A Rapid Handoff Protocol for Mobility in Bluetooth Public Access Networks

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Abstract

The availability of low power short range wireless technologies, such as Bluetooth, is enabling compact handheld devices to be connected to information networks for mobile and ubiquitous computing. The usage model assumed is that mobile devices connect to nearby access points which in turn are connected to an external network. This model provides an alternative to the expensive 3G mobile networks and benefits the user through higher bandwidths, lower costs and other location specific services not feasible over 3G. A key issues here is providing mobility. The mobile may move out of the range of one access point into that of another and a handoff would be required. In this paper, we first survey the various options for implementing handoff. We then adapt Cellular IP for use in a Bluetooth based access network and propose a new handoff protocol which exploits the specific features of the Bluetooth link layer. Simulations reveal that our proposed scheme reduces the handoff delay by more than an order of magnitude and has enhanced datarate capabilities compared to pure Cellular IP. The number of mobile handhelds supported at the access points is also increased.

Keywords: Bluetooth, wireless access, mobility, handoff, ubiquitous computing

1. Introduction

Bluetooth is a short range low power wireless technology designed especially for compact handheld devices. Among various other applications that are enabled through this short range connectivity, an important one is the possibility for handhelds to connect to a network access point. This access point may provide location specific services, such as airline information at an airport, enable transactions at kiosks, or act as a gateway to the Internet or other local networks. The basic usage model is that mobile handhelds enter public places such as supermarkets, airports, museums or cafeterias and connect to access points installed at these places, using Bluetooth.

Bluetooth allows adhoc connections to be set up between devices without the users having to know the device addresses or configurations. However, Bluetooth does not provide for seamless handoff when a mobile handheld moves from the range of one access point to another.

Mobility is an essential feature in public access spaces. The access situations may be divided into two categories - those with low user mobility and those with high user mobility. Low mobility situations are those in which the user is seated most of the time, such as inside a train or an airplane, a waiting lounge or a cafeteria. Examples of high mobility scenarios include access at supermarkets, museums, airports or train stations. In high user mobility areas, automatic handoff is essential to provide an acceptable level of user satisfaction for most applications.

The methods used for handoff should be optimized for the Bluetooth physical and Medium Access Control (MAC) layers to reduce handoff delay. In this paper, we propose new methods to adapt existing mobility mechanisms for use with Bluetooth.

The paper is organized as follows. The next section describes some of the existing methods used for handoff and mobility. Next, the connection establishment process in Bluetooth is described and the important features to be considered for the handoff protocol are mentioned. Our proposed method, namely the mobile Bluetooth Public Access (mBPAC) protocol, is described in section 4. A summary of the performance study of this protocol is presented in section 5 and section 6 concludes.

2. Existing methods

The methods used to support mobility in packet networks and in cellular telephony networks are recapitulated below.

2.1. Mobile IP

Mobile Internet Protocol (Mobile IP) [1], was designed to allow mobile nodes to connect at locations other than those to which they usually connect. Assuming that both the old and new locations support mobile IP, a foreign agent is set up at the new location and a home agent at the usual location. When a packet addressed to the permanent IP address of a mobile device arrives at the home agent, it is forwarded, or "tunneled," as per Mobile IP terminology, to the corresponding foreign agent. The foreign agent then forwards the traffic to the temporary IP address allotted to the mobile node at the new location.

The shift from one location to another is slow and infrequent. The detection of the loss of connection depends on the timeout period for route caches.

Using this method for supporting Bluetooth handoff in a local access area would mean that each time a node moves, its foreign agent changes. The change will be affected when the route cache expires. With each handoff, a new "tunnel" has to be set up from the home agent to the changing foreign agents. The handoff will be very slow. This kind of a solution does not allow most running applications to continue oblivious to the handoff. Thus, fast and seamless handoff cannot be achieved using Mobile IP alone.

