Resource Assignment for Integrated Services in Wireless Multimedia Networks

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Presentation Outline

1 Introduction and Problem Description

2 Bandwidth Allocation, Reservation, and Utilization

→ Connection level *Intra-Frame Statistical Multiplexing*

3 Bandwidth Partitioning

→ Priority Sharing with Restrictions (PSR)

→ The Smart Allocate Algorithm

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End Node Optimizations

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Introduction and Problem Description

- **Different broadband sources (traffic classes) require different amounts of bandwidth and have different transmission priorities**
  - Bandwidth: Video > Voice > Data
  - Priorities: Voice > Video > Data

- **Challenge for the network designer:**

  Develop techniques that can assign bandwidth to the different traffic classes in manner such that

  - a guarantee on the level of service can be provided to a portion of the time-critical traffic classes, and
  - the needs of the system (i.e. maximize the # of supported connections) are balanced against the needs of the applications

(Bandwidth prediction and reservation for bursty sources such as VBR video is an unsolved problem, so how do we allocate bandwidth for such sources)

Possible Approaches

Adapt the application:

- Use an appropriate (joint source-channel) video codec
  - very **low bit rate** with **high average PSNR** and **acceptable frame rate** (subband based, MPEG-4, H.263L etc.)
- Use a CBR voice connection (e.g GSM speech CODEC)

Adapt the communication layer:

- Carry out appropriate resource management (bandwidth reservation, allocation and utilization)
- Implement a “smart” bandwidth partitioning strategy
- Implement a complimentary MAC protocol

