Cisco Systems

Multimedia Traffic Engineering
The Bursty Data Model

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Agenda

- Opening Comments
- Background information
- The bursty data model
- The bandwidth calculation
- Closing comments

Opening Comments

- **Multiple choice question:**
  - **How many cable modems will a CMTS support?**
    - **A) 250 per upstream**
    - **B) One less than the number it takes to bring down the whole plant**
    - **C) No clue**
    - **D) It depends**
- **Factors to consider:**
  - **DOCSIS Bandwidth**
  - **DOCSIS addressing or Station Maintenance polling limitations**
  - **CMTS System Bandwidth (Wan BW, bus BW, PPS limits)**
- **This presentation will focus on a model for DOCSIS bandwidth**

The Basic Concept

- **The answer is:**

$$\frac{\text{CMTS Bandwidth Available}}{\text{CM Bandwidth Required}} = \text{Number of CMs Supported}$$

- **The CMTS bandwidth is predictable, but there does not exist a good model for the CM bandwidth required. As such, the question goes unanswered.**

Background

DOCSIS BW Downstream Variables

- **Downstream per Channel**
  - **Modulation (64QAM, 256QAM)**
  - **Symbol Rate**
  - **Annex A/B**
  - **FEC Frame Sync**
  - **FEC Parity Bytes**
  - **Trellis Coding**
  - **MPEG Framing**
  - **DOCSIS MAP, SYNC, UCD**
  - **DOCSIS MAC signaling**
- **Downstream per Packet**
  - **DOCSIS & Ethernet Framing**
  - **Payload Header Suppression**
  - **Baseline Privacy**

⇒ Most of the overhead in the downstream is per channel

DOCSIS BW Upstream Variables

- **Upstream per Channel**
  - **Modulation (QPSK, 16QAM)**
  - **Symbol Rate**
  - **DOCSIS IUCs for Req, Req/Data, IM, SM**
  - **DOCSIS MAC Signaling**

⇒ Most of the overhead in the upstream is <u>per packet</u>

- **Upstream per Packet**
  - **Minislot size**
  - **Short/Long last code word**
  - **Preamble length**
  - **FEC code word size**
  - **FEC error correction (t)**
  - **Guard time**
  - **DOCSIS & Ethernet Framing**
  - **Payload Header Suppression**
  - **Baseline Privacy**
  - **Concatenation**
  - **Fragmentation**

Additional Parameters for VoIP

- VoIP Parameters
  - CODEC type (G.711, G.729, …)
  - Packet length (10ms, 20 ms)
  - Voice Activity Detection
  - Grade of Service (1%)
- Customer Parameters
  - Lines per HHP
  - Avg calls per hour
  - Avg length of call
- CMTS Parameters
  - Static versus dynamic load balancing
  - Admission control limits
  - HHP per upstream
  - Ratio of upstreams to downstreams

DOCSIS Downstream Bandwidth

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Country	USA	USA	Europe	Europe
J.83 Annex	Annex B	Annex B	Annex A	Annex A
bandwidth (MHz)	6	6	8	8
constellation size	64	256	64	256
symbol rate (Msps)	5.056941	5.360537	6.952	6.952
alpha	0.18	0.11	0.15	0.15
bits per symbol	6	8	6	8
FEC Frame Sync	0.08%	0.05%	0.00%	0.00%
FEC Parity bytes	4.69%	4.69%	7.84%	7.84%
Trellis Coding Overhead	6.67%	5.00%	0.00%	0.00%
MPEG Header	2.13%	2.13%	2.13%	2.13%
MPEG Pointer Byte	0.54%	0.53%	0.53%	0.53%
PHY Layer BW	30.34	42.88	41.71	55.62
PHY Overhead	13.5%	12.4%	10.5%	10.5%
PDU Layer BW (Mbps)	**26.25**	**37.57**	**37.33**	**49.77**

