BLOCKING EVALUATION OF EE-OBS NETWORKS UNDER HETEROGENEOUS ON-OFF TRAFFIC

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Dynamic vs. static WDM optical networks (in terms of wavelength requirements \(^{(1,2)}\))

Simulation, a very **time-consuming** mechanism!

A **fast method** for **accurate** blocking evaluation of EE-OBS networks

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(2) A. Beghelli, A. Leiva, R. Vallejos, M. Aravena, **Static vs. Dynamic WDM Optical Networks under single-cable failure conditions**, ONDM 2009, Poster Session
Network Model
(any end-to-end dynamic network, e.g. EE-OBS)
Traffic Model

Data from 0 to 1

ON  ON  ON

Data from 0 to 2

ON  ON  ON

...  ...

Data from 0 to 10

ON  ON  ON

- Traffic demand between each node pair is assumed to be governed by an ON-OFF process
- Mean ON/OFF period of connection $c$ ($t_{ON}^c/t_{OFF}^c$)
- Traffic load of connection $c$

$$\rho_c = \frac{t_{ON}^c}{t_{ON}^c + t_{OFF}^c}$$

Heterogeneous traffic matrix

$$\begin{bmatrix}
0 & 1 & \cdots & N \\
0 & \rho_1 & \cdots & \rho_{N-1} \\
\rho_N & 0 & \cdots & \rho_{2(N-1)} \\
\vdots & \vdots & \ddots & \vdots \\
\rho_x & \rho_y & \cdots & 0
\end{bmatrix}$$
Proposed method

\[ B_{\text{net}} = \frac{\text{blocked}}{\text{total}} = \frac{\sum_{\forall c \in C} \lambda_c B_c}{\lambda} \]
Mean arrival rate of bursts of connection $c$

$$\lambda_c = \frac{1}{t_{ON}^c + t_{OFF}^c}$$

Proposed method

$$B_{net} = \frac{\text{blocked}}{\text{total}} = \frac{\sum \lambda_c B_c}{\lambda}$$
**Proposed method**

Mean arrival rate of bursts of connection $c$

$$\lambda_c = \frac{1}{t_{ON}^c + t_{OFF}^c}$$

Network total burst arrival rate

$$\lambda = \sum_{\forall c \in C} \lambda_c$$

Network total blocked burst arrival rate

$$B_{net} = \frac{\text{blocked}}{\text{total}} = \frac{\sum \lambda_c B_c}{\lambda}$$
**Proposed method**

Mean arrival rate of bursts of connection $c$

$$\lambda_c = \frac{1}{t_c^{ON} + t_c^{OFF}}$$

Network total burst arrival rate

$$\lambda = \sum_{\forall c \in C} \lambda_c$$

Blocking probability of connection $c$

$$B_c = 1 - \prod_{\forall l \in r_c} (1 - B_l)$$

Network total blocked

$$B_{net} = \frac{\text{blocked}}{\text{total}} = \frac{\sum_{\forall c \in C} \lambda_c B_c}{\lambda}$$
Proposed method

Mean arrival rate of bursts of connection $c$

$$\lambda_c = \frac{1}{t_{ON}^c + t_{OFF}^c}$$

Network total burst arrival rate

$$\lambda = \sum_{\forall c \in C} \lambda_c$$

$O(T_l \cdot 2^{T_l})$

Blocking probability of connection $c$

$$B_c = 1 - \prod_{\forall l \in r_c} (1 - B_l)$$

Network total blocked rate

$$B_{net} = \frac{\text{blocked}}{\text{total}} = \frac{\sum \lambda_c B_c}{\lambda}$$

For ARPANet, it took 4 hours to evaluate $B_l$ for all links!

