A Method of Data Transfer Control during Handoffs in Mobile-IP based Multimedia Networks

P.Venkataram[a] **R.Rajavelsamy**[a] **S.Laxmaiah**[b]
pallapa@ece.iisc.ernet.in *rajvel@protocol.ece.iisc.ernet.in* *laxman@protocol.ece.iisc.ernet.in*
[a]Protocol Engineering and Technology (PET) - Unit, ECE Department, IISc, Bangalore, India
[b]CRL, BEL, Bangalore, India

Applications that require untethered access, in real-time, to multimedia information sources are made possible by mobile multimedia networks. These include support for decision makers in the field, crisis management and response, law enforcement, etc. The multimedia applications demand constant and continuous flow of data from the integrated sources. So, the network should support continuous transfer of information to the mobile hosts. However, the handoffs initiated by the mobile hosts will not allow continuous data transfer and thus some data is lost during handoff. In case of real-time multimedia applications like Video-on-Demand(VoD), it is essential to consider the data transfer control during the handoffs to provide a reliable service to the mobile hosts.

We propose a mechanism to maintain the continuity of data transfer during handoffs in mobile-IP environments and minimizes the data loss during the period. This method performs efficient buffering of the data at the Base-station by using toggled buffers and enables to calculate optimal playout time for multimedia applications. The method has been tested on in-house wired/wireless networks. The results of this method showed enormous improvement in the continuity of data transfer during multiple handoffs while running multimedia applications such as video-on-demand(VoD) and Audio-on-demand(AoD).

I. Introduction

With the advancement in mobile networks and portable computing technologies, the transport of real time multimedia traffic over the mobile networks has become challenging due to the severe resource constraints of the wireless link and mobility of the users.

A key characteristics of multimedia type application services is that they require maintaining the continuity of data transfer. The population of the mobile users is growing at a rapid rate and the applications are becoming more bandwidth intensive, hence the traffic control of wireless networks has become a necessary element of mobile communications [1-2]. Due to the limitations of the radio spectrum, future wireless systems will use micro/pico-cellular architectures in order to provide a higher capacity. Because of the small coverage area of micro/pico-cells and the characteristics of the multipath and shadow fading radio environment, handoff events in future systems will occur at a much higher rate as compared to today's macro-cellular systems. Frequent handoffs in wireless/mobile networks introduce a new paradigm in the area of network congestion control [3-4]. In future, mobile networks are expected to support multimedia applications (video, audio, data, etc.), which will be an added challenge for designing predictive and adaptive algorithms for continuous data transfer for isochronous applications.

In this paper, a new data transfer control scheme is proposed to provide high degree of data transfer for multimedia traffic carried in microcellular, pico-cellular, and high speed wireless networks. The proposed scheme combines data transfer control, optimal playout calculation, and adaptive buffer management scheme to guarantee at call level QoS requirement of a real-time or non-real-time multimedia applications. This will maximize the resource utilization and minimize the data loss.

II. Mobile Multimedia Networks

A Mobile Multimedia Network consists of several cells where each cell comprising of multimedia servers and a base-station. The communication among the Base-stations could be through wired network (see figure 1). The base-stations could be PCs or workstations equipped with adaptors for wireless networking. The adaptor acts as gateways for communicating to the nearby mobile hosts and wired net-

works.
Mobile hosts could be a PDA(Personnel Digital Assistant) or LAPTOP equipped with a wireless adaptor card. Each base-station covers some part of geographical area. Network connectivity will be continuously maintained as users carrying variety of mobile hosts roam from one cell to another. The mobile hosts can access data from servers, intelligent peripherals and other users (wireless/wired) of the network through the base-station agents (PC's) used to facilitate the mobile-IP working.

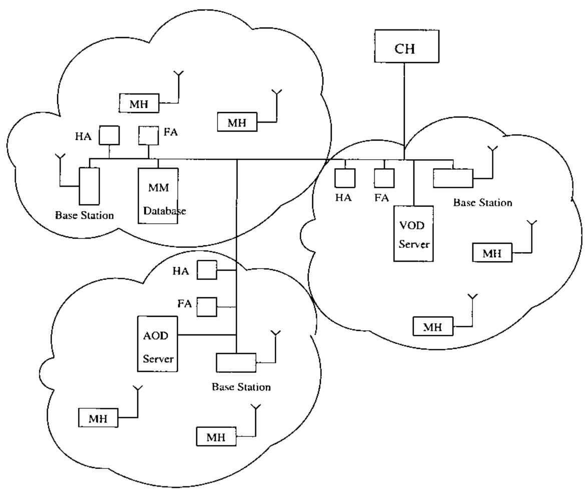

Figure 1: Mobile Multimedia Network

II.A. Multimedia Service Requirements

A typical distributed multimedia environment [5], in which, multiple remotely located users participate in a joint work or design project demand for:

