SIMULATION ISSUES OF OPTICAL PACKET SWITCHING RING NETWORKS

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KEYWORDS

Discrete event simulation, message exchange, packet switching, ring.

ABSTRACT

The paper focuses on discrete event simulation of a ring topology based on optical packet switching. The cell loss ratio was used to compare two simulation mechanisms. The first one utilizes the message exchange domain, while the other represents a message exchange simplification as the traffic for each node is generated separately. Results have been verified using the analytical procedure and compared to justify the use of the simplified model. It has been shown that the influence of message exchange mechanism on traffic pattern introduces changes to the calculated performance which cannot be included in the analytical or the simplified simulation model.

INTRODUCTION

A large number of telecommunication network evaluations by using simulation is based on evaluating just one node and drawing conclusions from these results. If the whole network's performance is to be evaluated by simulation, this model can be easily generalized by simulating each node independently. This simple model doesn't take into account changes introduces by intermediate nodes which serve traffic going from source to destination. Aggregation due to space switching and buffering in those nodes can significantly change traffic pattern. This is of the most importance, because the existence of traffic burstiness, or periods where packets arrive in a stream can impact the rejection ration in limited size buffers (Lackovic et al. 2003).

The aim of this work is to compare two simulation models of the same network. The first one is a simple generalization of a single node simulation, and regards each node independently. This is a simplification of the second simulation model, which uses the message exchange domain, and thus incorporates changes in traffic flows introduced by buffering and aggregation in nodes. Simulation results are compared to analytical procedure in order to justify the use of the simplified simulation model, and to determine the possible restrictions in cases where obtained results differ too much.

The network is based on the optical packet switching paradigm (Yao et al. 2000), which is considered to be a long term solution for the broadband optical networks. Fine packet level granularity combined with WDM and intelligence introduced in optical nodes are giving the answer to the increasing demand for QoS aware increasing communication demands.

ASSUMPTIONS

A ring topology (Figure 1) has been chosen to compare simulation and analytical results, because of transparent traffic demand structuring and parameterization.

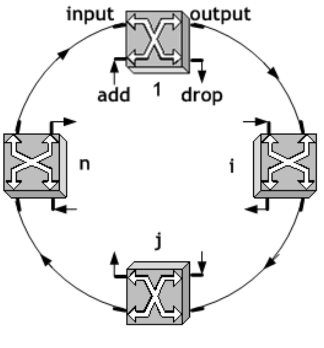

Figure 1: Network Structure

Each node has an optical packet switching capability. Switch is structured as an unblocking space switch with output buffering and full wavelength conversion. Nodes are capable of inserting (add) and extracting (drop) traffic from the ring (Figure 1). A cell based synchronous communication model was chosen, implying exchange of fixed sized packets (cells) in fixed time points (slot beginnings).

Traffic demands are equal between any node pair implying that each node generates the same traffic volume for each node in the network. This results in the same traffic load on all links in the ring.

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The cell loss ratio (CLR) was chosen as a communication evaluation property. The goal was to determine CLR dependency on topological parameters (number of stations), network parameters (number of wavelengths) and node structure (memory capacity). The analytical procedure and simulation will be used to calculate these dependencies.

Figure 2 depicts general node model. Input traffic flows are demultiplexed (demux section) and their wavelength is adjusted to match a free wavelength in the appropriate fiber delay line, or a free wavelength on the output (cell encoding section). Cell encoding section comprises tunable wavelength converters. A control unit determines the output wavelength according to the information extracted from packet headers, and information on the occupation of the buffer on the required output. Set of internally used wavelengths is the same as the set of input/output wavelengths. Therefore wavelengths used for potential cell buffering correspond to output wavelengths. Switching section does the space switching to the appropriate output. Switching is done on the demultiplexed packet level. Outputs are multiplexed and sent to the chosen fiber delay line.

