Dimensioning of IP Networks - A still incomplete Framework

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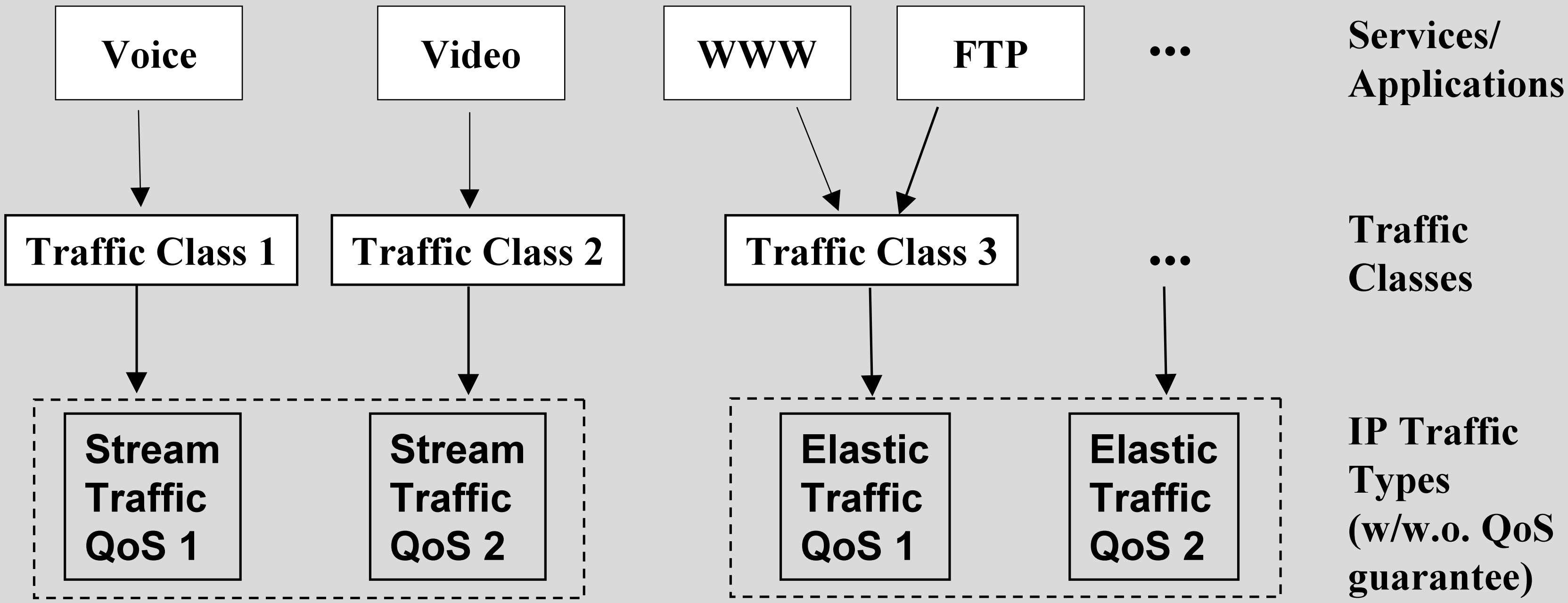
Introduction
Basic IP Traffic Classification



e.g.
- peak bitrate
- mean bitrate
- packet loss prob.
- end-to-end delay
- end-to-end blocking prob. (if adm. control)

e.g.
- mean docu size
- min. docu transfer rate (= min. througput)
- max. docu transfer time for docu of size x

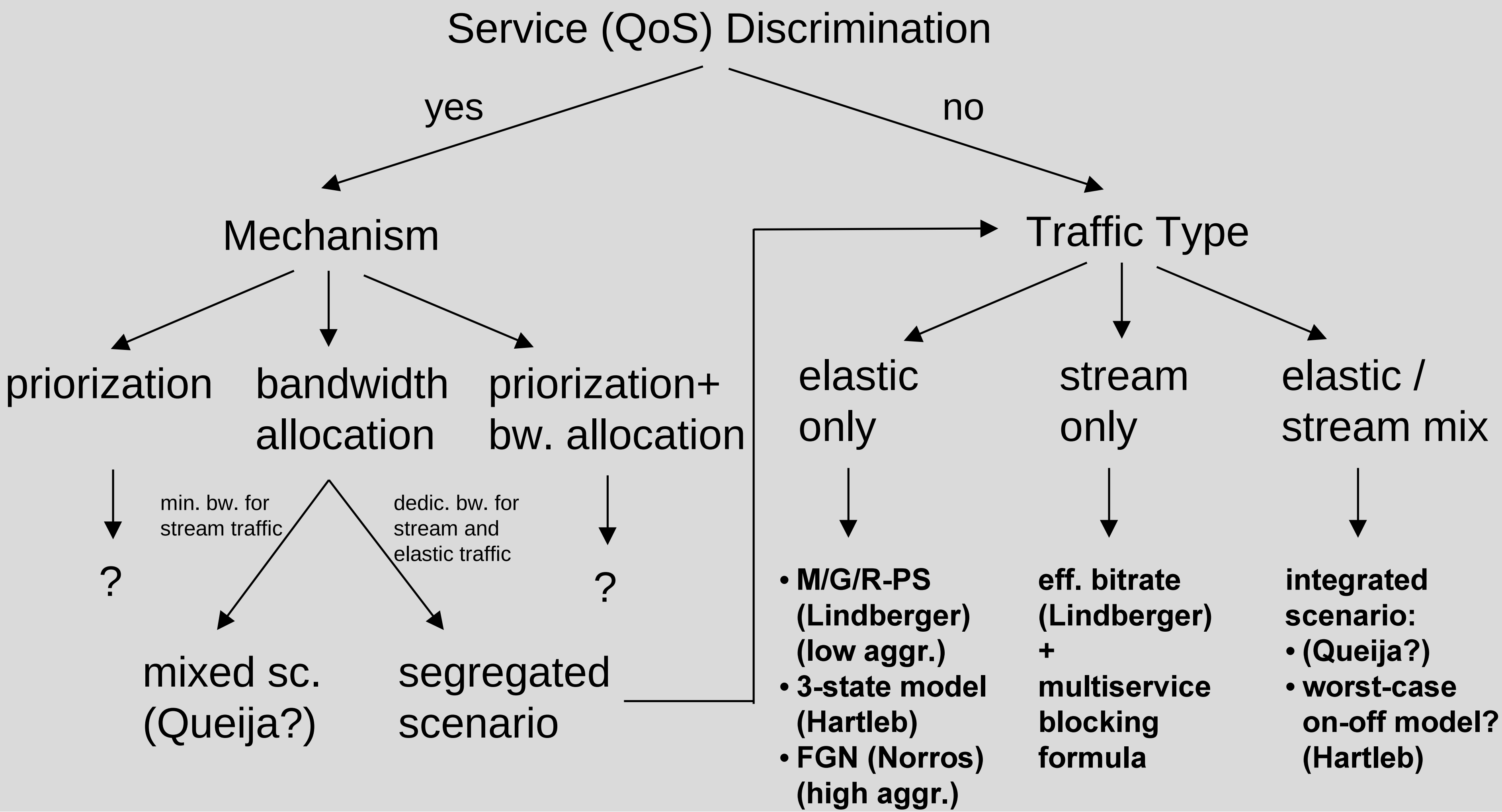
IP Traffic/ QoS Parameter

Introduction
IP Link Dimensioning - Basic Classification Criteria

Basic Classification Criteria:

- Elastic (TCP) vs. stream (UDP) traffic
- Service (QoS) discrimination:
  - complete sharing
  - priorization only
  - bandwidth reservation only
  - priorization and bw. reservation
  - .....
- Degree of traffic aggregation:
  - source models (e.g. Web-traffic)
  - models for low aggregated traffic (e.g. on access links)
  - models for high aggregated traffic (e.g. on backbone links)

Introduction
IP Link Dimensioning - Overview



2. Dimensioning for Stream Traffic

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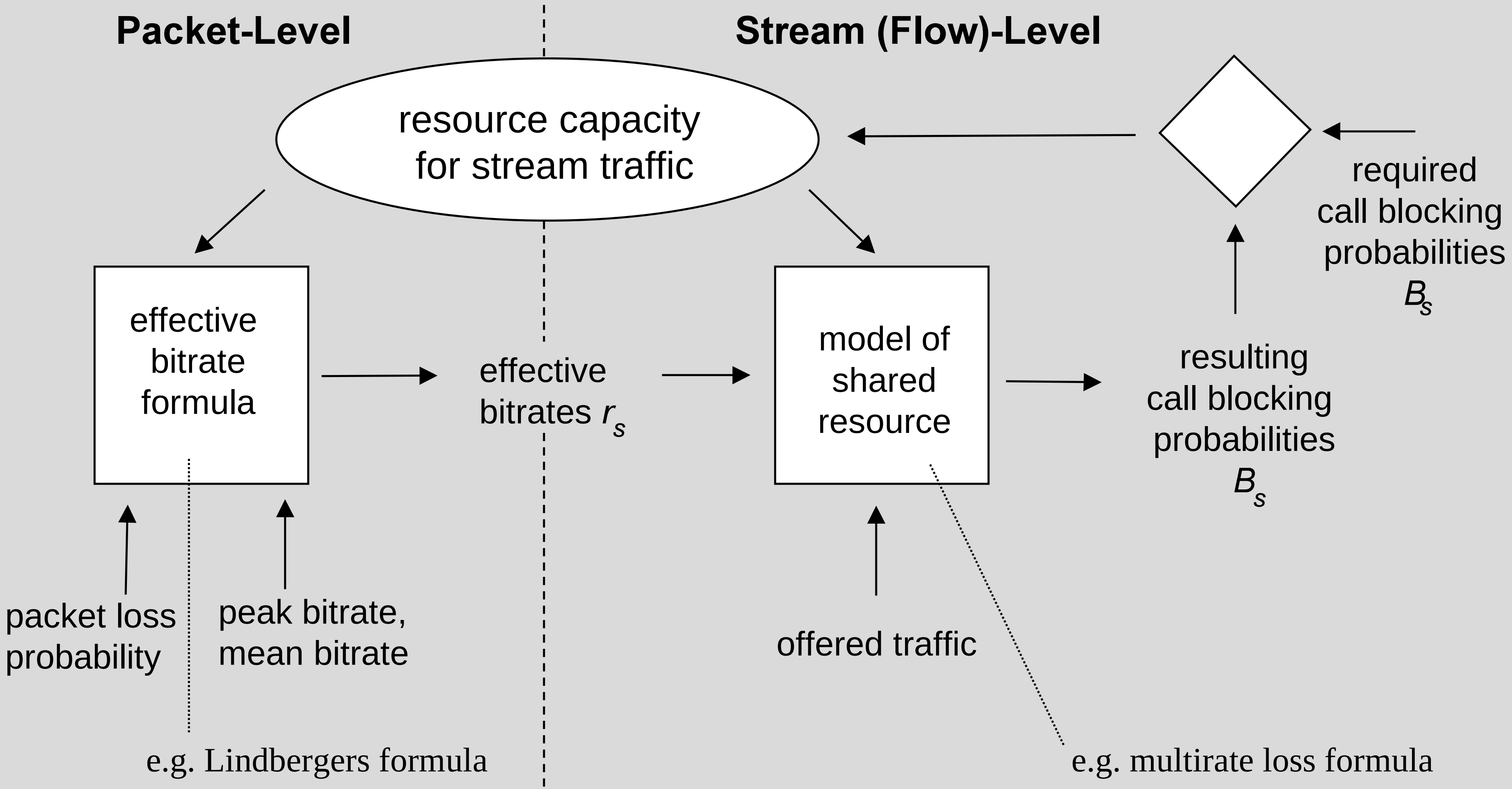
Link Dimensioning for Stream Traffic



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Link Dimensioning for Stream Traffic
Example: Lindbergers Effective Bitrate Formula

$$r(C) = \begin{cases} \gamma\, MBR & \text{if} \quad 0 \le C \le n^{*} \\ \gamma\, MBR \left(1 + 3\eta^{2}\, PBR \cdot \dfrac{PBR - MBR}{C^{2}}\right) & \text{if} \quad n^{*} \le C \le n^{**} \\ \gamma\, MBR \left(1 + 3\eta \cdot \dfrac{PBR - MBR}{C}\right) & \text{if} \quad C \ge n^{**} \end{cases}$$

with:

$$\gamma = 1 + \eta / 100$$

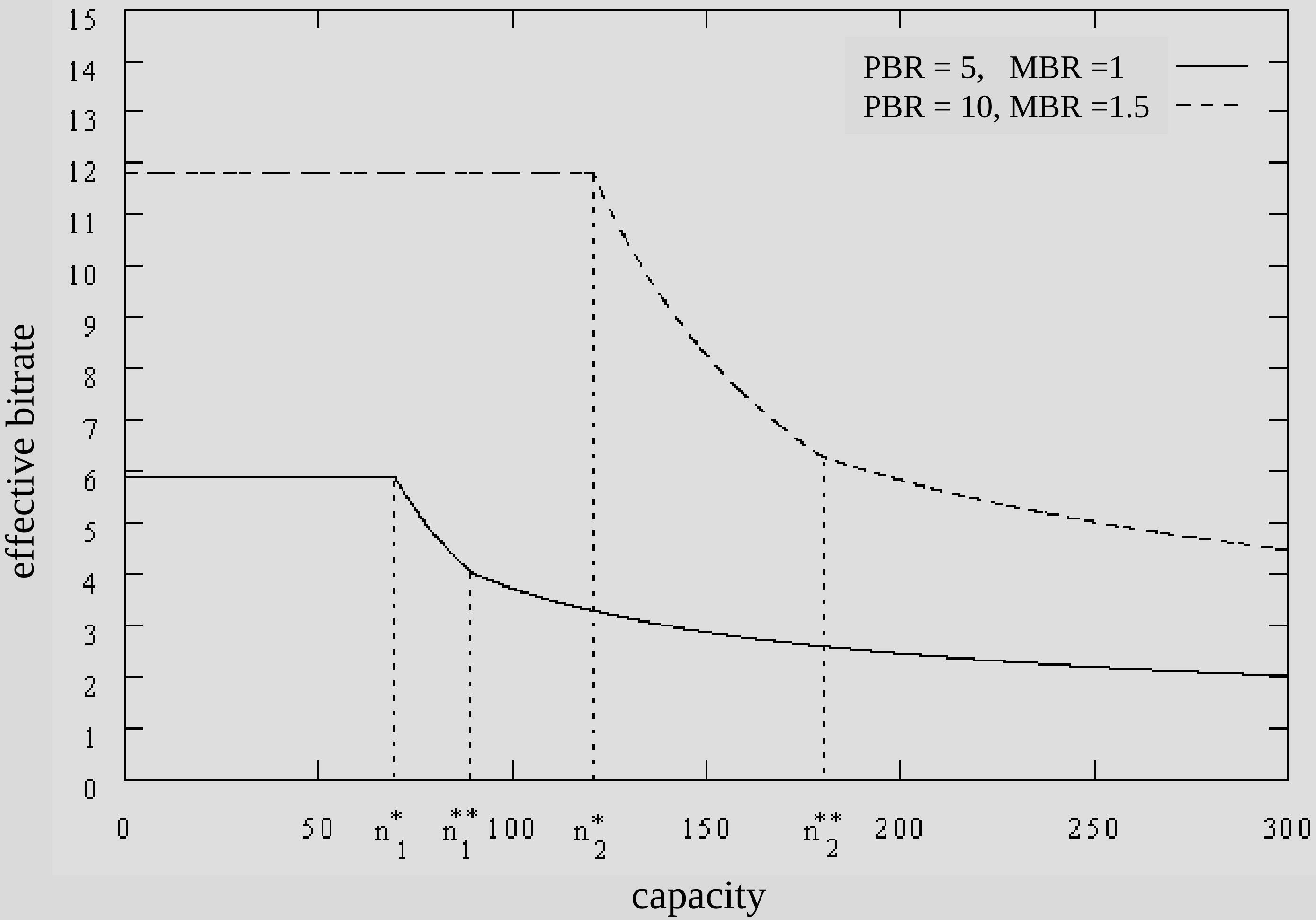
$$\eta = -2 \log P_{loss}$$

$$\eta^{*} = \begin{cases} \eta \sqrt{3MBR \cdot PBR} & \text{if} \quad PBR \ge 3MBR \\ 3\eta\, MBR & \text{else} \end{cases}$$

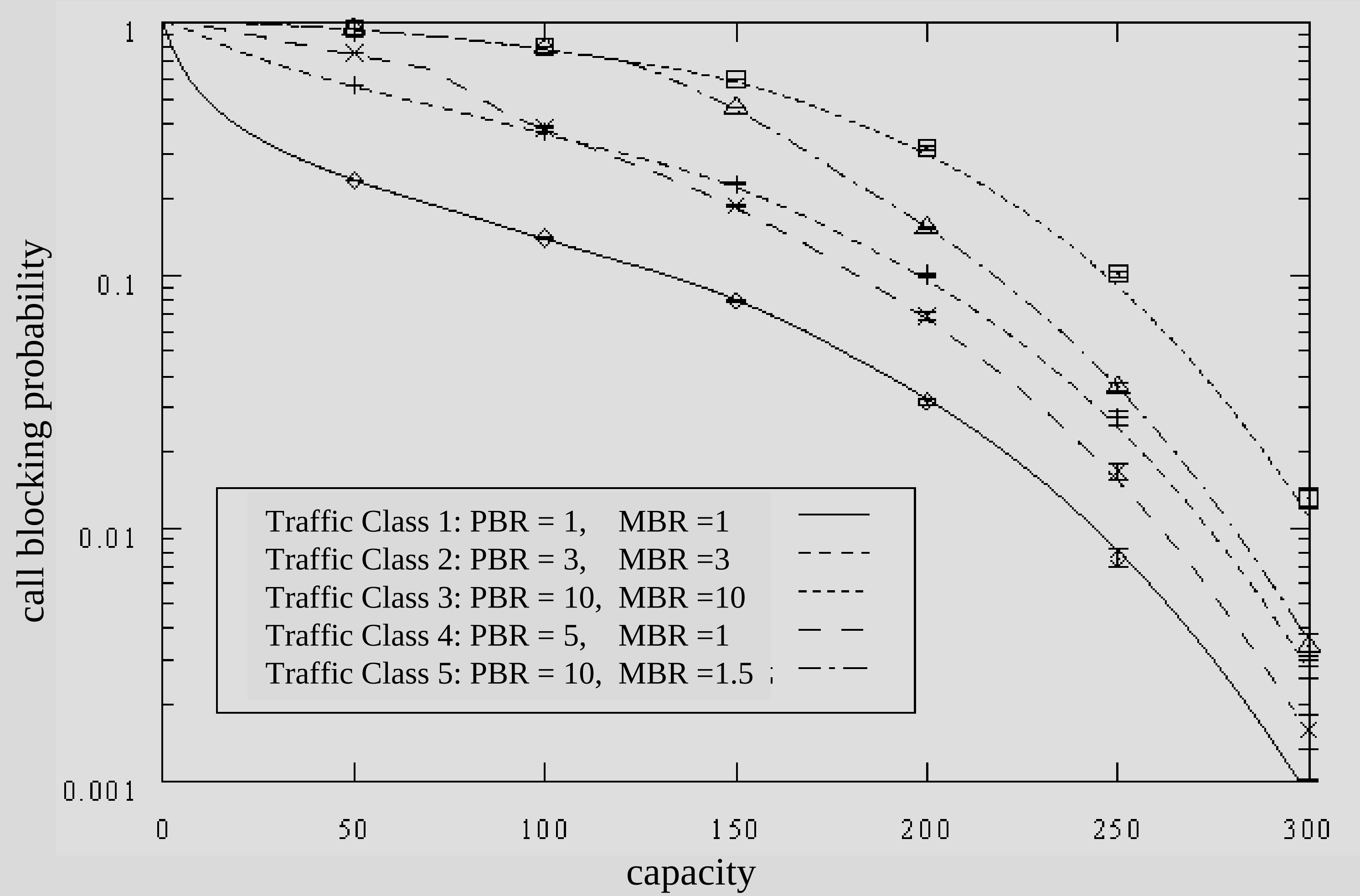
$$\eta^{**} = \begin{cases} \eta\, PBR & \text{if} \quad PBR \ge 3MBR \\ \eta^{*} & \text{else} \end{cases}$$

PBR = peak bitrate
MBR = mean bitrate
C = link (resource) capacity
r = effective bitrate of traffic class s
n^{*}, n^{**} = threshold values

Link Dimensioning for Stream Traffic
Example: Lindbergers Effective Bitrate Formula



