MOBILITY SUPPORT FOR BLUETOOTH PUBLIC ACCESS

Aman Kansal and Uday B Desai

Department of Electrical Engineering,
Indian institute of Technology Bombay, Mumbai-400076, India

ABSTRACT

Bluetooth technology offers the potential for low-cost, broadband wireless access for a range of mobile and portable devices. It can thus provide for ubiquitous computing across a wide range of devices. In this paper we explore the avenues for providing mobility in a Bluetooth access network. The existing methods for the same are briefly summarized and their shortcomings are pointed out. We then present a new protocol for enabling fast handoff for mobility and study its performance in terms of handoff delay and useful data bandwidth. The protocol is designed to work with standard Bluetooth hardware such that the system design is modular. It exploits the special Bluetooth link layer features to achieve significant improvement in the handoff delay and bandwidth performance.

1. INTRODUCTION

Bluetooth provides a low cost and low power short range broadband wireless communication solution for handheld and portable devices. This can enable a very powerful ubiquitous computing platform where each and every personal device is connected to the network. The technology may be used for connectivity in private areas, such as homes and offices or at public places and hot-spots. Access at public places is essential to make the environment truly ubiquitous and researchers are looking at various possible options ranging from long distance 3G to cheaper short range solutions including 802.11 and Bluetooth for providing this broadband access. The use of Bluetooth is attractive compared to 3G due to economy of implementation, faster deployment and ability to handle location specific services which may be uneconomical to provide over 3G. Bluetooth scores over 802.11 because its low power design makes it better suited to handheld devices.

In this paper we consider the problems in supporting mobility within a Bluetooth based public access network. The usage scenario is that Bluetooth enabled handheld devices connect to Bluetooth based access points which in turn are connected to other networks to provide location specific services or Internet connectivity. The access situations may be divided into two categories- low user mobility situations and high user mobility situations. Low user mobility occur at places where users are seated most of the time, say inside an airplane, train, waiting lounge or a cafeteria. Examples of high user mobility areas are supermarkets, museums, airports and other such hot-spots. In such situations users will frequently move out of the range of one access point into that of another. This requires fast handoff. The success of a short range access mechanism like Bluetooth depends on its ability to support this handoff.

In the next section we describe an existing solution for supporting mobility in access networks which has been adapted to Bluetooth. In section 3 we point out certain Bluetooth specific issues which need to be considered in the design of a handoff procedure. We then propose a new protocol for handoff which exploits the specific features and achieves significantly better performance than the exiting solution. In section 5 we analyse the bandwidth and delay performance of the proposed protocol. Section 6 concludes.

2. CELLULAR IP

Cellular IP (CIP) [1] is intended to provide local mobility inside an access network. It can interwork with Mobile IP to provide wide area mobility support.

2.1. CIP in BluePAC

The CIP protocol has been used for Bluetooth Public Access (BluePAC) in [2] and [3] for supporting handoff. The CIP network for BluePAC consists of a gateway which is connected to the Internet or other local networks, and routers, which reach out from the gateway to base stations. Base stations are the points to which mobile devices connect over Bluetooth and are spread across the access network. The base stations, routers and the gateway are connected over a high speed local area network.

CIP provides fast route updates to enable mobile nodes to change their point of attachment frequently. The mobile node sends its packets to the Internet through the gateway. The CIP router, which gets these packets from the base station, notices all IP datagrams sent by the mobile node and maps its source IP address to the base station interface from

0-7803-7448-7/02/$17.00

which the datagram was received. This prepares the route lookup table for reaching that mobile node and can be used when a packet from the gateway has to be sent to the mobile node. If the mobile node does not have anything to send for more than the cache timeout period, then it must send control packets to refresh the routing caches. Thus, if the mobile node changes location, the new location will become known within one cache timeout period.

2.2. Limitations of CIP in BluePAC

The CIP method has two limitations.

First, the handoff is not seamless. Packet loss and delay occur before the loss of connection is determined. The Bluetooth link supervision timer was used to detect loss of connection.

Second, after loss of a connection, it is the mobile node which has to search a new access point. However, the mobile node has no previous knowledge of access point addresses and will have to use the inquiry procedure to obtain it. This makes the handoff slow. Further, access points will periodically have to enter inquiry scan and page scan procedures, expecting new devices, even when there is no handoff taking place. This wastes bandwidth.

