Assessment of Blocking Performance in Wavelength Division Multiplexed Ring Networks with Bidirectional Links

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Quality of Service

- Service Support
  - (Ability to provide a service and assist in its use)

- Service Operability
  - (Ability to easily use and successfully handle a service)

- Service Accessibility
  - (Ability of a service to be obtained when requested)

- Service Retainability
  - (Ability of a service to be provided for a requested duration)

- Service Integrity
  - (Ability to provide a service without excessive impairment)

- Traffic Performance
- Availability Performance
- Transmission Performance
The model has been presented in:


This model applies for circuit-switched optical networks;

It takes into account real time input traffic;

It incorporates the correlation between the wavelengths used on successive links of a multi-link path.
Model for Computing the Blocking Probability

Model Assumptions:

1) Call requests arrive at each node according to a Poisson process with rate $\lambda$; each call is equally likely to be destined to any of the remaining nodes.

2) Call holding time is exponentially distributed with mean $1/\mu$; the offered load per station is $\rho = \lambda/\mu$. 
3) The path used by a call is chosen according to a pre-specified criterion (e.g. random selection of a shortest path), and does not depend on the state of the links that make up a path; the call is blocked if the chosen path cannot accommodate it; alternate path routing is not allowed.

4) The number of wavelengths per link, $F$, is the same on all links; each node is capable of transmitting and receiving on any of the $F$ wavelengths; each call requires a full wavelength on each link it traverses.

5) Wavelengths are assigned to a session randomly from the set of free wavelengths on the associated path.
Model for Computing the Blocking Probability

- For a network with \( N \) nodes, the blocking probability is given by

\[
P_b(q) = \sum_{l=1}^{N-1} \sum_{y_f=0}^{F} P_{b}^{(l)}(q, y_f) p_l
\]

\[
P_{b}^{(1)}(q, y_f) = \begin{cases} 
Q(0), & \text{if } y_f = 0 \\
0, & \text{otherwise} 
\end{cases}
\]

\[
P_{b}^{(l)}(q, y_f) = T^{(l)}(0, y_f)(1 - q)^{(l-1)} + \sum_{i=1}^{l-1} Y^{(l)}(i, q, y_f) q(1 - q)^{(l-i-1)}, \quad \text{for } l \geq 2,
\]
Model for Computing the Blocking Probability

To evaluate the blocking probability $P_b^{(l)}(q, y_f)$, the following probabilities need to be evaluated:

- $Q(\omega_f) = \Pr\{ \omega_f \text{ wavelengths are free on a link} \}$.

- $S(y_f | x_{pf}) = \Pr\{ y_f \text{ wavelengths are free on a link of a path} \mid x_{pf} \text{ wavelengths are free on the previous link of the path} \}$.

- $U(z_c | y_f, x_{pf}) = \Pr\{ z_c \text{ calls (wavelengths) continue to the current link from the previous link of a path} \mid x_{pf} \text{ wavelengths are free on the previous link, and } y_f \text{ wavelengths are free on the current link} \}$.

- $R(n_f | x_{ff}, y_f, z_c) = \Pr\{ n_f \text{ wavelengths are free on a two-hop path} \mid x_{ff} \text{ wavelengths are free on the first hop of the path, } y_f \text{ wavelengths are free on the second hop, and } z_c \text{ calls (wavelengths) continue from the first to the second hop} \}$. 
Model for Computing the Blocking Probability

- \( T^{(l)}(n_f, y_f) = \Pr\{ n_f \text{ wavelengths are free on an } l\text{-hop path and } y_f \text{ wavelengths are free on hop } l \} \).

- \( p_l = \Pr\{ \text{an } l\text{-hop path is chosen for routing a session} \} \).

- \( V^{(l)}(n_f, y_f | \omega_f) = \Pr\{ n_f \text{ wavelengths are free on an } l\text{-hop path and } y_f \text{ wavelengths are free on hop } l \mid \omega_f \text{ wavelengths are free on the first hop of the path and without converters along the path} \} \).

