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# Improving TCP Performance of DOCSIS Based Broadband Networks

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**Abstract:** Data-Over-Cable Service Interface Specifications (DOCSIS) is developed for data transmissions over cable networks; it is intended to support IP flows with significantly higher data rate links for high quality data, audio, video and interactive services. It is important to provide traffic scheduling mechanisms to support Quality of Service (QoS) for such applications. This study analyses the TCP performance over DOCSIS protocol in HFC broadband networks and also proposes an algorithm to improve the TCP performance. Simulations were in done in ns-2 with simple modification in MAC layer. The result proves that the proposed algorithm have less access delay, good throughput and good channel utilization when compared existing DOCSIS protocol.

**Key words:** Cable modem, cable modem termination system, hybrid fiber coaxial networks, data over-cable service interface specifications

## INTRODUCTION

By taking benefits of the existing broadband access techniques, cable network operators are in a unique position to compete with several other access technologies such as xDSL, ADSL and ISDN, etc. However, the key to success for cable modems is the ability to offer more than just best effort service and deliver voice and video services in addition to high-speed access (Golmie *et al*., 1999) and CATV infrastructure already connect a majority of homes and the Hybrid Fiber Coaxial (HFC) used in CATV networks can be used to deliver broadband services without requiring costly upgrade of existing network (Kuo *et al*., 2003).

Cable Operators, in the early 1990's saw the growth of cable networks and were driven to explore possibilities for transmitting data from the residential user to the service provider. By providing this capability, packet based services such as high speed internet access, video on demand and video conferencing could be used. This led to the formation of many research groups. Multimedia Cable Network System (MCNS), a collaboration of cable companies, was the first to come up with a specification. MCNS released the set of standards known as Data-Over-Cable Service Interface Specification 1.0 in 1997 which defines modulation and protocols for high speed bi-directional data transmission over cable systems (Godsay, 2003). DOCSIS 1.1 provides improved flexibility, security and QoS features. DOCSIS 2.0 increases upstream capacity through more advanced modulation techniques (Martin and Shrivastav, 2003). The capacities of downstream and upstream channels in HFC networks are asymmetric. Typically, the downstream bandwidth is about 30 Mbps, while the upstream bandwidth is about 3 Mbps (Ju and Liao, 2004).

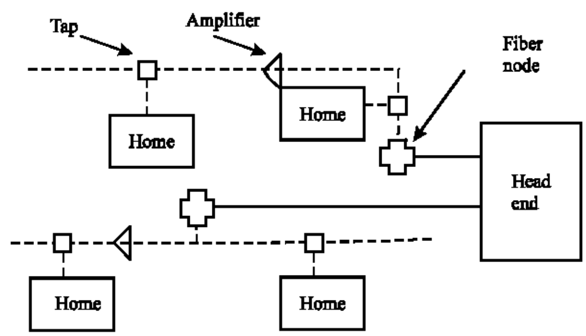

Fig. 1: A simple DOCSIS RF Network

In a HFC network, illustrated in Fig. 1, a fiber node, capable of serving 500 to 2000 subscribers, receives signals sent from the Headend via a fiber. These optical signals are then translated into electrical signals and sent to amplified tree-and branch feeder cables. Subscribers can receive or transmit signals by connecting their coaxial stations, i.e., set-top boxes or cable modems, to the taps of the network. With multiple access technologies, all subscribers within a branch can share the upstream bandwidth to send data back to the Headend (Lin *et al*., 2000; Griffith *et al*., 2004; Bhatia *et al*., 2005; Bartos *et al*., 2004).

In Fig. 2, the spectral allocation for the upstream and downstream cable modem services and the downstream

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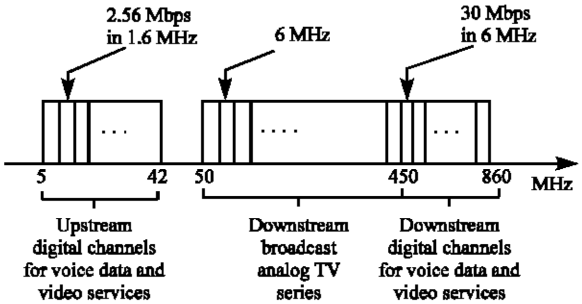