Link Dimensioning for Stream Traffic
Blocking Probability vs. Link Capacity



3. Dimensioning for low aggregated Elastic Traffic

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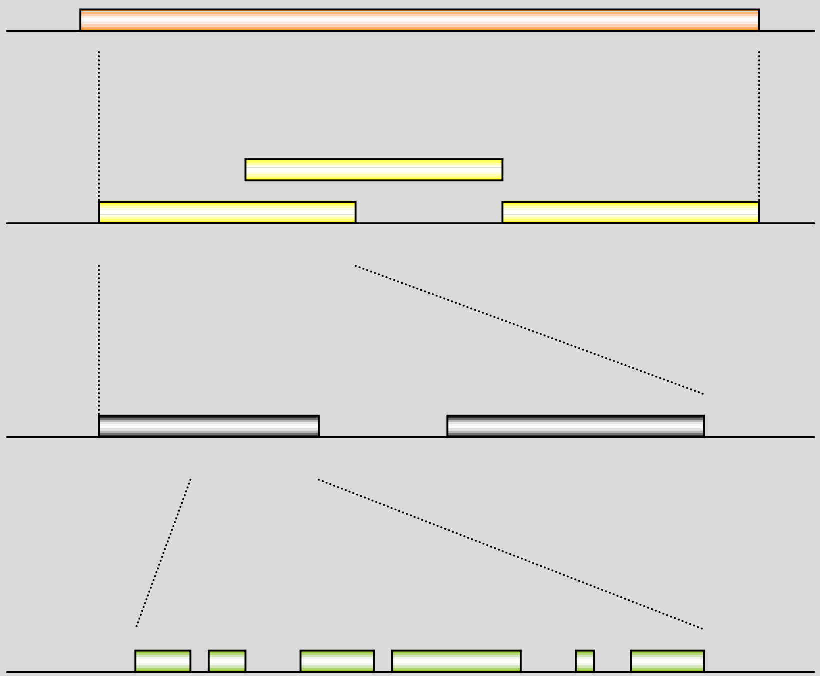
Dimensioning for low aggregated Elastic Traffic
Activity Model for Elastic Traffic



Session Level

Application level

Connection level (TCP)
File level

Burst and Packet level

Dimensioning for low aggregated Elastic Traffic
Elastic Traffic Characteristics (Example: Web-Traffic)

Measurements in educational and corporate environment, Spain 1997/98

Source: A. Reyes-Lecuona, E. Gonzalez-Parada, E. Casilari, J.C. Casasola, A. Diaz-Estrella, A page-oriented WWW traffic model for wireless system simulations, International Teletraffic Congress ITC-16, Edinburgh, 1999

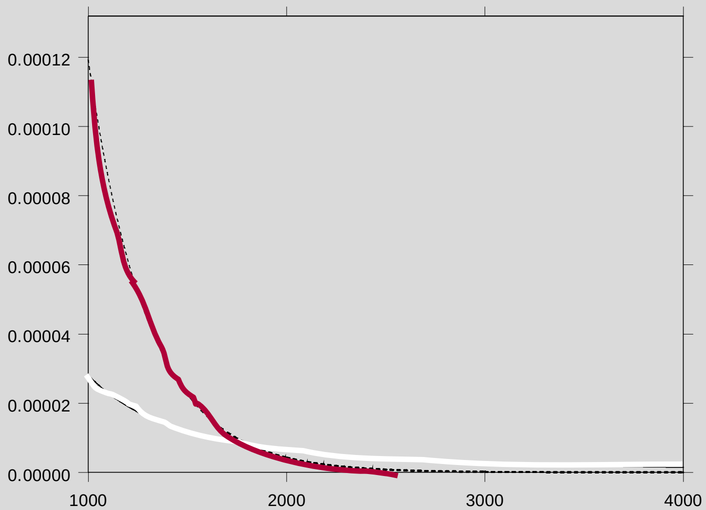
	Distribution	Mean	Standard Deviation
Session interarrival time	Neg.-exponential	Traffic dependent	
Pages/session	Log-Normal	23 ... 26	80 ... 170
Time between pages	Gamma	25 ... 35 s	135 ... 150 s
Page size	Pareto	40 ... 56 kByte	190 ... 200 kByte
Page delivery time	Network dependent	35 ... 75 s	
Packet size	Multimodal	40, 552, 576, 1500 Byte	
Packet interarrival time	Exponential	0,75 ... 1,2 s	

Dimensioning for low aggregated Elastic Traffic
M/G/R-PS Model - Motivation

Characteristics:

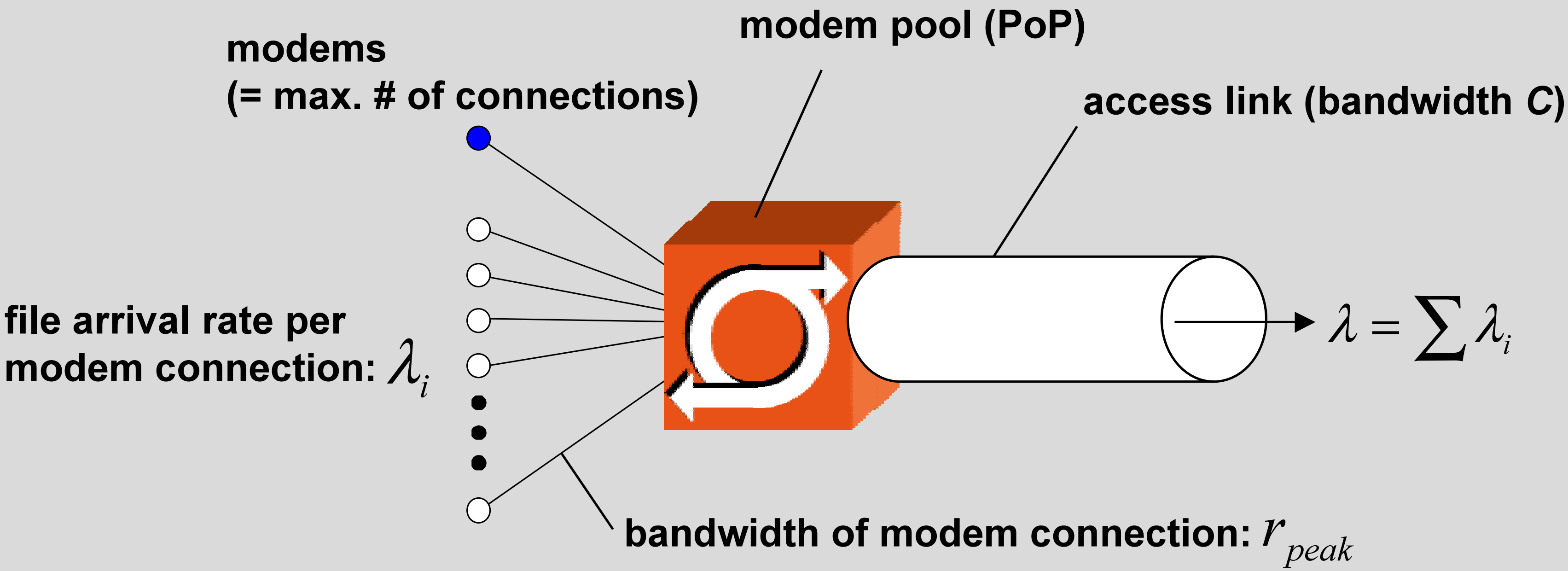
- Elastic traffic call ≙ single file to be transferred
- Poisson arrival process of files
- Heavy tailed file size distribution (Pareto distribution)
- Restricted bitrate of single source
- TCP/IP control loop

