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Mobility Prediction for Optimal Handover and Connection Management in Mobile Multimedia

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1. Introduction
The demand for broadband services is driven by the increased usage of On-line services, Internet Access, World Wide Web sites, Video on Demand, and other Multimedia applications. Hence it has become necessary to examine the feasibility of extending these services from the wireline domain to the wireless domain. As Asynchronous Transfer Mode (ATM) is the most promising technology in the wireline domain, capable of handling broad band services with their stringent Quality of Service (QoS) requirements, it follows that while trying to seamlessly extend the wireline domain into the wireless, ATM would appear to be the most suited technology [1]. Hence Wireless ATM (WATM) is being studied extensively and suggestions to incorporate a set of enhancements to ATM’s already existing set of functions in the wireline area to accommodate the wireless requirements, are under consideration. Wireless ATM in general covers Cellular Communications, Wireless LANs and Satellite Communications [2]. The focus in this paper is towards Cellular or Mobile ATM, and issues related to Mobility Management aspects have been addressed and solution proposed. Section 2 deals with general issues related to extending multimedia services to mobile networks. Section 3 elaborates on the issues related to Mobility Management only. Section 4 gives a brief view of the Virtual Connection Tree approach used in [1] [3] for mobility management. This is so because our approach is slightly based on this. Section 5 gives the features essential to achieve a good Mobility Management. Section 6 explains the features of the Dynamic Virtual Connection tree to achieve the objectives set out in section 5, while section 7 handles some implementation issues with different scenarios. Section 8 concludes.

2. Issues in Mobile ATM
Presently broadband services supported on wireline ATM networks have the advantages of a very low bit error rate and a high speed transmission media. The inherent robust nature of the ATM technique on these wireline networks can guarantee QoS to time sensitive Multimedia applications. As compared to this, Cellular Communications have the following major distinguishing features like a limited radio spectrum, time varying quality of the two-way physical link between mobile and base stations, inherent higher error rates due to the nature of the media and an unknown time-varying access point, which would necessitate suitable multiple access schemes for sharing the allotted radio spectrum and guaranteeing QoS.

Taking into consideration the above factors, the general issues that need to be addressed for the successful implementation of a Mobile ATM network are Mobility management, Network Access management, a suitable Media Access Protocol, QoS support and control and support functions in the fixed network, if any [1].

One of the major issues among those listed above is Mobility Management which encompasses Location Management, Connection Management and Handoff Management.

This paper focuses mainly on issues related to connection and handoff management, which would involve signalling and network control for dynamic re-routing of a set of virtual connections from one base station or radio port to another. A simple scenario explaining handover is shown in Fig. 1.
Here the Mobile Terminal (MT) moves from the region of base station BS1 to BS2. Its original connection path to the fixed network and the far-end fixed or radio port was through switches SW1, SW4 and SW5. This will now have to be changed to either SW5, SW3, SW2 and BS2 or SW5, SW4, SW2 and BS2 if a link between SW4 and SW2 exists (shown by the dotted line) and is available.

3. Mobility Management in Mobile ATM
To achieve an efficient hand over, Mobility Management in Mobile ATM networks should basically have the following features:
- Low latency,
- Scalability - i.e. hand over should be possible over any geographical location,
- Maintain QoS during handoff,
- Minimal buffering of the cells during the actual hand-over to avoid delay in information,
- Maintain data integrity, i.e. avoid cell loss, out-of-sequence cells and duplicate cells, when changing the path,
- Handle group hand-over as required for multimedia connections.

Various schemes have been investigated for this purpose. Some of them involve a 'tear down and set up' of new segment connection, while others do not.

Schemes which involve tearing down and set-up of new connection can be categorised as
- one-phase hand-off,
- path rerouting,
- path extension,
- base station based hand-off,
- combinations of these. [2]

Of the schemes that do not involve tearing down and setup of connections, one is the virtual connection tree [1][3]. The other scheme makes use of a connectionless technique with a homing algorithm [11].

