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Designing of multichannel optical communication systems topologies criteria optimization

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Abstract

This paper presents the issues necessary to solve in the designing process of multichannel optical communication systems topologies. The main design assumption is the acceptance of multichanneling in communication system realization. In particular, the basics of designing physical and logical topologies are shown. Also cost aspects of physical and logical topologies realization are shown.

1. Introduction

The tasks solved by means of present teleinformatic systems can be classified into two main groups. We can number the tasks related to executing communication operations between the parallel processing system elements in the first group. The other group of tasks is related with assurance necessity of data transfer environment for typical information services i.e.: file transfer, voice and picture transmission, teleconferences etc.

Designing of multichannel optical communication systems is a very complex computational problem. Its aim is to create links with given characteristics connecting any pair of network nodes with each other. In the designing process we can distinguish two main stages: designing of physical topology and designing of logical topology.

Specifying in the network structure physical and logical elements allows to get a number of original possibilities, such as: possibility to specify a set of logical topologies in the confines of one physical topology, whose architecture fulfil the requirements of run applications; possibility to build topologies using the point to point channels; realization simplification of broadcast and multicast network communication procedures; improvement of physical communication channels use efficiency.

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The above advantages are characteristic of all multichannel systems but the possibility of other efficient use has appeared only in optical systems.

2. Designing process elements

Topological designing of multichannel optical communication networks consists of a number of mutually related steps. In the first step, physical topology is created which is reflection of optical fiber routes connecting real system nodes. In the second step projection of the logical topology on the physical topology is performed. This process should take into consideration requirements which logical topology should fulfil and also possibility of realization on the resources of physical network. Because this task is most often NP-hard computational problem that is why designing of logical topology is split into four not necessarily dependent designing problems. These problems are:

- designing of correct virtual topology, whose transmitting nodes are directly connected with receiving nodes with the assumption that a number of optical transmitters and receivers is minimal;
- designing of optical routes on the physical topology with the assumption that a number of available wavelengths is limited;
- selection of wavelengths for different optical routes with the assumption that a number of available wavelengths is limited;
- packets routing on the basis of virtual topology routes with the assumption that transmitting and buffering delays of the information in the network are minimal.

In the third step, on the basis of manner analysis of the logical topology projection on the physical topology the type of building optical network is chosen. Optical communication networks classification is shown in Fig. 1.

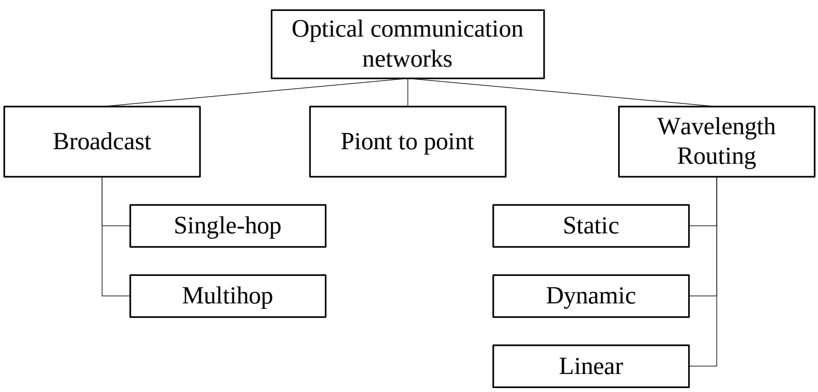

Fig. 1. Optical communication networks classification

3. Designing of physical topology

Designing of physical topology in a particular way affects on future functioning of the whole communication system. Particularly physical topology parameters define such characteristics as; lifeness, reliability, capacity, delays, etc. The most used optimization criterion is the network realization cost and its cohesion coefficient.

Designing of physical topology, particularly designing of optical fiber routes connecting individual nodes, must be closely connected with the designing process of logical network. The entire network capacity will be specified only at a physical not logical level. Because of that designing processes of physical and logical topologies should be related.

