HY537: Έλεγχος Πόρων και Επίδοση σε Ευρυζωνικά Δίκτυα

Βασίλειος Σύρης

Τμήμα Επιστήμης Υπολογιστών
Πανεπιστήμιο Κρήτης
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Network constraints
Effective bandwidths

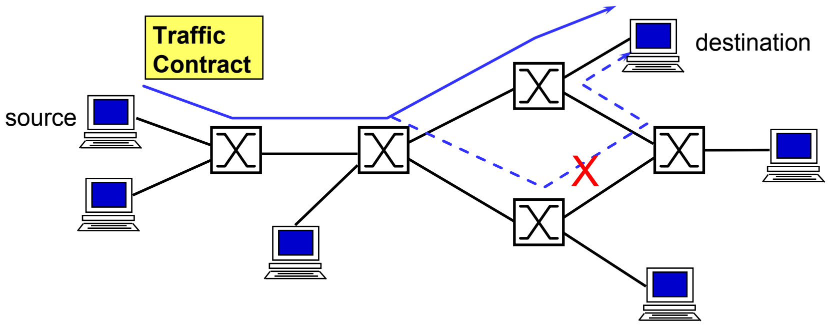
Network control for various service types

- **ATM and IP supports statistical multiplexing**
- **Network control different for guaranteed and elastic services**
- **Guaranteed services**
  - User-network contract
  - Call Admission Control - CAC
  - Open loop control
- **Elastic services (ABR):**
  - no CAC, except for MCR (Minimum Cell Rate)
  - Closed loop control

Time scales of network control

Traffic & Congestion Control Functions	Response time
Selective cell discard, frame discard, priority control and scheduling, Usage Parameter Control (UPC), traffic shaping	Cell time
Feedback controls	Round-trip propogation time
Routing, Call Admission Control (CAC)	Connection interarrival time
Network management control	order of minutes
Pricing	months, years

Routing and CAC

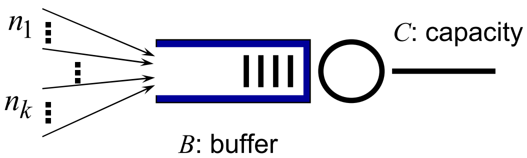


- **Routing**: find path from source to destination that fulfils user requirements (bandwidth, QoS)
- **Call Admission Control** (CAC): performed at every switch, determines whether there are enough resources to accept a call

Network constraints & effective bandwidths - 5

Call Admission Control (CAC)

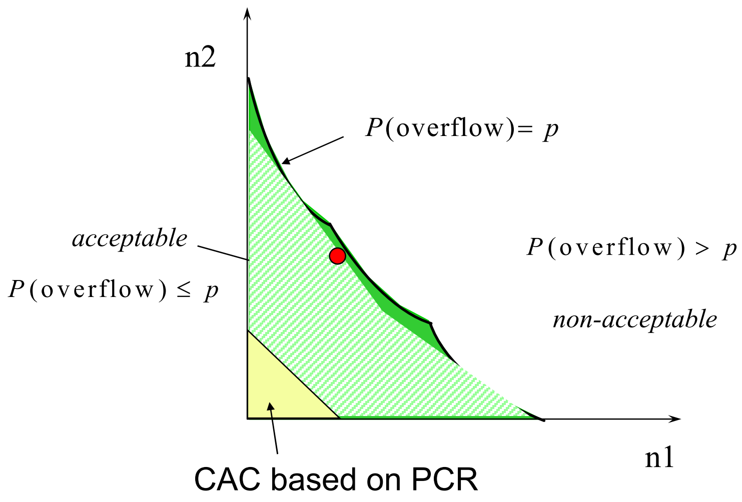
- k traffic classes (actual or contract types)
- class i contributes n_i sources



- QoS constraint (contract obligation): CLP ≤ p (e.g. p=10^{-8})
- What $(n_1,\ldots,n_k)$ do not violate QoS constraints ?
- Approaches to CAC:
  - Non-dynamic: based only on traffic contract parameters
  - Dynamic: includes on-line measurements and contract parameters

Network constraints & effective bandwidths - 6

Acceptance region



Simplifying the problem of CAC

Use *Effective Bandwidths:*

acceptance condition: $n_1 \cdot \alpha_1 + \ldots + n_k \cdot \alpha_k \leq C^*$

