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Performance Evaluation of the DOCSIS 1.1 MAC Protocol According to the Structure of a MAP Message

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***Abstract* - In Data Over Cable Service Interface Specification (DOCSIS) RFI v1.1, the control message, called MAP, is used to schedule the uplink radio frequency between the Cable Modem (CM) and the Cable Modem Termination System (CMTS). In this paper, we find out the appropriate MAP size and the ratio between contention slots and data slots in a MAP through computer simulations. We use the Common Simulation Framework (CSF) 13 PL9 to assess the performance of DOCSIS v1.1. We found that throughput and delay show best performance when the MAP size is 2 msec. We also found that 6 may be the best choice for the number of contention slots when the MAP size is fixed at 2 msec. We also discussed 58% of goodput for the upstream channel capacity.**

1. Introduction

Cable companies and manufacturers in North America established Multimedia Cable Network Systems (MCNS) in January 1996. They issued a request for proposals to retain a project management company to research and publish a set of interface specification for high-speed cable data services over hybrid fiber and coaxial (HFC) media [1],[2]. MCNS released its data over cable system interface specification (DOCSIS) for cable modem products to vendors [3]-[5]. It is a set of interface protocols between cable modem customer side and cable modem termination network side, including cable modem (CM) to customer premise equipment (CPE) interface [3], cable modem to RF interface [4] and cable modem termination system (CMTS) network side interface [5]. Especially, DOCSIS RFI v1.1 [4] defines radio frequency interface between CM and CMTS. The main parts of this specification are MAC protocol, QoS related concepts, and interaction between CM and CMTS. The MAC protocol defined in DOCSIS RFI v1.1 is based on TDMA. It uses the MAC management message called MAP to describe the usage of uplink channel. A given MAP may describes some slots as grants for particular stations to transmit data in, other slots as available for contention transmission, and other slots as an opportunity for new stations to join the link. From the manufacturer's aspect, the MAP size and the ratio between contention slots and grant slots are critical parameters to the performance of their products. The MAP size means an uplink interval length which is defined in the MAP message. The DOCSIS RFI v1.1 doesn't recommend the optimum value of these parameters though it defines the usage and elements of MAP. To resolve this problem, we assess the performance of media access control (MAC) protocol of DOCSIS v1.1 with respect to the value of the MAP size and the ratio of contention slots in the MAP. At present the only realistic way to evaluate the performance of DOCSIS compliant cable networks is through computer simulation. CableLabs have coordinated the development of an extensive discrete event simulation model (using OPNET) of the DOCSIS 1.0 medium access control (MAC) and physical layer protocols. This model is named the Common Simulation Framework (CSF) and version 13 was used for the work described herein [6]. In this paper, we use this simulation model with a few modifications to support DOCSIS RFI v1.1.

The rest of this paper is structured as follows. In section 2, we give general overview of the MAC operation described in DOCSIS RFI v1.1. In section 3, the CSF version 13 and the environment of simulation will be described. We will show the simulation results and conclude the paper in section 4 and 5, respectively.

2. DOCSIS RFI v1.1 MAC Protocol

2.1. Overview

The upstream channel is characterized by many transmitters (CMs) and one receiver (CMTS). Time in the upstream channel is slotted, providing for Time Division Multiple Access at regulated time ticks. The CMTS provides the time reference and controls the allowed usage for each interval. Intervals may be granted for transmissions by particular CMs, or for contention by all CMs. CMs may contend to request transmission time. Some of the MAC protocol v1.1 highlights include:

- Bandwidth allocation controlled by CMTS
- A stream of mini-slots in the upstream
- Dynamic mix of contention- and reservation-based upstream transmit opportunities

- Bandwidth efficiency through support of variable-length packets
- Extensions provided for future support of ATM or other Data PDU
- Quality-of-service features
- Support for a wide range of data rates.

