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Design and Management of Wireless ATM Networks

by

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A thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfillment of the requirements
for the degree of
Master of Engineering

Ottawa-Carleton Institute of Electrical Engineering
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March 10, 1998

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The undersigned recommendation to the Faculty of Graduate Studies and Research
acceptance of the thesis

“Design and Management of Wireless ATM Networks”

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in partial fulfillment of the requirements
for the degree of Master of Engineering.

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Abstract

Broadband, multimedia and economical implementation are the main characteristics for variety of future telecommunication services such as telephony, data, and multimedia applications. Broadband Integrated Services Digital Network (B-ISDN) provides what we need. Asynchronous Transfer Mode (ATM), as a leading technology, is used to implement B-ISDN.

A lot of research and development has been done recently on the design and use of ATM for wireline networks with fiber-optic links, but integration of ATM technology with wireless networks is still new. A wireless ATM system capable of supporting integrated voice, video and data services with Quality of services is designed in this thesis. The system architecture is described and a wireless ATM specific protocol stack is proposed. The proposed wireless ATM system provides broadband link and has very low deployment cost, which make it an ideal candidate technology for both small business and residential users.

The main results of the study are the descriptions of the design and management aspects of wireless ATM networks. The OPNET simulation tool is used to investigate the system performance behaviors under different traffic conditions. Mobility management and signaling are left for further study.

Acknowledgments

I am deeply indebted to Dr. Michael Devetsikiotis, who introduced me to this new field and supervised my dissertation. I have had pleasure of working on a variety of research projects on wireless ATM systems in collaboration with colleagues at Newbridge Network Corporation. The assistance of these colleagues is greatly appreciated. Finally, I wish to thank Weiya Ren, my wife for her patient and encouragement.

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Glossary

AAL	<i>ATM Adaptation Layer</i> Layer for converting upper layer data to ATM cells
ABR	<i>Available Bit Rate</i> ATM traffic class
AIU	<i>Air Interface Unit</i> Base station equipment name used in DAVIC
ATM	<i>Asynchronous Transfer Mode</i>
BER	<i>Bit Error Rate</i>
B-ISDN	<i>Broadband Integrated Services Digital Network</i>
BT	<i>Burst Tolerance</i> ATM traffic parameter
CAC	<i>Connection Admission Control</i>
CBR	<i>Constant Bit Rate</i> ATM traffic class
CDMA	<i>Code Division Multiple Access</i> Access control method
CDPD	<i>Cellular Digital Packet Data</i> European Wireless Data Network
CDV	<i>Cell Delay Variation</i> ATM QoS parameter
CDVT	<i>Cell Delay Variation Tolerance</i> ATM traffic parameter
CEC	<i>Commission of European Communities</i>
CL	<i>Connectionless</i>
CLP	<i>Cell Loss Priority</i> Field in the header of an ATM cell
CLR	<i>Cell Loss Ratio</i>

	ATM QoS parameter
CO	<i>Connection Oriented</i>
CPE	<i>Customer Premises Equipment</i> Network owned and operated by the user
CRA	<i>Collision Resolution Algorithm</i>
CRC	<i>Cyclic Redundancy Check</i> Error control method
CS	<i>Convergence sublayer</i> Sublayer of AAL
CTD	<i>Cell Transfer Delay</i> ATM QoS parameter
DECT	<i>Digital European Cordless Telecommunications</i> 2nd generation cordless phone system
ETS	<i>European Telecommunications Standards</i>
ETSI	<i>European Telecommunications Standards Institute</i> European standardization body
FCFS	<i>First Come First Service</i>
FEC	<i>Forward Error Correction</i>
GCRA	<i>Generic Cell Rate Algorithm</i> Algorithm used for traffic policing in ATM
GFC	<i>Generic Flow Control</i> Field in the header of an ATM cell
GSM	<i>Global System for Mobile Communications</i> 2nd generation mobile phone system
HBS	<i>Home Base Station</i> Base Station that serves the terminal
HEC	<i>Header Error Control</i> Field in the header of an ATM cell

HFC	<i>Hybrid Fiber Coax</i>
HIPERLAN	<i>High Performance Radio Local Area Network</i> Broadband wireless LAN
LAN	<i>Local Area Network</i>
LMCS	<i>Local Multipoint Communication System</i> Canadian broadband wireless network
LMDS	<i>Local Multipoint Distribution System</i> US broadband wireless network
MAC	<i>Medium Access Control</i> Layer corresponding to the lower part of the OSI 2 layer
MAN	<i>Metropolitan Area Network</i>
MCR	<i>Minimum Cell Rate</i> Parameter used in ABR traffic class
MID	<i>Multiplexing Identification</i> Field in an ATM cell carrying data of AAL3/4
MPEG	<i>Motion Picture Experts Group</i> Standards for compressing video
NIU	<i>Network Interface Unit</i> Subscriber equipment name used in DAVIC
NNI	<i>Network-Node Interface</i>
nrt-VBR	<i>Variable Bit Rate - Non Realtime</i> ATM traffic class
OAM	<i>Operation and Maintenance</i>
OSI	<i>Open Systems Interconnection</i> Layered reference model for communication systems
PCR	<i>Peak Cell Rate</i> Highest transmission rate of the terminal
PDU	<i>Protocol Data Unit</i>

PT	<i>Payload Type</i> A field in the header of an ATM cell
PTI	<i>Payload Type Identifier</i> Content of the PT field
PVC	<i>Permanent Virtual Connection</i> VC that is established using network management
QAM	<i>Quadrature Amplitude Modulation</i>
QoS	<i>Quality of Service</i>
QPSK	<i>Quadrature Phase Shift Keying</i>
RM	<i>Resource Management</i> ATM cell used for traffic management in ABR
RS	<i>Reed Solomon</i> A Forward Error Correction Code
rt-VBR	<i>Variable Bit Rate</i> RealtimeATM traffic class
SAR	<i>Segmentation and Reassembly</i> Sublayer of AAL
SCR	<i>Sustainable Cell Rate</i> ATM traffic parameter
SONET	<i>Synchronous Optical NETwork</i> Physical layer transmission standard
SVC	<i>Switched Virtual Connection</i> VC that can be established using call control signaling
TDM	<i>Time Division Multiplexing</i>
TDMA	<i>Time Division Multiple Access</i>
UBR	<i>Unspecified Bit Rate</i> ATM traffic class
UMTS	<i>Universal Mobile Telecommunications System</i> 3rd generation mobile system

UNI	<i>User-Network Interface</i>
UPC	<i>Usage Parameter Control</i> ATM function policing the traffic
VBR	<i>Variable Bit Rate</i> ATM traffic class
VC	<i>Virtual Connection</i> Connections in ATM are called VCs
VCC	<i>Virtual Channel Connection</i>
VCI	<i>Virtual Channel Identifier</i> Field in the header of ATM cell, used for routing
VP	<i>Virtual Path</i> Group of virtual connections
VPI	<i>Virtual Path Identifier</i> Field in the header of ATM cell, used for routing
WAN	<i>Wide Area Network</i>
WLAN	<i>Wireless LAN</i>

Chapter 1

Introduction

Asynchronous Transfer Mode (ATM) is the key technology in implementing Broadband Integrated Services Digital Network (B-ISDN) [1][4]. The main advantage of ATM is that it can combine various types of traffic into wireline networks, and scale well into different network types such as LAN, MAN and WAN.

The progress towards ATM transport in wireline networks has already started and the market demanding is strong. It can be expected that new applications exploiting all capabilities of the ATM transport technology will appear. Users will get used to this new service level and require to extend the same applications over wireless links. This implies that the wireless access interface has to be developed in order to support various ATM traffic class Quality of Service (QoS) parameters to a reasonable degree.

Users' tendency to seek for tetherless access to successful wireline network can also be seen historically. A short look back shows that all the current popular wireline networks have their own wireless extensions [2], as illustrated in Table 1-1. ISDN got its wireless access from DECT. Internet may be accessed with several techniques (e.g. with CDPD). HIPERLAN and wireless LAN (WLAN) will most likely turn out to be wireless access to Local Area Networks.

The main reasons for wireless ATM development can be seen as follows:

- users will require wireless access to ATM/B-ISDN networks

- multimedia applications need wireless platforms with multimedia support
- Universal Mobile Telecommunications System (UMTS) and WLANs cannot support all data that users need in the future

Wireless data access	Achieved data rates	Backbone network
DECT	< 1 Mbps (per user)	ISDN
GSM data (GPRS , HSCSD), CDPD	< 144 kbps (per user)	Internet
ISM band WLANs	300 kbps-2 Mbps (shared)	LAN
HIPERLAN	< 20 Mbps(shared)	LAN

GPRS = General Packet Radio System

HSCSD = High Speed Circuit Switched Data

Table 1-1: Network and Wireless Access Techniques

The benefits of wireless ATM access technology should be observed by users as improved services and improved accessibility. By preserving the essential characteristics of ATM transmission, wireless ATM offers the promise of improved performance and quality of service, not achievable by other wireless communications. Furthermore, wireless ATM access provides location independence, which removes a major limiting factor in the use of computers and powerful telecommunication equipment over wireline networks. The aim of this thesis is to investigate the design and management aspects of wireless ATM systems.

