Test Results for the Development of a Novel Region-Based DOCSIS Compliant Cable Plant System and Protocol to Optimally Reduce Contention Mini-slot Collisions and to Support QoS on DOCSIS 1.1/1.2 Networks

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ABSTRACT

The cable plant is a broad bandwidth channel into the home and community. Current Data-Over-Cable Service Interface Specification (DOCSIS) standards require meeting QoS objectives to enhance multiple and fast service environment. To fulfill this goal efficiently, the topology and the physical characteristics of the upstream channel present new challenges at both the physical and the media access layers. This is largely due to the presence of collisions in the contention channel that largely undermines the channel's capacity by making requests unavailable for advanced processing. However, if it is possible to reduce collisions effectively by means of a protocol that may lead into an earlier processing capability of different users service requests, the goal of QoS imposed by DOCSIS 1.1/1.2 could very well be met. Hence, the number of users could be increased and an improved service could be provided with the existing cable plant infrastructure.

We present results and a technique that achieves record reduction in contention mini-slot (CMS) collisions by means of dividing the stations in the network efficiently. A primary goal of the design is to keep the entire protocol at the Head-End (HE). The goal also includes leaving everything else in the current hybrid fiber/coax (HFC) systems unchanged. A station wishing to transmit sends a request to the HE using a contention channel. Since all the stations contend for a limited number of CMS at the same time on a single channel, requests get dropped uncontrollably when many of the CMS could be left unused. This inefficient use of channel capacity causes upstream bandwidth waste as well as unwarranted delay in processing requests. Furthermore, requests piles up in stations while new requests arrive and this results in under utilization of the data transfer over the network. Our technique shows that with small changes in the Medium Access Control (MAC) protocol at the HE, we can efficiently and dynamically divide the stations in the upstream based on load conditions to allot specific amount of CMS for each region. The mechanism also proposes for the collection of channel statistics and channel monitoring to statistically configure the necessary division for optimum performance. We have also developed a simulation and visualization tool using MATLAB and a suitable and effective traffic generator model that could be extracted from network parameters. The results prove that the proposed approach amounts for a record 40%-45% reduction in mini-slot (ms) collisions.

1. INTRODUCTION

1.1. Hybrid Fiber Coaxial Channel and DOCSIS

A HFC channel consists of stations and a HE. The channel in Fig. 1 is divided into upstream and downstream. The upstream and the downstream channel transports packets from individual stations to the HE and from the HE to the stations, respectively. The upstream channel carries both the approved user data and contention slots that contain the request of a station wishing to transmit. The downstream channel sends the grants/acknowledgements of the requests and data from the HE to the users. A review of HFC networks is given in [1].

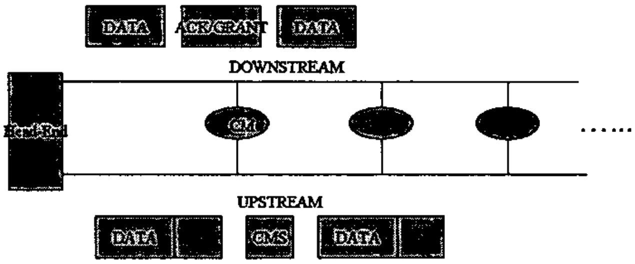


Fig 1. Abstract topology of a HFC cable plant.

DOCSIS specification includes extensive MAC and PHY-layer upstream parameter control for robustness and adaptability. DOCSIS 1.0 ensures the usage of the request/grant mechanism described above. It associates a single QoS per cable modem (cm). DOCSIS 1.1 furthers the goal of DOCSIS 1.0 by specifying different QoS level within a cm and the other cm(s) [2]. This imposes restrictions on the existent commonplace design for protocols that uses a single upstream channel concept and calls for the need of a protocol where the upstream will be intelligently divided for contention. The more accurately the network monitoring and the statistical prediction based divisions can be arranged, the more efficient the system can be.

1.2. Goals and Specifications

The most important goal of the design was that it be implemented in the current infrastructure. Only changes allowed were in the protocol at the HE that schedules and allocates the upstream CMS and data. We have taken the practical physical construction and dependencies of a cm plant into consideration [3]. Low latency, medium distance (80 km), typical ms sizes, data slot (DS) to collision slot (CS) ratios, modulation scheme, were somewhat important parameters to consider for the design since arbitrary changes in values for these during the simulation would affect the QoS requirements. TABLE 1 shows these constraints that we have used for the simulation.

