.11 handoff**

This case is similar to the handoff from Bluetooth to GPRS, the FA in the Bluetooth Access Point detects that a handoff is requested by using the control frame of the message sent by the Mobile Host Decision module. Once it receives the control frame, it sends its response in the next slot. Assuming the length of the packet to be of 5 slots, the total delay is 10-slot time, which is about 6 milliseconds. Once the Bluetooth AP receives the response, $FA_{BLUETOOTH}$ forwards the Request message along with the Mobile Host address to the $HA_{802.11}$ in the Home network. The $HA_{802.11}$ responds to the request within 2 ms of notification time [4].

Searching by the mobile 802.11 clients (which switched over from Bluetooth) for possible nearest AP takes place ONLY in a single channel as was sent by the acknowledgement packet when the client requested a handoff. Thus, even in the active scanning mode, the scanning time is reduced.

According to the analysis done in [9], we note that

*MinChannelTime= DIFS + (aCWmin + aSlotTime).*

According to 802.11b standard, aCWmin= 31 slots, aSlotTime= 20µsec and DIFS = 50µsec.

Thus MinChannelTime=670 µsec.

Using the analysis in [9] MaxChannelTime = 10.24 ms.

Now, in our case, the client scans only one single channel. Assuming that there is equal probability for this channel to be unused as well as to be free,

Total Search Time, s = ( $T_u$ + $T_e$ ) / 2 where $T_u$= Time needed to scan a used channel and $T_e$ = Time needed to scan an empty channel.

Now, $T_u$= $2T_d$ + MaxChannelTime & $T_e$ = $2T_d$ + MinChannelTime

Using Td = 65 ms (for 20 stations), Tu = 140.24 ms & Te = 130.67 ms; So, s = 135.5 ms

Now worst-case handoff execution time is 3 ms using a Spectrum 24 card.

**Thus, total handoff latency is: 6 + 2 + 135.5 + 3 = 146.5 ms**

**Case 4: Bluetooth to GPRS handoff due to disconnection**

This case is similar to Case 2: voluntary handoff to GPRS from Bluetooth. The only addition is the minimum time taken to detect loss of connection is $T_{polltimeout}$ when no paging attempt takes place. If however, paging attempt is taking place then worst case duration within which a break in connection will be detected is $T_{polltimeout} + T_{AP\_Page}$ = 70 + 128 slots = 198 slot time (about 124 milliseconds) since we assume that the Bluetooth AP does not send poll packets when it is paging for new devices to connect to the piconet.

Thus total delay is 124 + (6 + 2 + 2 + 800/1100) = 934 milliseconds to 1234 milliseconds.

**Case 5: Voluntary 802.11 to Bluetooth handoff**

This occurs when 802.11 and Bluetooth hotspot areas overlap as shown in Figure 5.

This case is similar to Case 1 in which GPRS connection handoffs to Bluetooth.

Minimum delay = 2 + 2 + (250 or 2.5) = 254 milliseconds

Average delay = 2 +2 + (250 or 1280) = 1284 milliseconds

Maximum delay = 2 + 2 + (250 or 2560) = 2564 milliseconds.

**Case 6: Bluetooth to 802.11 handoff due to disconnection**

This case is similar to Case 3: voluntary handoff to 802.11 from Bluetooth. The only addition is the time taken to detect loss of connection is $T_{polltimeout}$ when no paging attempt takes place. If however, paging attempt is taking place then worst case duration within which a break in connection will be detected is $T_{polltimeout} + T_{AP\_Page}$ = 70 + 128 slots = 198 slot time (about 124 milliseconds) as was discussed earlier.

Thus total delay is 124 + (**6 + 2 + 135.5 + 3**) = 270.5 milliseconds.

## VIII. CONCLUSIONS AND FUTUREWORK

In this paper we introduced Mobile-IP based Handoff algorithms' for different scenario's of switching from a Bluetooth connection to 802.11 connection or GPRS connection and vice versa. We have introduced certain elements of mobile IP to the GPRS network. We have shown the delay analysis on various handoff's. Thus we see that given proper modifications to the already existing Bluetooth/GPRS/WLAN architectures, we may allow any mobile device with hardware interfaces for all the three types of network to seamlessly operate in any network domain. Thus a single mobile device can be operated in a large area depending upon the network available without loosing connectivity.

Further work on the hardware and interference aspects of Bluetooth, GPRS and 802.11 would be needed for hardware interoperability.

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