Bandwidth Reservation, Utilization, and Partitioning

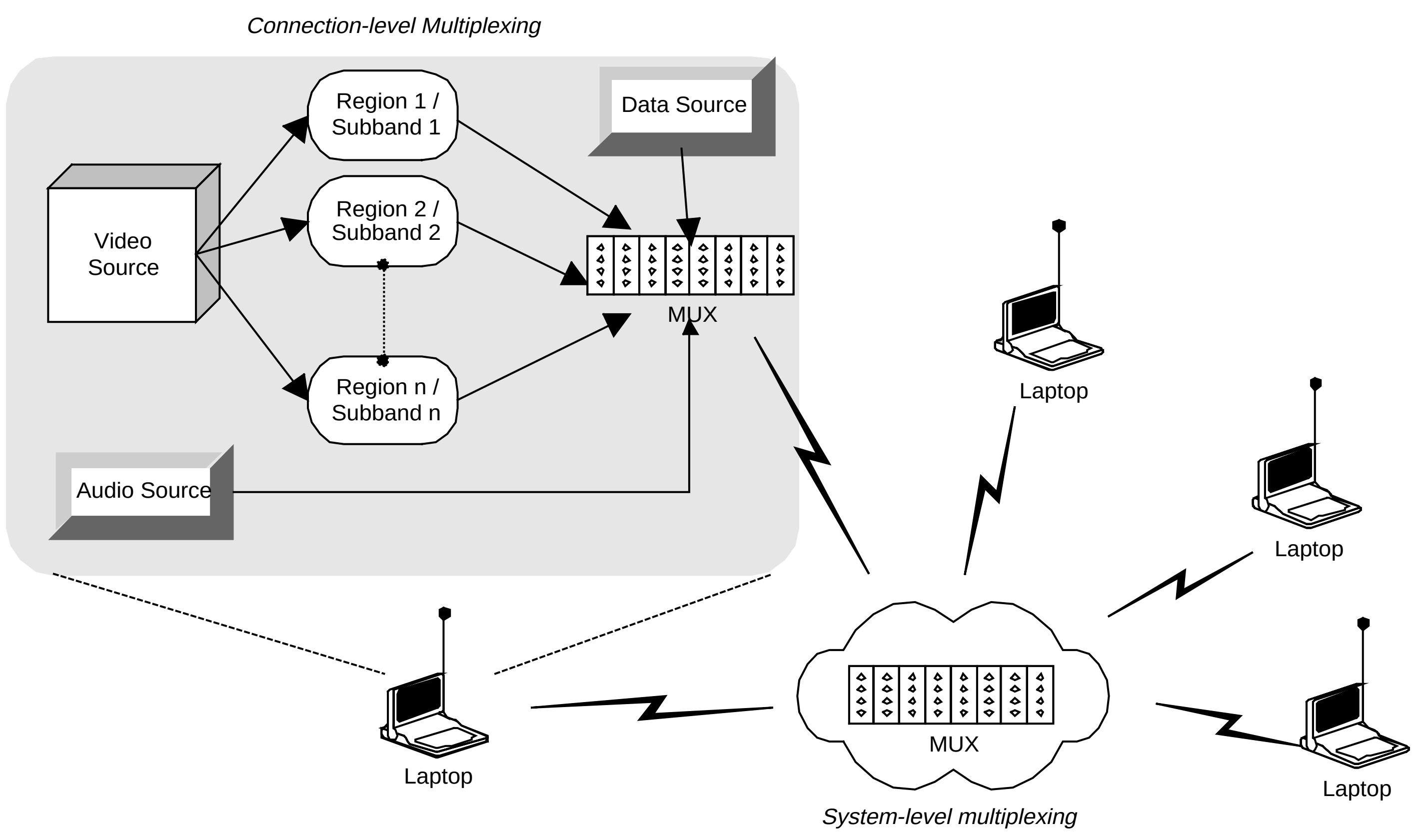
Question

Can performance guarantees be provided to VBR video without significantly under-utilizing the bandwidth?

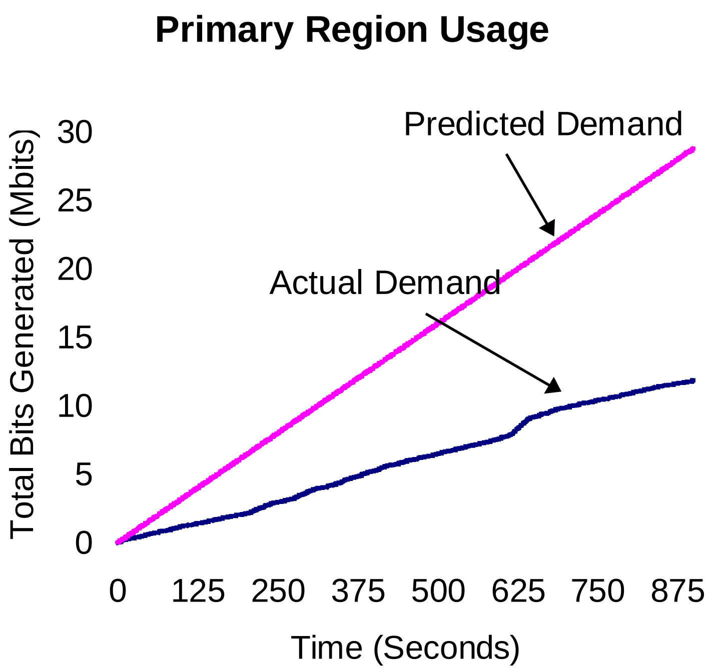
Answer

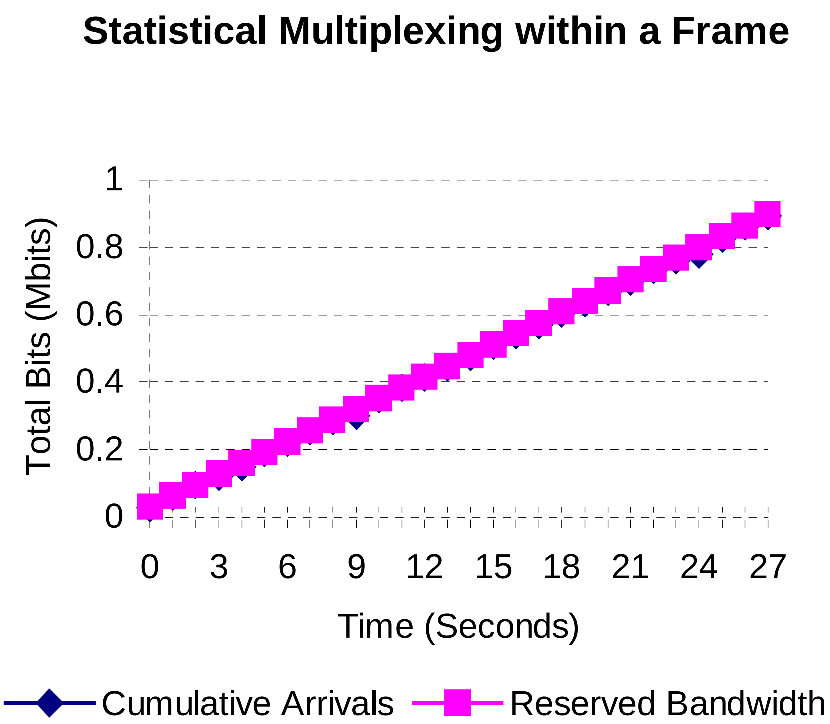
Yes! Use **Intra-frame statistical multiplexing**