- *resource sharing*, to integrate information on a more global basis, preserve investments, and ensure the use of a system's available information;
- *multimedia data integration*, such as images, graphics, sound, text, and structured data, to present information in a more immediate and understandable form;
- *local intelligence and autonomy*, to perform tasks independently of centralized systems;
- *graphical interfaces*, to reduce training costs and assist occasional and inexperienced users; and
- *vendor independence*, to achieve free from any specific hardware vendor.

A multimedia environment, presently, consists of applications accessing pagers, facsimile, answering machines, telephone lines, speech synthesis, and digital recording and playback. Its key contributions are the integration of multiple media into a cohesive nomadic information infrastructure and a graceful transition from desktop to nomadic locals. This integration is at the service and user interface levels.

II.B. Problems in Mobile Multimedia Networks

Contrary to wired networks, wireless ones have to cope with very specific effects [6-8]:

- The risk of collision of different bursts of information transmitted in the same time slot and at the same frequency, but originating at different transmitters.
- The presence of multipath propagation leading to fading (flat or frequency-selective) and time delay spread, which give rise to ISI (Inter Symbol Interference) can strongly increase the BER (bit error rate). The biggest challenge in WAN (Wide Area Network) environment is the large multipath spread (several microseconds) in conjunction with the mobility of the channel. The large multipath spread can cause excessive scheme, RNET (Radio Network), which is robust against existing Doppler Shifts and flat fading[9].
- The limited resources in the lower frequency bands which became worse as the mobile communications are used by more people and used data rate per user increases.

III. Handoff procedure

III.A. Basic Principle

Handoff is a basic mobile network capability for dynamic support of terminal migration. Handoff Management is the process of initiating and ensuring a seamless and lossless handoff of a mobile terminal from the region covered by one base-station to another base-station[10-12].

Nomenclature

- *Base-station (BS)*: A node in the wired and wireless networks that serves as an access point to many other nodes who desires to communicate with the mobile nodes.

- *Mobile host (MH)*: This node essentially represents the end user. The terminal connects to the network through a base-station, which serves as the access point.
- *Cell*: The basic region that can be covered by a base-station. The base-station can service all the clients (or mobile hosts) that are within its cell region.

Phases of Handoff Procedure

There are three phases in a handoff procedure.

- *Phase I*: The mobile host as well as the access point do several measurements continuously. For example, the signal strength is one parameter which might be measured by both the terminal and the access point.
- *Phase II*: Based on the measurements taken, a decision is made as to whether a handoff is required. For example, a decision to perform a handoff might be taken if the signal strength goes below a specified threshold.
- *Phase III*: The actual handoff of the terminal from one cell to another is done in this phase. There are essentially two sub-phases in the execution of the handoff.
  - New Link establishment.
  - Release of old link.

III.A.1. Types of handoff functions

- *Mobile Initiated handoff*: In this type of handoff, the mobile host has to manage the handoff. That is, it takes the measurements on the downlink, processes them, takes the decision to do the handoff, decides the target base-station, etc.
- *Mobile Evaluated handoff*: This is similar to the mobile initiated handoff except that the decision to do the handoff lies with the network.
- *Network Initiated handoff*: In this type of handoff, the network manages the handoff, which includes taking measurements on the uplink, processing them, deciding to do the handoff, deciding the target base-station, etc.
- *Mobile Assisted handoff*: This is similar to the network initiated handoff, except that the mobile assists the network by taking measurements along the downlink and relaying them back to the network.

III.A.2. Handoffs based on Number of active connections

The handoffs can also be classified based on the number of connections that a mobile terminal maintains during the handoff procedure.

- **Hard Handoff:** In this type of handoff, the mobile host switches the communication from the old link to the new link. Thus, there is only one active connection from the mobile terminal at any time. There is a short interrupt in the transmission. This interrupt should be minimized in order to make the handoff seamless.
- **Soft handoff:** In this type of handoff, the mobile host is connected simultaneously to two access points. As it moves from one cell to another, it "softly" switches from one base-station to another. When connected to two base-stations, the network combines information received from two different routes to obtain a better quality. This is commonly referred to as macro diversity.

