Architecture for Two-way Data Services Over Residential Area CATV Networks[1]

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ABSTRACT – *An architectural design for high speed residential data access using the traditional IEEE 802.3 medium access protocol over the existing CATV network is proposed. The described architecture is attractive in using the existing infrastructure combined with the exisiting access scheme in the residential area and thus it is cost effective and well suited for home internet access. However, the traditional CSMA/CD protocol is not suitable for the cable TV network due to its long propagation delay. Thus, we propose to combine the existing IEEE 802.3 CSMA/CD MAC with the segmented cable subnetworks so that a home user can get access to the internet as if he is using the Ethernet at* $10Mbps$*, or Fast-Ethernet at* $100Mbps$*. Only three subcarriers in the passband cable is used and therefore it will not interfere with the traditional broadcasting channels and the future digital video channels. The segmented cable are interconnected by the defined Cable Bridge (CB) and a simple flow control mechanism is proposed among the CBs. Functional components and operations of each CB will also be described. For a fair performance among the subnetworks, a prioritized queueing scheme is also proposed on each CB.*

1 Introduction

CATV (Community Antenna TV) networks are traditionally one-way, broadcasting, analog infrastructure for residential area TV distribution. However, two-way data access demands arise since more and more people at home want to make connections to the internet for WWW services. Internet services are becoming more and more popular not only to those special researchers, engineers, or students but also to all kinds of people who might want to make connections to the internet at home. Telephone modems have been used to provide this service to home but the access rate is limited to only several tens of $Kbps$. Another solution using cable modem over the existing CATV networks is receiving much attention in the industry. CATV network is the most important candidate for delivering integrated services to the subscribers as it is already installed at most of the families with a very high bandwidth available [1]. It can provide multiple channels in a single cable to carry analog or digital signals. Hence, it serves as a good infrastructure to connect the large number of home users who may be using the multimedia service, video broadcasting service, voice service, and the internet service [2], [3]. Many venders have been devoted to the design and manufacture of the cable modem which is intended for the data access over the cable.

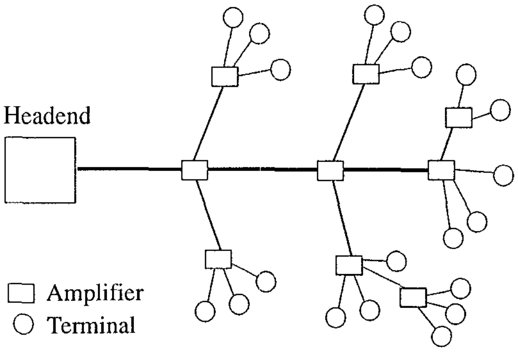

Figure 1: The tree-and-branch CATV networks.

The CATV network uses a tree-and-branch topology such that the number of users on the network is growable, as shown in Figure 1. Some amplifiers and splitters are required to extend the tree to each home user in the residential area. A head end is located at the end of the cable and it serves as a gateway between the cable and other signal sources such as ATM (Asynchronous Transfer Mode) backbone or the satellite channels. The cable is configured as a multi-channel bus using the frequency division multiplexing (FDM) technology [4], [5]. Each channel is referred to as a subcarrier which uses a passband of the frequency offset in the frequency spectrum of the cable. Digital data transmission can be achieved on each subcarrier by some modulation methods such as QPSK (Quadrature Phase Shift Keying) or Quadrature Amplitude Modulation (QAM). For two-way data services, some subcarriers are defined as the upstream channels for cable modems transmitting their data up to the head end and some other subcarriers are defined as the downstream channels for head end transmitting data down to each cable modem.

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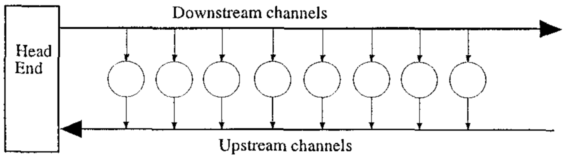

Figure 2: The logical structure of the CATV networks.

