Performance Study of ACTA as an Efficient High Speed Multi-Channel Integrated Services Network

Yong-hong Wang Lian-kuan Chen Kwok-wai Cheung
Department of Information Engineering
The Chinese University of Hong Kong
Shatin, N.T., Hong Kong

Abstract — ACTA has been proposed for high speed multimedia network. It is a simple multi-channel network protocol suitable for photonic implementation. It adopts slotted cycle to transmit packets and the cycle length is dynamically adjusted according to the network load. We study the performance of the ACTA protocol both for single-channel and multi-channel integrated services operations. Through the simulations, we have shown that the overhead of channel tuning is quite small. We also study the priority mechanism of ACTA, and analyze the relation between the node transmission quota and bandwidth allocation. In addition, we present a slot reuse scheme which requires only one additional access control bit, and demonstrate great improvement in network utilization. The simulation results show that ACTA network is a very promising candidate for the future high speed multimedia networks.

I. Introduction

As optical technology such as WDM is becoming more and more mature, many multi-channel optical network prototypes have been proposed recently. Among them are RAINBOW-2, MWTN, AON, etc.[1], all of which use circuit switching and mainly focus on the transportation function. With the availability of the multi-channel network architectures, it is desirable to design a media access layer which supports fast packet switching for multimedia applications, and with efficient channel utilization and good performance.

Here we introduce the ACTA protocol which has been proposed for high speed multi-channel bus/ring network[2]. It uses slotted cycles to transmit packets on the network and the cycle length is adjusted according to the instantaneous network load to achieve optimum performance. It requires only two access-control bits in a time slot, thus the protocol can be made slot compatible to ATM and the network can be used as an ATM traffic concentrator. It also has low node complexity and simple processing, and is suitable for photonic multi-channel implementation [3]. A 100-Mbps single-channel electronic dual-bus implementation has been successfully demonstrated in the CUM LAUDE NET project [4]. In this paper, we study the performance of integrated services on the ACTA networks, in particular, we compare the performance between the single-channel and the multi-channel case. The single-channel case has been studied in detail previously [5]. We demonstrate a destination release scheme for the ACTA protocol which can improve the network performance substantially. This scheme only requires an additional access control bit for each slot.

The paper is organized as follows. Section 2 presents the ACTA protocol and discusses some important features including cycle utilization, controlled load (L_c) and node transmission quota (N_q) and slot reuse. Section 3 demonstrates the simulation model and presents the simulation results. Finally, section 4 is the conclusion of this paper.

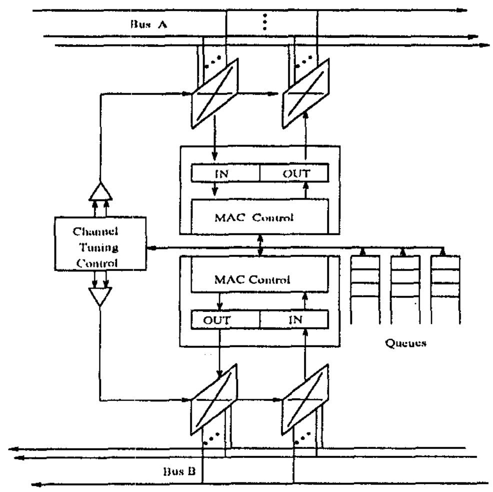

Fig. 1. The ACTA network node structure

II. ACTA Network

A. ACTA Network structure and Media Access Control

ACTA (Adaptive Cycle Tunable Access) protocol [2] was proposed as a media access protocol for multi-channel networks with bus or ring topologies. In this paper, we consider a dual-bus topology looped back to itself. Fixed size empty slots are continuously generated from the Head-of-Bus node in two directions of all channels. Each node consists of two pairs of receiver and transmitter modules, one for each bus as shown in Fig.1. The receiver modules are permanently connected to designated channels whereas the transmitter modules can be tuned to any output channel. In each node there are three queues for different outgoing traffic, namely voice, video and data. Each queue is divided into two individual subqueues for each direction.

