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Publication date:
2005

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Riaz, M. T., Pedersen, J. M., & Madsen, O. B. (2005). *SQoS based Planning using 4-regular Grid for Optical Fiber Metworks*. Department of Control Engineering, Aalborg University.

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SQoS based Planning using 4-regular Grid for Optical Fiber Networks

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***Abstract* — The recent research on Structural Quality of Service (SQoS) devised many useful properties that can enhance the network performance. Three different structures have been introduced, i.e. 4-regular Grid, N2R, and Honeycomb. These structures are now well described and proposed for the next generation optical fiber based network infrastructures. In the first step of SQoS based planning, this paper describes how 4-regular Grid structures can be implemented in the physical level of optical fiber network infrastructures. A systematic approach for implementing the Grid structure is presented. We used a case study of Hals (a small town in the north of Denmark) to apply the implementation procedure. The results are quite promising for the structural based network planning. Conclusion and discussion are presented, and further research is proposed.**

***Keywords* — Communication Network Topology & Planning, Next Generation Networks, FTTH, 4-regular Grid**

1 Introduction and Background of SQoS

The copper based network infrastructures have been serving access networks for more than 100 years. The increasing bandwidth demand is leading to a replacement of existing copper based networks with fiber optic networks, known as Fiber to the Home (FTTH). The main cause of increase in bandwidth demand is the use of Internet. Coupling with Internet, new applications have been introduced and soaring up the bandwidth demand exponentially. Many countries already have taken initiatives to implement FTTH. A significant deployment of FTTH is expected in near future.

The buildup of the copper based infrastructure is mostly done in an unstructured and non-systematic manner. The existing infrastructure is lacking a consideration of overall well defined network structural properties. There has not been much concern for reliability and almost no redundancy at the access network level. With the introduction of new applications, such as remote control, alarms, tele-medicine etc., the demands of network reliability is increased [1]. Many businesses depend now on electronic communication. The failure is becoming intolerable when considering the economical losses [2].

When designing a FTTH network infrastructure, it is recommended and proposed to consider Quality of Service (QoS) at the physical level of of network. As no protocol can perform better than the underlying physical structure, the physical structure of the network should be carefully planned [3].

To address the QoS related problems, and fulfilling the future demand for communication, the concept of SQoS was introduced. SQoS deals with the most demanding network performance parameters like latency, survivability or reliability, extendibility, and scalability from a structural viewpoint. Until now the graph structures i.e. N2R, 4-regular Grid, and Honeycomb are only theoretically analyzed [4], [5], [6], but there has not been conducted any research to implement these structures in real world networks.

As a first step of the SQoS based structure implementation, a procedure of mapping 4-regular Grid structures for a physical level of network is presented. A method is proposed to extract the possible 4-regular Grid structure from the potentials of road network. The method is yet applied on a small town in northern Denmark, Hals. The results are quite promising for the practical implementation. The implementation method is tested for access networks, but the results also apply for the higher hierarchies of networks. The resulted network is not a complete 4-regular Grid but a subgraph of 4-regular Grid. 4-regular Grid structures have some nice properties but it is relatively hard and costly to embed. The resulted network, however, does not contain fully 4-regular Grid structure but inherits some of the important properties and can be extended to the 4-regular Grid structure later on.

In Section 2, a short introduction to 4-regular Grid structures is presented. The topological routing scheme in 4-regular Grid is explained. After describing the 4-regular Grid structures, the implementation procedure is explained step by step in Section 3. The results are presented in Section 4, showing the resulting network by following the implementation procedure. The conclusion and discussion are given in Section 5. A proposal for further research is presented in Section 6.

2 4-regular Grid Structure

A 4-regular Grid structure S is modeled with node set N and line set L. Let dim_x and dim_y be positive integers. All the nodes in N are assigned a pair of coordinates (x, y) such that $0 \leq x \leq dim_x$ and $0 \leq y \leq dim_y$, and every such coordinate pair is associated to a node. Furthermore, no two nodes are associated to the same pair of coordinates. There are exactly $(dim_x + 1)(dim_y + 1)$ nodes in S. If a node u is associated to a coordinate pair (x_u, y_u), we write $u = (x_u, y_u)$ to ease the notation.