- **The quote rate for the downstream is closer to a payload rate**

DOCSIS Upstream Bandwidth

RF Bandwidth (MHz)	1.6	3.2	3.2	6.4
Alpha	0.25	0.25	0.25	0.25
constellation size	4	4	16	64
symbol rate (ksps)	1280	2560	2560	5120
bits per symbol	2	2	4	6
PHY layer bw (Mbps)	**2.56**	**5.12**	**10.24**	**30.72**

- **The quoted rate for the upstream is the raw bandwidth.**

DOCSIS Data Frame

FGLP	HDR	BPI	HCS	Ethernet	IP	TCP	Data	CRC
14-34	4	5	2	14	20	20	0 to 1460	4

values in bytes

- **FGLP refers to FEC, Guard Time, Last Codeword, and Preamble. These values are unique to the upstream.**
- **The other field are per packet overhead.**

IP Data "Discounts"

- **Bandwidth "discounts" for data:**
  - **Example: 1 down, 6 up, 2000 HHP per upstream**

Downstream Bandwidth
26 Mbps / 6 Rx / 2000 HHP
=> 2.2 kbps per HHP
@ 10 % Market Penetration
=> 22 kbps per Subscriber
@ 20 % logged on
=> 110 kbps avg per User
@ 20% downloading
=> 550 kbps peak per User

250x

Upstream Bandwidth
2.5 Mbps / 2000 HHP
=> 1.25 kbps per HHP
@ 10% Market Penetration
=> 12 kbps per Subscriber
@ 20% logged on
=> 60 kbps Avg per User
@ 20% downloading
=> 300 kbps per User

Note: MC28, no combining, Best Case, downstream

38 Mbps / 4 Rx / 500 HHP
=> 20 kbps per HHP

Bandwidth Ratio
550 kbps Downstream/
300 kbps Upstream
=> 1.8 Dn/Up BW

Prepared by:
John T. Chapman, Cisco

The Bursty Data Model

Today's Modeling Techniques

- **VoIP Modeling:**
  - **has a nice model based upon Erlangs and the probability of call blocking.**
    - **Cable VoIP model presented by Chapman in ET 2000.**
  - **The traffic characteristics are simple.**
  - **The model is complex, but manageable.**
- **Data Modeling**
  - **No good model is in common use.**
  - **Data traffic characteristics are diverse, and often unknown.**
    - **Many data types, many data rates, variable packet sizes…**
  - **Models are complex and are not always useable on a real network.**
    - **For example, Self-Similar Traffic based upon fractals.**

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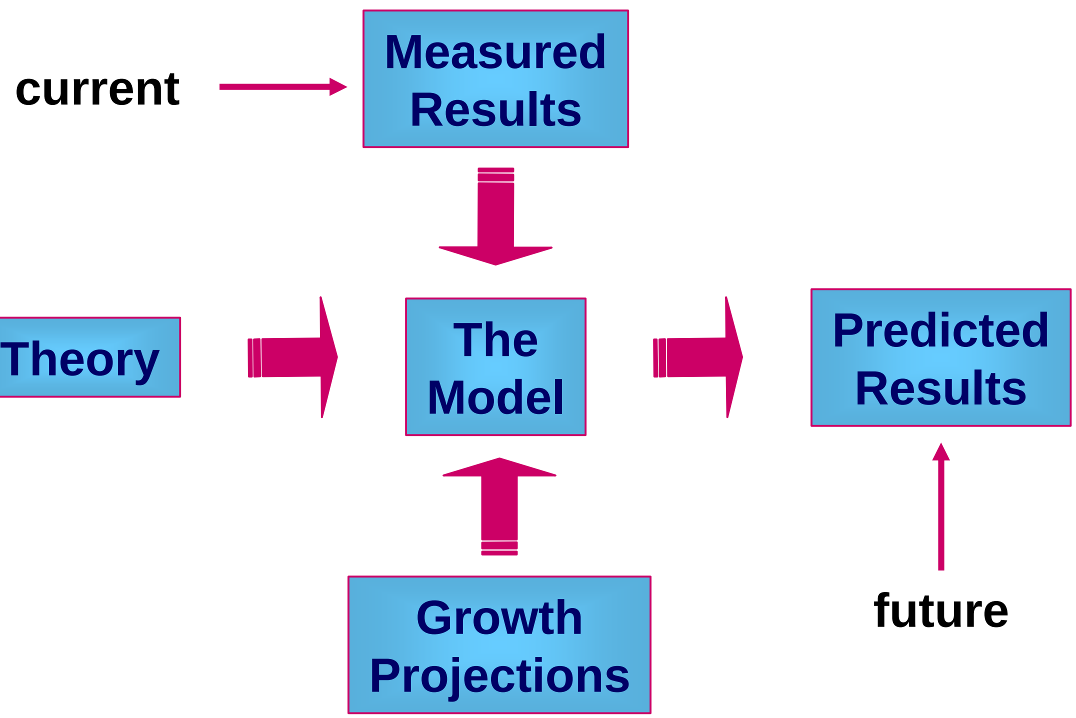
John T. Chapman, Cisco Systems

