A COMPARISON OF THE DVB/DAVIC, DOCSIS AND IEEE 802.14 CABLE MODEM SPECIFICATIONS

V. Rangel, C. Smythe, P. Tzerefos , S. Cvetkovic and S. Landeros
The University of Sheffield, 211 Portobello St., Sheffield S1 4DP, UK
email: victor@dcs.sfhef.ac.uk

ABSTRACT

Community Antenna Television (CATV) standardizing organizations are working on the provision of a unified standard that will allow the development of interoperable hardware and drive down the cost of implementation. The Digital Video Broadcasting (DVB)/ Digital Audio-Video Council (DAVIC), the Multimedia Cable Network systems (MCNS)/Data Over Cable Service Interface Specification (DOCSIS), and the IEEE 802.14 protocols are focused on the current cable modems. These protocols share a common goal to provide interface specifications for the support of the same services (e.g. telephony, internet access, remote access, videoconferencing, etc.). The aim of this paper is to provide a comparative analysis of reference architectures, Media Access Control (MAC) and physical layer characteristics; as well as a comparative performance evaluation in terms of volumetric data and efficiency among these cable modem protocols.

Keywords: CATV, DVB, DOSIS, IEEE 802.14, Euro-DOCSIS, MAC Protocol, QoS, performance comparison.

1. INTRODUCTION

Initially Community Antenna Television (CATV) networks were designed for analogue TV broadcasting (e.g. home entertainment). Turning CATV networks into bi-directional broadband digital data service infrastructures requires the development and standardization of new protocols. Cable companies are now exploring new technologies which can be used to support digital interactive multimedia applications over their CATV infrastructures, [3].

The current CATV standards activities, [23] and [24], are: 1*)* The *Digital Video Broadcasting* (DVB*)* which has adopted the Digital Audio-Video Council (DAVIC) recommendations with respect to CATV and has been responsible for the development of the European standard ETS 300-800, [14]; 2) The Multimedia Cable Network System (MSNS) group is producing the Data Over Cable Service Interface Specifications set of specifications which comprise of DOCSIS 1.0 [6] and DOCSIS 1.1[9] on behalf of the North American Cable industry and using cable modem technology; 3) the *ATM Forum Residential Broadband Working Group (RBWG)* is investigating the provision of Asynchronous Transfer Mode (ATM) across different CATV network topologies, [1]; 4) the *Internet Engineering Task Force (IETF)* is investigating the use of the Internet Protocol (IP) over Cable Data Networks (IPCDN), [17]; 5*)* Digital Audio-Video Council (DAVIC) is looking at the standards for complete end-to-end interactive multimedia delivery systems; 6) the Society of Cable Telecommunications Engineers (*SCTE),* an accredited American standard organization, is working on compatibility issues for cable telecommunications systems; and 7) The IEEE 802.14 was working on the specification of and ATM based CATV protocol but has disbanded as of November 1999 having realized that they failed to get the required industry interest and support.

The rest of this paper is structured as follows. In Section 2, we give some general overview of the CATV architectures. In Sections 3 to 5, we present a description of the network architecture, MAC protocols and PDU structures of the DVB/DAVIC, DOCSIS (1.0&1.1) and IEEE 802.14 protocols, respectively. In Section 6 we presents a comparative analysis in terms of the MAC and PHY layer characteristics; in this section, we also provide a comparative performance evaluation in terms of efficiency and output volume data at the PHY layer.

2. CATV ARCHITECTURES

Hybrid Fibre Coax (HFC) networks were originally designed for analogue audio and video broadcasts. Providing high performance multimedia services to the home over HFC networks presents difficulties due to the inherent problems of these architectures such as long propagation delays, signal attenuation, the high level of noise on the upstream channels and the fact that bandwidth is shared by all homes in the same loop.