The lines of the Grid structure are given as follows: Two nodes (x_u, y_u) and (x_v, y_v) are connected by a line if and only if $|x_u, y_v| + |x_u, y_v| = 1$. The structure used for our implementation will not be regular due to the corner and edges nodes. Despite not being regular, we still refer to it as the 4-regular Grid. The Grid can be drawn in many ways. Later, we will also use the word "Grid" as a short form of writing "4-regular Grids". The most suitable layout for our implementation is rectangular, composed with rows dim_x and columns dim_y. The total number of nodes in Grid is $|N| = dim_x \times dim_y$, and links is $|L| = 2dim_x dim_y - dim_x - dim_y$.

2.1 Routing, restoration and protection

Topological routing schemes can be used in Grid networks. Topological routing relies on the node address and topology of a network, without using the table lookup. This scheme is very useful in large-scale networks, because it minimizes the tables of complete networks, which is a resource consuming task [7], and also works for restoration and protection. The routing scheme is explained in [8] as:

Let p be a packet with destination (x_v, y_v). Whenever a packet p is received by a node (x_u, x_u) it is determined if it has reached its destination. If this is not the case, it is forwarded using the following algorithm. This also applies if (x_u, y_v) is the source node.

- Let $\Delta x = x_v - x_u$ and $\Delta y = y_v - y_u$.
- If $\Delta y < 0, p$ can be forwarded to $(x_u, y_u - 1)$, and if $\Delta y > 0$ to $(x_u, y_u + 1)$.
- if $\Delta x < 0, p$ can be forwarded to $(x_u - 1, y_u)$ and if $\Delta x > 0$ to $(x_u + 1, y_u)$.

If $\Delta y = 0$ or $\Delta x = 0$, the path is uniquely found. Otherwise several path exists. The protection and restoration are handled by different algorithms, depending on the type of failure. These are explained in [7], [9], [10].

3 Implementation Procedure

One of the main properties of Grid structures is being planar. This makes it relatively easier to embed in real world networks. To avoid the time consuming manual approach of embedding, the use of digital spatial road maps are proposed. The implementation procedure of Grid structure is explained in the following steps:

A. Digital road map network

A potential for network structures can be all the roads in a specific area where a network infrastructure is supposed to be planned. The road networks is a good base for the physical network structure; they are accessible to most of the houses and usually follow shortest paths to reach. It is relatively faster to deploy infrastructure traversing the road network due to the easier deployment and less complication in legislation issues. Other potential paths e.g. railway-tracks, footpaths etc. can be included in the road network. The road maps can be obtained in digital form, called digital road maps containing spatial road data. In digital maps these are usually represented by vectors. The vector maps are composed with small chunks of segment lines connected to segment points. The segment points are assigned their coordinates, which specify their geographical location. This information, called geographic data, is used later to support the Grid implementation.

B. Node degree of the road network

After obtaining the digital road network the next step is to start with the node degree of road network. The number of lines connected to a node is called node degree. The pragmatic estimation of average node degree in a road network is ≈ 3. Grid structures have maximum node degree 4. In the physical structure, nodes with degree > 4 are adjusted by removing lines which are less probable to be used. However, the road networks of degree 4 or more are found usually quite rare. The process of removing lines is usually done manually. An approach to make it automatic is to set a priority to roads, the low priority roads which are greater than degree 4 are removed.

C. Creating virtual Grid and sizing

To map the road network structure into Grid structure, a virtual Grid is first created. The size of Grid is important for supporting later steps of implementation, and the size of Grid depends upon two parameters: spacing and total size of Grid. To find the spacing between Grid's cells the least distance between any two crossing points is found in the road network. The cell size should be kept smaller than the distance between these two points. Making the size smaller will help for assigning the required number of nodes in Grid cells. When the cell size is determined, the total size can be determined from dividing it by the geographic size of road network. The Grid must cover the whole area where the network is planned.

D. Assigning nodes and mapping

In the first step, the road crossing points are identified. This is done by finding nodes with degree > 2 in the road network. These crossing points are then mapped to the nearest node in the Grid cell. After the crossing points are mapped, the roads are mapped to the nearest Grid lines. This is done by calculating the distance between Grid line segment points and road lines segment points. In Figure 1, the general scheme for mapping is illustrated.

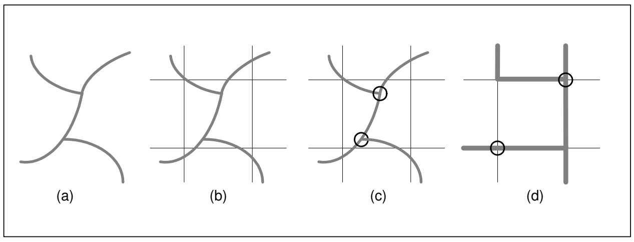

Figure 1. Assigning crossing nodes and mapping.