III.A.3. Handoffs based on the direction of the handoff signaling

Yet another way of classifying the handoffs is the direction of the handoff signalling.

- **Forward Handoff:** After the mobile terminal decides the cell to which it will make a handoff, it contacts the base-station controlling the cell. The new base-station initiates the handoff signaling to delink the mobile terminal from the old base-station. This is especially useful if the mobile terminal suddenly loses contact with the current base-station. This is referred to as forward handoff.
- **Backward Handoff:** After the mobile terminal decides the cell to which it attempts to make a handoff, it contacts the current base-station, which initiates the signaling to do the handoff to the new base-station. This is referred to as backward handoff.

III.A.4. Handoff Latency

We define the handoff latency 'L' as the amount of time from when the mobile is disconnected from the old base-station to when the mobile receives the first packet from the new base-station. The handoff can be computed as :

$$L = LD + LP + LN + LF$$

where:

- *LD* is the component of latency when the mobile discovers that it must handoff to a new wireless network, for example, moving out of a room or moving out of a building to outside.
- *LP* is the component of latency where the mobile must power on the new network interface. This includes any network registration time. This component of latency may or may not be visible to the user depending on whether or not the device was already on at the time the handoff occurred.
- *LN* is the component of latency where the mobile must inform the new base-station to start forwarding any data to the mobile. This is usually a function of the network latency.
- *LF* is the component of latency where the base-station sends the first data packet across the new network to the mobile. This component is a function of the network latency and bandwidth.

III.B. Handoff Using Mobile IP

The Mobile IP scheme is built around two components namely, *the home-agent* and *the foreign-agent* [13]. The home-agent is the entity that maintains a database of the current location of all the mobile terminals under its control. When a mobile node moves away from the home region to another region, the home-agent updates the database with the IP address of the foreign-agent that is currently controlling the mobile terminal. When an IP packet is sent to the mobile node, it first reaches the home-agent. The home-agent encapsulates the IP packet within another IP packet with the current foreign-agent as the destination (See Fig.2). When the foreign-agent receives the encapsulated IP packet, it removes the IP header information inserted by the home-agent and sends the IP packet to the mobile terminal. Though the path from the mobile terminal to the fixed nodes is optimal, this scheme does not result in an optimal path from the fixed host to the mobile terminal. Handoff is the process of passing the responsibility of communication connectivity from one base-station to another. The resulting handoff traffic is a function of many factors, such as the number of mobile hosts, the size of the wireless cells, the desired channel capacity and the MH migration of speed and direction. As the wireless cell size becomes smaller and smaller, signaling traffic as a result of handoffs can be substantial. Therefore there is a need to reduce this handoff traffic, so that more bandwidth can be devoted to data transfer. This calls for an efficient handoff mechanism.

Usually, a base-station keeps track of the mobile by the relative signal strength received from the MH. There are two thresholds, and initial and a final threshold, for both sending and receiving mobiles as shown in the figure 2 , into the realm of a base-station. These thresholds exist to prevent sudden spikes of signals. For example, if a signal is fading gradually over a predetermined period of time, then it will pass through the first threshold drop, and then a lower threshold drop. This insures that the signal will not drop suddenly and then return to its normal value. Assume that the signal has faded below the second threshold. The base-station interrogates the Markov model to determine the next most probable location which is mobile is likely to take. The first base-station now sends a message to the second base-station to reserve resources for the new user at the new location.

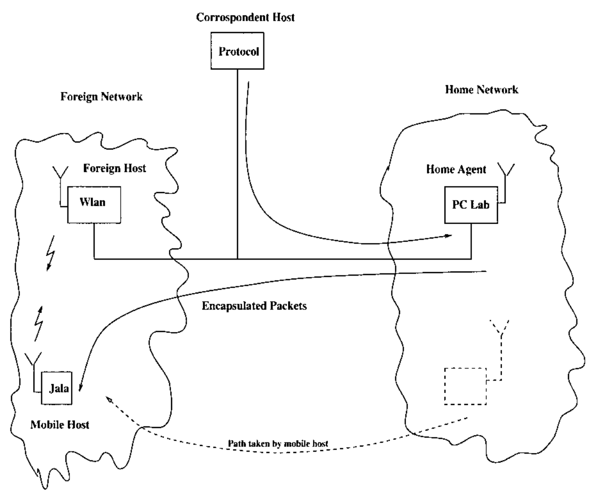

Figure 2: Handoff in Mobile IP

Resource allocation is held at the new location based on a pre-defined QOS requirement, and a timer is started at the new location. The purpose of the timer is to avoid holding the resources for an indefinite period of time, in case the mobile never enters the realm of the new base-station. When the new base-station completes the allocation, it sends an ACK to the old base-station. The new base-station is now waiting for the arrival of the mobile host.