Fig. 2: Spectral allocation for various HFC services

broadcast TV channels are illustrated. DOCSIS uses a Frequency Division Multiple Access (FDMA), in downstream as well as upstream transmission. Each FDMA channel is further slotted by Time Division Multiple Access (TDMA). The 810 MHz band, ranging from 50 to 860 MHz, is divided into downstream channels by frequency division. Each channel, having a width of 6 MHz in US or a width of 8 MHz in Europe, can be used to carry conventional analog broadcast video, digital video, telephony, or data services (Martin and Shrivastav, 2003; Griffith *et al.*, 2004; DOCSIS 2.0, SP-RFIv2.0-104-030730). The Cable Operator allocates a portion of the RF spectrum for data usage and assigns one channel to a set of CMs. A downstream RF channel is shared by all CMs in a one-to-many bus configuration (i.e., the CMTS is the only sender). The CMTS makes upstream CM bandwidth allocations based on CM requests and QoS policy requirements.

The upstream channel is divided into mini-slots which, depending on system configuration, normally contain between 8 to 32 bytes of data. The CMTS periodically sends a 'MAP' message to all CMs on a downstream channel that indicates upstream bandwidth allocation over the next MAP Time. The MAP provides slot assignments for particular CMs (i.e., data grants), provides opportunities for a CM to request bandwidth using a contention-based request process and identifies which slots are to be used for system overhead.

A service flow, represented by a service ID (SID), is mapped to a service class and a virtual queue inside the CM. A CM obtains its SID corresponding to the service for which it negotiates with the CMTS during registration or dynamic service establishment. Multiple service flows of single CM are possible if the CM requires several types of service. Whenever the CMTS schedules upstream transmission it considers each service flow rather than each CM. Therefore, packets from different service flows would acquire different QoS treatments even if they come from the same CM.

Upstream channel in DOCSIS is modeled as a stream of mini-slots. CMTS has the control to allocate and manage the bandwidth among CM subscriber for transmission during upstream. CMTS periodically transmits MAP message, which defines the transmission interval in upstream channel. All CMs look for the slot to send a request and get a data grant slot in later period. Thus the proper working of DOCSIS protocol depends greatly on sending MAP message to CMs in time. Our work in this study greatly related to problem of sending MAP message and its aftermath. Though similar studies on performance of TCP over DOCSIS protocol are already done in (Ju and Liao, 2004; Lia and Liao, 2001), our algorithm analyses and solves the problem in different manner.

## BANDWIDTH ASYMMETRY IN DOCSIS

In telecommunications, the term asymmetric refers to any system in which the data speed or quantity differs in one direction as compared with the other direction, for this reason HFC communication comes under the asymmetric type. In order to support TCP data transfer, data packets sent from CMTS to CMs through downstream channel must be acknowledged with sending Acknowledgment in the upstream channel. One of the problems that arise due to the ACK transmission in upstream direction is called ACK-Compression. ACK-Compression may be explained as follows, data packets arrive at the receiving host at the rate that the bottleneck link will support. If the receiver's ACK arrive at the sender with the same spacing, then by sending new data packets at the same rate the sender can avoid over-running the bottleneck link. It is by correctly exploiting this self-clocking property of TCP that congestion may be avoided. A TCP sender's self-clocking depends on the arrival of ACKs at the same spacing with which the receiver generated them. If these ACKs spend any time in queues during their transit through the network their spacing may be altered. When ACKs arrive closer together than they were sent, the sender might be mistake into sending more data than the network can accept, which could lead to congestion and loss of efficiency. So, ACK packets should not be delayed in transit to avoid this problem.

TCP behavior in HFC network may be defined by asymmetric ratio factor k as described in (Balakrishnan *et al.*, 1999) k may be given as

$$k = \frac{C_d}{C_u} \times \frac{L_a}{L_d} \quad (1)$$

Where, $C_d$ is Downstream channel Bandwidth, $L_a$ is ACK packet length, $C_u$ is Upstream channel Bandwidth and $L_d$ is Data Packet length. TCP behaves normally when k is less than or equal to one. When bandwidth is asymmetric (i.e., k>1), acknowledged packet arrive at bottleneck link in reverse direction at a rate faster than the bottleneck link (upstream channel) can support. As a result, the sender clocks out data at a slower rate and slows down the growth of the sender's congestion window. This in turn decreases the throughput in the downstream direction. So, the aim of the proposed algorithm is to improve the performance of TCP thereby increasing throughput and channel utilization.