Bursty Data Model Requirements

- **Simplicity:**
  - **Equations must fit on the back of an envelope.**
  - **Easy to put into a spreadsheet.**
  - **Easy to use by all. Approximations are fine. Complication avoided.**
- **Usefulness:**
  - **Must relate to measured parameters**
  - **Must be usable for bandwidth calculations**
- **VoIP and broadcast quality video handled with separate models**

The Role of the Model



- **Modeling what already exists is interesting, but modeling what does not yet exist is what is most important**

Modeling Objectives

- A model allows current measured results to be combined with theory and growth projections to predict future results
  - Measurement data is good for analyzing current networks and verifying model calculations
  - Modeling is required for predicting future

The Bursty Data Model

- **Average Scenario**
  - **Performance seen by the subscriber over a long time on a loaded network. (say 5 minutes)**
  - **Average case is the “short packet” scenario**
- **Peak Scenario**
  - **Performance seen by the subscriber over a short time on a loaded network. (say 1 second)**
  - **Peak case is the “long packet” scenario**
- **Max Scenario**
  - **This is the rate seen by the user when the network is not loaded.**
  - **This value is used to set the rate shaping on an interface.**

Model Scenarios

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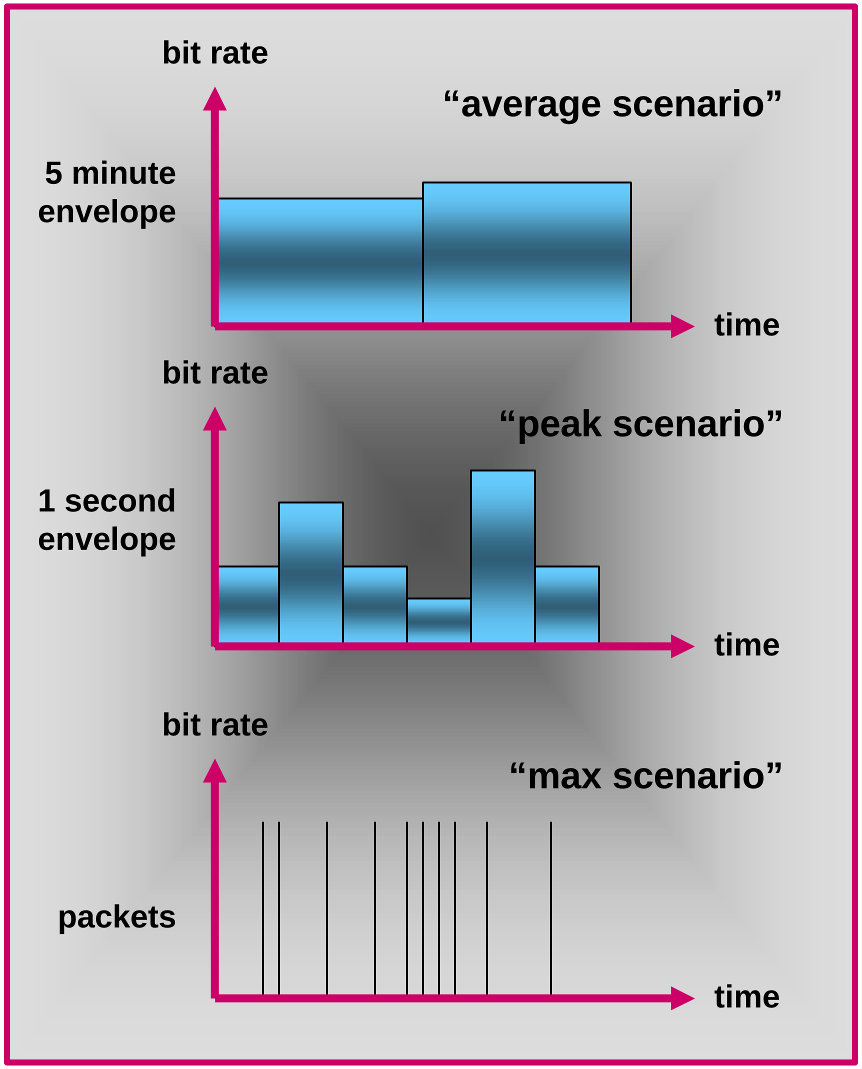