4. The Virtual Connection Tree approach
The pre-established virtual connection tree approach avoids segment 'tear down and setup', by setting up extra segments of a connection tree (from a so-called root switch to a set of base stations to within a footprint) during the connection setup phase [1]. Any interference from the Admission Controller is sought only when the mobile terminal is travelling across virtual connection trees. In this scheme the mobile terminals initiate their own handoff, when they realise that they have entered the region of the neighbouring new Base Station. This scheme is said to have the following advantages:
- Minimises cell delay and loss during handoff,
- Minimises burden on the Admission Controller,
- Maintains QoS during handoff,
- Effect of reduced cell (of cellular) size is not felt. Reducing cell size in cellular communication improves frequency re-utilisation, but would adversely effect the hand over situation. This problem is solved by the virtual connection tree approach.

The disadvantage cited in this method is the overloading of any base station due to a number of terminals moving into its region, for which the authors suggest limiting the allowed users to a certain number within a connection tree thereby reducing the probability of this occurrence. The other problem associated with this approach is, complex rerouting of accumulated cells at the old base station to the new base station which leads to disordered and lost cells, thus making this approach most suitable to ABR like services only [4].

5. Features of the Proposed method
After studying various scenarios of hand over and the two major techniques mentioned above, it was felt that some of the following issues need to be addressed to achieve an optimal hand over. The virtual tree concept seems to be a very good candidate to support QoS guaranteed services, because of the lack of 'set up and tear down' procedures. But other issues which need to be addressed are given below:
- A QoS sensitive scheme for wireless ATM will require a more global view of the network in terms of both switch and micro cell resources, and may have to include some measure of terminal mobility. [5]
- Scalability of the scheme - The hand over scheme will have to cater for mobile terminals which move with different speeds in different environments, such as within a city, in a suburb or on the highway.
- A variable number of virtual connections should be provided based on the mobile's mobility. This may be more appropriate than allocating a predefined set of virtual connections to each of the mobile users with in the span of the tree.
- How far apart are the nodes of the ATM network accessible to a cluster of Base Stations? And subsequently what is the maximum number of Base stations that can be connected to an ATM node? This would affect the decision on the size of a footprint and how much area coverage it can provide.
- How to decide on the optimal size of the footprint?
- How to decide on the root node?
• What would be an optimal size for the virtual connection tree?
• Some solutions to the above issues are:
• From 1 & 3 above, it is logical to include Terminal Mobility into our scheme. Hence we start from a minimal virtual connection tree and let it grow depending on the mobility characteristics of the mobile terminal. This way, we would not waste many virtual connections. It is obvious that what is needed is a dynamic resizing of the virtual connection tree, depending on the mobility of the mobile terminal. One needs to estimate how fast or slow the mobile terminal is moving and how many Base stations or ATM nodes it would cover over the duration of a call. The mobility of the mobile terminal in turn could depend on whether it is within a city, or in the suburb or on the highway.
• In case of dynamic resizing of the tree, which would involve connection set up and tear down when travelling across minimal virtual connection trees only, cell delay and loss would need to be minimised. This requires a scheme to predict the future movement of the mobile terminal and accordingly initiate ‘connection set up’ before the mobile terminal enters that area.
• The schemes hitherto suggested in the literature, expect all the functionality and control of the hand over to be managed from the view point of the fixed network. As suggested in [4] it is felt that some important information and decision making if handled by the cellular network could simplify this problem considerably. The Base Stations or the ATM switches above it can estimate the speed and direction of the mobile and use it to predict connection set up along the path of the mobile terminal.

