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COMPARING IEEE 802.14 AND MCNS STANDARDS FOR HYBRID FIBER COAXIAL NETWORKS

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Abstract— In this paper, we present a comprehensive review of two standards, IEEE 802.14 and MCNS, developed for the Hybrid Fiber Coax (HFC) CATV networks. After a brief introduction to the physical layer of the HFC networks, three major MAC protocol issues, including synchronization, collision resolution, and bandwidth allocation and scheduling, are identified. We then compare these two standards by illustrating their similarities and differences. Both standards offer data-link-layer security, upstream as a stream of minislots, downstream in MPEG-2 format, virtual queue, upstream bandwidth management, and request piggyback. But they have quite different mechanisms for ranging, upstream access, and collision resolution. Among them, IEEE 802.14 has reservation and isochronous access modes, while MCNS has reservation and immediate access modes. For collision resolution, IEEE 802.14 exercises a fairly complicated combination of priority control, n-ary tree walk, and multiple collision resolution engines, while MCNS uses a simple binary exponential backoff algorithm. The space left open by the standards, especially the allocation and scheduling issues, are also identified.

I. INTRODUCTION

To facilitate interoperability between cable modems and headends designed by different vendors, standardization is required. Two major associations working on the hybrid fiber coax (HFC) networks are *IEEE 802.14 Working Group* [1], [2], [3] and *Multimedia Cable Network System Partners Ltd.* [4], [5], abbreviated as MCNS. IEEE 802.14 Working Group was formed in May of 1994 by several vendors to develop international standards for data communications over cables. Due to the delayed progress, four major cable MSOs[1], including Comcast Cable Communications, Cox Communications, Tele-Communications Inc., and Time Warner Cable, established the MCNS camp in December of 1995 to create their own standard—Data Over Cable Service Interface Specifications (DOCSIS).

Both IEEE 802.14 and MCNS adopt a channelized approach, i.e. frequency-division multiple access (FDMA), in downstream as well as upstream transmission. Each FDMA upstream channel is further slotted by time-division multiple access (TDMA). Key features of IEEE 802.14's and MCNS's physical layer specifications are summarized in table 1.

		IEEE 802.14	MCNS
Downstream	**RF range**	88~860 MHz	50/54~860 MHz
	Modulation	64 and 256 QAM	64 and 256 QAM
	Channel width	6 or 8 MHz	6 MHz
Upstream	**RF range**	5~42 MHz	5~30 or 5~42 MHz
	Modulation	QPSK and 16 QAM	QPSK and 16 QAM
	Symbol rate*	160*M KBaud M=1,2,4,8,16,32	160*M KBaud M=1,2,4,8,16

*: The minimum channel spacing is $(1+\alpha)\cdot R_S$ where α is the spectral roll-off factor, and R_S is the symbol rate.

Table 1. Key features of IEEE 802.14's and MCNS's physical layer specifications

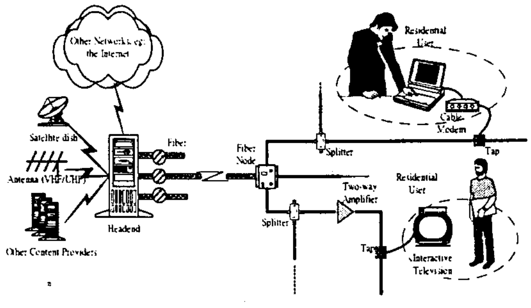

Fig. 1. An HFC network

Figure 1 represents an HFC system. A fiber node which can serve 500 to 2000 subscribers receives signals sent from the headend via a fiber. Then these signals are translated into cable signals by the fiber node and sent to amplified tree-and-branch feeder cables. Subscribers can retrieve or transmit signals by connecting their coaxial terminal units (CTU), i.e. set-top boxes or cable modems, to the taps on the network. With multiple access technologies, all subscribers within a branch can share the upstream bandwidth to send data back to the headend.

In this paper, we focus on the MAC and TC layers of the HFC protocols. Channel allocation in the TC layer has been described in this section. Three MAC protocol issues, including synchronization, collision resolution, and bandwidth allocation and scheduling, are examined in section II. Section III describes the basic mechanisms of IEEE 802.14 and MCNS during initialization and normal operations. Major similarities and differences between IEEE 802.14 and MCNS standards are identified and illustrated in section IV and section V, respectively. Finally, section VI concludes the paper.

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[1] MSO is the abbreviation for Multiple Systems Operator which refers to a company that operates more than one cable system.