➔ *Can we define* $\alpha_1, \ldots \alpha_k, C^*$ *such that*

- α_i depends on **source traffic statistics**, *as well as* **traffic mix, capacity, buffer, QoS**
- C^* depends on **traffic mix, capacity, buffer, and QoS**
- Calculation of α_i can be done off-line
- The **true** acceptance region is well approximated

➔ **YES !**

Statistical multiplexing gain

Important consideration:

- Statistical multiplexing gain: increased utilization when allowing some loss rather than zero loss

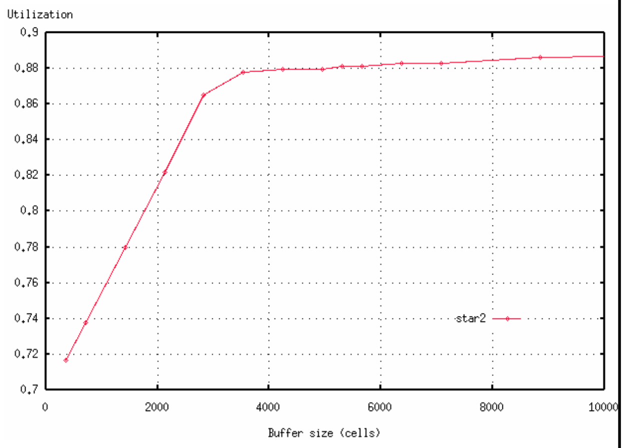
$$SMG = \frac{N_{\text{stat.}}}{N_{\text{det.}}}$$

- Why: 99.999% is much cheaper than 100%
- Enabled by burstiness of traffic sources and large capacity of transmission links

Network constraints & effective bandwidths - 9

Statistical multiplexing gain (cont.)

- Example of statistical multiplexing gain

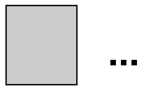


C=155 Mbps, CLP ≤ 10^{-7}, *Star Wars* traffic
mean=0.26 Mbps, peak=3.46 Mbps

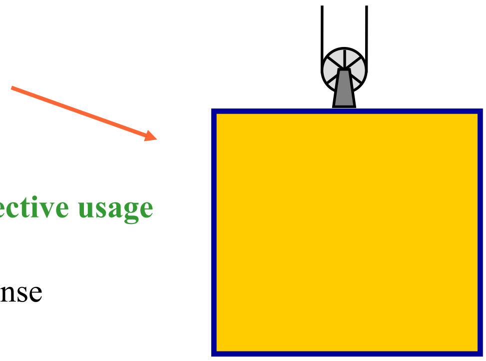
- Peak rate allocation achieves utilization 7.5% !

Network constraints & effective bandwidths - 10

Loading an elevator with boxes

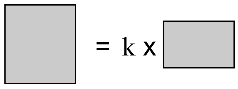


w_i , v_i



W_{max}, V_{max}

- What is the **relative effective usage** of a box ?
- Equivalently, in what sense



= k x   or $\alpha_1 = k \times \alpha_2$

w_1 , v_1 w_2 , v_2

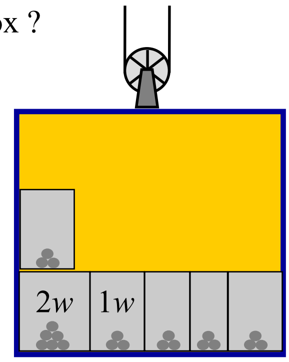
Key notion: <u>substitution</u>

Loading an elevator (cont.)

- What is the relative effective usage of a box ?
  - Depends on which constraint is active: *max. weight* or *max. volume*
  - Determined by operating point
- If *max. weight* is active, then effective usage equals box's *weight*

$$\sum_i w_i = W_{max}$$

$$\sum_i v_i < V_{max}$$



W_{max}, V_{max}

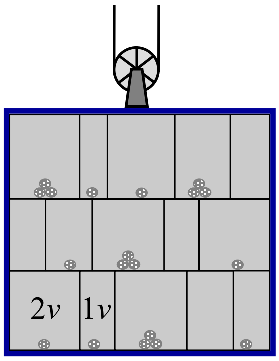
- **Effective bandwidth = weight**

Loading an elevator (cont.)