6. The Dynamic Virtual Connection Tree Approach

Based on the above features, an implementation of the required scheme is described below. As in the original virtual connection tree scheme the handover will be initiated by the mobile terminal.
• We start with a minimal virtual connection tree, preferably one that is isolated to a cluster of Base stations, for eg. 7, or to a two layer configuration as shown in Fig. 2. It is preferable that all these Base Stations be connected to one ATM switch. Hence a footprint is restricted to this cluster of Base stations. A set of connections on all links between the Base stations of the cluster and the ATM switch will be allotted to any mobile terminal at the time of connection set up with the fixed network. Hence, a set of Virtual Channel Numbers are booked only on those links connecting the cluster to the ATM switch, instead of booking Virtual Channel Numbers on links connecting to switches within the fixed network up to the root node, as proposed in the original scheme. This would result in considerable saving of virtual channel numbers and any associated resources allocated. It is felt that merely by allocating virtual channel numbers without actually reserving resources as stated in [1] may not guarantee QoS.
• A means to compute the mobility of the user, i.e. the mobile terminal’s speed and direction is essential in the implementation of the scheme. The accuracy of the information expected by the scheme can be quite crudely quantised into 3 or 4 levels of speed and 4 or 6 levels of direction.
• Depending on this mobility information, prior action will be initiated to move/grow the footprint and/or increase the depth of the tree
• This might require a footprint growth that is controlled by hierarchical layers of switches. If it is detected that the smaller footprint may not suffice, a larger footprint may be allocated which is controlled by a switch one level above the minimal footprint. This is explained in detail later.
• It is preferable to connect as many clusters as possible to one ATM switch (if necessary a dedicated one may be used), so that one gets a wide area coverage without intruding much into the fixed network resources and keeping the virtual connection tree isolated to the closest ATM switch.

• When hand off across the minimal virtual connection tree is necessary additional means of safeguarding the QoS can be assured by:
  • providing overlapping clusters or cells as explained later,
  • guarding some virtual connections in all footprints for migrating mobile terminals,
  • providing priority to migrating calls over new calls,
  • handling any contending requests with a service sensitive priority scheme
• The calculation of the speed and direction can be done either by the Base Station or by the ATM switch above it and information can be passed on to the different layers of switches in the hierarchy based on decisions taken at the lower layers.
• To resolve issues relating to Mobile Terminals which are starting calls while at the edge of a cluster, cluster with overlapping cells at the periphery could be used. Or, the TAM switch can start connections in the neighbouring clusters as a protective measure, and release them later when not needed.

7. Scheme Implementation

From Fig. 2 the footprint is minimal and occupies a one layer cluster of Base stations or a 2 layer cluster. Within each of these footprints a set of virtual connections will be given to each mobile user requesting access to the fixed network. Hand over within the footprint will not require connection
connection wasted will be limited to twice the number of active users, times the cluster size, minus one. Though a set of connections is reserved, only a pool of resources need be reserved for these connections and will be allocated as the users change connection. The control and allocation from the reserved pool can be handled by the Base Station or the ATM switches.

The decision about providing a 1 layer or 2 layer footprint can be made on the basis of statistics that need to be obtained from the coverage area. If it is a very crowded area, like within the city, fast movement is not likely and a 1 layer footprint would suffice. The probability of a number of users requesting service in such cells will be greater than non urban areas. Thus restricting the footprint to 1 layer will also restrict the number of virtual connections and resources to be reserved, because of the limited number of cells covered, thereby accommodating the higher number of users in such cases.

As the mobile terminal moves, the base station to which it is connected can deliver an estimate of its movement and direction to the required accuracy [8][7] and as stated earlier the information we need, does not have to be accurate. Let us define 3 speed levels of speed_level_1, speed_level_2 and speed_level_3, with speed_level_1 being the lowest. The direction also can be in discrete form to approximately indicate the next cluster or couple of clusters which the mobile terminal is most likely to enter. To understand the scenario better, see Fig. 3.

Each cluster (thick lines) CL1, CL2 ... is covered by a minimal virtual connection tree. Cluster CL1, CL2, and CL3 are connected to SW1: CL3, CL4, CL5 to SW2 etc., as shown by the thicker dotted lines. CL3 and CL5 are overlapping clusters across the domains of SW1 and SW2. When SW4 takes over, as and when necessary, its domain of coverage would be from CL1 to CL5, similarly for SW5, which are indicated by the thickest dotted lines. Though, three clusters come under the domain of switches SW1, SW2 and SW3, connection to mobile users will be restricted to only one cluster unless decided otherwise by the ATM switch due the cluster edge problem cited earlier.

