Estimation of the Effectiveness of Some of the Access Algorithms in Terms of Servicing Subscribers of the CATV Systems

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Abstract **- In this article is made comparative analysis of some of the access algorithms in terms of servicing subscribers of the CATV systems. There is shown a method allowing us to solve the collision problem and there is made comparison between some MAC protocols, used in CATV networks, using the following parameters: access delay, throughput, loss ratio and fairness.**

Keywords **– HFC, MAC protocols, 802.14, Access algorithms, Collision resolution.**

I. Introduction

The modern CATV networks are two-way and they are based on tree and branch topology. Each branch serves 125 to 500 subscribers. One of the limitations here is that the station can not listen directly to the upstream transmissions from other stations; hence, they are incapable of detecting collisions and coordinating their transmissions all by themselves. A multiple access technology other than carrier sensing is required so that all subscribers within a branch can share the available reverse bandwidth.

The MAC protocol for CATV systems must answer the following important requirements: dynamic bandwidth allocation to CBR (Constant Bit rate), VBR (Variable Bit Rate) and ABR (Available Bit Rate) traffic type; high channel throughput; low access delay; Support for a large number of stations and metropolitan area coverage.

II. The Main Collision Resolution Algorithms (CRA)

A. p-persistence

This algorithm is based on the well-known ALOHA protocol. Each station transmits its request in the available contention slot, with probability *p*. Unlike in traditional ALOHA, this rule applies to new requests as well as to retransmissions. The maximum achievable throughput of ALOHA is 36.7 % ($1/e$). The probability of successful transmission P_{SUCC} for *p*- prersistence is given by

$$P_{SUCC} = n.p.(1-p)^{(n-1)}, \qquad (1)$$

in which *n* is the number of contenders at the beginning of the slot. The system is stabilized when $p = 1/n$, under the Poisson traffic assumption. In order to estimate *n*, which is generally unknown, the pseudo- Bayesian algorithm is used at the head-end (HE).

B. N-ary Splitting Tree

In this group of algorithms, all stations involved in a collision are split into *n* subgroups. Then, each station that was involved in the collision randomly selects one of these subgroups. The first of the *n* subgroups retransmits in the subsequent available contention slot. All other stations enter waiting mode, until the resolution of the previous subgroup. The collision resolution process can be represented as a tree, in which each collision produces *n* new nodes. the best throughput is achieved with $n = 3$ (ternary tree). The following figure shows an example of the collision resolution process with ternary tree, in which the initial collision multiplicity equals 5. The numbers inside the tree nodes represent the stations that transmitted, and the numbers next to each node show the resolution order.

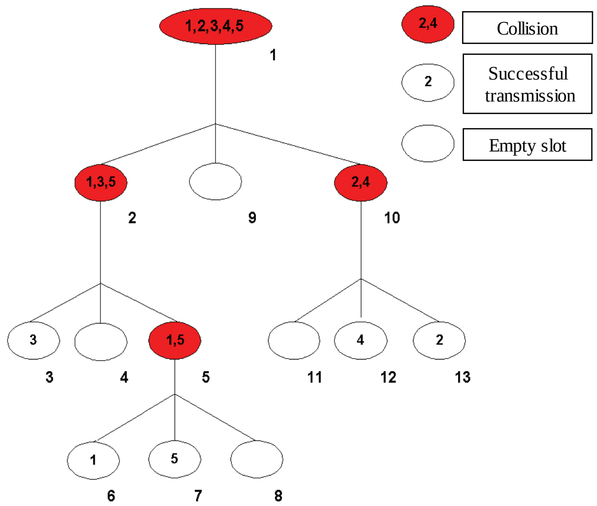

Fig. 1

The newcomers' transmission policy has a strong influence on the performance of the tree-algorithms. *Blocked access* retains new requests until the current contention is resolved, i.e. newcomers are not allowed in the contention slots used for retransmission. *Free access* allows newcomers

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to send immediately, in any contention slot. The order of collision resolution in the tree can be LIFO, in which new collisions are resolved first, or FIFO.

III. MAC LAYER ALGORITHMS

Here are presented some examples of MAC protocols and their collision resolution algorithms used in CATV networks. MAC protocols can be classified into two categories: distributed protocols and centralized protocols. There is no central controller in distributed protocols, like CSMA/CD and R-ALOHA protocols. The centralized protocols provide better timing mechanisms in avoiding collisions.

The Reservation slotted ALOHA scheme (*R-ALOHA*) [1], a modification of Slotted ALOHA is originally proposed to improve the throughput of a satellite channel beyond that of slotted ALOHA. R-Aloha is a distributed protocol. Each time slot here matches one cell. In case of successful transmission in one slot, the corresponding slot in the subsequent frame is reserved for the station. Stations that have new data check the current frame. Any idle slot will be available in the subsequent frame.