In CATV networks, the spectrum is divided into the forward, commonly referred to as downstream and Head-End (HE) to user, and return frequencies, commonly referred to as upstream and user to head-end. Table 1 shows the basic downstream and upstream spectrum allocations and the slight variations in the frequency ranges for the DVB/DAVIC, DOCSIS and IEEE 802.14 protocols. The downstream channels support the legacy analogue broadcast television (80-450MHz) and multiples of 1-6MHz or 1-8MHz channels in the 450-860MHz region for transmission of digital data. The upstream channels are also divided into 1-6MHz but the high ingress noise means that the data capacity is only 1-10Mbps per channel as opposed to the 28-40Mbps available in each downstream channel. In terms of modulation schemes, most manufacturers have implemented 64 and 256-Quadrature Amplitude Modulation (QAM) for the

ISBN 968-36-7763-0 / 22-25 May 2000 © ICT 2000

downstream and Quaternary Phase Shift Keying (QPSK) and 16-QAM for the upstream channels.

Feature	DVB/DAVIC	DOCSIS	IEEE 802.14
Upstream Modulation	QPSK,	QPSK, 16-QAM	QPSK, 16-QAM
Down-stream modulation	QPSK IB 16-,32-,..,256-QAM OOB	64-QAM or 256-QAM	64-QAM or 256-QAM
Upstream Frequency Range	5 – 65MHz	5 – 42MHz	5 – 42MHz (US) 5 – 65MHz (EU) 5 – 55MHz (JP)
Down-stream fre-quency Range	70-130MHz and/or 300-862MHz OOB 300-862MHz IB	80 – 60MHz	88-860MHz (A) 110-862MHz (B) 90-770MHz (C)
Upstream Channel Spacing	200kHz, 1MHz 2MHz	200, 400, 800 kHz, 1.6, 3.2MHz	200, 400, 800kHz 1.6,3.2,6.4 MHz
Down-stream Channel Spacing	1/2MHz OOB, 7/8MHz IB	6MHz	6/8MHz(A), 6MHz (B) and (C)

Table 1. Frequency allocation and modulation characteristics for CATV networks.

3. DVB/DAVIC

The DVB Project emerged from a group, called the Launching Group, of European broadcasters, consumer electronics manufacturers and radio regulatory bodies in September 1993. The main focus of DVB is the delivery of digital TV over satellite (DVB-S, [10]), terrestrial (DVB-T, [12]) and cable links (DVB-C, [13] for the downstream and DVB-RC, [14] for the upstream.

Figure 1 shows the DVB/DAVIC systems reference model for interactive services [14]. In the system model there are two channels established between the service provider and the user, they are the *Broadcast Channel* (BC) and the *Interaction Channel* (IC). The *BC* is a uni-directional broadband broadcast channel including video, audio and data. The *IC* is a bi-directional interaction channel, which is established between the service provider and the user for interaction purposes. It is formed by: 1) *Return interaction* path (also referred to as upstream channel), from the user to the service provider, which is used to make requests to the service provider. 2) *Forward interaction path* (also referred to as downstream channel), from the service provider to the user

The NIU consists of the Broadcast Interface Module (BIM) and the Interactive Interface Module (IIM). The user terminal provides an interface to both the broadcast and interaction channels. The interface between the user terminal and the interaction network is via the IIM. In the upstream, a 64-octet slot format is used for the transmission of data. The slot format is comprised of a Unique Word (UW) (4-octets) which provides a burst mode acquisition method, a payload area (53 octets) which contains a single message cell and a Reed-Solomon (RS) parity field (6-octets) which provides 3-octets RS protection over the payload area and a Guard

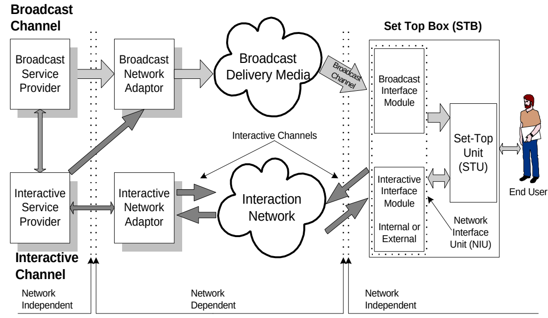

Figure 1. DVB reference model.