Statistical Multiplexing: Connection Level and System Level



Effect -- Improved Bandwidth Utilization



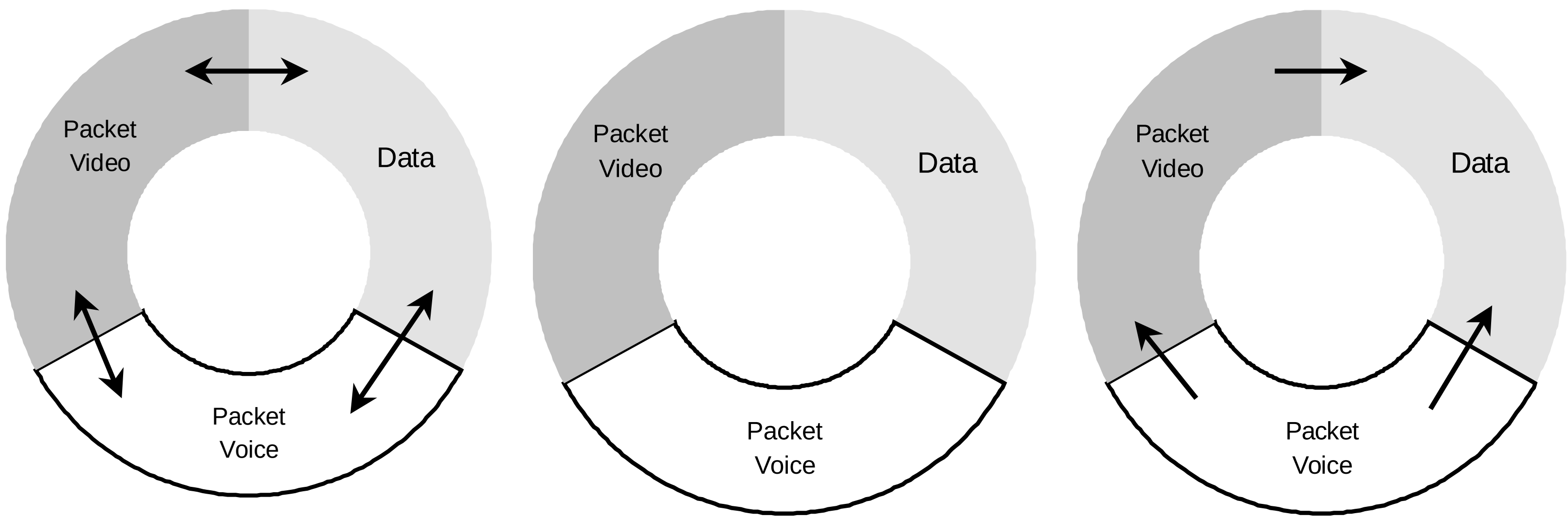


Bandwidth usage with and without <u>intra-frame statistical</u> multiplexing

Bandwidth Partitioning (Systems Perspective)

Possible Strategies:

+ Complete Sharing
+ Complete Partitioning (or Mutually Restricted Access)
+ Partitioning with Priority Borrowing (or Partial sharing)

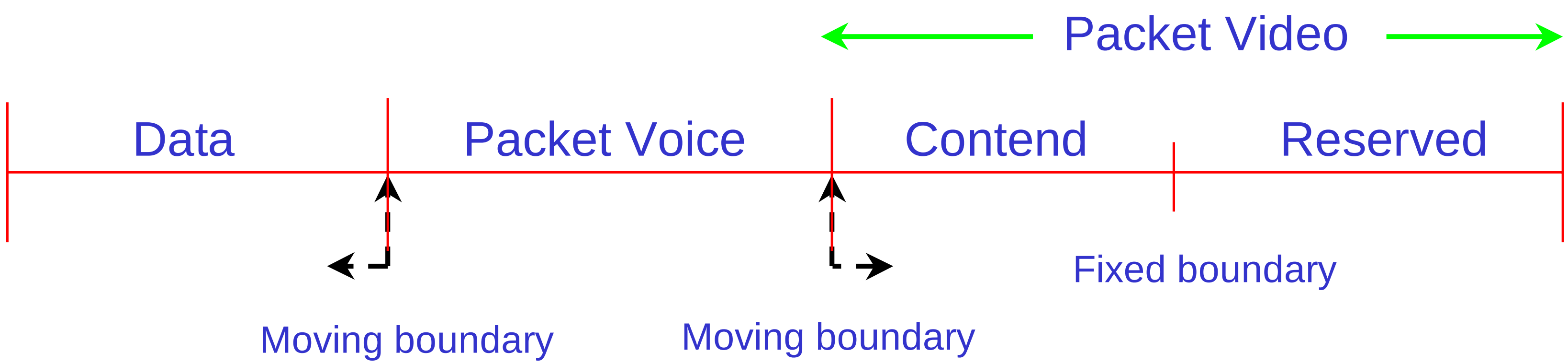


Strategy 1: Complete Sharing (CS)   Strategy 2: Complete Partitioning (CP)   Strategy 3: Priority Sharing (PS)