Extended Distributed Queuing Random Access Protocol (*XDQRAP*) [2] is a distributed algorithm in which each station maintains queues for transmission of both data and requests. The contention resolution algorithm is tree-based, and short one-cell messages can preempt long data messages. In the upstream channel, a data slot is followed by two (or three) contention slots. All stations must monitor for the feedback from the request transmission and update their data and request queues accordingly. In this way, the “source” station knows when to commence transmission, and the “destination” station knows when to commence reading the message. The HE remains passive throughout this scheme. The distributedschemes, however, do not use the inherent central control point of the network – the HE. It is more difficult to meet QoS demands with distributed implementations and they are more susceptible to errors.

The MAC Level Access Protocol (*MLAP*) [3] divides the upstream into frames of variable lengths, which are called blocks. Each block contains a number of contention slots and a number of data slots, and each data slot encapsulates an ATM cell. MLAP assumes that the HE scheduler can prioritize transmissions, as the stations can have a number of queues for different data sources, based on priorities, and can send priority information with requests. Stations can also use “piggybacking”. The algorithm used to resolve collisions in MLAP is START-*n* (*n*-ary Stack Resolution). START-*n* actually runs a free-access LIFO n-ary tree for each collided slot.

The Adaptive Digital Access Protocol (*ADAPt+*) [4] also relies on centralized control by the HE. The protocol defines frames of fixed sizes, in which the HE allocates the first regions for isochronous traffic (i.e. telephony) and the rest for available bit rate traffic. In the latter part, bandwidth is available for both request and data transmissions (contention mode) and the rest of the bandwidth is left for the reservation mode. The protocol supports data carriage in ATM cells. No original CRA is proposed in *ADAPt+*, and the authors suggest using any well-known algorithm.

The Centralized Priority Reservation (*CPR*) [5] uses the HE to manage the request and data channels in the upstream, and the grant and data channels in the downstream. This is achieved with knowledge of the exact delay for each station, and by “sandwiching” a number of contention slots between each data slot in the upstream. The *p*-persistence algorithm is used to resolve collisions.

The *Continuous mode with p-persistence* represents better kind of CPR but with the difference that it is required a frame structure of the upstream channel. The mechanism is self-regulating – at low loads there are plenty of contention slots, and when the load is high and there are not enough contention slots, the requests cannot be sent and therefore more contention slots will be allocated. The CRA that is used is once again *p*-persistence, and “piggybacking” is permitted. When the distance to the HE is sufficiently long, many requests are accumulated during the round trip delay (RTD) time, which leads to a long burst of data slots allocated by the HE. The proposed solution to this problem is to periodically insert a number of contention slots “by force”. These slots are called FMS (forced mini-slots). In general, if “piggybacking” is used and the average request size is *k* cells, the formula used to calculate the number of N_{FMS} is

$$N_{FMS} = \left(1 - v_p\right) e/k \,, \tag{2}$$

where v_p is the “piggybacking” arrival rate. the use of FMS reduces the proposed self-regulating continuous mode to a kind of clustered mode scheme with small frames.

Unilink protocol [6] is also a centralized protocol. The central node, called pacer, is not necessary to be located at the HE. The Unilink frame length is kept constant, but supports the transmission of variable-length messages by using concatenation, that is, a station is allowed to transmit in several consecutive slots, thus saving PHY and MAC overheads. The frame is divided into three regions: a periodic dedicated region (for synchronous traffic), a reservation region and a contention region. The boundaries between these regions are changed by the system controller according to load. A station wishing to communicate tries to seize one or more slots in the contention region using CSMA/CD. After successfully transmitting, the station may move transmissions to the reservation region.

Pipelined Cyclic Upstream Protocol (*PCUP*) operates in two modes: cyclic transmission mode and negotiation mode. In negotiation mode, the HE runs a membership control algorithm in order to permit the off-line stations to join in. Every 0.5 seconds or more, the HE sends a special *invitation* frame to all the inactive stations. Stations that were inactive since the last membership control become off-line and do not receive the current invitation. Then the HE performs *positioning*. In positioning, a transmission start time is assigned to each station, in a way that neutralizes propagation offsets. Data from different stations arrives in sequence to the HE and further away stations can start transmission before closer stations complete theirs. During positioning, the HE performs ranging and classifies the stations by an ascending order of distance.