1.1 Objective

This thesis explores wireless ATM systems being developed in North America.

The objective of this thesis is to:

- Review the demand for wireless ATM systems
- Review wireless ATM system requirements
- Discuss key design issues in wireless ATM system design
- Propose a wireless ATM system based on the key design issues
- Give wireless ATM protocol stack
- Suggest wireless ATM traffic control schemes
- Investigate the proposed system by simulations

The aim of this thesis is also to explore the problems of implementing wireless ATM systems and suggest solutions in the future development of such systems.

1.2 Overview

This thesis is organized as follows:

Chapter 2 reviews the characteristics of the ATM technology and terminology used in the thesis.

Chapter 3 gives the definition of wireless ATM and key issues to wireless ATM. Issues discussed include: architecture, physical layer, medium access control layer, data link layer, and connection establishment.

Chapter 4 extends ATM traffic management schemes to wireless ATM network. Wireless specific requirements are addressed.

Chapter 5 proposes a wireless ATM system capable of handling multimedia services with quality of service control.

Chapter 6 demonstrates how the design parameters affect wireless ATM network behavior using OPNET simulation tool.

Chapter 7 gives the conclusions and contributions, as well as suggestions for future research on the topic.

Chapter 2

ATM - Asynchronous Transfer Mode

Two major trends can be seen in today's telecommunication field: the evolution towards wireline broadband networks and the breakthrough of wireless communications. The merging of these two technologies is necessary in order for the two systems to fit and co-exist with each other and avoid serious mismatch between wireline and wireless networks in the future [3].

This chapter explains what ATM is and why B-ISDN will be needed to meet future telecommunication requirements.

2.1 B-ISDN and ATM

As our society becomes more and more information intensive, the number of users and the number of services in today's telecommunication field are expected to grow dramatically. The new services both require higher bit rates and need to provide multimedia services. None of today's telephone, telex, or packet networks can provide these new services because of the following reasons [4]:

1. Traditional telecommunication networks are specialized. Many telecommunication services have their own networks, and those networks are typically not suitable for supporting services other than those initially intended to be supported. Therefore, they can not provide multimedia services required

by future telecommunication services such as motion pictures combined with high-fidelity sound.

2. Existing telecommunication services such as telephone and telex can provide transmission rates of less than a megabit per second. New telecommunication services, however, require transmission rates of more than 100 Mbps. None of today's telephone, telex, or packet networks can provide this transmission rate.

Table 2-1 illustrates the typical application bandwidth requirement.

3. It would also be ineffective to build a new network for every new service. A new technology that can integrate various kind of services is needed.

Application	Service Type	Quality of Service (QoS)	Bit-Rate Range
Voice telephony	Connection Oriented (CO)/Constant Bit Rate (CBR)	Call blocking permitted Low-med cell loss OK Isochronous	2.4 -32 kbps
Digital audio	CO/CBR	Call blocking permitted Low cell loss required Low delay jitters	128 - 512 kbps
Teleconference & Digital video	CO/CBR or Variable Bit Rate (VBR)	Call blocking permitted Low-med cell loss required Low delay jitters	64 kbps - 384 kbps 1 - 6 Mbps
HDTV	CO/CBR	Call blocking permitted Low-med cell loss OK Low delay jitters	15 - 20 Mbps
General computer data	Connectionless (CL) Best Effort	No call blocking Low cell loss required Med delay & jitters OK	0.1 - 1 Mbps
E-mail	CL Best Effort	No call blocking Low cell loss OK High delay OK	9.6 - 128 kbps
High speed data	CL Burst Mode	Very low cell loss required Med delay & jitters OK	1 - 10 Mbps

Table 2-1: Typical Application Requirement [3]

Broadband Integrated Services Digital Network (B-ISDN) is developed to integrate all telecommunication services into one network. The Asynchronous Transfer Mode (ATM) technology is thought to be the key component in turning the B-ISDN into reality.

2.2 Features of ATM

ATM has been proposed as a target technology in overcoming the difficulties in existing transfer modes and allowing the creation of B-ISDN. ATM has the following features [4]:

1. Information is sent in short fixed-length blocks called cells. The cell consists of 48 bytes of payload and 5 bytes of header. The flexibility needed to support variable transmission rates is provided by transmitting the necessary number of cells per unit time.
2. ATM network is connection-oriented. It sets up a virtual channel connection (VCC) between the two ends before transmitting information. The VCC goes through one or more virtual paths (VP) and virtual channels (VC). Cells are switched according to the VP and VC identifier (VPI/VCI) value in the cell header, which is originally set at the connection setup and is translated into new VPI/VCI value while the cell passes each switch.
3. Information transfer in ATM networks is based on a low layer protocol free of complex flow control on a link basis. Flow control and error recovery are

performed on an end-to-end basis. Only header error control is performed within the core part of the network.

4. ATM resources such as bandwidth and buffers are shared among users. They are allocated to users only when they have traffic to transmit. Therefore network uses statistical multiplexing to improve the effective throughput.

2.3 ATM Networks

ATM networks consist of two kinds of interfaces: the Network-Node Interface (NNI) and User-Network Interface (UNI). ATM switches are connected to each other using the Network-Node Interface. Terminals are connected to the network using User-Network interface.

An ATM connection is called a virtual connection (VC). There are two main types of virtual connections; Permanent Virtual Connections (PVC) and Switched Virtual Connections (SVC).

- **Permanent Virtual Connections (PVC):** A PVC is a connection set up by some external mechanism, typically network management, in which a set of switches between source and destination ATM systems are programmed with the appropriate VPI/VCI values. PVCs always require some manual configuration.
- **Switched Virtual Connections (SVC):** A SVC is a connection that is set up automatically through the signaling protocol. SVCs do not require the manual interaction needed to set up PVCs and are likely to be much more widely used.

Signaling protocols are needed for establishing and managing connections across the network. When a terminal wants to establish a new connection (i.e., virtual circuit) with another terminal, it uses the UNI signaling to request the network to set up the connection. The calling terminal will use a set of traffic and Quality of Service (QoS) parameters to describe the traffic it has and the quality of the connection it requires from the network. When a switch receives a request to set up a connection, it will execute a Connection Admission Control (CAC) function to define whether it can accept the connection or not. If the connection is accepted, it forwards the request towards the called terminal. If the connection cannot be supported according to the parameters requested by the calling terminal, the switch will reject the connection setup request. If the establishment of a connection is rejected by a switch, a previous switch can try to reroute the connection via some other switches. When the setup request reaches the switch of the called terminal, the request is signaled to the called terminal using UNI signaling.

When a virtual connection is setup with specified descriptors, these descriptors make up a traffic contract between the user and the network. The network will guarantee the type and quality of traffic contract.

2.4 ATM Protocol Stack

Figure 2-1 shows that the protocol reference model consists of a user plane (U-plane), a control plane (C-plane), and a management plane (M-plane). The U-plane provides user information transfer, and the C-plane performs connection control functions

with signaling. The M-plane activities include the establishment of user VPs and Operation and Maintenance (OAM) related functions. This protocol stack is extended to wireless domain in Chapter 5.

Figure 2-1: The ATM Protocol Reference Model

2.4.1 ATM Layer

In C-plane and U-plane, ATM layer is above the physical layer. The ATM layer carries user cells and signaling information between a user and a switching node or between switching nodes.

The flexibility of ATM network is mainly achieved through the use of small data packets called ATM cells. These cells are routed through the network on the ATM layer. The ATM cell is 53 bytes and contains a 5 byte header. The header is modified by every switch on the virtual connection, but the payload remains the same across the network. The structure of the ATM cell is shown in Figure 2-2 .

Figure 2-2: ATM Cell at the User-Network Interface

The structure of ATM cells is similar in different nodes of the network with only one exception. The only difference is the use of the first four bits of the first byte. In UNI the bits are used for the GFC field, while in NNI they are used to extend the numbering space of the VPI. The use of the GFC is not specified yet. These four bits could be used by wireless specific features, which makes the GFC most interesting. For example, GFC set to 1111 signals the start of a frame in Chapter 6. VPI can be 8 or 12 bits depending on the interface, while the VCI is always 16 bits.