- If *max. volume* is active, then effective usage equals box's *volume*

$$\sum_i v_i = V_{\max}$$

$$\sum_i w_i < W_{\max}$$



$W_{\max}, V_{\max}$

- **Effective bandwidth = volume**

Loading an elevator (cont.)

- What is the relative effective usage of a box ?
  - Depends on which constraint is active: *max. weight* or *max. volume*
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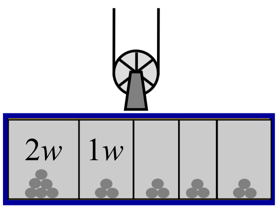
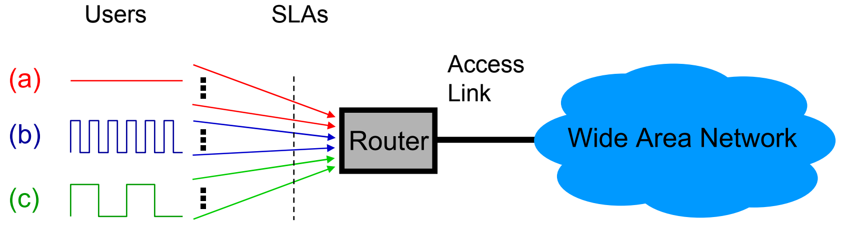


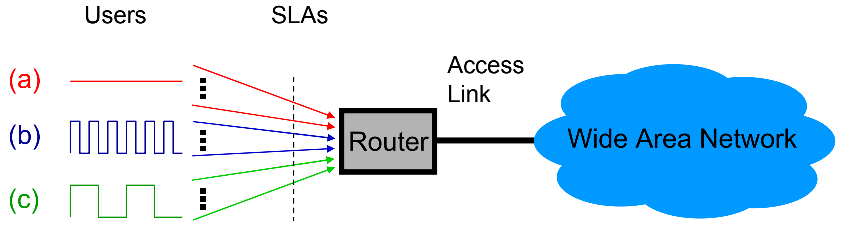
- **Effective bandwidth = ~~weight~~** = volume

Example: resource usage



- All user connections have the same duration and volume
- Some QoS is supported at the access link
- → What is the resource usage of each user?

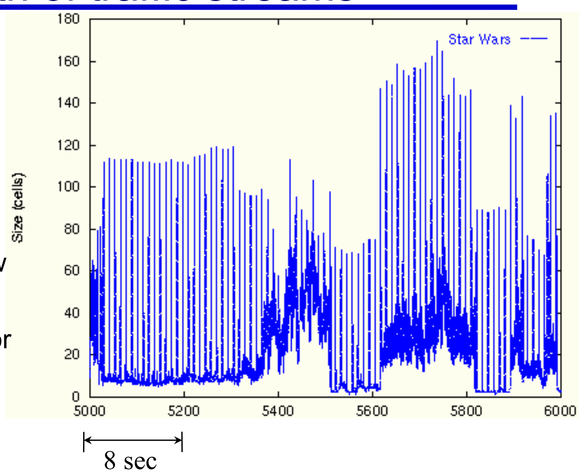
Example: resource usage (cont.)



- All user connections have the same duration and volume
- Some QoS is supported at the access link
- What is the resource usage of each user?
- → Answer: ***depends !***
  - "small" capacity: a < b,c
  - "medium" capacity: a=b < c
  - "large" capacity: a=b=c

Effective bandwidth of traffic streams

- Broadband traffic has burstiness in different time scales
- Effective bandwidth (resource usage) depends on time scales which are important for buffer overflow
- → How can we identify which time scales are important for overflow?
- Dependence on context



***Star Wars* MPEG-1 trace**

An effective bandwidth formula

- Effective bandwidth of a source of type *j*

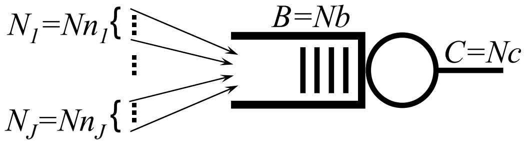
$$\alpha_j(s,t) = \frac{1}{st} \log E\left[e^{sX_j[0,t]}\right]$$

