A Novel Capacity Maximization Scheme for Multimedia Wireless ATM Systems Providing QoS Guarantees for Handoffs

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Abstract — Wireless ATM(WATM) is expected to provide significantly high bit-rate services to meet the demand for handling multimedia information. In a mobile wireless environment, handoff provisioning is a challenging problem and much effort has been contributed for efficient utilization of the limited radio resources. In this paper, we propose a capacity maximization method in a multimedia Wireless ATM system, which can be used for handoff prioritization by bandwidth reservation. Specifically, we propose to regulate the buffer by the Selective-delay Push-in (SDPI) scheme, and search for the optimal percentage of total bandwidth to be reserved for handoffs. Simulation results show that our scheme significantly improves spectrum efficiency and reduces handoff failure probability.

I. Introduction

The growth of cellular radio communications in the past decade has been remarkable. ATM has become a mature technology, which can be deployed for various types of applications. With ATM, applications with different bandwidth requirements can be easily supported because bandwidth is assigned on demand as long as there are sufficient resources. Users will not only need higher bandwidth; they will also demand mobility. Quality of Service (QoS) requirements such as bandwidth, delay bounds and cell loss rates must be met in order to provide users with multimedia services. However, existing wireless networks are not able to satisfactorily fulfill the demanding requirements of multimedia services. Wireless ATM networks are designed to provide high-speed communications and aim to meet the stringent requirements of wireless users [1-5].

Owing to the limited bandwidth, efficiency of resource utilization is a key issue in the design and implementation of multimedia wireless ATM networks. Wireless ATM networks deploy the micro-cellular architecture for better utilization of radio spectrum, resulting in increased rates of handoffs as mobile terminals move from cell to cell. The increased rate of session handoffs not only increases the signaling load on the network but also potentially adversely impacts the QoS with each handoff. Various handoff and channel allocation strategies have been proposed to utilize efficiently the limited resources while maintaining the QoS at an acceptable level [6-10]. Especially, channel allocation strategies with handoff prioritization have been investigated to decrease the probability of handoff failure, such as the guard channel scheme and queueing of handoff requests. These schemes serve to decrease the probability of handoff failure but increase the call blocking probability. Moreover, they are designed primarily for voice, data, or a mixed form of voice and data. Performance analyses of handoff were obtained by using fixed bandwidth circuit switching. That is, the bandwidth of each connection is equal to that needed to transport a digital voice or data signal, and each connection is given exclusive use of a small portion of the wireless bandwidth for the entire duration of that connection, i.e., per-call resource allocation. However, in the multimedia wireless ATM network, this approach is not adequate or efficient to meet the need of multimedia traffic. On the other hand, multimedia traffic can be provisioned by one of the following ATM services: Constant Bit Rate (CBR), Real-Time Variable Bit Rate (rt-VBR), Non-Real-Time Variable Bit Rate (nrt-VBR), Availabile Bit Rate (ABR) and Unspecified Bit Rate (UBR) service.

An analytical model which incorporates the idea of giving priority to handoff calls into channel assignment was proposed in [11]. Under the cutoff priority (e.g., guard channel) scheme, this model decides the number of total channels and reserved channels necessary for each cell to provide a prescribed level of QoS for a single traffic type. An accurate determination on the amount of bandwidth that a base station must reserve (to maintain a certain call blocking probability) is a very important issue in wireless networks. Furthermore, multiple sets of QoS requirements will have to be satisfied in the multimedia environment.

In this paper, the two keys of our proposed handoff prioritization method are: i)the WATM cell management in the buffer at the access point in order to increase the wireless channel capacity, ii) optimization of the percentage bandwidth to be reserved for handoffs. The delay tolerant services can be queued, and service types with lower BER requirement can be prioritized. The performance of the proposed scheme is evaluated by simulation in terms of cell loss probability and handoff failure probability. It is shown that the channel utilization of an access point is increased greatly by making use of our scheme. This paper is organized as follows. Section 2 describes the Wireless ATM system architecture; Section 3 presents a handoff prioriti-

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zation scheme; Section 4 shows the simulation results of the proposed handoff scheme; finally, in Section 5, presents the conclusions.