- **This model is derived in part from a behavioral description of what the subscriber and operator see when looking at the network.**
- **Defining 1 second and 5 minute measurement intervals provides two operating points for the network.**



The Three Model Scenarios

- Three scenarios are defined
  - Average Scenario
  - Peak Scenario
  - Max Scenario
- Each scenario has a measurement interval
  - 1 second for peak and 5 minutes for average.

Session Density	
Relative %	Direct %
20% of peak	1%
20% of avg	5%
25% of users	25%

- How many users will be on during each measurement interval, and how much bandwidth will each of those users consume?
  - How is 26 Mbits shared in one second?
- The average, peak, and max scenarios will all vote to see who is the worst case scenario.

Wall Street Analogy

- **Wall Street Analogy**
  - **Avg rate == quarterly sales**
  - **Peak rate == weekly sales**
  - **Packet rate == daily sales**

➢ **Quarterly sales can be predicted reasonable well. Weekly sales have large variations, whereas daily sales can be anything. Yet, a good factory must be able to respond well to daily and weekly fluctuations to be efficient.**

➢ **And so it is with this model. The avg rate is somewhat predictable and measurable, the peak rate is more difficult to predict, and the packet rate could be anything. Still, the network must have the headroom to be able to respond to a variety of packet arrival rates and peak rates.**