$X_j[0,t]$: load produced by source of type *j* in window *t*

- (s,t) = **operating point of the link**
  - depends on the link param. (C,B), traffic mix, and CLP (= $e^{-\gamma}$)
  - *t*: *time* parameter, related to time for buffer overflow
  - *s*: *space* parameter, depends on link's multiplexing capability, exponential tilt parameter of distributions

$$s = \frac{\partial \gamma}{\partial B}, \quad st = \frac{\partial \gamma}{\partial C} \qquad \text{where} \quad \gamma = -\log \text{CLP}$$

Mathematical justification



- *Many sources asymptotic* $P(\text{overflow}) = e^{-NI+o(N)}$

$$\lim_{N\to\infty} \frac{1}{N} \log P(\text{overflow}) = \sup_t \inf_s \left[\sum_{j=1}^{J} n_j \log E e^{sX[0,t]} - s(b+ct) \right] = -I$$

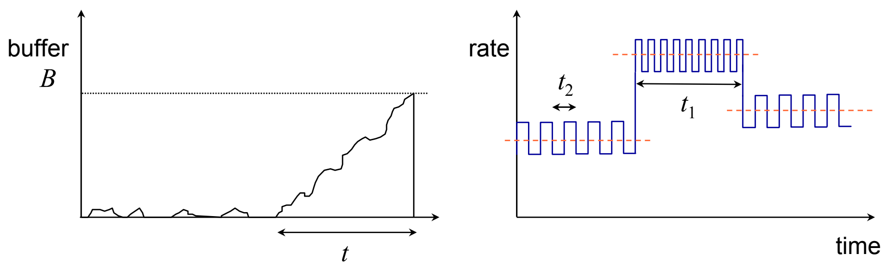
- If P(overflow) = $e^{-\gamma}$ then we must have

$$\sum_{j=1}^{J} N_j \alpha_j(s,t) \le C + \frac{1}{t}\left(B - \frac{\gamma}{s}\right) \quad \text{where} \quad \alpha_j(s,t) = \frac{1}{st} \log E\left[e^{sX_j[0,t]}\right]$$

$$= C_{eff}$$

Network constraints & effective bandwidths - 19

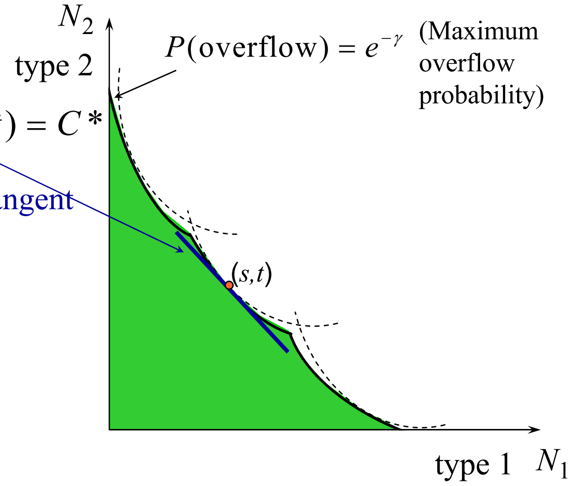
Operating point parameters *s,t*



- During the overflow, the inputs have a different distribution with higher means: exponentially tilted distribution with parameter *s* (= distribution of most probable behaviour)
- Overflow period has duration *t* => we care for contribution of input sources in window *t*
  - time scale of relevant burstiness = t_1, not t_2

Network constraints & effective bandwidths - 20

Acceptance region for two source types



$$N_1\alpha_1(s,t) + N_2\alpha_2(s,t) = C^*$$

effective capacity:

$$C^* = C + \frac{1}{t}\left(B - \frac{\gamma}{s}\right)$$

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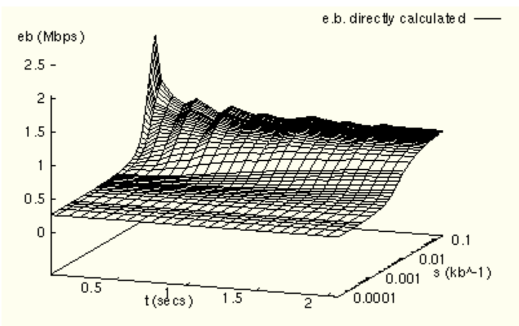
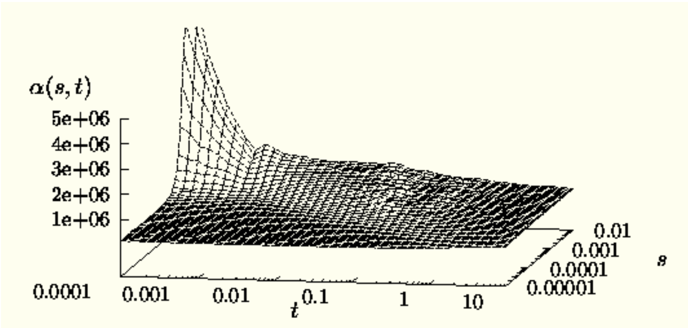
Effective bandwidth for MPEG-1 traffic