II. MAC PROTOCOL ISSUES IN HFC NETWORK

Two features of the HFC network pose challenges to the designers of its MAC protocol. First, since the propagation delay in the HFC network might be as long as 200 μs in IEEE 802.14 and 400 μs in MCNS which can be much larger than the transmission burst time in the upstream, most part of the cable, in the upstream, could be empty while waiting for a message to traverse to the headend. The headend needs to direct stations to adjust their timing to compensate the delay so that transmissions from stations can pipeline the cable. Second, because stations can only listen to downstream signals, they can not sense collisions by themselves if without the help from the headend. In fact, the headend can control how the upstream channel is shared by stations. Given these two features, three important issues, including synchronization, collision resolution, and upstream bandwidth management, in the MAC layer need to be resolved.

A. Synchronization

Figure 2 shows what the problem is and how to compensate the propagation delay imposed on each station. If the headend sends a message, M, to invite stations to transmit a message which should arrive at the headend at T_1, then the headend needs to send M no later than $T_1 - T_X$ so that every station can receive M and respond in time. T_X is the maximum round-trip propagation delay of the HFC network. *Station$_A$* receives M at T_{A1}. If *station$_A$* sends its response right away, the response will arrive at the headend at T_2 instead of T_1. The idea is that *station$_A$* has to wait its *Round-Trip Correction* time, *RTC_A*, and then sends the response, so that the response will arrive at the headend at exactly T_1. RTC_A is equal to $T_X - T_A$. The headend must help *station$_A$* to calculate its own round-trip delay, T_A, so that *station$_A$* can adjust its transmission starting time to achieve the MAC level synchronization.

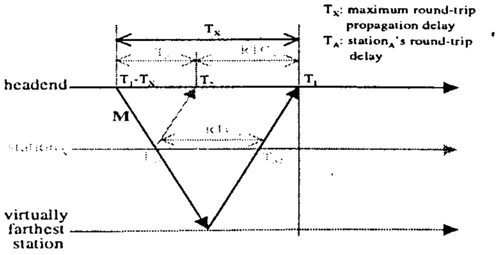

Fig. 2. Compensating propagation delay

B. Collision Resolution

There are three places, in the HFC network, where collisions might occur: 1) ranging responses, 2) bandwidth requests, and 3) immediate access messages. The first type will be discussed in the ranging algorithms. The third type only happens in the MCNS networks , and no further collision resolution algorithm, other than simple retransmission, is defined. Section V has more on this. A good collision resolution algorithm for collisions of the second type would reduce the *request access delay*, i.e. the time for a station to successfully transmit a bandwidth request to the headend, and improve the network throughput. In section V, the detailed collision resolution algorithms adopted in IEEE 802.14 and MCNS are described.

C. Bandwidth Allocation and Transmission Scheduling

The bandwidth allocation and transmission scheduling algorithms are left open to be designed by vendors instead of specified in the standards of IEEE 802.14 and MCNS. This is because allocation and scheduling do not affect interoperability. However, the performance of a cable network highly depends on these algorithms. In the upstream channel of a cable network, part of the bandwidth is reserved for stations to transmit their requests, and the other part is for data transmission. Hence, the utilization of the upstream bandwidth can be maximized by properly allocating the upstream bandwidth. Besides, to meet the growing time-sensitive services nowadays, not only fairness which is the main concern in traditional transmission scheduling algorithms but also quality of services, say priority, should be taken into account seriously.

III. BASIC MAC OPERATIONS OF IEEE 802.14 & MCNS

A. Initialization

The initialization steps of a just powered-up station are listed below:

1. Channel acquisition: Upon initialization or after signal loss, the station should acquire a downstream channel, by scanning the downstream frequency band until it finds a valid downstream signal. It then proceeds to achieve the physical level synchronization in order to align the bit stream. Then, the station can learn the characteristics of the upstream channel from specific management messages broadcast in the downstream channel by the headend and tune its transmitter to the upstream frequency band specified in the messages.
2. Ranging and power leveling: The headend periodically reserves a period in the upstream channel for newly arriving stations to proceed with the ranging and power leveling process. The headend broadcasts a ranging invitation message, which indicates where the ranging area is. In the process, a station sends a ranging request to the headend. Once the request is received successfully, the headend calculates the ad-

justment that the station needs to make and sends back a ranging response which encapsulates the adjustment to the station. Then the station adjusts itself accordingly. The station repeats these steps until the headend considers the station's ranging and power leveling are accurate enough.