2.4.2 ATM Adaptation Layer

ATM Adaptation Layer (AAL) adapts different services to ATM network. AAL receives the upper layer Packet Data Unit (PDU) and fits it into one or more ATM cells. It also provides timing and error control services. AAL is divided into two sublayers: segmentation and reassembly (SAR) sublayer and convergence sublayer (CS).

AAL provides four service classes, class A through class D, depending on the need for timing, bit rate characteristics and whether the service is connection-oriented or connectionless. Four different AAL protocols are provided for these four service classes, as shown in Figure 2-3 [24].

	service type			
	AAL1	AAL2	AAL3/4	AAL5
timing relation	yes		no	
bit rate	constant	variable		
mode	CO		CL	

Figure 2-3: Description of AAL Service Classes

AAL1 is intended for transmission of constant bit rate (CBR) traffic. In order to support the CBR services and circuit emulation, functions of source clock recovery and control of cell delay variation are included. The cell delay variation needs to be taken into account to avoid interruptions in the bit stream because of a delayed cell. The AAL1 PDU fits in one ATM cell and carries 47 bytes of data. One byte of the payload is used for header in every cell.

AAL2 is not standardized yet, but it is expected to be used mainly for variable bit rate (VBR) communications.

ATM adaptation layer three and four have been merged into AAL3/4. AAL3/4 performs error control on two levels: AAL-PDU and ATM cell. Error control is added both before and after the user data in the PDU. Furthermore, a cyclic redundancy code (CRC) field is added to every cell together with a multiplexing identification (MID) field which can be used to multiplex many connections into a single VC.

AAL5 is best suited for data communications. A trailer containing a CRC is inserted in the last cell of each PDU. For the time being AAL1 and AAL5 are the most common AALs used.

2.5 Statistical Multiplexing

In ATM networks, a user generates a number of cells necessary to transfer the amount of information he/she wants to. The amount of network resources required by each user thus constantly changes in proportion to the number of cells generated per unit time. When resources are shared among users, the amounts required by individual users do not take their peak values simultaneously. Hence, the network can reduce the total amount of network resources required for a fixed offered load - or it can accommodate more load with the same amount of resources. This phenomenon, called statistical multiplexing gain, is one of the main features of ATM networks. The main characteristics of ATM statistical multiplexing are the following [4]:

1. Peak cell rates have a large impact on statistical multiplexing gain, and this impact becomes larger as the ratio of the VC bandwidth to the VP bandwidth increases.
2. Burst length affects statistical multiplexing when the burst is shorter than buffer size.
3. When the number of multiplexable VC connections in a VP is large or the peak cell rate of a VC is low, the average cell rate is an important parameter.
4. For a fixed VP bandwidth, the statistical multiplexing gain becomes large larger when homogeneous VCs are multiplexed.

The assumption of statistical multiplexing is that users do not use the network at their peak rate at the same time. This assumption introduces a problem. When users do use the network at their peak rate simultaneously, congestion occurs. Congestion prevention and control are introduced in Chapter 4.

2.6 Traffic over ATM Networks

ATM is designed to support all kinds of telecommunication services and therefore it should also be able to carry all types of data. This section will present different kinds of traffic and the way they are carried over ATM. A set of traffic classes is defined to support the transmission of different kind of traffic [5].

- **Constant Bit Rate (CBR)**

This class is used for emulating circuit switching. The cell rate is constant. Cell loss ratio is specified for CLP=0 cells and may or may not be specified for CLP=1 cells. Examples of applications that can use CBR are telephone, video conferencing, and television.

- **Variable Bit Rate (VBR)**

This class allows users to send traffic at a variable rate. Statistical multiplexing is used and so there may be a small non zero random loss. Depending upon whether or not the application is sensitive to call delay variation, this class is subdivided into two categories: real-time VBR and non-real time VBR. While cell transfer delay is specified for both categories, cell delay variation (CDV) is specified only for real-time VBR. An example of real time VBR is interactive compressed video while example of nonreal time VBR is multimedia email.

- **Available Bit Rate (ABR)**

This class is designed for normal data traffic such as file transfer and email. Although the standard does not require the cell transfer delay and cell lose ratio to be guaranteed or minimized, it is desirable for switches to minimize the delay and loss as much as possible. Depending upon the congestion state of the network, the source is required to control its rate. The users are allowed to declare a minimum cell rate (MCR), which is guaranteed to the VC by the network. Most VCs will ask for an MCR of zero. Those with higher MCR may be denied connection if sufficient bandwidth is not available.

- **Unspecified Bit Rate (UBR):**

This class is designed for those data applications that want to use any left-over capacity and are not sensitive to cell loss or delay. Such connections are not rejected on the basis of bandwidth shortage (no connection admission control) and not policed for their usage behavior. In case of congestion, cells are lost but the sources are not expected to reduce their cell rate. Instead, these applications may have their own higher-level cell loss recovery and retransmission mechanisms. Examples of applications that can use this service are email, file transfer, news feed, etc. Of course, these applications can also use the ABR service, if desired.

2.7 Quality of Service Attributes

While setting up a connection on ATM networks, users can specify the following parameters related to the desired quality of service [6].

- **Peak Cell Rate (PCR)**

The maximum instantaneous rate at which the user will transmit. For bursty traffic, the inter-cell interval and the cell rate varies considerably. PCR is the inverse of the minimum inter-cell interval.

- **Sustained Cell Rate (SCR)**

This is the average rate as measured over a long interval.

- **Cell Loss Ratio (CLR)**

The percentage of cells that are lost in the network due to ~~error~~ errors and congestion and are not delivered to the destination.

$$\text{Cell Loss Ratio} = \frac{\text{Lost Cells}}{\text{Transmitted Cells}}$$

Each ATM cell has a "Cell Loss Priority (CLP)" bit in the header as illustrated in Figure 2-2. During congestion, the network first drops cells that have CLP bit set. Since the loss of CLP=0 cell is more harmful to the operation of the application, CLR can be specified separately for cells with CLP = 1 and for those with CLP = 0.

- **Cell Transfer Delay (CTD)**

The delay experienced by a cell between network entry and exit points is called the cell transfer delay. It includes propagation delays, queuing delays at various intermediate switches, and service times at queuing points.

- **Cell Delay Variation (CDV)**

This is a measure of variance of CTD. High variation implies larger buffering for delay sensitive traffic such as voice and video.

- **Burst Tolerance (BT)**

This determines the maximum burst size that can be sent at the peak rate. This is the bucket size parameter for the leaky bucket algorithm that is used to control the traffic entering the network. The algorithm consists of putting all arriving cells in a

buffer (bucket) which is drained at the sustained cell rate (SCR). The maximum number of back-to-back cells that can be sent at the peak cell rate is called Maximum burst size (MBS), BT and MBS are related as follows:

$$\text{Burst Tolerance} = (\text{MBS}-1) (1/\text{SCR}-1/\text{PCR})$$

- **Minimum Cell Rate (MCR)**

This is the minimum rate desired by a user.

Only the first six of the above parameters were specified in UNI version 3.0. MCR has been added recently and will appear in the next version of the traffic management document.

The QoS and usage parameters for ATM traffics are summarized in Table 2-1 [6]:

Parameters	CBR	rt-VBR	nrt-VBR	UBR	ABR
PCR and CDV	*	*	*	*	*
SCR, MBS, CDVT	N/A	*	*	N/A	N/A
MCR	N/A	N/A	N/A	N/A	*
Peak-to-Peak CDV	*	*			
Mean CTD			*		
Max CTD	*	*			
CLR	*	*	*		*

Notes: * specified

Table 2-2: ATM Service Categories

ATM technology was presented in this chapter. Its features will be used as the basis in the following chapters to discuss the design and management issues in wireless ATM network.

Chapter 3

Concept of Wireless ATM Network

Wireless plays an important role in the communication field. It is recognized that wireless systems will be required to support a wider range of telecommunication applications involving packet data, video, and multimedia in the future [4]. Since B-ISDN offers to integrate all communications into one universal system, it is natural to consider introducing wireless aspect into the B-ISDN - an integrated wireless ATM network.

3.1 Demand for Wireless Access to ATM

The main reasons for the need of wireless ATM can be generalized as follows [7]:

- Integration is superior to internetworking

While internetworking could be used to connect wireless systems into wireline systems, integration is more effective solution. Internetworking introduces overhead and leads to less transparent access to the fixed network.

- There is application need for wireless platform with multimedia support

Multimedia requires transmission of many different types of information simultaneously, placing strict and often contradictory requirements to the network.

The QoS of ATM can support these requirements.

- Traditional systems can not meet the demand

Mobile phone systems can not support the bandwidth, and wireless LAN services are too unreliable and not ATM compatible.

