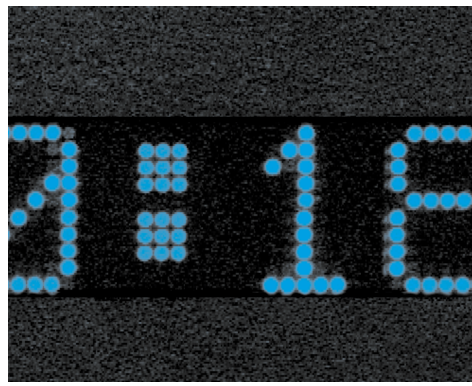
Symmetricom®

ATM Networks and Synchronization



WHITE PAPER

ATM Networks and Synchronization

Introduction

Bandwidth usage driven by the Internet is exploding. For the first time, data network traffic is surpassing that of voice. The Internet has created demand for new applications including video and desktop conferencing, audio telephony, and video on demand (VoD) services, further stressing circuit switched networks beyond their design limits.

Asynchronous Transfer Mode (ATM), conceived as a multi-service technology, is now the standard of choice for broadband networks. It is the world's most widely deployed back-bone technology. ATM allows a wide range of traffic types (voice, video, data, etc.) to be multiplexed in a single network. A key benefit of ATM technology is its ability to provide quality of service (QoS) guarantees to applications. Other benefits include:

- High performance via hardware switching
- Dynamic bandwidth for bursty traffic
- Scalability in speed and network size
- Common LAN/WAN architecture
- International standards compliance
- Reduced infrastructure costs through efficient bandwidth management

The QoS guarantees of ATM are in the form of bounds on end-to-end delay, packet delay, variation (jitter), and packet loss rate for a given data rate. Several classes of service including, constant bit rate (CBR), variable bit rate (VBR), available bit rate (ABR), etc., are defined in the context of ATM networks to satisfy the QoS needs of various applications. The transport of voice, data, video, etc. over ATM introduces several issues that must be addressed in order to deal with the problem of providing adequate quality on an end-to-end basis. Some of these issues are:

- Choice of adaptation layer
- Method of encapsulation of information packets in AAL packets
- Service class of selection in the ATM networks for control of delay and jitter
- Clock synchronization

This paper discusses the importance of synchronization in ATM networks and proposes approaches to clock recovery and synchronization. But first we will review some ATM fundamentals.

ATM Fundamentals

ATM is a high performance cell[1] oriented switching and multiplexing technology that utilizes fixed length packets to carry different types of traffic. All information is formatted into fixed length cells consisting of 48 bytes (8 bits per byte) of payload and 5 bytes of cell header. The fixed cell size ensures that time critical information, voice or video, is not adversely affected by long data frames or packets. The ATM header, needed to establish and maintain connections, is organized for efficient switching in high-speed hardware implementations and carries payload type information, virtual circuit identifiers, and header error check.

ATM is connection oriented and the two types of ATM connections are virtual path connections (VPCs) and virtual channel connections (VCCs). A VCC is the basic unit. It carries a single stream of cells in order from user to user. A VPC is a collection of VCCs. A VPC is created from end-to-end across an ATM network and all cells belonging to a virtual path are routed the same way through the ATM network.

An ATM model is illustrated in Figure 1. The ATM layer, on top of the physical layer, does cell multiplexing/de-multiplexing, generates/extracts ATM cell headers, and defines virtual paths. In the transmit direction, cell multiplexing combine cells from different virtual paths and virtual circuits into a single stream. In the receive direction, cell de-multiplexing directs the cells into the appropriate virtual paths and circuits.

The ATM Adaptation Layer is the standards layer that allows multiple applications to have data converted to and from the ATM cell. It is a protocol used to translate higher

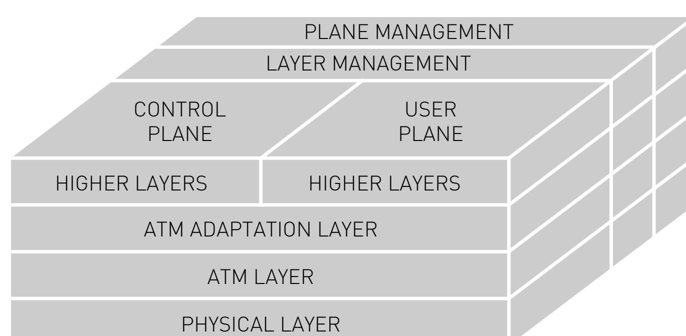


FIG.1 ATM Technology Model

[1] The terms "packet" and "cell" are used synonymously in this white paper.