3. Operational parameters download: This applies to MCNS only. The operational parameters can be divided into three types:

- Standard configuration settings: For example, NACS is either 0 or 1. If the value of NACS for a station is 0, the station is not allowed to access the network, and vice versa. Stations must be capable of processing this type of configuration settings.
- Optional standard configuration settings: For example, *Class of Service Configuration Setting* defines the parameters associated with a class of service. If this type of configuration setting is included in the downloaded parameters, stations must be capable of processing it, too.
- Vendor-specific configuration settings: If this type of configuration setting is included in the downloaded parameters, stations may or may not support it.

These operational parameters are required when a station registers to the headend.

4. Registration to the headend: In MCNS, a station sends a registration request, which contains the operational parameters, to the headend; the headend then 1) confirms the correctness of the operational parameters, 2) builds a profile for the station based on the standard configuration settings provided in the operational parameters, 3) assigns a Service ID (SID), to be discussed in section IV, to the station according to the classes of service supported, and 4) sends back a registration response to the station.

In IEEE 802.14, once a newly arriving station is properly ranged and power leveled, the headend sends an Assign Parameter message containing a primary Local ID (LID), to be discussed in section IV, a bandwidth management LID, and an initial security exchange, to the station. After the station replies to the Assign Parameter message, the registration process is finished.

After these initialization steps, the station enters the normal operation.

B. Normal Operation

Figure 3 shows a simple state diagram for the initialized stations of MCNS and IEEE 802.14. Initially, the station enters the *Idle* state. When a data message arrives, the station enters the *Collision Resolution* state and repeatedly tries to send a bandwidth request to the headend until the request is successfully received by the headend. Then the station enters the *Transmitting* state. If extra data messages arrive during the station's transmission, the station should enable the Piggyback mechanism and piggyback the extra bandwidth request to the headend. Once the station finishes sending data messages, and there are no more pending jobs, the station switches back to the *Idle* state.

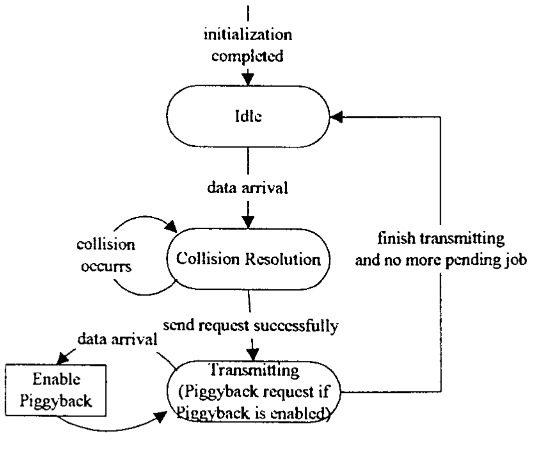

Fig. 3. A simple state diagram for initialized stations of MCNS and IEEE 802.14

IV. THE SIMILARITIES

There are many similarities between the specifications of IEEE 802.14 and MCNS, as shown in table 2.

<table>
<tr><th></th><th>IEEE 802.14</th><th>MCNS</th></tr>
<tr><td rowspan="2">Data-link-layer security</td><td colspan="2">Encryption algorithm: DES algorithm.</td></tr>
<tr><td>Key exchange protocol: Main Key Exchange or Quick Key Exchange protocol.</td><td>Key exchange protocol: base on RSA and DES algorithms.</td></tr>
<tr><td>Upstream as a stream of minislots</td><td>Minislot size = time of transmitting 8 bytes of data and other overhead.</td><td>Minislot size = time of transmitting 16 bytes of data and other overhead.</td></tr>
<tr><td>Downstream MPEG-2 format</td><td>MPEG-2 PID = 0x1FFD</td><td>MPEG-2 PID = 0x01FFE</td></tr>
<tr><td>Virtual queue</td><td>Each SID of a station maps to a virtual queue.</td><td>Each (LID,LQ) of a station maps to a virtual queue.</td></tr>
<tr><td rowspan="3">Upstream bandwidth management</td><td>The minislot usage assignment is described in the Bandwidth Management Cells, composed of several kinds of Information Elements.</td><td>The minislot usage assignment is described in the Allocation Map, composed of several kinds of Information Elements.</td></tr>
<tr><td colspan="2">The Information Element is used to describe the usage of some contiguous upstream minislots.</td></tr>
<tr><td colspan="2">Stations send bandwidth requests at request minislots and send data at the data minislots assigned by the headend.</td></tr>
<tr><td>Piggyback</td><td colspan="2">Stations can piggyback extra bandwidth requests when they transmits data in the data minislots.</td></tr>
</table>

Table 2. The similarities between the MAC layers of IEEE 802.14 and MCNS

A. Data-Link-Layer Security

Both IEEE 802.14 and MCNS provide capabilities of data-link-layer security. In IEEE 802.14, a Security Element (SE) which is one of the modules in the headend is in charge of secure communications between stations and the headend. The Data Encryption Standard (DES) specified in ANSI X3.92 [6] and X3.106 [7] is used as the encryption algorithm, and the 64-bit Cipher Block Chaining (CBC) mode is adopted. The size of the encryption key should be 40-bit wide at least, but 56-bit keys are recommended. Stations can obtain their unicast and multicast keys and be authenticated, by using the Main Key Exchange which is based on the Diffie-Hellman public key exchange protocol or Quick

Key Exchange protocol [1], when they join the network. Detailed information can be found in [1].