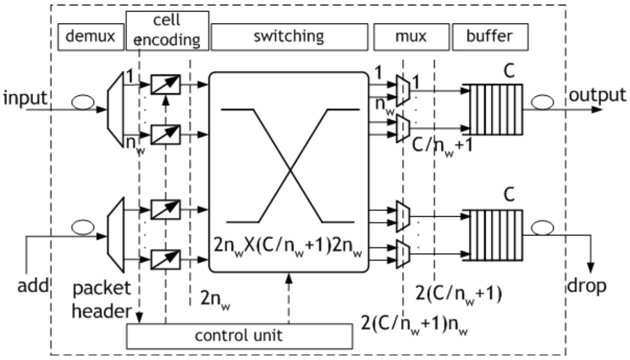


Figure 2: General Node Model

Each node output is buffered using fiber delay lines. Each buffer always contains a direct connection to the output which doesn't introduce any delay. Buffer capacity expressed in the number of cell that can be stored (C) is determined by the number of FDLs that introduce a delay:

$$C = n_{FDL} n_w, \qquad (1)$$

where n_{FDL} stands for the number of delay lines (not counting the direct connection), and n_w for the number of wavelengths used in the buffers. This number is equal to the number of wavelengths used in the network.

ANALYTICAL MODEL

Analytical model (Lackovic and Bungarzeanu 2003) is based on the Markov chain describing number of cells in each buffer. Each Markov chain state represent a number of cells in one buffer. Each transition represent the change of the number of cells in a buffer (Figure 3).

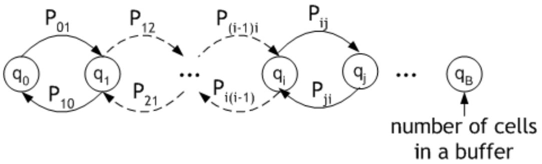


Figure 3: Markov Chain for one Buffer

For the CLR calculation the probability of each state (number of cells in a buffer) has to be calculated. This calculation is based on calculating the probability that a determined number of cells will arrive to a buffer in one time slot

SIMULATION MODEL

Simulation was performed on a simplified model, but with all characteristics that influence the network performance in terms of CLR. These include full wavelength conversion on all inputs and output buffering on all outputs. Switching is performed by strictly unblocking space switch.

This simulation model is based on the discrete event simulation. Modelling was performed using object-oriented paradigm of the *Cosmos* tool (Lackovic and Inkret 2001). Figure 4 depicts a class tacsonomy of the packet switching simulation. The implemented model is generalized implying that any topology can be structured and analyzed/simulated. The system contains (inherits) basic structural and discrete event simulation properties from the Cosmos base classes. It uses network algorithms for network/demand structuring. Base module contains structural properties (Lackovic and Inkret 2002) and the message exchange domain properties (ability to send/receive messages). Classes implementing concrete network components have been inherited from the base module class.

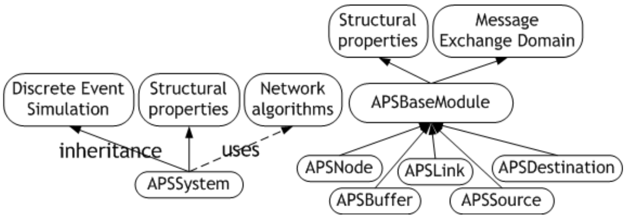


Figure 4: Class Tacsonomy

Cell Generation

The simplification of the cell generation model is important as it can introduce a considerable simulation speed-up. Large number of simulation iteration is required, as large number of time slots have to be simulated to obtain satisfactory CLR value accuracy, or to obtain any CLR value in the case of very rare cell rejections.

Cells are generated on each channel (wavelength) independently using a binomial distribution with the probability of cell generation equal to the channel load.

All channels on the same fiber/link have the same load because of the load balancing of all traffic on one fiber/link over its channels. Cell generation algorithm can be described as follows:

```
for all wavelengths on a fiber
  generate randomly 0<=n<1
  if n<=channel load
    randomly select a demand
    generate cell for the demand
    switch the cell to the output buffer
    if buffer not full
      store cell in buffer
    else
      discard cell
      notify demand/link
  end if
end for
```

Two different simulation models regarding cell generation have been defined. The first called independent traffic generation (ITG) generates cells using described method on all channels on all links, while the other utilizes message exchange domain (ME) and generates cells only on source links (connecting source and switch). These cells are exchanged between nodes using message exchange mechanism (Lackovic and Inkret 2002).