LAYER	SERVICES SUPPORTED
AAL1	Supports connection oriented services that require constant bit rates and have specific timing and delay requirements
AAL2	Supports connection oriented variable bit rate applications (ex. compressed voice and video)
AAL3/4	Supports connectionless and connection oriented variable bit rate services and also SMDS (originally 2 AAL types that have been combined)
AAL5	Supports connection oriented variable bit rate services (ex. MPEG)

TABLE 1 ATM Adaptation Layers

layer services into the size and format of an ATM cell. This layer holds the bulk of the transmission. There are four types of adaptation layers currently defined for ATM networks: AAL1, AAL2, AAL3/4, and AAL5. Each of these is designed to support specific services. AAL1 was designed to support circuit emulation over ATM networks. It is ideally suited for transporting Constant Bit Rate (CBR) traffic since it provides constant delay through the network. Table 1 defines the different adaptation layers and provides some examples of services supported.

Importance of Synchronization

ATM is asynchronous in nature, as its name implies. So why do we need synchronization?

Common to all packetized networks is delay. There is propagation delay, packetization delay, queuing delay, buffering delay, encoding delay, etc. Cell transfer delay (CTD) is the delay experienced by a cell between network entry and exit points. It includes propagation and queuing delays at various intermediate switches and service times at queuing points. Cell delay variation (CDV) is a measure of the cell transfer delay variance. In essence, CDV is jitter.

Synchronization issues arise while transporting voice, video, data, etc. over ATM due to cell delay variation. The presence of jitter introduced by the ATM network may distort the reconstructed clock at the receiver. Recovery of the network clock is critical to assure all data packets reach their final destination at the correct time and are reassembled without any losses, gaps, or errors. These losses, gaps, and errors are the cause of audible clicks, distortion, and dropped calls on voice services, freeze frames on video services, and corrupted data on data services.

Lack of proper synchronization is one of the causes for packet loss. Cell loss ratio (CLR) is proportional to long term accuracy – the better the synchronization level, the smaller the packet loss ratio. ITU-T I.356 specifies a CLR of $3X10^{-7}$ for Class 1 (stringent) service. It is strongly recommended that Stratum 1 or 2 level timing be deployed to reduce packet loss due to synchronization, maximize performance, and meet ITU-T I.356. See Appendix A for more information.

Clock Recovery Methods for CBR Services Transported over ATM Networks

As defined in ATM standard, ETSI TR 101 685 V1.1.1, there are three alternatives to eliminate or reduce the effects of CDV from CBR connections:

1. Using a network derived clock as the service clock (synchronous method)
2. Using Synchronous Residual Time Stamps (SRTS) to transmit service clock information
3. Using adaptive algorithms, such as PLL, to recover the clock

Synchronous Method
In this method, the service clock is directly derived from the network clock that must be traceable to a primary reference source (see Figure 2). The network clock is distributed through the synchronization of the physical layer connecting the ATM network elements. These ATM network elements may themselves be synchronized via an external physical timing interface or as a slave of another ATM network element via the physical layer connection.

This method is recommended when:

1. Traffic streams are merged and inter-working with PSTN
2. A network clock is available at the IWF and the service user does not require timing transparency

The synchronous method is one of the preferred methods for timing delivery of CBR services that require compliance to ITU-R Recommendations G.823 jitter and wander requirements because of its traceability to PRS. It requires all end stations and CBR sources to synchronize to the network clock. In other words, this method requires multiple BITS/SSU and/or primary reference source clocks. The advantages are redundancy and added reliability in the event one PRS and/or BITS/SSU fails or goes off frequency.