The new base-station is now monitoring for the arrival of the mobile host. There are two thresholds to be overcome as in the case of the sending base-station: *Initial Receiving Threshold (IRT)* and *Final Receiving*

Threshold(FRT), they are the inverse thresholds. If the mobile signal rises above the initial receiving threshold and gradually rises to the final receiving threshold, the new base-station now owns the mobile. The constraints are that the resource allocation timer has not expired at the new base-station. Handoff is now ready to be accomplished between the two base-stations.

With this method there may be a point in time when the signal strength is about the same in both base-station areas. The policy, here, is that the base-station which is monitoring the mobile will claim the mobile if the signal is above a certain pre-determined threshold. The mobile now belongs to the new base-station which signals the old base-station that it now is assuming ownership of the mobile. The old base-station must update its address pointers to point to the mobile's new location so that the packet destined for the mobile can be re-routed to the new location, as in the case or standard handoff procedures described above.

IV. Data transfer discontinuity during the handoff

Multimedia applications, such as presentational or conversational, require huge amount of data. In mobile networks, there would be maximum possibility of losing data due to mobility of the users and due to some other means. This causes inconvenience to the end-users(MHs) because of discontinuity of data transfer while handoff takes place. Loss of data would be more worst, if multiple handoffs takes place in sequence quite frequently.

Example:

Consider a video-on-demand service is being requested by a mobile host. The parameters of the services are: the video length to be transmitted is 100 minutes, data transfer rate in the correspondent host (CH) is 1.5 Mb/s, total number of bits of video information is equal to 9 Gb(100 min * 1.5 Mb/s). Let digitalised Video is split into, say, 100 parts requiring 9 Mb space in RAM for each part. So, 9 Mb is received at base-station from the CH as a first consignment. Let us assume that the base-station transfers at the rate of 1.5 Mb/s to the mobile host. So, it takes 6 sec for transferring first consignment.

The playout at the mobile host for the application starts atleast after receiving 9 Mb of data. Now, let us assume that the mobile host has initiated handoff call after running the application for 30 min. The handoff period is normally around two seconds. During this period, the amount of data transfered is 3 Mb (2 sec * 1.5 Mb/s) will be lost. The video information in between 30^{th} minute and 31^{th} minute will not be received by mobile host. Thus there is a discontinuity in the data received by the mobile host. This will deteriorate the quality of the application. Hence, it is essential to have a scheme for buffering the data during handoffs.

V. Proposed Data Transfer Control

In mobile-IP system, a mobile host always keeps its static home IP address, no matter what its current point of attachment in the Internet is. Packets addressed to it will always go via its home network and forwarded them to respective destination. Based on this principle the proposed data transfer has been designed.

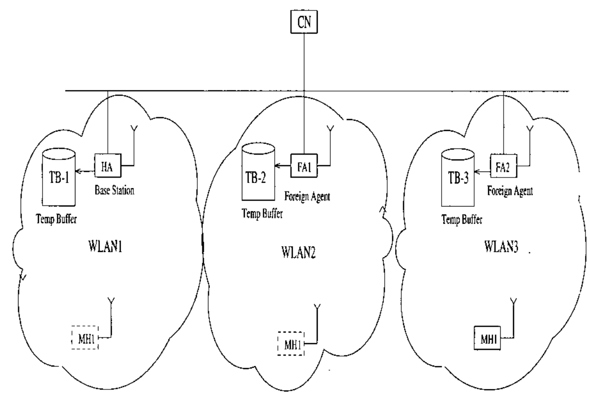

Figure 3: Proposed Data Transfer Scheme in Mobile IP

In addition to this, in mobile-IP when the mobile host is in its home network, it acts just like a normal stationary host. When it is away visiting a foreign network (i.e., a network other than its home network), the mobile host needs to obtain a temporary IP address (called care-of address) in this subnet. It then registers the care-of address with its home agent, a stationary host in the mobile host's home network that provides mobility support for mobile hosts. The home agent will therefore intercept packets destined to the mobile host in its home network and save them in a temporary buffer. Soon after the handoff completion it forwards them to the mobile host's current point of attachment for delivery to the mobile host. The forwarding is done by "tunneling" the packets to the mobile host's care-of address by encapsulating the original packet in another IP packet destined to the mobile host's care-of address. At the end of the tunnel, the packets are decapsulated and thus revealing the original packets before delivering to the mobile host. Packets originated from a mobile host is sent the same way as on other stationary hosts, except that the source IP address of the packets is set to be the mobile host's home IP address to preserve its home identity.