Independent Traffic Generation

This method represents a network simulation conducted as a generalization of a single node simulation. A lot of studies have been focused on just one node simulation due to the long simulation execution time needed to obtain feasible results. A way to shorten execution time is to regard each node as an independent simulation entity. Its connection to the other nodes is realized through analytical determination of link loads on its inputs and outputs. In each iteration (time slot) a cell generation function is called for all fibers on all links. The speed-up is achieved by the memory-less simulation because no real packets are exchanges in the network.

After each iteration a release function is called to release appropriate number of cells from each buffer:

```
for all buffers
  if cell number<nw
    remove all buffered cells
  else
    remove $n_w$ cells
  end if
end for
```

This exchange of generate and release function calls is a simulation of the bourn and dying processes of the Markov chain. Figure 5 depicts a simple scheme of basic generate and release model. The part in dotted lines is omitted in this model. Markov states are determined by the number of cells in each buffer.

Message Exchange Model

Message exchange based model assumed cell generation only on network sources (source links). Generation of cells on ring links is substituted by the message exchange mechanism. Generate function is modified to:

```
for all wavelengths on source fiber
  generate randomly 0<=n<1
  if n<=channel load
    randomly select a demand
    generate cell for the demand
    switch the cell to the output buffer
    if buffer not full
      store cell in buffer
    else
      discard cell
      notify demand/link
  end if
end for
```

Message exchange function can be defined as:

```
for all buffers
  send nw cells to egress node
    switch cells to the output buffer
    if buffer not full
      store cell in buffer
    else
      discard cell
      notify demand/link
  end if
end for
```

Release function is the same as in the previous case.

Basic generate-release model is not appropriate for the message exchange simulation because it gives advantage to some demands in terms of priority. The order of release function calls determines whether a node will receive cells by the message exchange mechanism before or after it has released its cells from the buffer. The cells generated on the source link in this simplified model will always arrive before or after the cell release and incoming exchanged cells what would produce too large or too small CLR for source links. Therefore the generate-release model has to be adjusted to eliminate the possible cell discrimination. Figure 5 with the buffer in dotted lines depicts a modified fair generate release model with added pre-buffering which using an order randomizer assures that no cells will be discriminated.

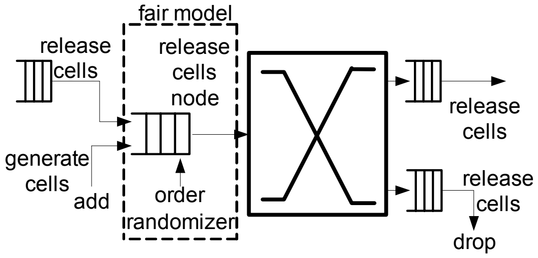


Figure 5: (Fair) Generate-Release Model

Modified generate function can be defined as:

```
for all wavelengths on source fiber
  generate randomly 0<=n<1
  if n<=channel load
    randomly select a demand
    generate cell for the demand
    store the cell in input buffer
  end if
end for
```

Modified message exchange is equal to:

```
for all buffers
  send $n_w$ cells to egress node
  store cells in input buffer
end for
```

Release function also changes, as it includes the release of the pre-buffered cells, what is the actual cell generation for the switch inputs:

```
for all input buffers
  randomize buffer order
  switch cells to the output buffer
  if buffer not full
    store cell in buffer
  else
    discard cell
    notify demand/link
  end if
end for
```

CALCULATIONS

Calculations include link and demand CLR by using analytical procedure and simulation. Simulation results were obtained by the ITG and ME simulation to verify the simplified simulation model. Both nodes with no buffering and with buffering capabilities have been taken into account.

No Buffering

Analyzed ring comprises 5 nodes without buffering capabilities. A 4 wavelength WDM system has been used to make the calculation shorter.

Figure 6 depicts dependency of the short demand CLR on the ring load. The graph contains analytical results (A), simulation results done by ITG (S), and simulation results obtained by ME simulation (S(ME)). A good match was obtained on smaller ring loads, but on the loads above 0.7 the difference between ME simulation results and those obtained by analytical procedure and ITG simulation grows. It is interesting to notice the change of relative difference sign between A/S and S(ME) results. S(ME) results are larger that A/S for smaller loads, but become smaller for larger ring loads.

