PON Functional Requirements: Services and Performance

Dolors Sala
Ajay Gummalla
{dolors,ajay}@broadcom.com

July 10-12, 2001

Ethernet in the First Mile Study Group

Objective

- **Outline the PON-specific functionality needed in EFM**
- **Other functionality common to all EFM topologies is not discussed**

Outline

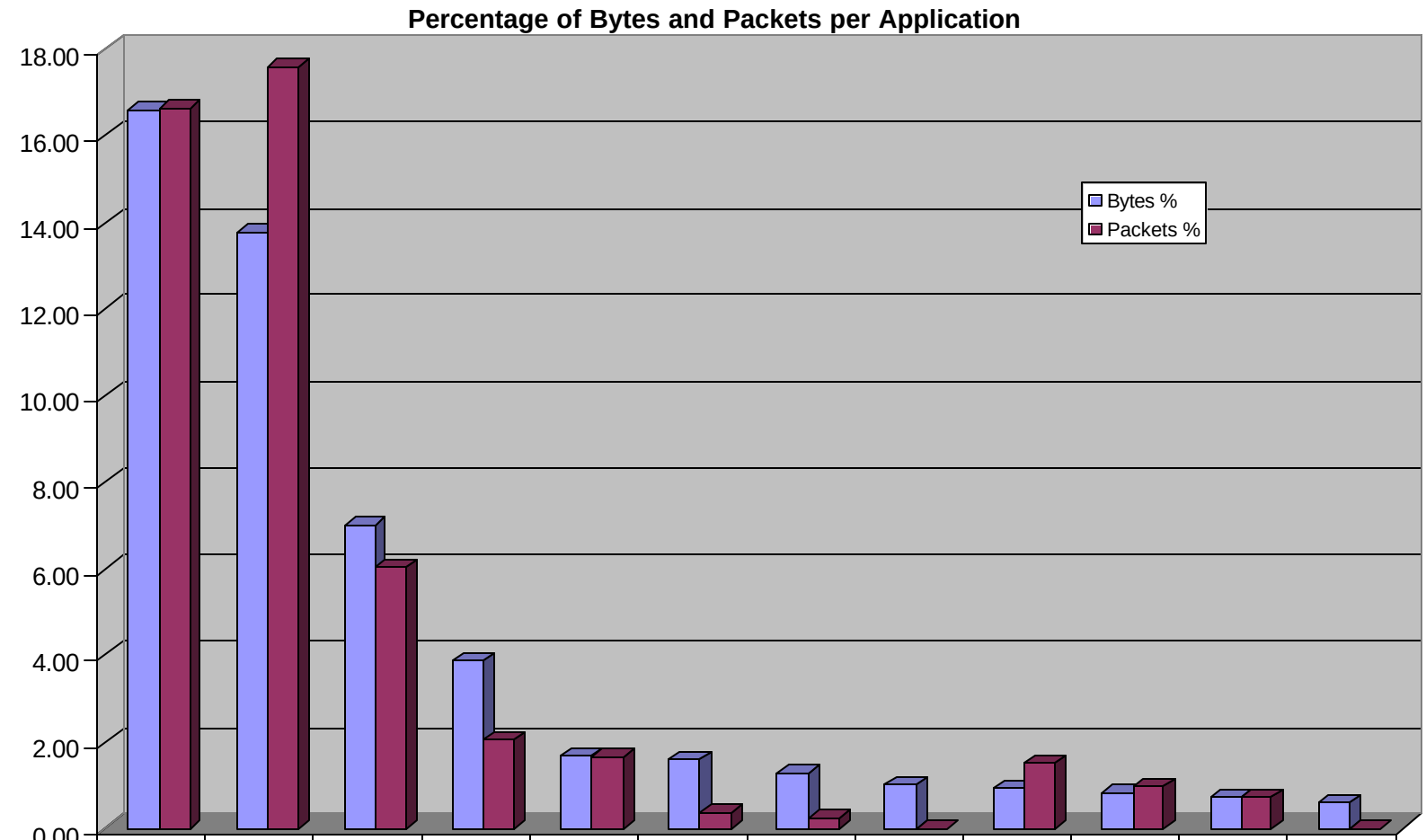
- **EFM Services and Requirements**
- **Overview of PON Multiple Access Solutions**
  - TDMA: unslotted, static, adaptive
  - On-demand: Polling, contention-based reservation
- **Summary of PON-specific Functionality**
- **Proposed PON Specification Approach**
- **Conclusions**