V.A. An Example

The complete scenario of communication between HA (Base-station) and MH during the Handoffs can be explained as follows (See Figure 3). Consider at an instant of time the mobile node MH1 has been receiving the data from the corresponding node CH through the temporary buffer, TB-1 at HA. Later MH1 moves from home network to a foreign network by intimating the home-agent (HA) about its mobility. So that the home-agent will suspend the transmission of the packets which are destined to the mobile host until the registration process is completed with the foreign-agent (FA1). During this handoff the home agent will buffer the data in temporary buffer (TB-1). After completion of registration of the mobile host with foreign-agent, the home-agent will send the buffered data to the mobile host through the new foreign-agent (FA1). The algorithm of the method is described in *Algorithm1*.

Alogrithm 1 : Data Transfer Control

```
START
  Establish connection between the CH and MH through the home-agent;
200:  Transfer the Data from CH to temp-buffer at HA;
  Send Data from temp-buffer to MH;
IF No hand-off initiated THEN
  HA sends data to MH;
ELSE
 begin
  suspend the transmission of data from HA to MH;
  check for hand-off completion;
100: IF hand-off complete THEN
  enable the data transfer from temp-buffer to MH;
  GO TO 200;
ELSE
  Store the data on to the temp-buffer in HA;
  GO TO 100;
  STOP
  END
```

V.B. Playout Time

Playout, in general, is the task that deals with the realization of arbitrary preorchestrated interactive multimedia presentations. The playout is comprised of several subtasks such as the device management, the data stream handling, the enforcement of the synchronization constraints, and handling of random user interactions. In case of mobile multimedia networks, since the nodes are mobile, the handoff latency needs to be considered while estimating the playout time for an application.

V.B.1. *Playout Time Calculation*

Playout time for time-dependent multimedia data is depending on the type of the streams used in that particular multimedia application. The playout time based algorithms provide functionality for partial interval playout, playout reversal, and playout deadline determination as required for real-time scheduling approaches [14].

The minimum playout time for a multimedia application in mobile networks with fixed delays strategy may be estimated as:

$$P_{min} = D + \beta * V + L$$

Where:

D = the one-way network delay estimate.
V = an estimate of the variation in network delay.
β= factor to accommodate changes in net.
β = 40 ; L = 4 sec.

Empirically we found that an average network estimated delay, D is 30 milliseconds, variation in network delay is 2 milliseconds, and handoff latency is 4 seconds in our network. Hence for a typical multimedia application playout time may be estimated as at least 5 seconds.

V.C. Buffer Space Requirement Estimation

Continuous playback of a media stream consists of a sequence of periodic tasks with deadlines, where tasks correspond to retrievals of media blocks from disk and deadlines correspond to the scheduled playback times. Although it is possible to conceive of systems that would fetch media quanta from the storage system just in time to be played, in practice the retrieval is likely to be bursty. Consequently, the information retrieved from the disk may have to be buffered prior to playback for smooth running of the system [15].

By managing the finite amount of buffer space the model allows the sender, for example, to transfer non-real-time data ahead of time if sufficient space is available at the receiver to store it. The pre-stored data can then be accessed when needed, allowing at the time real-time information to use a larger amount of the channel's capacity if so desired.

In the case of mobile multimedia playout systems the least maximum buffer required at the minimum playout time may be estimated as:

$$B(t,P_{min}) \geq R(t) \quad \text{if } t \leq P_{min}$$
$$\geq R(t) - r_c(t - P_{min}) \quad \text{if } t \geq P_{min}$$

Where:

$R(t)$ is the data received till time t.

$B(t,P_{min})$ = Data buffered till time t in the playout system which has P_{min} as the playout time.

r_c = Consumption rate of the playout system.

The least maximum buffer space required for a multimedia application running on a mobile network is 1.5 Mb X 5 = 7.5Mb.

VI. Simulation

We have simulated the proposed model of data transfer control and buffering data by configuring two wireless LANs over a wired network.

VI.A. Network environment

We set up two wireless LANs: *Network A* and *Network B*(see figure 4) which are extended to the existing Ethernet in our lab. The systems: PCLAB and WLAN are configured as base-stations for the Network A and Network B respectively. Both the base-stations are also nodes on the Ethernet.

