A Prioritized Random Access Scheme for DOCSIS-based HFC Network With Modified Back-off Algorithm

*Jinuk Sun, +Seung-eun Hong, and +O-hyung Kwon
*University of Science & Technology, Daejeon, Korea
+Electronics and Telecommunications Research Institute (ETRI), Daejeon. Korea
{pwsun, iptvguru, ohkwon}@etri.re.kr

Abstract

In DOCSIS (Data-Over-Cable Service Interface Specifications)-based HFC (Hybrid Fiber Coaxial) networks, CMs (Cable Modems) can obtain transmission opportunities by successfully sending a transmission request to CMTS (Cable Modem Termination System) in contention area. In usual practice, CMs access CMTS without utilizing their priorities although the priorities are allocated to all CMs. And this makes the high priority CMs obtain a bandwidth later than the low priority CMs.

In this paper we present an algorithm in which the high priority traffic can access CMTS earlier than the low priority traffic by modifying the method of selecting a back-off value.

To simulate this algorithm, OPNET 11.5 and DOCSIS library were used.

1. Introduction

With the recently rapid growth of need for many applications which require very wide bandwidth like Video on Demand (VoD), Voice over IP (VoIP), teleconference, online games and big file transfer service, it is necessary to access the broadband network that can support the demand of the services. The HFC network is the most widely used internet service to region internet users with xDSL (Asynchronous/Very High Speed Digital Subscriber Line) [1], FTTx (Fiber To The Home/Curb/Building) [2], and etc.

Since the Community Antenna Television (CATV) infrastructure, especially, already connects to a majority of homes, the HFC network used in the CATV has an advantage that it's possible to access the internet by just adding a cable modem without setting up the separate lines.

CATV network has the tree-and-branch topology. In the upstream direction, it is a point-to-multipoint form, and a multipoint-to-point form in the downstream direction. The CMTS, at the root of the tree, manages all traffics over the HFC network. All the CMs of subscriber that

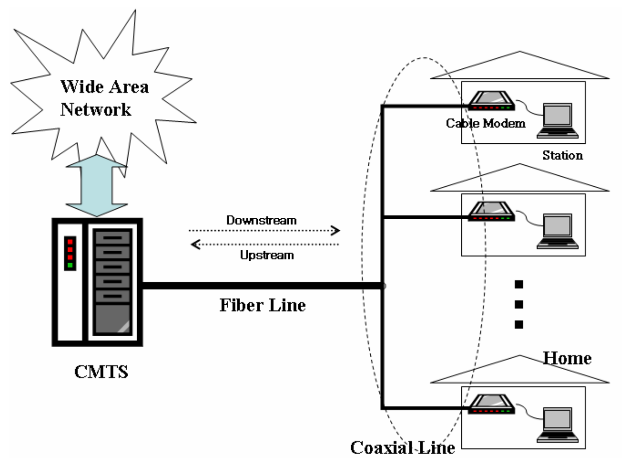


Figure 1. HFC network architecture

hope to join the network are connecting to the CMTS. They share the upstream channel by using a Time Division Multiple Access (TDMA) mode with dynamic bandwidth allocation.

Many protocols to support a control of exchanging the IP packet over HFC network were proposed. There exists DOCSIS [3],[4], the Digital Audio Visual Council (DAVIC) [5], the IEEE 802.14 [6],[7], Digital Video Broadcasting (DVB) [8], and etc. Among these standards, DOCSIS is the dominant specification and leading a market. DOCSIS has been developed and is being updated continuously by Multimedia Cable Networks Systems (MCNS) and CableLabs. DOCSIS 1.0, the first version, provides a best efforts service with simple prioritization. DOCSIS 1.1 supports various quality of services (QoS) for real-time traffic. Recently, CableLabs has finalized DOCSIS 3.0 that supports channel bonding which can increase the speed of internet by binding several channels.