For simplicity, a CATV network is usually represented by a logical dual bus structure as shown in Figure 2. Since each subcarrier is a broadcast medium, there are contention problems in the upstream channel when multiple cable modems wish to transmit on the channel simultaneously. Several medium access methods have been proposed for the two-way services over the CATV networks [6], [7], [8]. Most of the proposed methods use contention resolution schemes such as ALOHA to resolve the collision among multiple cable modems. However, the schemes could be more complicated if one wants to obtain high throughput in broadcasting channels with long propagation delay, i.e., using the tree resolution algorithm [9]. Meanwhile, standardization activity has been undertaken by IEEE 802.14 project [10] and DAVIC (Digital Audio Visual Council) [11]. It usually takes a long time for the standard process to be formally finalized. And even the standard having been released, it is quite uncertain whether the standard protocol will be widely used or not. Besides, the development of a new protocol is costly and time-consuming.

In this paper, we propose to use the traditional IEEE 802.3 CSMA/CD protocol over the existing cable networks while maintaining the transmission rate at $10Mbps$ or higher. Since the geographical size of a residential area is quite larger than the maximum segment size of the Ethernet, the cable is configured by dividing the cable into segments which we refer to as the *Segmented CAble (SCA) Architecture* . The proposed architecture is attractive in its advantages of using the existing infrastructure in the residential area and thus it is cost effective and well suited for home internet access. The proposed scenario is achieved by using only three subcarriers in the passband cable without interfering with the traditional broadcasting channels and the future digital video channels. The segmented cable are interconnected by the defined Cable Bridge (CB). Flow control mechanism is required between two CBs. Functional components and operations of each CB will also be described in this paper.

2 The Segmented Cable Architecture

The Segmented Cable Architecture (SCA) is shown in Figure 3. The cable tree is divided into several subtrees which we call the *Cable Segment (CS)*. In addition to the amplifiers, between adjacent CSs there are *Cable Bridges (CB)* for connecting two subtrees. Within each CS, the CSMA/CD protocol can be used to resolve the collision on the cable as defined by IEEE 802.3B - the broadband version of the IEEE 802.3 [13]. Each CS has a *Maximum Segment Length (MSL)* to model the maximum propagation delay within this CS. Each CS is a tree as shown in Figure 4. The MSL is defined as the cable length of the deepest branch plus the second deepest branch. By limiting each CS's MSL, a higher throughput for data transmission can be guaranteed. For example, we can achieve $10Mbps$ in each CS if we set the MSL to 2.5 kilometer, or $50Mbps$ within 1 kilometer.

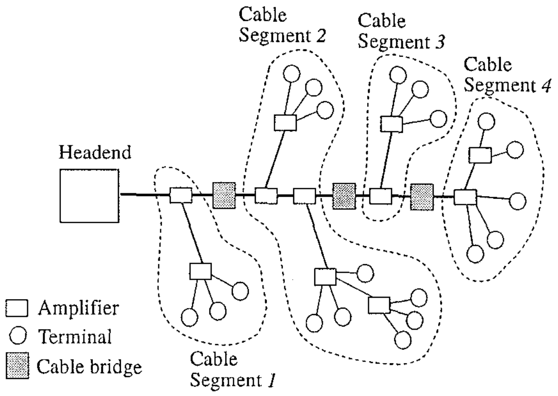

Figure 3: The segmented cable architecture for CATV networks.

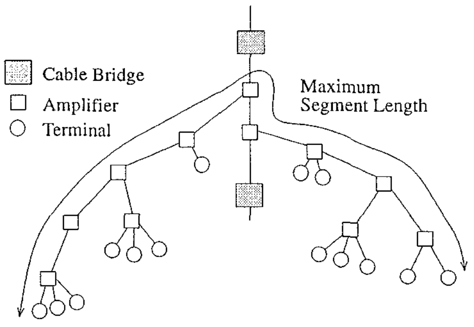

Figure 4: The maximum segment length of each CS.

Within each CS, all terminals are using the same subcarrier for upstream access. Therefore, CSMA/CD protocol is necessary for contention resolution in the upstream channel. We define the upstream subcarrier as *Channels A*, as shown in Figure 5 which explains the subcarrier configuration in a SCA network. In each CS, all terminals can communicate with each other in Channel A. For communications across two or more CSs, the packets are collected in each cable bridge and will be forwarded to the head end. Another subcarrier called *Channel B* is used to forward the inter-CS packets to the head end. And the head end will finally broadcast these packets to each CS using another downstream subcarrier called *Channel C*. To realize the architecture we may think Channels B and C as the superhighway along the cable and Channel A as the

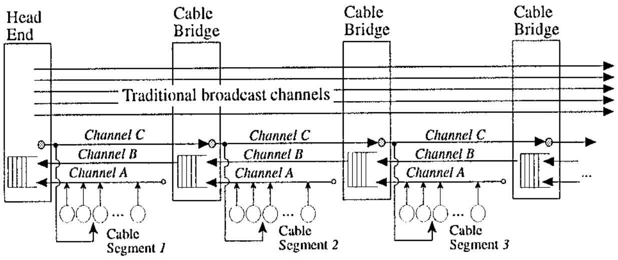

Figure 5: Subcarrier configuration in a SCA network.