II. Wireless ATM System Architecture

In order to establish wireless access to a fixed ATM network and to make the wireless operation transparent to a user, wireless access components extend the ATM technology to the air interface. The major components of a Wireless ATM system[12], as shown in Fig.1, are

- Mobile Terminal (MT), the end user equipment with a built-in radio interface operating in the 5GHz band and offering a wireless connection to an Access Point.
- Access Point (AP), the base station of the cellular environment, which is associated with mobile terminals.
- ATM multiplexer, to interconnect a collection of access points.
- Mobile ATM switch, to support interconnection with the rest of the ATM network.

Two entities control the allocation of bandwidth to ATM connections over the radio interface.

- Radio Resource Manager. This entity is located at the Access Point and takes part in the Connection Admission Control (CAC) process for a WATM terminal originated or terminated connection. It performs the Wireless Connection Admission Control (WCAC) and is responsible for the long-term allocation of bandwidth to ATM connection over the radio interface.
- Scheduler. This entity is responsible for scheduling the traffic transmitted through the wireless medium. In other words, it is the component that decides the time an ATM cell will be transmitted. There are two types of schedulers: the Master Scheduler, which runs in the Access Points, and the Slave Scheduler, which runs in the mobile terminals.

III. Handoff Prioritization Scheme

A. Virtual Circuit(VC) Reservation scheme

Bandwidth is the most scarce resource of the entire wireless communication system. It is of great importance to use this resource in the most efficient manner. Many studies have aimed to reduce the forced terminations of handoff calls. One simple way to reduce the forced terminations of handoff calls is to reserve some channels for handoff calls exclusively in each cell in the traditional wireless network [7][10], the so-called guard channel scheme. In [11], the optimal number of guard channels is determined for the voice system. In the multimedia wireless network, the reserved bandwidth should be decided so that the required level of QoS for all types of sessions may be guaranteed. In [13], the virtual connection is created when a mobile user tries to get access to the network by executing a call setup procedure. A virtual connection between an ATM switch and an access point is established by assigning two sets of virtual circuit numbers (VCNs). Two sets of numbers are required because each link require two VCNs (one for each direction). In any case, for each active call, only two VCIs (for uplink and downlink connections with the access point chosen by the mobile) are in use at any time. Once the connection demand in the wireless portion of the network is admitted, a mobile user can hand off to another access point. We propose to reserve bandwidth in Wireless ATM for handoff sessions. We address the critical question of how much bandwidth should be reserved for handoffs.

B. Selective-Delay Push-In(SDPI) scheme

In order to provide and maintain QoS, the Access Point is equipped with a cell buffer manager. If buffer management is assumed to use a single queue approach, arriving cells will be serviced in a first-in-first-out fashion across the Access Point. Owing to the burstiness of traffic, buffering at the Access Point is required. Each burst can cause queueing of cells, resulting in Cell Transmission Delay (CTD), Cell Delay Variation (CDV), and Cell Loss Ratio (CLR).

In general, the traffic can be categorized into two basic classes: real time traffic (RTT) and non-real time traffic (NRTT). RTT has a limitation on the maximum delay time. If an RTT WATM cell is not delivered to its destination within the maximum delay time, it would be dropped. The RTT source may be of CBR or VBR type. The NRTT is more tolerant to delay, but has more stringent requirement for cell loss probability. On the scarce wireless bandwidth, to reduce the forced terminations of handoff sessions, we can exploit the delay tolerant and loss tolerant properties of traffic at the packet level. Channel utilization can be increased at the expense of QoS degradation such as partial traffic delivery and WATM cell drops in a buffer. Criteria for such decisions can be based on the application specified quality of multimedia information which the system tries to satisfy. WATM cells from different mobile terminals are delivered to the buffer of Access Point by statistical multiplexing and FIFO service discipline.

First, we consider threshold-based cell discarding. Note that priority cell discarding is a popular congestion control technique in high-speed networks [14] which allows network resources to be used more efficiently, thereby making it easier to satisfy QoS requirement of different classes of traffic. In general, loss-sensitive traffic such data is given priority over loss-tolerant traffic such as voice and video. WATM cells are dropped from a buffer when they exceed the maximum tolerance delay time. The buffer size is based on the maximum tolerance delay time of this traffic. With this scheme, channel utilization will be increased while maintaining the minimum QoS requirement.

