A System Architecture for Mobile Broadband Access Using Wireless ATM

Manoneet Singh Subrat Kar Surendra Prasad D.Arvind
Dept. Of Electrical Engineering,
Indian Institute of Technology, Hauz Khas,
New Delhi-110016.
Phone +91-11-6861977, Fax +91-11-6966606
E-mail: manoneet@technologist.com, {subrat, sprasad}@ee.iitd.ernet.in

ABSTRACT

We present a system level architecture for supporting mobility in an ATM-based Wireless Personal Communication Network (PCN). The proposed architecture uses a networking scheme based on intelligent, multicast-based trees with distributed mobility management and predictive resource allocation at the base stations. The addressed functionalities include connection admission, location management and tracking and handoff procedure with QoS support. The associated protocols for implementing these functions are outlined and the architecture is compared vis-a-vis currently existing proposals in the literature. In doing so we discuss key design issues, and speculate on future directions in the development of broadband wireless packet communications systems.

1. INTRODUCTION

The emergence of portable multimedia computing platforms and growing demand for mobility among communication services has led to the need for extending ATM-like virtual connectivity from the wired to the wireless domain. The ATM cell relay paradigm, which forms the basis for the emerging B-ISDN, is now also being actively considered as a potential framework for next-generation wireless communication networks capable of supporting integrated, QoS-based multimedia services; leading to a truly tetherless and seamless connectivity for mobile applications [1].

The provisioning of Wireless ATM is fraught with several challenging and interesting issues, of which we mention just three here. *First,* in contrast to the reliable *physical* (wired) enviionment for which ATM was designed, the wireless medium suffers from high bit error rates and limited bandwidth, necessitating the use of sophisticated strategies to mask the influence of phenomena like fading, multipath propagation, Intersymbol Interference (ISI) and shadowing on the QoS of an ATM VCC (Virtual Connection Circuit). *Second,* the integration of W-ATM into the fixed B-ISDN requires that end-to-end connectivity be maintained through protocols that seamlessly *inter-network* the wired and wireline portions of the network. *Finally,* while current ATM standards proposed by the ITU are designed to provide connection-oriented support to wireline users at fixed locations, wireless users are *mobile,* and therefore require support for hand-off, location management and connection management functionalities. It is the last of the three aforementioned issues viz., mobility that forms the focus of this paper.

In an ATM network without support for mobile users, a (non mobile) user is able to communicate with a host along a single pre-determined virtual path, and QoS can be maintained for the connection by simply reserving bandwidth during connection setup at each router on the forwarding path. In an environment with mobile users, however, there exists a need to dynamically reroute ongoing connections to/from mobile users as these users move among multiple base stations. Connection rerouting schemes must exhibit low handoff latency, maintain efficient routes, and limit disruption to continuous media traffic while minimizing updates to the network switches. The situation is complicated by the fact that, in order to provide broadband services, the frequency re-use factor must be increased, leading to a very small size of cells in the wireless access segment of the network *(picocells)* and a consequently higher frequency of handoffs as mobiles move relatively quickly between the small-sized cells. Without some intervening mechanism, a mobile operating in such an environment would have to perform a connection setup each time a handoff occurs. This would not only seriously degrade the QoS guaranteed to the connection, but would also impose a great computational bottleneck on the network's call admission controller (CAC) performing the call processing and control functions in a centralized fashion.

Several alternatives for wireless ATM architectural design have been proposed in the literature to alleviate the mobility problem [2]-[5]. Among these is the virtual connection tree (VCT) [2], a construct that seeks to unburden the central network call processor by organizing a hierarchical grouping of backbone and wireless network resources, and making the handoff "mobile-executed", thereby reducing the computational load on the CAC. The VCT and its variants [4] have been widely discussed; it has been pointed out that in several situations, the mobile-initiated handoff does not provide an optimal performance. Specifically, issues such as ordering in packet sequences and handovers in congested picocells cannot effectively be addressed by the mobiles themselves [5].