Service Requirements

	Residential	SOHO (< 7 employees)	Commercial (50 employees)
Voice	3-4 lines BW= 0.15Mbps	7 trunk/phone lines BW < 1Mbps	20 trunk (3:1 split) BW = 1.28 Mbps
Video	80-120 SDTV Broadcast 5-10 HDTV 2 PPV and VOD 2 Video conferencing DSBW = 550 Mbps UPBW = 10 Mbps	4 VOD streams 1 Training stream 10-20 SDTV channels DSBW = 125 Mbps dedicated UPBW = 20 Mbps	0 SDTV channels 1 stream training Video conferencing 1/10 employees
Data	Web Access Peer to Peer Gaming Chat BW: Minimum 10 Mbps dedicated	Storage area networks ASP applications Web Access Peer to peer BW: 100 Mbps burst	 BW > 100 Mbps
Estimated Total	DSBW = 550 Mbps UPBW = 20 Mbps	DSBW = 225 Mbps UPBW = 120 Mbps	Variable
PON System @ 1Gbps	**~ 50 customers**	**~ 10 customers**	**Variable (Point to point candidate)**

Current Residential Applications

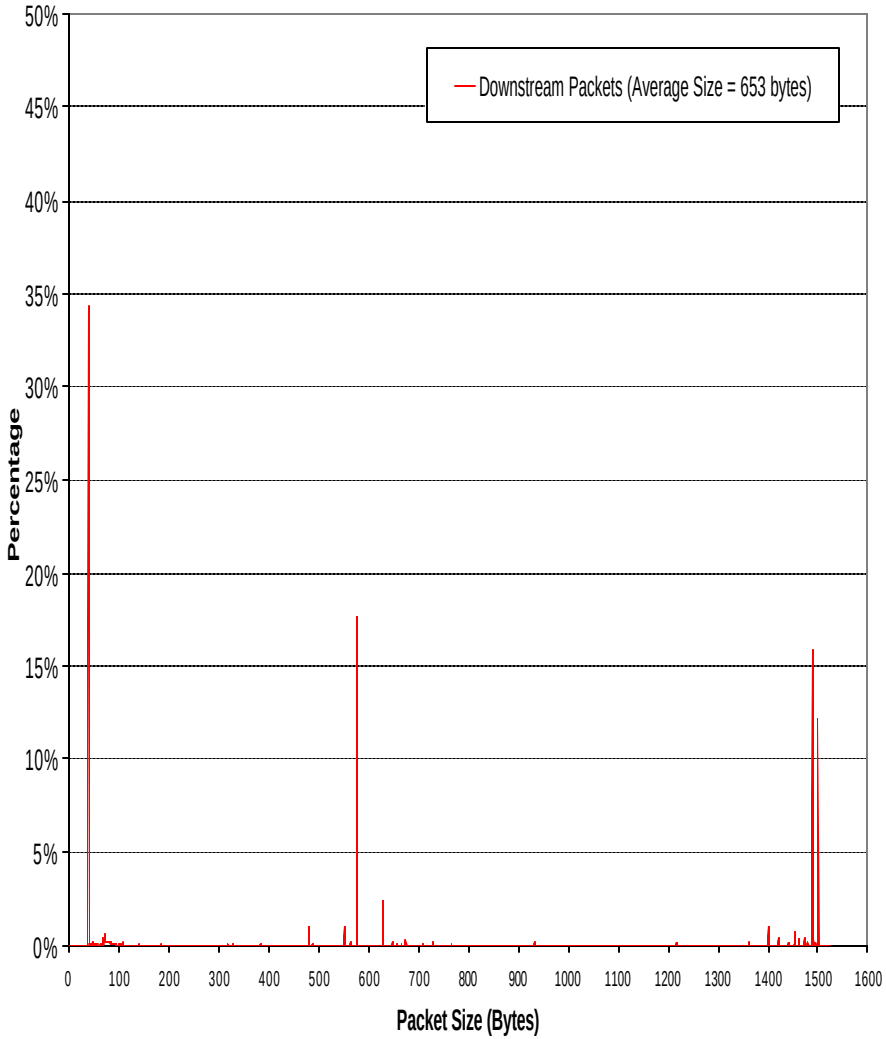
(Data collected at a cable head-end)