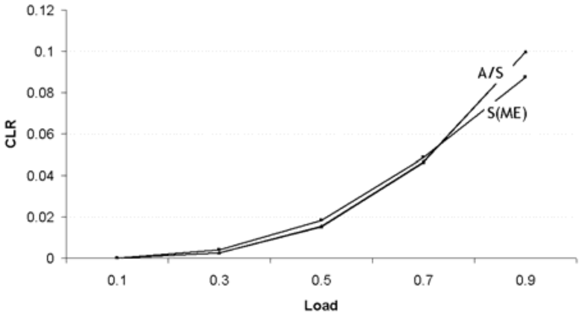


Figure 6: Short Demand CLR (1 Hop, no FDL)

Figure 7 depicts the longest demand CLR. Demand uses four ring links. The trends are the same as in the case of short demand with the visible differences between A and S results for the large ring loads.

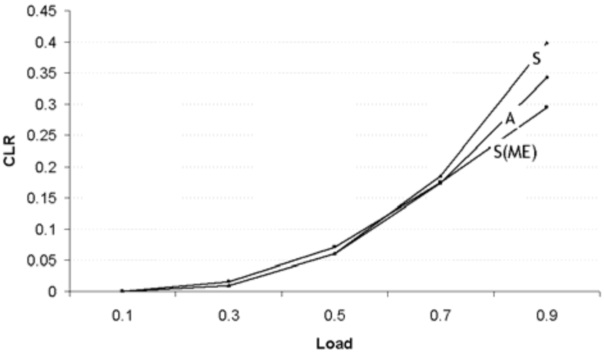


Figure 7: Long Demand CLR (4 Hops, no FDL)

Difference between A and S results is the consequence of inaccuracy introduced by the ITG simulation. Larger CLR for longer demand is caused by more links used by the large CLR. As the cells are not actually exchanged in the simulation, there is no continuity of communication in the network which would reflect the fact that the longer CLR transverses more links. This is implicitly assumed by the cell generate function. As all cells are generated independently on all channels, there is larger probability to generate a cell belonging to the demand that transverses larger number of links. If the cells for some demand are generated more often, the number of their rejections increases. The term cell generation has to be taken conditionally, because those cells just exist in the current simulation iteration (slot). Figure 8 depicts a case of 5 nodes in the ring. As all the demands have the same capacity, the probability of generating a cell for demand 1->5 will be 4 times larger than generating cell for the demand 1->2.

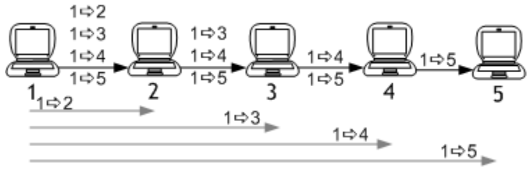


Figure 8: Influence of Generate Function on Long Demand CLR

Average link CLR is shown in Figure 9. The same conclusions as for short demand apply here.

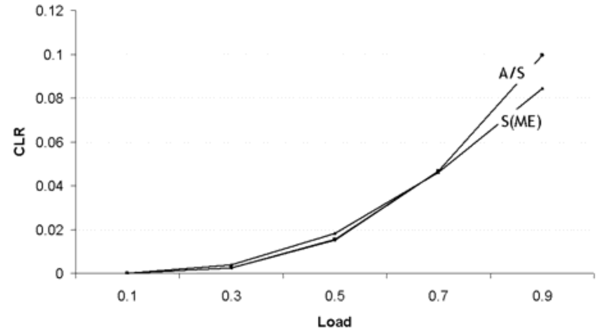
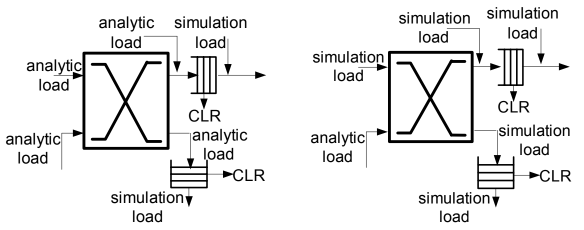


Figure 9: Average Link CLR (no FDL)

