The Merits of Reconfigurability in WDM-TDM Optical In-Building Networks

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Abstract: Blocking performance of an optical WDM-TDM in-building network is significantly improved by dynamic wavelength routing. We analyse optimum clustering of users which reduces system complexity while largely preserving network performance improvement.

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1. Introduction

Now that FTTH networks are bringing true broadband capacity up to the home's doorstep, the next challenge is to bring the broadband services inside the building up to the end user himself. The in-building network may even need to have a higher capacity than the access network, as it also has to provide fast transfer of huge files (HD video movies, file swapping between PC-s, …) between the user terminals and with the terabyte data servers inside the building [1]. For larger buildings, such as office buildings and multi-dwelling units (MDU) buildings, point-to-multipoint network topologies (tree, bus) are the most interesting ones as they minimize the network installation costs [2].

When adopting an all-optical network architecture with flexible optical routing of signals in the network nodes, also the network operation costs can be minimized, as the services can be provided on-demand and network resources are not wasted by providing them to in-active users. A similar strategy has shown to be effective in access networks [3]. For instance, in a MDU building where a number of independent households live with each having a different traffic pattern, the capacity demand may fluctuate substantially during the day. Some living units (LU-s) may not require capacity during daytime as the inhabitants are at work outside. In other LU-s where people are working from home extra capacity may be required. In the evening, when people are at home enjoying entertainment services, the capacity needs may be quite different again. Hence, by offering capacity-on-demand and responding to instantaneous traffic requests, the network throughput and thus the efficiency of the network resources can be improved considerably.

We have made an analysis of the improvement of network throughput which can be achieved by optical wavelength routing in an MDU building. Full network reconfiguration flexibility is realized when the wavelength routing is done per individual LU. However, this requires quite comprehensive and therefore expensive wavelength routers [4]. Alternatively, one may cluster the LU-s and do the routing per cluster, which reduces the router complexity at the expense of reduced flexibility. Fig. 1 illustrates this for a cluster size *c*=2 LU-s. Fig. 2 shows that a flexible wavelength router based on a broadcast-&-select architecture needs *N*/*c* optical gates (semiconductor optical amplifiers, SOA-s) for *N* LU-s, which is inversely proportional to the cluster size *c*.

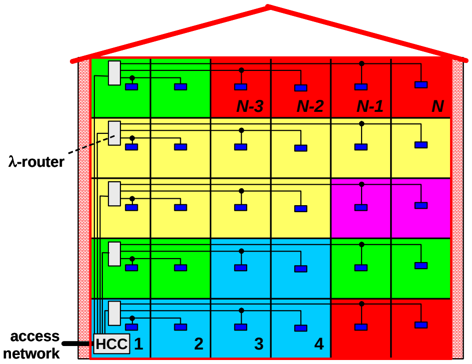

Fig. 1 MDU building network with wavelength routing for *N* living units (cluster size *c* = 2 living units)

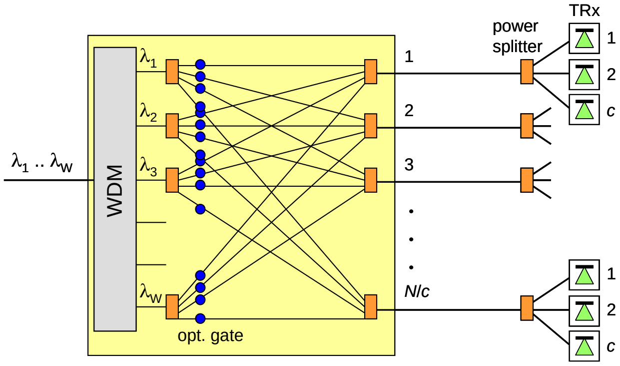

Fig. 2 Flexible wavelength router (*W*·*N*/*c* optical gates needed)