Band (1-octet) field which provides spacing between adjacent packets.

In the downstream, two signaling methods are used: downstream In Band (IB) and downstream Out of Band (OOB). The definition of the downstream OOB is beyond the scope of this paper (refer to [14] for further information). For the downstream IB, MAC PDU frames (or user data) are encapsulated into Motion Pictures Experts Group (MPEG2) frames. The MPEG2 frames are comprised of a 4-octet MPEG header, a 60-octet MAC Control Information (MCI) field for the control of its eight (8) associated upstream channels. An additional 4-octet field are reserved for future implementations and finally a 120-octet MAC message field which is the payload region for the encapsulation of the MAC PDU makes up the MPEG2 frame. A MAC PDU frame larger than 120 octets shall be split into separate MPEG2 frames. At the physical layer, a 16-octet RS parity field is added to each MPEG frame to form a RS-coded packet of 204-octets.

4. DOSCIS

In DOCSIS 1.0 [6] and DOCSIS 1.1 [9] the transmission path over the cable network is performed by the Cable Modem Termination System (CMTS) at the Head-end (HE) and the Cable Modem (CM) at the customer premises. The reference architecture, shown in Figure 2, contains three interface categories:

- Data interfaces which include the CMTS Network Side Interface (CMTS-NSI) between the CMTS and the data network [4] and the CM to Customer premises equipment Interface (CMCI) [5];
- Operations support systems and telephone return path interfaces which correspond to network element management layer interfaces between the network elements and the high level Operations Support Systems (OSSs) [7], and the interface between the CM and the telephone return path for the cases where the return path is not available or provided from the cable network, [8] respectively, and;
- RF interfaces, defined in [6] and [9], describe interactions between the CM and the cable network, the CMTS and the cable network (in both the upstream and downstream paths).

ISBN 968-36-7763-0 / 22-25 May 2000 © ICT 2000

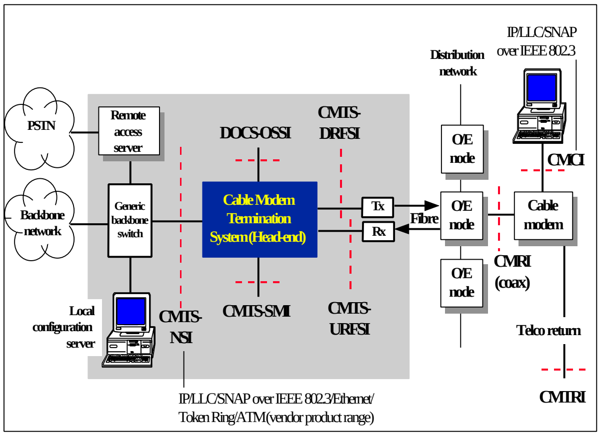

Figure 2. DOCSIS reference architecture.

The main function of the DOCSIS 1.0 protocol is the transparent transfer of Internet Protocol (IP) messages across the cable system. The QoS provision is limited to prioritization and frame concatenation. An extended QoS definition is provided in DOCSIS 1.1 for the support of IP QoS based on the Type Of Service (TOS) field as well as advanced scheduling techniques [9] .

For the upstream, at the physical layer, DOSCSIS MAC frames (which are composed of Ethernet frames) are segmented into PHY codewords, which are of variable size (ranging from 16 to 253 octets) and they include Forward Error Correction (FEC) parity, also of variable size (from 0 to 10 octets). Both a preamble and a guard time field of variable lengths are then added at the beginning and at the end of all the codewords, respectively, for synchronization purposes from the CM to the CMTS. These codewords are transmitted as continuous series of minislots. The size of the minislot is set by the CMTS during initialisation but can be varied. The length of a minislot must be multiples of 6.25µs (i.e. 8, 16, 32 bytes etc.)

For the downstream, DOCSIS MAC frames are encapsulated into MPEG2 frames (comprised of 4-octet MPEG Header, a 1-octet pointer field and a 183-octet DOCSIS Payload field. Each MPEG2 frame may contain multiple DOCSIS MAC frames, and a single DOCSIS MAC frame may span multiple MPEG frames.