The HE allocates transmission quota, t_i, for station i, as follows:

$$if \sum (b_i + W_i) < CBT,\ t_i = \max(b_i, 1) + W_i \qquad 3)$$

$$if \sum (b_i + W_i) > CBT,\ t_i = \max(\frac{CBT.\beta_i}{\sum \beta_i}, 1) + W_i \qquad 4)$$

$$if \sum (G_i + b_i + W_i) < CBT,\ t_i = \max(G_i + b_i, 1) + W_i \qquad 5)$$

$$if \sum (g_i + b_i + W_i) < CBT < \sum (G_i + b_i + W_i),$$

$$t_i = \max(g_i + b_i, 1) + W_i + (CBT - \sum (g_i + b_i)).\frac{G_i - g_i}{\sum (G_i - g_i)} \qquad 6)$$

$$if\,(CBT - \sum b_i) < \sum (g_i + W_i) < CBT,$$

$$t_i = \max((CBT - \sum (W_i + g_i)).\frac{\beta_i}{\sum \beta_i}, 1) + W_i + g_i \qquad 7)$$

$$if \sum (g_i + W_i) > CBT,$$

$$t_i = \max((CBT - \sum W_i).\frac{\alpha_i}{\sum \alpha_i}, 1) + W_i \qquad 8)$$

where CBT is cycle time; W_i is guard-band time; α_i and β_i are traffic urgency parameters; g_i is the minimum number of guaranteed cells at station i; G_i is the requested number of guaranteed cells at station i.

After that, the HE then computes the transmission starting time S_i for station i, precisely as follows:

$$S_i = \sum_{j=1}^{i-1} t_j - \tau_i\,, \qquad (9)$$

where t_j is the allowed transmission duration for station j and τ_i represent propagation delay. Prioritized bandwidth scheduling (i.e. t_j computation) is performed at the end of the cycle, for two traffic classes: guaranteed and best-effort. A special frame sent to the station specifies the new transmission frequency. In the last slot, the station sends its buffer status to the HE in order to facilitate the subsequent cycle scheduling.

IV. Simulation Study

On the following figures are shown the results from the comparison of access delay, throughput, loss ratio and fairness of three MAC protocols - PCUP, R-Aloha and Unilink. The simulation researches are made in the following assumptions:

– A 40 MHz band can be divided into multiple upstream channels. Each of them can be 1 MHz to 6 MHz wide and 1.6 Mbps to 10 Mbps in capacity. We assume the upstream frequency range to be 8-26.5 MHz and 1.544, 2.048, 6 and 10 Mbps transmission rate per channel. By this assumption, 17, 14, 5 and 3 upstream channels can be used simultaneously. Each branch serves 125 to 500 homes. That means an upstream channel is shared by about 30, 35, 100 and 167 subscribers respectively. The scale of network is assumed to be 80 km.

– The length of an upstream cell is assumed to be 424 bits, which is equal to 275 μS transmission time with the 1.544 Mbps transmission rate. Moreover, stations have a limited buffer size of 500 cells. Each station‘s hardware addresses is 48 bits.

Three types of traffic models, recommended by IEEE 802.14, are applied in the simulations. Traffic model A contains only ABR service. In traffic model B, CBR applications contribute 50% traffic load, the rest 50% remains to be ABR. And in traffic model C, the VBR applications present 30% traffic, CBRs pump 30% and the rest is for ABR service.

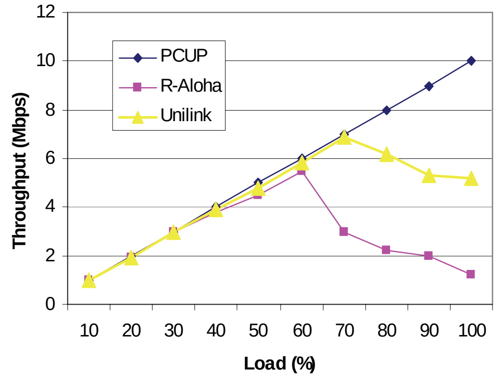

Fig. 2

On the Fig. 2 is shown the ratio between the PCUP, R-Aloha and Unilink throughput and Load under the traffic model B. The channel capacity is 10 Mbps. The Load (%) is defined as ratio between arrival cells and link capacity. Obviously, the throughput of R-Aloha and Unilink are not ideal under heavy traffic. Because of PCUP's centralized bandwidth scheduling, it achieves excellent channel throughput under various traffic types.