2. Analysis of network performance improvement by wavelength routing

The network performance has been analyzed for a typical MDU building with N living units. We assumed that the network can deploy W independent wavelength channels, each with a data transport capacity B. We also assumed that a LU, when active, needs a capacity R. The traffic statistics of an LU are modeled as an on/off process with Poisson-distributed call generation statistics, having a call birth rate λ and a call completion rate μ, which yields a probability $p=\lambda/(\lambda+\mu)$ that an LU is in the on-state. As we assume that the LU-s behave independently, the probability that k out of the N LU-s are active is given by the binomial distribution

$$\Pr[k]=\binom{N}{k}p^{k}(1-p)^{N-k} \qquad (1)$$

Using Chernoff's upper bound, with $M_k(s)$ the moment generating function of Pr[k] and parameter s>0 , we find

$$\Pr[k>D]\le e^{-sD}M_k(s) \qquad (2)$$

By optimizing s such that the bound is as tight as possible, we can derive

$$\Pr[k>D]\le\left(\frac{p}{D}\right)^{D}N^{N}\left(\frac{1-p}{N-D}\right)^{N-D} \qquad (3)$$

Congestion in a wavelength channel will occur when more than $D=B/R$ living units want access to the channel; see Fig. 3, where a call in channel λ_2 is rejected when it cannot be assigned to an other wavelength channel by means of wavelength reconfiguration. Without wavelength reconfiguration, the probability of network congestion is

$$\Pr_{no\_reconfig}(\rho)=1-\left(1-\Pr_{block}(\rho)\right)^{W}=1-\left(1-\Pr[k>(B/R)]\right)^{W} \qquad (4)$$

where the relative network load $\rho = p\cdot N\cdot R\,/\,(W\cdot B)$. The network congestion probability is significantly reduced when a rejected call can be transferred to an other wavelength channel in which still sufficient capacity is available. When assuming that the call can fit fully into an other channel and no fragmentation is needed, all wavelength channels together may be seen as one common pool of resources, and the threshold for network congestion becomes $D=W\cdot B/R$. Hence when using wavelength reconfiguration the probability of network congestion is

$$\Pr_{reconfig}(\rho)=\Pr[k>(W\cdot B/R)] \qquad (5)$$

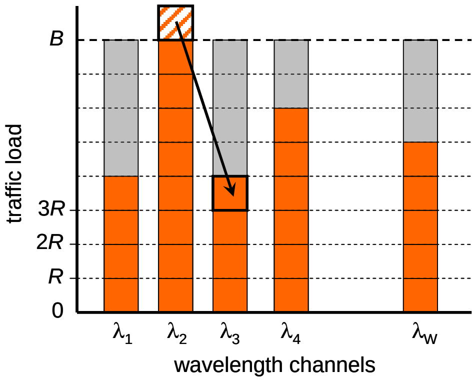

Fig. 3 **Reallocating traffic load to avoid network congestion**

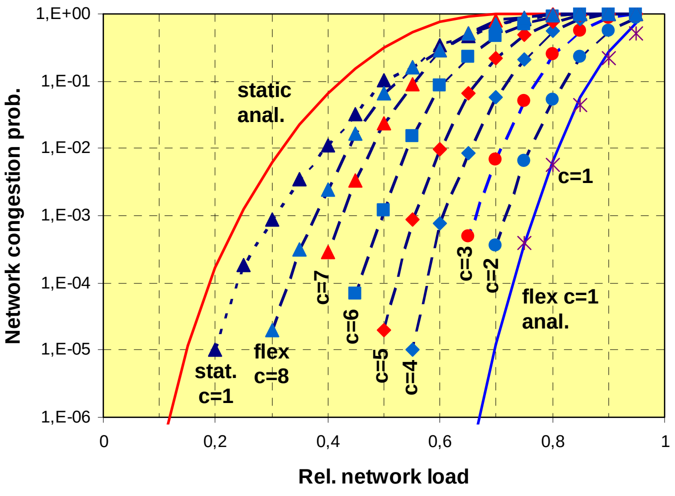

Fig. 4 Network congestion probability without and with wavelength reconfiguration, for various cluster sizes

3. Results from analysis and simulations

The congestion probability of a multi-wavelength network has been analyzed for an MDU building with 10 floors and 16 LU-s per floor, so in total N=160 LU-s. The network has W=10 independent wavelength channels, each with B=1GbE (Gigabit Ethernet) capacity. We assume that an LU, when active, demands fast Ethernet, so R=100MbE capacity. Hence each wavelength channel can host up to B/R=10 active LU-s, and the whole network can host up to