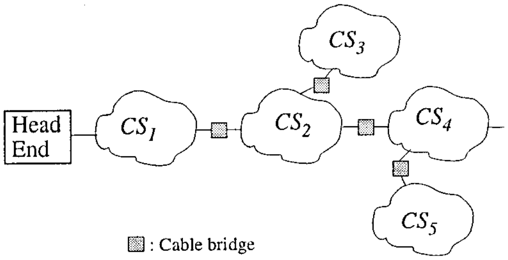

Figure 6: The logical tree structure of a SCA network.

branch which connects the local towns to the highway. To ensure the fairness along the superhighway, some gateway control mechanism is necessary. Since the packets are forwarded, some temporary buffers in the cable bridge is also necessary.

The proposed SCA network shown in Figures 3 and 5 is logically a cascaded bus network. A bus-type network is more simple to design, manage, and maintain. Several metropolitan area networks have been designed using a bus structure, i.e., IEEE 802.6 DQDB (Distributed Queue Dual Bus) [14], or the CRMA (Cycle Reservation Multiple Access) [15]. While these metropolitan area networks are also physically bus networks, they are hard to be installed and wired. However, the proposed SCA network is a logically bus-type and a physically tree-type networks. A physically tree-type network is very easy to install especially in the residential or metropolitan area.

Some designers would like also to have a logically tree-type network for reliability or management purpose. The proposed SCA network can be designed as a logically tree-type network, as shown in Figure 6. Here the Channel B is still used for inter-CS communications. For both tree-type and bus-type SCA networks, Channel C is used for downstream packet broadcast. Therefore, the bandwidth of Channel C may be several times greater than that of the Channel A or B, for example, using QAM (Quadrature Amplitude Modulation), or alternatively, using multiple channels for Channel C.

One problem arises in the bus-type SCA network, namely the reliability problem. Since these CBs are linearly cascaded, a fault in one of the CBs would cause the segments following that CB out of order. Thus, a bypass mechanism in the CB is

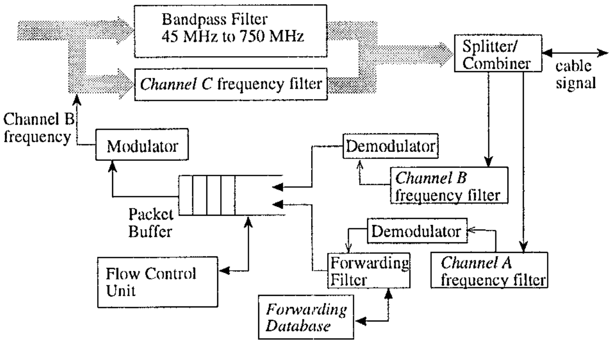

Figure 7: Functional block diagram of a cable bridge.

very essential when there is a fault or power failure occurred within the CB. This will be discussed in the next section.

3 Cable Bridge Architecture

Each cable bridge has a territorial CS. For simplicity, we call the cable bridges which are closer to the head end as the upper cable bridges or the upstream cable bridges, and those in the opposite side as the lower or the downstream cable bridges. Each cable bridge has the following functionalities:

1. Storing and forwarding the packets to upper cable bridge from its territorial CS in Channel A.
2. Storing and forwarding the packets to upper cable bridge from lower cable bridge in Channel B.
3. Broadcasting the packets from upper cable bridge to its territorial CS in the downstream Channel C.
4. Propagating the traditional TV signal to the lower cable bridges.

A functional block diagram of the cable bridge is shown in Figure 7, where several frequency filters are used for extracting the passband signals in which the Channels A, B, and C are modulated and transmitted. Another bandpass filter is used for bypassing the frequencies ranging from $45MHz$ to $750MHz$ which are used for traditional analog TV or future digital interactive TV. Modulation in Channels A, B, and C should be more reliable as the upstream signal can be very noisy. QPSK (Quadrature Phase Shift Keying) is a robust modulation scheme which is suitable for the upstream channel [11].