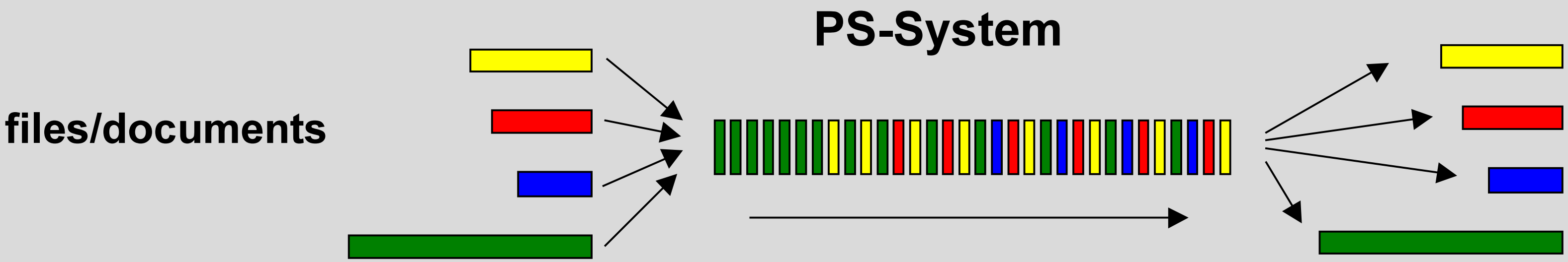
M/G/R-PS Model



Pareto distibution vs.
neg. exponential distibution

Dimensioning for low aggregated Elastic Traffic
M/G/R-PS Model





Dimensioning for low aggregated Elastic Traffic M/G/R-PS Model

Required Input:

- IP flow characterized by:
  - document (file) arrival rate (neg. exp. distributed): λ
  - mean file size: x_{mean}
- max. bitrate of single source: $r_{peak} < C$
  (*C* = access line bandwidth)

Dimensioning Objective:

- determine the link capacity C to guarantee an average transfer time E{T(x)} for a file of size *x*

or:

- determine the link capacity C to guarantee an certain average throughput for all file transactions

Link Dimensioning with M/G/R-PS-Model
Expected Transfer Time as Dimensioning Objective

Expected sojourn time (or transfer time)
E{T(x)} for a file of size x:

$$E\{T(x)\} = \frac{x}{r_{peak}}\left(1 + \frac{E_2(R, R\rho)}{R(1-\rho)}\right) = \frac{x}{r_{peak}} \cdot f_R$$

"delay factor" (f_R)

where: $R = C / r_{peak}$ (# of servers)

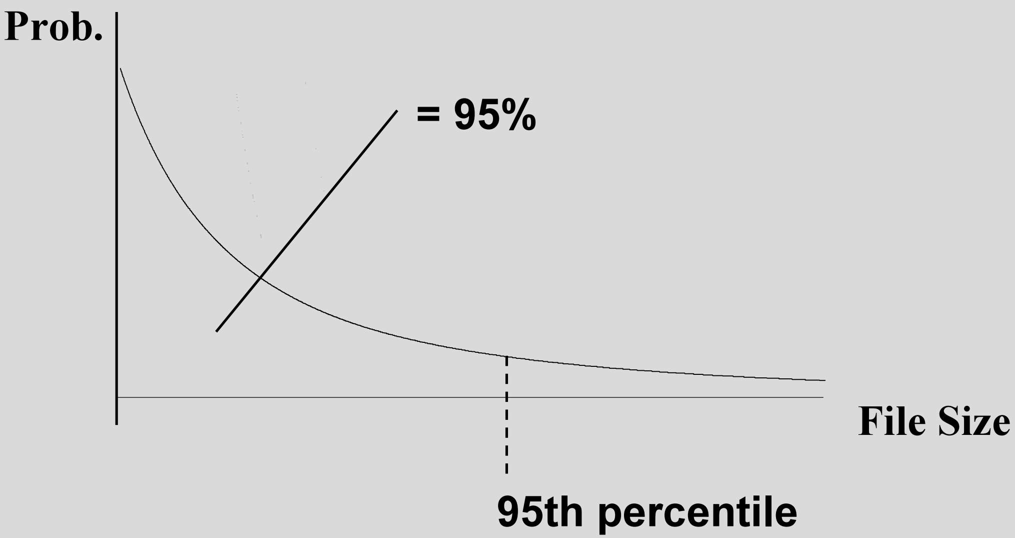
$\rho = \lambda \cdot x_{mean} / C$ (link utilization)

E_2 = Erlang's second formula (Erlang C formula)

Link Dimensioning with M/G/R-PS-Model
Expected Transfer Time as Dimensioning Objective

Question: Which file size x should be taken for E{T(x)}?

Proposal: Take the 95th percentile of an assumed file size distribution e.g. a Pareto distribution.



Link Dimensioning with M/G/R-PS-Model
Average Throughput as Dimensioning Objective

Average bitrate (throughput) *D* during the file transfer phase:

$$D = \frac{r_{peak}}{\left(1 + \frac{E_2(R, R\rho)}{R(1-\rho)}\right)} = \frac{r_{peak}}{f_R}$$

Link Dimensioning with M/G/R-PS-Model
Possible Solutions for different Access Peak Rates r_{peak}

1) $(\lambda_1 + \lambda_2)$ with $\bar{r}_{peak} = \frac{1}{\rho}\left(\rho_1 r_{peak1} + \rho_2 r_{peak2}\right) \rightarrow C$

2)
$$\left.\begin{array}{llll} \lambda_1 & \text{with} & r_{peak1} \rightarrow & C_1 \\ \lambda_2 & \text{with} & r_{peak2} \rightarrow & C_2 \end{array}\right\} \quad C = C_1 + C_2$$

3)
$$\left.\begin{array}{llll} (\lambda_1 + \lambda_2) & \text{with} & r_{peak1} \rightarrow & C_1 \\ (\lambda_1 + \lambda_2) & \text{with} & r_{peak2} \rightarrow & C_2 \end{array}\right\} \quad C = \max(C_1, C_2)$$

