PERFORMANCE OF INTEGRATED SERVICES ON A HIGH SPEED MULTIMEDIA NETWORK

Y.H.Wang L.K.Chen K.W.Cheung

Department of Information Engineering
The Chinese University of Hong Kong
Shatin, N.T., Hong Kong

Abstract — We study the performance of integrated services on a multiaccess integrated bus/ring network called ACTA (Adaptive Cycle Tunable Access) network. It is based on adaptive variation of cycle lengths according to the network load. The traffic characteristics for multimedia are first discussed. We then present simulation study of the integration of voice/video/data traffic on the ACTA network. The results show that ACTA network can support multiple services very well, thus, it can serve as a low-cost stand-alone multimedia LAN/MAN or a traffic concentrator for ATM networks.

I. Introduction

During recent years, great advancement has been achieved in communication and computer technologies. This raises most people's expectation on computer and telecommunication networks which can only be fulfilled by a new generation of high-speed, fully-integrated multimedia network. A multimedia network should have the following basic characteristics:

1. It can provide large bandwidth to meet the requirement of broadband services such as digital video.
2. It can provide real-time data transfer ability to support many time-sensitive applications.
3. It can support the integration of different kinds of traffic.
4. It has high performance and fair access even under heavily loaded traffic.

Many multiaccess bus/ring networks have been proposed (see e.g., [1] - [7]), such as the FDDI, and DQDB. However they are not ideal for high speed multimedia network. The performance of FDDI depends on the round-trip delay of the token which affects its efficiency. The subsequently proposed FDDI-II is not an integrated scheme, which leads to increase cost and complexity of the network. The protocol of DQDB cannot be extended to multiple channels, and its operation is somewhat complicated. Here we introduce a protocol called ACTA (Adaptive Cycle Tunable Access). It has been proposed as a high speed multi-channel bus/ring network [4]. It adjusts the cycle length according to the network load to achieve optimum performance. It also has low node complexity, simple processing and can be implemented easily.

In the next section, we discuss the ACTA protocol. In section 3, we present the characteristics of traffic source models and analyze the MPEG compressed video using a recently proposed video source model, called Cyclostationary Autoregressive (CAR) model. Section 4 describes the simulation model and present the simulation results. The performance of ACTA networks based on simulation results is also analyzed.

II. ACTA Network

ACTA protocol is one of the simplest multi-channel protocols [4]. It has low node complexity and is suitable for high speed photonic implementation [6]. It requires only two control bits per slot in the media access, thus it is compatible to ATM and many other protocols. A 100Mbps implementation has been successfully demonstrated in the CUM LAUDE NET project [5].

A. Network structure

In this paper, the ACTA network is assumed to be a dual-bus looped back to itself [Fig.1]. ACTA network adopts slotted cycle to transmit packets. Fixed size empty slots are continuously generated from the Head-of-Bus node in opposite directions. The structure of the node is shown in Fig.2 . Each node consists of two pairs of receiving and transmitting modules, one for each bus. There are three queues for each node to buffer the outgoing packets, one for each kind of traffic, namely, voice, video and data. Each node simply monitors the channel and reads in the slot when the packet's destination address matches its own address. For transmission, the channel access procedure is described in [4]

B. Cycle Utilization

The cycle length is adjusted based on the network load, that is:

$$\text{New cycle length} = \frac{\text{current cycle length} \times \text{cycle utilization}}{\text{controlled load } L_c}$$

The cycle utilization is the number of slots used in the cycle divided by the cycle length, and the controlled load is a normalized parameter specifying the desired throughput under heavily overload condition. When the cycle utilization is larger than the controlled load, the new cycle length will increase, and when cycle utilization is smaller than the controlled load, the new cycle length will decrease. From a statistical point of view, the maximum utilization is set by the control load.

0-7803-2509-5/95 US$4.00 © 1995 IEEE

C. Advantages of ACTA Protocol

First is its simplicity. Unlike DQDB, no request registration is required for ACTA. Each slot in a cycle requires only two access-control status bits, thus the protocol can be made slot compatible with other protocols such as ATM, and consecutive slots going to the same destination can be transmitted together, simplifying the reassembly process for large packets. Second is its high performance. ACTA is independent of the round-trip delay, with a normalized throughput ≥ 0.9, and fairness can be maintained fairly well. Network utilization is high even when only a single node is transmitting. Also ACTA protocol can adapt to different traffic load, due to its adaptive cycle mechanism. This is demonstrated in later section.