Another drawback is that the CIP must run on the mobile nodes as well. The handhelds may be compact dedicated devices not using IP at all. In this case CIP cannot be used.

3. BLUETOOTH SPECIFIC ISSUES

3.1. Connection Establishment

Connection establishment in Bluetooth [4] consists of two phases:

Inquiry: This phase is required if the address of a device to which a connection is required is not known. This may take upto 10.24 seconds in an error free environment.

Paging: This phase is required to synchronize the frequency hop sequences of the devices among which the connection is being set up.

The paging procedure cannot be eliminated from the connection establishment phase as the hop sequences have to synchronized for any communication to take place. If the clocks of the two devices are synchronized to within $-8 \times 1.28s$ to $7 \times 1.28s$, and the page scan mode used is R0 or R1, which are both mandatory scan modes as per the Bluetooth standard, then the page procedure will succeed within 1.28s, otherwise it may take upto 2.56s. Data, except voice, cannot be sent while a device is paging others. The scanning device spends only a few slots in scanning and can continue to stay in scan mode even during data transfer. The inquiry procedure however may be eliminated if the address information can be known through other means.

A single device can page and connect upto 7 active devices to itself. The device to whose hop sequence all other devices are synchronized after connection establishment is called the master. The group of the synchronized devices is called a piconet.

3.2. Channel Sharing

The wireless channel is time division duplex and further time shared among devices connected to one master. The channel access is controlled by the master in each piconet. Alternate slots are used for sending and receiving. A slave can transmit only after it receives a packet from the master. The master sends out packets in alternate slots and uses the intermediate slot to listen for a packet from the slave to which it transmitted.

3.3. Who Should be Master

When a piconet is being established between the mobile nodes and the access point catering to them, the issue whether the access point should be master or the mobile nodes, needs careful consideration. Typically the device which pages becomes the master and the scanning device becomes the slave. The access point should preferably be the master in the piconet to allow better channel sharing among the mobile nodes which are made slaves. If the mobile nodes are masters, the access point will have to involve itself in multiple piconets, reducing its bandwidth capacity. Since there will be no coordination between mobile devices this will also make the implementation of channel sharing and handoff difficult.

Thus, a handoff protocol must specify the page scan and inquiry scan modes to be followed by the devices in the access network, the polling scheme to be used, and decide who should be master.

4. NEIGHBORHOOD HANDOFF PROTOCOL

We propose a new handoff protocol, referred to as the Neighborhood Handoff Protocol (NHP), to achieve fast handoff, allowing data applications to run oblivious to the handoff. Our method also prevents packet loss during the handoff and attempts to achieve efficient utilization of bandwidth at the Bluetooth layer. This protocol does not require any changes to the mobile nodes and has to be implemented at the access points alone above the standard Bluetooth layer. NHP eliminates the time consuming inquiry procedure from handoff and provides for very rapid detection of connection loss.

The access points near the entrances to the access network are designated to be entry points. They are implemented on the same hardware but perform a different function as described below. The mobile nodes are allowed to enter the access network only at the entry points and not at any arbitrary location inside the access network.

The operation of the protocol consists of two activities:

Entry: An entry point constantly carries out inquiry. Whenever it detects a new device it establishes a connection with it, obtaining its address and clock information. It also informs the mobile node to use page scan mode R1. The entry point closes the connection and passes the address and clock information received from the newly arrived mobile node to the nearest access point. The access points and the entry points are connected over a high-speed LAN. That access point temporarily suspends its data communications and pages the new device. As the address and clock information are known, the page procedure will succeed within 1.28s.

Handoff: The polling scheme to be used is round robin, in which the master polls each slave one after the other. Data requirements may be different for different slaves and the packet slot duration may be varied between 1 and 5 slots for this. In this scheme, a polling attempt will occur once in every duration of the poll round. This duration will depend on the number of slaves and the packet slot durations, and may be a maximum of 80 slots (50ms) for seven slaves when multislot packets of length 5 are used. The slave always has to acknowledge a packet it receives from the master, even if there is no data to send. So, if the slave does not reply, loss of connection is detected. Thus connection loss can be detected within 50ms. (For voice packets using reserved slots, no acknowledgement is required, but if the master stops receiving packets in the reserved slots, loss of connection will be assumed.) There will be no packet loss since at most one packet could have been sent within one poll round, and this will be retransmitted at the Bluetooth layer itself.