2.2. Cellular Telephony

Mobility is well supported in cellular telephony networks and ongoing calls are maintained even as the mobile station moves from the range of one base station to another. These networks do not rely on loss of connection to initiate handoff but actively track the link quality to check when a handoff may be required. Various parameters such as bit error rate (BER), carrier-to-interference ratio (C/I), distance, traffic load, signal strength or combinations of these may be used for link quality evaluation. The algorithms are difficult to employ in Bluetooth because:

1. The Bluetooth hardware will have to perform link quality measurements. The standard does provide the provision for Received Signal Strength Indicator (RSSI), but this is an optional feature and is currently not supported by most available hardware implementations. The RSSI resolution may not be enough for most cellular handoff algorithms.

2. The mobile station is required to carry out link quality measurements and assist the handoff algorithm. A large variety of mobile devices are expected to connect to a public access network and it would be preferable if the handoff protocol does not require any change to the standard Bluetooth implementation at the mobile nodes.

2.3. Cellular IP

Cellular IP (CIP) [2] is is intended to provide local mobility inside an access network.

The handoff is faster and more efficient than in Mobile IP, and is based on a simpler and more flexible infrastructure compared to that of cellular telephony. The handoff is not seamless and packet losses may occur during or after the handoff.

The CIP protocol has been used for Bluetooth public access in [3] and [4] for supporting handoff. The reference architecture used in [3] is shown in Fig. 1.

The access network is accessed by the mobile Bluetooth nodes through base stations, which allow access through Bluetooth transceivers. The access network is connected to a public network like the Internet through the CIP Gateway. The CIP agent configures the arriving mobile nodes and assigns them IP addresses.

CIP provides fast route updates to enable mobile nodes to change their point of attachment frequently. The CIP protocol notices all IP datagrams sent by the mobile node and maps its source IP address to the base station interface from which the datagram was received. This prepares the route lookup table for reaching that mobile node on each CIP router, using which the data received for the mobile node at the gateway can be forwarded to the appropriate base station. If the mobile node does not have anything to send for sometime then it must send control packets to refresh the routing tables. As the routes are updated frequently within the access network, the node is free to move from the range of one base station to another. No “tunnel” is required to be set up through a home agent as in Mobile IP. Thus, CIP solves the problem of local mobility within the access network.

The CIP ideas are good for applications which can tolerate certain handoff delay and packet loss. However, the method suffers from the following drawbacks:

1. The handoff is not seamless. Loss of connection is detected through route cache timeout. The Bluetooth link supervision timer is suggested for detecting loss of connection. This

