Dynamic Routing, Rearrangement, and Defragmentation in WDM Ring Networks

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Simulation studies of dynamic routing with rearrangement in WDM ring networks indicate that up to five additional paths may be accommodated with 16 wavelengths. Dynamic alteration of a path's wavelength is necessary to achieve this.

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1. Introduction

This paper describes an investigation of dynamic routing of increasing traffic in four-fiber WDM ring networks [1] without wavelength conversion. To date, most studies of routing in ring networks have assumed that the traffic is static i.e. once a path is set up, it never changes [2,3]. While some work has been done on dynamic routing, where paths may be set up and torn down as time progresses [4], the movement of paths between wavelength to accommodate extra paths is a new feature of this work. Here, multiple "stacked" rings [5] may be modeled, with a new ring being added when blocking takes place, except if all the rings are used up.

A key feature of this work is the evaluation of defragmentation and rearrangement. If a ring has been operating for a long time, spare capacity will become fragmented over many wavelengths – much like free capacity becoming fragmented over a computer hard disk. A defragmentation algorithm must be executed to consolidate the free capacity into a few large blocks, and allow further paths to be routed without blocking. The basic operation that such an algorithm carries out is to consolidate capacity by moving several paths from one wavelength to another. To do this requires wavelength-agile tunable transmitters and receivers, implying extra hardware cost. This allows optical paths to have their wavelengths changed while still carrying traffic, such as SDH/SONET or ATM.

A related activity is rearrangement, where a new path being set up may move other paths out of the way to make room for it. In turn each of these paths may have further paths moved out of their way, and so on. The extent to which this reiterates in this way depends on the depth of recursion in the rearrangement algorithm. The defragmentation algorithm calls the rearrangement algorithm.

The objective of this work was to begin an investigation and discussion into the validity of this technique, in the first instance, by comparing performance with and without rearrangement and defragmentation, for varying depths of recursion.

2. Rearrangement

Rearrangement is carried out by a recursive function. Its function is to copy a path from wavelength w_{from} to wavelength w_{to}. For stacked rings, each wavelength on each stacked ring is allocated a unique wavelength number. The required depth of recursion is also specified, and is decreased by one on each recursive call. To prevent paths from being moved into the location of the original path, wavelengths are marked as "used" and nothing can be moved into them. The function proceeds as follows:

- Terminate unsuccessfully if the required depth of recursion is zero.
- Terminate unsuccessfully if $w_{from} = w_{to}$.
- Terminate unsuccessfully if w_{to} is marked as "used".
- Save the network configuration i.e. the sizes and locations of all paths.
- Mark w_{from} as "used".
- For each path on w_{to} in the way:
  - Try to relocate the path to each other unused wavelength in turn, by repeatedly calling the rearrangement function recursively.

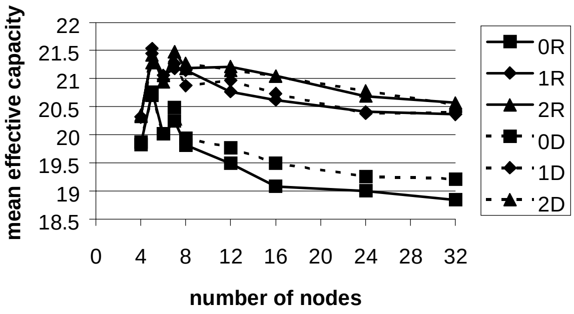

Fig. 1. Mean effective capacity for an 8-wavelength WDM ring with churn of 0.1

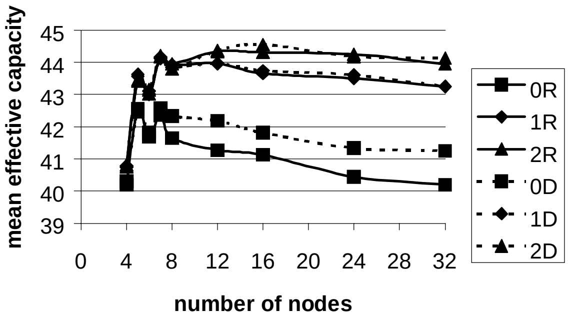

Fig. 2. Mean effective capacity for two 8-wavelength stacked WDM rings with a churn of 0.1.