User Data Profile

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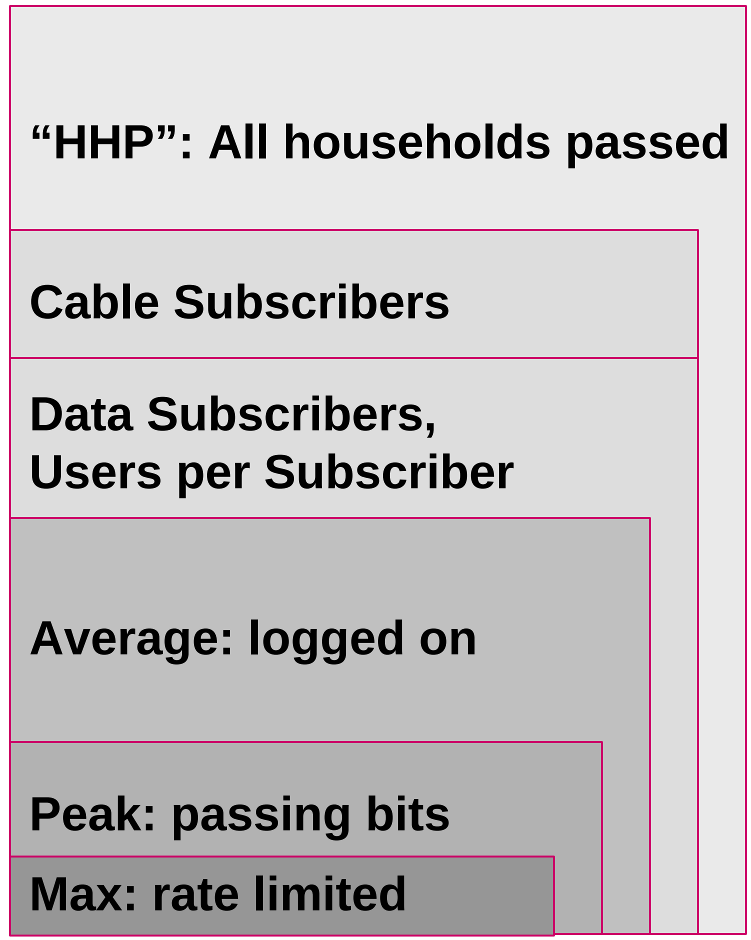
Down Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	2,000	1518	165
Peak	256	1518	21
Average	80	400	25

Up Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	384	1518	32
Peak	100	1518	8
Average	24	64	47

- **Bandwidth numbers are the most important**
- **Packet size and rate is tracked so that overhead per packet can be calculated and impact on system switching can be assessed.**

Carving up HHP

- Cable Subs = HHP * MP_c
  - 2000 * 65% = 1300
- Data Subs = HHP * MP_d
  - 2000 * 10% = 200
- Data Users = HHP * MP_d * Data Users per HHP
  - 2000 * 10% * 1.5 = 300
- Users for avg scenario = Data Users * SD_a
  - 300 * 25% = 75
- Users for peak scenario = Users_avg * SD_p
  - 75 * 20% = 15
- Users for max scenario = Users_pk * SD_m
  - 15 * 20% = 3



Using Measured Results

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- **Monitoring of IP packets for both measurement intervals can supply**
  - **Mix of applications by examining the TCP/UDP port number**
  - **Number of users by looking for unique IP addresses**
  - **Size of packet per application**
- **The following can be calculated for each scenario:**
  - **Bandwidth per user.**
  - **Nominal packet size per user**
  - **Nominal PPS per user.**
- **These measurements provide the basics for the Bursty Data Model.**

Building the Subscriber Profile

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- **How does the subscriber profile relate to the actual applications being run on the network?**
- **Proposal: (for average and peak scenarios)**
  - **Use the same model for each application**
  - **Use a weighted average to sum together the application profiles to get the subscriber profile.**
  - **The "weighting" for each application is the percentage of subscribers which are running that application at any one time.**
- **For Max scenario, use the CM rate limiting value programmed into the CMTS**

Generation of Subscriber Profile

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Up Stream	Bit Rate	Pkt Size
Peak	100	1518
Average	24	400

MP_a = market penetration of application within subscriber base

=> Web Traffic * $\%MP_a$
+ E-mail * $\%MP_a$
+ Gaming * $\%MP_a$
+ Video Streaming * $\%MP_a$
+ Audio Streaming * $\%MP_a$
+ etc

Up Stream	Bit Rate	Pkt Size
Peak	100	1518
Average	24	400

Sum of {Application profiles * market penetration}

Down Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	2,000	1518	165
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Up Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	384	1518	32
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Average	24	64	47

Observations

- **Market Penetration (MP_a) usage**
  - **If each subscriber were only running one application at one time, then the sum of the MP_a percentages would be 100%.**
  - **If each subscriber were running two applications at one time, then the sum of the MP_a percentages would be 200%.**
  - **A subscriber typically has one foreground application and several background applications at the same time.**
  - **A reasonable target may be to have the MP_a numbers to sum between 100% and 200%.**