EuroDOCSIS [2] is based on the DOCSIS MAC specification and DVB/DAVIC physical frequency plans. It was designed to be compatible with DVB-RC [14] infrastructures. Some of the key points of the Euro-DOCSIS specification are as follows: DVB-RC Compliant ITU-J.83, [19] Annex A. In the downstream it uses QAM modulation for 8MHz channelization (64-QAM:38Mbps and 256-QAM: 52Mbps); 5-65MHz upstream frequency range and data rates of: 0.320, 0.640, 1.280, 2.560 and 5.120Mbps for QPSK and 0.640, 1.280, 2.560, 5.120 and 10.24Mbps for 16-QAM; and Compatible with 8MHz, DVB physical layer operating in European cable plants.

5. IEEE 802.14

Following a better process among voting members the IEEE 802.14 will disband as of March 2000. This was the result of the slow standardisation process within the IEEE, which failed to observe the time to market constraint and lost industry support. The latest draft specification (Draft 3, R3 [18]) will remain as a proposed specification within IEEE for three years after which time, if there is no interest by any other group or body, not necessarily within IEEE, it will be withdrawn. A brief description of the proposed specification is shown bellow.

The IEEE has specified three physical layer specifications to reflect the European, the United States and Japanese requirements. These are known as types A, B and C which reflect the ITU J.83 Annex A, B and C recommendations [19], respectively. Types A and C differ with respect to the upstream channel bandwidth (type A is 8MHz and types B and C are 6MHz).

The PHY consists of the Transmission Convergence (TC) and Physical Medium Dependent (PMD) sublayers. The MAC sublayer is itself composed of the MAC Convergence Subprocess (MACCS), the ATM and the MAC Access Arbitration (MAA) sublayers. The aim of this sublayering is to multiplex the Logical Link Control (LLC) and ATM traffic streams as effectively as possible so that the appropriate QoS is supplied.

For the upstream, at the MAC layer, MAC PDUs (up to 2000-octet length) are segmented into ATM cells using the AAL5 protocol and passed to the MAA process, which adds 1-octet to each ATM cell to construct an ATM PDU (APDU). For the downstream, the APDU frames are encapsulated into MPEG2 packets of 188-octet length, (which are comprised of 1-octet synchronization field, 3-octet MPEG header and 184-octets of APDU payload).

6. A COMPARISON OF SPECIFICATIONS

Service comparisons

The DVB/DAVIC, DOCSIS 1.0 and IEEE 802.14 protocols, currently support services such as: Internet access (ftp, email, wold wide web, etc) and interactive set-top boxes. The DOCSIS 1.1 protocol has been designed specifically for the support of QoS and Voice over IP (VoIP), including services such as mixed voice, data and video. The full range of QoS provided by DOCISIS 1.1 to meet the needs of the applications are: Unsolicited Grant Service (UGS); UGS with Activity Detection (UGS-AD); real-time Polling Service (rtPS); Non-Real-Time Polling Service (nrtPS); Best Effect Service (BE) and Committed Information Rate (CIR.

IEEE 802.14, as the DOCSIS 1.1 protocol, supports VoIP and QoS such as CBR, VBR and ABR. DVB/DAVIC is expected to support internet telephony, VoIP and videoconferencing by 2000, and multimedia home services by 2001.

MAC comparisons

At the DVB/DAVIC MAC layer, four access modes are provided with this system. The first mode (Contention Access) is based on contention access mechanism, which lets users send information at any time with the risk to experience collisions. The second and third modes (Fixed Rate and Reservation Access) are contentionless based, where the INA either provides a predefined amount of slots to a specific NIU, or a given bit rate requested by a NIU until the INA stops the connection on NIU's demand. These access modes are dynamically shared among time slots, which allows NIUs to know when contention based transmission is or is not allowed. This is to avoid a collision for the two contention-less based access modes. The fourth mode is the Ranging Slots Access, in which slots are used to measure and adjust the time delay and the power.