Sharing Strategies -- Pros and Cons

CP	CS	PS
• Blocking level for each class easy to adjust	• Blocking level among classes not adjustable	• May be tunable to variable blocking requirements
• Complete Protection from overload of other classes	• No protection from overload of other classes	• May offer protection against overload from other classes
• Requires too much bandwidth	• Better Bandwidth usage than CP	• More efficient bandwidth usage than CP and CS

Proposal -- Priority Sharing with Restrictions (PSR)

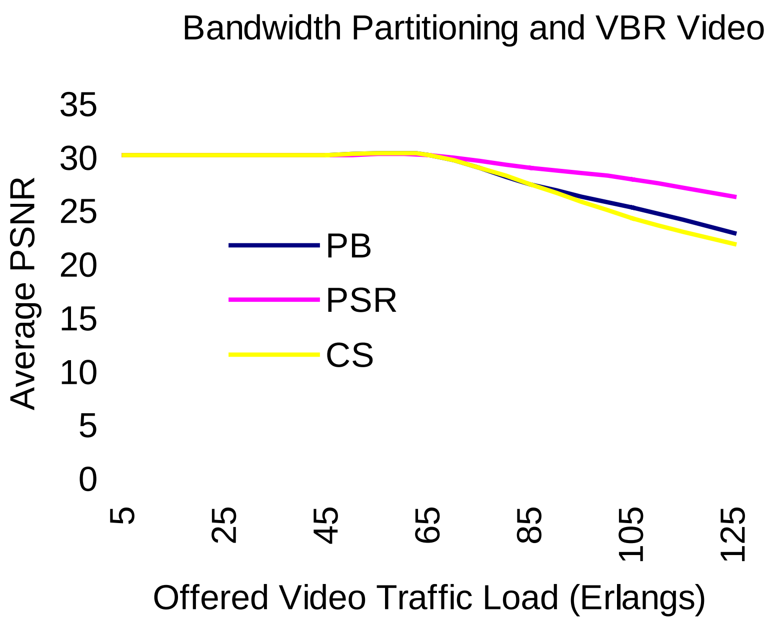


Requester \ Reserved	Data	Voice	Video-Dynamic	Video-Static
Data	-	BP	BP	BP
Voice	B	-	B	BP
Video-Dynamic	B	BP	-	BP
Video-Static	X	X	X	-

B --- Borrow

BP --- Borrow, but Preemption possible

Comparison of Bandwidth Partitioning Schemes



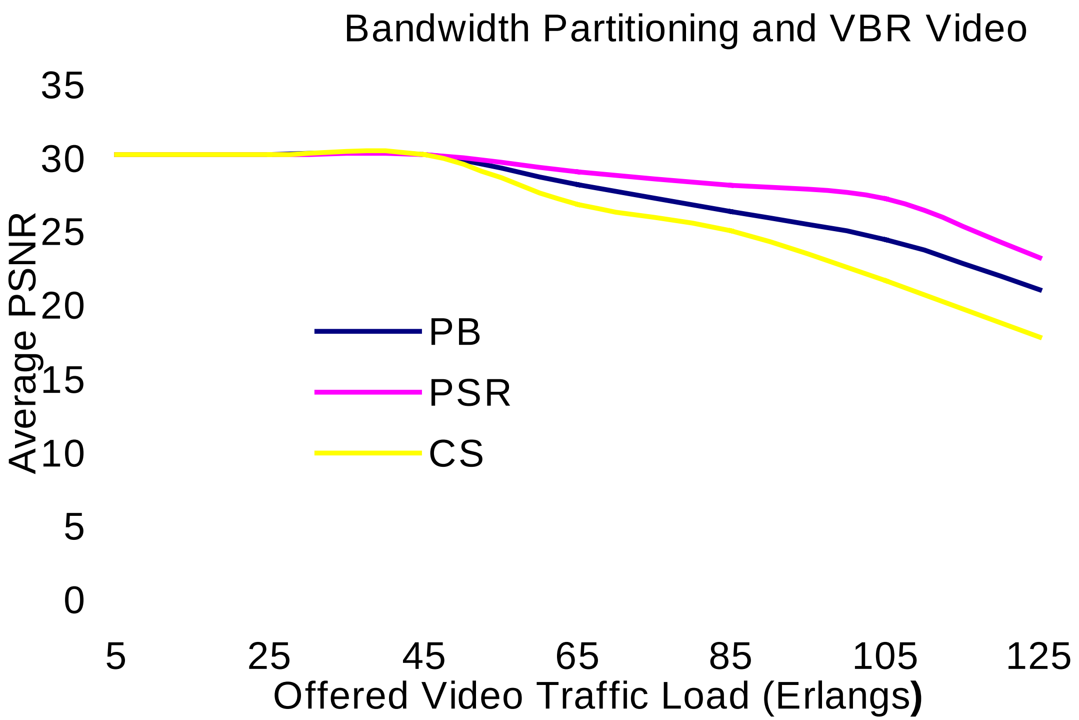
<u>Voice + Data Traffic</u>

Voice Traffic Load	= 30 Erlangs
Data Traffic Load	= 10 Erlangs

<u>Video Traffic</u>

Compression	= Region-based H.263
Avg. Frame Rate	= 7.5 Hz
Avg. Video Bit rate	= 24 kbps
Image Dimensions	= QCIF (176 x 144)
# of Regions/Image	= 5
Peak for primary Region	= 20 kbps
Avg. PSNR	= 30.4 dB