Model Hierarchies

- **Simplest**
  - **Today, basic web traffic has led to a single subscriber profile**
- **Moderate**
  - **Use the same template for each application, and combine to create the single subscriber profile**
- **Extreme**
  - **Multiple combinations of applications combine to create different service profiles**
    - **Silver, Gold, Platinum**
  - **Multiple service profiles combine to create the average subscriber profile**

Multiple Tiers of Service

Platinum

Up Stream	Bit Rate	Pkt Size
Max	384	1518
Peak	100	1518
Average	24	400

Gold

Up Stream	Bit Rate	Pkt Size
Max	384	1518
Peak	100	1518
Average	24	400

Silver

Up Stream	Bit Rate	Pkt Size
Max	384	1518
Peak	100	1518
Average	24	400

MP_t = market penetration of service level within subscriber base

=> Platinum * $\%MP_t$
+ Gold * $\%MP_t$
+ Silver * $\%MP_t$

Sum of {tier profiles * market penetration}

Down Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	2,000	1518	165
Peak	256	1518	21
Average	80	400	25

Up Stream	Data Profile		
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*
Max	384	1518	32
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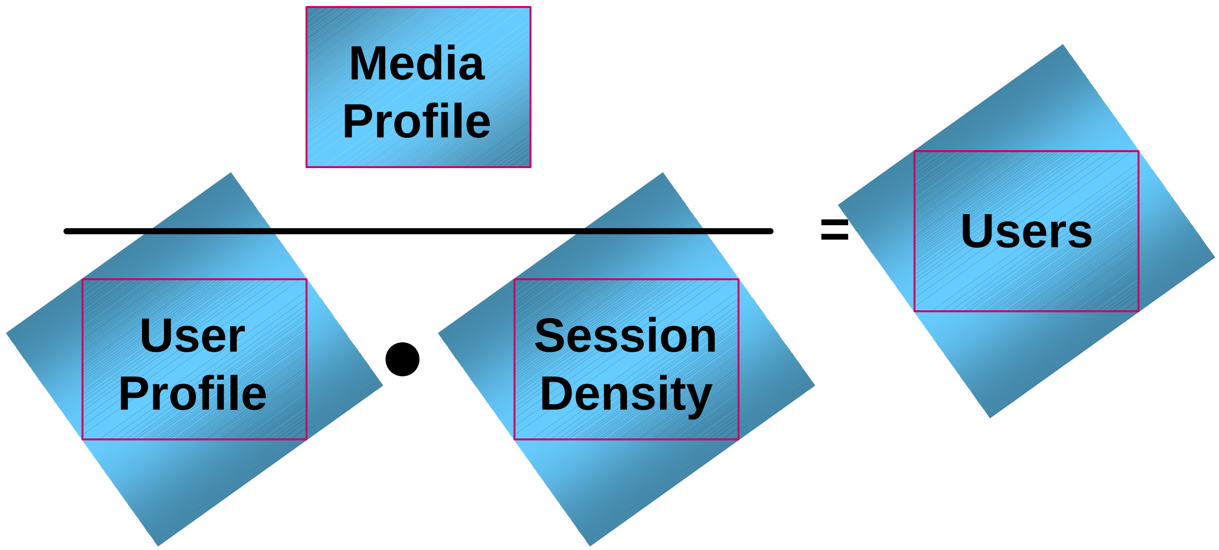
Calculations

Bursty Data Model Fundamentals



- **The model may also be used in reverse.**
  - **If the number of users and the user data profile is known, the session densities may be calculated.**
  - **Likewise, if the number of users is known and session density is known, the user data profile may be calculated.**

Downstream Calculation

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Down Stream	Data Profile			Downstream		Session Density		Users per Down stream
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*	Pkt Rate *pps*	Ses-sions	Relative *%*	Direct *%*	
Max	2000	1518	165	1931	12	20% of peak	1%	1173
Peak	256	1518	21	1931	92	20% of avg	5%	1832
Average	80	400	25	7185	287	25% of users	25%	1150

D/S Payload	26.25 Mbps
D/S Admission	90%

Max Users per Downstream: 1150

- Inputs to the model are underlined
- The inverse of MP% for avg, peak, and max equals the over-subscription for each scenario.