In the designing process of physical topology the heuristic algorithms creating dendrite topology can be used and next with the genetic approach the topological characteristics could be improved in order to increase its maximal capacity and cohesion coefficient.

4. Designing of logical topology

The projection problem of the required virtual topology on the given physical topology is formally described below. The following inputs to this problem are given:

1. The physical topology $G_p = \left(V, E_p\right)$ composed of weighted, undirected graph where V is a set of network nodes and E_p is a set of links connecting nodes. The fact of graph undirection results from that links in physical networks are of bi-directional character. Graph nodes correspond to the network nodes (packet switch) and links correspond to the fibers connecting the mentioned nodes. Because links are undirected, each link may have two fibers or two multiplexed transmission channels based on the same fiber. Each link has weight which corresponds to the distance between the nodes. The node marked as *i* is joined to $D_p\left(i\right)\cdot D_p\left(i\right)$ switches with wavelength routing where $D_p\left(i\right)$ is called *i* node physical degree which equals to a number of physical links going out (or going in) of the *i* node.
2. The number of available wavelength channels in each physical fiber is equal to *M*.
3. The matrix of $N \times N$ elements is a flow matrix where N - is a number of network nodes. Flows between the nodes *i* and *j* are placed in *(i,j)* table element. Traffic stream may be asymmetric i.e. the traffic between the nodes *i* and *j* may be different from the traffic between the nodes *j* and *i*.
4. The number of lasers and filters which are network transmitters and receivers respectively.

Our goal is to specify the following elements:

1. The virtual topology $G_v = (V, E_v)$ defined as a graph which has the node output degree equal to the number of transmitters in the node and node input degree equal to the number of receivers in the node. Nodes in the virtual topology correspond to the physical topology nodes. Each link between the pair of the virtual topology nodes corresponds to the directed, completely optical connection routes between corresponded physical topology nodes. Each of these links may use many different physical connection routes. Very important designing process element is to get so-called optimal routing in which it is possible to create communication network with a limited number of wavelength in each physical channel.
2. The wavelength for the optical routes such that if any two optical routes share the same optical channel they must use different wavelength obligatory.
3. Size and configuration of the optical switches in the intermediary nodes. Some of the logical topology is defined, and allocation of wavelength could be determined by size and switches configuration.

We could put together this fascinating problem as an optimalization one. In this case we will use the following symbols:

- *s* or *d* are used as the upper or lower indexes, describing the source and destination of packets respectively;
- *i* or *j* are representing beginning and final optical path nodes;
- *m* and *n* denote the final paths,which are contained in the optical path.

Input data of the algorithm:

- Number of nodes N
- Maximum number of the wavelength based on the single fiber M
- Physical topology P_{mn}, where $P_{nm} = P_{mn} = 1$ only if direct connection exists between the nodes; $n, m = 1, 2, ..., N$. If connection does not exist, then $P_{nm} = P_{mn} = 0$. In both cases optical connections are treated as duplex.
- Distance matrix is defined as an optical distance d_{mn} between the nodes *m* and *n*. More often this distance is expressed as the essential time for sending the optical signal between a pair of nodes. Therefore, according to prior assumptions, optical lines are considered duplex $d_{mn} = d_{nm}$ and $d_{mn} = 0$ if $P_{mn} = 0$.
- Number of transmitters in the node *i* is equal to T_i ($T_i \geq 1$). Likewise, a number of receivers in the node i is equal to R_i ($R_i \geq 1$).

- The flow matrix l_{sd}, describes an average traffic rate between the nodes *s* and *d*, where $s,d = 1,2,...,N$. The traffic rate for $l_{ss} = 0$. Therefore, we assume, that frequency of the packet appearance in the note *s* and its length, characterizes exponential arrangement. Therefore, standard of the queue $M/M/1$ could be employed to describe each and ever one network connection. The value l_{sd} should be expressed in each per packet per second.
- Capacity of each channel is equal to C.