Comparison of Bandwidth Partitioning Schemes



voice = 60 erlangs

data = 10 erlangs

Optimal Bandwidth Partitioning

Problem

Can performance guarantees be provided to VBR video without significantly under-utilizing the bandwidth **and** can this be done in conjunction with minimizing the blocking probability for voice and data traffic?

Alternatively

How do we decide, how much of the available bandwidth should be allocated to each traffic class?

Solution

Allocate bandwidth so the maximum call blocking probability is minimized

Minimize the Maximum Blocking Probability

Problem Statement

Given the aggregate load D_i for each traffic type T_i and the total system bandwidth B, determine the allocated transmission capacity for each traffic type such that

$$\Theta = \max_i P(d_i(t) \geq B_i)$$ is minimized

subject to $\sum_{i=1}^{N} B_i = B$ where $d_i(t)$ is the instantaneous demand

Minimize $\Theta = \max_i P(d_i(t) \geq B_i)$

Theorem

Let X_1, …, X_N be independent random variables taking their values from the interval [0, 1]. Their probability distributions are otherwise arbitrary and not necessarily identical. Set $X = \sum_i X_i$ *and* $D = E(X)$ *then for any* $C \geq D$ *the following estimation holds:*

$$P(X \geq C) \leq \left(\frac{D}{C}\right)^C e^{C-D}$$

Furthermore, this estimation is best possible in the following sense: For any fixed $\varepsilon > 0$ *and for any fixed D and C with* $C \geq D$ *there exist infinitely many counter examples for which the reverse holds.*

Minimize $\Theta = \max_{i} P(d_i(t) \geq B_i)$

New Problem Statement

Given the aggregate load D_i for each traffic *type* T_i and the total system transmission bandwidth *B*, determine the allocated transmission capacity for each traffic type, such that

$$\Theta = \max_{i} \left\{ \left(\frac{D_i}{B_i} \right)^{B_i} e^{B_i - D_i} \right\}$$ is minimized

subject to $$\sum_{i=1}^{N} B_i = B$$

Basis for Determining B_i s

Can prove: Allocation of B_i is *asymptotically optimal if and only if*

$$\left(\frac{D_1}{B_1}\right)^{B_1} e^{B_1 - D_1} = \ldots = \left(\frac{D_N}{B_N}\right)^{B_N} e^{B_N - D_N}$$ holds !

Thus the problem is solved by letting,

$$\left(\frac{D_i}{B_i}\right)^{B_i} e^{B_i - D_i} = \sigma$$

and iteratively searching for a value $0 < \sigma \leq 1$ for which $\sum_{i=1}^{N} B_i = B$ holds within a given error bound $\varepsilon > 0$

Basis for Determining D_i

Method

If X_i is the size of i^{th} frame (or region or subband) in a video sequence which has *n* frames, and if we define:

$$Y_n = \max\left(X_1, X_2, \ldots X_n\right)$$

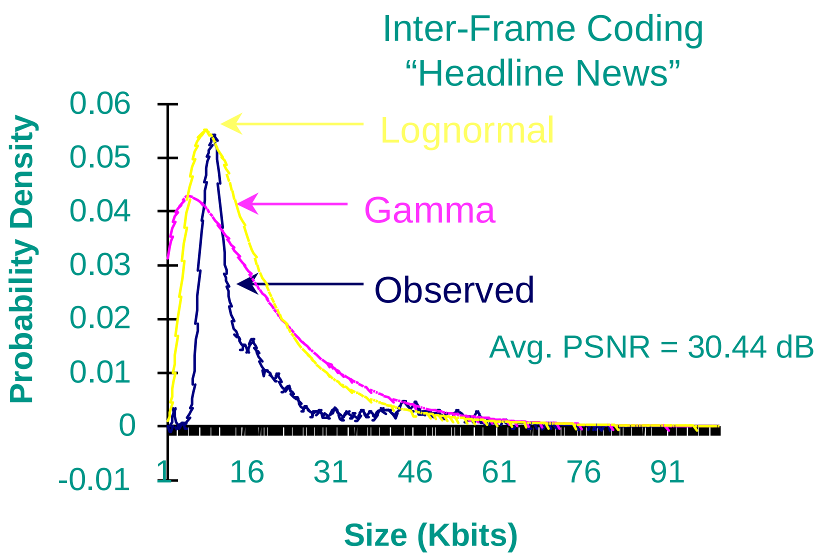
then by letting $Y = \lim_{n \to \infty} Y_n$ and deriving $f_{Y_n}(y)$