After recognizing a packet from Channel A or Channel B, the packet is forwarded to the packet buffer. Packets from Channel B are directly shifted into the buffer, while packets from Channel A are fed into the forwarding filter first. The forwarding filter is a mechanism used for distinguishing the packets to be forwarded from those packets which are only transmitted within the CS. A forwarding database is a lookup

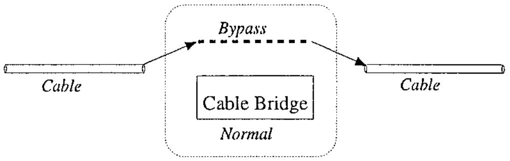

Figure 8: The bypass function of a cable bridge during a power failure condition.

table associated with each forwarding filter for the decision of whether forwarding the packet or not. Although there are proposed and standard methods for transparent bridge routing, we can still use a simpler method in the SCA network since the network topology is linearly cascaded . The learning of forwarding on each cable bridge depends upon the destination address it receives in each packet. There are three types of destination address sent on the cable, as follows.

1. **CASE 1:** Packets from CS or lower cable bridge destined for the head end to go outside of the cable. Usually in this case, the cable serves as a router.
2. **CASE 2:** Packets from this CS destined for another CS. In this case, the packets should be forwarded to the head end via Channel C.
3. **CASE 3:** Packets are transmitted only within the CS.

Packets should be forwarded in cases 1 and 2 and should not be forwarded in case 3. Each CS should maintain a forwarding database to control the packet filtering. The bridge learning scheme defined by IEEE 802.1d spanning tree algorithm can be used here. According to the scheme, the cable bridge can collect the source address located in its CS whenever there is a packet sent out by the users located in this CS. Furthermore, we don't need to establish the spanning tree since it is already there, the linear cascaded structure.

The flow control unit is responsible for resolving the congestion in the packet buffer since there are two input sources to the buffer. Also we should guarantee a fair access to the upstream channel in such a linear cascaded queueing system. The system can be modeled by a famous tandem queueing system which will be introduced in the next section. A simple flow control scheme will also be proposed after the next section.

To provide a more robust solution for the proposed SCA networks, a bypass mechanism may be designed as shown in Figure 8. During a power failure or a system fault condition in a CB, an automatic bypass system will be triggerred to pass the signal to or from its territorial CS. As a result, two adjacent CSs are combined into one CS and the speed of the related CS should be decreased by half.

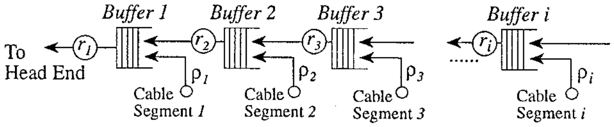

Figure 9: Tandem queueing in the SCA networks.

4 Tandem Queueing System

The tandem queueing system was encountered in most of the wide area packet switching network. It has been analyzed and the result is shown to be very complicated in terms of the end-to-end packet delay and the mean queue length [16], [17]. Here we use a very simplified approach to model the system. A tandem queueing system is represented in Figure 9, where *Buffer i* denotes the packet buffer in the ith cable bridge. Let the cable bridges be numbered from upstream to downstream, i.e, CB_1 to CB_i and so is each CS associated with each cable bridge, i.e., CS_1 to CS_i. Each *Buffer i* is associated with a server for sending the packets in *Buffer i* to *Buffer (i-1)* at a service rate r_i. Also let CS_i have an offer load ρ_i of sending packets to be forwarded. Suppose that there are all together n cable bridges, then *Buffer i* is loaded by an input rate of $\rho_i + r_{i+1}$. When $\rho_i + r_{i+1} > r_i$, an infinite queue length will occur. A discussion on performance consideration will be given based on M/D/1 queueing system in the next section. A flow control mechanism for preventing the congestion will be given following the next section.