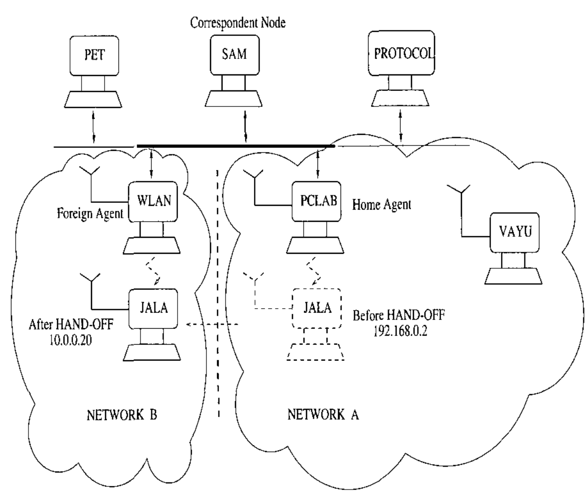

Figure 4: In-house wired/wireless Network Topology

VI.B. Experiment

We configured the system, JALA (Lap Top) is as MH, which will be running the mobile host daemon. In JALA Wireless LAN API iwspy is used to support Mobile-IP. The system, PCLAB (i486 66) acts as a home agent (HA), which runs Home agent daemon. The mobile will initially be in its home network and will posses a long term IP address in its home. The WLAN (P 133) is configured as a foreign-agent (FA). FA allocates the 'co-located care-of-address' for the newly moved mobile hosts into its wireless net work. PROTOCOL (P 75) and SAM (SPARC 4) are used as correspondent hosts (CHs) in the experiment. Each CH initiates some multimedia applications. It may be possible that CH can be any host in the internet.

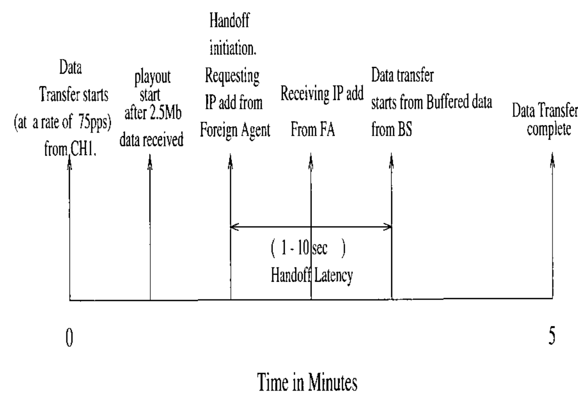

Figure 5: Timing of handoff events in the Handoff Process

We start all the daemons: home agent daemon at the PCLAB, Mobile agent daemon at the JALA, and foreign agent (FA) at WLAN systems. At the outset the mobile agent registers with the home agent. In order to initiate the movement of mobile host from its home-agent to any foreign network (WLAN in this case), we will move the JALA(Lap Top) from HA domain to the FA domain, as the signal strength of HA decreased below the threshold value, dynamically the mobile host (JALA) will run the DHCP client, since only WLAN answers for DHCP request, it will provide a new IP address to JALA, thus JALA effectively is moved into foreign network (WLAN network).

Now based on the above setup, some multimedia applications are initiated at MH as a client. The client requests for multimedia document (may be a MPEG file) from the server, which could be a correspondent host. As the MPEG file is being played, the mobile host will initiate a handoff and moves to the foreign network, the MPEG file is buffered at the base station for some time, during the process of registration, and later continues the transfer of the MPEG file.

To avoid the discontinuity in playout during the handoff a sizable data has to be buffered at the mobile before the actual playout starts. A simple buffer allocation scheme has been proposed. The scheme calculates least maximum buffer required at the minimum playout time for a multimedia application by looking at the network traffic and type of the multimedia document, a pre-defined size of the document is buffered. So the application on the client side will start only after this minimum buffer is filled.

All our experiments are conducted with minimum buffer criteria, i.e., the playout starts after receiving the data around 2.5Mb.

VI.C. Results

We have conducted the experiment for five different applications with occurrence of multiple handoffs .The results are tabulated.

Handoff Time in Sec	Avg % of Pkts Lost without Data transfer scheme	Avg % of Pkts Lost with Data transfer scheme
1	2.16	0.47
2	3.06	0.60
3	3.88	0.76
4	4.53	0.90
5	5.32	1.00
6	6.01	1.08
7	6.55	1.26
8	7.48	1.56
9	8.03	1.62
10	9.20	1.96

Table -I Handoff statistics for VoD application

Table-I describes the Average percentage (in 10 Trails) of Packet lost during the handoff for 10Mb VoD application with and without data transfer scheme

It is observed that for the UDP based application, as the handoff time increases ,the data loss also increases randomly with some positive amount without Data Transfer Scheme, where as with the scheme data loss is negligible.