Each module pair has two packets buffers, one for the transmitter and the other for the receiver. The network node reads in the packet from its channel at current time slot when the destination address of a packet in that slot matches its own address. For transmission, the media ac-

0-7803-3925-8/97 $10.00 ©1997 IEEE

cess procedure is described in [2].

Each node can be in one of the following five states:

1. IDLE - The packet queues are empty. There is no packet to be transmitted.
2. TUNING - The packet queues are not empty. The node transmitter is tuned to the channel where the outgoing packet is destined.
3. WAIT - The packet queues are not empty. The node waits for the start of a new cycle.
4. DEFER - The packet queues are not empty. A new cycle has already started, but the current slot is occupied.
5. ACCESS - The packet queues are not empty. The node is allowed to access the current empty slot.

Fig.2 shows the state transition diagram for a node. Although channel tuning is a transient state, we incorporate it into the state diagram to demonstrate the prominent characteristic of ACTA.

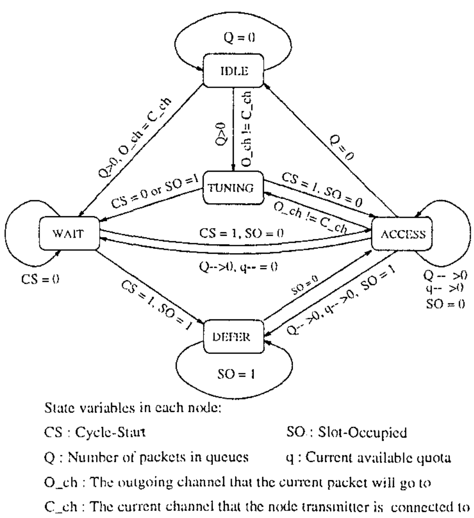

Fig. 2. State transition diagram of ACTA node operation

B. ACTA Cycle Utilization

A. Cycle Adaptation Algorithms

In ACTA networks, the cycle length is adjusted according to the network load as follows:

$$C_n = \frac{C_c \times U_c}{L_c} \tag{1}$$

where C_n is the new cycle length calculated through the above algorithm. C_c is the length of current cycle that the end node observed. U_c is the cycle utilization which is the number of slots used in the cycle divided by the cycle length, and the controlled load L_c is a parameter specifying the desired throughput under heavily overloaded condition. When the cycle utilization U_c is larger than the controlled load L_c, the new cycle length C_n will be increased. On the contrary, when the cycle utilization is smaller than the controlled load, the new cycle length will be decreased. From a statistical point of view, the maximum utilization is determined by the controlled load L_c.

B. Node Transmission Quota N_q

A network node with a larger quota can send more packets within one cycle, thus it can use more bandwidth than the other node with a smaller quota. To allocate the network bandwidth fairly, the simplest method is to allocate the same quota N_q to every node. Thus when the current cycle length is long enough, every node can send the same number of packets within this cycle as long as it has enough packets waiting in the queue.

Assuming uniform traffic distribution, the traffic loading for the two directions at each node is uneven. Upstream nodes could have more packets than downstream nodes have. If there is one kind of traffic on the network, the fairness can be kept efficiently by the adaptation of cycle length. However, if there are multiple traffic types in the network, the quota allocation among various nodes will affect the bandwidth allocation among different priority traffic. The upstream nodes will be starved for higher priority traffic while the downstream nodes will still have quota for the lower priority traffic. Thus, a better scheme should used which can adjust the node quotas to match the traffic distribution to eliminate this unfairness among different traffic priorities. We shall demonstrate a new quota allocation scheme for the single-channel network such that each node has a quota directly proportional to its node position. For multi-channel networks, the head-of-line blocking effect has to be considered. When a node tunes its transmitter to a new channel, it must wait for the new cycle start flag for that channel. Thus within a cycle, the traffic load on each channel will not follow the same distribution as for the single-channel case. In this situation, it is not straightforward to decide how to assign the quota to achieve fairness among various traffic classes. In our simulation of the multi-channel ACTA network, we will show that a uniform quota assignment for all nodes is sufficient to achieve a very good performance.