III. Traffic Source Model for ACTA Network

In our simulation studies, we assume there are three kinds of traffic: data, voice and video. Due to their different characteristics, they have been simulated using different source models.

A. Data Source Model

Data Traffic here means non-real-time computer-related services like file transfer, terminal emulation, etc. One simple model for data service is the Compound Poisson model. In this model, the packets are generated in batches, the number of packet per batch follows a poisson distribution, and the interarrival time also conforms to exponential distribution. We can control the traffic intensity by changing the parameter of the source model.

B. Voice Source Model

Voice is the main traffic in telecommunication networks. In an integrated computer network, it is still important, but the portion of capacity allocated for voice is much less. Here we consider the voice as a constant bit rate (CBR) traffic, that is 64Kbps PCM voice. Since the transmission of voice requires strict bounded packet delay, we assign the highest priority to voice traffic in our simulation.

C. Video Source Model

Digital Video is expected to become a major traffic component of multimedia communication. The statistical properties of video sources have been studied by many people (see e.g.,[8] - [10]). In this section, we discuss the characteristic of MPEG-1 video source and the recently proposed CAR model [11].

MPEG is an international standard for video compression. MPEG standard has already advanced in several phases. We only consider MPEG-1 which contains the basic properties of subsequent standards. MPEG-1 defines three types of frames, I (Intraframe), P (Prediction) and B (Bidirectional prediction). Different types of frames have different compression ratios, therefore MPEG video is a kind of variable bit rate (VBR) traffic. The whole MPEG video sequence is separated into Groups of Pictures (GOP's). A GOP is expressed as:

$$\underbrace{\overbrace{IBB...B}^{M_2}}_{1}\underbrace{PBB...B}_{2}......\underbrace{PBB...B}_{M_1} \tag{1}$$

In each of the M_1 subgroups , there are M_2 frames. Among these M_2 frames, there are $(M_2 - 1)$ B frames. So a complete GOP has M_1xM_2 frames as showed in (1), and it has only one I frame. The I-P-B frame pattern of an MPEG-1 sequence is usually fixed. The I frames have a large amount of data which show up as peaks in Fig.3 and arrive periodically . P and B frames have less amount of data. Thus MPEG-1 video shows both periodicity and randomness. The randomness is mainly due to the changing content of pictures.

Based on the measurement of full-featured MPEG-1 sequences, it is found that the correlation between two consecutive I-frames is also noticeable. Using its mean, standard deviation and first order coefficient of auto-covariance function, we set up a first order AR model for the I sequence[11]. Also, the data amount of P frames has strong relation to its previous I frames. When a quantization scale is selected, the ratio of data amount of P-frame to its previous I frame is fixed. The amount of data for two consecutive P-frames are almost the same. With the maximum compression ratio, the amount of data of B-frames in the entire sequence are nearly constant with a small random variation. Thus we established the Cyclostationary Autoregressive (CAR) model for MPEG video source. Fig.4 shows the video data generated by CAR model. In the simulation, the MPEG-1 video source has the frame rate equal to 30 frame per second and the average bit rate is 1.5Mbps.

IV. Simulation Results and Analysis

We have simulated the integrated services which include voice, video and data traffic and analyzed the throughput and delay performance of ACTA network based on the simulation results. The bit rate is assumed to be 100Mbps, and with only one channel and 64 nodes. During the simulation, all time units, such as simulation time, interarrival time and delay time are normalized with respect to the slot duration τ_s. All distance units are normalized with respect to $\tau_s \times c$, where c is the speed of light in the transmission medium. The nodes are uniformly spaced at one unit apart. The throughput is normalized to the channel capacity and the maximum value is 1.0. The traffic is assumed to be uniformly distributed in the network, and the destination is also uniformly distributed. During each cycle, each node can send at most N_q packets, which is the quota for the node. In the simulation, N_q is set to be the same for all nodes to ensure fair bandwidth utilization among all nodes.