## EFFECT OF ASYMMETRY IN DOCSIS PROTOCOL

The CMTS periodically sends the MAP message to all CMs. This MAP message defines the slots in which a CM can send Request for data grant and bandwidth grant for CMs. The obvious thing that may be known from this is that unless MAP message received correctly in time a CM cannot send request. This in turn increases the access delay for particular CM that is waiting to send data. The Fig. 3 describes the problem that is taken for solving. The proposed method yielded better results compared to (Ju and Liao, 2004). The parameter d_map in the Fig. 3 is taken as problem of constraint. It is the time difference between when a MAP is sent and when it becomes effective.

The problem taken in this study is, when MAP is sent well before its effective time there is a great opportunity that some request from the CM will reach the CMTS after the MAP send and has to wait for one more MAP time to get their request slot processed. This greatly increases the access delay of those CMs that send request to CMTS. The number of minislots required to transmit a acknowledgement packet is given $N_{u\_ack}$ as defined by (Ju and Liao, 2004) as:

$$N_{u\_ack} = \frac{L_{ack}}{C_u} \times \frac{1}{T_{ms}} \quad (2)$$

Where $T_{ms}$ is time period for one mini-slot on the upstream channel and the Number of pending request [$N_p$_req] per MAP would be given by:

$$N_{p\_req} = \frac{d\_map}{T_{ms}} \times \frac{1}{N_{u\_ack}} \quad (3)$$

$N_{p\_req}$ is the number of pending request that arrives during the d_map time. The proposed algorithm works on

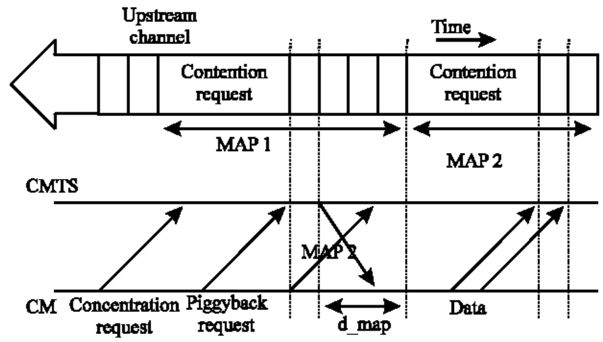


Fig. 3: d_map problem

to allocate those many slots with unicast request grant at the start of the MAP itself. The number of slots required for sending unicast request, num_utslots is calculated dynamically and those many slots are allocated at the beginning of the MAP time.

$$num\_utslots = size\_ureqgrant \times size\_utqueue \quad (4)$$

where size_utqueue is the number of requests waiting in the queue for CMs who has m_alloctime greater than d_map, which is made to decrease or increase dynamically in each MAP according to number of data grants during d_map. size_ureqgrant is the number of minislots required to transmit a unicast request.

The algorithm is explained clearly in next section of discussion in which it looks in to the parameters like size_utqueue, size_ureqgrant, etc.

## DYNAMIC BANDWIDTH ALLOCATION ALGORITHM FOR THE D-MAP PROBLEM

Table 1 explains clearly the steps in the proposed algorithm, by which the problem of d_map time has been solved. The modifications in CMTS are more compared to that of CM, since CMTS controls the allocation of bandwidth to CM through MAP message.

The description of the parameters used in the algorithm is as follows. The map_etime is given for the end of a particular MAP. d_map is already known parameter. m_allocstime is a particular start time for allocation of slots for data grant. A program structure is explained with various methods like Release Unicast Req, Fill job, Alloc-BW ureq, etc. The algorithm goes like this, first the condition of problem is checked and those many slots in d_map are queued in separate job list. These jobs are given unicast request grant at the start of the MAP. Thus the CM that is about to transmit the piggyback request in d_map is 100% sure of getting served with the request in same MAP itself. This greatly reduces the access delay of those CMs.