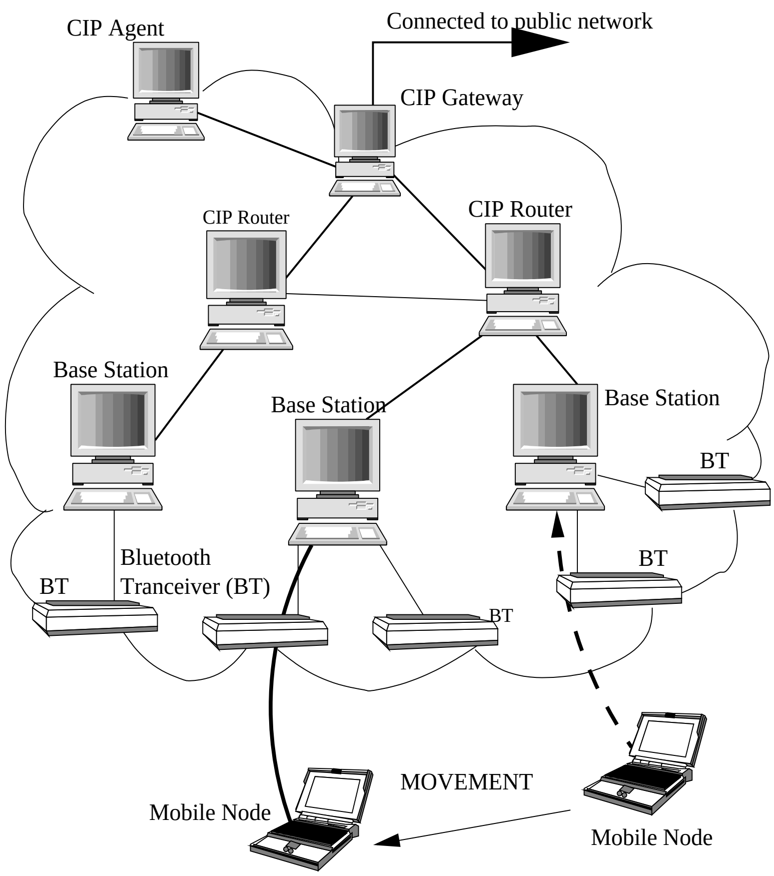

Fig. 1. Cellular IP for Bluetooth based public access, [3]

timeout value is 20 seconds by default. Thus, packet loss and delay occur.

2. After loss of a connection, the mobile node has to search for a new access point, which will then switch role from slave to master. However, the mobile node has no previous knowledge of access point addresses and will thus have to use the time consuming inquiry procedure to obtain that information. 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. Performing scan at access points reduces the robustness of the access network as analysed in section 5.4.

3. The Cellular IP protocol must run on the mobile nodes as well. This is not preferable for public access as many different mobile devices may have to be served. The mobile node should be transparent to the implementation of CIP in the access network, including its choice of cache timeout values and other parameters chosen to suit the network load.

Better handoff performance may be obtained if the specific features of Bluetooth are exploited. The number of mobiles supported by an access point will also increase if less bandwidth is wasted in handoff related operations. In the next section we describe certain issues which need to be considered in designing an efficient handoff protocol.

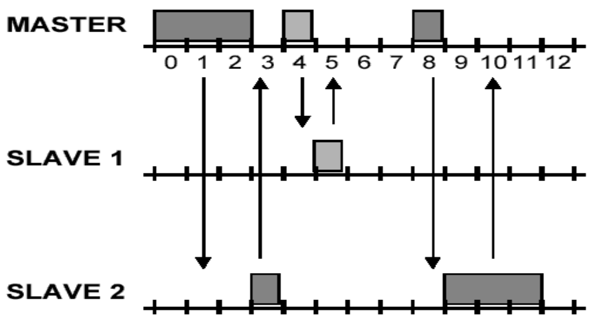

Fig. 2. Wireless medium access control within the piconet

3. Bluetooth Specific Issues

3.1. Connection Establishment

Connection establishment in Bluetooth [5] 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. If the clocks of the two devices are synchronized to within $-8 \times 1.28s$ to $7 \times 1.28s$, then the page procedure will succeed within $N_{page} \times 16$ slots (one slot is 625 μs in Bluetooth standard). N_{page} is 1 for page scan mode R0 and 128 for scan mode R1, leading to paging times upto 0.01s for R0 and 1.28s for R1. When the synchronization is worse than mentioned above, it may take upto $N_{page} \times 32$ slots, or double the times above.

The paging procedure cannot be eliminated from the connection establishment phase as the hop sequences have to synchronized for any communication to take place. Data, except voice, cannot be sent while a device is paging others.

The inquiry procedure however may be eliminated if the address information can be known through other means.

3.2. Channel Sharing

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. 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 (Fig. 2).

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,
- the polling scheme to be used, and
- who should be master within the piconets.

4. The mBPAC Handoff Protocol for Mobility Support

The mobile Bluetooth Public Access (mBPAC) protocol for supporting handoff of a mobile moving from the range of one access point to that of another is described here. The access network uses CIP. The CIP routers and gateway are not changed, as all Bluetooth specific functionality is taken care at the base stations. The CIP base stations are however modified to implement mBPAC, which adapts them to the special features of Bluetooth. The base stations present themselves as standard CIP base stations to the CIP access network. At the same time mBPAC also make the CIP implementation in the access network transparent to the mobile nodes. Additional mBPAC communication is required between the neighboring base stations.