In this work, we consider a simple threshold-based discarding (TBD) scheme. Under this scheme, the buffer is partitioned by n thresholds, $T_1, \ldots, T_n$, that correspond to n+1 priority classes. Cells of priority class i enter the buffer up to threshold level T_i. Once the buffer level is above T_i, arriving cells of class i are dropped. Note that only new arrivals are dropped; class-i cells that are already in the buffer are never dropped and are eventually served, as shown in Fig.2.

Second, while TBD scheme is used, we can also give other priority to the delay sensitive traffic over delay tolerant traffic selectively. It is called selective-delay push-in (SDPI) scheme. With this scheme, WATM cells of delay tolerant traffics can be delayed in favor for cells of delay sensitive traffics. The SDPI policy works as follows. When the buffer level is above T_i, if there exist delay-tolerant cells within T_i, an arriving delay-sensitive cell pushes out the latest arrived delay-tolerant cell and positions at the end of the buffer within T_i. If any delay-tolerant cell is not within T_i, an arriving delay-sensitive cell is discarded, as shown in Fig. 3. Especially, by adjusting the parameter between delay sensitive traffics and delay tolerant traffics without violating the QoS requirement, more efficient channel utilization can be achieved.

IV. Simulation Results

Computer simulations are conducted to investigate the packet-level and call-level performance of the handoff scheme. WATM cells initiated from new multimedia sessions are assumed to arrive according to independent and identical Poisson arrival processes. Handoff arrivals also follow independent and identical Poisson distributions. The fraction of the total traffic due to handoffs is kept fixed while the total offered traffic is varied. The simulation was conducted for one case where handoffs account for 50% of the total traffic; i.e., 50% of each type of traffic is assumed to be handoff traffic. Channel holding time of each session within a cell has an exponentially distributed duration. An ON/OFF multimedia source model is assumed. When the source stays in the ON state, it generates WATM cells at the peak rate, and no WATM cells are generated while the source stays in the OFF state. In order to describe the multimedia source precisely, we assume that WATM cells are generated at the ON state for voice and data traffic. Furthermore, VBR video source may be modeled as the superposition of multiple identical ON/OFF sources [15]. We consider three types of traffic sources; namely, voice, video, and data. We predetermine the amount of bandwidth required by sessions in each class of traffic, based on the source activity model. Specifically, we measure bandwidth in terms of Units of Bandwidth(UB), where each voice session occupies one UB, each video session occupies 9 UBs and each data session occupies 2 UBs. The parameters of the simulation set up are given Table 1 [15-17].

In hopes of improving performance, we investigate two schemes: TBD without SDPI and with SDPI. In the TBD scheme, the priority is given according to loss sensitivity, based on the maximum tolerance delay time. In the SDPI scheme, the priority is given according to delay sensitivity, based on the TBD scheme. In Fig. 4, three kinds of calls with ON/OFF source model are transmitted to the Access Point and the WATM cells are buffered according to the SDPI scheme using the delay and loss sensitivity. The performance of this algorithm depends on the fraction of total traffic for delay tolerant traffic because delay tolerant WATM cells are delayed, not discarded. This figure shows the cell loss probability vs. total session arrival rate. As the fraction of data traffic is increased in total traffic, cell loss probability (CLP)for each traffic type decreases. In our simulations, we use 30% of the total traffic as the data traffic as a fixed parameter. After determining the data fraction, we determine the optimal fraction for delay sensitive traffic for maximal utilization. In Fig. 5, two cases are compared. The first case is 50% voice, 20% video, and 30% data. The second is 60% voice, 10% video, and 30% data. Note that when the buffer occupancy exceeds the buffer size, data cells will be discarded. For simulation purposes, the buffer size is assumed to be infinite, such that no data cell will be discarded. With voice and video CLP curves, we can get the fraction for each traffic type such that the system capacity is maximized. According to Table 1, the QOS requirements of voice and video are 10^{-2} and 10^{-4}, respectively. The optimal fractions are decided via observation. After that, we compare the performance of the SDPI scheme and to the case without SDPI scheme. Fig. 6 shows the performance improvement when the SDPI scheme is used. We can get the maximal utilization at total arrival rate 0.9 with SDPI scheme, but without the SDPI scheme, the admissible arrival rate is 0.77. In Fig. 7, handoff failure probability is analyzed. Here we use 10% bandwidth of the capacity for handoff session. We investigate the new session blocking and handoff failure probability as the reserved percentage of the total bandwidth is increased, in Fig. 8 and Fig. 9. With SDPI scheme, the optimal percentage is about 10%, and 3% for that without SDPI scheme while satisfying the QoS requirements for all types for sessions.