TABLE 1

SPECIFICATIONS FOR THE CABLE PLANT SIMULATION PARAMETERS

Length of upstream	80 km
Propagation Delay	5 μs/km for coax and fiber
Upstream modulation	16 QAM
Data rate	6.0 MS/s * 4 bits/S * 1 byte/8 bits = 3.0 MB/s
DS/CS (typical)	4:1
DS size	1600 bytes
CS size	400 bytes
ms size	16 bytes
# of ms/DS	100
# of ms/CS	25
Upstream bandwidth	37 MHz
1 event	1 s
# stations	250

1.3. Previous Work

John discussed about the performance and implementation issues of contention resolution protocols [4]. He clearly indicated the conceptual properties of contention based systems. These properties deal with the request sending and processing mechanism for a typical cable plant. The discussion made it clear that these properties help a systematic development of protocols to resolve contention.

Kathleen [5] talked about the simulation issues based on which we have developed the simulation and visualization tool along with suitable traffic models that could be generated from the network parameters. The paper discussed the inflexibility problems associated with simple and easy simulation tools like OPNET or ns2. It also described the problems associated with a typical Poisson or Markov traffic packet generator.

Previously it was proposed that the network should be able to offer bandwidth and delay guarantees to the flows generated by the services [6]. To fulfill this criterion, proposals were made to improve the schedulers in the HE.

John [7] proposed a dynamic distribution mechanism of the overall channel bandwidth between the contention and the reservation channel. He also stressed on the importance of the capability of the HE to control the station operation. This was proposed by feeding channel information to the stations.

1.4. Acronyms and Notations

QoS	Quality of Service
DOCSIS	Data-Over-Cable Service Interface Specification
CMS	contention mini-slot
ms	mini-slot
CS	collision slot
DS	data slot
HE	Head-End
HFC	hybrid fiber/coax
MAC	Medium Access Control
cm	cable modem
MS	Mega Symbols
QAM	Quadrature Amplitude Modulation

2. THE SIMULATED HFC ARCHITECTURE

2.1. Simulation Models

Although, traffic sources such as Poisson or Markov are amenable and widespread in use, they do not depict the true characteristics of traffic generators. Neither do they take into account of the user interaction with the systems. These optimistic traffic models thus terribly affect the results from a simulation [5]. We have developed a model that could generate a Poisson or Markov distribution that would not have these inadequacies. To create such a well-behaved traffic model, the first step is to extract network parameters such as probability of ON-OFF duration, expected number of ON-OFF for a given amount of time to model a Markov source, or similar parameters for a Poisson process. From these probabilistic and statistical models we have generated our desired model by using Bayes' estimation, i.e. $p^k(1-p)^{n-k}$ where p is the given probability of an ON/OFF event for Markov. k and n are the number of occurrences of the ON/OFF event chosen for the given p and the total number of occurrences of ON/OFF events, respectively. We simply generate a Poisson traffic distribution to apply Bayes' estimation along with channel upper or lower bounds. These new models give us the advantage to incorporate user activities by means of their duration expectation and expected number of users at a given time of the day. Fig. 2 shows the comparison between a Poisson model generated in the traditional way and the Bayes-Poisson model generated using our process. Notice that, the dashed curve is unpredictable where the solid one stays well within the defined upper and lower threshold for most of the time for the given probability and variation.

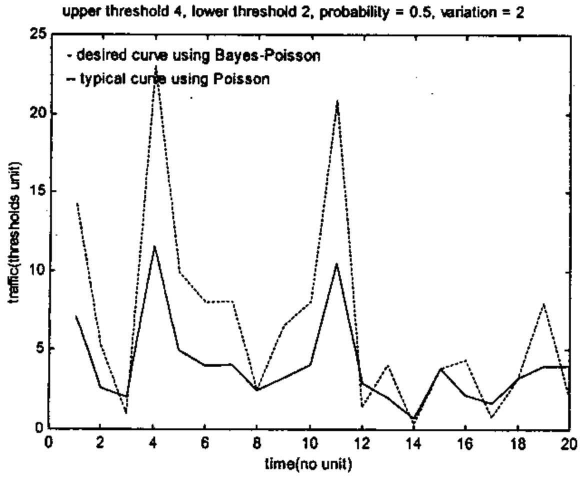
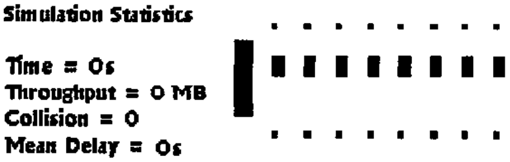


Fig 2. Comparison between the Poisson model and our Bayes-Poisson simulation model.