First, we study the performance of ACTA network with single traffic. For data traffic, the results were given in [4], which also showed the high throughput and fairness of the network. For video, the simulation work was presented in [12]. The traffic was assumed to be real-time MPEG-1 video generated from the CAR model. The simulation results and discussion for integrated traffic are presented next.

A. Pure Voice(uncompressed PCM)

Fig.5 and Fig.6 illustrate the performance of pure voice traffic versus applied loads at various control loads (L_c). As the applied load increases, the throughput increases and approaches the maximum set by the controlled load parameter. Generally, the larger the controlled load, the larger the maximum throughput. However if L_c is too large (say 0.99), the response of the cycle-length adaptation will be very slow, which will reduce the throughput and affect the fairness. So there is an optimum value for L_c. We recommend the value 0.90-0.95 for L_c. Since the voice traffic has a constant packet rate, and the bit rate of a single voice channel is very small compared with the network bit rate , the multiplexing of this kind of traffic is very desirable. In our simulation, even when the applied load is 0.83, the average delay is only 1.0 ms. Beyond that the delay increases rapidly. An experiment was performed to study the subjective quality of real PCM voice samples at various loads. Under the above traffic load, we obtained the delay information of a certain voice channel. The voice samples were segmented, and a variable delay which corresponds to the simulated delay was added in. The modified voice which emulated the transmission through network was then played back. The subjective audible result shows that even under heavily loaded condition, the voice quality is still acceptable. So we recommend the maximum applied load for voice to be ≤ 0.83.

B. Comparison with Leaky Buckets under MPEG-1 video

Fig.7 and Fig.8 shows the simulation results of pure MPEG-1 video traffic for various controlled load. Compared with Fig.6, we can see the slope of video delay is not as steep as voice delay at the critical point. This is because MPEG-1 source is bursty.

The performance of MPEG-1 video is also compared between ACTA and constant bit-rate leaky buckets. A leaky bucket liked controlled buffer is used to buffer a single MPEG-1 video stream(1.5Mbps). The output bit rate of the leaky bucket is taken to be 1.5Mbps, 3.0Mbps, 10Mbps, 20Mbps, 50Mbps and 100Mbps respectively. The average and maximum delays for the various constant bit-rate sinks are shown in Table 1. In ACTA network with 64 unidirectional MPEG-1 video transmissions (which corresponds to a normalized throughput of 0.5 or one MPEG-1 video per node), the average delay is less than 2 ms and the maximum delay is only 15.2 ms. Thus the average bandwidth utilization is better than a 30Mbps constant bit-rate sink as far as a single node with a single MPEG-1 video transmission is concerned. Even under heavily loaded condition, say when the applied load is 0.84 (with 112 video transmissions), the average delay is only 6.6 ms, which is still roughly equivalent to a 10Mbps constant bit-rate sink with one MPEG-1 video transmission. From the curve, we show that ACTA network can accommodate bursty traffic very well.

C. Scheduling for Integrated traffic

When integrated traffic is considered, how to schedule different classes of traffic become very important. It is necessary to assign a priority to different traffic. There are several kinds of priority schemes to schedule the traffic, such as dynamic order of priority and static order of priority [15] [16]. In our simulation model, the static order of priority scheme is selected mostly due to the characteristic of traffic. Also the static order priority has the simplest complexity that can ease the design and operation of the node. Thus it is suitable for high speed network.

D. Voice and MPEG-1 Video

Fig.9 and Fig.10 show the performance of the integration of voice and MPEG video, with voice having a higher priority. When the applied load of voice traffic is fixed and the traffic of video increases, the throughput of voice is stable, and the delay is kept small. This shows that in ACTA network, the higher priority traffic is independent of the lower priority traffic.

E. MPEG-1 Video and Data

Fig.11 shows the simulation result of the integration of video and data traffic. The applied load of data is kept at 0.4 and video traffic load is varied from 0.24 to 1.3. When the total applied load does not exceed the network capacity, all the arriving packets are served. When video traffic increases, until the total load approaches the controlled load, the throughput for data traffic decreases. Finally the data traffic is kicked out and the whole network bandwidth is taken by the high priority video traffic. This demonstrates that the ACTA network can support the static priority scheme very well.