5 Performance Consideration

If the transmission rate on Channel B is fixed, then we may think the server for outputting packets in *Buffer i* is a deterministic server. Let the service rate $r_i = 1$ for all i. Also let $\rho_i = \rho$, for all i. Then, the queueing system in each cable bridge is a standard $M/D/1$. Refer to [18], an $M/D/1$ queuing system with a deterministic service rate of 1 and an input utilization factor of ρ would have a mean queue length $\overline{q}$ equal to

$$\overline{q} = \frac{\rho}{1-\rho} - \frac{\rho^2}{2(1-\rho)} \tag{1}$$

CB_i is loaded by $(n-i+1)\cdot\rho$. Assume that the server in the $M/D/1$ queuing system is fairly shared by these $(n-i+1)$ traffic sources. Hence, the queuing system becomes a single server queuing system with a deterministic service rate of $1/(n-i+1)$. Let $\overline{q}_i$ represent the mean queue length of the *Buffer i*. The system can be approximated by the queue length of the $M/D/1$ system with a service rate of 1 and an input utilization factor of $\rho\cdot(n-i+1)$. That is

$$\overline{q}_i = \frac{\rho\cdot(n-i+1)}{1-\rho\cdot(n-i+1)} - \frac{\rho^2\cdot(n-i+1)^2}{2(1-\rho\cdot(n-i+1))} \tag{2}$$

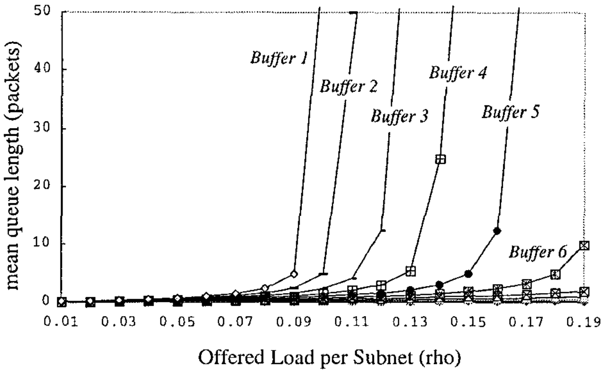

Figure 10: Mean queue length on each cable bridge.

In Figure 10, we plot the mean queue length of each cable bridge. We assume there are totally 10 CSs and each CS is producing a traffic load from 0.01 to 0.2. When the offered load is only 0.1, the mean queue length grows to infinite.

6 Flow Control

The proposed flow control scheme includes two parts, the prioritized queueing and the feedback policy. Let's assume a condition that $\rho_i = 1$ and $r_i = 1$ for all $i = 1, 2, ..., n$. In this case we have $\rho_i + r_{i+1} = 2 > r_i = 1$. If CB_i serves the packets from Channel A and Channel B with equal probability, then packets from CS_i will be served in an output rate of 0.5 in *Buffer i* and in an output rate of 0.25 in *Buffer (i-1)*. As a result, the equivalent service rate of the packets from CS_i in the first cable bridge is $1/2^{(i-1)}$. However, packets from the first CS has an equivalent service rate of $1/2$. This is an unfair condition to all of the terminals in each CS and it is the reason to propose a prioritized queueing scheme. Also we need a feedback scheme when the buffer space is insufficient to store the packet. The proposed feedback scheme prevents packet loss very simply and efficiently as described in the following text.

6.1 Prioritized Queueing

To prevent the unfairness as described above, the service rate for packets from Channel B and Channel A needs to be controlled. We refer to the packets coming from Channel B as the cross traffic and the packets from Channel A as the local traffic. *Buffer i* is reconfigured into two queues, *A-Buffer* for local traffic and *B-Buffer* for cross traffic, as shown in Figure 11. A scheduler is inserted before the server for controlling the service rate of each buffer. Let s_i denote the equivalent service rate for *A-Buffer* in CB_i, $s_i < 1$ for all i. Then the equivalent service rate for *B-Buffer* is $r_i - s_i$. For simplicity, we let $r_i = 1$ for all i. Also let u_i represent the equivalent service rate for packets from CS_i in the first cable bridge. Thus, we have

$$\begin{aligned} u_1 &= s_1 && (3)\\ u_2 &= s_2(1 - s_1) && (4)\\ u_3 &= s_3(1 - s_2)(1 - s_1) && (5)\\ u_4 &= s_4(1 - s_3)(1 - s_2)(1 - s_1) && (6)\\ &\cdots && (7)\\ &\cdots && (8)\\ u_n &= s_n(1 - s_{(n-1)}) \cdots (1 - s_2)(1 - s_1) && (9) \end{aligned}$$