C. Slot Reuse Scheme

There are two common slot-reuse schemes, namely, the destination release scheme and the use of erasure nodes ([6] - [7]). We have studied the Destination Release method on the ACTA network. We here introduce an additional access control bit "Slot-Released" (SR) in each time slot. When a packet reaches its destination, the node will set the Slot-Released bit on the slot, and then release the slot at once for reuse by subsequent nodes. The end node then checks the Slot-Released bit of each slot to calculate the cycle utilization by counting the number of released slots and dividing it by the cycle length. The new cycle length can be computed by the same algorithm as in the case without slot reuse.

With slot reuse, the cycle utilization computed here does not correctly represent the bandwidth utilization in each cycle. However, the controlled load mechanism still works well. It dynamically introduces some unused bandwidth in every cycle to make sure that every node on the bus have an opportunity to send packet in the worst case. The cycle length becomes smaller than before due to the slot reuse, thus the network bandwidth can be utilized more efficiently.

Although the ACTA protocol is discussed on a dual-bus structure, it can also be used on a single ring topology. On a single ring, some packets may need to go through the head node to reach the destinations. The ACTA protocol can easily accommodate this situation. The end node simply forwards the packets that have not been read by their destinations to the new cycle during the cycle generation. Empty slot generation can be halted temporarily but will be resumed once the through traffic is forwarded. The cycle adaptation mechanism is still valid. This shows the flexibility of the ACTA protocol.

III. Simulation Results and Performance Analysis

We have performed the simulation for integrated services which include voice, video and data, and analyzed the throughput and delay performance. Data Traffic refers to non-real-time computer-related services. This kind of traffic can tolerate relatively long time delay but is sensitive to data error and is highly bursty. A model for data service called the Compound Poisson model is used for the simulation. In this model, the packets are generated in batches where the number of packets per batch follows a Poisson distribution, and the interarrival time among the batches also conforms to an exponential distribution. The data traffic is assigned the lowest priority. We consider voice as a constant bit rate (CBR) traffic, that has a 64-Kbps PCM format. Since the transmission of voice requires strictly bounded packet delay, we assign the highest priority to voice traffic. For video traffic, MPEG-1 video source is assumed. The MPEG-1 video shows both periodicity and randomness. In our simulation, the video data is generated through a recently proposed Cyclostationary Autoregressive (CAR) model [8]. The bit rate of each MPEG-1 sequence is 1.5 Mbps.

In our simulation, the ACTA network consists of 512 nodes and 8 channels. The bit rate is 100Mbps per channel. The packet size is 512 bytes. All time units, such as the simulation time, interarrival time and delay time, are normalized with respect to the slot duration τ_s. The simulation time is set to be 500,000. 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 and the traffic is assumed to be uniformly distributed in the network. The throughput is normalized to the bus capacity. We first present the performance of ACTA protocol for single traffic and then for integrated traffic.

A. Performance for Single Traffic Class

Comparison between Single-Channel and Multi-Channel

Fig.3 shows the average throughput and access delay versus applied load L for both single-channel and multi-channel ACTA networks. As the applied load increases, the throughput increases and approaches its maximum. In the single-channel network, if there are packets waiting in the queue, the node can use up its quota as long as it can find empty slot within a cycle. while in multi-channel networks, the transmitters have to tune from one channel to another according to the outgoing packets. Thus the cycle length of any channel will have a stronger relation to the burstiness of the input traffic. Because the channel tuning is not required, the single-channel network can provide a slightly better performance than the multi-channel case. In Fig.3, when applied load is smaller than the controlled load L_c, the throughput is the same for both single-channel and multi-channel networks, and the difference of delay is quite small (less than 10 time slots). Thus we can conclude that the difference in performance between single-channel and multi-channel ACTA network is not significant. The result is expected to be valid for other traffic classes such as voice and video.