In the MCNS, stations use the Baseline Privacy Key Management Protocol to get authenticated and obtain encryption keys used to encrypt the user data PDUs. The Key Management Protocol uses RSA [8], [9], a public-key encryption algorithm, and the Electronic Codebook (ECB) mode of DES to secure key exchanges between stations and the headend [10]. Detailed information can be found in [10], [11].

B. Upstream as a Stream of Minislots

Both IEEE 802.14 and MCNS model an upstream channel as a stream of minislots. The upstream frequency band is divided into channels by frequency division, and each upstream channel is divided in time into a stream of minislots. In IEEE 802.14, the duration of one minislot is equal to the time required to transmit 8 bytes of data and other overhead including the physical layer header and the guard time. In MCNS, the time required to transmit 16, although other values can be chosen, bytes of data plus other overhead is the duration of one minislot. The size of a minislot is designed to carry a request PDU. Each minislot has an integer identifier, called the *minislot number*, which is assigned by the headend. The minislot number is 16-bit wide in IEEE 802.14 and 32-bit wide in MCNS. When the minislot number counts to its maximum value, it wraps back to zero. Note that there is no implication that any PDU can actually be transmitted in a single minislot. Concatenated multiple minislots can be used to transmit a PDU.

C. Downstream MPEG-2 Format

In order to improve the robustness of demodulation, facilitate common hardware for both video and data, and provide an opportunity for the possible future support of other types of traffic over the HFC networks, both IEEE 802.14 and MCNS adopt the MPEG-2 PID multiplexing [12] technology to multiplex the downstream traffic. The headend encapsulates downstream PDUs in MPEG-2 transport packets to form an MPEG-2 transport stream. The stream then may be multiplexed with other types of streams, for example video streams, and finally be transmitted over the HFC network to the residential stations. Once the MPEG-2 stream is received by the stations, it would be demultiplexed by the Transmission Convergence (TC) sublayer and passed to the corresponding higher layer.

D. Virtual Queue

In addition to a globally unique 48-bit MAC address, a station would be assigned one or more 14-bit IDs by the headend during the registration process. The ID is named as Local ID (LID) in IEEE 802.14 and Service ID (SID) in MCNS. When it is necessary, the headend can assign more IDs to a registered station. The dynamically assigned 14-bit IDs other than the fixed 48-bit MAC address are important to the MAC protocol of IEEE 802.14 and MCNS. For example, the headend may assign a multicast ID to several stations so that it can manage a group of stations easily. In the following two paragraphs, we explain the usage of these IDs in MCNS and IEEE 802.14, respectively.

In MCNS, a station obtains its SIDs corresponding to the classes of service for which it negotiates with the headend during registration. The headend would remember the mappings between stations, SIDs and classes of service. We can imagine that each SID of a station maps to a *virtual queue* inside the station. A virtual queue is the elementary entity that participates in the MCNS MAC protocol. Hence a registered station maintains a separate state machine, as shown in figure 3, for each of its virtual queues. From the point of view of the headend, whenever it does the scheduling or collision resolution, it considers each virtual queue instead of each station. In figure 4, $station_A$ is assigned three SIDs, each of which corresponds to a virtual queue inside. The headend would schedule the upstream minislots for each virtual queue according to the class of service that the SID represents and other criteria.

