Project	**IEEE 802.16 Broadband Wireless Access Working Group<http://ieee802.org/16>**
Title	**Proposal for an ARQ Error Correction Mechanism for the 802.16.1 MAC Layer**
Date Submitted	**2000-06-15**
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Re:	This is in response to the IEEE 802.16.1 voiced need for an ARQ Error Correction option
Abstract	An Automatic Repeat Query (ARQ) Mechanism option is being proposed for adoption into the IEEE 802.16.1mc-00/15.
Purpose	To provide an optional MAC Layer ARQ Mechanism that when used alone can cost-effectively and efficiently improve the performance of low bit error rate FBWA channels, and when concatenated with a PHY layer FEC can effectively improve the performance of high error rate FBWA channels, while still supporting traffic latency requirements.
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1. INTRODUCTION

The wireless medium over which Fixed Broadband Wireless Access (FBWA) channels operate is by nature dependent on a region's statistically variable propagation environment. Moreover the error rate and availability requirements of a FBWA system is application depedent. This means that the transmission inefficiecies of forward error correction (FEC) for FBWA systems may not be appropriate for a number of cost-sensitive applications. An automatic repeat query (ARQ) mechanism can be a more efficient and cost-effective means of achieving the required error performance for many cost-sensitive applications.

A common goal expressed by many IEEE 802.16.1 participants is that the proposed IEEE 802.16 Air Interface FBWA Standard, when approved should cost-effectively and efficiently improve performance and permit low-cost FBWA Subscriber Terminals (STs)/CPE implementations.

What follows is a proposal for a MAC Layer fast selective repeat ARQ mechanism option that when used alone can cost-effectively and efficiently improve the performance of low bit error rate FBWA channels, and when concatenated with a PHY layer FEC can effectively improve the performance of high error rate FBWA channels, while still supporting traffic latency requirements. An FEC-ARQ hybrid approach has the complementary appeal of an FEC that usually assumes stability of the channel error statistics and the ARQ that does not.

2. ARQ DETAILED DESCRIPTION

Data transmission and ARQ in only the downstream direction will be described. The ARQ is applied in the upstream in an identical manner. The ARQ relevant portions of the MAC are described first, then the data structures enabling the implementation of the MAC followed by a description of the traffic scheduling and ARQ algorithms. Finally the key benefits that can result from the proposed ARQ are listed.

3. RELEVANT PORTIONS OF THE MAC

The Access Point (AP) MAC through the use of a MAC frame controls access to the wireless media. Each MAC frame consists of a downstream and an upstream portion. Contained within the downstream portion are the frame descriptor header, subscriber reservation request acknowledgments, downstream cell acknowledgments and downstream data cells. The upstream portion of the MAC frame consists of a short slotted Aloha contention period in which the subscriber terminals request reservations followed by upstream cell acknowledgements and upstream data cells.

The mapping of subframes within the MAC frame is communicated by the AP to the Subscriber Terminals (STs) via the frame descriptor header. For the purposes of this description, the most important section of the frame descriptor header is the downstream burst map.

The downstream burst map includes a maximum of sixteen entries (one for each burst, thereby limiting the downstream portion of the MAC frame to no more than 16 bursts). Each burst map consists of a Subscriber Unit-Access Identifier (SU-AID), the traffic type of the burst, and the number of cells contained within the burst. The frame descriptor header and thus the downstream burst map are sent out at the beginning of a MAC frame.

4. MAC DATA STRUCTURES

1. **Subscriber Unit List:** contains a list of actively registered SU-AIDs, with a pointer from each entry to a set of traffic queues.
2. **Subscriber Unit Traffic Queues:** For each SU that is actively registered with an AP, there is a set of traffic queues, one queue per traffic type.
3. **Cell Acknowledgement Map:** Each time a cell is sent from the AP to a ST, the AP expects to receive a positive or a negative acknowledgement of the cell's arrival. Since no more than six cells of a given traffic type for a particular SU can be sent within a single MAC frame, it is not necessary to retain the acknowledgements status for more than six cells of a given traffic queue. Each queue therefore has six bit acknowledgement state of the most recently sent six cells.
4. **Pending Reservation Queue:** For each traffic type, there is a circular buffer containing a single entry for each SU with traffic awaiting a reservation.
5. **Downstream Frame Reservation Schedule:** Contained within this structure is a map of all downstream bursts to be sent during the downstream portion of the subsequent MAC frame. Entries for each burst include the SU-AID, the traffic type of the burst, and the number of cells contained within the burst.

