Dimensioning of IP Networks - A still incomplete Framework

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1. Introduction
Introduction
Basic IP Traffic Classification

Voice                  Video                  WWW                  FTP
  |                        |                        |                     |            ...
  Traffic Class 1        Traffic Class 2    Traffic Class 3    ...
  Stream Traffic QoS 1   Stream Traffic QoS 2 Elastic Traffic QoS 1 Elastic Traffic QoS 2

Services/Applications
Traffic Classes
IP Traffic Types (w/w.o. QoS guarantee)
IP Traffic/QoS Parameter

- peak bitrate
- mean bitrate
- packet loss prob.
- end-to-end delay
- end-to-end blocking prob. (if adm. control)
- mean docu size
- min. docu transfer rate
  (= min. throughput)
- max. docu transfer time
  for docu of size x

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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

Service (QoS) Discrimination

- yes
- no

Mechanism

- prioritization
- bandwidth allocation
- prioritization+ bw. allocation

yes
- min. bw. for stream traffic
- ?
- mixed sc. (Queija?)

no
- dedic. bw. for stream and elastic traffic
- ?
- segregated scenario

Traffic Type

- elastic only
- stream only
- elastic / stream mix

elastic only
- M/G/R-PS (Lindberger) (low aggr.)
- 3-state model (Hartleb)
- FGN (Norros) (high aggr.)

stream only
- eff. bitrate (Lindberger) + multiservice blocking formula

elastic / stream mix
- integrated scenario:
  - (Queija?)
  - worst-case on-off model? (Hartleb)
2. Dimensioning for Stream Traffic
resource capacity for stream traffic

Packet-Level

- effective bitrate formula
- packet loss probability
  - e.g. Lindbergers formula
- peak bitrate, mean bitrate

Stream (Flow)-Level

- effective bitrates $r_s$
- model of shared resource
- offered traffic
  - e.g. multirate loss formula
- required call blocking probabilities $B_s$
- resulting call blocking probabilities $B_s$

resulting call blocking probabilities $B_s$
Link Dimensioning for Stream Traffic
Example: Lindbergers Effective Bitrate Formula

\[ r(C) = \begin{cases} 
\gamma \text{MBR} & \text{if } 0 \leq C \leq n^* \\
\gamma \text{MBR} \left( 1 + 3\eta^2 \frac{PBR - \text{MBR}}{C^2} \right) & \text{if } n^* \leq C \leq n^{**} \\
\gamma \text{MBR} \left( 1 + 3\eta \frac{PBR - \text{MBR}}{C} \right) & \text{if } C \geq n^{**} 
\end{cases} \]

with:
\[ \gamma = 1 + \eta / 100 \]
\[ \eta = -2 \log P_{\text{loss}} \]
\[ n^* = \begin{cases} 
\eta \sqrt{3\text{MBR} \cdot PBR} & \text{if } PBR \geq 3\text{MBR} \\
3\eta \text{MBR} & \text{else} 
\end{cases} \]
\[ n^{**} = \begin{cases} 
\eta PBR & \text{if } PBR \geq 3\text{MBR} \\
\eta^* & \text{else} 
\end{cases} \]

\(PBR\) = peak bitrate
\(\text{MBR}\) = 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

Traffic Class 1: PBR = 1, MBR = 1
Traffic Class 2: PBR = 3, MBR = 3
Traffic Class 3: PBR = 10, MBR = 10
Traffic Class 4: PBR = 5, MBR = 1
Traffic Class 5: PBR = 10, MBR = 1.5
3. Dimensioning for low aggregated Elastic Traffic
Dimensioning for low aggregated Elastic Traffic Activity Model for Elastic Traffic

Session Level
Application level
Connection level (TCP)
File level
Burst and Packet level

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# Dimensioning for low aggregated Elastic Traffic

## Elastic Traffic Characteristics (Example: Web-Traffic)

Measurements in educational and corporate environment, Spain 1997/98  

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

![Graph showing Pareto distribution vs. negative exponential distribution](image)

M/G/R-PS Model

Pareto distribution vs. neg. exponential distribution
Dimensioning for low aggregated Elastic Traffic
M/G/R-PS Model

modems
(= max. # of connections)

file arrival rate per
modem connection: \( \lambda_i \)

bandwidth of modem connection: \( r_{peak} \)

modem pool (PoP)

access link (bandwidth C)

\( \lambda = \sum \lambda_i \)

PS-System

files/documents

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

Required Input:

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

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
Expected sojourn time (or transfer time)

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

where:

\[ R = \frac{C}{r_{\text{peak}}} \quad \text{(\# of servers)} \]

\[ \rho = \frac{\lambda \cdot x_{\text{mean}}}{C} \quad \text{(link utilization)} \]

\[ E_2 = \text{Erlang’s second formula (Erlang C formula)} \]

"delay factor"
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:

$$D = \frac{r_{peak}}{\left(1 + \frac{E_2(R, R\rho)}{R(1 - \rho)}\right)} = \frac{r_{peak}}{f_R}$$
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Link Dimensioning with M/G/R-PS-Model
Possible Solutions for different Access Peak Rates $r_{peak}$

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

2) $\lambda_1$ with $r_{peak1} \rightarrow C_1$
$\lambda_2$ with $r_{peak2} \rightarrow C_2$
\[ C = C_1 + C_2 \]

3) $(\lambda_1 + \lambda_2)$ with $r_{peak1} \rightarrow C_1$
$(\lambda_1 + \lambda_2)$ with $r_{peak2} \rightarrow C_2$
\[ C = \max(C_1, C_2) \]

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

\[ r_{\text{peak}} = 64 \text{ kbit/s} \]
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

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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: $a_i = \frac{var_i}{m_i}$
- 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 (\( H = \max(H_i) \))

\( x \): buffer size

\( \varepsilon \): buffer overflow probability
Dimensioning for high aggregated (mixed) Traffic

FGN Model: Packet and Flow Level Parameter Mapping

**Packet-Level**

- Packet level traffic descriptors for aggregated traffic: \( m, a, H \)
- Packet level QoS descriptors for aggregated traffic: \( \mathcal{E} \) (delay, delay-variation)

**Flow-Level**

- Buffer size \( x \)
- Effective bitrate of aggregated traffic

Norros' Formula

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

C(m,H)/m

\[ C(m,H)/m = \frac{a^3}{\varepsilon(x-1)} \]

a = 3
ε = 0.001
x = 1000

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

*) Assumption:
given routing scheme, given topology

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

- 100 TCP sinks
- $C_{\text{modem}} = 64 \text{kbit/s}$
- file size: 12KByte
- file arrival rate: 0.009788 1/s (per active modem connection)
- $C_{\text{acc}} = 192 \text{kbit/s}$
- $C_{\text{agg}} = 1.088 \text{Mbit/s}$

100 TCP sinks
- access node 1 (modem bank with 100 modems)
- aggregation node (access router)
- backbone node (backbone router)
- 1000 TCP sources
- Web-Server

*) for elastic traffic
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).