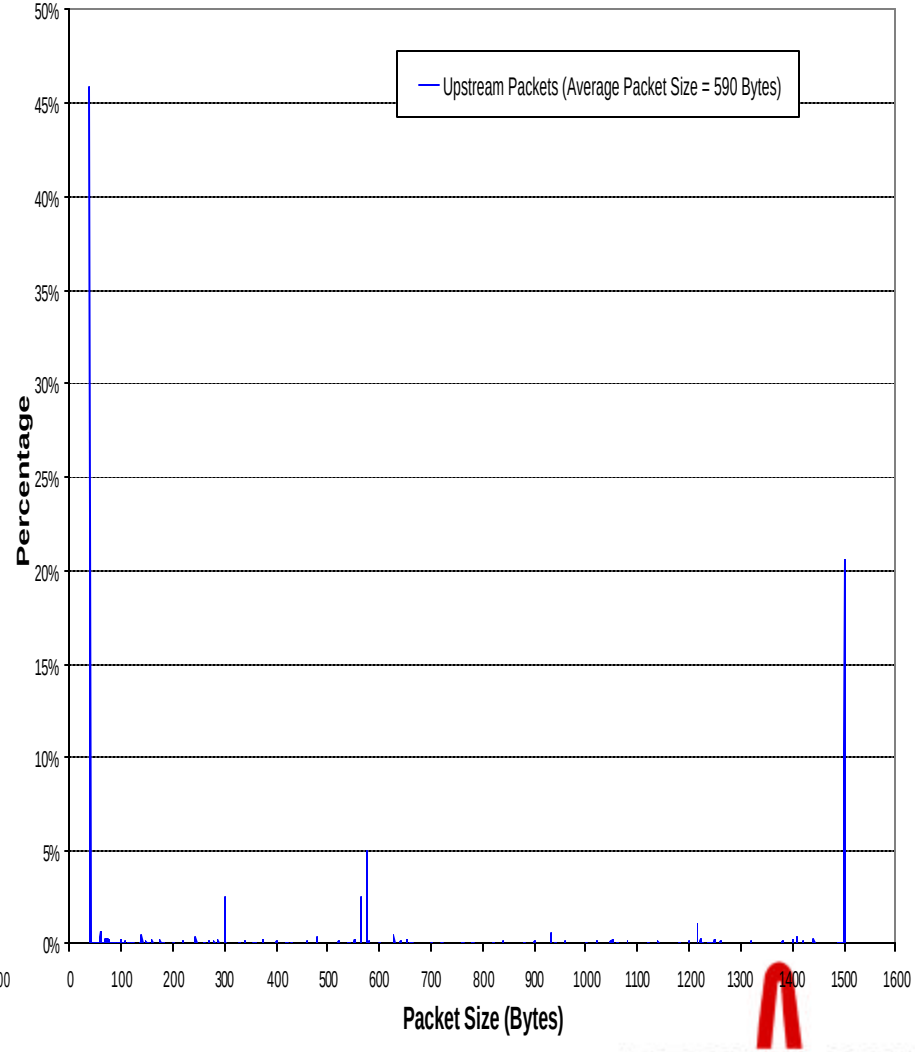


	www-http	nntp	Napster1	port 1646	Video-conf	port 9120	domain	port 11999	synoptics-trap	smtp	Napster2	pop3
Bytes %	16.60	13.78	7.00	3.87	1.67	1.59	1.29	1.01	0.93	0.83	0.70	0.59
Packets %	16.64	17.60	6.01	2.06	1.64	0.38	0.23	0.00	1.51	0.95	0.70	0.00