5. TRAFFIC SCHEDULING ALGORITHMS

Cell Entry to the MAC: When a cell enters the MAC, it is de-multiplexed into the traffic queue corresponding to the SU and traffic type. If the queue had been empty upon cell arrival, the SU's SU-AID is entered into the pending reservation buffer for the corresponding traffic type.

Cell Scheduling: MAC frame burst maps are generated less than one frame in advance of the time that they are to be sent over the air. The cell scheduler first checks the pending reservation request buffer for the highest priority traffic type to see if any cells of that type are awaiting transmission. If there is an entry in the buffer (indicating that there may be traffic of that type queued-up), the scheduler reads the SU-AID from the buffer and uses it as an index into the SU list to reference the SU's traffic queue for that traffic type.

Because of the implementation of the cell scheduling algorithm, it is possible for entries to remain in the pending reservation queue even though no more traffic is pending. In that case, the scheduling controller removes the entry from the pending reservation buffer and makes no corresponding entry in the downstream schedule/burst map.

If there is traffic in the queue at the time the pending reservation is processed, the scheduling controller places the SU-AID into the tail end of the buffer, in order to keep the reservation open for potential cell retransmissions.

Cell Acknowledgment: The six bits of acknowledgment map for traffic queue corresponds to the acknowledgement state of the most recently sent cells. The data are sent to the ST during the downstream portion of the MAC frame, and are expected to be acknowledged during the upstream portion. The acknowledgment sent by a ST contains a six-bit map, with a 1 bit indicating positive acknowledgment and a 0 bit indicating negative acknowledgment. This six-bit map is transferred into the acknowledgment map for the corresponding SU-AID and traffic type.

Garbage Collection: During downstream transmission of the bursts that were scheduled in the previous frame, the MAC has time to remove positively acknowledged cells from traffic queues. The garbage collector checks each queue's acknowledgment map. Any cell with positive acknowledgment has been received correctly and thus no longer need to remain queued up. They are removed from the queue, and the count of pending cells for that particular traffic queue, is decreased by one.

ARQ Mechanism: retransmission of cells that were negatively acknowledged (or not positively acknowledged) is automatic as a result of the operations described above.

Two aspects of the MAC design force this to be true. First, only positive cell acknowledgement causes a cell to be removed from a traffic queue, thus leaving a cell in the traffic queue until its reception is confirmed. Second, because the cell scheduler continues to add the ST access identifier to the pending reservation buffer, the reservation for that ST and traffic type is kept open until all cells have been positively acknowledged. A processor re-sequences acknowledged received cells. As each cell of data contains a sequence number in its header, re-sequencing can be performed in the MAC/ARQ layer or in a convergence sublayer without any additional complexity.

6. KEY BENEFITS OF THE PROPOSED ARQ APPROACH

1. Allows a BWA system to provide error correction without requiring sending unnecessary FEC overhead to each ST.
2. Allows a fast turnaround ARQ mechanism for support of fixed bit rate and low latency traffic, by including the ARQ mechanism in the channel access mechanism.
3. Since the bandwidth for the ACKS/NACKS is always allocated within the MAC frame, the delay for receiving feedback from the far end of the link is always deterministic. Also since there need not be any contention for bandwidth for sending an ACK/NACK, the overall bandwidth efficiency of the network is improved
4. Since the ACK/NACK bits are always located in the same place in the MAC frame, there need to be no separate identifier symbols and there not be any packet sequence numbers accompanying the ACKS/NACKS.
5. The scheme is simple to implement because the six-bit ACK/NACK bitmap is stored directly on the six-bit acknowledgement bitmap of the traffic queue.

This allows cells that have been successfully transmitted, to be removed from the traffic queue at some other time during the MAC frame.

6. The traffic schedule that defines all of the traffic to be sent in a MAC frame is identical to the on-air frame descriptor header. This allows the header to be assembled at the same time the control flow for the MAC is being assembled. This simplifies hardware.
7. Can be supplemented with a Physical Layer FEC to form a Hybrid ARQ-FEC to effectively improve the performance of BWA channels with high error rate.