4.1. mBPAC Handoff Protocol

The mBPAC handoff protocol is aimed at achieving a fast and seamless handoff with low handoff delays and good performance in terms of user bandwidths in the access network.

First, the desirable traits of an ideal handoff algorithm are mentioned. Then a handoff algorithm that closely matches the ideal characteristics is proposed.

4.1.1. Desirable Traits

1. The handoff should take place very fast. Data applications and higher layer protocols such as the TCP, should not be affected by a handoff occurring at the wireless physical layer. It would be excellent if real time interactive voice or multimedia applications may be supported.
2. Ideally, there should be no packet loss in the handoff.
3. The handoff protocol should not consume a significant bandwidth of the wireless channel.

4. The handoff protocol should not require changes to the standard implementation on the mobile nodes. In a public access network, it is desirable if the protocol can function through modifications to only the access points, and no changes be required in the Bluetooth implementations on the wide variety of mobile nodes that are expected to be present.

5. For portability, the protocol should be based on only the mandatory Bluetooth features.

6. The protocol should not require excessive coordination among access points This is to save bandwidth in the network connecting the access points as they may themselves be connected wirelessly for ease of deployment.

4.1.2. Operation of mBPAC Handoff Protocol

The mBPAC enabled base stations are organized into two categories:

1. **Entry Points:** These are located at the boundaries of the network or other places where the access network provider wants to allow mobile nodes to enter the public access network. Their resources are dedicated to discovering new devices through inquiry.

2. **Access Points:** These span the entire access region and provide the data or other application services to the mobile nodes connected to them. They accept devices through handoff from entry points or other access points.

The access points and the entry points are connected over a high speed local area 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. The entry point may at this point perform device registration and authentication tasks as required by the access network provider for monitoring network access or billing. 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 point receives a neighbor message for handoff request in its neighbor message queue and will process it as in case of handoff from any other neighboring access point. The connection will start with the newly entered mobile once the handoff is complete.

Handoff: Handoff consists of two steps:

Detecting loss of connection: The method for detecting loss of connection is based on the polling scheme in the piconet. Polling scheme specified for mBPAC 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 duration may be adjusted for this, using single slot packets for slaves with low datarate requirements and multislot packets of length 3 or 5 for higher datarates. Data packets themselves act as poll packets. A slave is required to acknowledge every packet it receives from the master as per Bluetooth specification. If no poll reply occurs for the timeout period, $T_{pollreplytimeout}$, connection is assumed broken. At the mobile, too a similar procedure is followed to detect loss of connection. At both the access point (master) and the mobiles (slaves) the timeout value, $T_{pollreplytimeout}$, is specified to be equal to the maximum number of slots that may pass between two successive poll turns.

$T_{pollreplytimeout}$ depends on the number of slaves in the piconet and whether the access point is involved in paging. When no paging is taking place, $T_{pollreplytimeout}$ may be a maximum of 80 slots, or 50ms for seven slaves with multislot packets of length 5. When the master is involved in paging, for processing a handoff message from a neighbor, the timeout is increased both at the master and the mobiles. A HOLD packet is sent to the mobiles just before the master enters paging to suspend their timers for a duration equal to T_{AP_Page}. The timer is resumed either on expiry of the T_{AP_Page} duration or if the master sends a regular poll message before that. T_{AP_Page} is the maximum time an access point spends on paging for a slave on receiving a neighbor message, or 128 slots (80ms).

The loss of connection will be detected at the first unsuccessful poll attempt itself because only the second poll attempt can occur within $T_{pollreplytimeout}$. No data will be lost as the packet sent will be unacknowledged and will be retransmitted at the link layer itself.

Restoring connection with new access point: Once 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*, $T_{pollreplytimeout}$ time units 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*. These messages wait in the neighbor message queue at the access points to which they are sent until the access point processes them. Each access point receiving the neighbor message finishes its poll round and checks if the neighbor message queue has any pending messages. If there is a pending message, the access point sends a HOLD message to all its connected slaves to suspend their connection loss detection timers for a duration of T_{AP_Page}.