V. Conclusions

This paper has shown that handoff performance can be improved by buffer management and optimal reservation of radio resources for handoffs. We determined the optimal ratio of total arrivals for each traffic types in order to achieve maximal channel utilization. We proposed a novel capacity maximization method that further enables handoff prioritization in multimedia Wireless ATM. Computer simulations have shown that efficient channel utilization can be achieved by means of a new buffer management scheme we call the SDPI. In addition, when the optimal percentage of radio resources are reserved for handoffs, handoff performance is improved without violating QoS requirements.

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Table 1 System Parameters of Simulation

Parameter Name	Value
channel capacity	1.92 Mbps
WATM packet length	424 bits
channel holding time	1 minute
average peak rate of voice	32 Kbps
average length of ON state for voice	0.35 (s)
average length of OFF state for voice	0.65 (s)
maximum tolerance delay time for voice	20 (ms)
maximum allowable CLP for voice	10^{-2}
average peak rate of data	64 Kbps
average length of ON state for data	0.52 (s)
average length of OFF stste for data	1.0 (s)
maximum tolerance delay time for data	∞
maximum allowable CLP for data	0
average peak rate of video	320Kbps
average length of ON state for video	33 (ms)
average length of OFF state for video	67 (ms)
maximum tolerance delay time for video	150 (ms)
maximum allowable CLP for video	10^{-4}
buffer size	∞