2.2. Simulation Tools

As we have mentioned earlier, although common, OPNET and ns simulators are programmatically comprehensive and less easily modifiable. So, we chose MATLAB for our simulation and created a simulator with visual interface that is easily adaptable. Being a user friendly software, MATLAB, with the on-line help menu and easy programming and testing interface, allowed us to test all possible variations within the DOCSIS framework. Fig. 3 below shows an example of the visual interface. The user can monitor the simulation for a given time-step, a given amount of data transfer, or any other specific condition defined by the observer.



Simulation Statistics

Time = 0s
Throughput = 0 MB
Collision = 0
Mean Delay = 0s

Fig 3. MATLAB visual interface for channel monitoring

3. SIMULATION AND DESIGN

We ran our simulations on variable numbers of DS and CS over 24 second periods. Although the numbers of DS and CS were changed, their overall numbers were held constant due to the specifications that we have decided on earlier. We have shown the results of the simulations in Fig. 4. The figure indicates that increasing number of CS has the advantage of reducing collisions. However, this does not necessarily mean that the overall channel performance has improved. In fact, the channel performance degrades if fewer DS were used since although large quantity of CS reduces the collision, lower throughput results from the lower rate of data transportation. Fig. 5 shows the throughput characteristics for the same cases as in Fig. 4. Notice that, for the extreme case where number of DS is four times higher than that of the number of CS, there is no throughput and the collision rate is 100%. This test is designed to check the consistency for the rest of the graphs in our simulator. The solid line on Fig. 5 is coincident upon the time axis showing no throughput where it shows 100% collision in Fig. 4. This simply is the test case where 100% collision means no throughput. This happens when a smaller number of collision slots are used compared to the number of the stations.

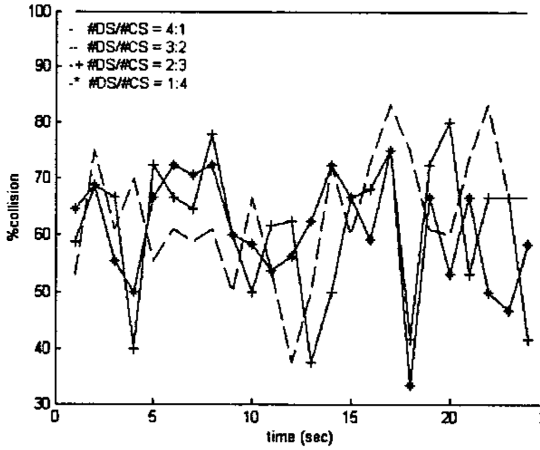


Fig 4. Collisions for different numbers of DS and CS for an upstream channel.

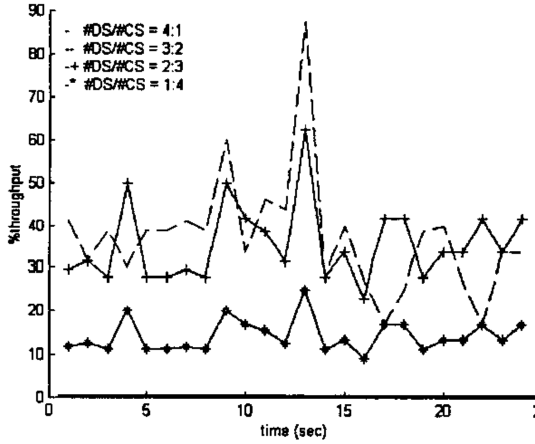


Fig 5. Throughput for different numbers of DS and CS for an upstream channel.

To optimize the situation, one upstream channel seems to be an inadequate choice for collision reduction and throughput increase at the same time since the upper bound of performance is limited due to the restrictions of a single network. Hence, it would be a vantage to be able to dynamically divide up the network and optimize on each portion for a given load condition at a given time. This suggested us to modify the simulator further so that we can test our algorithm. Fig. 6 shows the algorithm. The algorithm will take into account channel statistics and load conditions for a given period and will check for the optimum division of the network. First, it will create a square matrix of the contending stations from the network. Next, it will divide up the network into two optimum regions traversing upon all possible equal divisions. Then, it will take each segment and divide it further until it reaches the time limit or the physical limit. Finally, it will try to combine the small regions to achieve the ratios that will yield the optimum network within a given time period or feasible network.