The paper is structured as follows. Section 2 has an overview of the DOCSIS upstream operation. In the Section 3, we propose a modified back-off algorithm for prioritized random access in the DOCSIS protocol. Section 4 describes our experimental configuration and reports our results. Finally, Section 6 brings to a conclusion of our work.

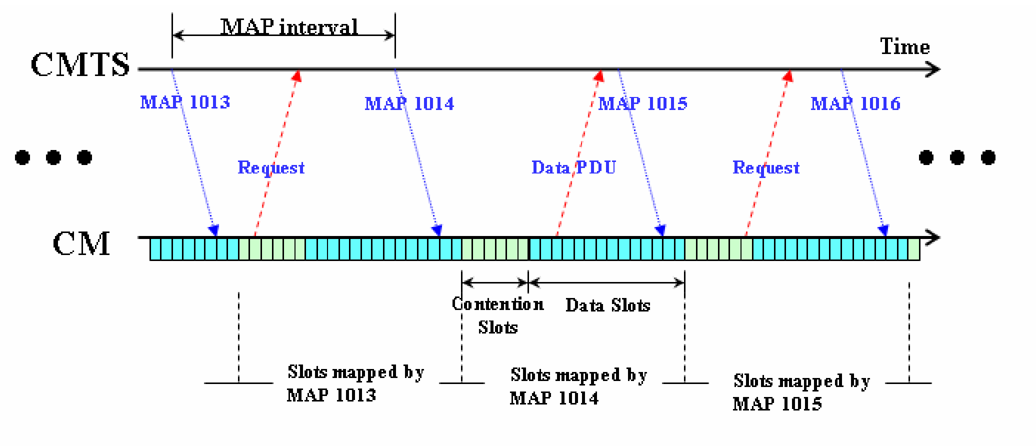


Figure 2. Upstream operation of the DOCSIS MAC protocol

2. DOCSIS Upstream Operation

Because of the topology of HFC network (multipoint-to-point, on upstream), a collision occurs when multiple CMs try to send their data at the same time to the CMTS. For reducing the chance of collision and for efficient scheduling services, six QoS types are defined.

- **Unsolicited Grant Service (UGS)** supports real-time service flows that generate fixed size data packets on a periodic basis, such as Voice over IP.
- **Real-Time Polling Service (rtPS)** supports real-time service flows that generate variable size data packets on a periodic basis, such as MPEG video
- **Unsolicited Grant Service with Activity Detection (UGS-AD)** supports UGS flows that become inactive for substantial portions of time, such as Voice over IP with silence suppression.
- **Non-Real-Time Polling Service (nrtPS)** supports non real-time service flows that require variable size data grants on a regular basis, such as high bandwidth FTP.
- **Best Effort Service (BE)** provides efficient service to best effort traffic.
- **Committed Information Rate (CIR)** can be defined a number of different ways.

UGS, rtPS, UGS-AD and nrtPS avoid request contention by an unsolicited grant/polling mechanism. Only during BE service, there occur collisions because of using req-uest contention for getting a bandwidth.

Once a bandwidth request successfully arrived at the CMTS, the CMTS allocates a bandwidth and notify by sending allocation MAP message to the CM periodically. MAP consists of contention slots and data slots (see Figure 2). Contention slots describe when and how many times CM can send a transmission request. A CM allocated a bandwidth can transmit its data within data slot.

When a CM wants to transmit a request on the conte-ntion area, before sending, it has to scan the whole MAP for finding the contention slots. (In these slots, informa-tion which a CM can have a chance to transmit its bandwi-dth request is recorded. If the slots are intended for unica-st, this is an invitation for a particular CM. If for broadca-st, any CMs can transmit.)

After that, it has to execute binary exponential back-off window algorithm. The beginning of this algorithm is cho-osing a random number within an initial window. After deferring its transmission opportunity as the selected num-ber, CM can transmit its request. If a CM does not receive any response (grant or pending) to its request from the CMTS, it assumes that a collision occurred. Then the CM doubles its back-off window size and retries the procedure. The window size can be increased to the maximum size specified by MAP message. This process has to be repea-ted for a maximum of sixteen times. If the number of retry passed sixteen, the packet will fall into disuse.