In this paper, we propose to augment the Virtual tree topology using mechanisms that guarantee more reliable QoS during handoffs and provide local hotspot relief besides reducing the computational burden on the mobiles, in effect simplifying their design. In particular we envisage the use of three schemes where the *base stations* can be expected to play a significant role. The first is mobile tracking through sectored antennae. If the mobility patterns of a mobile can be made available to the base stations in the multicast cluster, the base stations can intelligently reserve resources for mobiles that may be anticipated to enter the pico-cell served by the them *(predictive resource reservation).* The second idea is to borrow channels from adjacent cells if a particular base station is overloaded. Since this process may not be implementable real time, base stations must use the advance warning provided by the motion information of the mobile to predict a hotspot and initialize channel borrowing measures, forcing a handoff of the overloading mobile *(Base station assisted handoffs).* The third idea is to use caching at the base stations and local re-transmissions on the downlink to counter the effects of high BER experienced on the wireless link. We elaborate these ideas in the sequel.

The remainder of this paper is structured as follows. In Section 2, we describe the components and salient features of the proposed Wireless ATM network architecture, elaborating the construct of the *Intelligent Multicast Tree* (IMT) which forms the essence of this proposal. In Section 3, the network protocols to be implemented in the present scheme are briefly outlined. Section 4 offers a performance evaluation of the architecture using 3 different simulation models. Section 5 summarizes the major notions contained in this paper.

2. THE PROPOSED ARCHITECTURE: SALIENT FEATURES

In this section, we describe the components, organization and key features of the proposed IMT-based architecture. It may be pointed out that the 'intelligence' in the IMT really derives itself from the buffering and switching capability embedded in the base stations, which, when coupled with information about mobility patterns of the MHs, helps to reduce the processing burden on both the CAC and the mobiles, and enables a more distributed sharing of computational load among the various entities in the network.

2.1 Components

The Wireless Access structure based on Intelligent Multicast Trees (IMT) is shown in Fig. 1. The Radio Access Region consists of the union of many IMTs, each defined by a cluster of contiguous picocells. An Access Point/ base station manages and regulates traffic in one picocell. Each base station (BS) is connected to the Root Switch of that IMT by a Virtual Path through a network of fiber links and is assumed to be equipped with directional, sectored antennae. Sectoring is important in this scheme, not only to increase the effective channel reuse factor and assist in directional channel borrowing during hotspots, but also to facilitate the estimation of velocity and position of mobile terminals, as discussed in [6].

A MH (Mobile Host) is admitted once into an IMT, based on a statistically pre-computed look up. When it hands off between Access Points inside the IMT, the network CAC (Call admission Control) is not invoked; the mobile's movement inside the IMT is thus transparent to the rest of the network. Only when it moves out of the cluster of the IMT is the existing connection replaced with another to the Root Switch of the second Tree. By making the IMTs large and overlapping, frequent handoffs across clusters can be avoided.