Assumptions:
- same file size *x*
- same target delay factor

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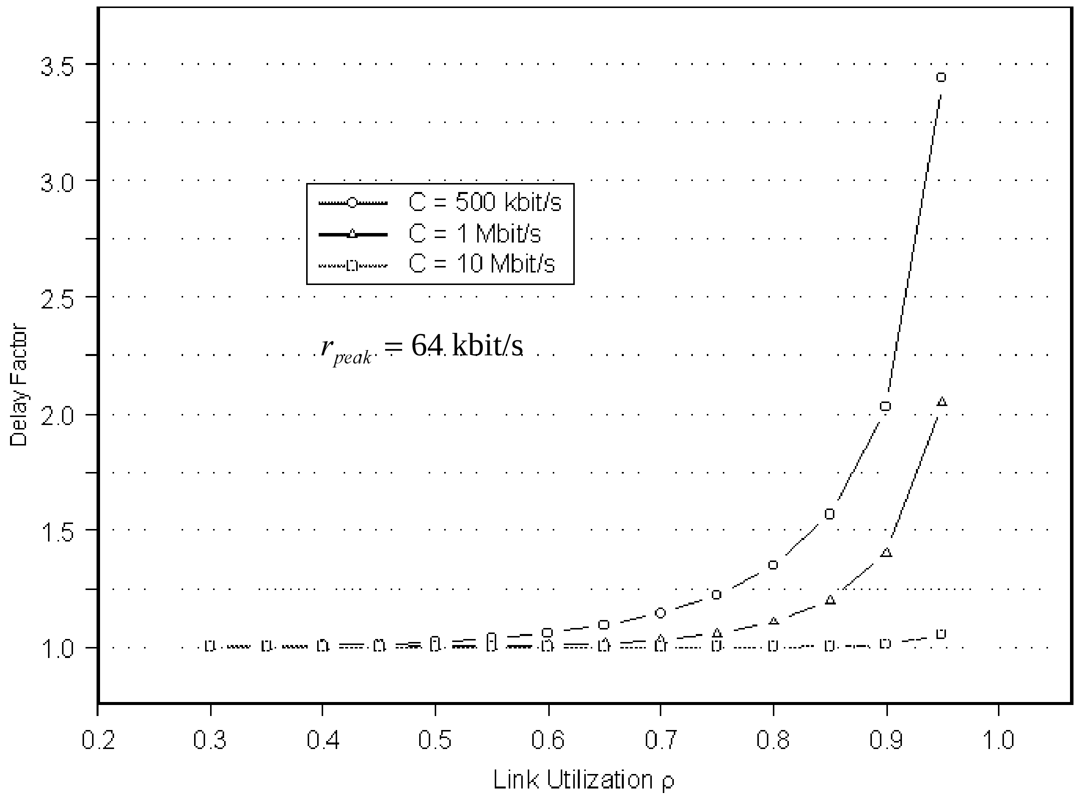
Link Dimensioning with M/G/R-PS Model
Delay Factor wrt. Link Utilization and Link Capacity



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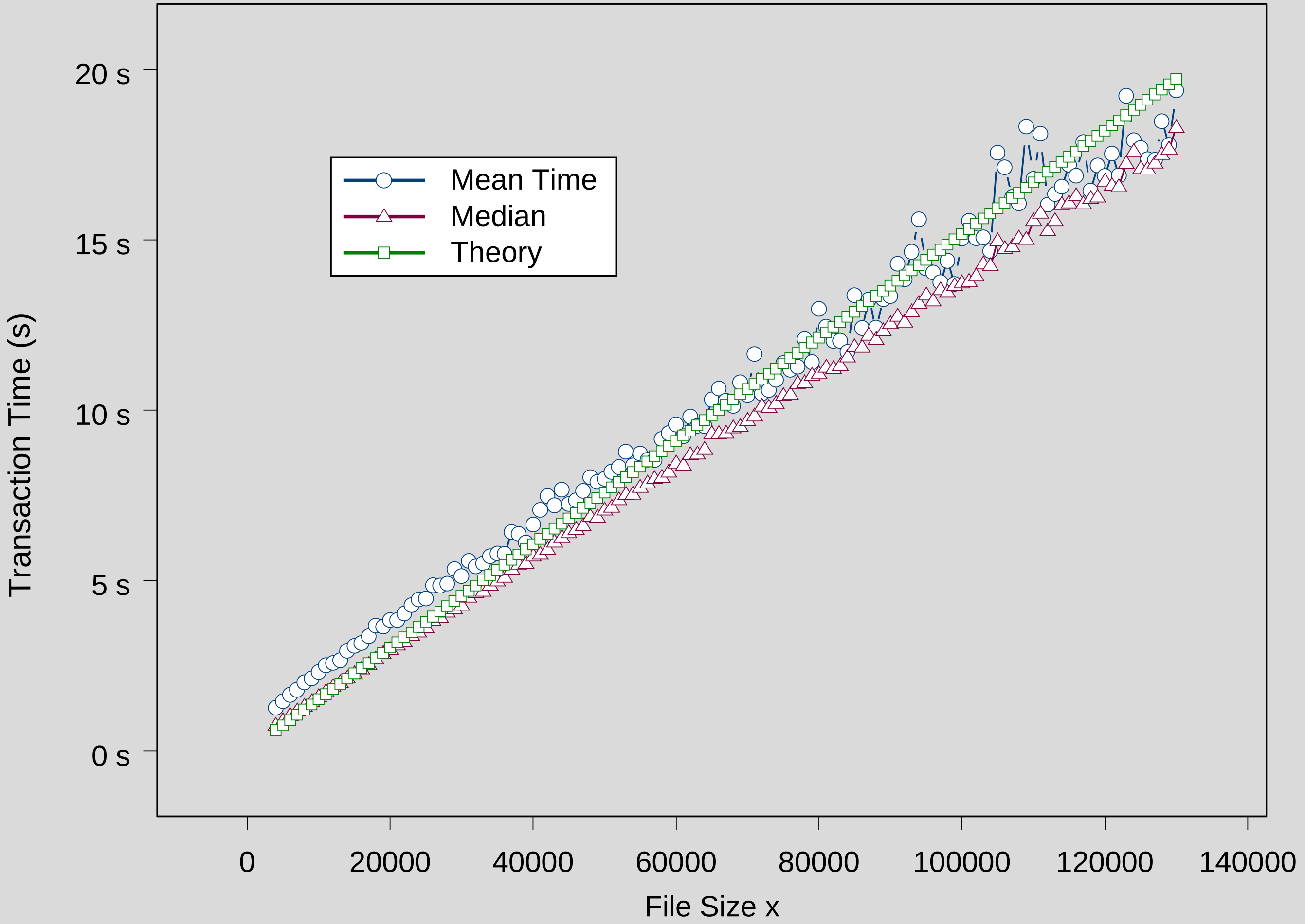
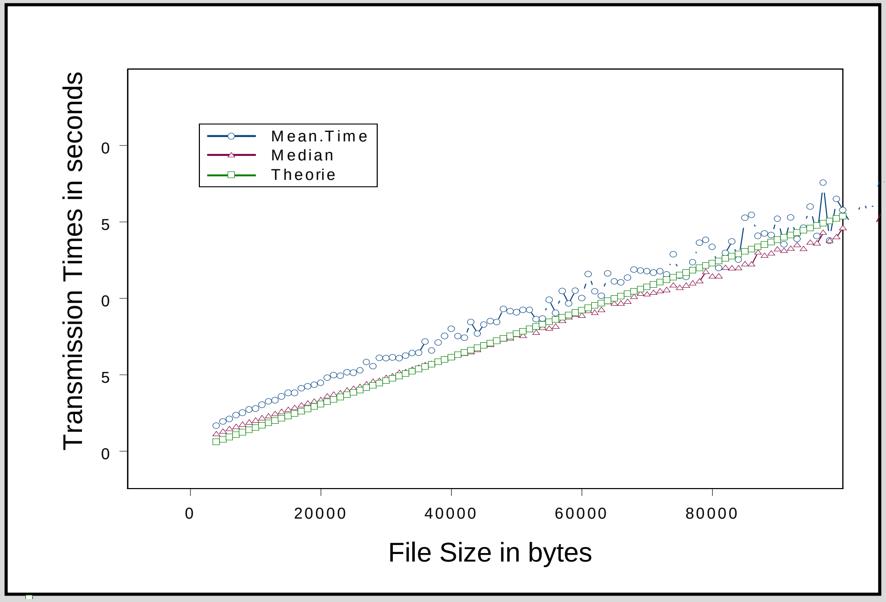
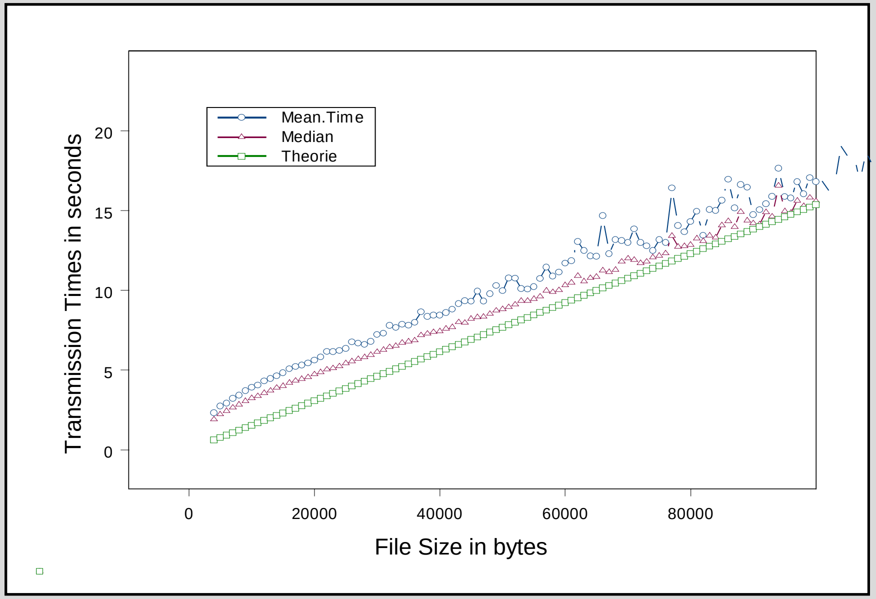
Link Dimensioning with M/G/R-PS Model
Simulation Results: Transaction Time vs. File Size