A few exceptions can occur to the general scheme of assigning crossing point nodes and mapping. As an example: in case of two roads sharing the same Grid line or two connection nodes sharing the same Grid node, the exception is made by finding the second or third nearest line or node. An example of implementing Grid structure is illustrated in Figure 2.

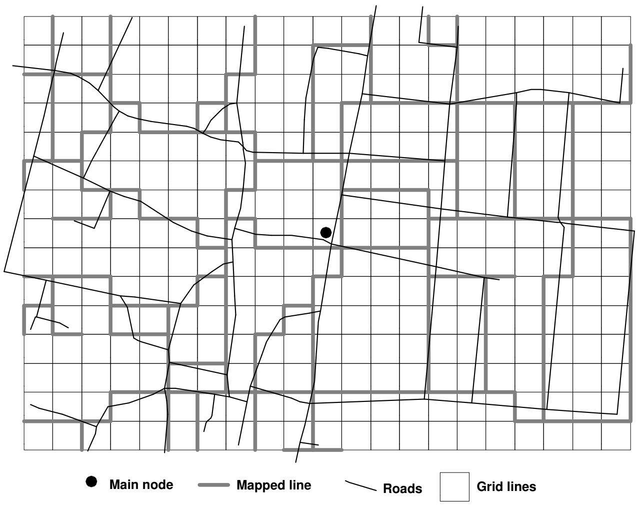

Figure 2. An example of implementing Grid structure in Hals.

E. Identifying Grid's distribution nodes and removing unused lines

When crossing points and lines are assigned, all the unused lines and nodes are removed from the Grid. The remaining nodes in the Grid, where the connection points are assigned, are now renamed to Grid's distribution nodes. Figure 3 shows the removal of unused lines and nodes.

F. Network termination assignments

Network Terminations (NTs) are assigned to the nearest Grid's distribution nodes. NTs are grouped into different classes of users: ordinary households, public institutions, business etc. The households are not given any redundancy due to a higher cost. In [11], we have shown how the redundancy can be

Figure 3. Reduction of unused lines and Grid's distribution nodes identification.

obtained by using a combined wired and wireless solution in a cost effective way. The public institutions and important businesses should be prioritized for the redundancy. With the increasing use of telerobotics [12], [13], teleoperations [14] and other control applications like alarms and remote surveillance etc., the demand of reliability is becoming more critical. The requirement of higher reliability can be provisioned by two or more independent lines.

G. Further reduction and distribution network

The outcome of the previous steps is all the possible physical paths mapped into Grid structure. This would be the maximum potential which the road network could offer mapped into the Grid structure. Obviously not all the paths would be used. The costly and lengthy paths should be avoided, therefore the fiber laid from NTs to main nodes should follow the shortest or cheapest paths.

To estimate the needed fiber in physical lines for the network, the Grid's routing scheme can be used. By using topological routing [7] the shortest path can be obtained. The fiber laid in network should follow the shortest path. Even though the obtained network is not a complete Grid, it is still possible to find the path using protection and restoration algorithms, but it will not guarantee the shortest path always. A less complicated and efficient way is to use the shortest path algorithms to find the shortest path. A distribution network is established and provided redundancy with at least two independent paths, as shown in Figure 4. The distribution network will be used to connect public institutions and businesses due to their high QoS and reliability demand.

Figure 4. Including distribution network in Grid network.

Figure 5. Resulting network after following the implementation procedure.

4 Results

The implementation procedure is applied in a central part of Hals. The implementation procedure is mostly tested by a semi-manual approach, and the resulting network is illustrated in Figure 5. The resulting network shows the structural properties of the road network supporting the Grid structure. The mapping of the Grid structure is considered only at the physical level of network. It has been tried to ensure the reliability at the physical level. Any failure at physical level would restrict the reliability at the higher levels of the network. Today, the physical structure of access network is mostly based on tree structures, which do not provide redundancy and good structural properties. If the Grid structure is mapped onto the tree structure, the performance would not be improved much. It is mainly because the physical structure would not support the logical level of structure. Therefore the argument made by SQoS based planning of looking the structure at the physical level is quite valid [4].

The results show that it is difficult to obtain a fully regular structure for physical networks due to the certain nature of real world road networks. It follows that the resulting network is not regular either. But it is relatively easy to obtain a regular structure in the future by including more lines and nodes. If the network is planned without considering any structure, it becomes harder and more expensive to extend the network and guarantee the future's increasing demand of QoS and reliability.