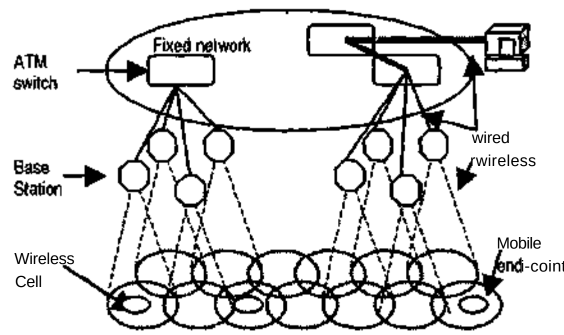


Fig.l: Schematic of the architecture

2.2 Mobility Based Predictive Resource Reservation: Blind vs. intelligent multicast

The goal of any multicast-based mobility approach is to minimize the impact of disruption in loss and delay sensitive continuous media traffic by grouping the neighbors of the cell in which the mobile user is currently resident, and perform advance multicasting of data to the base stations in this group. The mobile can then freely roam in the area covered by the multicast, without invoking the network call acceptance capabilities during each handover. Although the approach is fast and statistically guarantees QoS, the overhead of buffering data for each mobile host in multiple base stations in the cluster could form a potential implementation bottleneck in the future. The use of mobility information based on motion estimates of the mobiles can alleviate this problem. By processing the mobility information of the mobiles available to them along with the multicast data, the base stations can effectively allocate their resources, reducing the net buffering overhead per admitted mobile. Note that since this processing is done by the base stations themselves, the CAC as well as the mobiles are not burdened computationally.

2.3 Hotspot Alleviation: Using the Velocity and Position Estimates

As far as the wireless bandwidth is concerned, overload conditions might occur if the communication requirement of a number of wireless terminals populating a picocell (or cluster of adjoining picocells) exceeds the total capacity of all access points within their reach. In the Virtual tree [2], such a hotspot radio congestion state would simply cause the incoming mobiles to be dropped, thereby increasing the call-dropping probability. The problem can be alleviated by the use of Channel borrowing, which, atleast in a semi-dynamic way, is known to be a viable method to alleviate local radio congestion in cellular systems [7]. The protocol that an overloaded Access Point must follow to borrow channels is necessarily lengthy and this could cause a break in the service received by the mobile. Using motion prediction, however, a picocell can predict a hotspot and initialize hotspot relief measures so as to be able to deploy them quickly when a hotspot actually occurs. In specific, the base station can pre-empt the borrowing of spare channels in neighboring cells to relieve local congestion. Sectoring in this setup enables the borrowed channels to be used in such a way that interference between co-channel cells is minimized.

2.4 Caching for Error Control

The final application of base station 'intelligence' in the IMT architecture is in caching ATM packets and performing local retransmissions of lost or corrupted packets, alleviating the problems caused by high BERs on the wireless link. This local retransmission not only reduces the effective latency, but also circumvents the need for repeated transmissions back from the source terminal, preserving the end-to-end semantics of the Wired ATM protocol. By detecting missing packets and generating corresponding negative acknowledgements, the base stations can shield the sender from transient situations of very low communication quality and temporary disconnectivities on the wireless link. In doing so a substantial increase in effective throughput can be expected.

3. NETWORK PROTOCOLS

In this section, we briefly delineate the major protocols that manage mobility in the given architecture. These protocols are shown in Figs. 2 through 4.

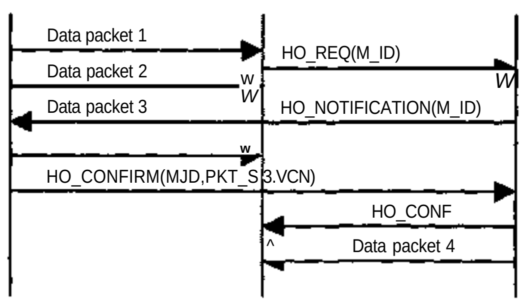


Fig. 2: Handoff protocol message flow

Intra-cluster Handoff Protocol

The message flow for the handoff of a MH between two picocells that are part of the same IMT is indicated in Fig. 2. The handoff is initiated when, based on its beacon measurements and some hysteresis, the MH transmits a handoff request to a new base station BS2. While the request is being delivered and processed, packets continue to be transmitted to/from the MH through BS1. The control message to activate forwarding on BS2 includes a sequence of identifiers that identify the sequence of packets last received by the MH from BS1. Once the handoff is accomplished, the old base station automatically tears down the routing entry for MH and de-allocates its resources accordingly. By adopting a *make-break* strategy for the handoff, ATM cell flow disruption is minimized, and the sequence of cells can be effectively maintained.