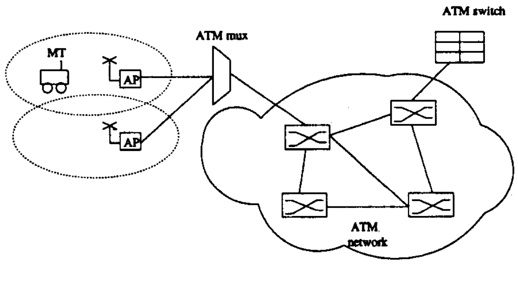

Fig. 1. A Wireless ATM Network Architecture

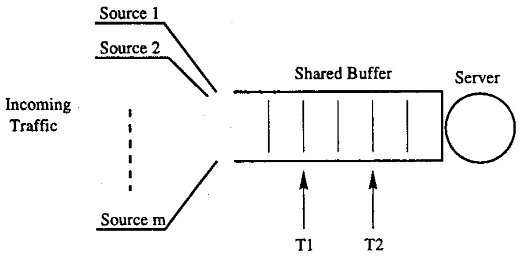

Fig. 2. Threshold-based discard scheme operation

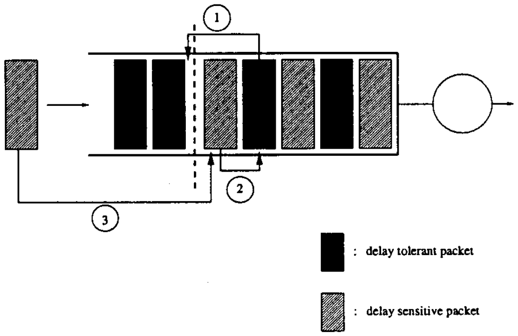

Fig. 3. Selective-delay push-in scheme operation

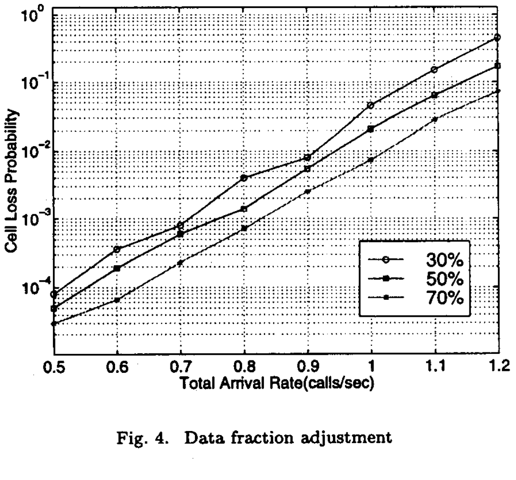

Fig. 4. Data fraction adjustment

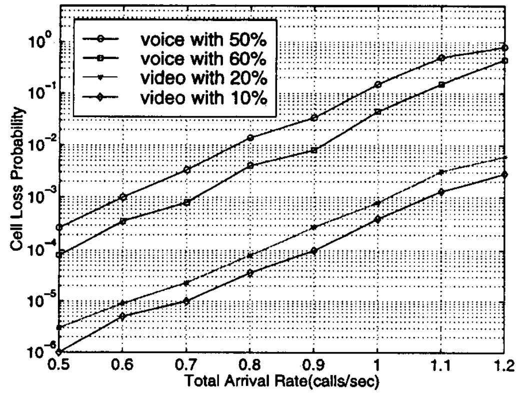

Fig. 5. Voice and video fraction adjustment

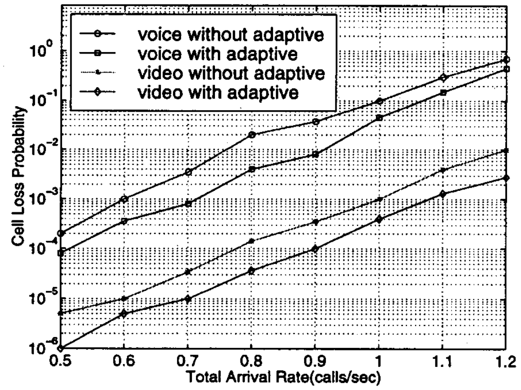

Fig. 6. Cell loss probability vs. total arrival rate

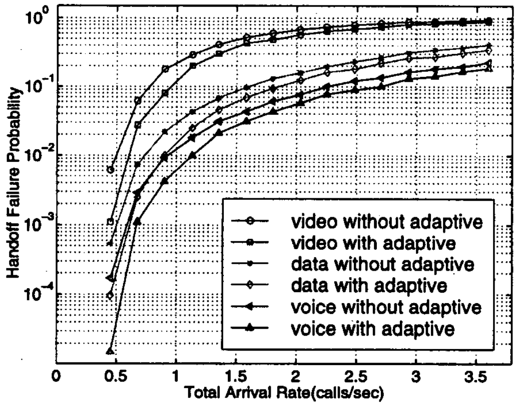

Fig. 7. Handoff failure probability vs. total arrival rate

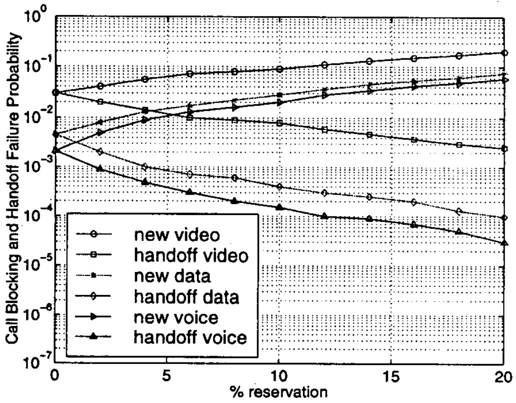

Fig. 8. New blocking and handoff failure probability vs. % reservation with SDPI scheme

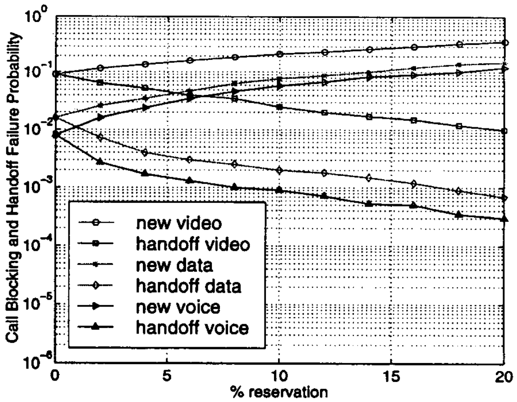

Fig. 9. New blocking and handoff failure probability vs. % reservation without SDPI scheme