3.2 Wireless ATM Services

There will be two main categories of services in wireless ATM systems. First, wireless access is used as a replacement for wireline access to ATM. It is expected to happen in places where wiring is difficult or expensive to install or the terminals are movable but not actually mobile. Secondly, the wireless ATM system is used to offer narrowband applications. These applications could be supported by other mobile systems or narrowband wireless LANs, but are cost efficient if supported in the wireless ATM model type system already installed in the premises.

3.2.1 Wireline ATM Replacement Applications

In this category, the applications are typical B-ISDN applications without any specific mobility features. The main benefit derived from wireless ATM in this category is that no wiring is needed. Thus the wireless ATM networks in this category must provide near wireline network QoS to a stationary user. The user should not be able to notice the difference between using wireless and wireline ATM systems with the same access bandwidth.

It would be possible to use directive antennas in this situation in order to achieve lower cell lost rate without the use of retransmission technology. The quality of the

handover function does not need to be considered because the terminals are expected to be stationary. This category of applications is the main driven force for wireless ATM networks currently.

3.2.2 Narrowband Applications

Most of narrowband applications are dedicated mobile applications capable of operating at a lower QoS as they would use mobile specific features. Typical applications include client server, e-mail, paging, messaging, groupware, games, etc. Since mobility is expected, they are more tolerant for the temporary QoS degradation. The applications are expected to produce up to 1 Mbps asymmetric bursty non-real-time traffic.

The integration of mobile systems with B-ISDN would mean the introduction of mobile specific features into the B-ISDN standards. Many issues have to be solved and standardized before commercial wireless ATM systems can be introduced. One of the most important technical issue is the introduction of mobile ATM terminals. Location management has to be introduced [20][21]. Signaling needs to be modified to enable mobile connection control [19]. On the radio link, error control needs to be used to ensure sufficient quality of service.

It is likely that the first wireless ATM network will be designed to meet the needs of specific user groups. It is easier to satisfy the needs of a known user than to support all possible features. The wireless ATM system presented in this thesis describes an ATM wide area network supporting stationary wireless terminals only. Terminals within the network are movable, but no mobility is assumed.

3.3 Key Issues to Wireless ATM

Various of researches have been conducted in leading universities and industry institutions around world [20][3][8]. The following key issues are recognized with the development of wireless ATM networks.

3.3.1 Architecture

The architecture proposed by most researchers composed of a large number of small transmission cells. Each cell is served by a base station. All the base stations in the network are connected via wireline ATM networks as illustrated in Figure 3-1 [22]. The use of ATM switching for intercell traffic avoids the crucial problem of developing a new backbone network with sufficient throughput to support intercommunication among large number of small cells [3].

In wireline ATM replacement applications, since all terminals are stationary, some of the limitations faced by narrowband applications are removed. The most noticeable one is handoff. This makes small cell structure more appropriate for wireline ATM replacement applications.

Figure 3-1: Wireless ATM Network Architecture

3.3.2 Physical Layer

The basic design issue for next generation wireless networks is the selection of modulation methods and a set of bit rates. A bit rate in the range of 5 -10 Mb/s can be achieved using the existing wireless technologies in a picocellular environment. Therefore, with the exception of HDTV, most other ATM applications in Table 1-1 can be supported. The preferred technique may actually vary with specific application scenarios, so that it is likely that both TDMA and CDMA solutions will co-exist [3].

CDMA provides an efficient integrated solution for frequency reuse and multiple access, and can typically achieve a net bandwidth efficiency 2 -4 times that of TDMA [9]. However, a major weakness of CDMA is that for a given system bandwidth, spectrum

spreading limits the peak user data rate to a relatively low value.

TDMA can be used to achieve high bit rates. In a pico-cellular environment, we can achieve a bit rate in the range of 8 -50 Mb/s [23]. These rates should be sufficient enough to accommodate most of the broadband services.

3.3.3 Medium Access Control Layer

One of the major problem for wireless ATM is to find a suitable channel sharing/medium access control technique at the data-link layer. Shared media access leads to poor quantitative performance in wireless networks.

When spread spectrum modulation is used, CDMA is the de-facto mode of operation. Performance results from earlier studies show that packet CDMA can achieve good traffic multiplexing efficiency and performance for CBR, VBR and low-speed interactive data services [3], but CDMA traffic capacity is limited to less than or equal to 1 Mb/s at higher speed.

Narrow band modulation (TDMA) can also be used, and researchers also suggested slotted ALOHA with exponential back-off as the protocol used for MAC. Slotted ALOHA has considerably better delay performance at low utilization than a fixed allocation scheme and fits well with the statistical multiplexing of ATM [8]. The simulations in Chapter 6 uses this protocol.

The other two candidate MAC protocols that worth mentioning are DAVIC [10] and 802.14 [11]. They are summarized below:

The DAVIC specified by Digital Audio Visual Council is a standard aimed to promote the success of digital audio visual applications and services to maximize interoperability across countries and applications/services.

DAVIC describes the bi-directional information flow between Air Interface Unit (AIU) at the head-end access node and Network Interface Unit (NIU) at the subscriber premises. There are two packet modes specified in DAVIC -- MPEG2-TS and ATM. In case of ATM transportation, both the upstream and the downstream frames are divided into time slots that encapsulate one ATM cell.

The downstream scheme in DAVIC is Time Division Multiplex (TDM) and the time slot types are divided into frame start slots and random access slots. The upstream scheme is Time Division Multiple Access (TDMA). Time slot types are divided into polling response time slots, contention time slots, and reservation time slots. When an NIU has information packets to transmit, it contends for reservation time slots by sending a request in contention time slots. Simultaneous accesses of contention slots result in collisions. The Collision Resolution Algorithm (CRA) is not specified in DAVIC. The DAVIC downstream and upstream frame structures are shown in Figure 3-2.

Figure 3-2: DAVIC Frame Structures

Another MAC protocol candidate is 802.14. 802.14 describes the behavior of subscriber stations and the Head Controllers (HC). There are also two types of packet modes specified in 802.14 -- ATM and variable length PDU. The downstream channel is structured as a stream of 6 octet allocation units. Multiple allocation units can be used to carry an ATM cell or a variable length PDU. The upstream channel is a multiple access medium. The upstream channel is divided into minislots of 8 octets each. Multiple minislots are concatenated on an upstream to carry ATM cells and variable length PDU.

There are also two types of minislots in upstream - reservation minislots and contention minislots. Contention slots are used for initial information transfer request. Further bandwidth request are done by piggyback. Ternary tree contention resolution

algorithm is specified in 802.14 as CRA. Synchronization is down by HC broadcasting time-stamped frames at regular interval.

3.3.4 Data Link Layer

Wireless ATM needs a custom data link layer protocol, and it should be as transparent as possible. A custom data link protocol is needed due to high error rate. The data link protocol may contain service type definition, error control, segmentation and reassembly, and handoff support [3].

A service type field is needed so as to indicate whether a packet is of type supervisory control, CBR, VBR ABR etc. The service type field simplifies base station protocol processing. Wireless ATM should provide error control due to high noise interference and poor physical level characteristics of the wireless medium [15].

Applications in wireless ATM service categories tend to require broadband, highly reliable non-real-time data transfer services or narrowband time critical services. The bandwidth and bit error rate of the radio link are hard to predict. To achieve low CLR, both the FEC and retransmission technology is likely to be used [15]. Retransmission introduces delay, therefore a trade-off has to be made between the CLR and delay parameters. It is assumed that a reasonable QoS could be offered for these traffic classes while the terminal is not moving, but the user is likely to notice the execution of a handover.

3.3.5 Connection Establishment

This section describes connection establishment for fixed wireless terminals. In order to establish connections between a terminal and a base station, the terminal must be located first. This can be done by searching and registration [8]. Searching is a function by which base stations broadcast query information to the entire network to assist the terminal registration. Registration is a process that terminals make it known to the network at a well known base station. Subsequent queries about the terminal are directed to this Home Base Station (HBS) using static routing mechanism.

During connection, a terminal generates a connection signal, specifying the network address of the two end-points. When the request arrives at the HBS, the destination HBS is located by using standard ATM signaling. The destination HBS then consults the destination terminal, which in turn decides whether to accept the connection or not. If the destination terminal accepts the call, it signals to its HBS. A virtual circuit is then created between the two end-points and the connection is established.

In this chapter, the concept and requirement of wireless ATM systems was introduced. Some design issues were raised. In next chapter, wireless ATM traffic management techniques are to be introduced.

Chapter 4

Wireless ATM Traffic Management

Integration of wireless connections with a backbone broadband network is an essential and challenging task since wireless users may need to access the communication services offered by wireline broadband networks. This implies that wireless networks must provide cell based transport, bandwidth on demand as well as support multimedia applications.