At the DOCSIS MAC layer, data transmission is based on a request/grant scheme. The CMTS provides timing, ranging, registration, transmission and contention resolution information for every CM in the cable plant in regular intervals. In the upstream each minislot can be used either for contention, contention/data, initial maintenance or station maintenance purposes. A CM with data to send needs to issue a request, using the contention minislots.

On the other hand, at the (IEEE 802.14) MAC layer, like the DOCSIS protocol, data transmission is based on a grant/request scheme. The head-end allocates transmission resources in the upstream channel to users for contention and reservation based data transfer.

The IEEE 802.14 and the DVB/DAVIC protocols use ATM transfer at its only minimum data element, while DOCSIS protocol uses a scheme that favors the delivery of variable length internet protocol packets. This was chosen in an attempt to keep cost and complexity of cable modems down. However DOCSIS includes the required hooks for the definition and transfer of ATM MAC Protocol Data Units (PDUs).

PHY comparisons

The modulation scheme for DVB/DAVIC is only QPSK in the upstream, and for the downstream channel two modulations signals are provided. The modulation scheme for downstream OOB is QPSK and for the downstream IB is either 16-,32-,… ,or 256-QAM. For the upstream transmission, there are four data rates; namely 6176, 3088, 1544 or 256kbps, and for the downstream OOB data rates of 1.544 or 3.088Mbps may be used. For Downstream IB channels no other constrain exits than those specified by DVB-C [13], but it is expected that multiples of 8kbps will be used.

The modulation scheme for the DOCSIS upstream channels is QPSK or 16-QAM where for the less noisy downstream channels the modulation can be either 64- or 256 - QAM.

For the downstream channels MPEG-TS is used for carrying DOCSIS MAC frames. This allows the coexistence of both data and MPEG video on the same channel. The effective bandwidth including all overheads is either 320,640,… , or 5120kbps (QPSK), 26.97Mbps (64-QAM) and 37.98Mbps (256-QAM) for a 6MHz channel.

On the other hand, the IEEE has specified three physical layer specifications to reflect the US, European and Japanese requirements. These are known as types A, B and C which reflect the ITU J.83 Annex A, B and C recommendations.

Performance comparisons

The parameters considered for the comparison of the upstream and downstream efficiency and volumetric data are presented in Table 2. A comparison of the volume of data transferred upstream and downstream by a user data transmission request for the DVB/DAVIC, DOCSIS and IEEE 802.14 protocols are shown in Figures 3 and 5, respectively. Figures 4 and 6 show the upstream and downstream efficiency for the same protocols, respectively.

In Figures 3 and 5, the linear curves represent the expected output value for each user message assuming no protocol overhead. Thus, a user message length of 1500 octets creates an output volume of 1500 octets.

	Parameter	DOCSIS [bits]	DVB/DAVC [bits]	IEEE [bits]
US	Slot size	128	512	48
	Preamble size	16	---	16
	Codeword size	288	---	288
	FEC (RS) parity	48	48	48
	Guard Band size	8	8	8
DS	RS parity	42	128	128
	RS block size	976	1632	1632

Table 2. Performance evaluation parameters.

For the upstream data volumes, Figure 3, the IEEE stepped curve is caused by the encapsulation of APDU cells into codewords (of 36 octets), which are transmitted as continuous (6-octet) minislots. Therefore a user message of 1500-octets causes the upstream to support (350 6-octet minislots) 2096 octets, which results in 71.6 % upstream efficiency (Figure 4), and the DVB equivalent is (32 frame slots) 2048-octets, (73.2% efficiency), whereas the DOCSIS output volume is (115 minislots) 1840 octets (81.5 % efficiency). The DOCSIS curve (Figure 3) is caused by the encapsulation of MAC frames into codewords, which are transmitted as continuous series of minislots.

The upstream DVB stepped curve is caused by the AAL5 approach, producing ATM cells, which are then encapsulated and transmitted throughout the upstream channel as 64-octet frame slots.