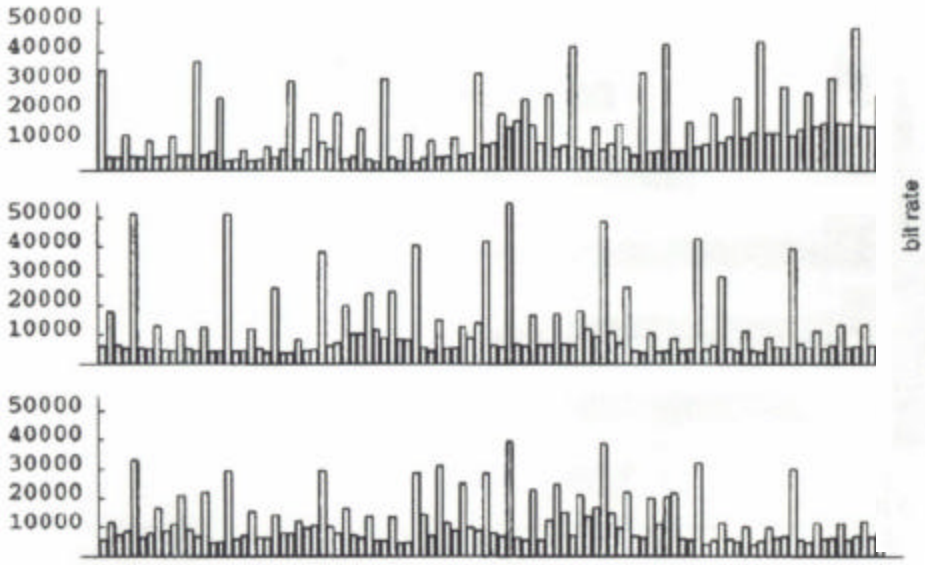
Current Residential Traffic

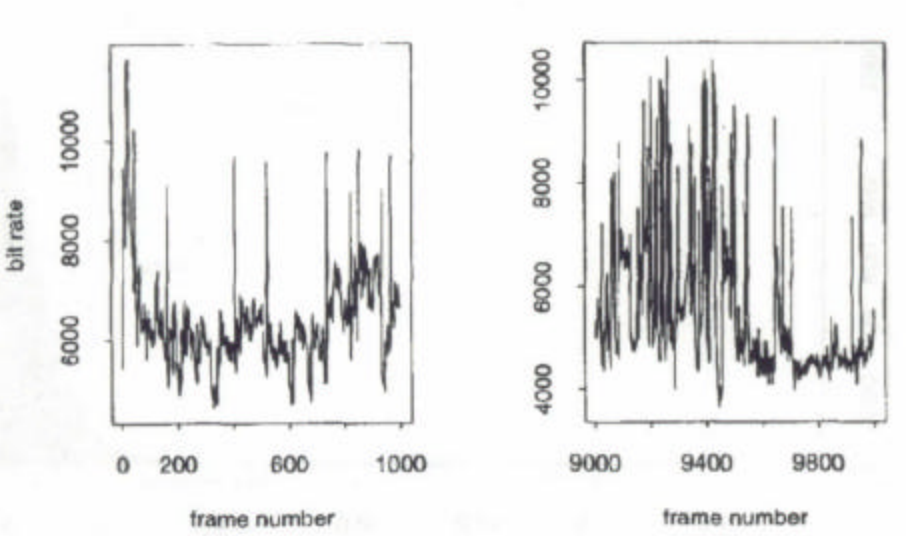
(Data collected at a cable head-end)