As described in Chapter 2, ATM networks use statistical multiplexing to achieve network efficiency. The assumption of statistical multiplexing is that users do not use the network at their peak rate at the same time. Therefore, if users do use the network at their peak rate simultaneously, congestion occurs. In this chapter, congestion prevention and control schemes are introduced. A wireless ATM network traffic control mechanism is suggested.

4.1 ATM Generic Functions

It is observed that events responsible for congestion in broadband networks have time constants that differ by orders of magnitude due to the burstiness of the data traffic, the unpredictability of the resource demand and the large propagation delay versus the large bandwidth. Therefore, multiple controls with appropriate time constants are necessary to manage network congestion.

To meet the objectives of traffic control in ATM networks, the following functions and procedures are suggested by the ATM Forum Technical Committee [6].

- **Connection Admission Control**

Connection Admission Control (CAC) is defined as ~~the a~~ a set of actions taken by the network during the call set up phase in order to determine whether a connection request can be accepted or should be rejected.

Based on the CAC algorithm, a connection request is progressed only when sufficient resources such as bandwidth and buffer space are available along the path of a connection. The decision is made based on the service category, QoS desired, the number and conditions of existing connections. Routing and resource allocation are part of CAC when a call is accepted.

- **Usage Parameter Control**

Usage Parameter Control (UPC) is defined as the set of actions taken by the network to monitor and control traffic at the end-system access. Its main purpose is to protect network resources from user misbehavior, which can affect the QoS of other connections, by detecting violations of negotiated parameters and taking appropriate actions.

- **Generalized Cell Rate Algorithm (GCRA)**

This is the so called "leaky bucket" algorithm, which converts a bursty stream into a more regular pattern. Basically, all arriving cells are put into a bucket, which is drained at the sustained cell rate. If too many cells arrive at once, the bucket may overflow. The overflowing cells are called non-conforming and may or may not be

admitted into the network. If admitted, the CLP bit of non-conforming cells may be set so that they will be first to be dropped in case of overload.

Note that for CBR traffic, the average and peak rates are same and so the GCRA is applied with a drain rate of PCR and CDVT as the burst parameter.

- **Priority Control**

The end-system may generate different priority traffic flows using CLP bit. The network may selectively discard cells with low priority if necessary such that, in case of congestion, to protect the network performance for cells with high priority as far as possible.

- **Traffic Shaping**

Traffic shaping is a mechanism that alters the traffic characteristics of a stream of cells on a connection to achieve better network efficiency while meeting the QoS objectives, or to ensure conformance at a subsequent interface.

Examples of traffic shaping are peak cell rate reduction, burst length limiting, reduction of CDV by suitably spacing cells in time, and queue service schemes.

- **Network Resource Management**

Network Resource Management (NRM) is responsible for the allocation of network resources in order to separate traffic flows according to different service characteristics, to maintain network performance and to optimize resource utilization. This function is mainly concerned with the management of virtual paths in order to meet QoS requirement.

- **Frame Discard**

If a congested network needs to discard cells, it may be better to drop all cells of one PDU than to randomly drop cells belonging to different frames. This is because one cell loss may cause the retransmission of the whole frame, which may cause more traffic when congestion already happened. Thus, frame discard may help avoid congestion collapse and can increase throughput. If done selectively, frame discard may also improve fairness.

- **Feedback Control**

Feedback control is defined as the set of actions taken by the network and by the end-systems to regulate the traffic submitted on ATM connections according to the state of network elements.

- **ABR Flow Control**

The ABR service category uses the link capacity that is left over and is applied to transmit critical data that is sensitive to cell loss. That makes traffic management for this class the most challenging by the fluctuation of the network load condition, the burstiness of the data traffic itself and the CLR requirement.

It is agreed that ABR flow control is suitable for wireless ATM [4]. There are two reasons. First, the concept of traffic management between the virtual sources and the virtual destinations in ABR flow control is apparently appropriate when applied to wireless ATM such that the wireless part can be managed separately. Secondly, the

instability of wireless link needs feedback mechanism to control the traffic flow. Feedback control is specified for ABR traffic by the ATM Forum.

4.2 Class Based Wireless ATM Connection Admission

As far as the wireless spectrum is concerned, overload conditions might occur if the communication needs of a number of wireless terminals populating a small area exceed the total capacity of their Home Base Station (HBS). Connection control functions are required to keep the probability of a congested radio state suitably low [12]. In addition, these wireless connection control functions need to be simple enough and must be based on the class of each wireless connection.

Three types of wireless sources are considered differentiated on the basis of the action initiated when a radio congestion state is encountered.

Type I sources: ABR/UBR traffic. This class of traffic relies on the network's best-effort delivery of messages and is delay tolerable. Packets of type I traffic are stored in terminals until wireless channel resources are available.

Type II sources: VBR traffic. The characteristics of this kind of traffic is its burstiness.

Type III sources: CBR traffic. This type of traffic does not vary with time.

Both class II and class III traffic must be blocked when a congestion state is encountered where no wireless channel resources are available.

Regarding wireless resources, the purpose of connection admission control is to limit the number of in-progress wireless connections such that, once a wireless

connection is established. the probability of its encountering a congested radio state is acceptably low so the required QoS can be guaranteed.

When a new connection seeks admission, the HBS will admit (or reject) the request based on both the class of the connection and the number of wireless connections of each class already admitted to the system. By taking into account bandwidth requirements, the connection admission decision can then be made such as to guarantee the quality-of-service metrics. It is important to note that once a connection is admitted, its QoS is guaranteed and the probability of encountering a radio congestion state is limited to a guaranteed predefined level for each class of wireless connection.

4.3 Scheduling

In this section, we discuss three different scheduling mechanisms which define how the wireless spectrum of any HBS is shared among connections within its domain.

The following upstream frame and cell structure are used throughout this thesis. Suppose an upstream frame consists of polling response time slots, contention time slots, and reservation time slots as specified by the DAVIC standard (see Figure 3-2). The boundary among these three kinds of time slots are configurable. A good example is when the network becomes heavily loaded, the number of contention time slots can be reduced. However, at certain time, the number of each type of time slots is fixed.

Let's assume the total number of reserved time slots at certain time equals to C , and C_1 , C_2 , C_3 are the number of time slots assigned to type I, II, III connections initially,

$C = C_1 + C_2 + C_3 = C$. The value of C_1 , C_2 , C_3 is updated at the beginning of each fixed admission period and remains unchanged during that period.

Three simple scheduling mechanisms are listed.

- **Complete Partitioning** - In this scheme, the total number of reserved time slots are partitioned into three distinct groups, and they are assigned exclusively to each type of connections. This scheme is illustrated in Figure 4-1a. The resources reserved for each type of connections are wasted when that type of traffic is underloaded.
- **Complete Sharing** - All reserved time slots are shared on the first-come first-service (FCFS) base whenever sufficient resources exist. Complete sharing is illustrated in Figure 4-1b.
- **Prioritized Type II, III traffic Connections** - In this scheme, type III connections can use up to $C_3 + C_1$ bandwidth and type II connections can use up to $C_2 + C_1$ bandwidth if there is still spare bandwidth available in C_1 that is not taken by type III connections as illustrated in Figure 4-1c. Capacity not used by type II and type III connections is available for type I connections. Type II and III connections have pre-emptive priority over type I connections, but type I connections can not preempt type II, III connections because preemption means service interruption for type II and III traffic which is not acceptable. This assumption is based on that Type III traffic has higher priority over Type II traffic. If both Type II and Type III traffics are given equal priority, then there should be served as first-come first service basis.

- a) complete partitioning
- b) complete sharing
- c) prioritized type II, III traffic

Figure 4-1: Resource Sharing Schemes

4.4 CDV Consideration

Since both CBR and VBR traffic have cell delay variation (CDV) requirement, this has to be considered during time slot assignment. The best solution for this is that

evenly spacing all the time slots assigned to a given connection in the upstream frame. The problem with this kind of assignment is that it may result in severe frame fragmentation. That is, some slots could never be used by CBR and VBR connections since they could not meet the CDV requirement set by these connections. Therefore, even these network resources are available, certain CBR and VBR connections still may not be accepted.

In actual time slot assignment, the following method may be considered. Suppose a frame time equals to S millisecond and the CDVT requirement of a connection equals to T millisecond. Let us assume that the total number of time slots in a frame equals to N . This makes each slot time in a frame equal to S/N millisecond. Therefore, the assigned time slots to the given connection can be NT/S slots away from their ideal positions. Of course, any two adjacent assigned time slots should also be at least NT/S away. Traffic shaping can be applied at the base station to further ensure the traffic conformance.