It may be noted here that the entire handoff procedure described above requires the use of in-band mobility enhanced signaling (MES) between the Base stations and the MH, the details of which are omitted in this discussion for reasons of brevity. Also note that the above description is not applicable for the case of handoffs forced by Base station during hotspot conditions.

Multi Access Scheme

To provide Class-based Quality of Service to mobile applications in the cluster, a multiple access scheme, similar in spirit to the distributed queuing resource update multiple access (DQRUMA) [8] is proposed in conjunction with a rate-controlled Static priority Queuing based service discipline at the base stations. The latter is shown diagrammatically in Fig. 3.

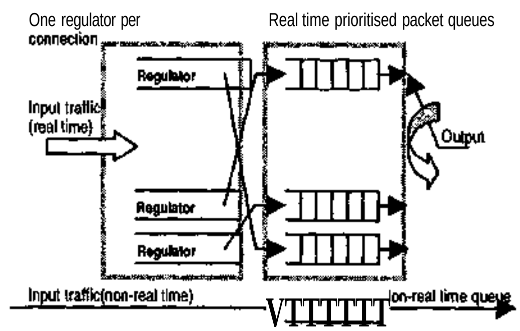


Fig 3: Rate controlled static priority queueing

Connection Setup Protocol

A mobile can request a connection setup in an IMT cluster by randomly accessing the Call Admission Request Segment of the local base station's signaling field with its local identification number (M_ID) and traffic parameters of the required QoS. The setup and connect functions to the backbone are handled by the root switch, and successful establishment of an ATM VCI/VPI and decision to admit are transmitted to the mobile in the connection acknowledgement field of a later frame. Once the connection has been admitted, data exchange can proceed following the mobile's ID (M_ID) being successively multicast to all base stations in the IMT. The above sequence of steps is enumerated in Fig. 4.

4. SIMULATION RESULTS

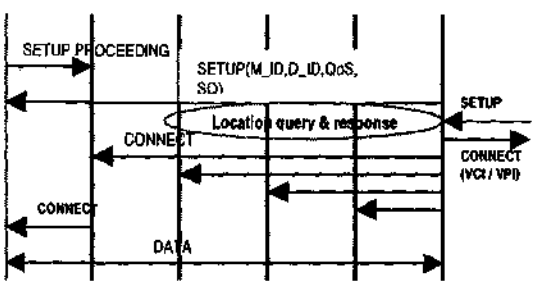
Three types of simulations have been used to characterize the performance of the proposed architecture for various operating parameters of the system. This first simulation is performed to calculate the dropping probability for a given number of connections admitted into the multicast cluster. The model assumes a cluster of 20 picocells each having a bandwidth equivalent to a total of 20 voice calls. User mobility is modeled in this simulation according to the *'random walk'* approach, whereby, at any instant, the mobile may remain in its current picocell, or handoff to any of the adjacent picocells (adjacent picocells being defined as those having common edges), with an equal probability. In case it handoffs into a picocell that is already serving its maximal capacity, the mobile must be dropped. Fig. 5 plots this dropping probability against the number of connections admitted into the cluster.

The second simulation model augments the first one described above by incorporating a Poisson distributed call arrival rate and plotting the dropping probability for various values of the arrival rate for a fixed number of users. The results are indicated in Figure 6.

The third and final simulation involves fixing a random, exponentially distributed lifetime for each connection admitted into the cluster during call set-up, and tearing down the connection when the lifetime is elapsed. The remaining system is identical to the one in the second simulation. In this case, the arrival rate of calls per second being equal to the Erlang load on the system due to incoming calls; the number of users in the system is fixed and the dropping probabilities for various values of Erlang load are plotted. Results are presented in Figure 7.