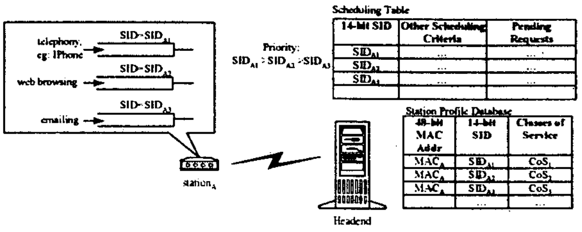

Fig. 4. Scheduling and SIDs in MCNS

In IEEE 802.14, a station's virtual queue is identified by one of the station's 14-bit LIDs and a 6-bit Local Queue identifier (LQ). The hierarchical relationship between LQ and LID is illustrated in figure 5. We can imagine that an LID of a station maps to a *virtual station* which also contains several local queues identified by an LQ. A virtual queue is also the elementary entity that participates in the IEEE 802.14 MAC protocol, and a station would maintain a separate state machine for each of its virtual queues. When a station sends a bandwidth request for its virtual queue to the headend, it needs to fill the 24-bit Queue Identifier (QID) field in the Request PDU. Note that a QID is used to identify a request in a virtual queue. The QID field is constructed from the virtual queue's LID, LQ, and a 4-bit Request Priority (PRI). A station should use the PRI field to indicate the priority of a request if the request is for transmitting 802.2 LLC data. With the information, the headend may do complicated scheduling for individual data flows. In figure 5, when the headend does the scheduling job, it first considers each virtual queue and the scheduling criteria in the scheduling table. If it decides to schedule the virtual queue with $LID = LID_{A2}$ and $LQ = LQ_{A3}$, it checks the pending requests of that queue and may first schedule the one with the highest priority.

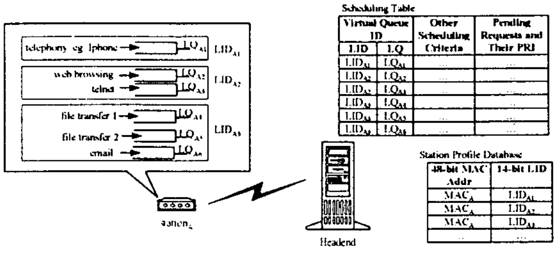

Fig. 5. Scheduling and QIDs in IEEE 802.14

E. Upstream Bandwidth Management

The upstream bandwidth management is achieved by broadcasting, multicasting, or unicasting the *bandwidth allocation map* which is called Downstream Bandwidth Management Cell in IEEE 802.14 and Allocation Map in MCNS. Since stations cannot listen to the upstream channel, the headend must coordinate accesses to these minislots from the stations. The headend assigns the usage of upstream minislots and describes the assignment in the bandwidth allocation map. Once the map is sent over the downstream channel, stations can learn the assignment from the map and proceed accordingly.

Basically, some of the upstream minislots are assigned as *request minislots*, and others are assigned as *data minislots*. Request minislots are used to carry bandwidth requests made by stations. Unless specified in the bandwidth allocation map, every station has access right to the request minislots. Data minislots are used to carry data.

In fact, the bandwidth allocation map is composed of several kinds of *Information Elements* (IE). Each one of the IEs is used to describe the usage of some *contiguous* upstream minislots. For example, the Request Minislot Allocation Element is one kind of the bandwidth management IEs in IEEE 802.14, and it is used to specify the location of request minislots and collision-resolution parameters.

F. Piggyback Requests

In addition to contending the request minislots, a station can also send its bandwidth request through piggyback. A specific field in the header of upstream data PDUs is reserved for piggyback. The bandwidth request made through piggyback should be subject to administrative limits. The access delay can be much reduced if most of the requests are sent to the headend through piggyback instead of request minislot contention.

V. THE DIFFERENCES

Table 3 summarizes the differences between the MAC layers of IEEE 802.14 and MCNS; these differences are examined in this section.

	IEEE 802.14	MCNS
Ranging	P-persistent collision resolution	Binary exponential backoff collision resolution
Access Modes	Normal reservation Piggyback reservation CBR access	Normal reservation Piggyback reservation Immediate access
Collision Resolution Algorithms	Latest draft [3]: First transmission rule: priority + FIFO Retransmission rule: n-ary + p-persistence Multiple collision resolution engines Old draft [1]: P-persistent + ternary-tree walk algorithm + multiple collision resolution engines	Binary exponential backoff + backoff window

Table 3. The differences between the MAC layers of IEEE 802.14 and MCNS

A. Ranging

In section II, we introduce the basic idea of ranging, and we now describe the detailed ranging procedure.

The steps of ranging procedures in IEEE 802.14 and MCNS are listed below,

1. Get global timing reference: After being powered up, the station should listen to the *sync* message sent periodically by the headend at an interval of tens of milliseconds. The headend and each station have a free running clock. The sync message contains a timestamp that records the time at which the headend transmits the message. The station should set its local clock to the time in the sync message. After several times of "syncing", the station's clock rate can synchronized to the clock rate of the headend, as step(a), step(b), and step(c) shown in figure 6. Note that this process continues even after the initialization.