Appendix: Associated Diagrams

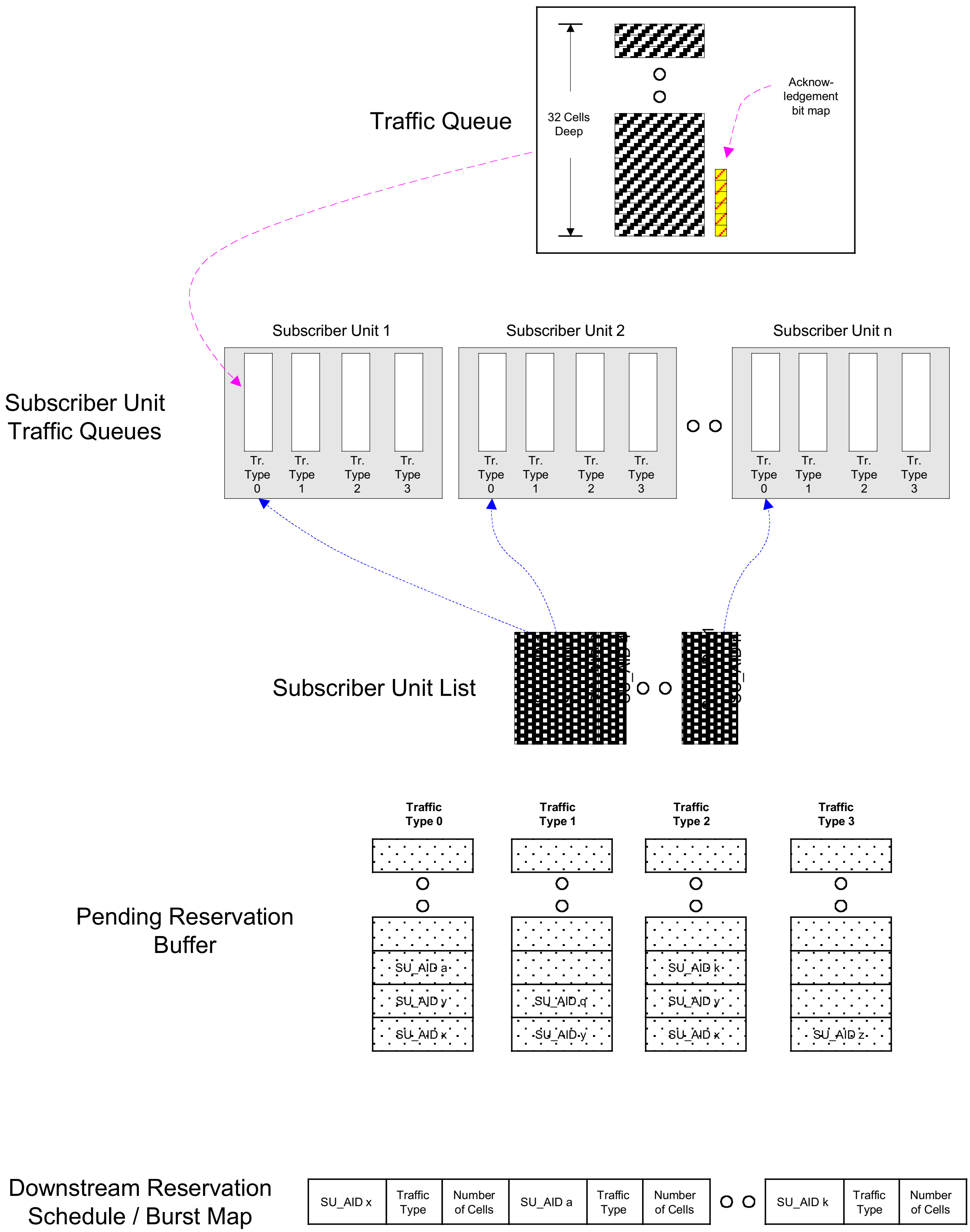