For the downstream data volumes (Figure 5), user data (for the three protocols) is encapsulated and transmitted using an MPEG2-TS frame structure. The stepping is caused by the MPEG fixed frame length of 188 octets. The downstream IB output volume for the DVB/DAVIC protocol, is bigger than those produced by the IEEE and DOCSIS protocols, due to the considerably MPEG2 MAC control information and RS parity field which is added to each MPEG2 frame at the physical layer. For the same (1500-octet) user message, the DVB/DAVIC downstream IB volume is (13 RS-coded blocks of 204 octets) 2652 octets, which results in 56.6% downstream efficiency (Figure 6), the IEEE equivalent is (10 RS-coed blocks of 204 octets) 2040 octets (73.5% efficiency), whereas the DOCSIS volume is (14 RS coded blocks of 128 octets) 1792 octets (83.7% efficiency).

Figure 4 shows that the upstream efficiency for the DOCSIS protocol is bigger than the equivalent of the other two protocols. It is to be expected, since both the DVB/DAVIC and IEEE must encapsulate every single datagram in ATM (AAL5) cells and suffer the overhead penalty for Segmentation and ReAssembly (SAR). In Figure 6, the downstream efficiency for the DOCSIS protocols is also better that those for the DVB and IEEE protocols. In this case, the DVB protocol presents the lowest efficiency, due to the great MAC control information (of 60-octets) contained in each MPEG2 frame at the physical layer, where only 120 octets actually corresponds to the MAC message. The MAC control information is comprised of MAC Flags and MAC Flag Control, which contains slot configuration for its related 8 upstream channels.

In the above comparisons it must be noticed that the FEC (RS parity) field and codeword lengths have been selected to minimize the protocol overhead. In an operation system these values will reflect the signal to noise ratio of the CATV plant itself, thus the volume efficiency reflects the noise environment. Performance evaluation focusing on a single MAC can be found in [25] and [22] for DOCSIS, [21] for DVB, [15] and [16] for IEEE 802.14.

Although the primary aim of the DVB, DOCSIS and IEEE protocols is similar, there are many fundamental differences in how they wish to realize that aim. In essence this is reflected in the IEEE's attempt to produce an open solution which is capable of operating worldwide and which will interoperate with private networks. In contrast, the DOCSIS solution is US-centric, where as the DVB solution is EU-centric.

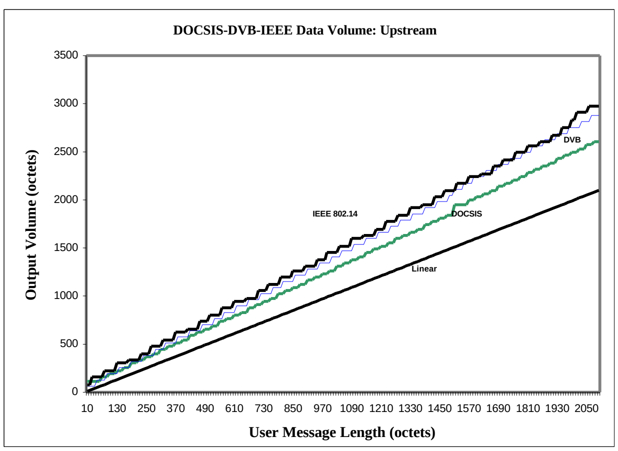

Figure 3. Upstream volumetric comparisons.

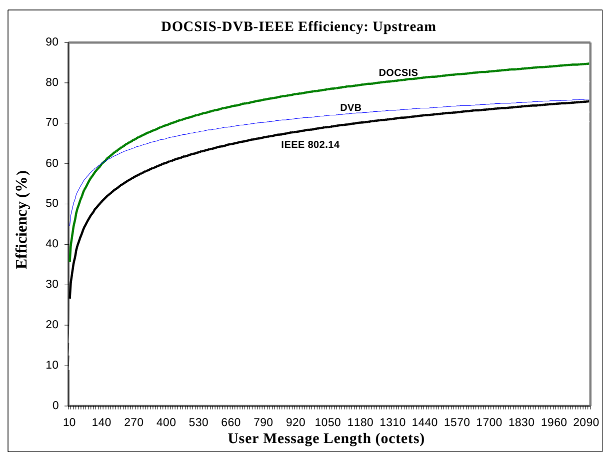

Figure 4. Upstream efficiency comparisons.