$s_k$: $i$-th component is state of connection $i$ in link $l$; (ON=1; OFF=0)
**Improved method**

\[
B_l = \frac{\text{blocked}}{\text{total}} = \frac{\sum \lambda(\vec{s}_k) P(\vec{s}_k)}{\sum_{\|\vec{s}_k\| \leq W_l} \lambda(\vec{s}_k) P(\vec{s}_k)}
\]

\(\vec{s}_k\): \(i\)-th component is state of connection \(i\) in link \(l\); \((\text{ON}=1; \text{OFF}=0)\)

Set of recurrence relations

\[
B_l = \frac{\text{blocked}}{\text{total}} = \frac{\beta(T_l, W_l)}{\sum_{j=1}^{W_l} \beta(T_l, j)}
\]

\[
\beta(u, j) = \begin{cases} 
0, & u \leq j = 0 \\
(1 - \rho_u)[\beta(u-1, j) + \alpha(u-1, j) \cdot \lambda_u], & u > j = 0 \\
(1 - \rho_u)[\beta(u-1, j) + \alpha(u-1, j) \lambda_u] + \beta(u-1, j-1) \cdot \rho_u, & u \geq j > 0 
\end{cases}
\]

\(O(T_l \cdot 2^{T_l})\)

4 hours in ARPANet

\(O(T_l^2)\)

< 1 sec!
Numerical Results

- **Eurocore**
  - 11 nodes
  - 25 bi-directional links

- **NSFNet**
  - 14 nodes
  - 21 bi-directional links

- **EON**
  - 20 nodes
  - 39 bi-directional links

- **UKNet**
  - 21 nodes
  - 39 bi-directional links

- **ARPANet**
  - 20 nodes
  - 31 bi-directional links

- **Eurolarge**
  - 43 nodes
  - 178 bi-directional links
Numerical Results

• Event-driven simulator, developed in C++

• $10^6$ bursts

• Exponential and Pareto ($\alpha=1.5$) distributions for ON/OFF periods

• Mean ON period: 5 ms, 10ms and 25 ms for UKNet, European and US networks

• Heterogeneous traffic matrix: $\rho_c \sim U[\rho-0.2; \rho+0.2]$

• Shortest path balanced routing
Numerical Results

(Exponential)
**Numerical Results**

(Pareto)

- **Eurocore**
  - Mathematical $W=15$
  - Simulation $W=15$
  - Mathematical $W=13$
  - Simulation $W=13$
  - Mathematical $W=8$
  - Simulation $W=8$

- **NSFNet**
  - Mathematical $W=20$
  - Simulation $W=20$
  - Mathematical $W=18$
  - Simulation $W=18$
  - Mathematical $W=16$
  - Simulation $W=16$

- **EON**
  - Mathematical $W=37$
  - Simulation $W=37$
  - Mathematical $W=40$

- **UKNet**
  - Mathematical $W=12$
  - Simulation $W=12$
  - Mathematical $W=14$
  - Simulation $W=14$
  - Mathematical $W=16$
  - Simulation $W=16$

- **ARPANet**
  - Mathematical $W=3$
  - Simulation $W=3$
  - Mathematical $W=2$
  - Simulation $W=2$
  - Mathematical $W=1$
  - Simulation $W=1$

- **Eurolarge**
  - Mathematical $W=12$
  - Simulation $W=12$
  - Mathematical $W=14$
  - Simulation $W=14$
  - Mathematical $W=16$
  - Simulation $W=16$
Conclusions

• A fast and accurate method for blocking evaluation of end-to-end dynamic networks (e.g. EE-OBS)

• Low computational complexity obtained by using recurrence relations

• Next step: extending the method for alternated routing
Previous Work

- Simulation
- Poisson traffic
- Single link/node
- Homogeneous traffic

 Mathematical method\(^{(1)}\)
- ON-OFF traffic\(^{(1)}\)
- Network-wide\(^{(1)}\)
- Heterogeneous traffic

\(1\) R. Vallejos, A. Zapata-Beghelli, M. Aravena, Fast Blocking Evaluation of EE-OBS Networks, Photonic Network Communications, April 2007