For fairness, we must let

$$u_i = u_{(i+1)}, 1 \leq i \leq n - 1, \forall i \qquad (10)$$

As a result, we have

$$s_{(i+1)} = \frac{s_i}{1 - s_i}, 1 \leq i \leq n - 1, \forall i \qquad (11)$$

And

$$s_i = \frac{1}{n - i + 1}, 1 \leq i \leq n, \forall i \qquad (12)$$

That is,

$$\begin{aligned} s_1 &= \frac{1}{n} && (13)\\ s_2 &= \frac{1}{n-1} && (14)\\ s_3 &= \frac{1}{n-2} && (15)\\ s_4 &= \frac{1}{n-3} && (16)\\ &\cdots && (17)\\ s_{n-1} &= \frac{1}{2} && (18)\\ s_n &= 1 && (19) \end{aligned}$$

6.2 Feedback Control

The feedback mechanism is needed for *Buffer i* to send the congestion notification back to the traffic sources (both cross and local traffic) which are producing too many packets, for example, to make feedback on both CS_i and the $(i+1)$th cable bridge. When *A-Buffer* is running out, the feedback is sent on Channel A on which CS_i is transmitting, as shown in Figure 11. Since the CSMA/CD protocol is used on Channel A, the feedback signal can be sent by simply producing continuous redundant packets on the Channel. This can easily prevent terminals on the Channel from sending out packets since each terminal will sense a busy carrier. For *B-Buffer*, the same scheme can be applied and each cable bridge senses the carrier before it sending out the packets on Channel B. We refer to this kind of flow control as the *Implicit Feedback Flow Control (IFFC)*. The rule of IFFC method is as follows.

- Whenever the buffer is full, send the redundant packets (busy signals) on the input channel.

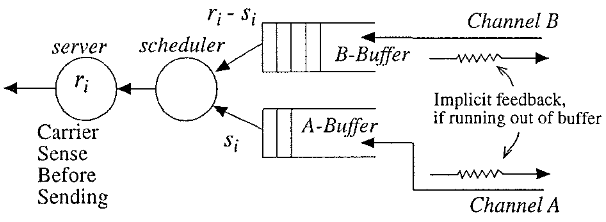

Figure 11: Prioritized queueing and implicit feedback flow control.

Therefore, each terminal on the input channel cannot send any packet out if the buffer is full, which means that no packet will be lost during the transmission to the headend. With this reliable flow control, the SCA system becomes a very robust interconnected network.

6.3 The Scheduler

There are two buffers in each CB and we have defined the equivalent service rate for each buffer, i.e., s_i for *A-Buffer* and $r_i - s_i$ for *B-Buffer*. However, the packets in these two buffers are to be sent on the same output channel. We need a scheduler to arrange the packets, as shown in Figure 11. A very useful scheduler can be used for our system, namely the *Generalized Processor Sharing (GPS)* server proposed in [19]. A Generalized Processor Sharing (GPS) server is work-conserving and operates at fixed rate r. It is characterized by positive real numbers ϕ_1, ϕ_2, ..., ϕ_N. Let $S_i(\tau, t)$ be the amount of session i traffic served in an interval $(\tau, t]$. A session is backlogged at time t if a positive amount of that session's traffic is queued at time t. Then, a GPS server is defined as one for which

$$\frac{S_i(\tau,t)}{S_j(\tau,t)} \geq \frac{\phi_i}{\phi_j}, j = 1, 2, \ldots, N \tag{20}$$

for any session i that is continuously backlogged in the interval $(\tau, t]$. Thus, session i is guaranteed a rate of

$$g_i = \frac{\phi_i}{\sum_j \phi_j} r \tag{21}$$

GPS is an attractive multiplexing scheme. However, analysis of a GPS system is quite complicated especially when it is combined with Tandem queueing system.