It then pages the mobile node using the clock and address received from the neighbor. Since the page scan mode used at the mobile is R0, each page train needs to be attempted only once, which means both trains can be tried out in 32 slots. Four page attempts are made for robustness, leading to T_{AP_Page} equal to 128 slots, which is 80 milliseconds. As a very recent clock record is used, paging will succeed in the first attempt.

The *Neighborhood set* will depend upon the space in which the access network is deployed. Figure 3 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* $T_{pollreplytimeout}$ ago could have moved to only the access points marked *P* now. Thus, the cardinality of the *Neighborhood set* is expected to vary between 2 and 4 in most cases. This assumption is used in simulating the performance of mBPAC.

The specified protocol has all the desirable characteristics specified in section 4.1.1 except the fourth one since the access handoff mechanism does require some control of the scan and connec-

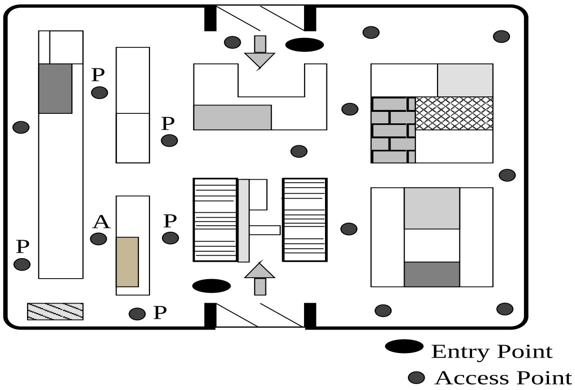

Fig. 3. Sample arrangement of access points and entry points in a Bluetooth access network running mBPAC

tion activity at the mobile. No standard behavior for Bluetooth devices regarding when they should perform scanning is specified in the standard and hence this is not perceived as a major limitation.

One disadvantage of this protocol is that it produces a hard separation between entry points and access points. Hence, extra entry points need to be installed for every location at which entry into the access network is to be provided.

This protocol always sends lost mobile information to all members of the *Neighborhood set*. It may be possible for certain access locations that user mobility patters follow a certain trend and mobility typically takes place between some known access points. Sophisticated algorithms to learn the mobility patters and exploit those to reduce the number of access points to which neighbor handoff messages are sent would help to reduce the wastage of data slots on false paging attempts. Some attempts at path prediction for mobile devices have been made in [6].

4.2. Robustness

It is important to evaluate the robustness of the access network in case a mobile node which does not follow the mBPAC protocol comes into the range of the mBPAC access network.

Intruding Devices: As the entry points and access points never go into inquiry scan or page scan, the device cannot inquire or page the components of the access network and connect to them on its own. Hence the mobile node must connect to the access network through the entry point which will authenticate it. The access network is thus robust to unwanted intruding devices.

Malicious Devices: After the device has been accepted into the network, it may stop following the mBPAC protocol. When the device is in connection state, it can either carry on with data communication, be put in HOLD state to suspend its connection timeout timer, or may have to enter page scan on detecting loss of connection. In case it does not follow the protocol, it will either stop transferring data, or not suspend its connection timeout timer or not detect loss of connection to enter page scan. In either of these cases all what can happen is that the mobile device loses connection and is unable to connect again. The only effect on the network will be that some false page attempts will take place. They will stay limited to one *Neighborhood set* as the device cannot connect repeatedly and cause too many page attempts at that access point leading to any performance degradation. The device can re-enter only through the entry point. Also, since it has entered through an entry point, where its device properties can be recorded, the network can keep a record of which device malfunctioned or stopped following the protocol for any reason.

Hence the access network is fairly robust to mobile devices not following the mBPAC protocol.

5. Simulation Results

A simulator has been built to evaluate the behavior of the access network with different numbers of stationary and mobile nodes. The simulator is designed to capture all the relevant features of the Bluetooth data link layer which affect the performance of mBPAC. It implements the complete frequency hopping scheme specified to study the effect of paging and inquiry procedures on connection establishment and the handoff protocol. The simulator implements the correct Bluetooth addressing and timing as per the standard.