- *Star Wars* MPEG-1 trace

Network constraints & effective bandwidths - 22

Effective bandwidth for Ethernet traffic

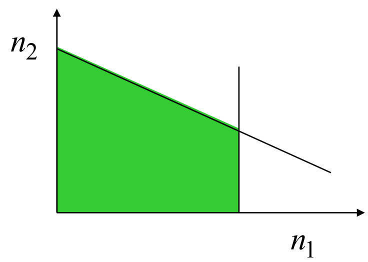


- Bellcore Ethernet trace

Multiple QoS constraints

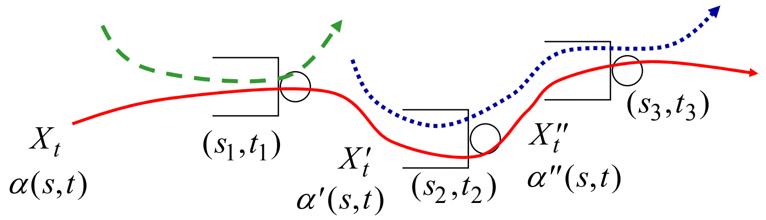
- Acceptance region described by multiple constraints
- Example: Priority queuing
  - two classes: $J_1 > J_2$
  - for J_1: $P(delay > B_1 / C) \le e^{-\gamma_1}$
  - for $J_1 \cup J_2$: $P(buffer\ overflow) \le e^{-\gamma_2}$
- Two constraints:

$$n_1 \alpha_1(s_1, t_1) \le K_1$$
$$n_1 \alpha_1(s_2, t_2) + n_2 \alpha_2(s_2, t_2) \le K_2$$



Decoupling bandwidths

Is the effective bandwidth of a stream constant in a network?



- Effective bandwidth of a traffic stream defined for single link
- In general $\alpha(s,t) \neq \alpha'(s,t)$
- Under realistic multiplexing conditions (conditions for "decoupling") $\alpha(s,t) = \alpha'(s,t)$
- Economic arguments suggest that (*s*,*t*) does not vary much

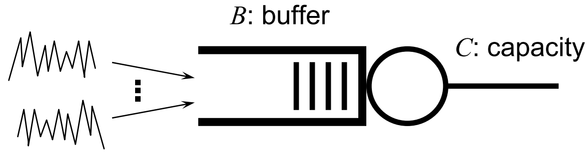
$$s = \frac{\partial \gamma}{\partial B}, \quad st = \frac{\partial \gamma}{\partial C} \qquad t = \frac{MC \text{ per unit } c}{MC \text{ per unit } b}$$

The msa and lb tools

- The tools work on files with measurements of load in consecutive fixed length intervals
- The input has the following format:

```
# epoch_in_msecs = 40
# bits_per_info_unit = 424
65
4
5
8
...
```

Traffic analysis tools



INPUT
- Buffer, Capacity
- traffic mix (percentage of each traffic type)
- traffic traces

OUTPUT
- *P*(overflow)
- *s*,*t* parameters
- effective bandwidth

Traffic trace:
e.g., 1 epoch=10 msec

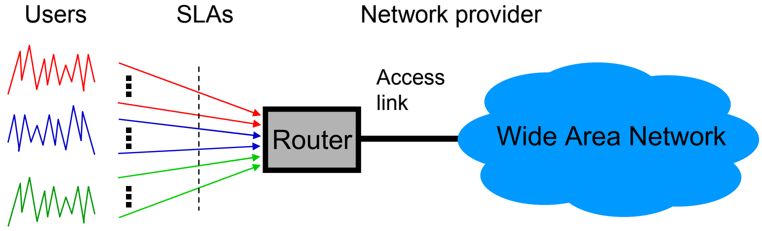
Epoch	Cell or packet count
0	111
1	24
2	20
…	…