Link Dimensioning with M/G/R-PS Model
Transaction Time vs. File Size wrt. Round Trip Time





RTT = 30ms

RTT = 300ms

4. Dimensioning for high aggregated (mixed) Traffic

Dimensioning for high aggregated (mixed) Traffic
FGN Traffic Model

Fractional Gaussian Noise (FGN) Traffic Model:

IP flow ***i*** (self similar traffic) characterized by:

- mean bit rate: m_i
- normalized variance: $a_i = var_i / m_i$
- Hurst-parameter: H_i

Dimensioning for high aggregated (mixed) Traffic
Link Dimensioning with FGN Model

Norros effective bitrate formula for self similar traffic (which can be described by a FGN model):

$$C = m + \left(\kappa(H)\sqrt{-2\ln\varepsilon}\right)^{1/H} a^{1/(2H)} x^{-(1-H)/H} m^{1/(2H)}$$

with: $\kappa(H) = H^H(1-H)^{1-H}$

m: mean bitrate of input traffic (sum of m_i)

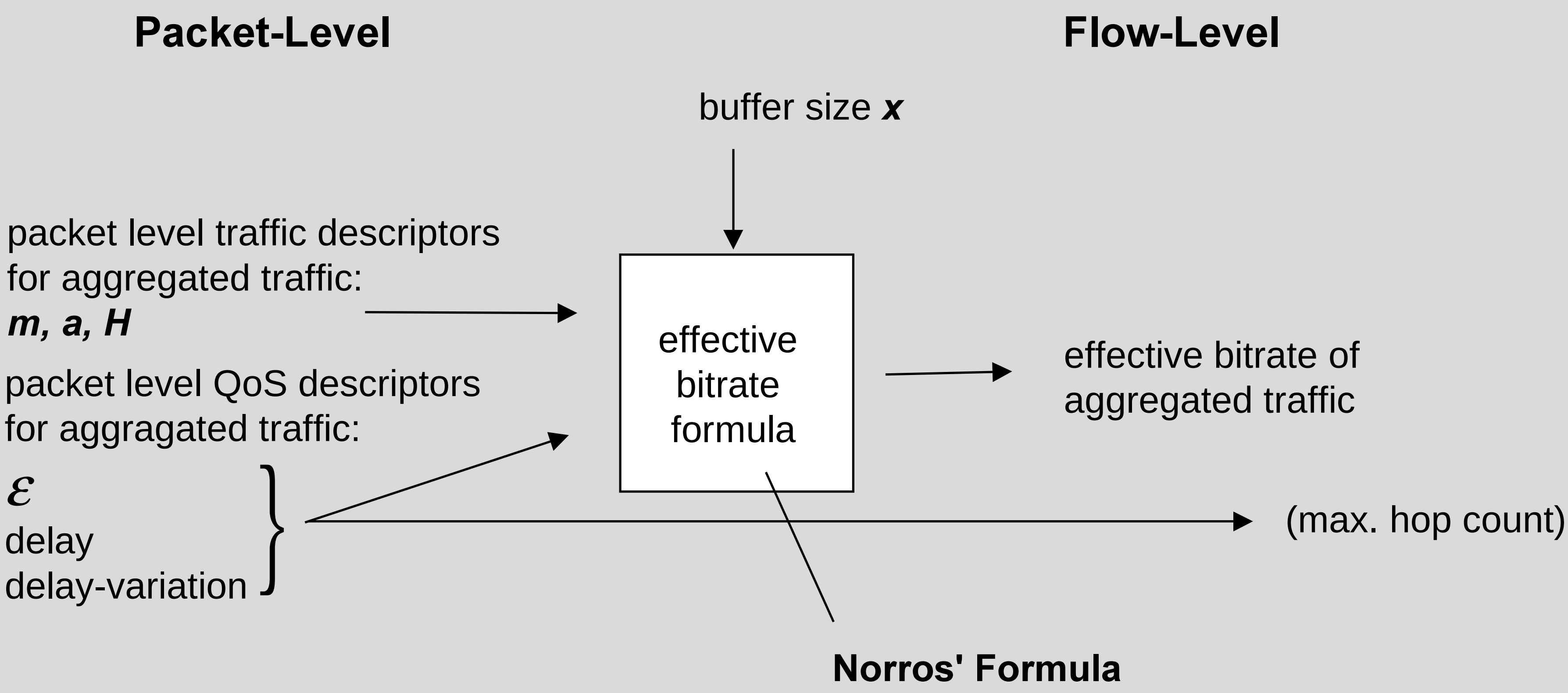
a : normalized variance of input traffic (assumed to be equal for all flows ***i***)

H: Hurst parameter of input traffic ($H = \max_i(H_i)$)