Figure 6 illustrates an UDP application's packet loss with and without Data Transfer Scheme under various Handoff latencies.

Figure 7 illustrates the least maximum buffer required for the UDP-based application without Data Transfer Scheme.

Figure 8 describes the packets dropped for TCP

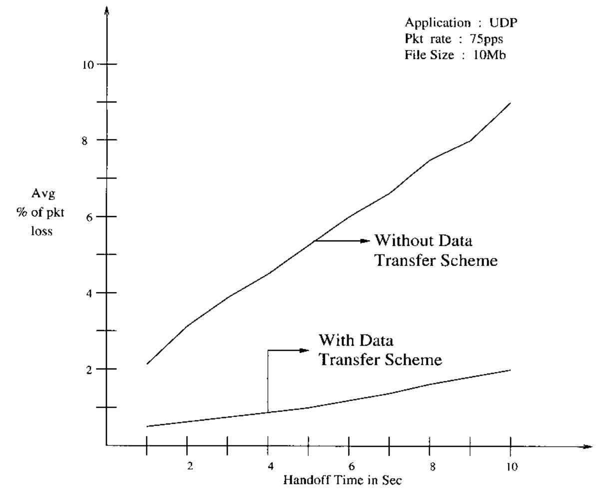

Figure 6: Avg Percentage of Packet lost Vs Handoff Time

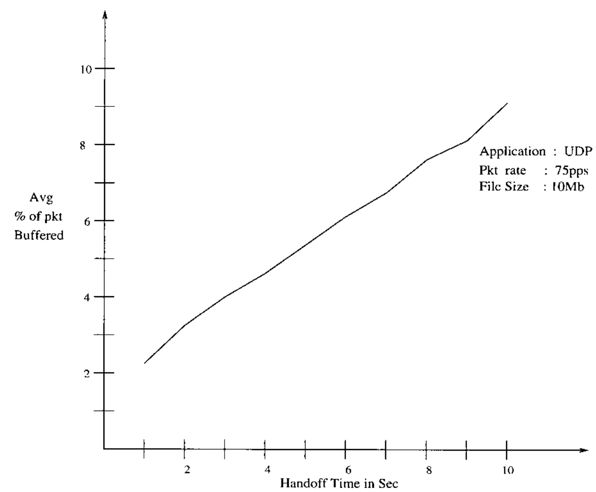

Figure 7: Avg Percentage of Packet Buffered Vs Handoff Time

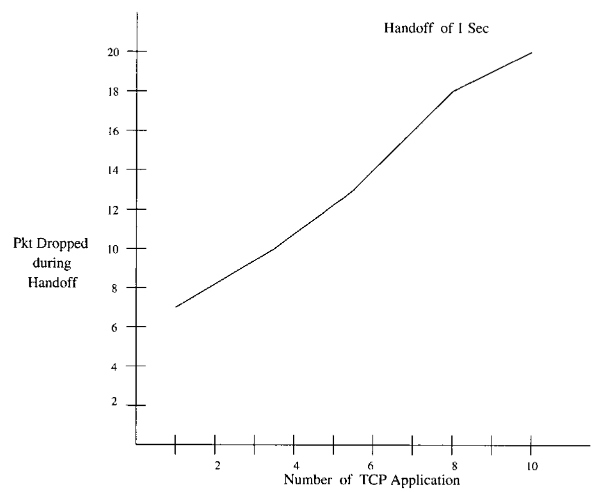

Figure 8: Packets Dropped Vs Number of TCP Application

based multimedia applications without Data Transfer Scheme.Where as Figure 9 describes the packet loss for several UDP applications with and without Data Transfer Scheme.