2.2. Upstream bandwidth allocation

The upstream channel is modeled as a stream of mini-slots. The CMTS must generate the time reference for identifying these slots. It must also control access to these slots by the cable modems. For example, it may grant some number of contiguous slots to a CM for it to transmit a data PDU. The CM must time its transmission so that the CMTS receives it in the time reference specified. The basic mechanism for assigning bandwidth management is the allocation MAP. The allocation MAP is a MAC management message transmitted by the CMTS on the downstream channel which describes, for some interval, the uses to which the upstream mini-slots must be put. A given MAP may describe some slots as grants for particular stations to transmit data in, other slots as available for contention transmission, and other slots as an opportunity for new stations to join the link. Many different scheduling algorithms may be implemented in the CMTS by different vendors; this specification does not mandate a particular algorithm. Instead, it describes the protocol elements by which bandwidth is requested and granted.

2.3. The allocation MAP MAC management message

The allocation MAP is a varying-length MAC Management message that is transmitted by the CMTS to define transmission opportunities on the upstream channel. It includes a fixed-length header followed by a variable number of information elements (IEs). Each information element defines the allowed usage for a range of mini-slots.

2.4. Quality of Services

DOCSIS version 1.1 provide the following 5 classes of service for the traffic.

- Unsolicited Grant Service (UGS)
- Real-Time Polling Service (rtPS)
- Unsolicited Grant Service with Activity Detection (USG-AD)
- Non-Real time polling service (nrtPS)
- Best effort Service (BE)

UGS support isochronous traffic such as CBR type traffic. The CMTS gives periodic grant for this traffic. The rtPS provide the rt-VBR type service in ATM but uses the polling mechanism to support the real time traffic. USG-AD is new service in the DOCSIS version 1.1. It uses the CM activity detection technique and gives the grant when the CM is active. This service can support voice traffic with silence suppression. nrtPS and BE are similar to non-real time VBR and UBR services in ATM. To provide these QoS to the incoming traffic, following concepts are added in the DOCSIS version 1.1.

- Packet Classification and Flow Identification
- Service Flow QoS Scheduling
- Dynamic Service Establishment
- Fragmentation

3. The Simulation Model

3.1. The CableLabs DOCSIS model

In this paper, we use the DOCSIS common simulation framework (CSF) version 13 [6] to perform performance evaluations.

The CSF is a baseline model, based on the OPNET simulation package. Originally OPNET(formerly MIL3) and Cablelabs developed it as a joint initiative in order to produce the core model for simulating data protocols of Hybrid Fiber Coax (HFC) networks including the DOCSIS and the IEEE 802.14 protocols. In the CSF13, the CMTS periodically generates the arrangement messages SYNC, UCS and MAP. The 'SYNC' provides the CM with global timing reference, the 'UCD' information about the upstream channel and the 'MAP' the composition of a specified upstream region. Specifically, every MAP determines the bandwidth distribution of a fixed upstream channel using a number of IEs. The assumptions of the model are:

- When a CM issues a request and is waiting for the MAP allocation response, it cannot use any other contention opportunities;
- The load offered from each cable modem is the number of packets per second for which a cable modem attempts to request upstream bandwidth;
- The throughput for each cable modem is the number of data packets per second received at the headend;
- The mean access delay for each cable modem is the time between the CM receiving the transfer request and the packet being received at the headend

Table 1. Simulation parameters

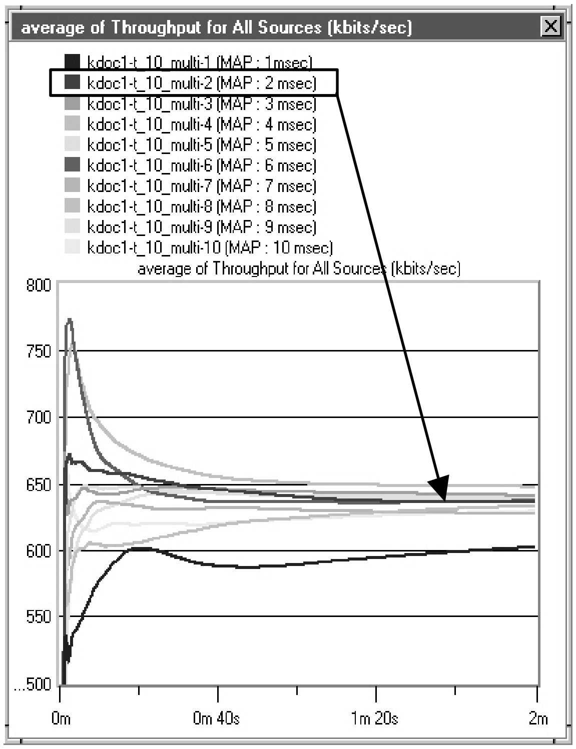
Parameter	*Value*
Upstream channel capacity (QPSK)	2.56 Msps (symbol per second)
Downstream channel capacity (64QAM)	26.97 Mbps
Backoff limit	1 – 8
Minislot	16 byte/minislot, 25 μsec/minislot, 4 ticks/minislot
MAP size	1 – 20 msec
Number of contention slots in a MAP	4 – 80 (increased by 4 slots per 1 msec interval)
Maximum number of minislots in a MAP	800 (20msec/25μsec)
Maximum number of IEs in a MAP	240
Number of CMs	10 – 100