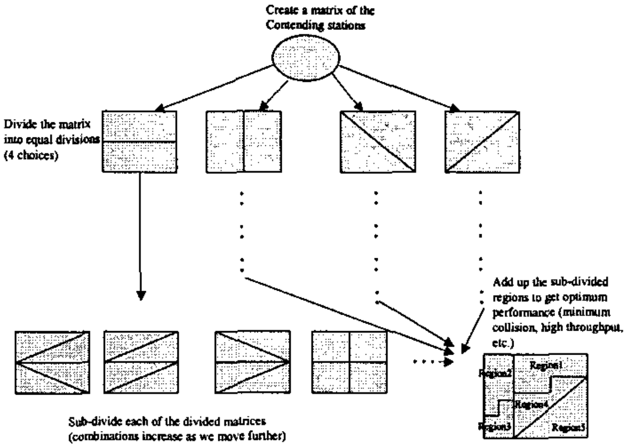


Fig 6. The proposed algorithm to meet DOCSIS QoS objectives and reduce collision.

4. RESULTS AND ANALYSIS

We modified our simulator and checked for the three cases where the network was divided into two equal divisions, one-third and two-thirds, and one-fourth and three-fourths. The numbers of DS and CS were kept constant. We have shown the results from one such simulation in Fig. 7. Although the improvement is clear, as we have expected, in some cases, some divisions did not show any improvement for a certain load and channel condition. That's why there is no one choice of division and the algorithm needs to be dynamically adjusted for varying conditions and powerfully optimizing the result. We have also calculated the overall reduction in collision as an rms value for each of the divisions. On average, it tends to be 40% - 45% below the case where no division is applied. The credit also goes to the fact that the merit of divisions allows smaller number of stations to contend on a divided network. This definitely improves the performance when intelligently divided since in each portion of the network, a balanced number of stations contend and hence, collision is reduced. Thus, the division of the network provides more controllability for the HE. Also, the randomness associated with each of the network opens possibilities to have less collisions in at least a few regions where if only one channel is used, the whole channel may end up with high collision in a more random manner. With this kind of statistical and prediction dependent scheme, each region can provide for a certain rate of data transmission, collision, and mean delay/jitter. The regions would thus allow for better controllable QoS for a given region and may even be designed to take QoS into consideration for a given region by dividing the regions accordingly.

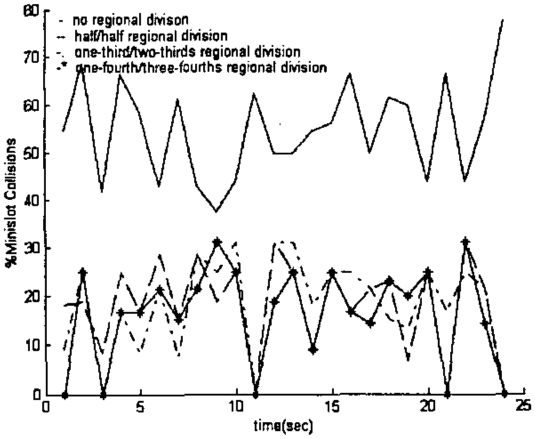


Fig. 7. Performance evaluation for regional divisions vs. no regional division

5. CONCLUSIONS

We have developed a flexible simulator and visual interface using MATLAB to test our proposition to develop an algorithm for cable networks that would improve it's QoS performance by reducing collisions and dividing the network into regions. We built a traffic model based on Bayes' statistics that can generate traffic patterns from network parameters and can take into account more realistic scenarios of network behavior. We have also shown that allocating different bandwidths for DS and CS do not improve the network performance since collision and throughput can not both be optimized at the same time. We have proposed an algorithm that creates a matrix of the contending stations and continuously divides it with different combinations and finally adds some of the divisions to get the optimized regions of performance. Finally, test results showed that, due to more controllability at the HE and channel statistics consideration, the division of a network yields 40% - 45% reduction in collision while the overall performance increases accordingly. Currently, we are developing algorithms for the optimized upstream as well as downstream. Various other aspects of DOCSIS including packet formats, one common grant/ack field for each regions, scheduling, upstream and downstream bandwidth increment, and a logical contention resolution method due to the benefits of a fragmented network are under consideration for improvement related to this concept that would lead into further development for an optimal DOCSIS compliant cable network in the future.

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