V. Conclusion

The simulation results show that ACTA network can support integrated traffic very well. Even with 312 pair of voice calls (the corresponding load is 0.2) and 64 video transmissions (the corresponding load is 0.48), the average delay of voice and video is less than 1 ms and 19.4 ms respectively, and the network still has abundant bandwidth for data traffic. Thus, the ACTA network can be used as multimedia LAN/MAN or as an ATM traffic concentrator.

Acknowledgement

This project is partially supported by Hong Kong University Grant Committee Direct Grant 220 500 650

References

[1] J.O.Limb and C.Flores, "Description of Fasnet– A Unidirectional Local-Area Communications Network," Bell Syst. Tech. J, 61, pp.1413-1440, 1982

[2] F.E.Ross, "An Overview of FDDI: The Fiber Distributed Data Interface," IEEE J. Selected Area in Commun., 7, pp.1043-1051, 1989

[3] R.M.Newman et al. "The QPSX MAN," IEEE Communications Magazine, pp.20-28, Apr. 1988

[4] K.W. Cheung, "Adaptive-Cycle Tunable-Access(ACTA) Protocol: A Simple, High-Performance Protocol For Tunable-Channel Multiaccess(TCMA) Network," ICC'93, paper 16.1, pp.166-171, Geneva, Switzerland, 1993

[5] K.W.Cheung, C.T.Yeung, W.K.Lam et al, "CUM LAUDE NET - A High-speed Multimedia Integrated Network Prototype", First ISMM international Conference on Multimedia and Distributed Applications, Hawaii, 1994

[6] K.W.Cheung, L.K.Chen, C.Su, C.T.Yeung and P.T.To, "Tunable-Channel Multi-Access(TCMA) Networks: A New Class of High Speed Networks Suitable for Multimedia Integrated Networking", SPIE Multigigabit Fiber Communication Systems, vol.2024, pp.122-133, 1993

[7] K.Kubota, H.Yokota and T.Tanaka, "Proposal of New Ring Access Control and Connection Admission Control Method," Electronics Letter, Vol.29, No.8, 15th, April 1993

[8] P.Pancha and M.El.Zarki, "Bandwidth Allocation Schemes for Variable-Bit-Rate MPEG Sources in ATM Networks," IEEE Trans. on Circuits and Systems for Video Technology, Vol.3, No.3, June 1993, pp.190-198

[9] M.Nomura, T.Fujii and N.Ohta, "Basic Characteristics of Variable Rate Video Coding in ATM Environment," IEEE Journal on Selected Areas in Communications, Vol.7, No.5, June 1989, pp.752-760

[10] B.Maglaris, D.Anastassiou, P.Sen et al. "Performance Models of Statistical Multiplexing in Packet Video Communications," IEEE Trans. on Communications, Vol.36,No.7, July 1988, pp.834-844

[11] H.S.Wang and Y.H.Wang, "A Generic Video Source Model and Its Statistical Multiplexing Properties," IEEE Workshop on Visual Signal Processing and Communications, New Brunswick, New Jersey, USA., September 19-20, 1994.

[12] Y.H.Wang, L.K.Chen, K.W.Cheung and H.S.Wang, "Performance of MPEG-1 Video On Multiaccess Integrated Network", Asia-Pacific Conference on Communications (APCC'95), Osaka, Japan, June, 1995

[13] W.E.Burr et al, "A Comparison of FDDI Asynchronous Mode and DQDB Queue Arbitrated Mode Data Transmission for Metropolitan Area Network Applications," IEEE Trans. on Communications, Vol.42, pp.1758-1768, 1994

[14] C. M. ARAS. et al "Real-Time Communication in Packet-Switched Networks", Proc.of the IEEE, vol.82, No.1, pp.122-138, Jan, 1994

[15] J.Liebeherr et al "Dual Bus MAN's with Multple-Priority Traffic", IEEE J. Selected Area in Commun., Vol.11, No.8, pp.1202-1213, Oct. 1993

[16] R.M.Watson and S.Ward "Prioritization in FDDI Networks ", Computer Communication, Vol.17, No.1, pp.35-45, Jan. 1994