Video Traffic Characterization





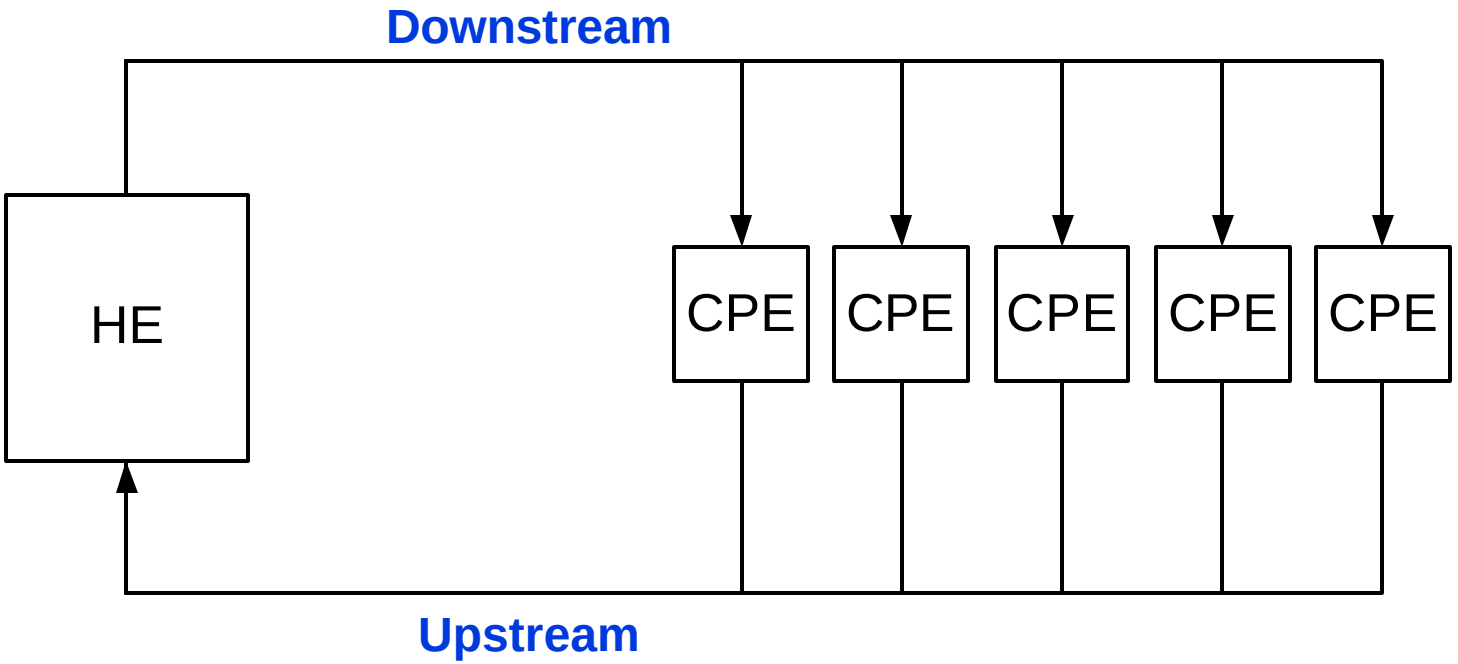
- **MPEG encoding: IBBPBBPBBPBB**
- **Rate depends on movie**
  - Frame size ranges from few to thousands kilobits
  - Stream rate ranges from few Kilobits to Mbps

25 Frames per second	Mean Frame Size (Kilobits)			Stream Rate (Kbps)	
	I	P	B	Mean	Peak
Terminator	37	14	6	135	935
Bond	83	41	10	315	2082

PON Objective

- **Specify an adaptive sharing mechanism supporting:**
  - Up to 64 CPEs sharing 1Gbps upstream
  - 2-20 Km distance
  - Support integrated services: Voice, Video, Data

PON Topology Abstraction



Multiple Access

- **Extended CSMA/CD: Asynchronous and Distributed**
  - PAUSE: could be seen as a busy signal
  - PAUSE + IDLE: extends CSMA/CD to PON architecture
  - Problem: round-trip delay to detect busy signal is too large
- **Centralized Alternatives:**
  - Basic mechanism: Head-end arbitrates access of CPEs
    - Stop all CPEs with PAUSE message
    - Define a GRANT message to allow a particular CPE to transmit a period of time
  - Several schemes differing in complexity and performance

Centralized Solutions

- **Static TDMA: HE assigns bandwidth to CPEs**
  - Basic TDMA
  - Static TDMA: adds ranging
- **Adaptive TDMA: CPE sends state information to HE (Reservation)**
  - Polling : Initiated by HE
  - Contention-based reservation: Initiated by CPE

Basic TDMA

- **Simplest mechanism:**
  1. HE sends a GRANT to a particular CPE
  2. The CPE uses its granted bandwidth by transmitting data as it fits
  3. Data arrives at HE
  4. When HE detects the end of the transmission, it sends a grant to the next CPE (I.e., go to step 1)
- **There is still a round-trip delay between CPE transmissions**
  - HE must guarantee no overlap between consecutive transmissions. Without knowledge of distance between CPE and HE, the earliest next transmission can start is after one round-trip propagation delay.
  - Need ranging to avoid this round-trip time of guardband.