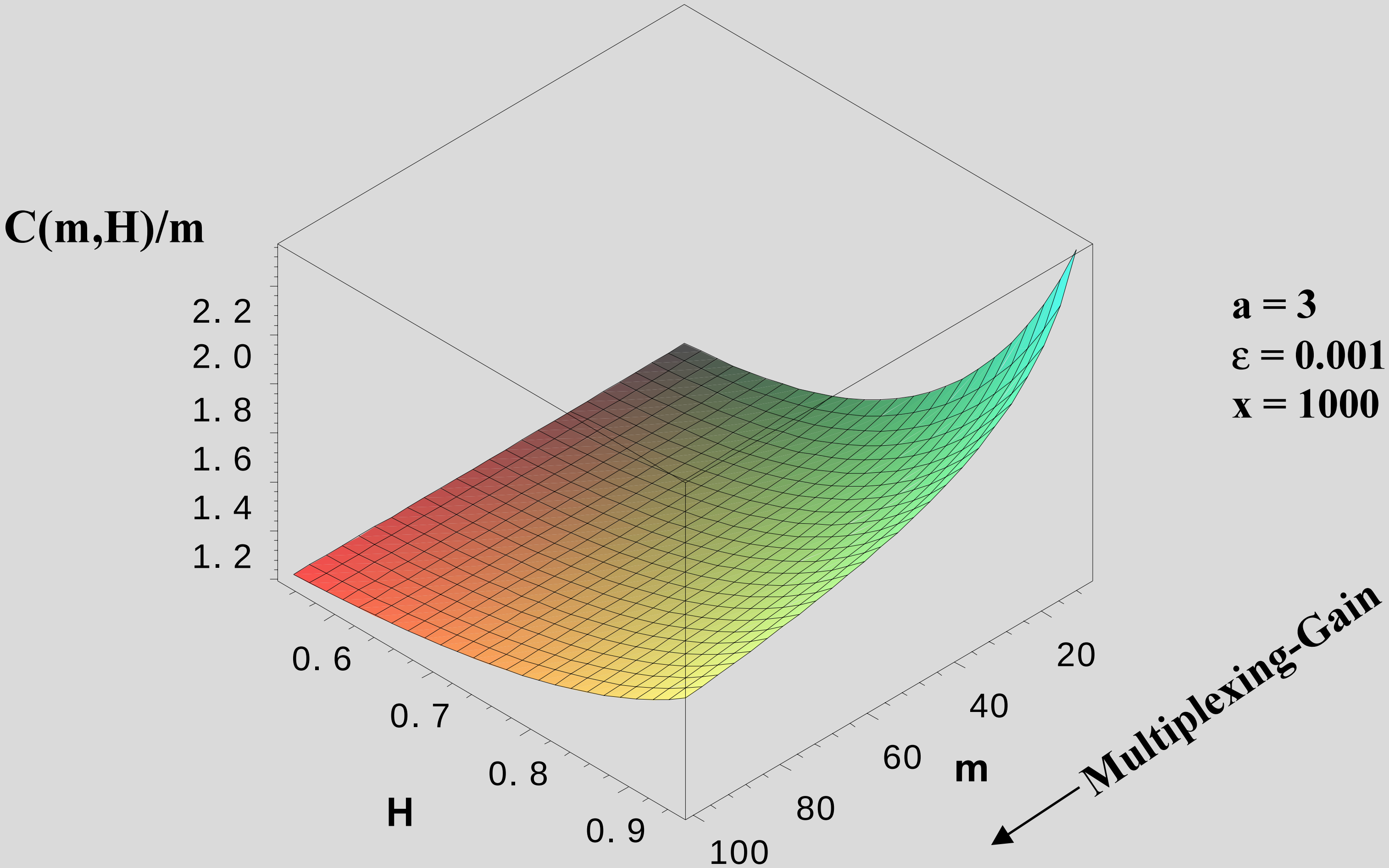
x: buffer size

ε : buffer overflow probability

Dimensioning for high aggregated (mixed) Traffic
FGN Model: Packet and Flow Level Parameter Mapping



Dimensioning for high aggregated (mixed) Traffic Capacity vs. mean Bitrate and Hurst Parameter



5. IP Network Dimensioning

IP Network Dimensioning
Core Network Dim. with Mean/Effective Bitrate Model*

*) Assumption:
given routing scheme,
given topology

1. determine flow paths (for each o/d traffic relation) according to the given routing scheme
   ↓
2. determine aggregate traffic on each network link (e.g. sum of mean bitrates of IP flows)
   ↓
3. individual dimensioning of each link (with single-link dimensioning formula)

remark:
max. end-to-end delay is guaranteed by max. hop count

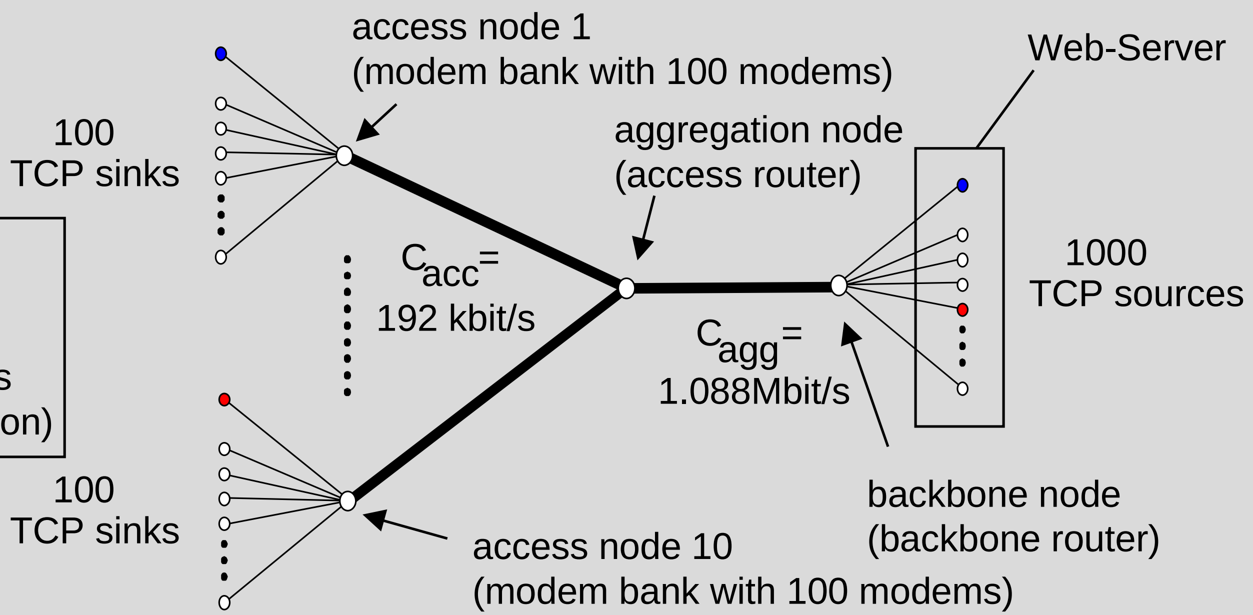
IP Network Dimensioning
Access Network Dimensioning with M/G/R-PS Model*

*) for elastic traffic

- The whole access network is regarded as a single processor sharing system
- The model is based on a single link model described by a M/G/R-PS queue
- Each link is dimensioned to have the same delay factor

Example:

C_{modem} = 64 kbit/s
file size: 12KByte
file arrival rate: 0,009788 1/s
(per active modem connection)



6. Summary

Summary
IP Link Dimensioning - Open Issues

- Improve M/G/R-PS model to take into account different r_{peak} values, different RTT (no fair sharing!) and influence of the TCP start and congestion avoidance behaviour.
- Investigate application field of FGN (Norros) model: under which conditions is it suitable for high aggregated (mixed elastic/stream) traffic?
- Which dimensioning formula works well in the low aggregated mixed elastic/stream traffic scenario?
- Find dimensioning formulas for scenarios where priorization and/or bandwidth reservation is applied (i.e. scenarios with service discrimination).