The CMTS schedules data slots with reference to pa-ckets successfully arriving at CMTS without a collision. The scheduled information is recorded in the next MAP and transferred to the CMs through the downstream. The CMs scan the MAP for their grant or grant pending message. If a grant is found in the MAP, the CM sends its data PDU at exactly scheduled time. If a grant pending is found, the CM waits for the next MAP without sending the request again.

3. Modified Back-off Algorithm

In DOCSIS MAC protocol, the probability distribution shows uniform when a random number is generated for executing the binary exponential back-off algorithm. This makes that the probability of any value being selected within the contention window is identical. The selected radom value is the number of transmission opportunities that a CM defers before transmitting a request.

That is, the access delay to the CMTS is in proportion to this number because a transmission is delayed proportionally to the number. There is no correlation with the priority of a CM and access delay.

We propose a new back-off algorithm for prioritized random access over DOCSIS cable network in this paper. The CMs with the highest or lowest priority use the exponential distribution and the others use normal distribution instead of the uniform distribution when calculating the random numbers. The following equations indicate exponential (1) and normal distributions (2).

$$f(x) = \begin{cases} \lambda e^{-\lambda x}, & x > 0 \\ 0 \quad , & \text{o.w.} \end{cases} \tag{1}$$

$$f(x) = \frac{e^{-((x-\mu)^2/(2\sigma^2))}}{\sqrt{2\pi}\sigma} \tag{2}$$

where μ = mean, σ = deviation

The exponential distribution and the normal distribution weight a selection probability of back-off value to an intended position. About 95% of the values are within two standard deviations away from the mean ($\mu - 2\sigma \sim \mu + 2\sigma$) in the normal distribution. That is, the random value of 95% can be generated in the determined period. In Figure 3, for normal distributions we have to determine a mean value and a deviation value to meet this condition. A mean value is located at the center of each period, $\mu = \frac{Window\_size}{Max\_pri+1} \times (Max\_pri - my\_pri + 0.5)$.

Because the size of each area is 4 times of a deviation value, the deviation value is expressed as

$$\sigma = \frac{Window\_size}{(Max\_pri+1)\times 4} \times \frac{Max\_pri+1}{All\_CMs} \times CMs .$$

Where All_CMs is the total number of the CMs joining the network and CMs is the number of CMs that have the identical priority to this CM. Wen-Kuang Kuo have explained the estimation of contenting CMs [9].

For the exponential distribution, to meet the same condition as the normal distribution (95% of selection probability), we find mean and deviation value by the following cumulative distribution function (CDF).