Table 1: Proposed algorithmic steps

```
Start MAP Processing
Handle Req ()//all kind of request are processed
Allow BW ()//bandwidth allocation for data
            //grant
D_MAP = map_etime – d_map;
If (m_allocstime < D_MAP)
{
assign data grants
}
else
{
assign datagrant
Relase Unicast Req ();
Size_utqueue ++;
Filljob [queue];//separate queue for unicast req
Alloc BW ureq ();
}
Alloc BW ureq ()
{
assign the ureq grant in the map start
}
```

The part of algorithm explained above is implemented in CMTS. The algorithm for CM is a simple one. The CM give priority to send a piggybacked request first, if the request seems to go in d_map region it goes for requesting unicast request and then contention request as the last priority.

## RESULTS AND PERFORMANCE EVALUATION

The NS-2 Simulator has been used to do simulations of the proposed model and the scheme. The existing NS-2 simulator has been slightly modified to support the proposed algorithm. The algorithm implements the basic DOCSIS architecture defined in (DOCSIS 2.0, SP-RFIv2.0-104-030730).

At initialization time, each CM registers itself with the CMTS. At least two service flows are created for each CM, one in the upstream and one in the downstream direction. A summary of simulation parameters has been given in the Table 2.

The analysis is made for both upstream as well as downstream direction. The parameter analyzed includes Access delay, Throughput, Channel utilization and Collision rate. The simulation results are shown below, downstream and upstream separately have been analyzed.

**Upstream analysis:** Mean access delay is the time a packet takes to reach the Headend from the time the packet arrives at the station. A comparison of the access delay for the current DOCSIS system and the system that uses the proposed scheme is shown Fig. 4, where the axes represent the Number of CMs and the access delay (sec), respectively. The upstream Throughput in DOCSIS may be given as

Table 2: Simulation parameters

| | |
|---|---|
| Upstream bandwidth | 5.12 Mbps |
| Downstream bandwidth | 30.34 Mbps |
| Number of CMs | 5-500 |
| Service flow | Best effort |
| MAP time | 51.024 ms |
| Agent | TCP Reno/Del Ack |
| d_map | 5 ms |
| Packet size | 1460 |
| Simulation run | 500 s |

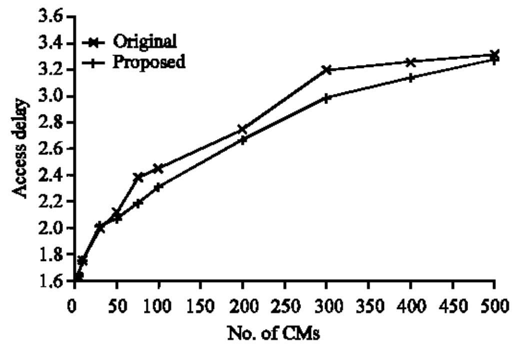


Fig. 4: Access delay comparisons

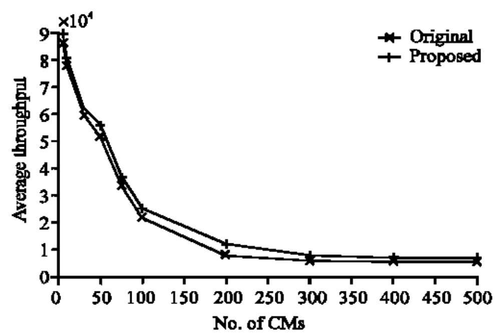


Fig. 5: Average throughput comparisons

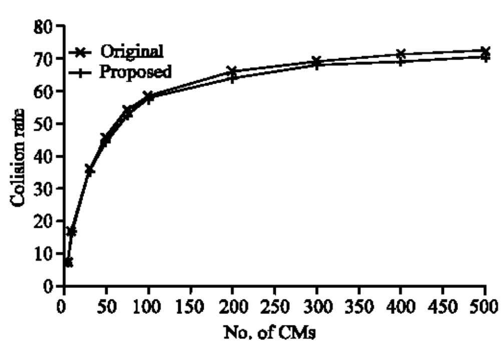


Fig. 6: Collision rate comparisons

$$Th = \frac{\text{Bytes sent} * 8}{\text{Delay}_{total\_access}} \quad (5)$$

where Bytes Sent is the total data sent in the data grant request and $\text{Delay}_{total\text{-}access}$ is the total access delay