Finding variable

- Virtual topology is described by the nonsymmetrical adjacency matrix *V*. The value $V_{ij} = 1$ if presented topology consists of the optical path between the nodes *i* and *j*. Otherwise, if there in no connecting path $V_{ij} = 0$. We must become aware that the above statement in contrast to the previously described optical channels does not mean, that virtual channels should be duplex, for example $V_{ij} = 1$ does not mean $V_{ji} = 1$.
- Routing, the parameter l_{ij}^{sd} describes traffic between *s* and *d* nodes through the intermediate virtual link V_{ij}. It is noticed, that stream from node *s* to node *d* can be separated into two different components, which use different sets of optical paths.
- Routing in physical topology, the variable $p_{mn}^{ij} = 1$ if and only if optical connection P_{mn} exists in the virtual path V_{ij}. Otherwise, $p_{mn}^{ij} = 0$.
- Wavelength color covering, the value $c_k^{ij} = 1$ variable if the path starts with the node *i* and ends with the node *j* contains color k, where $k = 1,2,...,M$. Otherwise, $c_k^{ij} = 0$.

Dependencies:

- In virtual topology the connectivity matrix V_{ij}:

$$\sum_j V_{ij} \le T_i \quad \forall i, \tag{14}$$

$$\sum_i V_{ij} \le R_j \quad \forall j. \tag{15}$$

The above equations are true only if all the transmitters in the node *i* and all the receivers in the node *j* are used.

- In the physical route the parameters p_{mn}^{ij}:

$$p_{mn}^{ij} \le P_{mn}, \tag{16}$$

$$p_{mn}^{ij} \leq V_{ij} \,, \tag{17}$$

$$\sum_m p_{mk}^{ij} = \sum_n p_{kn}^{ij} \quad \text{if} \quad k \neq i, j \tag{18}$$

$$\sum_n p_{in}^{ij} = V_{ij} \,, \tag{19}$$

$$\sum_n p_{mj}^{ij} = V_{ij} . . \tag{20}$$

In virtual topology traffic parameters l_{ij}^{sd}:

$$l_{ij}^{sd} \geq 0 \,, \tag{21}$$

$$\sum_j l_{sj}^{sd} = l_{sd} \,, \tag{22}$$

$$\sum_i l_{id}^{sd} = l_{sd} \,, \tag{23}$$

$$\sum_i l_{ik}^{sd} = \sum_j l_{ik}^{sd} \quad \text{if} \quad k \neq s \,, \tag{24}$$

$$\sum_{s,d} l_{ik}^{sd} \leq V_{ij} * C \,. \tag{25}$$

- Optical paths color covering c_k^{ij}:

$$\sum_k c_k^{ij} = V_{ij} \,, \tag{26}$$

$$\sum_{ij} p_{mn}^{ij} \cdot c_k^{ij} \leq 1 \qquad \forall m,n,k \,. \tag{27}$$

Criteria of the optimalization:

- Minimizing of the delay:

$$\min \sum_{ij} \left[\sum_{sd} l_{ij}^{sd} \left(\sum_{mn} p_{mn}^{ij} * d_{mn} + \frac{1}{C - \sum_{sd} l_{ij}^{sd}} \right) \right] . \tag{28}$$

- Minimizing of the initial load (equivalent to minimizing of the maximum flow of the link):

$$\min \left[\max \left(\sum_{sd} l_{ij}^{sd} \right) \right] \equiv \max \left\{ \frac{C}{\min \left[\max \left(\sum_{sd} l_{ij}^{sd} \right) \right]} \right\} \quad \forall i, j \,. \tag{29}$$

Equations explanation. The previously presented equations are based on the principle to sustain stream and source, and also on none-conflict routing. None-conflict routing means that two optical paths included in the same optical fiber cannot share the same wavelength.