Once the loss of connection has been determined, new connection must be established. We define the *Neighborhood set* of an access point *A* as the set of all access points into whose range a mobile node may have ventured after having been known to be present in the range of access point *A*, 50ms ago. As soon as loss of connection is detected, the current access point sends the clock and address of the missed mobile node to all the access points contained in its *Neighborhood set*. Any unsent data packets are also forwarded to these. Each of these access points pages the mobile node using the clock and address received from the old access point. The paging procedure is not reattempted and it is assumed that if the paged device is not found, another access point must have found it or the node would have moved out of the range of the public access network. As a very recent clock record is used, paging will succeed in the first attempt and the connection can be resumed within 1.28s.

The *Neighborhood set* will depend upon the space in which the access network is deployed. Since 50ms is a small duration for a walking user, the *Neighborhood Set* of *A* will consist of access points whose ranges are adjacent to that of *A*. Fig.1 shows the floor plan of an exhibition hall. Consider the access point *A* marked in the figure. It is clear that a mobile node which was in the range of *A*, 50ms ago could have moved to only the access points marked *P* now.

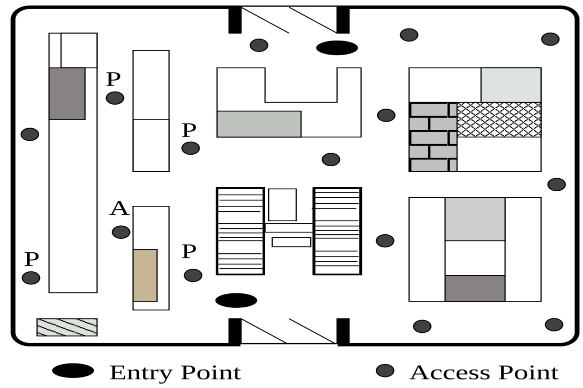

Fig. 1. Sample arrangement of access points and entry points in a Bluetooth access network running NHP

The handoff times can be further reduced and bandwidth efficiency increased by incorporating sophisticated mechanisms for predicting the paths of the mobile nodes, either based on physical constraints or through learning from observed patterns. Some attempts at characterizing paths of mobile nodes are made in [5].

5. PERFORMANCE ANALYSIS

5.1. Handoff Delays

The handoff delay observed for the BluePAC protocol in [2] was 5s and the loss of connection was detected in 8s. There was only one mobile device. The delay includes the time for inquiry and paging. In NHP, we expect a worst case delay of 1.28s and an average delay of 0.64s in connection setup after loss of connection, which is detected in 50ms in the worst case. Thus, the worst case of NHP is nearly 4 times better than the average case of BluePAC.

5.2. Datarates

The maximum datarate achievable is that obtained by using the DH5 packet, which carries 339 bytes in 5 slots. Each slot is 625μs. The datarate in the direction from the mobile node to the access point may be lower and a single slot packet is used for this direction, making the datarates assymetric.

Suppose the number of slaves in the piconet is s, where $s \leq 7$. Assume each slave requires the highest available datarate and bandwidth is shared equally. One 5 slot packet can be sent once in $s \times 6$ slots ($s \times 10$ slots if datarate is symmetric in both directions). The datarate achieved by one slave would be

$$D = \frac{339 \times 8}{6 \times s \times 0.000625}\ kb/s \qquad (1)$$

When handoff is present, this datarate will decrease. If k paging attempts take place at one access point in every n seconds, the datarate becomes:

$$D_h = \frac{(n - 1.28k)}{n} D\ kb/s \qquad (2)$$

This is because each paging attempt takes 1.28s.

Walking speed for a medium sized person at normal pace is found to be 1.11m/s through experiments in non-crowded areas. The range of one access point being 10m, a handoff will be required every 20m or less. At 1.11m/s, this leads to one handoff in $n = 18.01$s for a single mobile person. The value of k depends on the number of mobile nodes in the network and the cardinality of the *Neighborhood Set* of an access point.