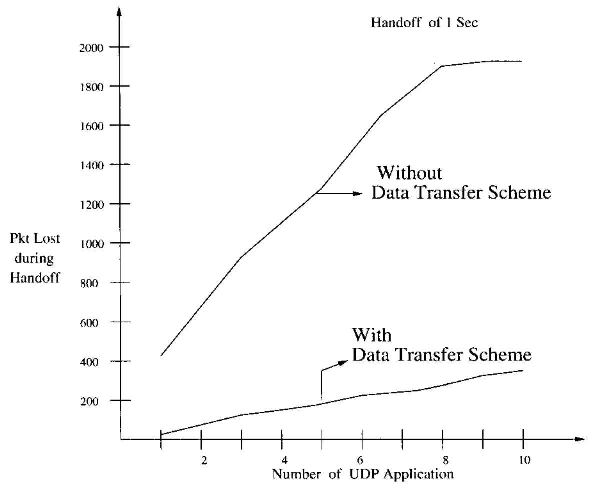

Figure 9: Packets Lost Vs Number of UDP Application

Handoff Method	Handoff Latency	Average Data lost
Handoff without Buffering	1 Sec	1.39 Kb
Handoff with Buffering	1 Sec	0.30 Kb

Table - II Results of experiments with and without buffering during Handoff

Table-II describes the results of experiments for 1Sec handoff latency, with and without buffering at the base station.

VII. Conclusion

Real time mobile multimedia networks are challenging due to severe resource constraints of the wireless link and mobility of the nodes. This paper gives a brief introduction to mobile multimedia networks, multimedia service requirements, problems in mobile multimedia networks and mobile IP. One of the severe problem is the discontinuous data transfer during handoff which hinders the quality of application. We have proposed a method of continuous data transfer using buffering mechanism and simulated. It is observed through experiments that the buffer space increases with the increase in the number of handoffs. Also there was minimum loss of data during handoffs for different multimedia applications. However some overheads are associated with this mechanism such as buffer space and processing time.

References

1. Lamaire RO, *et. al*, "Wireless LANs and Future Mobile Networking: Standards and Future Directions", *IEEE Communication Magazine*, pp. 86-94, Aug. 1996.

2. Rappaport TS, **Wireless Communications Principles and Practices**, Prentice-Hall, Inc., New Jersey, 1996.

3. Acampora AS, and Naghshineh M, "An Architecture and Methodology for Mobile-Executed Handoff in Cellular ATM", *IEEE Journal on Selected Areas in Communications*, 12(8):1365-1375, October 1994.

4. Goodman DJ, Pollini GP, and Meier-Hellstern KS, "Network Control for Wireless Communications", *IEEE Communication Magazine*, pp. 116-124, Dec. 1992.

5. Garg V and Wilkes J, **Wireless and Personal Communications Systems**, Prentice-Hall, 1996.

6. Venkataram P, "Techniques for Achieving Highly Reliable and High Capacity in Multimedia Wireless Networks" *Proc. of Intl. Symposium on Wireless Communications for the Next Millennium (ISWCM'98)*, pp. 122-130, Sept. 1998.

7. Venkataram P, Chockalingam A, and Roy A, "Performance of a Link Control Protocol for Local Wireless Multimedia Communications", *IEEE Proc. of GLOBECOM* Sydney, pp. 107-112, Nov. 8-12, 1998.

8. Chockalingam A, Zorzi, Milstein LB, and Venkataram P, "Performance of a Wireless Access Protocol on Correlated Rayleigh Fading Channels with Capture",*IEEE Trans. on Communications*, Vol.46, No.5, pp 644-655, May 1998

9. N. Chelouche, A. Hethuin, L. Ramel, "Digital wireless broadband corporate and private networks: RNET concepts and applications," *IEEE Comm. Mag.*, vol. 35, no. 1, Jan 1997, pp. 42-51.

10. Venkataram P and Sureshbabu P, "A QoS adaptation algorithm for Multimedia Wireless Networks", in a special Issue on **Multimedia Wireless Networks** of *Journal of Indian Institute of Science*, vol 80, No 3, pp. 195-215, March-April 2000

11. Seshan S, Balakrishnan H, and Katz RH, " Handoffs in Cellular Wireless Networks: The Daedalus Implementation and Experience", *Kluwer International Journal on Wireless Personal Communications*, January 1997.

12. Balakrishnan H, Seshan S, and Katz RH, "Improving Reliable Transport and Handoff Performance in Cellular Wireless Networks", *ACM Wireless Networks*,Vol 1, No 4, December 1995.

13. Perkins C, "IP Mobility Support, Internet Draft (draft-ietf-mobilip-protocol-17.txt)", 1996.

14. Ramjee R, Kurose J, Towsely D, and Schulzrinne H, "Adaptive playout mechanisms for packetized audio applications in wide-area networks", *Proceedings of IEEE Conference on INFOCOM)*, pp. 680-688, June 1994.

15. Gemmel J and Christodoulakis S,"Principles of Delay-sensitive Multimedia data Storage and Retrieval", *ACM Trans. on Information Systems*, Vol. 10, No. 1, pp. 51-90, Jan. 1992.