Equations (1) and (2) guarantee, that the number of optical lines, received and sent, in the optical paths of each node, at least is equal to input or output node degree. Equations (3) and (4) invoke the following problem, p_{mn}^{ij} can only exist if there is a physical fiber equivalent to our optical path. Formulas (5)-(7) are multiple equations characterizing route from the source to its destination. However, equations (8) to (12) are responsible for packet routing in the virtual network, they guarantee that it is possible to overload path channel with many different flows of steam. Equation (13) requires that the optical path could be assembled with only one color. Formula (14), restricts a number of colors, so colors utilized in different paths are mutually exclusive and are cancelling each other in one physical connection.

Equations (15) and (16) describe two possible optimalization criteria. In formula (15) in the deepest parenthesis, the first component is tied to propagation delay of connection ***mn***, which is utilized by the optical path ***ij***. The second component is tied to queue delay and also during transfers of the packets through the optical link ***ij***, using for each optical path the following queue type M/M/1. If we assume, that routing will be base of the shortest path in physical topology then meaning of this value p_{mn}^{ij} will be established. Additionally, if we omit all of the delays in the optimalization queue in formula (15) and if we make simplification to the formula $\sum_{sd}\sum_{ij}\sum_{mn} l_{ij}^{sd} \cdot p_{mn}^{ij} \cdot d_{mn}$, which is consider as a linear programming, in which all of the variables V_{ij} and c_k^{ij} require complete numerical solution, but the variables l_{ij}^{sd} do not require them.

The role of the function described by (16) is also non-linear and it is described as a maximum size minimalization of any flow through optical path. This is also connected with the virtual topology creation process, which has to maximize accessible load, if the matrix flow is increasing.

Conclusion

In conclusion to the presented analysis, we could presume that modern metallic transmission environment does not meet the requirements presented before high capacity transmission environment. Therefore it is required to utilize high capacity transmission environments based on the optical cables. The high efficiency could be achieved only if use wavelength methods for multiplicity divisions.

In order to use completely all the features of the high capacity optical network, we are required to build them on the base of irregular physical topology. Therefore, the design of the logical topology is not only limited to description of the network that connects particular nodes, but also requires the description of the possible ways to implement logical topology, based on the physical source. Stability of the topology, guarantee perfect minimalization of the routing messaging procedure in the network.

Therefore, the importance for real time help desk services, such as voice transmission, videoconferences or e-commerce, makes virtual topology the only optimal solution. In another work, the attention was focused mainly on the resistance toward fault-tolerance communication, definitions and analysis of the standard topology.

References

[1] Hajder M., Mazurek M., Dymora P., *Virtual topologies of multinode wide networks*, Poznań University of Technology, Poznań, (2002) 197.

[2] Bannister J.A., Fratta L., *Topological Design of the Wavelength-Division Optical Network*, in proc. IEEE INFOCOM'90, San Francisco, CA., (1990) 1005.

[3] Mukherjee B., Banerjee D., Ramamurthy S., Mukherjee A.: *Some Principles for Designing a Wide-Area WDM Optical Network*, IEEE, (1996).

[4] Xin Y., Rouskas G., Perros H. G., *On the Design of MPlS Networks*, Department of Computer Science North California State University, (1997).

[5] Acampora A.S., *A Multichannel Multihop Local Lightwave Network,* in proc. GLOBECOM'87 Tokyo, Japan, (1993).

[6] Marsan M.A., Bianco A., Leonardi E., Neri F., *A Comparison of Regular Topologies for All-Optical Networks*, in proc. INFOCOM'93 San Francisco, (1993).

[7] Karasan E., Ayanoglu E., *Performance of WDM Transport Networks*, IEEE J. Selected Areas Commun., (1998).

[8] Gen M., Cheng R., *Genetic Algorithms and Engineering Optimization*, John Wiley & Sons Inc., New York, (2000).