$$F(x) = 1 - e^{-\lambda x} = 0.95 \tag{3}$$

Thus, $x \cong \frac{3}{\lambda}$, where x is the size of the area of the

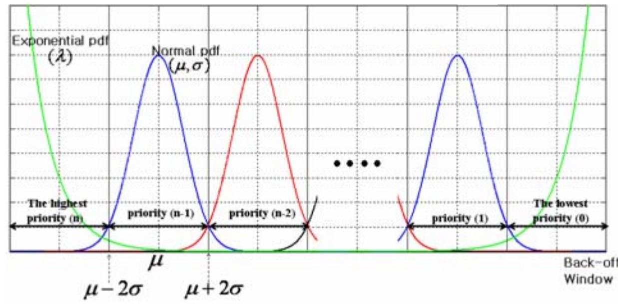


Figure 3. Exponential and Normal distribution for multi-level priority

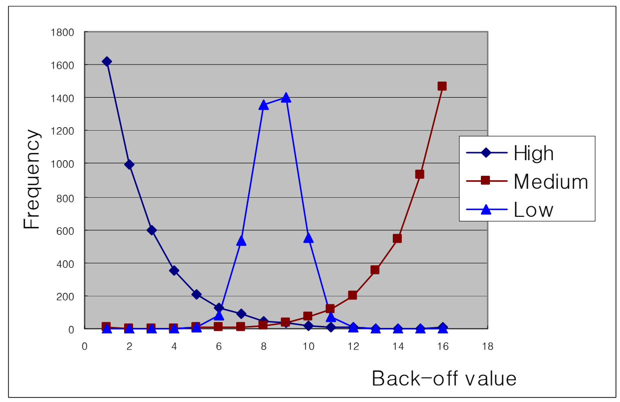


Figure 4. Distribution of the back-off value

highest or lowest priority since

$$x = \frac{Window\_size}{Max\_pri+1} \times \frac{(Max\_pri+1)\times CMs}{All\_CMs}$$

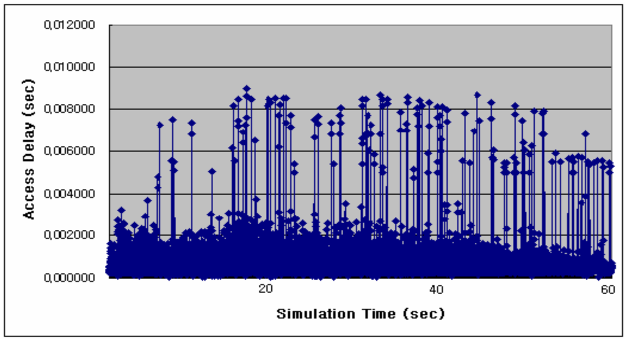
$$= \frac{Windows\_size \times CMs}{All\_CMs}$$

and $\mu = \sigma = \frac{1}{\lambda}$,

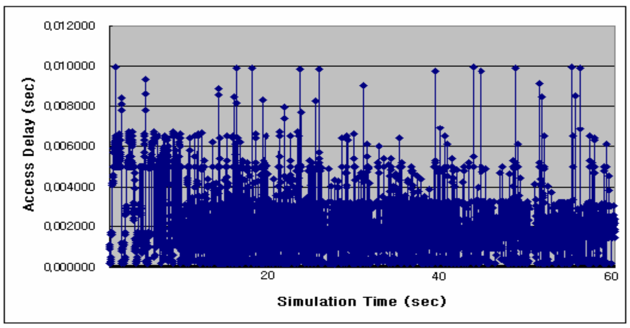
$$\mu = \sigma = \frac{All\_CMs \times 3}{Window\_size \times CMs} .$$

When determining the variances of the exponential and normal distributions, we take the portions of CMs having the specific priority among the all CMs into consideration. If the rate is high, the variance has a large number. This is why collision probability of the period increases when CMs trying to transmit in the period of a constant size increase. The mean outcome is the most frequently appeared number. If a CM has a medium priority, its mean outcome of the pdf will be a center value of the window. They are determined as follows.

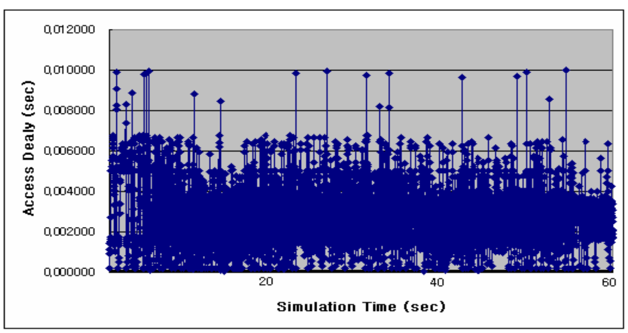
For example, a CM whose priority is 2 has the normal distribution with 48 of mean and 4 of variance within the 64 of window size. This makes that a CM can control its access delay by itself because it has the ability to choose back-off value by its priority.