For simplicity, we still use an M/D/1 queueing system to approximate the SCA network. For any buffer with equivalent service rate $r < 1$, the mean queue length under input load ρ is approximated by the mean queue length of the buffer with a service rate of 1 under input load $\frac{\rho}{r}$. According to Equation (12), the equivalent service rate for *A-Buffer* of the ith CB is $\frac{1}{n-i+1}$. Let $\overline{qa_i}$ denote the corresponding mean queue length and $\overline{wa_i}$ denote the corresponding mean waiting time. By M/D/1 queue, we have

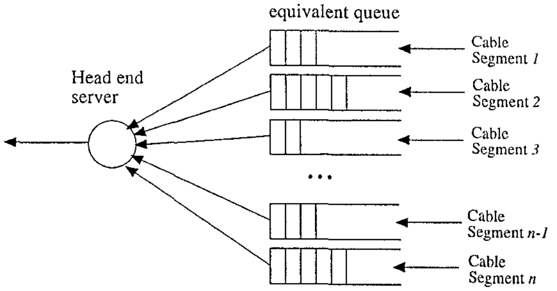

Figure 12: Equivalent queueing system for approximating the SCA networks.

$$\overline{qa_i} = \frac{\rho \cdot \beta_i}{1 - \rho \cdot \beta_i} - \frac{(\rho \cdot \beta_i)^2}{2(1 - \rho \cdot \beta_i)} \tag{22}$$

$$\overline{wa_i} = \frac{\rho \cdot \beta_i}{2(1 - \rho \cdot \beta_i)} \cdot t \tag{23}$$

where $\beta_i = n - i + 1$ and t represents the mean service time of the packets. For example, the service time of a $512 - Byte$ packet at $10Mbps$ transmission rate is $\frac{512 \cdot 8}{10^7} = 0.4096msec$.

Since it is an upstream access, packets are required to be transmitted to the head end. Packets from CS_i are stored and forwarded in between the $(i-1)$th CB and the first CB (the head end itself) as well as queued in the ith CB. To calculate the end-to-end performance from the ith CB to the head end, we define an equivalent queue for each CS, as shown in Figure 12. Packets from each CS are imaged as if they are queued in one equivalent queue and then transmitted directly to the head end server. Therefore, each CS_i has an equivalent mean queue length, denoted by Q_i, and an equivalent mean waiting time, denoted by W_i. Assume that CS_i has an offer load ρ, we approximate Q_i by the summation of the following two terms:

1. $\overline{qa_i}$
2. $\overline{qb_j}, j = 1, \ldots, i-1$

where $\overline{qb_j}$ is defined as the mean queue length of the *B-Buffer* of the jth CB with service rate $r_j - s_j$ under input load ρ on each CS_i. When $r_j - s_j < \rho$, $\overline{qb_j}$ grows to infinity. This means $Q_i \to \infty$. When $r_j - s_j > \rho$, we add the queueing effect that each *B-Buffer* of the jth CB is imaged as if it is loaded by ρ. Then, Q_i can be approximated by

$$Q_i = \overline{qa_i} + \sum_{j=1}^{j=i-1} \overline{qb_j}, \tag{24}$$

where

$$\overline{qb_j} = \frac{\rho \cdot \alpha_j}{1 - \rho \cdot \alpha_j} - \frac{(\rho \cdot \alpha_j)^2}{2(1 - \rho \cdot \alpha_j)} \tag{25}$$

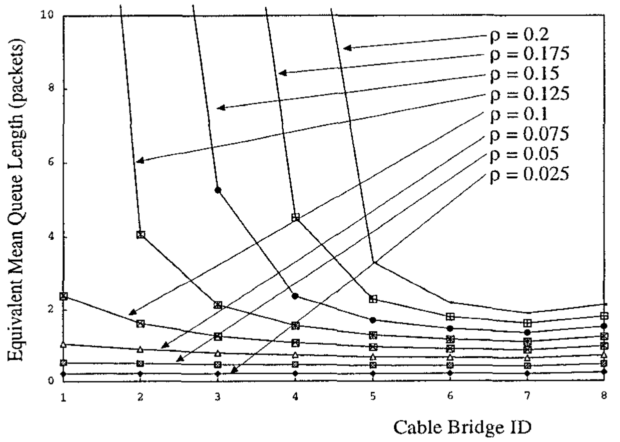

Figure 13: Equivalent mean queue length of each cable bridge.

$$\alpha_j = \frac{n-j+1}{n-j} \tag{26}$$

The same approach can be applied to the approximation of the equivalent mean waiting time W_i. We have

$$W_i = \overline{wa_i} + \sum_{j=1}^{j=i-1} \overline{wb_j}, \tag{27}$$

where

$$\overline{wb_j} = \frac{\rho \cdot \alpha_j}{2(1-\rho \cdot \alpha_j)} \cdot t \tag{28}$$

Where $\overline{wb_j}$ is the waiting effect that each CB contribute to the total waiting time W_i.