Let us consider different scenarios here.

Case 1: The mobile terminal is in center of cluster CL4 and moving with speed_level_1, in some direction. The corresponding base station will make the decision that the probability of this mobile terminal moving over to CL5 or CL3 is quite remote and it is already accommodated for movement with in cluster CL4 and no action is taken.

Case 2: The mobile terminal is in the center cell of cluster CL4 and moving with speed_level_2 towards an easterly direction. Then the Base Station in this cell would keep SW2 informed about the mobile terminal’s movement. SW2 will then set up connections in CL5 for the moving mobile terminal thereby increasing the size of the virtual connection tree to two clusters. Meanwhile SW2 will continue to monitor this mobile terminal via information from base stations in CL5. As the mobile terminal enters CL5, which is the overlapping cluster between the domains of SW2 and SW3, the base stations in CL5 will inform SW3 and the mobile terminal will be allotted a new set of connections in this cluster by the ATM switch SW3 and a hand over from SW2 to SW3 would occur gracefully, as and when it is initiated by the mobile terminal. Once the mobile terminal is in CL5, SW2 would pass on the information to SW5 for a connection transfer from SW2-SW5 to SW3-SW5. This will require a set of control messages which need to be passed on between the switches, and can be implemented using a set of messages as mentioned in [2].

The difference when compared to these approaches and our approach is that connection requirements are predicted, requested and obtained well before the mobile terminal enters a cell or cluster.

Case 3: The mobile terminal is in CL2 and moves with speed_level_3 in a south-easterly direction. The corresponding base station in CL2 will inform SW1, which in turn will inform SW4 that a connection switch over to SW2 might occur as the speed level is high. Once the mobile terminal enters CL3, the overlapping cell SW2 will inform SW4, to change over the connection from SW1-SW4 to SW2-SW4. SW4 will now inform SW6 about the requirement for a connection setup.
between SW6 and SW5 as it anticipates the mobile might enter the domain of SW5. By the time the mobile moves to CL4 and CL5, SW2 would have informed SW5 and a connection switch over from SW6-SW4 to SW6-SW5 will occur gracefully. The overlapping of regions covered by the ATM switch help, because the actual switch over can occur when the mobile terminal is in an overlapping cluster, thereby giving enough time for a new connection set up. Depening on the speed, as the mobile terminal moves, the ATM switches can de-allocate the virtual channel numbers from the previous cluster after a certain time limit.

The drawback of this scheme are:

- probability of wrong prediction of direction and speed,
- probability that a new connection could not be set-up for a migrating user.

7.1 Intermediate Cells buffering

While a connection is being handed over it is necessary to buffer the cells coming in to the old Base Station till the actual hand over has occurred and then send them over to the new Base Station. In this case, as the Mobile Terminal initiates a new Virtual Connection Number which has been allocated to it by the ATM switch covering its BS, the base station informs the other one that the Mobile terminal has entered its cell. The old Base Station will then save all incoming cells for that terminal till it is given an end signal by the ATM switch which has now started directing the cells to the new Base Station. The new Base Station waits till it receives all the cells from the old Base Station and the end signal, before transmitting the new cells that it has buffered till then. As no delay is introduced during hand over, the buffering requirements and associated delay are minimal. The transfer of cells across base station can take place via the air interface or via the fixed path between the Base Stations through the ATM switches. If the fixed path between the Base Stations exceeds one ATM switch it would be advisable to transfer the cell over the air interface rather than via the fixed path. Protocols for this have been suggested in the literature and any of these or combination thereof could be employed for this purpose[2].

8. Conclusion

A new scheme for efficient handover and connection management that can support the guaranteed QoS during handover is suggested in this paper. The schemes takes into consideration the mobility of the mobile terminal, predicts its speed and direction thereby dynamically setting up virtual connection as the mobile terminal moves. Also it has taken into account the coverage area and the scheme is independent of this.

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