The msa tool

Functions:
- Trace file, link operating point => resource usage
- Link resources (capacity, buffer), traffic mix, load => QoS
- Link resources (capacity, buffer), traffic mix, QoS => load
- Capacity (buffer), traffic mix, load, QoS => buffer (capacity)

With the use of scripts:
- QoS as a function of buffer size
- Load as a function of buffer size
- Acceptance region for two traffic types

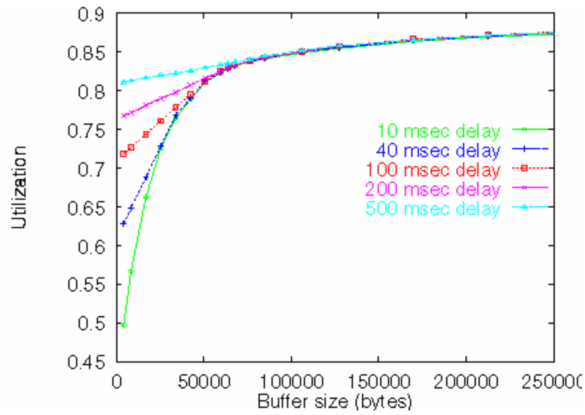
Some management questions



- What combinations of user types can the provider accept?
- What is the effect of increasing the link resources or of traffic shaping on the multiplexing capability of the link?
- What traffic parameters should a user choose?

Resource dimensioning and traffic shaping

Internet WAN
p=2.3 Mbps, *m*=6.4 Kbps
C=34 Mbps
P(overflow)=10^{-6}

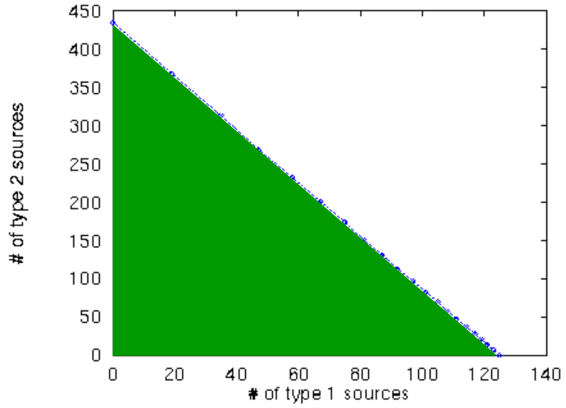


➔ Effects of traffic shaping depend on buffer size

Acceptance region

C=155 Mbps, *B*=750 Kbytes
P(overflow)=10^{-6}

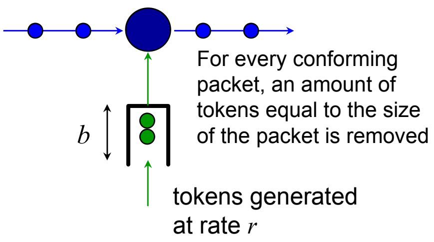
Internet WAN traffic:
Type 1: *m*=1 Mbps, *p*=10.2 Mbps
Type 2: *m*=0.3 Mbps, *p*=8.9 Mbps



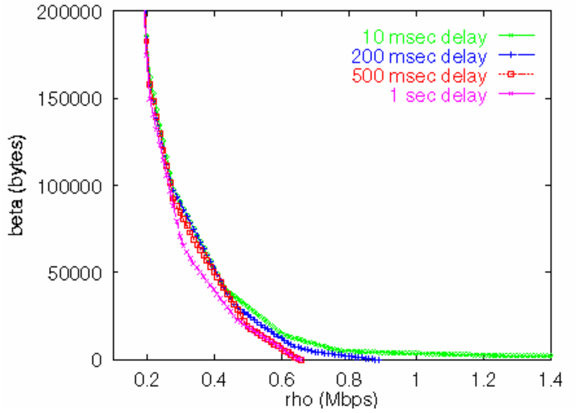
Acceptance region

Token bucket parameter selection

- Token (or leaky) bucket is a widely used traffic descriptor:
  - ATM (GCRA)
  - Internet (Integrated & Differentiated Services, MPLS)
  - Policy-based management
- Token or leaky bucket (r,b): r is token rate, b is bucket size