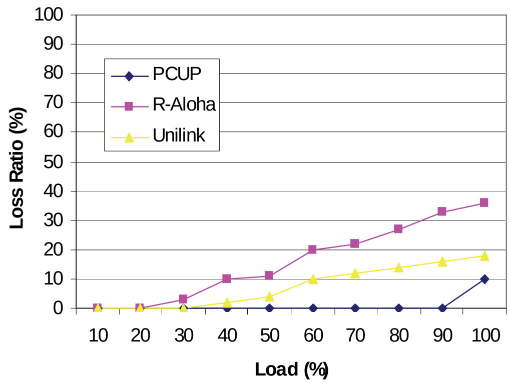

Fig. 3

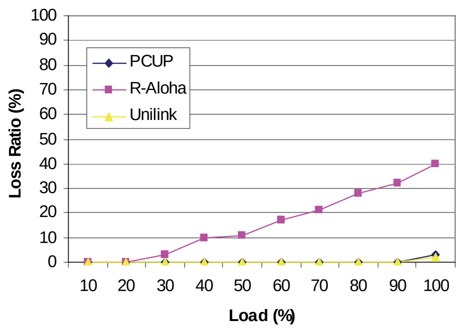

Fig. 4

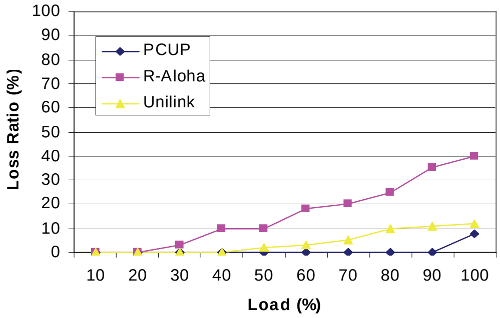

Fig. 5

On the fig. 3, 4 and 5 are shown the ratios between loss ratio and load equals to ABR, CBR and VBR traffic for the three protocols under traffic model C. In Fig. 3, we find that UniLINK has better performance than PCUP. UniLINK has only 3.1% loss ratio (lost cells/ arrival cells [%]) when the system is fully loaded, while PCUP has 5.1% loss ratio. Comparing Fig. 5 with Fig. 3, the curves are similar, but UniLINK achieves lower loss ratio of VBR traffic. This scenario is due to applying reservation scheme over VBR traffic. In R-ALOHA protocol, every cell is treated in the same way, i.e. no priority. So it behaves in a similar way under various traffic types.

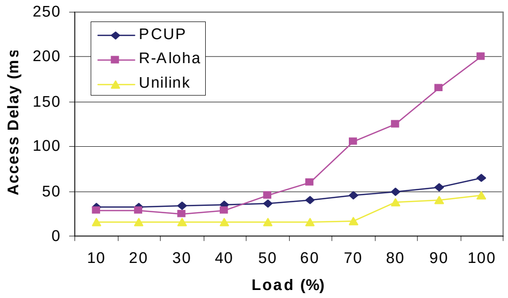

Fig. 6

Fig. 6 presents the dependences between the Access Delay and the Load for the three protocols. R-ALOHA has larger access delay when traffic load is high. Because of higher collision ratio under heavy traffic, collided cells may be retransmitted many times. Thus access delay grows up accordingly. There is the shortest access delay in Unilink protocol, which is a little better than the access delay in PCUP and in Unilink tne access delay is relatively constant.

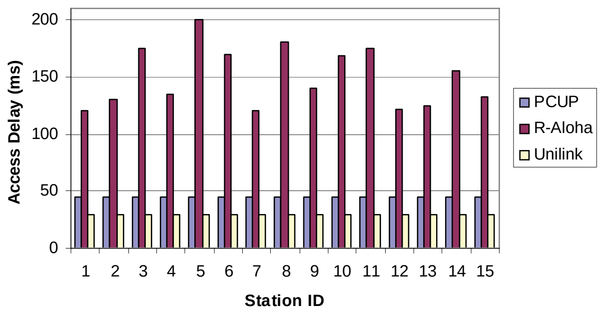

Fig. 7

This constance in the access delay in these two protocols is obvious on Fig. 7, where is shown the histogram of the distribution of access delay. For its obtaining are used statistic data for randomly select 15 stations from 167 stations sharing the 10 Mbps channel. There can be made more conclutions from that histogram for another important parameter of the CATV systems – fairness.

V. Conclusion

The conducted analisyses and simulation reserches shows that in PCUP and Unilink can be guaranteed constant low rate of access delay while in R-Aloha it is not. This shows that R-Aloha is not suitable in CATV networks. Unilink is more suitable when is needed short access delay and PCUP is prefered when it is required high throughput of the system. That is confirmed by the statistic information, taken from the research of the upstream parameters.

References

[1] Simon S. Lam, “Packet Broadcast Networks-A Performance Analysis of the R-ALOHA Protocol”, November 1979

[2] C. Wu, G. Campbell, “The Extended DQRAP(XDQRAP) algorithm”, DQRAP Research Group Report 94-3, Dec. 9, 1994.

[3] http://www.comsoc.org/ci/private/1996/mar/bisdikian.html

[4] http://www.comsoc.org/ci/private/1996/mar/sriram.html

[5] Dolors Sala "MAC Protocols for Multimedia Data over HFC Architecture"Georgia Tech Technical Report GIT-CC-95-48, October 27, 1995.

[6] Chris Grobichki, J. M. Ulm, “UniLINK as a media access protocol for community cable