- \( W^{(l)}(y_f | \omega_f) = \Pr\{ y_f \text{ wavelengths are free on hop } l \text{ of an } l\text{-hop path} \mid \omega_f \text{ wavelengths are free on the first hop of the path and without converters along the path} \} \).
For a unidirectional $N$-node ring, the probability that an $l$-hop path is used for routing a session is given by:

$$p_l = \frac{1}{N-1}, \text{ for } 1 \leq l \leq N - 1$$

For a bidirectional ring with $N$ nodes, $p_l$ is given by:

$$p_l = \begin{cases} 
\frac{2}{N-1}, & \text{for } N \text{ odd and } 1 \leq l \leq \frac{N-1}{2} \\
\frac{2}{N-1}, & \text{for } N \text{ even and } 1 \leq l < \frac{N}{2} \\
\frac{1}{N-1}, & \text{for } N \text{ even and } l = \frac{N}{2}
\end{cases}$$
WDM Ring Networks

- Ring topology is attractive because it allows the implementation of efficient self-healing protection schemes.
- The implementation of WDM ring networks is regarded as the first deployment phase of optical networking.
- Rings with bidirectional transmission over a single fibre allow a cost reduction.
- On the other hand, bidirectional transmission over a single fibre limits the network scalability due to accumulated ASE noise and crosstalk.
- Using suitable optical filtering, a WDM self-healing ring network can accommodate more than 40 nodes for a node spacing of about 40 km; but, for an increase of the node spacing to 80 km, the network can only accommodate about 14 nodes.
Assessment of Blocking Performance
WDM Ring Networks with
Unidirectional and Bidirectional Links

WDM ring network with 14 nodes, and with 4, 8, 12, or 16 wavelengths per fibre.
Assessment of Blocking Performance
WDM Ring Networks with Unidirectional and Bidirectional Links

WDM ring network with 40 nodes, and with 4, 8, 12, or 16 wavelengths per fibre.
Assessment of Blocking Performance
WDM Ring Networks with
Unidirectional and Bidirectional Links

Unidirectional WDM ring network with 10 nodes.

Bidirectional WDM ring network with 40 nodes.

These results suggest a four-fold capacity increase for the bidirectional ring with respect to the unidirectional ring.
Assessment of Blocking Performance
WDM Ring Networks with
Unidirectional and Bidirectional Links

Unidirectional WDM ring network with 14 nodes.

Bidirectional WDM ring network with 56 nodes.
Influence of Wavelength Interchange
WDM Ring Networks with
Unidirectional and Bidirectional Links

Unidirectional WDM ring network with 10 nodes and with (wi) or without wavelength interchange in all nodes
Influence of Wavelength Interchange in WDM Ring Networks with Unidirectional and Bidirectional Links

Bidirectional WDM ring network with 10 nodes and with (wi) or without wavelength interchange in all nodes
Influence of Wavelength Interchange
WDM Ring Networks with
Unidirectional and Bidirectional Links

10-node
unidirectional
WDM ring network
with wavelength
interchange in all
nodes

40-node
bidirectional WDM
ring network
wavelength
interchange in all
nodes
Four-Fold Capacity Increase of Bidirectional Rings over Unidirectional Rings

- The four-fold capacity increase offered by bidirectional rings may be explained as follows:
  - The bidirectional ring requires twice the number of wavelengths and associated resources with respect to the unidirectional ring.
  - The bidirectional ring halves the average distance between nodes, thereby doubling again the available resources.

  Average hop-length for unidirectional rings: \( \frac{N}{2} \)

  Average hop-length for bidirectional rings: 
  \[
  \frac{N}{N - 1} \times \frac{N}{4} \quad (for \ N \ even)
  \]
  \[
  \frac{N + 1}{4} \quad (for \ N \ odd)
  \]
Conclusions

• Using a model for computing the session blocking probability, we assess the blocking performance of unidirectional and bidirectional WDM ring networks with 14 and 40 nodes.

• It is shown that a bidirectional 40-node ring network has a blocking performance close to the performance of a unidirectional 10-node ring network.

• Increasing the number of nodes up to 56, it is verified that a bidirectional 56-node ring network has a blocking performance similar to the 14-node unidirectional ring, which confirms the four-fold capacity increase of bidirectional rings over unidirectional rings.

• Concerning the influence of wavelength interchange, it is also shown that the four-fold capacity increase of bidirectional rings over unidirectional rings still holds.
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