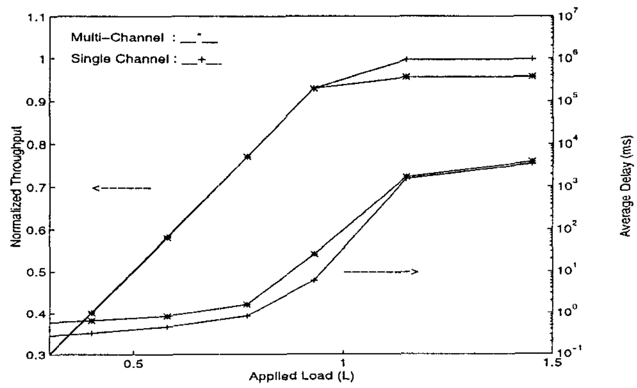

Fig. 3. Performance comparison between single-channel and multi-channel ACTA network for data traffic ($L_c = 0.95$)

Slot Reuse with Uniform Data Traffic Distribution

We have performed the simulation with destination released slot reuse. The packets are allowed to go through the end node. The result is given in Fig.4. The normalized throughput can be as large as 3.5 while the average delay is still quite small (63.3 ms). If the traffic increases further, the network throughput can approach 4, which is the theoretical limit. If the traffic is non-uniform but has higher locality, the slot reuse scheme will be more efficient[7]. Since the slot utilization is increased significantly by slot reuse, the cycle length is also much reduced. For example, when the applied load is 0.93, the average cycle length is 300 without slot reuse versus 19 with slot reuse. The average cycle length under different applied load is listed in Table 1.

The fairness issue for data traffic has been studied previously[2]. For applied load which does not exceed the controlled load (L_c) and is uniformly distributed, the fairness of ACTA network is quite good. We have studied the performance of voice and video (MPEG-1) traffic respectively, and made the comparison with leaky buckets[5]. Results showed that the ACTA network can accommodate both constant and bursty traffic very well and can serve as a traffic concentrator, say for a large ATM network.

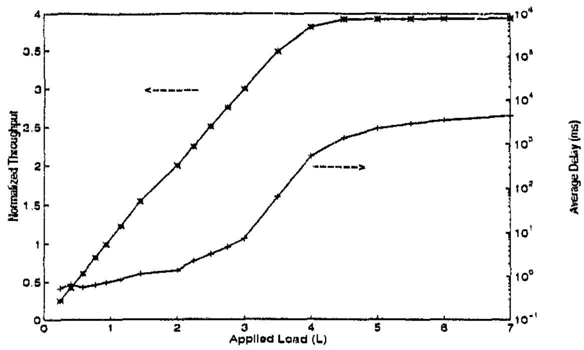

Fig. 4. Performance of ACTA network for data traffic with destination released slot reuse

L	0.5	0.7	0.9	0.95	1.0	1.25
C_l	13.0	13.2	19.0	151.9	189.6	232.2

(a)

L	2.00	2.25	2.50	2.75	3.00	3.50
C_l	82.4	125.5	160.1	169.2	195.2	239.9

(b)

Table 1. Average cycle length (C_l) at various applied load(L). (a) without the slot reuse. (b) with the slot reuse for uniform destination pattern.

B. Performance of Integrated Traffic

In our simulation model, the static order of priority scheme is used, when the integrated traffic is considered. This scheme has low complexity and can simplify the design and operation of the node. Thus it is suitable for high speed networks.

PCM Voice and Data with Non-Uniform Quota Allocation

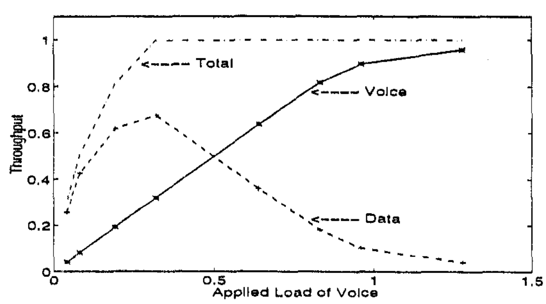

Fig. 5. Throughput for integration of voice and data traffic on single-channel with non-uniform quota allocation.