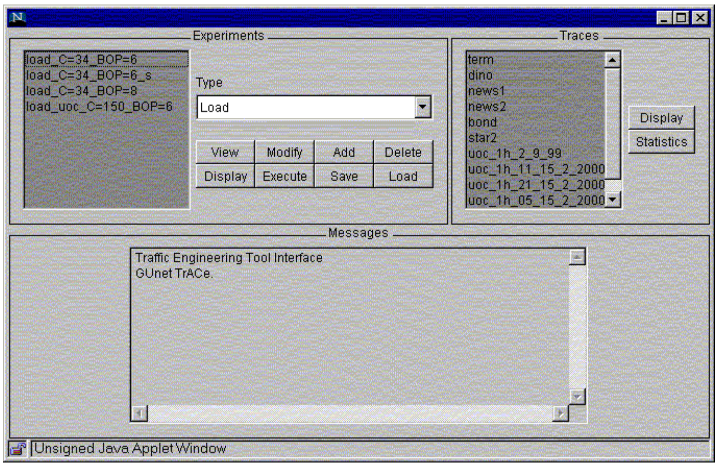


Indifference curve



➔ Traffic shaping affects the lower right portion of the indifference curve

Web-based interface for traffic engineering tools



- Interface: http://trace.ucnet.uoc.gr/interface/src/index.html
- Tools & manuals: http://www.ics.forth.gr/netgroup/msa/

Conclusions

- Acceptance region defines the “**technology set**” of a network for guaranteed services
- Effective bandwidths provide a mathematically rigorous approximation of the acceptance region
  - can be approximated by a set of **linear constraints**
- The effective bandwidth of a stream is a function of the **operating point** of the link
  - defined by network resources and consistency of traffic mix
- The effective bandwidth is a **good “proxy”** for the relative resource usage among traffic streams

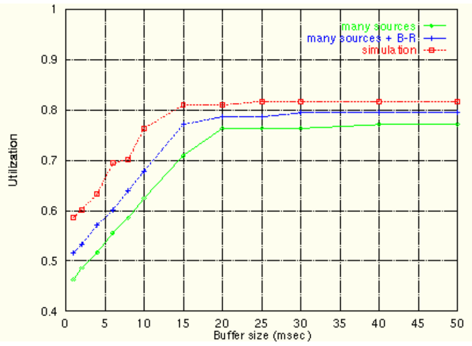
Network constraints & effective bandwidths - 35

Experimental results

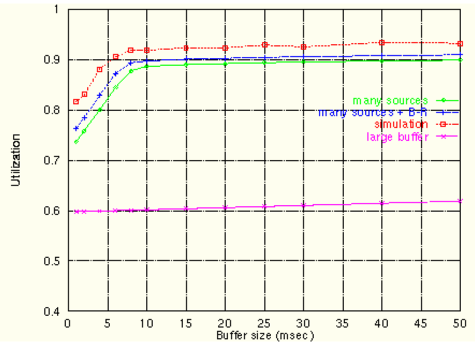
- Effective bandwidth for real traffic
- CLP estimation: theory vs. simulation
- Achievable utilization: theory vs. simulation
- Parameters *s,t*: theory vs. simulation
- Parameter *s,t* for real traffic
- Parameters *s,t* for different traffic mix

Network constraints & effective bandwidths - 36

Achievable utilization



C=34 Mbps

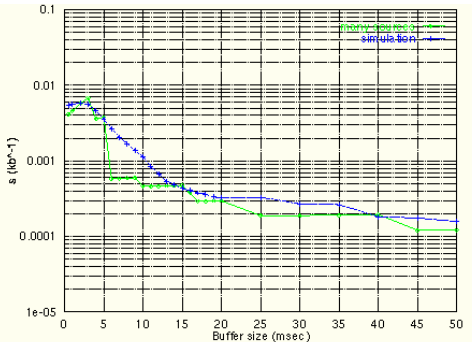


C=155 Mbps

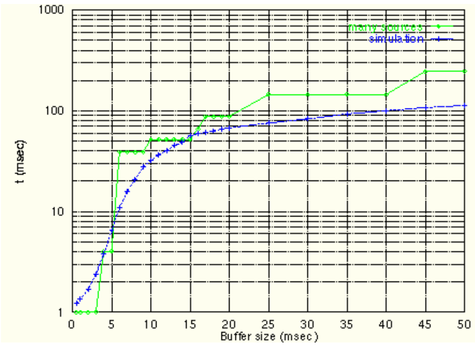
- *P*(overflow)=10^{-7}
- *Star Wars* traffic