Synchronous Residual Time Stamp Method
This method transports information about the source clock across the ATM network to eliminate playoff buffer depletion or overflow. In the SRTS method, the difference between the service clock and network clock is encoded into alternate cells. At the receiver, the clock

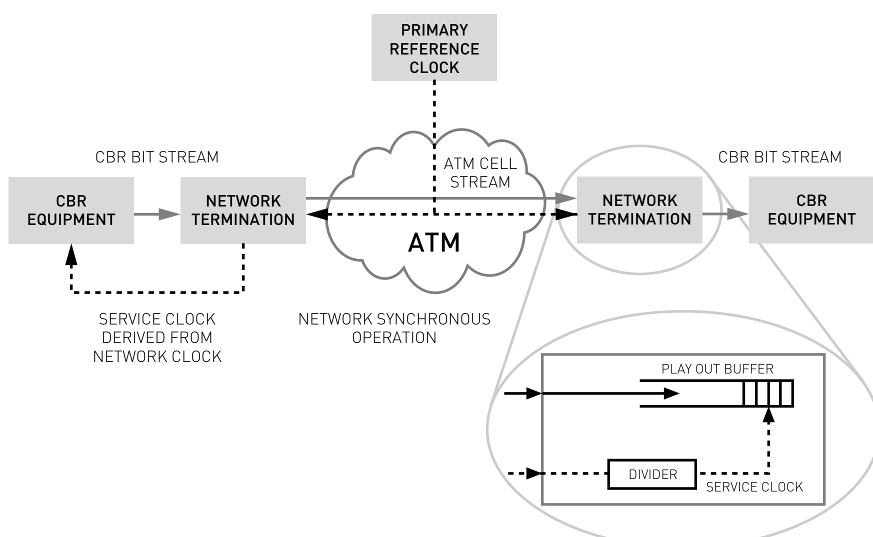


FIG.2 Synchronous Method

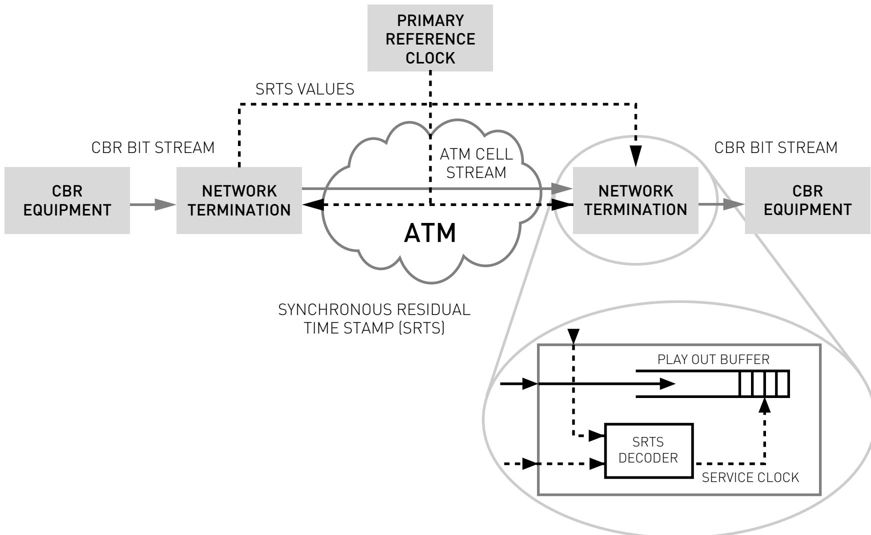


FIG.3 SRTS Method

and resolved. Three synchronization methods are available: synchronous method, SRTS method, and adaptive clock method. The synchronous and SRTS methods require traceability to a PRC. They are the preferred and recommended methods for services that require compliance to ITU-R G.823. The synchronous method has the advantage of multiple primary reference sources and/or BITS/SSU that provide redundancy and added reliability.

To reduce packet loss due to synchronization and maximize performance in ATM networks and to meet packet loss requirements in ITU-T I.356, it is strongly recommended that Stratum 1 or 2 clocks be deployed in the ATM network.

is reconstructed from the time stamp information with respect to a PRS. The SRTS method is shown in Figure 3.

The SRTS method is essentially insensitive to CDV, robust against cell losses, and suitable for limiting the wander caused by CDV. This method is recommended when frequency transparency is required through an ATM network. This method is also preferred because of traceability to PRS but unlike the synchronous method, the SRTS method does not require all end stations and CBR sources to be synchronized to the network clock. Because SRTS only requires one primary reference clock source, there are no backups if the primary reference clock source fails or goes off frequency.

Adaptive Clock Method
The adaptive clock method uses an adaptive algorithm, typically a PLL, to determine how the buffer at the receiver is emptied. Once the trend is determined, the receiver clock frequency can be increased to bring the buffer level back to a nominal value and lock in the receiving clock to that of the transmitter. Since the adaptive clock method does not require traceability to PRS, it is cost effective and used when it is not possible to provide a common clock to the transmitting and receiving end stations (see Figure 4).