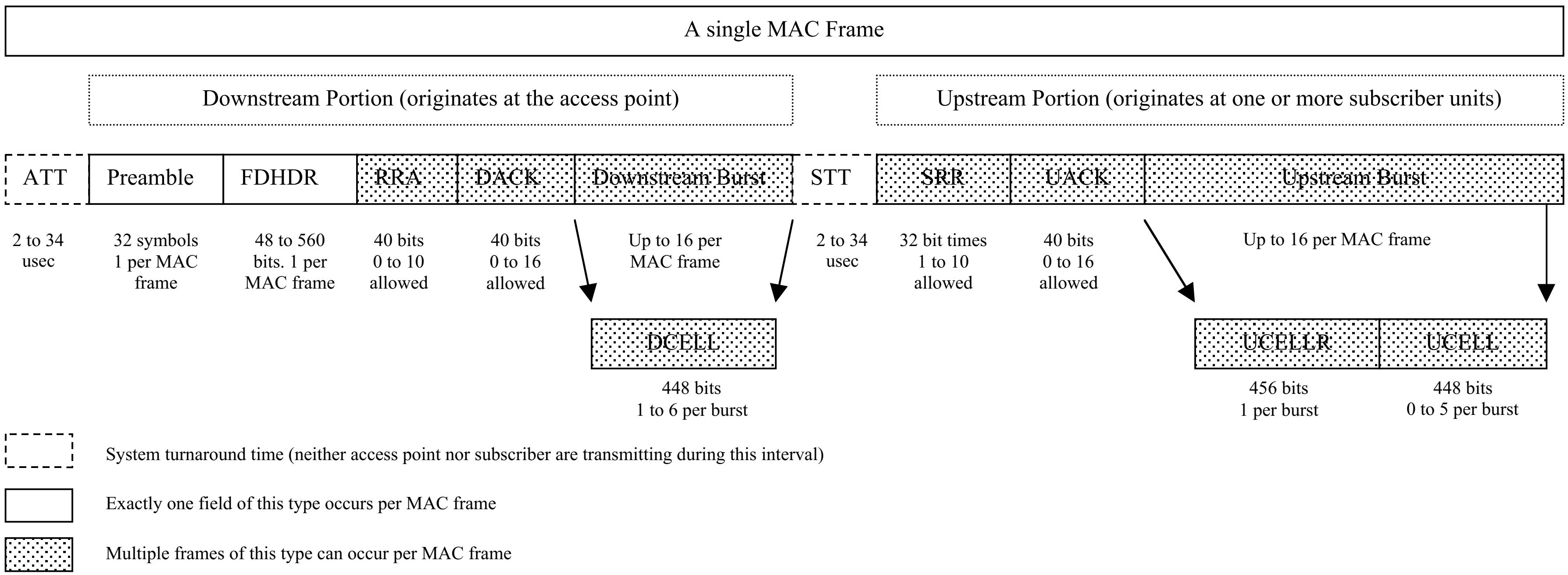
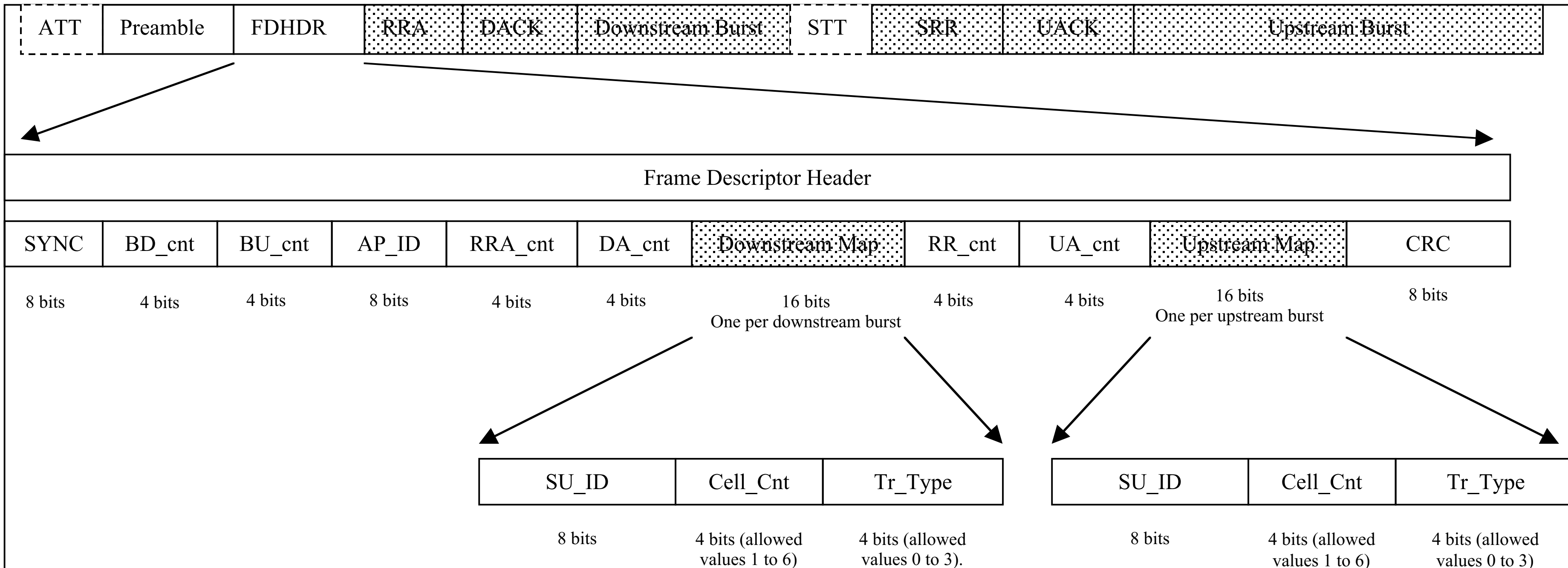