Any unused time slots by type II, III traffic according to the scheduling scheme described in 4.3 can be used by polling, contention and type I traffic, in that order. Note special attention should be paid to polling response time slots. This is explained in next section.

4.5 Guard Time Slots

Polling is used to assist terminals entering the network and request terminal status in this system. Guard time slots should follow polling response time slot during the terminal network entry period to avoid interference with adjacent slots before terminals

are time aligned [10]. The number of guard time slots needed to follow a polling response time slot depends on the upstream capacity and the base station cell radius. Again, suppose an upstream frame time equals to S millisecond and there are N time slots in each upstream frame as assumed in 4.4, let us further assume the base station cell radius equals to R km, and therefore the two way propagation delay from edge terminals to the base station is about $2R * 10^{-2}/3.8$ milliseconds given light speed of about $3.8 * 10^8$ m/s at free space. This is equivalent to $2NR * 10^{-2}/(3.8 * S)$ time slots and these slots can not be used by any other traffic. After the terminals are sufficiently time aligned, the number of guard time slots following the polling time slots can be reduced, but at least one guard time slot is needed. This is mainly to prevent the time drifting at the terminals.

Both ATM and wireless technology are still in their infancy. Researchers have started building experimental wireless ATM networks, and are implementing different protocols over it. In this chapter, wireless ATM connection control was discussed. An example wireless ATM system is proposed in next chapter, and its traffic characteristics are examined in Chapter 6.

Chapter 5

An Integrated Wireless ATM System

An integrated wireless ATM system is designed in this chapter. The system is to support integrated voice, video, and data services with quality of service (QoS) control as described in previous chapters. Both wireline and wireless users are supposed to exist within this network.

5.1 Wireless ATM System Requirement

The aim of the wireless ATM network is to provide transparent wireless access to wireline ATM networks. Some of the requirements that the wireless ATM networks are to [7]:

- support standard ATM services. This means that the ATM traffic classes should be supported with sufficient QoS
- support broadband connections and still guarantee the quality of service. Different applications need different quality from the network. Some are delay critical; some are critical to the loss of data; some produce bursty data; some need constant bandwidth, etc. The current wireless LAN capable of supporting the required bandwidth offers no guarantees about quality of service.
- tightly integrated to the fixed ATM systems. In order to reduce the overhead caused by internetworking. The existing infrastructure should be reused as

much as possible. This includes the reuse of ATM switches, B-ISDN signaling protocols, wiring, ATM/B-ISDN terminals, etc. This may be the most important factor that has impact on the economical possibilities to introduce a new system.

- offer standard ATM access to fixed users. Strong tendency for developing ATM LANs has been identified [24]. In the future a large number of ATM terminals, mostly computers, are assumed to be present in the premises of the companies operating wireless ATM networks. The adoption of the wireless ATM system is much easier if users and terminals can roam between wireline and wireless ATM systems. If the fixed infrastructure of the wireless ATM network offers the services of a standard wireline ATM network, the cost of having to operate two systems can be avoided.

5.2 Wireless ATM System Architecture

In order to meet the wireless ATM system requirement, the proposed wireless ATM system must provide wireless terminals with high speed cell relay services qualitatively similar to those provided by wireline ATM networks, thereby therefore facilitating seamless support of network based multimedia applications on both wireline and stationary wireless terminals. The architecture of the system is shown in Figure 5-1.

The system architecture shows that there are three types of terminals connected to the network: wireline data networks, business service gateways (wireless) and residential

gateways (wireless). The business service gateway and residential service gateway are differentiated on the different interfaces and cost requirements. For example, there may be a T1 interface card on each business service gateway (CPE), but there is only one or two POTS on each residential service gateway (CPE). Also, residential service gateways have to be a lot cheaper than business service gateways in order to be economically feasible. Such a wireless ATM system offers transparent B-ISDN connections to both wireline and stationary wireless terminals.

Figure 5 - 1: System Architecture for An Integrated Wireless ATM Network

The base stations (BS) are one of the ATM switches in this system. It is connected to the ATM network in the same way as other ATM switches using the NNI. CPEs are connected to base stations in the same way as wireline terminals connected to ATM switches using UNI. The CPEs are movable within the area of the base stations. The BSs offer transparent ATM UNI signaling.

The following scenario explains how the traffic is generated at the headend and distributed to the customer equipment in the proposed wireless ATM systems:

- Telephony, data and video signals are initiated at central offices, headend, satellites or any combination of the three.
- The digital signals are then combined and transmitted to multiple wireless ATM base transceiver (BTS) placed either on towers or atop existing buildings using fiber optic cable, microwave links or satellite downlinks.
- Each BTS typically can provide coverage to an area around 5 km in radius [23]. BTSs are strategically positioned for overlapping coverage to provide nearly seamless coverage.
- From the BTS the integrated signals are distributed over the airwaves to households and businesses, where the telephony, data and video signals are received using a small unobtrusive rooftop antenna.
- The combined signals are then split into standard telephony, data and video signals for distribution throughout the home or businesses.

5.3 The Radio Interface

The fixed wireless ATM system under consideration belongs to LMCS/LMDS band system. Local Multipoint Communications Systems (LMCS) being developed in Canada and Local Multipoint Distribution Systems (LMDS) in United States are broadband wireless telecommunication common carrier services in the 28 GHz range. They are developed to carry basic and advanced communication services such as “wireless” cable TV, Internet access, video conferencing and various other multimedia. A specific description of the radio interface specific layers are out of the scope of this thesis. Readers are recommended [13][25] for more information.

The bandwidth allocation for LMCS/LMDS systems is regional dependent. The following frequency bands varieties are supported by the system in different countries [23].

- Japan 23.0 - 23.6 GHz
- Canada 27.35 - 28.35 GHz
- US 27.5 - 28.35 GHz
- South America 28.5 - 29.5 GHz
- Europe 40.5 - 42.5 GHz

For example, the bandwidth allocation for LMDS in US is anticipated to be close to that shown in Figure 5-2 [13]. The 150 MHz band from 29.1-29.5 GHz and 850 MHz from 27.5-28.35 GHz. A licensee will have access to approximately 1 GHz of spectrum over a fairly large geographical area. The above bands will typically be used to provide

asymmetric services, for instance, with the 850 MHz for downstream (base station to subscriber) services and the 150 MHz for upstream (subscriber to base station) services. The planned segmentation of the band enables full duplex operation with easily realizable filters to achieve the isolation required between transmit and receive signals in both the base station and CPE transceivers.

Figure 5 - 2 : Expected LMDS Allocation

The proposed system can be configured to work well under different bandwidth allocation, therefore can be used in different countries as shown in the previous page.

5.3.1 Wireless ATM Protocol Stack

The wireless ATM system follows a protocol layering harmonizing with that of wireline ATM. New wireless channel specific physical, medium access control (MAC) and wireless network control layers are integrated into the ATM protocol stack as illustrated in Figure 5-3. This means that regular ATM network layer and control services such as setup, addressing, VC multiplexing, cell prioritization, etc. will be used for wireless services as well.

	User Plane	Control Plane	Management Plane
Data Link Layer	AAL Layer		
	ATM Layer		
Physical Layer	Transmssion Convergence Layer	Medium Access Control (MAC)	Timing Management
	Physical Medium Dependent Layer		Transmssion Power Management

Figure 5-3: Proposed Wireless ATM Protocol Stack

5.3.2 Physical Layer

As discussed in Chapter 3, there are two candidates for the multiple access technology; Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA). CDMA is a spread spectrum technology using orthogonal spreading codes, while TDMA allocates time slots for different connections. TDMA is to be used in this wireless ATM system because the peak user data rate limitation at CDMA technology.

The terminals will both transmit data towards the base station (uplink) and receive data from it (downlink). This duplex operation has to be supported in the radio interface. One possibility would be to reserve different frequencies for the downlink and the uplink. This is called Frequency Division Duplex (FDD). The other possibility would be Time Division Duplex (TDD). In the Time Division Duplex, the uplink and the downlink are located at the same frequency, but uplink and downlink data is transmitted in different time slots. FDD is used in the proposed wireless ATM system.

5.3.3 Medium Access Control Layer

On top of the physical layer is the Medium Access control (MAC) layer. The MAC layer defines the characteristics of the radio interface. As the radio interface is the bottleneck of a wireless ATM system, the MAC layer has a major role defining the quality of the whole system. The MAC layer's main duty is to multiplex the traffic of many connections into the radio link.