Smaller CLR values for the ME simulation for large ring loads can be explained by examining the link loads in the case of analytical procedure, ITG and ME simulation. Analytical procedure assumes calculated link loads, just like the ITG simulation. As all cells are generated independently, fluctuations introduced by buffering and traffic aggregation which occurs on the output switch ports cannot be taken account. This is especially visible for large ring loads, where the large CLR values (even up to 50%) influence the link load afters buffer. Figure 10 depicts differences in link loads introduced by ME simulation. Simulation load is the analytic load influenced by rejection in aggregation points/buffers. The simulation load is thus present in simulation after the buffering, but only in the ME simulation this load is the actual load that enters the next node. In the ITG simulation the egress node load doesn't influence the next node, because the ingress traffic for the next load is generated independently according to the average link load obtained by analytical calculation.



a) ITG simulation

b) ME simulation

Figure 10: Analytic and Simulation Load

Figure 11 depicts the link loads obtained from simulation. Two links have been taken into account. The *A*1 link is the access link in the node 1, while the 1->2 link is the ring link connecting nodes 1 and 2. It is visible that the *A*1 link has the same load in ITG and ME simulation, while the difference between 1->2 link loads grows with the ring load increase. This is the consequence of growing CLR.

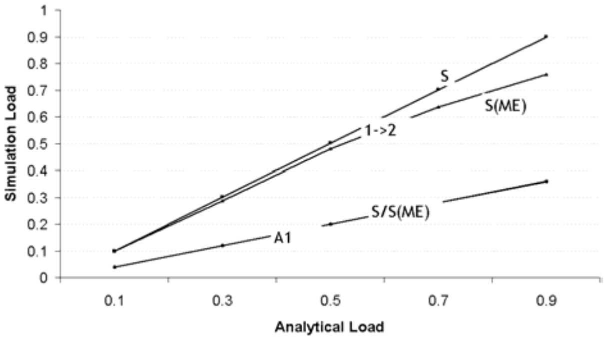


Figure 11: Mean Simulation Link Load (no FDL)

Buffering

The second calculation group focuses on nodes with buffering capabilities. Analyzed network has 5 nodes and 4 wavelengths with 1 FDL buffers. Figure 12 - Figure 14 depict the same calculations as in the previous case.

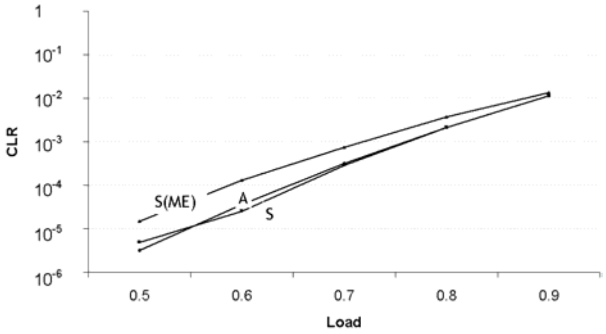


Figure 12: Short Demand CLR (1 Hop, 1 FDL)

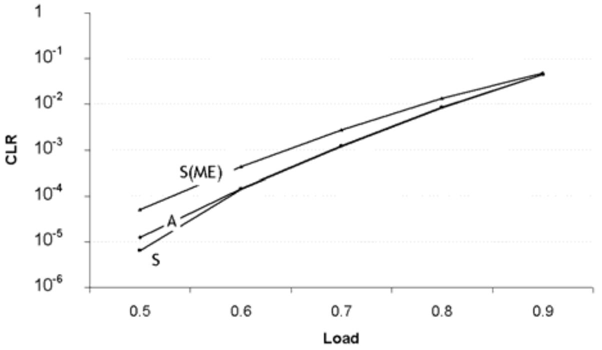


Figure 13: Long Demand CLR (4 Hops, 1 FDL)

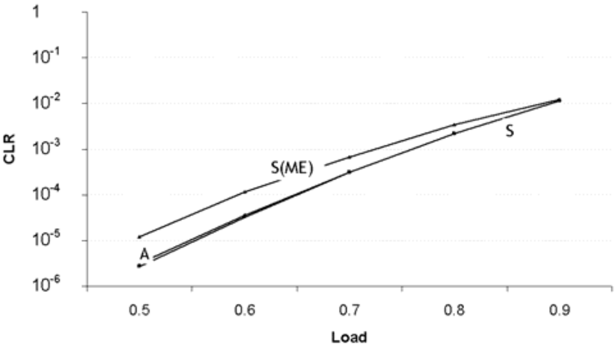


Figure 14: Average Link CLR (1 FDL)

A good match is obtained between analytical and ITG simulation results on almost all loads. The difference on large loads for long demand, which was present for the no buffering case, is now suppressed by small rejection probability which eliminates the described inaccuracy of the ITG simulation for longer demands. The difference exist for small loads where the simulation inaccuracy is caused by the very rare cell rejection events.