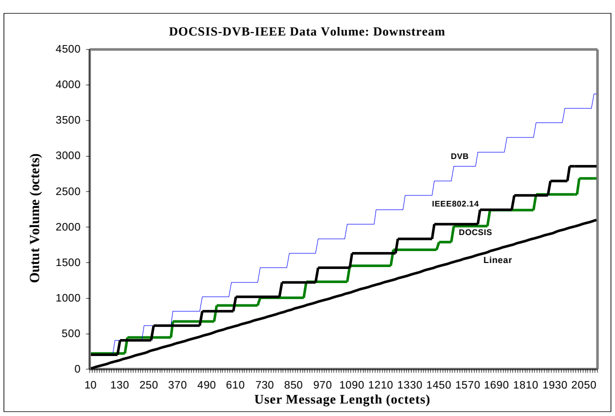

Figure 5. Downstream volumetric comparisons.

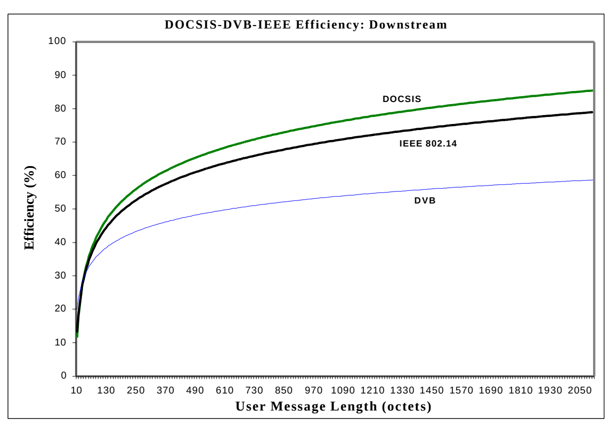

Figure 6. Downstream volumetric comparisons.

CONCLUSIONS

In this paper, we have given an overview of the DVB/DAVIC, DOCSIS and IEEE 802.14 reference architectures and MAC protocols. A comparison of the MAC and PHY layer protocol show that the DOCSIS protocol(upstream and downstream) produces less data overhead than the equivalents produced by the DVB and IEEE. Comparing the DVB and IEEE protocols, in the upstream, the DVB specification is more efficient than the IEEE. However in the downstream, the IEEE produces less data overhead than its equivalent DVB specification.

The DVB, MCNS and the IEEE 802.14 groups are each producing their own cable modem specification. At the PHY layer these specifications are similar. However, at the MAC layer the solutions provided by the same groups have little in common. The IEEE 802.14 and the DVB encapsulate every datagram in ATM AAL5 and suffer the overhead penalty for Segmentation and Reassembly (SAR), while the DOCSIS uses a scheme that favors the delivery of variable length internet protocol packets rather than ATM transfer, in an attempt to keep cost and complexity of cable modems down.

ACKNOWLEDGEMENTS

The main author would like to thank the National Autonomous University of Mexico for funding this work.

REFERENCES

[1], ATM Forum, *"ATM Forum Technical Committee: Residential Broadband Architectural Framework"*, AF-RBB-0099.000, ATM Forum, July 1998.

[2], Achilleoudis N. "*DOCSIS 1.0 Key Achievements"*, Cisco Systems, Inc. May 3, 1999.

[3], Azzam, A., "*High Speed Cable Modems"*, McGraw-Hill, 1997, ISBN 0-07-006417-2.

[4], *"Cable Modem Termination System-Network Side Interface Specification"*, DOCSIS MCSN Consortium, SP-CMTSNSII01-960702, 1996.