3.2. Simulation parameters

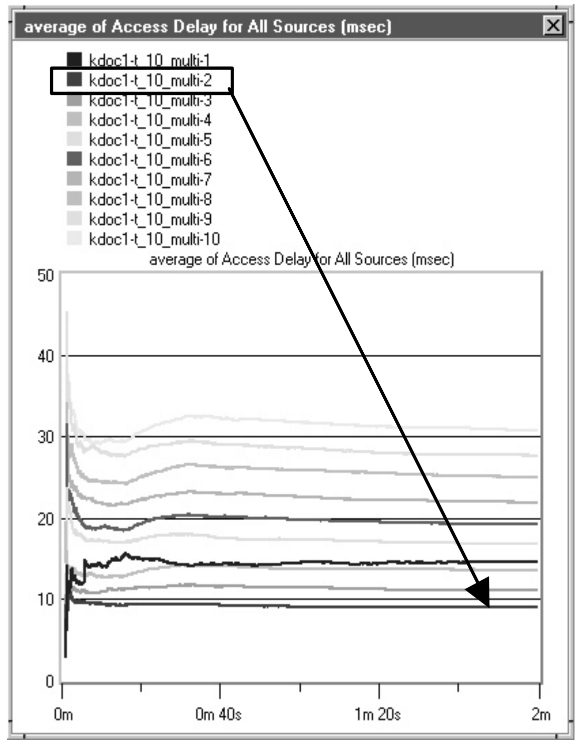
To evaluate the performance of DOCSIS 1.1 MAC protocol, we use the OPNET 6.0 for simulation. The parameters used in simulation are given in Table 1. The values selected for the simulation parameters are typical values used in actual implementation or default values proposed in the specification [7]. All sources create packets of constant length, variable between simulation runs from 64 to 512 bytes, with a constant interarrival rate.

4. Simulation Results

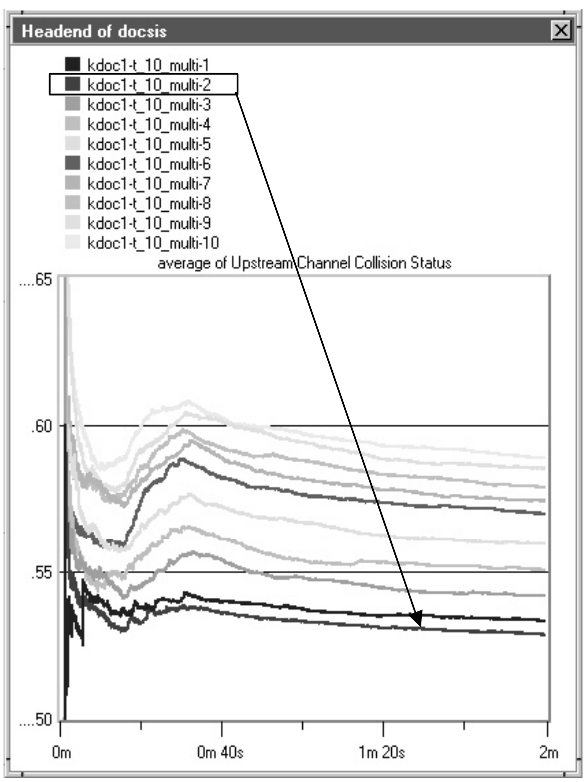
In this section, we plot the simulation results with various simulation parameters. We assess the performance with respect to the MAP size, the number of contention slot and offered load.