Table 1. Delay of MPEG source for various constant bit rate sinks

Bit Rate	Average Delay	Maximum Delay
100Mbps	0.65 ms	2.36 ms
50Mbps	1.31 ms	4.72 ms
30Mbps	2.17 ms	7.86 ms
10Mbps	6.40 ms	23.3 ms
3Mbps	22.6 ms	78.5 ms
1.5Mbps	123.9 ms	277.1 ms

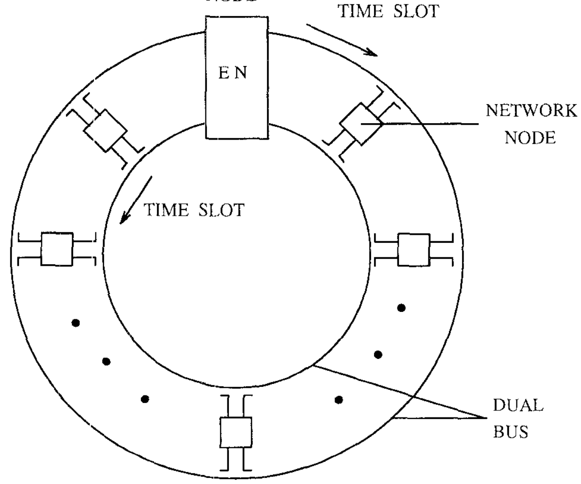

Fig. 1. ACTA Dual Looped Bus Network

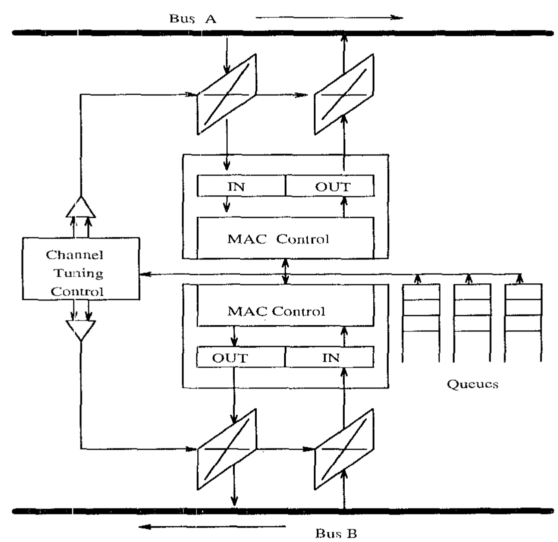

Fig. 2. ACTA Node Structure

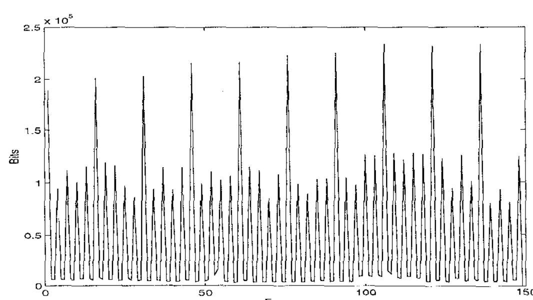

Fig. 3. Video Data of Real MPEG-1 Sequence: flower garden

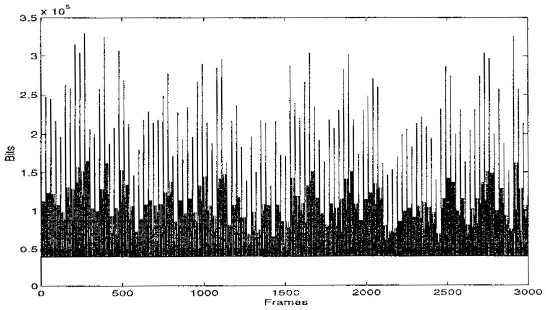

Fig. 4. Video Data Generated by CAR Model

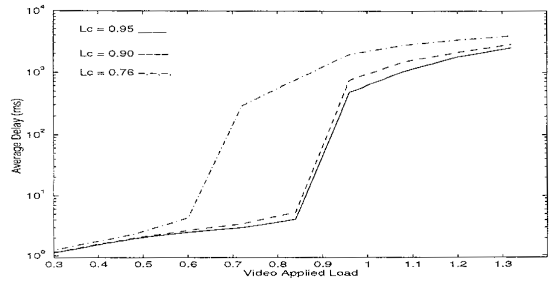