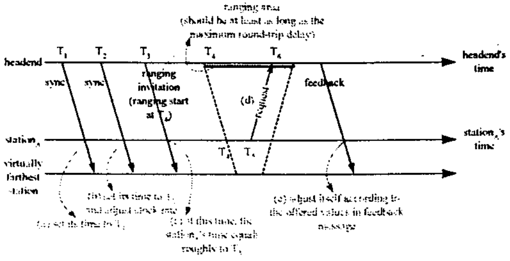

Fig. 6. A ranging process

2. Identify the ranging area: The headend also periodically broadcasts a *ranging invitation* message, from which the station can learn where the ranging area is, to invite all unranged stations to join the network. The starting point of the ranging area is described, by explicitly identifying the starting minislot number, in the message.

3. Send the ranging request: After finding the ranging area, the station can send its ranging request to the headend in the ranging area. The exact sending time

depends on the collision resolution algorithm adopted in the ranging process, as step(d) in figure 6. If the ranging request is successfully received, the headend would evaluate the timing offset and other miscellaneous parameters that the station should tune to accordingly. These adjustment parameters are then encapsulated in a ranging feedback message, which is sent back to the station.

4. Adjust according to the feedback message: The station is roughly ranged after adjusting its parameters according to the offered values in the feedback message, as step(e) in figure 6. The ranging process is repeated until the headend considers that no more adjustment is required to be performed by the station.

For step 3, MCNS adopts a binary exponential backoff algorithm to resolve the collision during the station's ranging process. In the header of the ranging invitation message, two parameters, Ranging Backoff Start (RBS) and Ranging Backoff End (RBE), indicate the initial and maximum backoff window size used in the binary exponential backoff algorithm. Initially, the unranged station sets its Ranging Backoff Window (RBW) values to RBS. Then it randomly selects a number, say N, between 0 and $2^{RBW}-1$ and transmits its ranging request at the Nth minislot after the starting minislot of the ranging area. If a collision occurs, the station should 1) set the value of RBW as $min(RBW*2, RBE)$, and 2) re-select N and transmit the request again. This process is repeated until the ranging request is successfully received by the headend.

IEEE 802.14 uses the p-persistent algorithm to resolve the collision during the ranging process. The unranged station first generates a real number, say X, between 0 and 1. If X is greater than or equal to P, specified in the ranging invitation message, then the station is qualified to transmit the ranging request this time, or else the station needs to wait for the next chance. If a collision occurs, the station just needs to re-select X and try again. This process is repeated until the ranging request is successfully received by the headend.

B. Access Modes

In addition to the normal reservation and piggyback reservation modes supported in both standards, Constant Bit Rate (CBR) services are also supported in IEEE 802.14. A CBR bandwidth allocation request can be made by a station for its virtual queue, such that periodical grants, at a desired frequency, are allocated until the station explicitly releases the CBR service. This kind of access mode offers better support for the isochronous traffic.

In MCNS, immediate access mode is provided. When the load of network traffic is low, the headend may assign a region of minislots as immediate access minislots. Stations can transmit not only data but also their bandwidth requests in these immediate access minislots. If the transmission was successfully received by the headend, positive feedback will be issued to the station. Even if the transmission is collided, the station can retransmit its request or data next time, i.e. no further collision resolution protocol is enforced.

C. Collision Resolution Algorithms

IEEE 802.14: a combination of priority control, n-ary tree walk, and multiple collision resolution engines

The latest draft of IEEE 802.14 combines four techniques, which are prioritized admission control mechanism, FIFO mechanism, n-ary tree algorithm, and the idea of multiple collision resolution engines, into its collision resolution algorithm. Stations exercise the first transmission, priority and FIFO, for the newly arriving requests and the retransmission rule, n-ary tree and p-persistence, for the collided requests. The prioritized admission control mechanism is used to discriminate requests of different priorities, which range from 1 (lowest) to 8 (highest). The FIFO mechanism, which compares the request arrival time and the specified admission time boundary, is used to prevent excessive collisions. The n-ary tree algorithm randomly splits stations collided in a previous minislot into n, the split value, ways but the stations whose selected value is larger than the number of allocated minislots will be blocked from retransmission and should retry next time. The latter part is in fact the p-persistence mechanism. Stations can get the parameters of these mechanisms from the bandwidth allocation map and proceed accordingly. We use an example, shown in figure 7, to illustrate how these mechanisms work together.