[5], "*Cable Modem to Customer Premise Equipment Interface Specification*", DOCSIS, MCSN Consortium, SPCMCII01-960702, 1996.

[6], "*Data-Over-Cable Interface Specifications - Radio Frequency Interface Specification"*, 1997, MCNS Consortium, SP-RFII01-970326.

[7], "*Data-Over-Cable Service Interface Specifications – Operations Support System Interface Specification"*, 1997, MCNS Consortium, SP-OSSI-I01-970403.

[8], "*Data-Over-Cable Service Interface Specifications – Cable Modem Telephony Return Interface Specification"*, 1997, MCNS Consortium, SP-CMTRI-I01-970804.

[9], "*Data-Over-Cable Interface Specifications - Radio Frequency Interface Specification"*, 1998, MCNS Consortium, SP-RFIv1.1-981214.

[10], EN 300 421, *"Framing structure, channel coding and modulation for 11/12 GHz satellite services"*, ETSI, August 1997.

.[11], EN 300 468 v1.2.1, "*DVB; Specification for Service Information (SI) in DVB systems"*, ETSI, Feb 1998.

[12] EN 300 744 v.1.2.1, "*Framing structure, channel coding and modulation for digital terrestrial television"*, ETSI, January 1999.

[13], ETS 300429, *"Digital Video broadcasting: Framing structure, channel coding and modulation for cable systems"*, ETSI, Version 1.2.1, April 1998.

[14], ETS 300 800, "*Digital Video Broadcasting: Interaction Channel for Cable TV Distribution Systems (CATV")*, ETSI, September 1999.

[15], Golmie N., Mouveaux F. and Su D, *"A Comparison of MAC Protocols for Hybrid Fibre/ Coax Networks: IEEE 802.14 vs. MCNS"*, Procs. of the 16th Intern. Conference on Comms, June 1999, Vancouver Canada.

[16], Golmie N., Sailntillan Y., Su D., *"A Review of Contention Resolution Algorithms for IEEE 802.14 Networks"*, IEEE Communications Surveys, 1st quarter 99, pp. 2-12.

[17], IETF, *"Telephony-Return Interface (TRI) Management Information Base (MIB) for DOCSIS compliant Telephone-Return CMs and CMTS"*, July 1998.

[18], IEEE 802.14 Subcommittee, "*IEEE 802.14 Broadband CATV Protocol*, Draft 3, Release 3", IEEE 802 Publications, November 1998.

[19], ITU-T, *"Recommendation J.83: Transmission of Television, Sound Programme and Other Multimedia Signals"*, April 1997.

[20], ITU-T, *"Recommendation J.112: Transmission Systems for Interactive Cable Television Services"*, Prepublished, March 1999.

[21], Schunke K., *"Performance Evaluation of the DVB/DAVIC Cable Return Channel System ETS 300 800"*, Procs of IBC '98, Amsterdam, Sep. 1998, pp.52-57.

[22], Sdralia V, Smythe C, Tzerefos P, and Cvetkovic S, "*Performance Characterisation of the MCNS DOCSIS 1.0 CATV Protocol with Prioritised First Come First Serve Scheduling*", IEEE Transactions on Broadcasting, Vol.45, No.2, June 1999, pp.196- 205.

[23], Smythe C, Basso C, Hartley S, Tzerefos P and Cevtkovic S, "*Standards for Interactive Multimedia Delivery Across CATV Infrastructures"*, Procs IBC 97, IEE Publication No.447, Sept 1997, pp.43-48.

[24], Tzerefos P, Smythe C, Stergiou I, and Cvetkovic S, "*Standards for High Speed Digital Communications over Cable TV Networks"*, Procs of the 6th IEE Conference on Telecs, IEE Publication No.451, 1998, pp.224-229.

[25], Tzerefos P, Sdralia V, Smythe C and Cvetkovic S, "*Delivery of Low Bit Rate Isochronous Streams of the DOCSIS 1.0 Cable Television Protocol*", IEEE Transactions on Broadcasting, Vol.45, No.2, June 1999, pp.206-214.