Fig.5 shows the throughput results for integrated voice and data. We assume traffic is uniformly distributed. In order to obtain a better performance in the ACTA network, a non-uniform quota allocation scheme has been used. The allocation of quota is directly proportional to the node position, that is, the upstream node has a larger quota while the downstream node has a smaller quota, in proportion to the expected traffic loading. The applied load matrix of voice and data used in the simulation is given in table 2. When the total applied load is smaller than the network capacity, all arriving packets are served. If the voice traffic keeps increasing, the throughput for data traffic will decrease after the total load reaches the value of the controlled load. Finally the data traffic is rejected and the whole network bandwidth is taken up by the high priority voice traffic.

No.	1	2	3	4	5	6	7
L_v	0.041	0.082	0.205	0.328	0.655	0.819	0.983
L_d	0.24	0.40	0.58	0.77	0.93	1.15	1.45

Table 2. Applied load matrix of voice (L_v) and data (L_d) traffic.

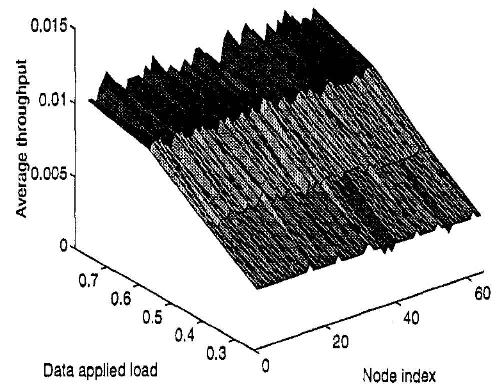

Fig. 6. Fairness of data in the integration of voice and data traffic (voice traffic referred to Table 2)

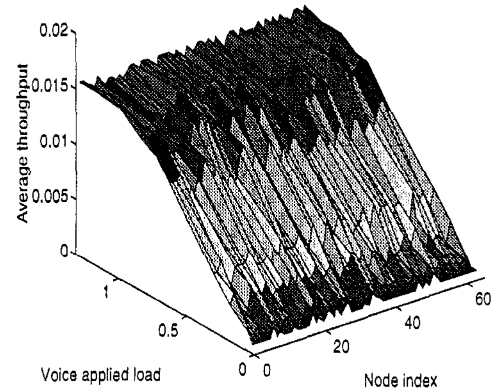

Fig. 7. Fairness of voice in the integration of voice and data traffic (data traffic referred to Table 2)

Although the quota is unevenly distributed among the nodes in one direction, for two directions, the fairness of bandwidth allocation is maintained fairly well as a whole due to symmetric allocation. Fig.6 and Fig.7 show the fairness results of various applied load for data and voice respectively. It is clear that good fairness can be achieved in ACTA networks as the bandwidth allocation of each node is independent of its physical position. When the total applied load does not exceed the network capacity, the data traffic is quite fair. If the total load is larger than the network capacity, the data traffic can only use the available bandwidth after the network has transmitted the voice packets, thus this shows some fluctuation in the throughput. This fluctuation is mainly due to the number of voice connections at each node which is a random multiple of 64 Kbps and has a certain amount of deviation.

PCM Voice and MPEG-1 Video

In the simulation, we use an MPEG-1 video source with a frame rate of 30 frames per second and an average bit rate of 1.5Mbps. Fig.8 and Fig.9 show the performance of the integration of voice and MPEG video, with voice having a higher priority. The applied load of voice traffic is assumed to be fixed (= 0.2). When the video traffic increases, the throughput of voice is stable, and the delay is small. This demonstrates that in ACTA network, the performance of higher priority traffic is independent of that of the lower priority traffic and it can support the static priority scheme very well.