$W{\cdot}B/R$=100 active LU-s. The network congestion probability as a function of the relative network load (i.e. the actual load, normalized on the network's capacity $W{\cdot}B$) has been calculated using the equations derived above. The results are shown by the solid curves in Fig. 4. The "static" curve represents the performance without wavelength reconfiguration, the "flex" curve shows the performance with reconfiguration. Next, a traffic simulator has been programmed in C++. The simulation results are shown by the marker points in Fig. 4 for various cluster sizes c. The simulation results confirm the analytical ones; note that the latter are from Chernoff's upper bound, so this bound gets tighter when the average number of LU-s per wavelength channel increases. Full reconfiguration flexibility for each LU is achieved for a cluster size c=1. For $c \geq 2$ the flexibility is reduced, which degrades the network performance but also reduces the router complexity (see Fig. 2).

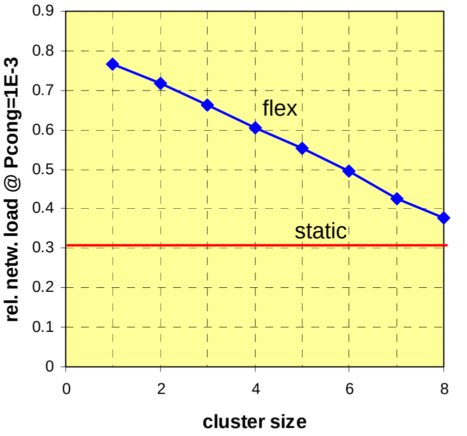

Fig. 5 **Max. network load for a network congestion probability of 10^{-3}, versus cluster size *c***

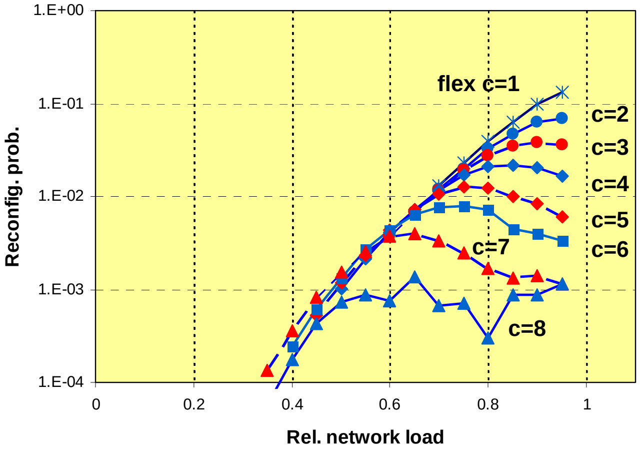

Fig. 6 **Reconfiguration probability per LU**

The results in Fig. 4 show that flexible network reconfiguration by reallocating wavelength channels can significantly reduce the network congestion probability. E.g., when a maximum congestion probability of 10^{-3} is accepted, the network can be loaded only up to 30% when no wavelength reconfiguration is possible (static case, c=1). However, with full flexibility (flex case, c=1) the load can be increased up to 76%, so 2.5 times higher. With partial flexibility, i.e. by clustering the LU-s so $c \geq 2$, the allowable network load decreases gradually as shown in Fig. 5. With c=4 the allowable load is still a respectable 60%, but by further increasing the cluster size to c=8 the allowable load goes down to 38%, close to the static case.

When the network load grows, the probability that a cluster needs to be reallocated to an other wavelength channel increases as well, as shown in Fig. 6. However, when the wavelength channels get filled up, i.e. at larger network loads, with larger c the clusters become too large to be reallocated and to fit into an other channel, so the reconfiguration frequency decreases.

4. Conclusions

Dynamic network reconfiguration by flexibly assigning wavelength channels to individual living units in an MDU building can significantly increase the allowable network load for a given network congestion probability. The complexity of the wavelength routing devices may be reduced by clustering multiple LU-s together and doing the wavelength assignment per cluster; however, this is at the expense of reducing the allowable network load. For a typical MDU building (160 living units, requesting 100MbE each, with 10 wavelength channels providing 1GbE capacity each), a cluster size of 4 LU-s may be a good compromise between system complexity (so system costs) and network performance improvement.

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5. References

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