Ranging Performance Impact

- **If CPE distance is not known guardband must account for propagation delay**

Servicing CPEs at 2 msec periods		Guardband overhead (at 1Gbps based on distance)		
Guardband size (bytes)		750	3750	7500
Number of CPEs	Average burst size (bytes)	2Km	10 Km	20Km
5	50,000	1 %	7 %	13 %
16	15,625	4.8 %	19 %	32 %
32	7,812	9.6 %	32 %	49 %

To overcome round-trip delay ranging is required

Ranging Mechanism

- **Requires:**
  - Ranging operates in separate time slots independent of the data transmissions
  - The size of ranging periods must be large to account for the large guardband
  - A common timing reference is established between HE and CPE
- **Ranging mechanism:**
  - HE allocates the ranging regions and asks CPE to respond at specific time
  - CPE sends a ranging request in a ranging region
  - HE computes the time offset from the difference between expected time and actual arrival time
  - HE sends time adjustment to CPE with the ranging response.
  - Repeat until time difference is within acceptable range
- **Any multiple access technique can be used in ranging periods:**
  - Polling: Poll each inactive CPEs individually in a regular basis
  - Contention-based: ranging periods are broadcast (free for all) and random access is applied

Static TDMA

- **Assumes**
  - Timing reference, ranging and registration
  - Defines slotted system:
    - Divides upstream in slot units to assign bandwidth
    - Common slot timing between HE and CPE
    - GRANT specifies slot time and number of slots granted
  - Can pipeline GRANTs on the wire
  - HE assigns slots to CPE based on SLA
- **Handshake mechanism: periodic grant Þ data transmission**
  - HE schedules bandwidth in advance and sends GRANTs earlier than when they become active
  - CPE stores its own grants and transmits in the slots assigned and for the duration granted
- **Issues:**
  - No statistical multiplexing across CPEs: no knowledge of CPE queue state to assign unutilized bandwidth to other CPEs

Adaptive TDMA

- **Assumes: CPE sends state information to HE**
  - Define a request message that contains the information of the amount of bandwidth needed to transmit the frames in its queue
  - HE assigns the guaranteed minimum bandwidth in a static manner (periodic grant) and additional bandwidth on demand based on requests.
- **Handshake:**
  - For guaranteed bandwidth: periodic grant ⇒ data (+ request) ⇒ additional grants
  - If no bandwidth guaranteed: request ⇒ data (+ request) ⇒ grants
- **Issues:**
  - Allows reassignment of bandwidth to a different CPE when not needed (statistical multiplexing across CPEs)
  - Bandwidth guaranteed can go wasted. Allocate minimum to send first request.
  - How to send FIRST request?
    - Polling
    - Contention