Fig. 8. Delay for Various Video Traffic Load

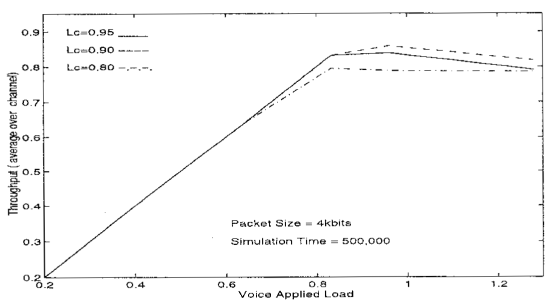

Fig. 5. Network Throughput for Voice Traffic

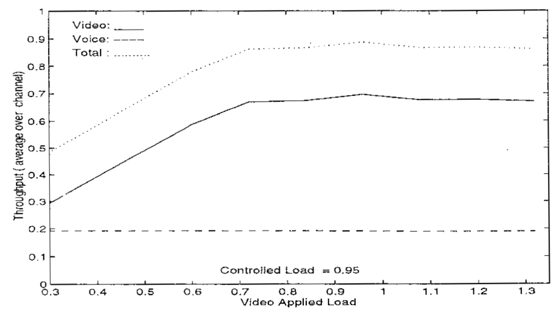

Fig. 9. Throughput for Integration of Voice and Video Traffic

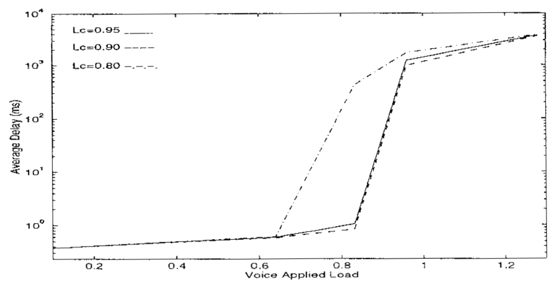

Fig. 6. Delay for Various Voice Traffic Load

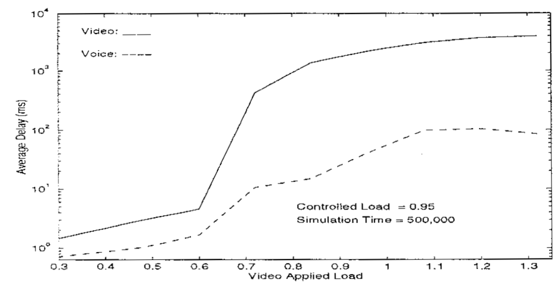

Fig. 10. Delay for Integration of Voice and Video Traffic

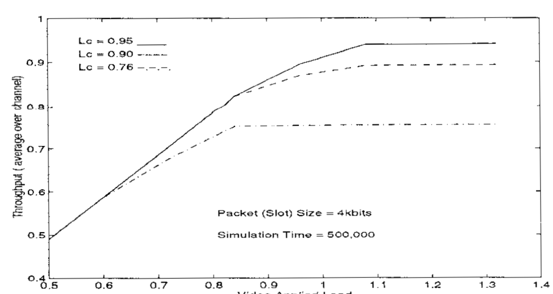

Fig. 7. Network Throughput for Video Traffic

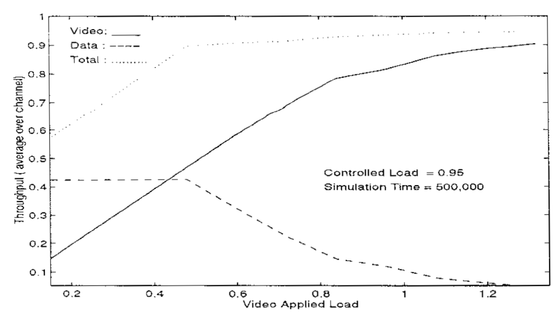

Fig. 11. Throughput for Integration of Video and Data Traffic