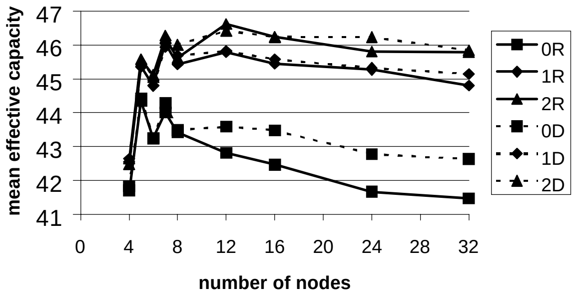

Fig. 3. Mean effective capacity for a 16-wavelength WDM ring with churn of 0.1.

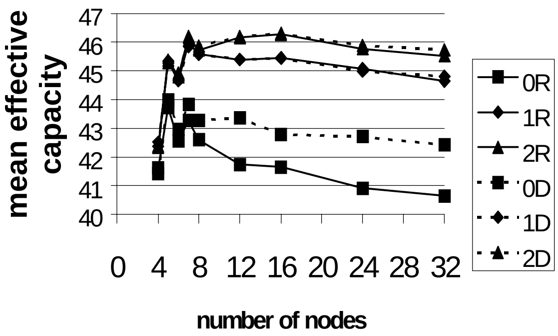

Fig. 4. Mean effective capacity for a 16-wavelength WDM ring with churn of 0.3.

  - If all of these rearrangements failed, restore the network configuration and exit this reconfiguration unsuccessfully.
- Move the path from w_{from} to w_{to}
- Terminate successfully.

3. Defragmentation

The defragmentation algorithm works by trying to clear all paths off individual wavelengths onto other non-empty wavelengths. The objective is to increase the number of empty wavelengths:

- START:
- For all wavelengths, in order of increasing total path length on the wavelength.
  - Save the network configuration
  - Try to shift each path to another non-empty wavelength by using the rearrangement function.
  - If wavelength cleared successfully, goto START.
  - Restore the network configuration.
- Try next wavelength.

4. Results

Fig. 1 to Fig. 4 depict the simulation results, under negative exponentially distributed traffic. Throughout, the traces on the graph are referred to as R0, R1, R2, D0, D1 or D2. “R” denotes rearrangement only while “D” denotes defragmentation as well. The number is the level of recursion that the rearrangement operates to, and one less than the depth that defragmentation operates to. The points making up the graphs are joined up purely for visual convenience. This is not intended to imply that the results are valid for results other than 4, 5, 6, 7, 8, 12, 16, 24 or 32 nodes.

In the simulations, uniformly distributed paths were added to the ring(s) randomly at a higher rate than they were removed until blocking occurred, with the "effective capacity" of the ring being mean number of paths that can be routed before blocking. The churn determined the ratio of the rate of paths being removed to paths being added. The simulations were 1,600 events (i.e. blockings) for 8 wavelengths and 80 events for 16 wavelengths.

5. Conclusions

The following principal conclusions can be drawn from this work:

- In all the graphs, there is only a slight tendency for the capacity of the ring to decrease as the number of nodes increases.
- Defragmentation only yields marginally better performance than rearrangement, for the same level of recursion, particularly for 1D and 2D. In the case of 0D, there is a discernible difference although it is not large. Recursion of depth two for rearrangement (2R) does not yield significantly better results than rearrangement with recursion of depth one (1R). It is hence questionable whether the algorithmic complexity involved in using higher levels of recursion can be justified.
- The ability of the ring to accept new paths is slightly influenced by whether the number of nodes is odd or even; the graphs are smooth for 8 or more nodes because only even numbers of nodes were simulated above 8.
- The churn has little influence on the effective capacity (Figs. 3 and 4), particularly for higher levels of recursion. While it has some influence when the level of recursion is zero, this is to be expected because in the absence of rearrangement, increasing the churn is forcing the ring to be rearranged by the traffic being placed on it.
- One 16-wavelength stacked ring (Fig. 3) can accommodate two more paths than two 8-wavelength stacked rings (Fig. 2), even although the same number of wavelength channels exist in both cases. It hence seems likely that a single ring with a large number of wavelengths is more efficient than several smaller stacked rings with the same total number of wavelength channels.

This paper has presented some results on dynamically rearrangeable WDM rings. The results indicate that more capacity may be carried over a WDM ring by using this technique, for example, 5 extra paths for a 16-wavelength ring. To make this technique practical, the feasibility of constructing hardware to change a path to a different wavelength, without significant disruption, will have to be investigated.

6. References

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