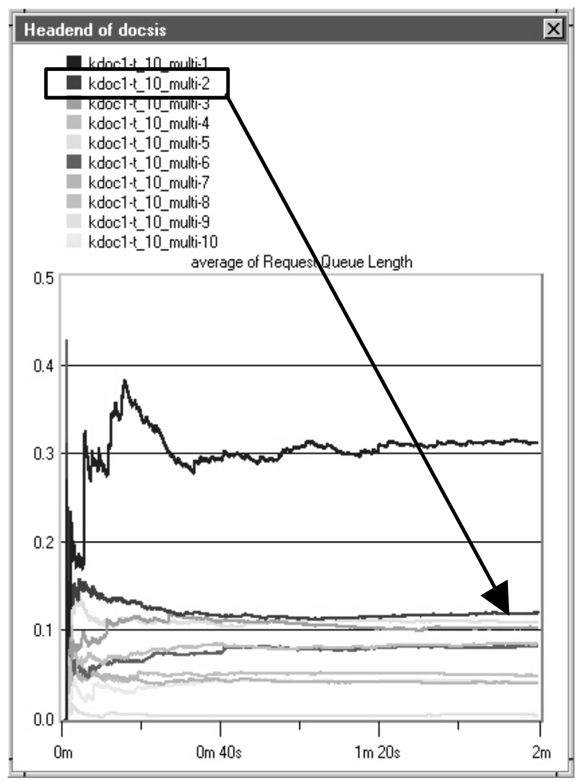
(a) Throughput



(b) Access Delay



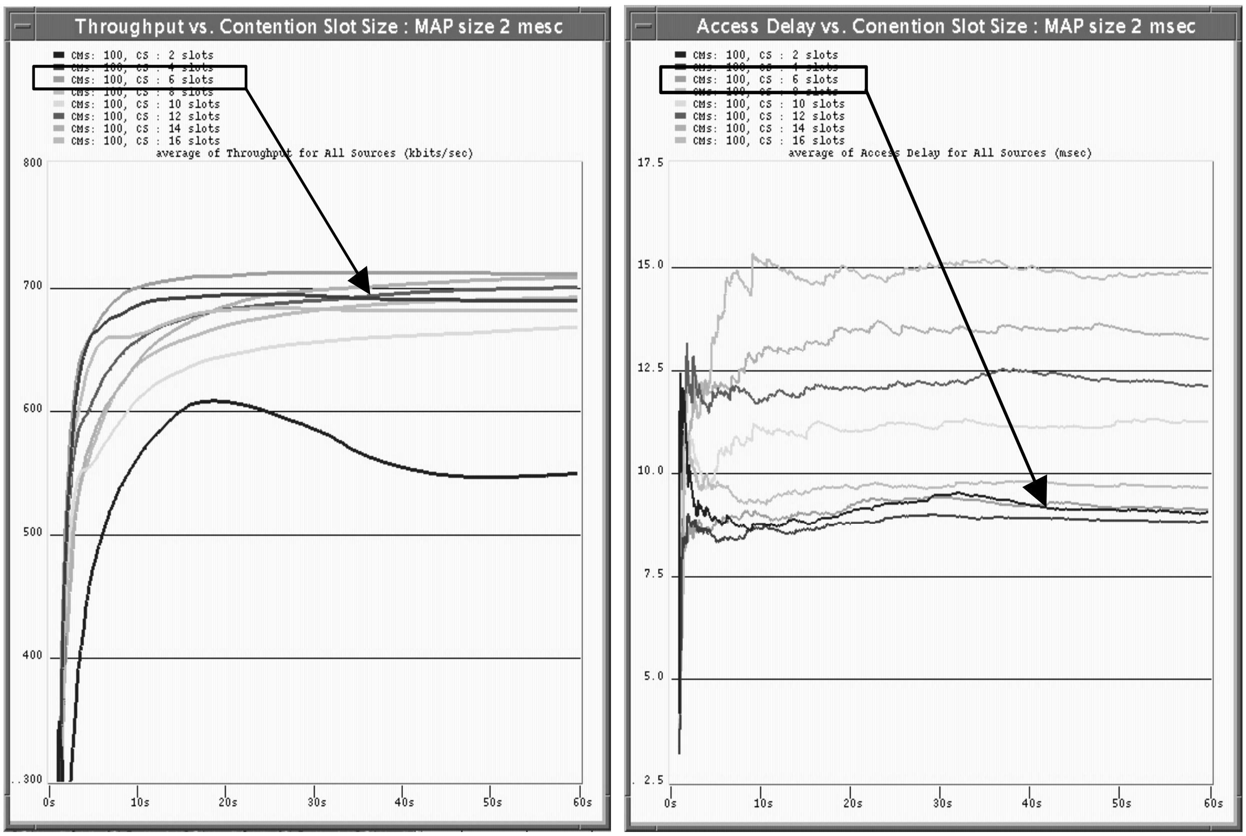
(c) Channel collision status



(d) Average buffer size in the request Q

Figure 1. Performance evaluation for various MAP size

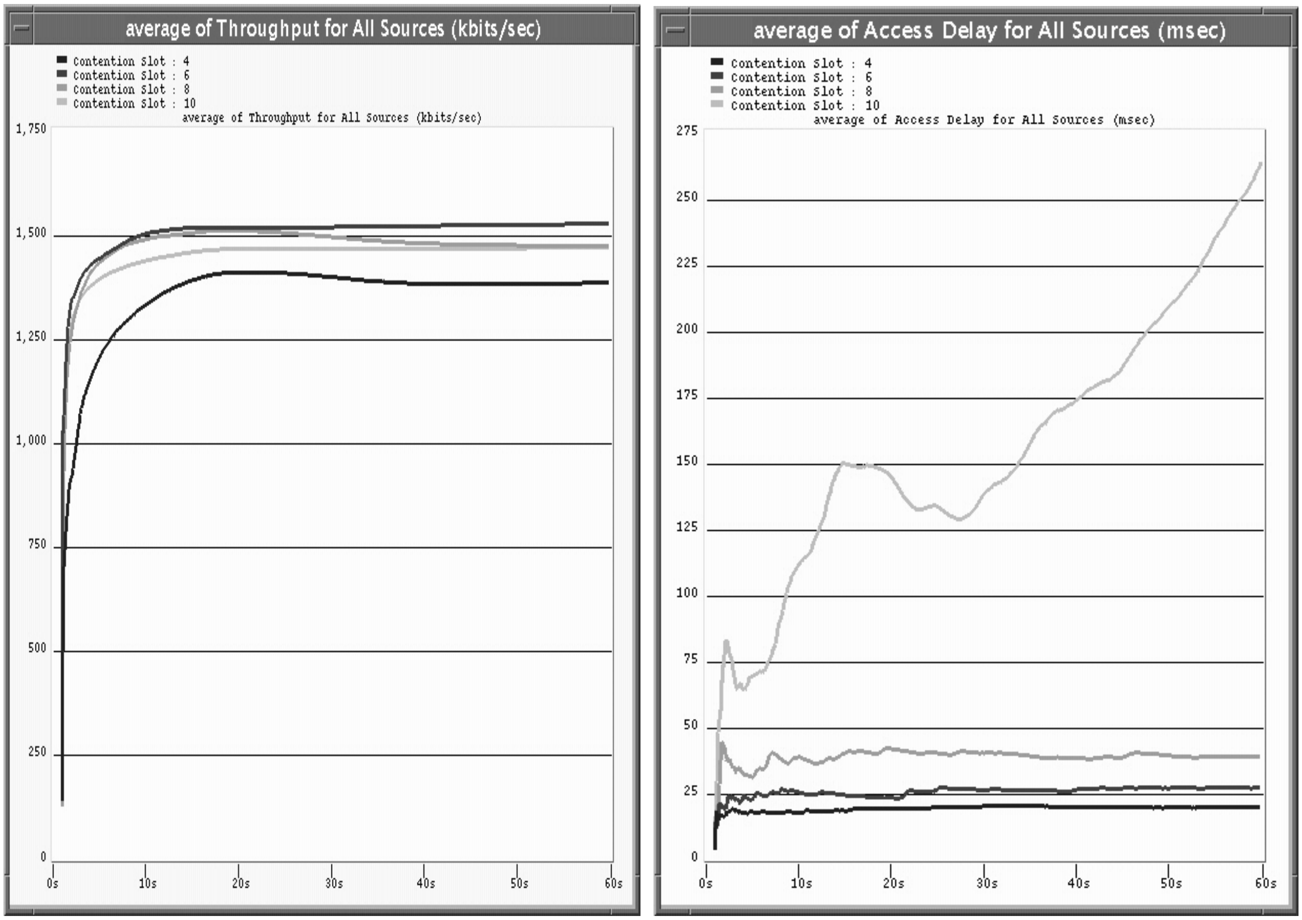
Figure 1 shows the performance comparison when we change the MAP size from 1 msec to 10 msec with 10 CMs, each CM generating traffic with mean of 70 kbits/sec. Here, the x axis means simulation time. As shown in graph (a), when the MAP size increase from 1msec to 2 msec, there is big throughput increase, however there is no significant difference when the MAP size change from 2 msec to 10 msec. The access delays and channel collision status show lowest value