Polling

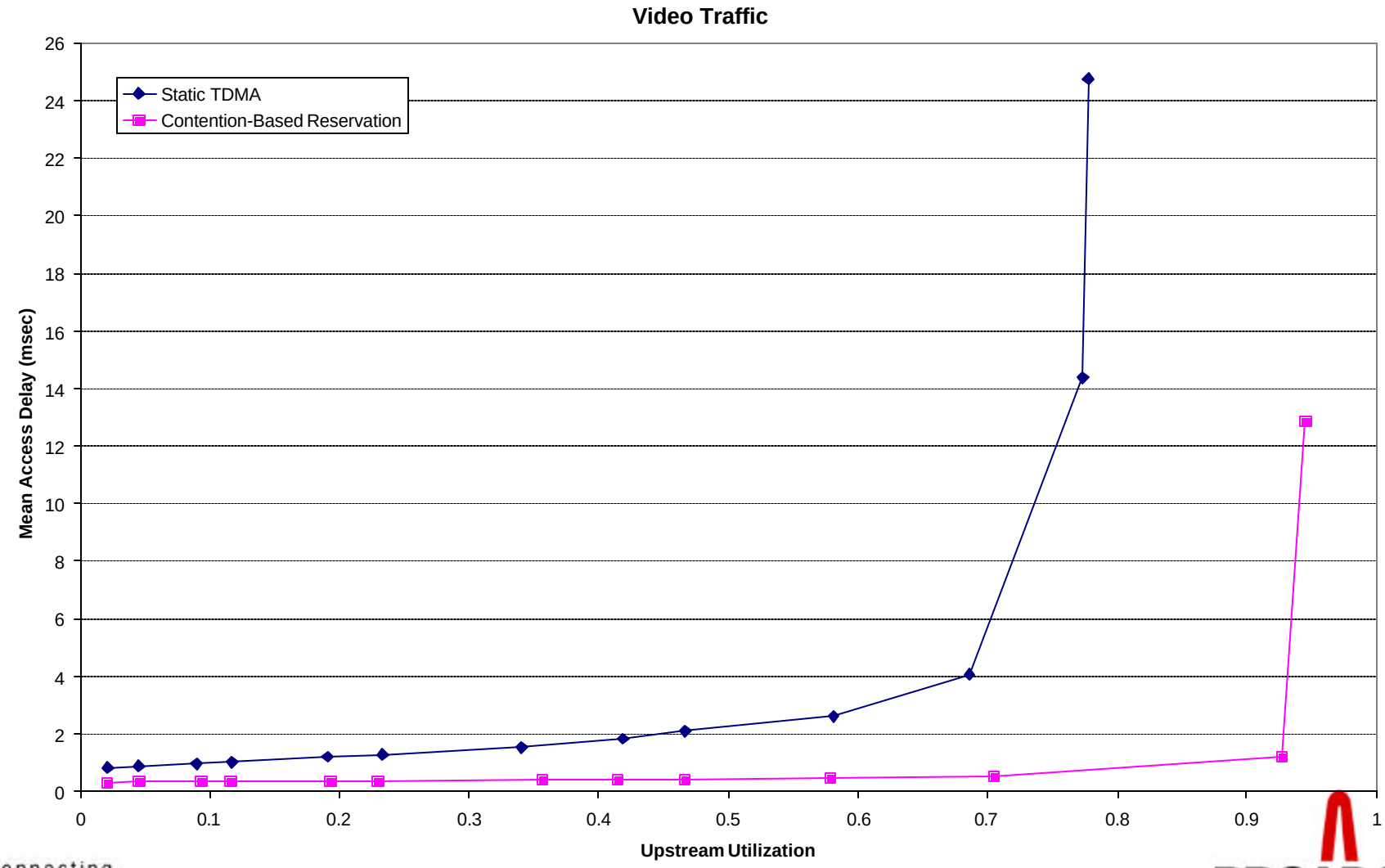
- **Mechanism:**
  - HE polls each CPE individually by sending a grant to the CPE
  - The CPE uses the grant to send the request if the CPE needs additional bandwidth
- **Handshake: poll Þ request Þ grant (+request) Þ data**
- **Issues:**
  - Poll bandwidth overhead is not significant with few CPEs
  - Frequency of individual polls determines latency in access

Contention-based

- **Contention-based reservation mechanism**
  - Contention slots are shared poll opportunities
  - Assign slots for transmission of requests: any CPE can transmit
  - Resolve collisions using contention resolution mechanism (i.e., BEB)
- **Handshake:**

  contention slot ⇒ request ⇒ grant (+ request) ⇒ data
- **Issues:**
  - Less need to predict individual needs: statistical multiplexing of request opportunities
  - Adds the need for a contention resolution algorithm
  - Decide allocation of contention slots