The adaptive clock method relies heavily on CDV induced in the network since the mean rate of cell arrivals is a measure of the source clock frequency. Since there are no specified algorithms or guidelines, the performance of the adaptive clock is in the hands of the receiving equipment designer.

The adaptive clock method is recommended when long-term frequency transparency is required through an ATM network and no strong requirements on wander and temporary frequency offset (due to wander) at the service interfaces exists.

Summary

ATM, a multi-service technology, is here to stay. It offers its customers many benefits and virtually an unlimited range of allocations. ATM services are profitable and getting a regulatory boost. It is the protocol of choice for many leading service providers worldwide.

ATM networks are subject to delay, like all packetized networks. These delays become synchronization issues that must be addressed

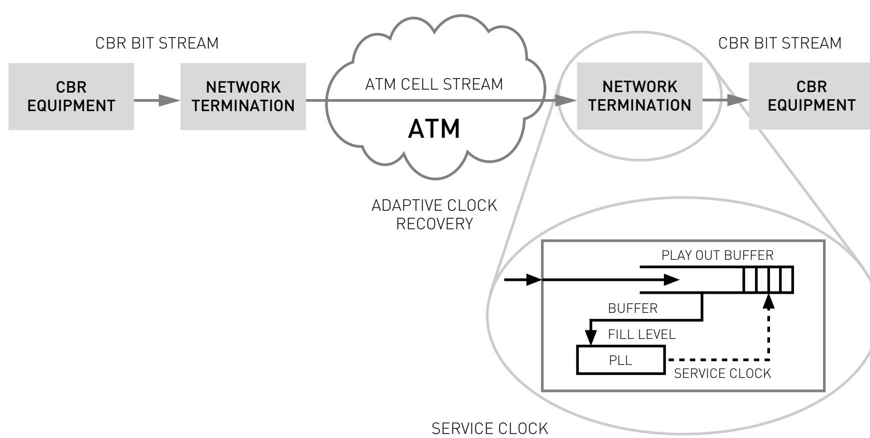


FIG.4 Adaptive Method

Glossary

ABR *Available Bit Rate*
Class of service intended for delay tolerant best effort applications

AAL *ATM Adaptation Layer*
The standards layer that allows multiple applications to have data converted to and from the ATM cell. A protocol used that translates higher layer services into the size and format of an ATM cell

ATM *Asynchronous Transfer Mode*
A standard for broadband networks that allows a wide range of traffic types to be multiplexed in a single physical connection oriented network

BITS *Building Integrated Timing Supply*
Provides distribution of timing references

CBR *Constant Bit Rate*
Class of service intended for real time applications with stringent requirements on delay, jitter, and loss rate

CDV *Cell Delay Variation*
A measure of the cell transfer delay variance

CLR *Cell Loss Ratio*
Ratio of total lost cells to total transmitted cells in a population of interest

CTD *Cell Transfer Delay*
The delay experienced by a cell between network entry and exit points. It includes propagation and queuing delays at various intermediate switches, and service times at queuing points

IWF *Interworking Function*
Gateway between the mobile network and data network infrastructure

MAN *Metropolitan Area Network*
A network that provides regional connectivity within a metropolitan area

MPEG *Moving Pictures Expert Group*
Family of standards used for coding audio-visual information (e.g., movies, video, music) in a digital compressed format

PLL *Phase Locked Loop*
A mechanism whereby timing information is transferred within a data stream and the receiver derives the signal element timing by locking its local clock source to the received timing information

PRS *Primary Reference Source*
Equipment that provides a timing signal whose long-term accuracy is maintained at 1×10^{-11} or better with verification to Coordinated Universal Time (UTC), and whose timing signal may be used as the basis of reference for the control of other clocks within a network

PSTN *Public Switched Telephone Network*
The world's collection of interconnected voice-oriented public telephone networks, both commercial and government-owned

SMDS *Switched Multimegabit Digital Service*
A connectionless, MAN service, based on 53-byte packets, that targeted the interconnection of different LANs into a switched public network

SRTS *Synchronous Residual Time Stamp*
A clock recovery technique in which difference signals between source timing and a network reference timing signal are transmitted to allow reconstruction of the source timing at the destination

SSU *Synchronization Supply Unit*
Provides distribution of timing references

TIE *Time Interval Error*
The time difference between a real clock and an ideal uniform time scale, after a time interval following perfect synchronization between the clock and the scale