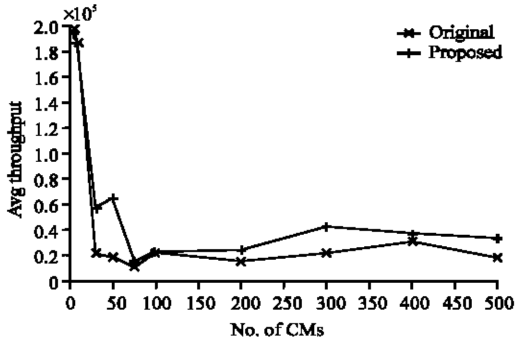


Fig. 7: Average down stream throughput comparisons

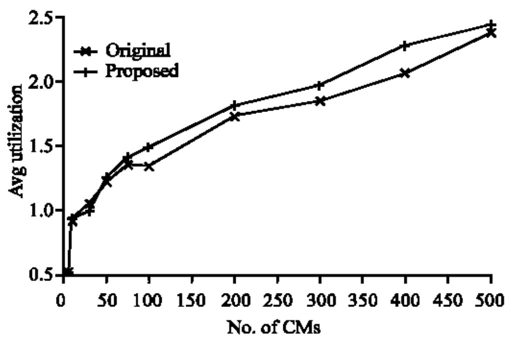


Fig. 8: Average upstream utilization comparisons

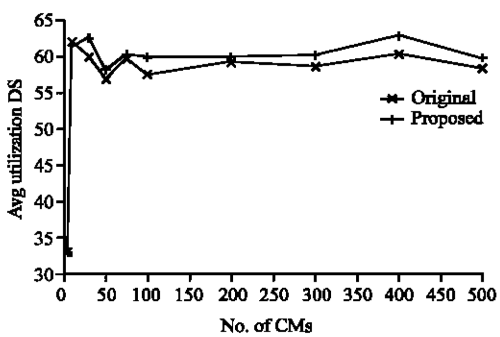


Fig. 9: Average downstream utilization comparisons

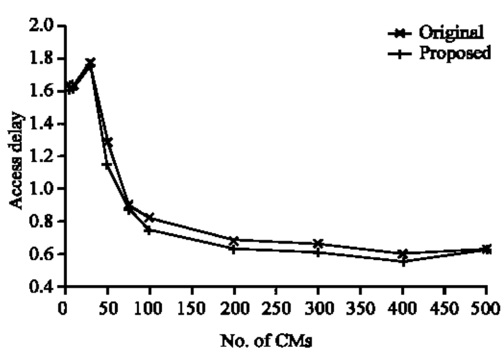


Fig. 10: Access delay comparisons in down stream

from the time the packet arrives at CM until when the data has been received by CMTS. The upstream throughput comparison is shown in Fig. 5, where the axes represent the Number of CMs and the throughput in bps.

The Collision rate comparison is done, which also seemed to have better results. Since the Number of CMs that contend for best effort slot is reduced due to availability of unicast request slots, collision rate is reduced in upstream direction. Figure 6 shows the collision rate comparison of original and proposed methods.

**Downstream analysis:** The analysis is continued in downstream direction also. The problem of asymmetric channel leads to ACK compression which is responsible for making CM buffer size full, that give rise to reduce in downstream throughput. On applying the algorithm throughput showed good improvement than that of original method. The Average downstream throughput comparison is shown in Fig. 7.

Channel utilization is defined as the ratio of total observed bandwidth to the theoretical or the practical bandwidth. Since there is improvement in sending more number of ACK packets, utilization increases in upstream direction which is followed by sending more number of data packets in downstream direction. Thus there is a good increase in channel utilization in both the directions. The comparison between the original method and proposed method for utilization in upstream as well downstream is shown in Fig. 8 and 9 respectively, where axes are Number of CMs and Utilizations respectively.

Access delay is the last parameter that calculated and compared in downstream direction. Figure 10 shows that comparison, which shows as incase of upstream, downstream direction also have less access delay compared to original method of DOCSIS.

## CONCLUSIONS

The performance analysis is made in DOCSIS MAC protocol and an algorithm to improve performance is also proposed. The algorithm proved to be efficient and provided better performance in most of the important parameters than the original method.

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