Fig.2 plots the datarates obtained for $k = 4$, assuming 4 neighbors and one handoff attempt from each.The datarates for the best case of BluePAC protocol are also shown, assuming channel is shared equally among all slaves. The best case for BluePAC occurs when the inquiry succeeds in 2.56s and the random backoff delay in inquiry response is 0. The worst case scenario would have an inquiry delay of 10.24s and a random backoff delay of 0.64s for each handoff. These numbers are as per the Bluetooth standard. The paging delay is assumed to be 0.64s on the average, for both NHP and BluePAC. The worst case in BluePAC does not allow any $k > 1$. The time taken to detect connection loss, which could be a maximum of 50 ms in NHP and several seconds in BluePAC, has not been accounted for in this plot. This factor will cause a further degradation of performance in BluePAC but will not affect NHP significantly. The datarate seen by a mobile node is same as that by a stationary node as the time spent in paging by an access point affects both the mobile and stationary nodes equally.

The performance needs to be simulated for practical values of k which arise in an access network with a given number of mobile nodes and typical mobility patterns.

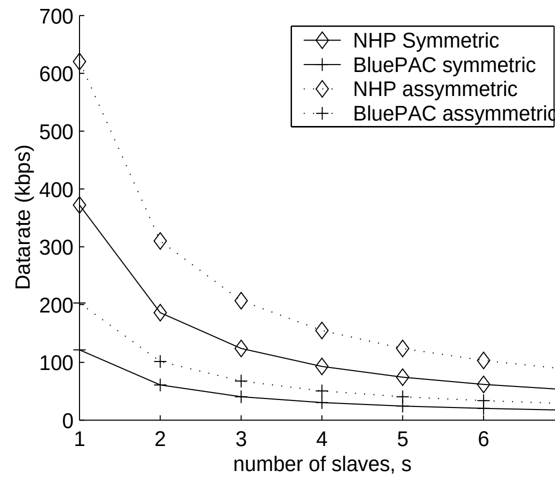

Fig. 2. Datarates for varying s, k=4 and 4 neighbors.

6. CONCLUSIONS

The paper has discussed the basic problem of supporting mobility in an access network. The existing method was reviewed and the shortcomings pointed out. The special characteristics of the Bluetooth link layer which affect the design of the handoff protocol have been mentioned. A new protocol to achieve faster handoff has been proposed and its bandwidth performance has been analysed. The performance of the proposed NHP has been shown to be much better than that of the BluePAC method. The practical application of the protocol to a usage scenario will be simulated in the course of the project. The validity of the assumptions made in the design and analysis will be checked through simulations and the protocol will be further improved for real time handoff to support interactive voice applications. These are ongoing activities.

7. REFERENCES

[1] A Campbell, J Gomez, C-Y Wan, and S Kim, “Cellular IP,” Internet draft, draft-ietf-mobileip-cellularip-00.txt, January 2000, http://comet.ctr.columbia.edu/cellularip/pub/draft-ietf-mobileip-cellularip-00.txt.

[2] Simon Baatz, Matthias Frank, Rolf Gopffarth, Dimitri Kassatkine, Peter Martini, Markus Scetelig, and Asko Vilavaara, “Handoff support for mobility with IP over bluetooth,” in *Proceedings of the 25th Annual Conference on Local Computer Networks (LCN’00)*, Tampa, FL, USA, November 2000.

[3] M Albretch, Matthias Frank, Peter Martini, Markus Scetelig, Asko Vilavaara, and A Wenzel, “IP over bluetooth: Leading the way to a new mobility,” in *Proceedings of the 24th Annual Conference on Local Computer Networks (LCN’00)*, Lowell, MA, USA, October 1999, pp. 2–11.

[4] “Bluetooth specification version 1.1: Core,” Bluetooth SIG, http://www.bluetooth.com.

[5] Anurag Chandra, Deepak Bansal, Rajeev Shorey, Ashutosh Kulshreshtha, and Manish Gupta, “Characterization of mobility patterns based on cell topography in a cellular radio system,” in *Proc. IEEE Int. Conference on Personal Wireless Communications (ICPWC)*, Jaipur, India, February 1999.