This section summarizes the simulations carried out to evaluate the performance of the proposed mBPAC access schemes.

5.1. Handoff Delay

The handoff delay consists of two components:

1. The time to detect loss of connection, which depends on:
   (a) The number of devices connected to the AP as this affects the duration of a poll round in each piconet.
   (b) Whether the mobile leaves in connection state or when the access point was in page state.
2. The time to resume a new connection at the new AP into whose range the mobile has moved in after loss of connection. This depends on the paging delay for starting the connection and the number of neighbor messages waiting in the queue.

To evaluate the effect of the above factors, simulations are performed for cases with varying number of mobile nodes already connected to AP when the new mobile, with which a connection is to be resumed, arrives. For each of the above cases, the simulation is tried with different numbers of neighbor messages waiting in queue that have to be processed before the the new mobile can be handled. As the number of neighbors for a given access point is expected to be four in most cases, at any given instant, messages from not more than three neighbors can be waiting when the neighbor message for the new mobile arrives.

Let the number of devices already connected to the access point when the mobile arrives be s and the number of neighbor messages to be processed before the paging attempt for the mobile can be made be k.

The times taken to resume connection after neighbor AP has sent the message for paging the mobile are given in Table 1 for all possible s and k. The times taken to detect loss of connection are listed in Table 2. The effect of the AP being involved in processing a neighbor message before detecting connection loss is reported in Table 3.

All values given are averaged over 100 runs. The delay values are in number of slots.

Table 1. Handoff Delays: Time to resume connection after neighbor message received for varying *k* and *s*. (Delay values in slots)

s	*k*=0	*k*=**1**	*k*=**2**	*k*=**3**
1	25.50	150.28	292.00	408.78
2	23.72	157.76	290.42	431.78
3	23.44	164.62	311.34	437.52
4	24.64	169.16	314.30	455.86
5	33.06	177.32	327.24	478.86
6	32.94	186.18	334.98	491.36

The paging delay depends on when exactly the paging starts after the neighbor message is received. When there is no neighbor message in queue the paging can start after one poll round gets over and the AP checks if its neighbor message queue is not empty. The time to detect loss of connection also depends on where in the poll round the turn for polling the moved device comes. Due to this, the detection of connection loss may not always take longer when more devices are connected.

Table 2. Handoff Delays: Time to detect loss of connection after mobile moves out of range for varying *k* and *s* (Delay values in slots).

s	*k*=**0**	*k*=**1**	*k*=**2**	*k*=**3**
1	1.00	2.04	1.24	1.62
2	2.18	3.00	2.67	4.18
3	3.56	3.94	3.86	2.36
4	4.16	4.16	5.40	6.26
5	4.84	5.04	5.00	7.22
6	6.21	6.79	7.64	7.32

It is apparent that the time to detect loss of connection is negligible unless the mobile moves away when the AP is paging another mobile.

From the above three tables, it can be seen that the delay for resuming connection varies from 25 slots to about 500 slots. The time taken to detect loss of connection is a maximum of 161.48 slots. Combining the above information the handoff delays have been plotted in Figure 4.

5.2. Datarates

To study the datarate performance it is assumed that *s* stationary devices are connected to an AP and s_m mobile devices are moving in and out of its range. Also, the cardinality of the *NeighborhoodSet*

Table 3. Handoff Delays: Time to detect loss of connection if the mobile moves out of range when AP is paging another mobile for varying s.