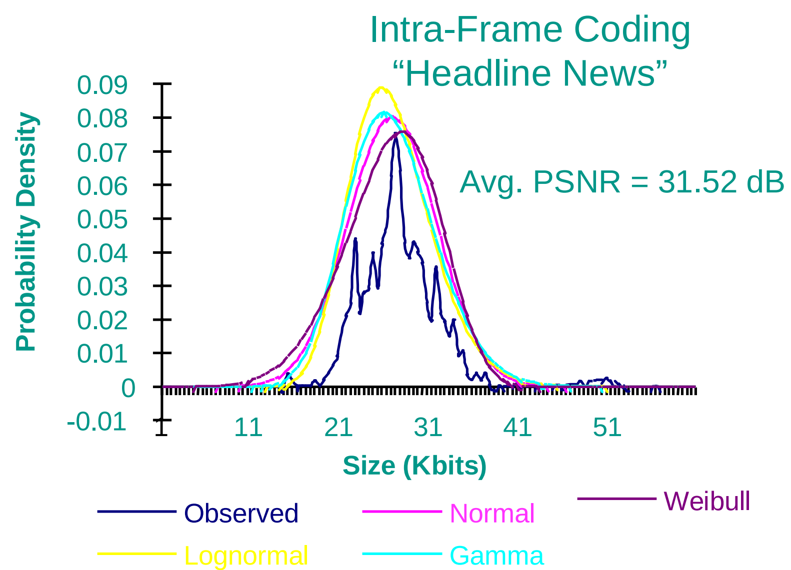
we can calculate the mean η_y and determine D_i

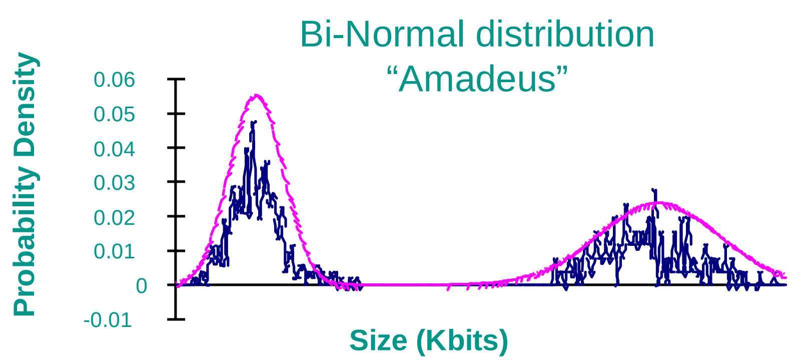
$$D_i = M \times \eta_y$$

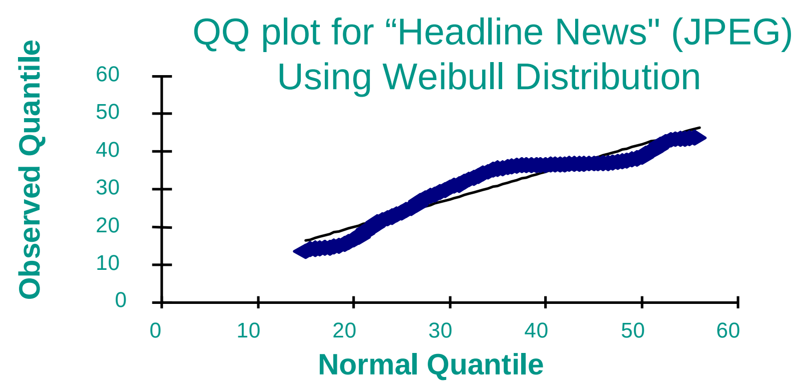
where *M* is the # of video connections to be supported

Statistical Characterization (VBR Video)