In the resulting network, shown in Figure 5, the nodes are placed at the crossing points of roads. But in real-world the situation is bit different, nodes are not placed at the crossing points, but they are usually placed at some distances. This issue can be handled by compromising the placement of lines at both sides of roads. A scheme for placing lines at the both sides of roads is illustrated in Figure 6. This reduces the reliability of mapped structure in some little extent.

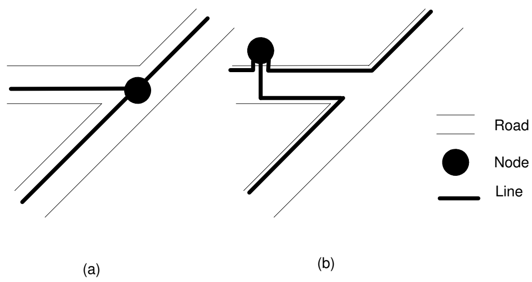

Figure 6. Re-mapping for line and node placement.

5 Conclusion and Discussion

In this paper, we have shown a general scheme for mapping the Grid structure onto the physical level. It is described how the Grid structures can be implemented in access networks, in a rather straight-forward manner, leading to topologies with nice and well defined properties. Yet, the implementation procedure is applied using a semi-manual approach. The implementation procedure seems quite promising as a base for fully automated implementation. In this paper, we considered mainly access networks. However, the same method can be applied to the higher hierarchies of networks e.g. metropolitan and long-haul networks, where the reliability demand is even higher. An advantage of Grid structures is the possibility of topological routing and algorithmic support for restoration and protection in case of failures. The implementation of Grid structure can break the limit of using simple rings, which are mostly used for supporting the topological routing and restoration. Moreover, if the structural properties of a physical network are known, the possibility to ensure the quality of service is improved while looking at the integration of different physical and logical levels of network.

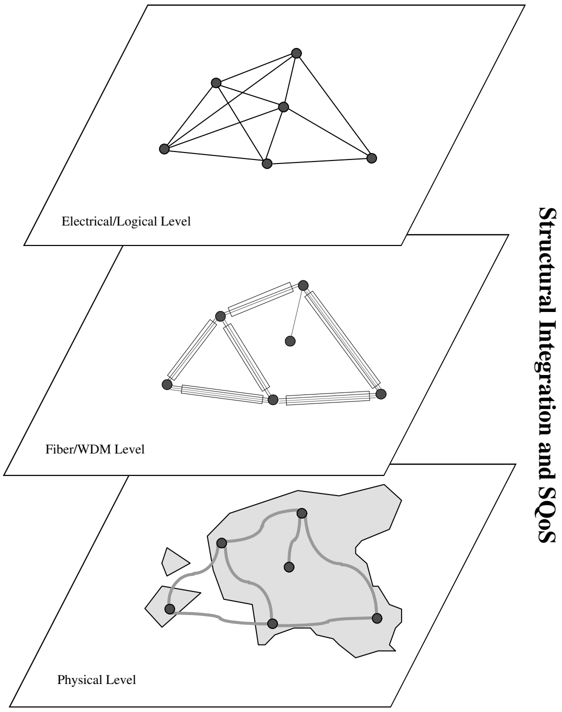

Figure 7. Different levels of network and structural integration.

So far the Grid structure is implemented at the physical level. The next level is fiber optic cable placement, called fiber level. Even a fully regular Grid structure can be obtained at fiber level with employing different layouts by stretching multiple fiber in a single physical line, but the relationship between physical level and upper levels should be as close as possible in order to achieve the maximum degree of SQoS. In fiber level, using multiple wavelengths of light in a fiber optic - known as Wavelength Division Multiplexing (WDM), the deficiency of obtaining regular structures can be improved further, and the same phenomenon continues to the higher levels. Therefore, all the levels should be seen in an integrated fashion. An illustration of different levels of network concerned for SQoS planning is given in Figure 7. Having the knowledge of structures at each level let us know what the network is offering regarding QoS and reliability.

6 Further Research

The SQoS based planing using Grid structure at physical level is presented in this paper. The next step is to look at the fiber level. It should be investigated that to what extent it is possible to obtain the complete Grid in fiber level. Furthermore, similar investigation should be conducted on the higher network levels, i.e. WDM level, and electrical level.

The possibility of implementing other structures introduced by SQoS should be investigated. A comparative research should be conducted on using other structures in order to know which is the better suited structure for the particular level of network.

Further modeling and simulations are required in order to test the presented implementation procedure for fully automated implementations of Grid structure. One of the important issues in network planning is the cost. The cost analysis of SQoS based planning and traditional planning should be conducted as well.

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