s	1	2	3	4	5	6	7
Delay (slots)	133.00	138.54	142.56	148.98	151.90	157.06	161.48

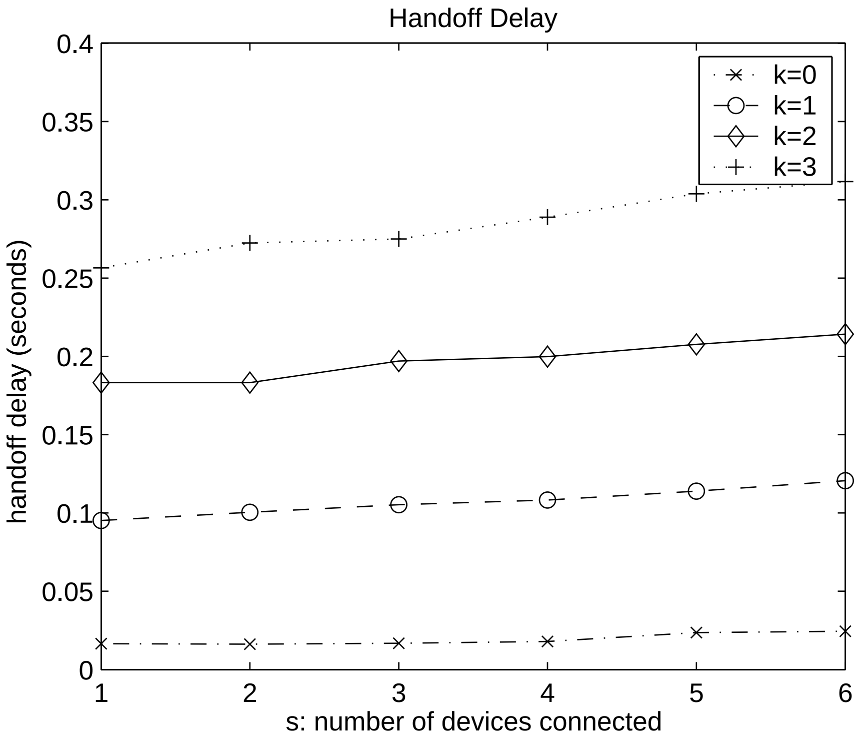

Fig. 4. Aggregate handoff delay for varying s and k.

is assumed to be N. This means that each handoff would produce $N-1$ false neighbor messages leading to wasted paging attempts. As the maximum number of mobiles that may connect to an AP is 7, s and s_m vary between 1 and 7 under the constraint that $s + s_m \leq 7$. These ranges cover various possible load conditions and number of mobiles that may be present in the access network.

The number of data slots obtained by a mobile node, within a duration of 20 seconds for varying s and s_m at $N = 4$ are presented in Table 4 and in Table 5 for $N = 2$.

The above measurements in terms of slots may be converted to actual datarate achieved based on which packet type is used for data transfer by the mobiles and access points. The maximum datarate is achieved when multislot packets of length 5 are used without any forward error correction, that is DH5 packets. The datarate achieved by one mobile device for the case $N = 4$ is plotted in Figure 5. All datarates shown in the plots are symmetric datarates, that is, same datarate is available from the AP to mobile and from the mobile to the AP.

It is apparent from the figure that the maximum datarate achieved is 215.43 kbps while the

Table 4. Data slots allotted to a mobile node in a duration of 20s for varying s and s_m ($N = 4$).

s	s_m=**1**	s_m=**2**	s_m=**3**	s_m=**4**	s_m=**5**	s_m=6
1	7897	5345	4088	3342	2851	2501
2	5260	3979	3220	2725	2377	
3	3946	3168	2661	2307		
4	3153	2630	2269			
5	2625	2250				
6	2249					

Table 5. Data slots allotted to a mobile node in a duration of 20s for varying s and s_m ($N = 2$).

s	s_m=**1**	s_m=**2**	s_m=**3**	s_m=**4**	s_m=**5**	s_m=6
1	7962	5422	4171	3429	2943	2603
2	5307	4034	3287	2797	2455	
3	3979	3214	2716	2365		
4	3183	2670	2312			
5	2652	2284				
6	2272					

minimum datarates are above 61 kbps with the AP loaded to full 7 devices. This gives better performance than a typical phone modem based network access. The performance is far better than 2.5G, EDGE, GPRS or other high datarate services available for mobile access.