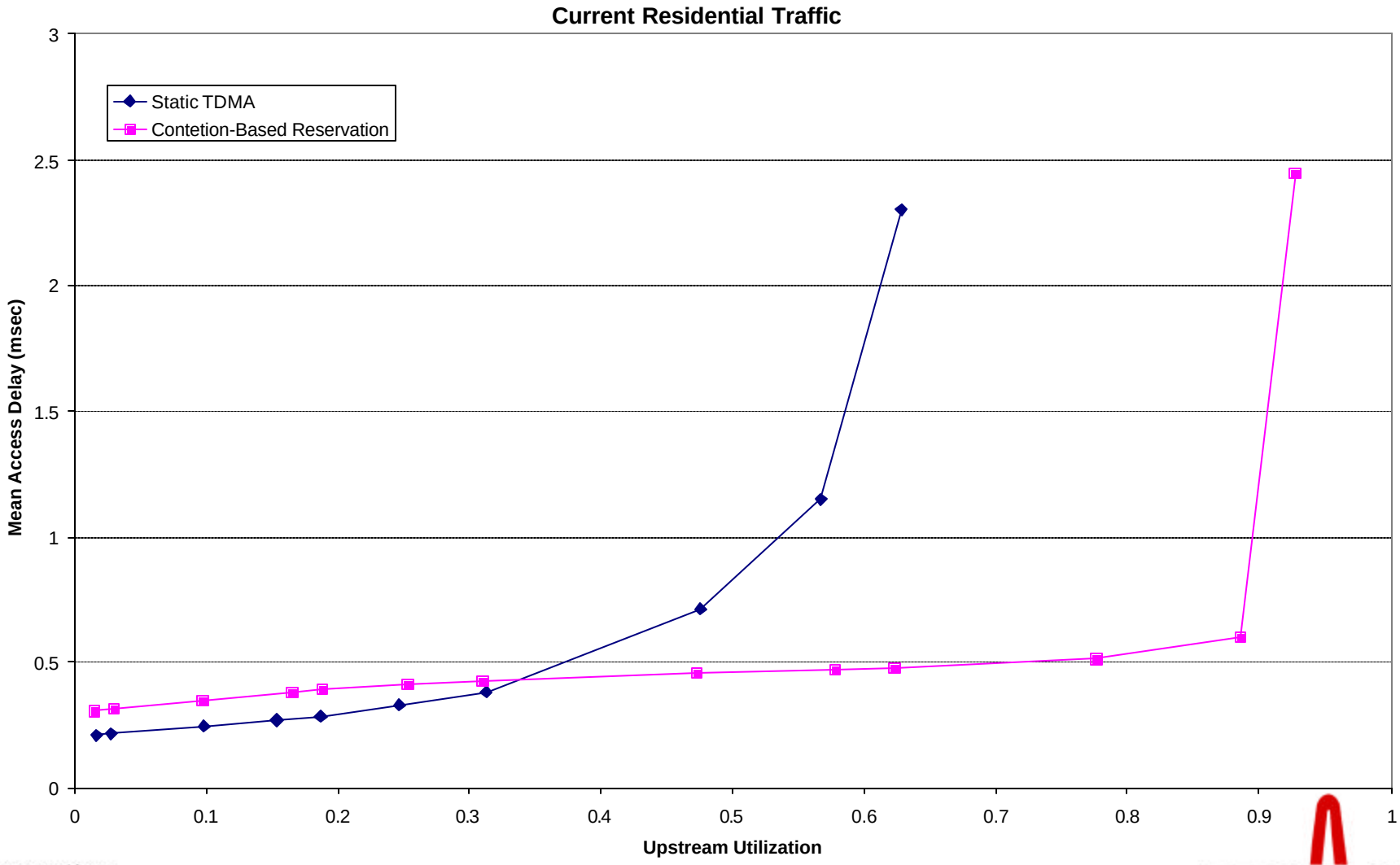
Video Traffic



Connecting everything™

BROADCOM®

Current Residential Traffic



Summary of Features

	Grant msg	Ranging	Request msg	Poll msg	Contention	ServiceBW
CSMA/CD					Ö	**On Demand**
Unslotted TDMA	Ö					**Fixed**
Static TDMA	Ö	Ö				**Fixed**
Adaptive TDMA	Ö	Ö	Ö			**Variable**
Polling	Ö	Ö	Ö	Ö		**On Demand**
Contention-based	Ö	Ö	Ö		Ö	**On Demand**

PON-Specific Functional Requirements

Minimal functionality needed to operate in a PON network:

- **Timing & Synchronization**
- **Ranging: ability to pipeline transmissions in the wire**
- **Reservation: CPE ability of sending state information to HE**

This functionality specifies a basic sharing system

Requires new message definitions but no header modifications

Additional Functionality

- **To define a controlled and fair sharing system, additional functionality is needed:**
  - Priorities and QoS : ability to give differentiated service across CPEs
    - Use of 802.1P priority levels
  - Policing: ability to control the sharing of downstream bandwidth
    - Internal HE policy established with handshaking
  - Billing : ability to charge per use (sharing allows reuse bandwidth and hence to define other than flat-rate policies)
    - Monitoring at HE
  - Security: ability to protect information due to broadcast nature (more important than in point-to-point, but also needed)
    - Define common mechanism for all EFM topologies

Conclusions

- **PON-specific functionality is in the handshaking and internal to CPE and HE but not in interface (header formats)**

- **Specification approach:**
  - Define a single PON MAC control frame that carries the PON-specific information.
  - PON-specific functionality includes:
    - Timing and Synchronization
    - Ranging
    - Multiple access scheme
  - The specification of the op-codes and parameters is an independent and well defined task that can advance in parallel to other EFM efforts
  - Leverage knowledge of existing solutions to reduce specification time