when the MAP size is 2 msec in (b) and (c) respectively. The average request buffer size in the CMTS is shown in (d). There is also a significant difference from the case of 1 msec and 2 msec. We ran several scenarios varying the load and number of CMs. When the offered load and number of CMs increase, that phenomenon is more clear that 2 msec is the appropriate number for the MAP size in the cable network. If the MAP size is 1 msec, there are several performances degradation factors such as MAP processing time, transmission fragmentation, etc. The fragmentation is initiated when the grant length is less than the requested length. The CM MAC calculates how many bytes of the original MAC frame, including overhead for a fragmentation header and CRC, can be sent in the received grant. The fragmented frame is 10 bytes bigger than a normal frame for the same information data, because fragmented frame includes 6 bytes extended header and 4 bytes fragment CRC. When a fragmentation occurs, there are at least 36 bytes (6 bytes + 16 bytes : fragmented frame overhead + 14 bytes : Physical layer overhead) extra overhead for MAC frame. The physical preamble overhead is normally from 14 bytes to 34 bytes for a frame. When the map size is 1 msec, there is more frame fragmentation and extra headers (MAC and physical) are used. This is the reason that the throughput for the 2 msec MAP size shows higher than that for 1 msec MAP size. It also causes the longer access delay for the 1 msec MAP size.