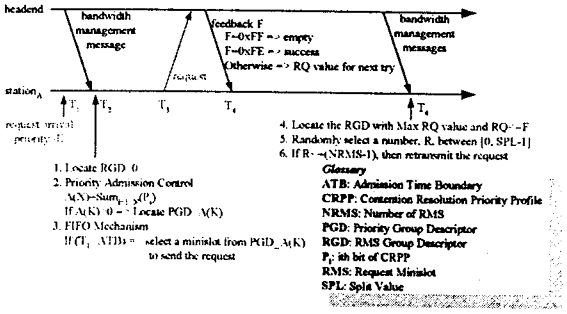

Fig. 7. Collision resolution algorithms in the latest IEEE 802.14 draft.

1. At T_1, one of the $station_A$'s virtual queues generates a new request, with priority equal to K. IEEE 802.14 divides request minislots into several groups, each of which has a Resolution Queue (RQ) value, to facilitate the tree walk algorithm. A newly arriving request can only use the request minislots whose RQ value is zero.

2. At T_2, $station_A$ receives the bandwidth management message which describes the allocation of some continuous request minislots. The format of bandwidth

management PDU is shown in figure 8; in the PDU's header, the *Contention Interleave Identifier* (CIL) and *Starting Minislot Number* (SMS) represent 1) the specified request minislots belong to the collision resolution engine whose ID is CIL, and 2) the number of the first request minislot is SMS. The *Request Minislot (RMS) Group Descriptor* M (RGD_M) in the PDU describes the allocation of request minislots whose RQ value is M. The minislots in the RGD_0 are further divided into several groups, each of which is identified by a *Priority Group Descriptors* (PGDs). Each of the groups has its associated priority. The *Number of RMS* ($NRMS$) in the RGD_Ms ($M > 0$) and PGDs represents how many minislots are in the group. After $station_A$ learns the allocation of request minislots whose RQ value is zero from RGD_0, it proceeds to the Priority Admission Control and the FIFO mechanism, to be described below, to decide whether it is eligible to transmit request and, if yes, which request minisots it can use.

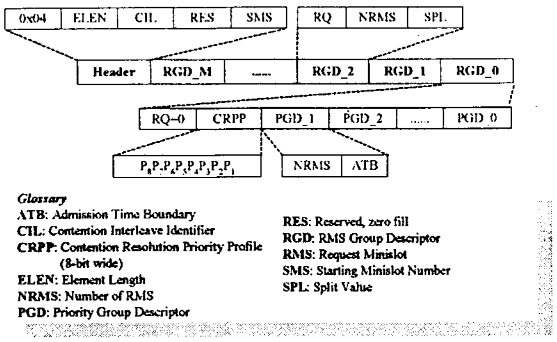

Fig. 8. IEEE 802.14 Bandwidth Management Message PDU format.

- Priority Admission Control: The headend regulates the station's access to the request minislots by assigning the *Contention Resolution Priority Profile* ($CRPP$), which is an 8-bit field in the bandwidth management message header shown in figure 8. For example, in figure 7, the priority of the request of $station_A$ is 5, and the value of CRPP is $0xb00111000$. $Station_A$ has to calculate the value of $A(x)$ where $A(x)$ is $\sum_{i=1}^{x} P_i$, x is the priority of the request , and P_i is the ith bit of CRPP. The request is eligible for proceeding the FIFO Mechanism if the value of $A(x)$ if greater than zero. Therefore, the headend can 1) prohibit requests with priority lower than P from access request minislots by setting the low P bits of CRPP to zero , and 2) control the access, from eligible requests with different priorities, of request minislots group.
- FIFO Mechanism: After identifying the PGD to be used, $station_A$ should compare the arrival time of the request with the *Admission Time Boundary* (ATB) in the PGD. Only when the request arrival time is smaller than the ATB, $station_A$ is permitted to randomly select a request minislot from PGD to send the request.

3. At T_3, $station_A$ sends the request.
4. At T_4, $station_A$ receives the feedback message. If the value, say F, of the feedback message is $0xFE$, the contention is successful; otherwise, the contention is failed. In the latter case, $station_A$ should first locate the RGD , in the next bandwidth management messages, with the greatest RQ value among the RGDs whose RQ value is smaller than or equal to F to retry the request transmission. The retry process is based on the n-ary tree walk algorithm, as step(4), step(5), and step(6) shown in figure 7. $Station_A$ randomly select a number, say R, between 0 and $SPL - 1$. SPL is the abbreviation of *Split Value* and is a field in the RGD. If R is smaller than the value of $NRMS$ in the RGD, then $station_A$ can retransmit its request at the Rth minislot of the request minislots described by the RGD. Otherwise, this step is repeated.