Upstream Calculation

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Up Stream	Data Profile			Upstream		Usage		Users per Upstream
	Bit Rate *kbps*	Pkt Size *bytes*	Pkt Rate *pps*	Ses-sions	Pkt Rate *pps*	Relative *%*	Direct *%*	
Max	**384**	**1518**	**32**	**5**	**150**	**20% of peak**	**1%**	**475**
Peak	**100**	**1518**	**8**	**18**	**150**	**20% of avg**	**5%**	**365**
Average	**24**	**64**	**47**	**52**	**2424**	**25% of users**	**25%**	**207**

U/S Payload	**2.56 Mbps**
U/S Admission	**80%**

Max Users per Upstream: 207

- **Avg BW is the limiting case**

Downstream & Upstream

Direction	Subs allowed	LC ratio	Subs per group max	Subs per group final	Subs per Group	Max HHP per Direction
Downstream	1150	1	1150	1150	766	7664
Upstream	207	6	1241		128	1277

Users per HHP	1.5
%MP of data	10%

- **In this example, the system is downstream limited**

Notes

- **Additional requirements must now be calculated**
  - **PPS handling of CMTS**
  - **Any limits due to Initial and Station Maintenance**
- **Calculation notes:**
  - **If average subscription rate is different for upstream and downstream, then this comparison must be done on HHP**
  - **Calculation can be done backwards, starting with the number of subscribers and ending with the bandwidth profile.**
  - **To properly calculate the number of sessions per upstream, the overhead per packet must be included in the per packet calculations.**

The Math

- **For each case (Avg, Peak, Max) and for each direction (d/s, u/s)**
  - **ds_sub_pps = ds_sub_kbps * 1000 / 8 / ds_sub_pkt_bytes**
    - **80 * 1000 / 8 / 400 = 25 pps per subs**
  - **ds_sim_sessions = ds_mbps * 1000 * ds_admission_limit / f(ds_sub_kbps)***
    - **26 * 1000 * 80% / 80 = 260 simultaneous sessions per d/s**
  - **ds_kpps = ds_mbps * 1000 * ds_admission_limit / 8 / ds_sub_pkt_bytes**
    - **26 * 1000 * 80% / 8 / 400 = 6.5 kpps per d/s**
  - **ds_subs = ds_sim_sessions / ds_usage**
    - **260 / 20% = 1,300 subs per d/s**

- *** f(ds_sub_kbps) adds in per packet overhead**

The Math

- For each direction (d/s, u/s)
  - ds_subs_per_domain_max = domain_ratio_ds * ds_subs
    - 1 * 1250 = 1250 subs max d/s per domain
    - 6 * 275 = 1650 subs max u/s per domain
  - subs_per_domain = MIN(ds_subs_per domain_max, us_subs_per_domain_max)
    - MIN(1250, 1650) = 1250 subs per domain
  - ds_hhp = subs_per_domain / domain_ratio_ds / mp_cm
    - 1250 / 1 / 20% = 6250 hhp per d/s
    - 1250 / 6 / 20% = 1040 hhp per u/s

Perspectives

Traffic Barometer

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- Using "% logged on" and "% downloading" may not be easily measurable. What is measurable from the CMTS is:
  - CMs per upstream & downstream
  - Bandwidth in terms of Mbps and PPS per u/s, d/s, and WAN port.
- Use CMTS statistics to calculate (for down and up)
  - Average Mbps per CM: for example, 20 kbps
  - Average PPS per CM: for example, 5 PPS
  - Average packet size: for example, 400 bytes