Figure 1 MAC Data Structures



Field Tag	Description
ATT	Access point turnaround time. This time varies with the distance to the farthest subscriber terminal
Preamble	Physical layer synchronization sequence. Used for frame acquisition and channel estimation.
FDHDR	Frame descriptor header. Describes the complete contents of the remainder of the MAC frame. Size varies.
RRA	Reservation Request Acknowledgement. Acknowledges a request by a subscriber for upstream time slots; can also communicate delay.
DACK	Downstream ack or nack of a single upstream burst from a previous MAC frame.
Downstream Burst	One or more data cells with the same traffic type being sent to a particular subscriber terminal.
DCELL	Downstream cell. Contains one ATM cell of payload data.
STT	Subscriber turnaround time. Varies with distance to farthest subscriber unit (maximum distance is 5 km).
SRR	Subscriber unit reservation request contention interval. Multiple slots can be made available during times of heavy request traffic.
UACK	Upstream ack or nack of a single downstream burst from a previous MAC frame.
Upstream Burst	One or more data cells with the same traffic type being sent from a particular subscriber terminal.
UCELLR	Upstream cell with additional reservation request for the following MAC frame.
UCELL	Upstream cell with no reservation request. Access point knows to expect this.

Figure 2 Structure of the MAC Frame



Field Tag	Description
SYNC	Short 4 symbol sync burst.
BD_cnt	Bursts Downstream Count. Number of subscriber units that will be sending payload data in this MAC frame.
BU_cnt	Bursts Upstream Count. Number of subscriber units having payload data sent to them in this MAC frame.
AP_ID	Access Point ID. Identifies the access point that originated the frame descriptor header.
RRA_cnt	Downstream Acknowledgment Count. Number of upstream cell acknowledgements being sent downstream in this MAC frame.
DA_cnt	Reservation Request Acknowledgment Count. Number of acknowledgments being sent in response previous requests.
Downstream Map	Identifies the subscriber unit being sent cells, the number of cells to be sent, and the traffic type being sent.
RR_cnt	Upstream Acknowledgment count. Total number of downstream cell acknowledgments being sent upstream in this MAC frame.
UA_cnt	Reservation Request count. Total number of reservation request slots that will be made available in this MAC frame.
Upstream Map	Identifies the subscriber units that have been granted reservations, the number of cells to be sent by each, and the traffic type allowed.
CRC	Cyclic Redundancy Check. Allows each subscriber terminal to verify correct receipt of the frame descriptor.
SU_ID	Subscriber Unit ID. Identifies the subscriber unit acting as the data source or sink in the burst.
Cell_Cnt	Cell Count. Total number of ATM cells to be sent in this particular burst.
Tr_Type	Traffic Type. Defines the type of traffic that the subscriber unit is allowed to send or will be receiving during the current frame.

Figure 3 Frame Descriptor Header Structure