Collision Resolution Engine

Each collision resolution engine of the headend periodically assigns minislots for stations to transmit data or bandwidth requests and processes the incoming requests. With multiple collision resolution engines, the collision resolving efficiency can be improved. We use an example to illustrate the improvement. In figure 9, $station_A$ and $station_B$ have newly arriving requests at T_2 and T_3, respectively. With the existence of only CRE_1, $station_A$ can learn the minislot allocation from the bandwidth allocation map sent by CRE_1 at T_1 and then send its request at T_5. But $station_B$ can not learn the minislot assignment on time. Hence $station_B$ has to wait for the next bandwidth allocation map to learn the minislot assignment. Finally $station_B$ sends its request at T_7. However, with the existence of both CRE_1 and CRE_2, $station_B$ can learn the minislot assignment from the bandwidth allocation map sent by CRE_2 at T_4 and then send its request at T_6 which is earlier than T_7. MCNS: Binary exponential backoff + Backoff window.

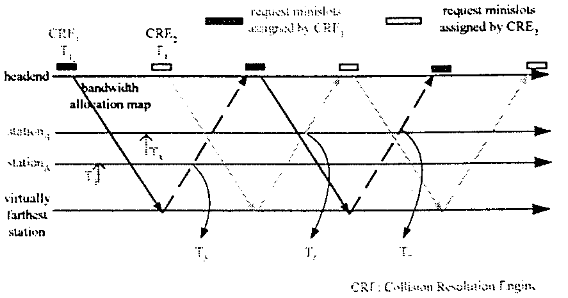

Fig. 9. Interleaving the operations of multiple collision resolution engines

MCNS: binary exponential backoff

MCNS adopts a binary exponential backoff algorithm to resolve the collision in the request minislot contention process. The format of bandwidth management PDU, which includes the header and several number of IEs, of MCNS is shown in figure 10. The *Alloc Start Time* in the header is used to indicated the starting minislot number of the described minislots. Each IE contains three fields:

- SID: The SID is used to indicate which station(s) the IE is sent to.
- Interval Usage Code (IUC): The IUC is used to identify the usage of the described minislots. A few values of IUC is illustrated in figure 10.
- Offset: The Offset is used to indicate the starting offset of the minislot described in the IE. For example, the minislot number of the first minislot in some IE with $Offset = 10$ is $AllocStartTime + Offset$.

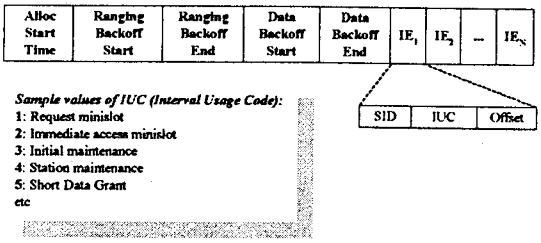

Fig. 10. MCNS Bandwidth Management PDU format.

Data Backoff Start (DBS) and *Data Backoff End* (DBE) are used to indicate the initial and maximum backoff window size used in the algorithm. These two parameters are exponents of window sizes represented in power-of-two. For example, if the value of DBE is 10, the maximum backoff window size is $2^{10} = 1024$. We use an example to illustrate how this algorithm works. Consider a station whose initial backoff window is 0 to 15, i.e. the value of DBS is 4, and it randomly selects the number 7. The station does not contend for any request minislot until it has deferred a total of 7 contention transmission opportunities. If the contention was failed, the station increases its backoff windows size by a factor of two, as long as it is less than the maximum backoff window size. Then the station randomly selects a number within the new backoff window and repeats the deferring process described above. This retry process continues until the times of collision reaches 16, at which time the request is dropped.

VI. CONCLUSION

In this paper, we gave an overview of the operations of IEEE 802.14 and MCNS, including how to register to join the cable network, how to request bandwidth, and how to resolve a collision. The similarities and differences between the MAC-layer specifications of IEEE 802.14 and MCNS were examined. Three major differences between IEEE 802.14 and MCNS might have impact on the performance of the HFC network. Finally; we raise the following concerns that deserve further studies. We have tried to answer some of them in [13].

- The performance of collision resolution algorithms, especially the one in IEEE 802.14, is not clear. Since the network propagation delay is large, we need a good collision resolution algorithm that can minimize the number of retransmissions and the amount of resolution overhead. Further studies can investigate how to tune the parameters of the algorithms to achieve better performance and compare these algorithms.
- Do we need to have immediate access ? And, if yes, how to allocate the immediate access bandwidth under the varying traffic load is another research issue.
- Both IEEE 802.14 and MCNS offer the priority services for virtual queues in the network. How does the headend schedule stations' data transmissions when it receives bandwidth requests from these virtual queues?

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