In Figure 13, we plot the equivalent mean queue length under offer load ρ for *CSs 1 to 8*. The offer load ρ is in between the range of 0.025 to 0.2. When $\rho = 0.1$, the equivalent mean queue length of each CB is under 3 packets. Since there are 8 CBs sharing the single upstream channel B, the total utilization is 80% and each CS fairly shares the upstream bandwidth. When ρ grows higher, the equivalent mean queue length of some CBs becomes infinite large. In this case, the IFFC will be effective to prevent the packet loss.

In Figures 14 and 15, we plot the equivalent mean waiting time under offer load ρ for *CSs 1 to 8*. The offer load ρ is again in between the range of 0.025 to 0.2. In Figure 14, we show the result by assuming a fixed packet size of 512 bytes. Each CS is operated at $10Mbps$. When $\rho = 0.1$, the equivalent mean waiting time of each CB is under $4msec$. In Figure 15, the packet size is set equal to 1024 bytes. The result is similar. The equivalent mean waiting time of each CB is under $8msec$.

7 Conclusion

In this paper, The segmented cable architecture for high speed internet access in the residential area is described in

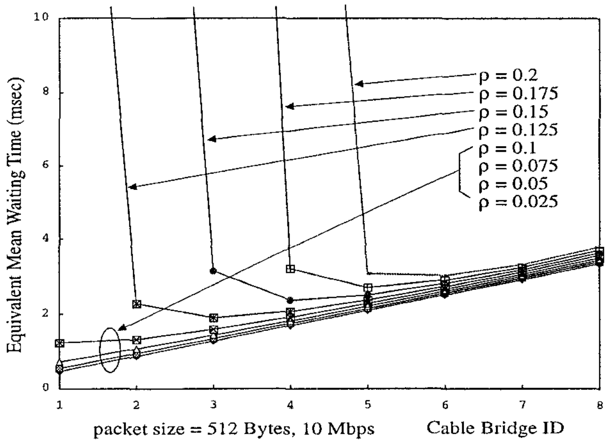

Figure 14: Equivalent mean waiting time of each cable bridge (packet size = 512 bytes).

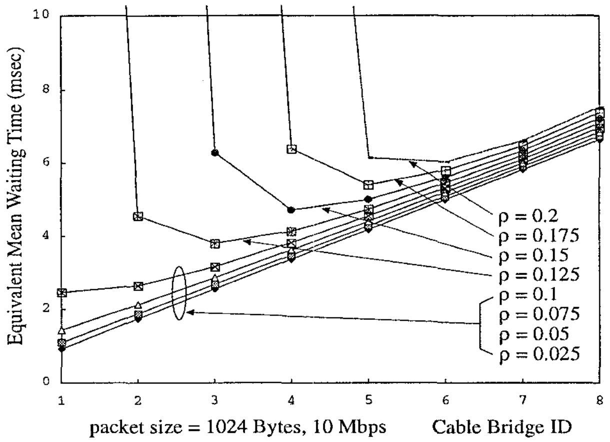

Figure 15: Equivalent mean waiting time of each cable bridge (packet size = 1024 bytes).

this paper. The proposed architecture is attractive and very cost-effective in its advantages of using the existing CATV infrastructure and the traditional IEEE 802.3 CSMA/CD MAC protocol. We use very simple flow control scheme and prioritized queueing to prevent the congestion of the tandem queueing effect in the proposed system. This makes the proposed system a reliable and robust network for home internet users.

The proposed SCA network has the following attractive characteristics:

1. *The proposed SCA network is a physically tree-type network and can be logically configured into bus-type or tree-type network.*
2. *The cost of the network is low as the CATV networks have been already installed in most of the residential areas.*
3. *Since the cable is segmented, bandwidth can be reused.*
4. *The user population on each CS is not big because the geographical area of each CS has been controlled. Besides, each CS operates at a higher bit rate, then each terminal gets more bandwidth from the shared channel.*
5. *The speed is adjustable. For example, we may limit the size of each CS in* $500m$*, so that each CS can operate at* $50Mbps$ *using CSMA/CD.*
6. *The noise problem on the upstream channel can be eliminated because cable bridge regenerates the signals on the channel. This implies that the channel modulation scheme which results in a higher transmission rate can be used, e.g., QAM.*

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