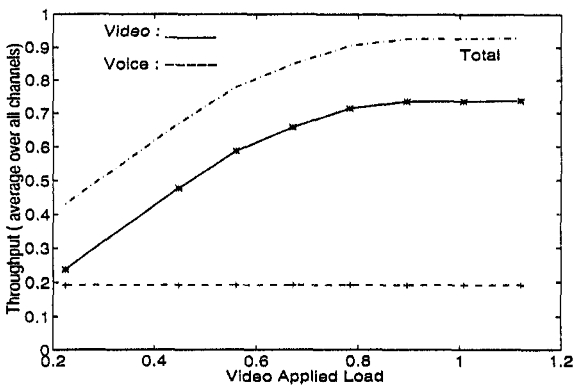

Fig. 8. Throughput for integration of voice and video traffic.($L_c = 0.95$)

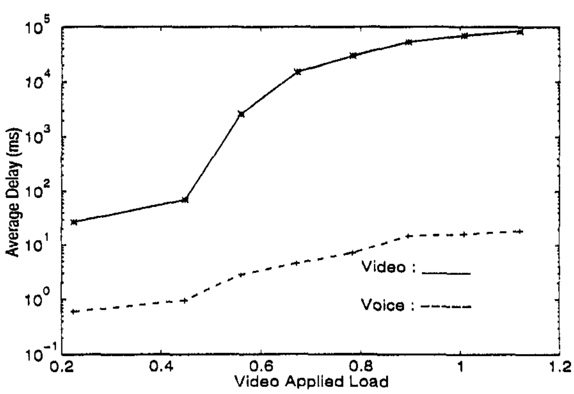

Fig. 9. Delay for integration of voice and video traffic. ($L_c = 0.95$)

IV. Conclusion

We have studied the performance of integrated services in ACTA networks, and show that ACTA is a simple and efficient network protocol. The protocol is suitable for networks with speed varying from several hundreds of Mbps to tens of Gbps. Each slot requires only two access-control bits for the case without slot reuse (Cycle-Start, Slot-Occupied) or three access-control bits (Cycle-Start, Slot-Occupied and Slot-Released), thus the protocol can be easily made slot compatible to many other standards such as ATM standard. The performance is independent of the round-trip delay time and the normalized throughput can be ≥ 0.9. The fairness can be maintained fairly well even under heavily loaded conditions. ACTA protocol can also employ slot reuse to increase bandwidth utilization. Multi-channel ACTA network can provide a large aggregated bandwidth with a very small channel tuning overhead. The simulation results show that ACTA network can support integrated traffic very well. Thus ACTA network is a very promising candidate for the future high speed multimedia networks.

References

[1] J. Paul E. Green, "Optical Networking Update," *IEEE J. Selected Areas Commun.*, vol. 14, pp. 764–779, June 1996.

[2] K. W. Cheung, "Adaptive-Cycle Tunable-Access(ACTA) Protocol: A Simple, High Performance Protocol For Tunable Channel Multiaccess(TCMA) Network," in *ICC'93*, vol. 1, Geneva, Switzerland, pp. 166–171, 1993.

[3] 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.

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

[5] Y.H.Wang, L.K.Chen, and K.W.Cheung, "Performance of Integrated Services on A High Speed Multimedia Network," in *GLOBECOM'95*, vol. 2, Singapore, pp. 780–784, 1995.

[6] M. W. Garrett and S. Q. Li, "A Study of Slot Reuse in Dual Bus Multiple Access Networks," in *IEEE INFOCOM'90*, vol. 2, pp. 617 – 629, 1990.

[7] M. A. Rodrigues, "Erasure Node: Performance Improvement for the IEEE 802.6 MAN," in *IEEE INFOCOM'90*, vol. 2, pp. 636 – 643, 1990.

[8] H. S. Wang and Y. H. Wang, "A Generic Video Source Model and Its Statistical Multiplexing Properties," in *IEEE Workshop on Visual Signal Processing and Communications*, New Brunswick, New Jersey, USA, Sept. 1994.