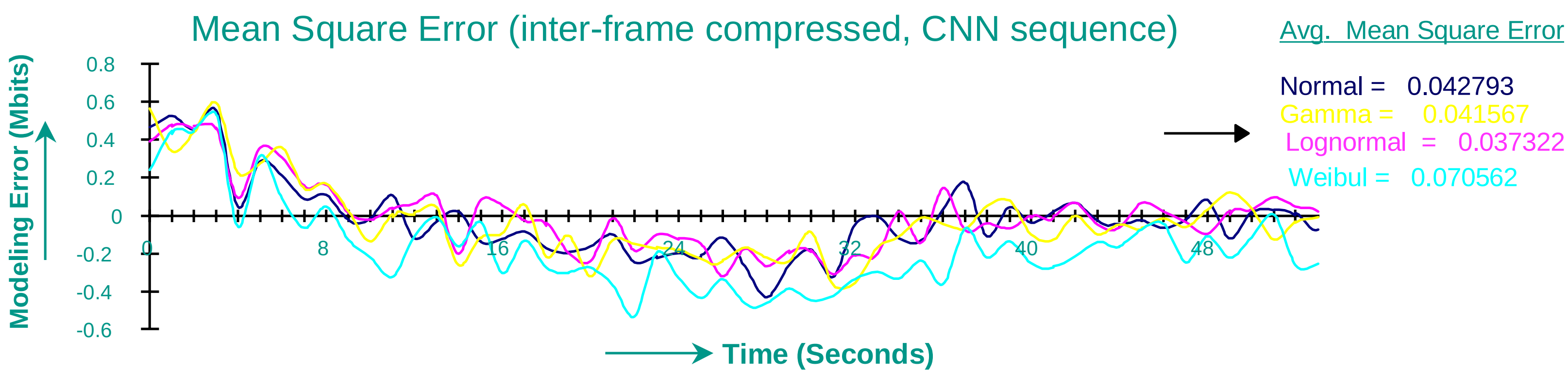


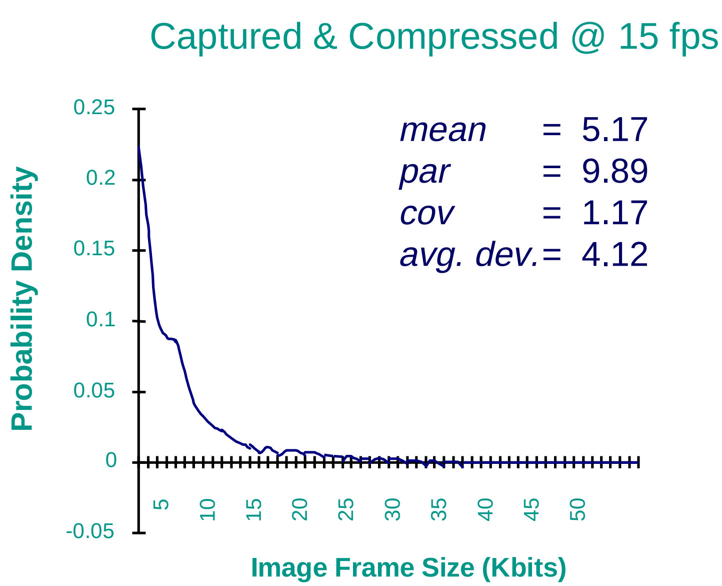


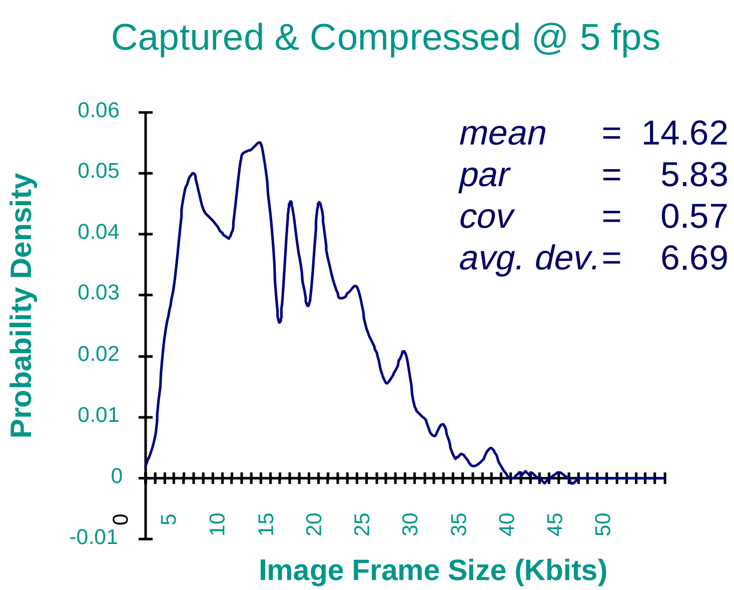




Statistical Characterization (VBR Video)







Determining $f_{Y_n}(y)$ and $D_i \; (\eta_y)$

Results from distribution-based modeling of single VBR video sources

Coding Technique	Request Video				Conference Video	
	High Capture Rate		Low Capture Rate		High Capture Rate	Low Capture Rate
	High Action	Low Action	High Action	Low Action	Low Action	Low Action
Intra-Frame	Normal	Normal/Gamma	Normal/Weibull	Weibull	Bi-Normal	Bi-Normal
Inter-Frame	Bi-Normal	Gamma/Lognormal	Normal	Gamma	Gamma-Pareto	Lognormal

Notice, most video frame distributions can be described as:

$F_x(x) = 1 - e^{-g(x)}$ where $g(x)$ is a increasing function of X

then we can prove, $F_Y(y) = \exp[-e^{-\alpha(y-u)}], \quad -\infty < y < \infty$

Determining $f_{Y_n}(y)$ and $D_i(\eta_y)$

- Thus knowing $F_Y(y)$ the mean can be computed as:

$$\eta_y = u + \left(\frac{0.577}{\alpha}\right)$$

where u and $\alpha\,(>0)$ are the location and scale parameters

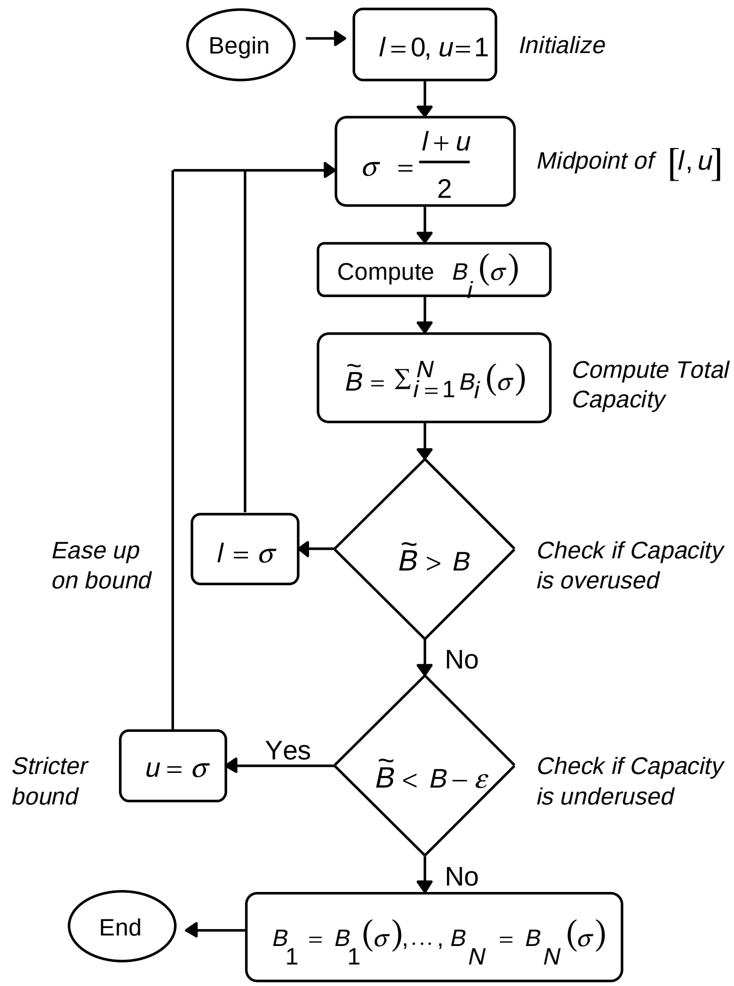
- For Voice connections:

$$D_a = M \times C$$

where C is CBR (e.g. GSM - 13 KHz, DECT - 32 KHz, …) and M is the estimated number of voice connections

Note: Can use D_i s for Network Capacity Planning !

The Smart Allocate Algorithm



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illustrative Example

Assume TDM-based system with 99 BBU

Let the aggregate average demands be

D_1 (voice) = 20 Erlang and D_2 (video) = 40 Erlangs

Then the **Load Proportional** approach gives

B_1 = 33, B_2 = 66, with Erlang's blocking probability = 1 %

Smart Allocate algorithm gives

B_1 = 37 and B_2 = 62, blocking probability = 0.57%

Improvement of 43% !

Conclusion -
Advantages of PSR + **Smart Allocate** Algorithm

- Accommodates all traffic classes without shutting out any single one
- Provides QoS guarantees for on-going VBR real-time video communications. This guarantee does not come at the expense of bandwidth and other traffic classes.
- Robust and insensitive to statistical assumptions. Does not require detailed knowledge of traffic, only aggregate average values (detailed statistical information is typically unavailable)
- Allocation based on minimizing a bound on the blocking probabilities that is proven to be asymptotically optimal - significant as it signifies that for large number of systems it is sufficient to know aggregate flow rates.

Current Projects at MSR
Peripatetic Computing for the Next Millenium

- Ad-Hoc multi-hop home networking
  - Protocols, Routing algorithms, architecture, roaming, locating, performance etc
- Hardware for hand-held communicators
  - RF issues, form factor, capacity, capability, user requirements, user interface etc.
- QoS in mobile multimedia
  - Content-Sensitive Video Coding (beyond MPEG-4), Resource assignment and management, etc.
- Operating system support for mobile users
  - caching, hoarding, prediction, data management, disconnected operations etc