5.3. Support for Real Time Interactive Audio

The handoff delays vary between 16 to 408 milliseconds, with typical handoff delays expected at 125 milliseconds. For interactive audio, round trip delays upto 250 ms are required while delays upto 400 ms are considered tolerable. Data loss upto 5% is acceptable [7]. This means that the handoff delays small enough to allow an interactive audio conversation have been achieved.

The datarates vary from 61 kbps in full load conditions to 215 kbps at low loads with handoff. These datarates are enough for supporting an interactive voice call over the access network. Streaming media requiring upto the datarates mentioned above can of course be supported.

5.4. Comparison with pure CIP

CIP performance without the mBPAC modifications has been reported in [3] for handoff purposes. The handoff delays for mBPAC are better by more than an order of magnitude. The total time to resume connection after the mobile once moves out of range is found to be about 25 seconds in

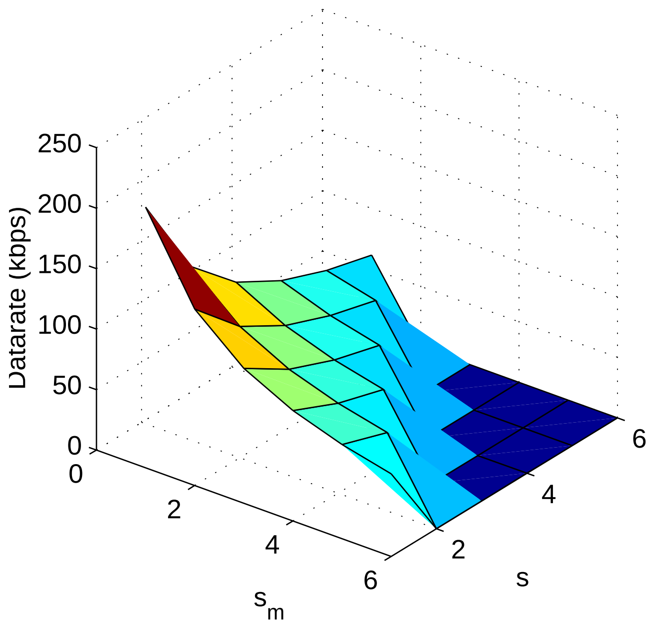

Fig. 5. Datarate achieved with DH5 packet type at a mobile terminal for varying s and s_m ($N = 4$).

[3].

The time to detect loss of connection was calculated to be a maximum of 198 ms and found to be a maximum of 162 ms in the simulations presented in Table 3 for mBPAC. On the other hand the time taken to detect connection loss was 20 seconds in the pure CIP used in [3].

The time to resume connection, ranging from 25 to 500 ms as seen in Table 1 for various load conditions was 5 seconds in [3]. This is because the time consuming inquiry is involved in that method.

The datarate achieved in pure CIP would be much lower as much more time would be wasted in connection re-establishment. This would also reduce the number of mobile nodes the access network can support.

The pure CIP method is less robust. In that method, the access points perform inquiry and connect as slaves, later performing a master slave switch to make the mobile node a slave. A malicious mobile node can repeatedly inquire and establish connection with an access point and each time refuse the master slave switch. That would waste significant bandwidth at the access point.

6. Conclusions

The increasing popularity of handhelds and the ability to provide wireless connectivity through Bluetooth has generated a strong need for public access networks which accept Bluetooth enabled devices. An important issue in these networks is the support for mobility inside the access network. This paper discussed the various available options for providing mobility and described our new handoff protocol which promises rapid and lossless handoff, achieving efficient utilization of the bandwidth at the MAC layer. The handoff is fast enough to allow interactive audio applications to run oblivious of handoffs at low network loads. The access mechanism proposed also makes the CIP implementation in the access network transparent to the incoming mobile nodes and does not require any change to the standard hardware implementations on mobiles. The proposed schemes improve the performance of existing methods significantly in terms of handoff delay, datarates available to mobile nodes and the number of mobiles supported at an access point.

7. References

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