The access to a TDMA radio link can be either centrally controlled or some kind of random access algorithm can be implemented. The random access algorithm is used in most of the current LANs. In a centrally controlled TDMA system, a base station assigns time slots to terminals. The terminals use the time slots to transmit and receive traffic. The time slots are dynamically allocated to the terminals according to their needs and the resources available in the radio interface. The centralized control mechanism allows the network to maintain a total control over the radio link. This makes it easier to guarantee a fair service to all terminals. For this reason a centralized control of the radio interface is adopted to meet the requirements of the wireless ATM system. To be specific, reservation ALOHA is used as the Medium Access Control protocol for this wireless ATM system. That is, during initial access period, terminals contend for network resources using ALOHA random access protocol. Following traffic will be sent using the reserved network resources assigned by the base station. As pointed out in Chapter 3, ALOHA protocol works well under low system throughput. This is suitable for the wireless ATM system since a low initial take rate (the number of users within certain base

station) is to be expected. The uplink and the downstream frame structure of the radio link are described in Figure 3-2.

5.3.4 Data Link Layer

The wireless ATM system proposed in this chapter is supposed to offer QoS similar to that of the fixed ATM network. A radio link is always less reliable than the optical fiber link on which the wireline ATM is based. Therefore it will be necessary for the system to use special techniques to improve the QoS offered by the radio link. It is suggested that Reed Solomon (RS) code is to be used as FEC. The RS code adds overhead trailer to the cell, so that a limited number of transmission errors can be corrected on the other side of the radio interface.

Sometimes transmission errors on radio links occur in groups. In this case, RS code only is not sufficient. Therefore, interleaving may also be required. Retransmission is not recommended because it introduces additional delays and requires complex buffering methods to be used in order to preserve the sequence of the cells. For time sensitive applications the retransmission of cells is clearly impossible. If cells are lost during transmission, higher layer applications are expected to have some kind of retransmission implemented.

5.3.5 Connection Establishment and Network Resource Allocation

During network entry period, a base station broadcasts a message to the whole network to assist a CPE entering the network. If a terminal receives this message, it

identifies itself to the network by responding a network entry message. After the authentication process, the base station assigns a terminal ID to this CPE. The base station also send synchronization information to the CPE. After the CPE is sufficiently synchronized, the base station may allocate network resources to the CPE. Note there is not ATM payload flowing between the CPE and base station yet by now even though the CPE is already connected to the network.

In case of PVC connections, the network operator connects the payload traffic by assigning a fixed number of time slots to this CPE using the rule described in Chapter 4. In case of SVC connections, the CPE must first reserve network resources by sending a reservation request message to the base station using the contention time slots in the upstream. Any collision resolution algorithm (CRA) can be used if collision occurs. In the reservation request message, the CPE specifies the type of traffic it has, and the QoS parameters it wants. The base station may then use the CAC algorithm described in Chapter 4 to decide whether the request can be accepted or not. If the connection request is granted, the CPE can then send payload ATM traffic to the network in the reservation time slots.

A CPE can have more than one connections. One of the connections, called the control connection, is used for sending cells of signaling messages and to control the operation of the radio interface (identities, transmission power control, etc.). The rest of the connections are payload connections. If the CPE does not have uplink traffic, it uses the random access channel to request for bandwidth to be allocated for a connection. If

the CPE already has uplink traffic connections. further bandwidth request can be "piggybacked", that is, the request is coded into a MAC PDU carried the uplink traffic.

5.4 System Capacity

In a typical network, with a 500 MHz LMDS license band, 100 channels of television can be provided using approximately 100 MHz of spectrum, with the remaining 400 MHz available for two-way voice, data and multimedia services.

Assume 16 and 64 QAM modulation are used for upstream and downstream respectively. This results in the modulation efficiency of about 3.2 bits/Hz for the upstream and 5 bits/Hz for downstream. Also assume the upstream and downstream bandwidth ratio is 150:850 as mentioned in 5.2 and an 1x frequency reuse factor, the total downstream data rate is greater than 1.5 Gb/s and the upstream data is greater than 150 Mb/s [23].

5.5 System Cost

It is difficult to compare the broadband, two-way, wireline systems, such as "hybrid fiber coax"(HFC) or "fiber-to-the-curb" (FTTC), with wireless ATM system since there are so many variables that will differ between service areas. There is general agreement, however, that the infrastructure cost of a wireless distribution system will be significantly less than that of a wireline distribution system designed to provide the same services, particularly at low take rates [13]. This is due to the fact that one has only to

deploy a system up to the point of the base station. At that point no further investment is required until households passed actually become customers. Only then does the service provider have to invest in and install the customer premises equipment. With a “wireline” system the neighborhood must be “wired” as if everyone will eventually be a customer. There is, therefore, a large initial outlay for a “wireline” system before anyone actually becomes a paying customer.

5.6 Services

Wireless ATM system allows two-way communications. It can ~~provides~~ provide internet access, videoconferencing, and phone service.

5.6.1 Broadcast TV

In its digital form, wireless ATM system offers image quality superior to what most cable-TV subscribers receive over standard coaxial cable with lower cost. Since the proposed wireless ATM system is a LMCS/LMDS band system, this can be shown by existing LMCS/LMDS system. For example, CellularVision USA Inc, is beaming 49 channels of TV programming to 12,500 customers in Brooklyn’s Brighton Beach for a monthly rate of that’s about 30% less than traditional cable with super quality.

5.6.2 Telephony

Because wireless ATM system can handle thousands of voice channels, one should not discount its potential for providing voice service. It is unlikely however wireless ATM system will be built just for POTS, but voice represents a good source of incremental

business. But since mobile access is problematic at 28 GHz, wireless ATM system is not likely to compete with cellular telephone and personal communication services.

5.6.3 Internet/Data

Wireless ATM system delivers faster internet connections than the new and much hyped cable modems. With a standard \$200 modem card inserted into a PC, wireless ATM subscribers will be able to cruise the internet at speeds as high as 54Mbps--twice as much fast as the latest cable modem.

Wireless ATM system can not only provide access to the Internet, it can also be used to interconnect local area networks, create campus area networks and serve as a medium for asynchronous transfer mode and SONET. These capabilities permit wireless ATM operators to focus on business customers first.

In this chapter, an ATM based wireless system capable of supporting multimedia services was introduced. The proposed wireless ATM system is a LMCS/LMDS band system. Although wireless ATM systems are not restricted to LMCS/LMDS systems, it is generally agreed that LMCS/LMDS systems can be utilized to extend ATM to wireless communications. Effort is being made to deploy LMCS/LMDS in North America. The success of LMCS/LMDS systems certainly will help the development of wireless ATM networks.

Chapter 6

Wireless ATM Traffic Modeling and Analysis

The purpose of this chapter is to investigate the wireless ATM system defined in Chapter 5 quantitatively. The evaluation model used in this chapter consists of four parts: the system model, the traffic model, the simulation parameters and the output measurements.

6.1 System Model

Different system models will have different results on the performance of the system. The most important ones are MAC protocol and the TDMA frame structure.

As mentioned in Chapter 5, the reservation ALOHA is used in this evaluation process. This protocol uses slotted ALOHA to access the shared media at start up. If a terminal has more than one ATM cell, the base station will reserve time slots for it. Therefore, only the first cell will be contention-based. The following cells will use reservation time slots, hence contention-free.

When a terminal starts up, it first synchronizes itself with the base station. then it contends for network resources. OPNET simulation tools are used in this evaluation process [25].

The uplink frame structure is described in Figure 3-2. In the downlink, the GFC field of the first time slot (Frame Start) is set to 1111 to signal the start of a new frame. When the terminals receive this cell, they can synchronize themselves to the base station and start transmitting.

6.2 Traffic Generation Model

The CATV traffic generation models[14] are used in this simulation. Four types of traffic generation models are specified by the Cable TV Protocol Working Group. The following three types are used to represent bursty and smooth traffic sources.

- **Source Type 1 - ABR Traffic**

The first kind of bursty traffic is generated by a batch Poisson arrival model (see Figure 6-1). According to this model, a message is generated by a terminal instantaneously and has a random length equal to X_i bytes. The arrival process of messages is a Poisson process with parameter λ and the mean interarrival rate of the messages is λ messages/sec. Consequently, the interarrival time T of the messages is exponentially distributed with mean $E(T) = 1/\lambda$ second. The bursty traffic generation source is defined in Table 6-1.

Figure 6-1: Batch Poisson Traffic Model

Message Sizes & Probabilities	(X1, X2, X3, X4, X5, X6) & (P1, P2, P3, P4, P5, P6)	(64, 128, 256, 512, 1024, 1518 bytes) & (0.6, 0.06, 0.04, 0.02, 0.25, 0.03)
Mean Message Size	$E(X)$	368.1 bytes
Mean Bit Rate	R	
Mean Interarrival Time	$t = \frac{E(X) * 8}{R}$	
Arrival Rate	$\lambda = 1/t$	See Table 6-2

Table 6-1: Summary of Bursty Traffic Source Characterization

- **Source Type 2 - VBR Traffic**

The second type of bursty traffic is 53 byte messages. The whole 53 bytes are passed to the MAC layer for transmission.