Network constraints & effective bandwidths - 37

Parameters *s*,*t*: theory vs. simulation



Parameter *s*

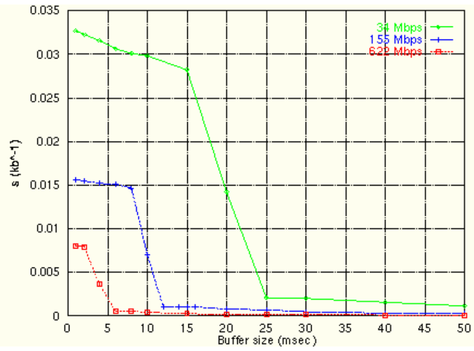


Parameter *t*

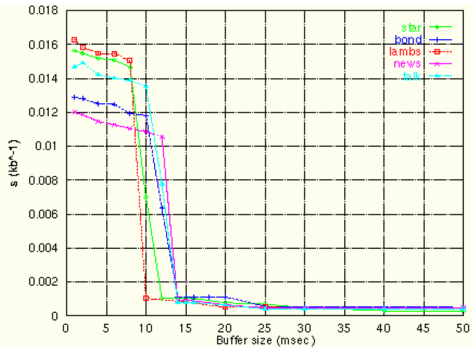
- *C*=155 Mbps, Util.=0.93
- *Star Wars* traffic

Network constraints & effective bandwidths - 38

Parameter *s* for MPEG-1 traffic



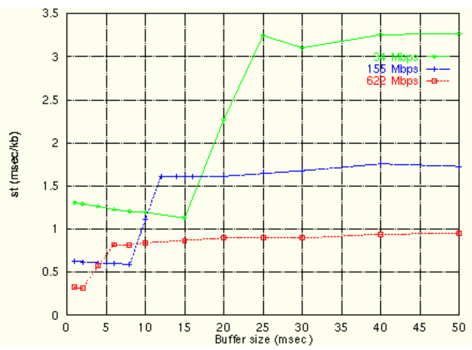
Star Wars



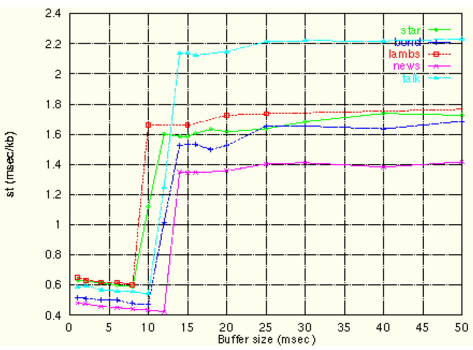
Various contents, C=155 Mbps

- P(overflow)=10^{-7}

Parameter *st* for MPEG-1 traffic



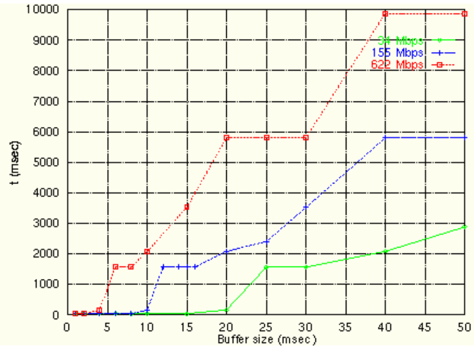
Star Wars

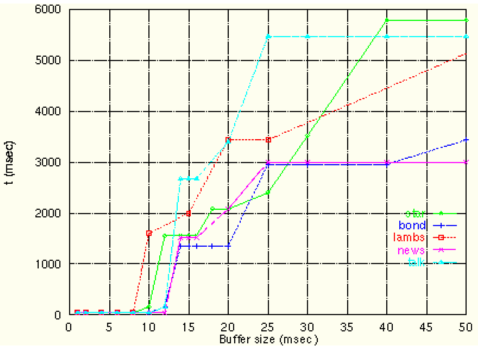


Various content, C=155 Mbps

- P(overflow)=10^{-7}

Parameter *t* for MPEG-1 traffic





Star Wars

Various content, C=155 Mbps

- P(overflow)=10^{-7}

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