(a) High Priority



(b) Medium Priority



(c) Low Priority

Figure 5. File Transfer Protocol Traffic

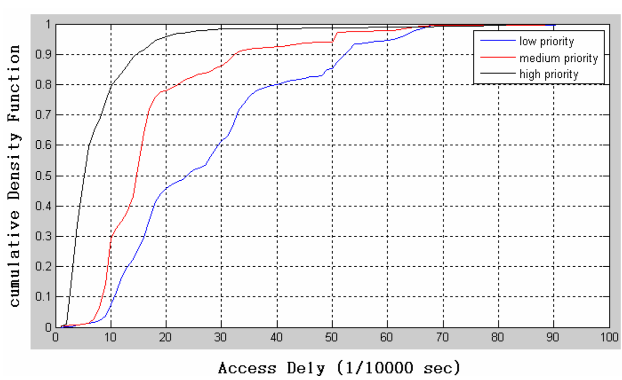
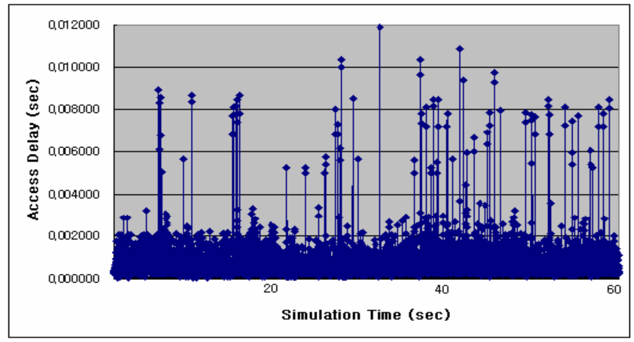
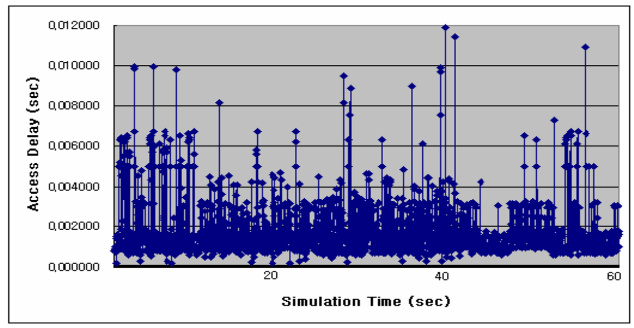


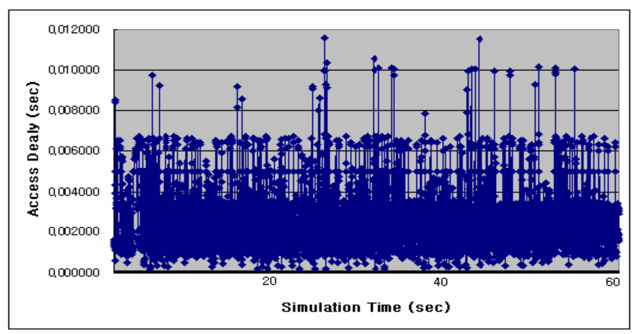
Figure 6. CDF, FTP



(a) High Priority



(b) Medium Priority



(c) Low Priority

Figure 7. Database Access Traffic

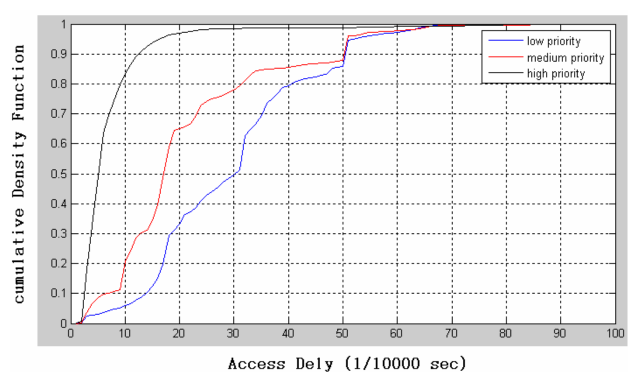


Figure 8. CDF, Database Access

MAP Inter-arrival Time	0.005 sec
Upstream Data Rate	1.28 Mbps
Data Back-off Start/End	5/8
Number of Contention Slots	32
Number of high priority CMs	20
Number of medium priority CMs	20
Number of low priority CMs	20
Run Application	FTP, Database access
Simulation time	60 sec