(a) Throughput (b) Access Delay

Figure 2. Performance Comparison for the Contention Slots size I

In Figure 2, we present channel throughput and packet access delay when the contention slot size changes from 2 to 16 slots and the MAP size is fixed at 2 msec and the number of CMs is 100. The total offered load is 740 kbits/sec here. In the throughput graph in (a), throughput shows highest values when the contention slot size is 6. The access delay has no big difference when the contention slot size is 2 to 8 slots. We found that 6 slots is the best choice for the contention slot size when the MAP size is fixed at 2 msec. To verify this result, we ran the same simulation scenario with a higher load condition of 1700 kbits/sec. There are 4 curves in the Figure 3 which are the cases of 4 slots, 6 slots, 8 slots and 10 slots MAP size. When the contention slot size is 6, in (a) throughput shows its best value and the delay is second one. Access delay increases as the contention slot size increases because the time of information transmission portion in the MAP is reduced. This is why access delay is growing continuously when the MAP size is 10 slots.

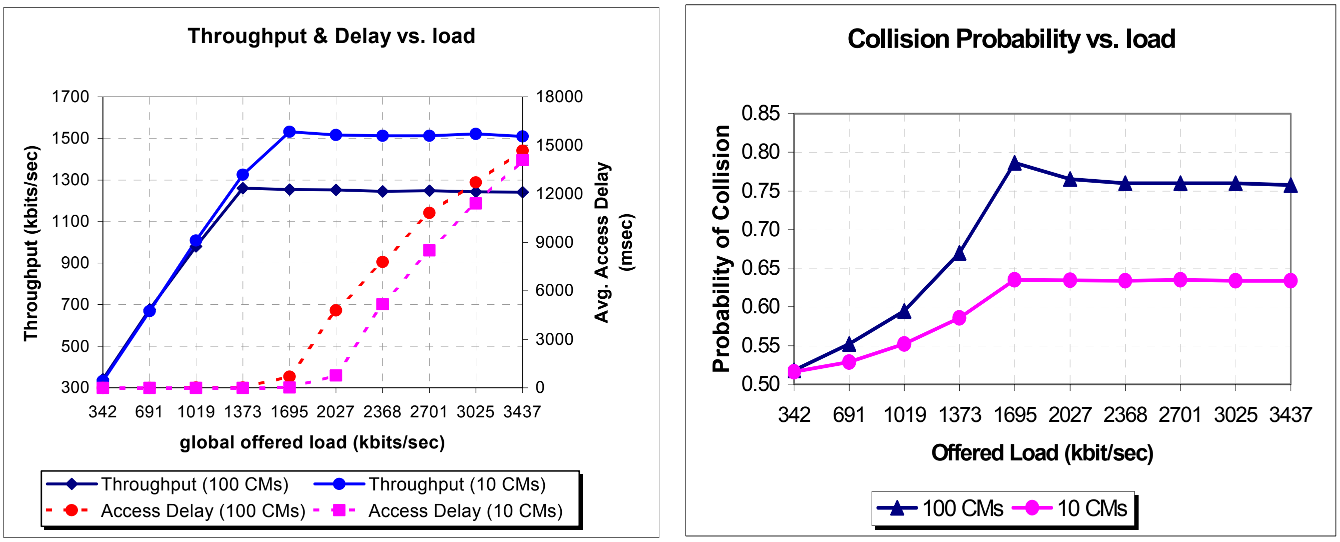


(a) Throughput (b) Access delay

Figure 3. Performance Comparison for the Contention Slots size II

The throughput, access delay and the collision probability are shown in Figure 4. The channel throughput does not exceed 1505 kbits/sec. Here, there are 10 CMs, the MAP size is 2 msec, and there are 8 contention slots. For offered loads below 2067 kbps the mean access delay varies between 6.9 - 19.8 msec. With higher offered loads the mean access delay increases sharply. As shown in (b) Figure 4, collision probability increases until the offered load reaches 1717 kbps where it saturates to 0.639. When the system is under-loaded, the CMTS assigns more slots for contention than predetermined contention slots. For example, MAP consists of 40 slots and the contention slot is assigned by 16. If there are only 10 slots for the upstream data, the CMTS allocates the remain slots to contention. This means that the channel collision probability increase when the offered load increase since the contention period is reduced and the offered load is increased. The CMTS allocates the upstream MAP in the following sequence; system control, UGS, UGS-AD rtPS, nrtPS, BE and contention. But, the CMTS guarantee the minimum number of contention slots. The simulation results show that for an upstream channel capacity of 2.56 Mbps with 10 CMs, the maximum goodput cannot exceed 1.5 Mbps. This goodput is 58.5 % of the upstream channel capacity. It is due to the packet overhead and MAC protocol issues.

In Figure 6, even though the network is under-loaded, there is gap between offered load and throughput. This is also caused by the MAC and Physical layer packet overhead, unused capacity and the multiple access scheme's MAP structure. When the number of CMs increases to 100 rather than 10, overall performance is more degraded than the case of 10 CMs because there is more collision within the CMs.



(a) Throughput and delay (b) Channel collision probability

Figure 4. Performance comparison for the offered load

5. Conclusions

To assess the performance in the DOCSIS, we used CSF 13 PL9 model which was built by OPNET, Broadcom and Sheffield University (UK). To find the appropriate value for MAP size, we performed simulation for varying the MAP size from 1 msec to 16 msec with different offered load condition. We found that throughput and delay shows better performance, when the MAP size is 2 msec. When the offered load increases, the performance gap between 2 msec MAP and other sizes are more pronounced. We also found that 6 may be the best choice for the contention slots when the MAP size is fixed at 2 msec. In this scenario, the maximum channel goodput is about 58.5 % of the channel capacity. If we set 2 msec as the MAP size, it consists of 40 minislots. A MAP can transmit about 1 or 2 packets since a mean packet size is 420 byte and a minislot is assigned to 16 bytes (the packet needs 27 minislots without counting physical overhead). Even when a cable modem has more than a single packet to transmit, it can only request upstream channel bandwidth for a single packet. In this paper, we mentioned several performance issues in the DOCSIS MAC protocol for the generation cable network. There is more performance issues in the CMTS scheduling algorithm, traffic classifier and ranging mechanism. The results of this paper will be helpful to the further performance study in the DOCSIS protocol and the parameter configuration for the CMTS equipment.

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