Difference for the ME simulation are reflection from the previous calculation group where ME simulation produced larger CLR values for the lower ring loads. In this case the CLR considerably influences the simulation link load. As the simulation load is equal to the analytical load, there is no influence on the CLR which was present in the previous calculation group.

Only the buffering and aggregation issues on the switch outputs influence the CLR. Larger CLR result can be explained by changes in the traffic characteristics imposed by nodes. These changes are not present in the ITG simulation as traffic is generated in each slot, and there is no influence of one slot to the other, except in the number of buffered and rejected cells. Figure 15 depicts histogram of arrived number of cells in a buffer. It is clear that the distribution of cell number changes with the ME mechanism introduction. The number of slots with larger number of incoming cells increases, what increases the rejection probability and CLR. Figure 16 depicts histogram of buffered cells with the number of cells which are going to be directly transmitted. An increase in probability of larger number being buffered is visible. Large number of buffered cells increases the probability of cell rejection in the next slot.

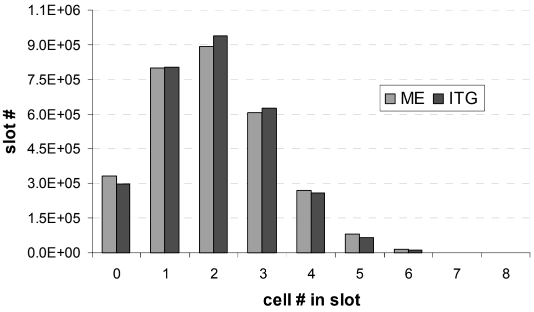


Figure 15: Arrived Cell Number Histogram
(4 wl, 1 FDL)

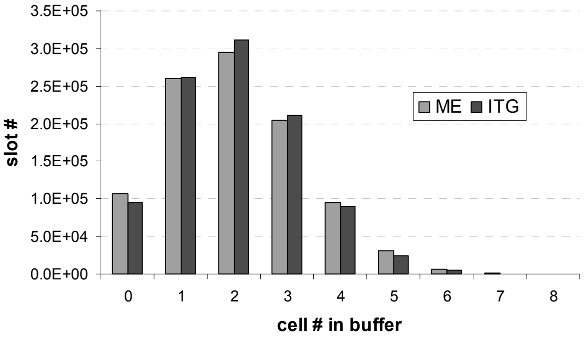


Figure 16: Buffered Cell Number Histogram
(4 wl, 1 FDL)

CONCLUSION

This work was focused on investigating the properties of the packet switched uniform ring topology. PSUR nodes have the optical packet switching capability. Ring links are equally loaded due to the unidirectional communication and same traffic demands between all ring nodes. CLR was chosen as the performance evaluation criteria. CLR calculation was performed using analytical procedure based on the Markov chain, and discrete event simulation. Simulation was based on independent generation of traffic (ITG) for each node, and on message exchange simulation (ME).

The CLR results for all the cases were compared in order to verify the simulation model, and to evaluate the simplification introduced by the ITG simulation. A good fit between ITG simulation and analytical procedure results was achieved. The ME simulation produced larger CLR values, showing the CLR underestimation by other methods. This difference was caused by changes in traffic characteristics which cannot be taken into account by analytical procedure and ITG simulation. These procedures produced CLR overestimation on very large ring loads and no buffering capabilities. In those cases the CLR becomes very (unrealistically) large and affects effective (simulation) load, which becomes smaller than the analytically calculated load. These findings show that the simple generalization of the simulation of one node to the network simulation is sometimes not good enough, as it does not take into account the influence of nodes on the traffic model.

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