Table 1. OPNET Simulation Parameters

Figure 4 shows a graph in which the data was appeared by OPNET standard library. The x-axis means the generated back-off values and the y-axis means their appeared frequencies. Almost all of the back-off values are generated at both of the edges for the exponential distribution and at the center of the window for the normal distribution.

4. Simulation and Results

OPNET 11.5A provides with an excellent environment for simulating a DOCSIS network scenario. In our simulation, we have consisted of a HFC network with a CMTS connecting an IP network and 60 CMs that were divided into three classes of priority (high, medium, and low). The set parameters for this scenario are shown in Table 1.

The file transfer protocol (FTP) traffic data has been generated for 60 seconds. As shown in Figure 5 (a) ~ (c), we can confirm that the access delays to CMTS are different according to the priorities. The access delay means how long it takes time for a packet to arrive to the CMTS from a CM without a collision. If a collision occurs during a transmission, the access delay will increase.

Overall the access delay of high priority traffic, as expected, is the smaller than those of medium and low priorities. But this is not always true. In figure 5.(a) and 7.(a), there exist some points that show the access delays are much larger than the average even though they are high priority traffics. This is why there remains a very small probability choosing a large back-off value when a number is generated by the exponential distribution. Moreover, every time a collision is occurred, the access delay is accumulated. In the same manner, there are very small access delays at low priority traffic as shown in Figure 5.(c) and Figure 7.(c).

In Figure 6, we can confirm definitely the difference between high priority and medium (or low) priority from the cdf (cumulative density function) curves. Ratios of 2ms or less access delay are 96% for high, 78% for medium and 46% for low priority traffics.

For a database access application, we have met the similar results with the ftp application in Figure 7 and 8.

5. Conclusion

In this work, we have given an overview of the DOCSIS protocol and proposed a modified algorithm for prioritized random access over HFC cable network. We have shown that the high priority traffic can access earlier than the low priority traffic by using the proposed algorithm.

6. References

[1] Humphrey. M., and Freeman, J., “How xDSL supports broadband services to the home”, *IEEE Network*, Jan.-Feb, 1997, pp.14~23.

[2] Koonen, A.M.J., “Technologies and Applications of FTTx”, *IEEE Lasers & Electro-Optics Society*, Oct. 2006, pp.294~295.

[3] CM-SP-MULPIv3.0-I03-070223, “Data-Over-Cable Service Interface Specifications DOCSIS 3.0”, Cable Television Laboratories, Inc, May. 2007.

[4] [Online] Available: http://www.cablemodem.com/

[5] Yasuda, H., Ryan, H.J.F., “DAVIC and interactive multimedia services”, *IEEE Communications Magazine*, Sept. 1998, pp.137~143.

[6] J. Eng, and J. Mollenauer, “IEEE project 802.14: Standards for digital convergence,” *IEEE Commun. Mag*., vol. 33, Apr. 1995, pp.20 ~ 23.

[7] IEEE Project 802.14/a, IEEE, 1998.

[8] Interaction Channel for Cable TV Distribution Systems (CATV), ETSI Digital Video Broadcasting (DVB) Group, 1998.

[9] Wen-Kuang Kuo, Sunil Kumar, and C.-C. Jay Kuo, “Improved Priority Access, Bandwidth Allocation and Traffic Scheduling for DOCSIS Cable Networks”, *IEEE Transaction on Broadcasting*, vol. 49, Dec. 2003, pp.371~382