VCC *Virtual Channel Connection*
Connection that carries a single stream of cells in order from user to user

VPC *Virtual Path Connection*
A collection of VCCs

References

1. ETSI TR 101 685 V1.1.1 (1999-08) Standard, 'Transmission and Multiplexing™; Timing and Synchronization Aspects of Asynchronous Transfer Mode (ATM) Networks'
2. ITU-T Recommendation I.386, 'B-ISDN ATM Layer Cell Transfer Performance'
3. T1X1.3/2002-018, 'Synchronization in a Hybrid Packet/Circuit Environment'
4. International Engineering Consortium, http://www.iec.org
5. Institute for Telecommunication Sciences, http://www.its.bldrdoc.gov
6. T1X1 Technical Subcommittee, http://www.t1.org/t1x1/t1x1.htm
7. *'The Jitter Time Stamp Approach for Clock Recovery of Real Time Variable Bit rate Traffic'*, W. Su and I.F. Akyildiz, November 2000

Appendix A: Cell Loss Ratio and Synchronization

The absence of acceptable levels of synchronization can lead to packet loss and subsequently, negative impacts.

For voice calls, packet loss causes:

- Call cut offs (dropped calls)
- 'Pops' during conversations
- Voice distortion

For voice band data, packet loss causes:

- Call cut offs (dropped calls)
- Retraining – modems re-engage in initial handshaking to re-establish communications
- Modem speed re-negotiation during call (transmission rate re-education)
- Throughput degradation – bit error ratio/block error ratio resulting in retransmission

Cell loss ratio (CLR) is defined as the ratio of total lost cells to total transmitted cells in a population of interest. The cell loss ratio is proportional to the long-term accuracy – the better the synchronization level, the smaller the CLR.

Consider the following three cases:

1. ATM network has Stratum 1 timing
2. ATM network has Stratum 2 timing
3. ATM network has Stratum 3 timing

In each case, de-jitter buffers at the packet egress points will absorb phase change until there is a need for buffer adjustment. The need for buffer adjustment is due to the fact that the buffer has grown too large or the buffer has shrunk to the point where the intended range of delay variation cannot be accommodated, and too many losses occur. When the buffer is re-adjusted, assume that at least one packet will be lost. Further assume that a 10 ms phase change will require a buffer re-adjustment. With Stratum 1 ($1X10^{-11}$) traceable timing,

$$\frac{\Delta T}{T} = 10^{-11},$$

where ΔT = phase change
T = time between buffer adjustments

$$\Rightarrow \quad T = 0.01/10^{-11} \text{ seconds}$$
$$= 10^{9} \text{ seconds}$$
$$= 16.67X10^{6} \text{ minutes}$$

If one packet were lost for each observation interval, T, then assuming 50 packets per second (3000 per minute) is transmitted,

The sync related cell loss ratio
loss ratio $=1/(3000X16.67X10^{6})$
$= 2X10^{-11}$

Using similar assumptions to calculate synchronization related cell loss ratio for Stratum 2 ($1X10^{-10}$) and Stratum 3 ($4.6X10^{-6}$), CLR (Stratum 2) = $2 X 10^{-10}$ and CLR (Stratum 3) = $9.2X10^{-6}$.

In these examples, the ITU-T I.356 cell loss ratio requirement is met with Stratum 1 or 2 level timing but not Stratum 3 level timing.

SYMMETRICOM, INC.
2300 Orchard Parkway
San Jose, California
95131-1017
tel : 408.433.0910
fax : 408.428.7896
info@symmetricom.com
www.symmetricom.com

SYMMETRICOM EMEA
150 Wharfedale Road
Winnersh Triangle, Nr. Wokingham
Berkshire
RG41 5RB, United Kingdom
tel : 44 (0) 1189 699 799
fax : 44 (0) 1189 277 520
info@symmetricom.com

SYMMETRICOM LATIN AMERICA
1560 Sawgrass Corporate Parkway
4th Floor
Sunrise, Florida
33323
tel : 954.331.4592
fax : 954.331.4601
info@symmetricom.com

SYMMETRICOM ASIA PACIFIC
Unit 1005, Jubilee Centre
42–46 Gloucester Road
Wan Chai
Hong Kong
tel : 852.2529.7180
fax : 852.2529.7190
info@symmetricom.com