Traffic Barometer

- **Track this metric as the network grows, and use it to predict new growth.**
  - **Use MTRG. Also track increase in subs per upstream over time, etc.**
  - **Not granular enough to pick up traffic peaks.**
- **Although a good rule of thumb, it should be combined with theory to correctly predict new traffic patterns.**

The Complete Profile

- **A more complete subscriber profile should include**
  - **Bandwidth**
  - **Latency**
  - **Jitter**
  - **Allowable packet loss**
- **Last three requirements are more QOS related**
- **Service levels (Silver, Gold, Platinum) could differ based upon bandwidth only, QOS only, or both bandwidth and QOS.**
  - **A low latency service for gaming, for example, would be interesting.**

Latency

- The DOCSIS protocol was designed for "graceful degradation"
  - As the network becomes overloaded, latency increases and bandwidth decreases.
  - This has the net effect of slowing down TCP flow
  - The network arrives at a new stable, but slower operating point
- The bursty data model is used to manage bandwidth with respect
  - to provisioning of subscribers,
  - bandwidth over-subscription, and
  - accommodation of services.
- Latency, jitter, and packet loss are controlled by QOS
  - QOS can be implemented for each of the service profiles.

Latency

- **Latency**
  - **First is time to get a request through.**
    - **Statistically related to, the number of request slots and**
      - **the number of subs (with concatenation) or**
      - **the number of packets (no concatenation).**
    - **Piggybacking of requests reduces latency on back to back transfers.**
  - **Second is the time to issue a grant.**
- **This model is ignorant of scheduling tricks and of latency. So, scheduling and QOS will manage latency**

Packet Size

- **Packet Size is a secondary but necessary factor.**
  - **It impacts the PPS loading on switch fabrics**
  - **Impacts DOCSIS bandwidth due to per packet overhead**
  - **Impacts DOCSIS latency since there is a req/gnt latency per packet.**
- **PPS of CMTS must be greater than the sum of the avg pps which is derived from avg pkt size.**

Closing Comments

- How do you measure customer satisfaction?
- How do you verify that this is a good number?
- Model drives requirements. Requirements feed back into model.
- There is room in the market for an additional, more complex, statistical based model. One does not seem to exist yet.
- The Bursty Data Model may vary over time. The important points are:
  - It is a simple model
  - The same model can be re-used for applications and tiers of service so that the results can be easily averaged.
  - Ability to use the model to derive meaningful results.
- Use the Bursty Data Model in conjunction with the Traffic Barometer.

Closing Comments

- **Networks which carry data, voice, and video must be engineered if they are to operate properly.**
- **There is certainly room for other models.However they should incorporate the same objectives of**
  - **parameters can be determined through intuition, calculation, or measurement**
  - **relates to all traffic types and accommodates service tiers**
  - **can be used to calculate the network loading and the number of users that can be supported.**
- **The MMTE Bursty Data Model allows the following equation to be solved:**

$$\frac{\text{CMTS Bandwidth Available}}{\text{CM Bandwidth Required}} = \text{Number of CMs Supported}$$

Resources Internal to Cisco

- **Directory of documents from John T. Chapman:**
  - http://wwwin-eng.cisco.com/Eng/NUBU/Cable/VoIP-Architecture/
- **MMTE Capacity Analysis Spreadsheet**
  - http://wwwin-eng.cisco.com/Eng/NUBU/Cable/VoIP-Architecture/csco-cmts-capacity.xls
- **MMTE Capacity Planning Spreadsheet**
  - http://wwwin-eng.cisco.com/Eng/NUBU/Cable/VoIP-Architecture/csco-traffic-eng-master.xls
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Bursty Data Model Fundamentals

$$\frac{\text{Media Profile}}{\text{User Profile} \bullet \text{Session Density}} = \text{Users}$$

- **The model may also be used in reverse.**
  - **If the number of users and the user data profile is known, the session densities may be calculated.**
  - **Likewise, if the number of users is known and session density is known, the user data profile may be calculated.**