5. CONCLUSIONS

This paper proposes a system architecture to provide mobility support in a futuristic wireless ATM based Personal Communication network (PCN). The architecture augments the static virtual connection tree concept presented in [2] by introducing the notion of *intelligent multicast;* whereby the mobility management functionality is distributed among the various entities in the network *(mobile hosts, base stations and wireline switches).* In doing so, system resources *(buffers, wireless bandwidth)* can be utilized more efficiently, hotspot conditions can be alleviated and, in effect, the call blocking rates can be reduced. In this paper, we sketched the network protocols to be used for the present scheme, and characterized the performance of the architecture through 3 different simulation models. A more rigorous and comparative evaluation of performance forms the subject of future work.



M_ID: Mobile Identifier* (local) OJD:Oestination Identifier # (local)
QoS: Quality of Service parameters SQ: Setup Request #

Fig.4: Connection setup procedure

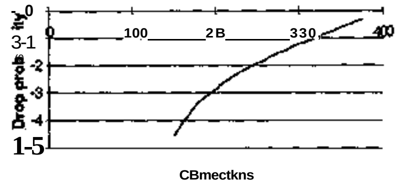


Fig. 5 Log (Dropping Probability) vs. No. of admitted Connections(N)

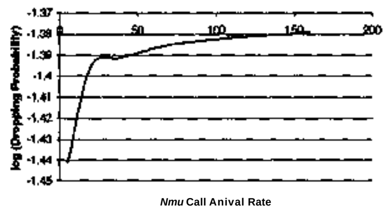


Fig. 6. Log (Dropping Probability) vs. Call Arrival Rate per Picocell (N=300)

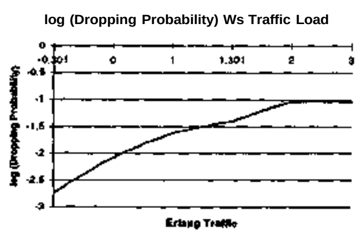


Fig. 7. Log (Dropping Probability) vs. Erlang Load

REFERENCES

[1] D. Raychaudhuri, L. J. French, R. J. Siracusa, S. K. Biswas, R. Yuan, P. Narasimhan and C. A. Johnston, "WATMnet: A Prototype Wireless ATM System for Multimedia Personal Communications", *IEEE Journal on Selected Areas in Communications,* Vol. 15, No.l, pp. 83-95, Jan 1997.

[2] Anthony S. Acampora, Mahmoud Nagshineh, "An Architecture and Methodology for Mobile-Executed Handoff in Cellular ATM Networks", *IEEE Journal on Selected Areas in Communications,* Vol.12, No. 8, pp. 1365-1374, October 1994.

[3] M. Veeraraghavan, M. J. Karol and K. Y. Eng, "Mobility and Connection Management in a Wireless ATM LAN", *IEEE Journal on Selected Areas in Communications,* Vol. 15, No.l, pp. 50-68, Jan 1997.

[4] O.Yu and V.Leung, "Extending B-ISDN to Support User Terminal Mobility over an ATM Based PCN", *Proc. GLOBECOM '95,* pp. 2289-2293, 1995.

[5] Bernhard Walke, Dietmar Petras, and Dieter Plassman, "Wireless ATM: Air Interface and Network Protocols of the Mobile Broadband System", *IEEE Personal Communications* Vol. 3, No.4, pp. 50-56, Aug. 1996.

[6] Martin Hellebrandt, Rudolf Mathar and Marcus Schiebenbogen, "Estimating Position and Velocity of Mobiles in a Cellular Radio Ntework", *IEEE Trans. Vehic. Tech.,* Vol. 46, No.l, pp. 65-71, Feb. 1997.

[7] Tak-Shing, Peter Yung and Wingh-Shing Wong, *"Hot Spot Traffic Relief in Celluler Systems", IEEE Journal on Selected Areas in Communications,* Vol. 11, No.6, pp.934-939, Aug.1993.

[8] MJ. Karol, Z.Liu and K.Y.Eng, "Distributed Queuing Packet Request Update Multiple Access for Wireless ATM Networks", Proc. ICC '95, June 1995, pp. 1224-1231.