- **Source Type 3 - CBR Traffic**

This constant rate traffic source is defined as follows: 48 byte messages delivered periodically at rate λ . The 48 byte messages are transmitted as ATM cells so a 5 byte header is added.

Three traffic models are investigated in this simulation. They are listed in Table 6-2.

Traffic Model	Traffic Source	Traffic Rate
1	Source type 1	0-100%
2	Source type 1 Source type 2	20% 80%
3	Source type 1 Source type 3	0-60% 40%

Table 6-2: Simulation Traffic Models

1) Traffic Model 1

The network has N terminals, where N is a parameter specified in Table 6-3. All terminals generate an equal amount of traffic of type 1 only. For each fixed N, the arrival rate, λ , of messages at each terminal will range from (approximately) 0 to the maximum possible rate sustained by the system (saturation).

2) Traffic Model 2

This traffic model tests the performance of high-priority packets in the presence of bursty data. An example might be voice traffic in the presence of LAN type traffic. The traffic mixture consists of the following:

Type 1 traffic makes up 20% of the applied load.

Type 2 traffic makes up 80% of the applied load.

The traffic is generated equally by all terminals.

3) Traffic Models 3

This traffic model tests the performance of the system to a mix of bursty and constant rate traffic. The traffic mix consists of the following:

- A varying load of type 1 traffic. One half the terminals (odd numbered terminals) generate type 1 traffic at an equal rate.

- Fixed load of type 3 traffic, consisting of 40% of the total gross capacity. One half of the terminals (even numbered terminals) generate type 3 traffic at an equal rate.

6.3 Network Topology

The topology of the network to be simulated is the wireless ATM system proposed in Chapter 5. Supposing a frequency reuse factor of 1 is available in adjacent sectors/cells using alternative horizontal/vertical polarization of the RF signal. Assume 500MHz of spectrum being available for each cell. The cells use either OMNI or sectored antennas appropriate to the desired cell site configuration. Modulation efficiency is available at 3.2 or 5 bits/Hz by using 16 or 64 QAM modulation scheme. Therefore, data rate over the wireless links is about 25.6 Mb/s and using 6 or 9 MHz of spectrum in each direction. This resulting 55-80 channels available in each sector/cell. Services below 25.6 Mb/s will be statistically multiplexed together in the down link, and distributed over a number of users using TDM. In the uplink, users can share single 25.6 Mb/s link, on a TDMA basis, to form an aggregate of approximately 4-6 Mb/s per 6 MHz carrier. Table 6-3 shows one channel configuration parameters for simulation runs. The results are discussed in the following sections.

Simulation Parameter	Values*
Maximum Number of Active Stations	50, 100, 150
Base station cell size	5 km
Downstream Data Transmission Rate aggregate for all channels	25.6 Mb/s
Spacing between terminals	Evenly distributed
Upstream Data Transmission Rates	4 Mbps
Propagation Delay	3×10^8 m/s for free space
Length of Simulation Run	20 sec
Length of Run Prior to Gathering Statistics	5% of simulated time
Guardband and Pre-amble between Transmissions from Different terminals	duration of 5 bytes at all speeds
Head End processing delay	1.5 ms

Note: All other PHY overheads such as FEC, CRC, and synch are assumed to be of zero length

Table 6-3: Network Configuration Parameters

6.4 Network Behavior Under ABR Traffic Only

First the network behavior under LAN type of traffic is simulated in OPNET.

6.4.1 Take Rate

Figure 6-2 shows the mean access delay vs. total throughput for the first traffic model for 50, 100, 150 subscribers. This corresponding to the take rate (number of users using the services) of 400-1200 users in an 8-sectored cell. Type 1 traffic has relatively short packets, so most of the traffic will be transmitted in the random access slot. From this simulation result, it is clear that the throughput of the network will largely depend on the

random access protocol used. In our case, the reservation aloha is used. the throughput of the system is about 37% of the offered load. The take rate has little effect on the system when the system already becomes largely populated.

Figure 6-2: Take Rate Impact

6.4.2 Transmission Speed

In order to investigate how upstream capacity affects the performance of the network, a set of different upstream transmission speeds are tested and the mean access delay vs. upstream transmission speed for 1 Mb/s and 4 Mb/s are plotted in Figure 6-3. The access protocol still has the major effect in this simulation. As the upstream transmission speed increases, the total throughput also increases and the throughput increments is proportional to the upstream speed.

Figure 6-3: Upstream Speed Impact

6.4.3 Network under Overloaded Conditions

Next, the network behavior under over loaded situation is investigated. This time, an offered load of upto 120% upstream capacity is generated by terminals. The result is shown below in Figure 6-4. From Figure 6-4, it is clear that as the offered load approaches the network capacity (saturation state), both the Mean Access Delay and throughput deteriorates dramatically.

Figure 6-4: Network Overloaded

6.4.4 Cell Size

Suppose the base station coverage radius increases from 5km to 10km. The network behavior is shown in Figure 6-5. From Figure 6-5, it is clear that there is no significant difference between 5km and 10km cell size. In practice, however, big cells need more transmission power for both terminals and base stations except for the relative longer propagation delay. Of course, the cell size can not increase forever. As discussed in Chapter 5, more guard time slots are needed as the two-way propagation delay increases. This is one of the reasons why small cells are preferred for real-time applications. For non-delay sensitive ABR traffic, large cells are acceptable.

Figure 6-5: Cell Size Impact

6.5 Network Behavior Under Mixed of ABR and CBR Traffic

This test is designed to show the network ability to deliver constant rate traffic in the presence of LAN type traffic. The result is taken from 150 terminals, with type 3 traffic counts for 40% of the total load, and type 1 traffic varies from 0 upto 60% of the total offered load. The total offered load in this case is set to 50% of the upstream capacity. Figure 6-6 plots the mean access delay vs. throughput for the type 1 and type 3 traffic.

From Figure 6-6, it is clear that as the type 1 traffic increases, both type 1 and type 3 traffic mean access delay increases, but type 3 traffic throughput only decreases slightly.

Figure 6-6: Network Under ABR+CBR Traffic

In this chapter, the system behaviors for the proposed wireless ATM system were investigated. From the results, it is demonstrated that the Medium Access Control (MAC) protocol has deterministic impact on the efficiency of a wireless ATM system. Therefore, design a good MAC protocol is the most critical issue in system design. From the simulation, it also shows that high priority traffic can be delivered efficiently and promptly.

Chapter 7

Conclusions, Contributions and Future Research

While wireless communication is experiencing fast evolution, the wireline network has been going towards B-ISDN with ATM technology. ATM will offer data rates that are considerably higher than current wireline network services. Integrating with ATM will set extremely hard requirements on the wireless air interface. Various kinds of wireless ATM systems are under development in North America.

Conclusions

The following conclusions are obtained based on the observation made and the research results in this thesis.

1. There are emergency needs for the development of wireless ATM systems as discussed in Chapter 3. People see this is a natural extension of the wireline ATM.
2. Wireless ATM has the several advantages - cost effective, suitable for special environment where wirelines are impossible, good for asymmetrical traffic such as internet access, high capacity, guaranteed quality of services, etc.
3. ATM connection admission control can be extended to wireless ATM domain with wireless specific considerations. This is discussed in Chapter 4.

4. An efficient MAC protocol is key to a successful wireless ATM system. This is shown in Chapter 6. The best candidates now available are DAVIC and 802.14. They are described in Chapter 3.
5. Fixed wireless systems are under development in North America and around world. LMCS/LMDS systems are good examples of fixed wireless ATM systems.

Contributions

The work in this thesis has resulted in the following contributions to the area of wireless ATM system design and management.

1. Recognized the social demand for wireless ATM systems.
2. Identified the requirements for wireless ATM systems.
3. Proposed a wireless ATM system can handle multimedia services and still provide quality of services guarantee.
4. A wireless ATM protocol is introduced.
5. Wireless ATM connection control schemes were designed and discussed in chapter 4.
6. Investigated the system behavior of the proposed wireless ATM system in Chapter 6. Demonstrated an efficient MAC protocol is key to a successful wireless ATM system through simulations.

Future Research

The observations and results detailed in this thesis opens up a wide area for wireless ATM system design and management. The following list identifies tasks that would provide further insight into the wireless ATM system presented in this paper.

1. Comparison of various wireless ATM MAC protocols
2. Wireless ATM signaling
3. Mobility management in wireless ATM system
4. RF characteristics of wireless ATM systems

As the successful implementation of ATM/B-ISDN in wireline networks, wireless ATM could be seen as inevitable development of near future.

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