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SQoS as the Base for Next Generation Global Infrastructure

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Abstract. The convergence towards a unified global WAN platform, providing both best effort services and guaranteed high quality services, sets the agenda for the design and implementation of the next generation global information infrastructure.

The absence of design principles, allowing for smooth and cost efficient scalability without loss of control over the structurally based properties may prevent or seriously delay the introduction of globally available new application and switching services.

Reliability and scalability issues are addressed from a structural viewpoint. The concept of Structural Quality of Service (SQoS) has been introduced as an attempt to establish a base for reliability management in complex large-scale communication infrastructures. Two approaches to provide SQoS are introduced, and results for the *N2R(p;q;r)* family of vertex symmetric graph structures are presented and discussed.

Finally, some relevant research initiatives are presented.

1 Introduction

The IT infrastructure has evolved from a set of more or less vertically integrated networks dedicated to specific application service types, towards an interworking set of horizontally integrated and converging infrastructure platforms, common for literally all services. The complete digitalisation of voice and video services makes this evolution possible and forms the base for convergence. It also opens up the potential for bringing data and telemetric services with strong QoS requirements into the WAN area, previously limited to the LAN area due to the relatively high costs in dedicated leased-line based WAN infrastructures.

The backbone WAN networks are typically built as interconnected sets of optical rings. The structure originally followed the hierarchical structure in the telephony networks, but is evolving more and more in direction of ad hoc networks, not following an overall commonly agreed upon architecture. This makes the possibility of establishing well-specified global infrastructure services with high QoS demands increasingly difficult.

Under existing policies of a liberalised telecommunications market, this could lead to a replication of the existing architectures as well as an infrastructure only covering the most profitable areas in the densest populated parts. That would prevent the possibility of generally extending services with stronger SQoS demands to the wide area on a global scale and thereby missing a large-scale new market potential. Both industry and the public authorities have now finally recognized this situation. EU initiatives are in progress for the coming period to find solutions to this problem.

The evolution of new telecommunication services is causing a fast increasing dependency on the availability of the services for the society. Likewise, it is recognized worldwide, that the need for an efficient and rapid deployment of state-of-the art telecommunications infrastructure is a prerequisite for the further development of the telecommunication market. Although the liberalised market has been successful in developing new services, the theory of a market driven evolution of the telecommunication infrastructure, based on a competitive market, has shown itself to be a failure and requires reconsideration [1], [2], [3]. Some of the consequences of the present situation include increased costs due to parallel infrastructures, concentration of the competition to the larger towns, and the lack of transparency prevents large-scale expansion of demanding applications across multiple-operator based networks. Like almost all other fundamental and similar wide area services, such as roads, supply of water and electricity, the necessary telecommunication infrastructure has to be a common, shared resource, available on equal terms for the service providers in competition, eliminating geographical barriers. Regarded from the user side, equal rights on fair terms for access to fundamental infrastructures is the only realistic way to establish the free choice of service providers, and, hence, to increase competition.

The demand for real broadband capacity, supplied on top of ring- or mesh structured optical fibre nets, has up to now been limited to the operators backbone networks, expanded on an ad hoc basis into the limited high-end professional market. For the SME's and residential users traditional low speed modems, xDSL and CATV modems using the existing tree shaped copper infrastructure have been sufficient.

The exponential growth in the demand for IT communication has reached a point where the existing copper based underlying infrastructure needs to be replaced with optical fibres in the local loop. This replacement will take a minimum of 5 to 10 years in order to establish a complete future proof infrastructure, reaching all potential customers and probably longer if a coordinated effort is not established in order to minimize this rather costly process. For dependable distributed network applications, long-term reliability and availability requirements need to be specified. From a provisioning viewpoint, policies for operation under failure, supporting graceful degradation, are to be specified. Provisioning services to dependable applications should be based on pre-negotiated QoS contracts, including guaranteed reliability levels based on thorough reliability modelling, involving the current customer portfolio, failure policies, as well as the underlying network infrastructure.

This situation calls for new planning methods and tools in order to speed up the process and to ensure the potential for providing new demanding WAN based services and applications. There is a need for a common set of guidelines for the planning and installation of telecommunication infrastructures, providing consistency and transparency.

One major factor to be investigated here is the topological requirement for supporting QoS in WAN. Due to prohibitive computational requirements of algorithms, it is today impossible to ascertain the consequences of topological restructuring, including failures, in large networks. Application of graph structures with special properties in the infrastructure design may solve this problem.

2 Structural Quality of Service, SQoS

Structural Quality of Service, SQoS [4], or sustainable QoS [5] is dealing with parameters primarily related to architecture and structural properties in the infrastructure in order to support QoS. The SQoS concept should, in this context, not be confused with the recently introduced concept of Secure QoS using the same abbreviation.

In this context, SQoS forms the base for support of a variety of services established across the infrastructure, demanded by the communication services. Requirements relate primarily to delay, reliability and capacity issues. Explicit knowledge of the inherent topological properties is important in order to provide a viable platform for providing differentiated QoS.

The backbone infrastructure in a WAN network today is typically built as a meshed network interconnecting a number of local fibre optical ring structures, extending into part of the local access WAN area. The nodal redundancy is obtained either by duplication of equipment or by geographical diversity. Although the backbone structure in general allows for at least triple connectivity globally, most operators have chosen a service provisioning strategy based on ring structures at this level as well. One reason being, that this choice is supported by automatic and fast restoration algorithms on the optical fibre level, and the fact that the meshed structures in general are build in an ad-hoc manner, causing complex time-consuming restoration algorithms, generally unsupported. This is preventing the full utilisation of the inherent potential for higher SQoS. For the support of mass driven best effort demands this is sufficient, given that the last mile access in general only provides for single line connectivity. For higher SQoS demands, time-consuming restoration algorithms cannot compensate for the permanent availability of more, physically independent lines.

In the MAN area a straight forward possibility is to combine the wired and the wireless based network in a joint service provisioning platform, offering at least the potential for dual independent access for the end-user, and to a large extend even more. In general, wireless communication technologies suffer from limited bandwidth and less reliable link services, but could on the other hand play an important role for improving the overall reliability of an entire communication facility, since failures in wireless links are of a different nature than in wired links.

This is opposed to the present situation, where wireless access networks are seen as competing with the wired access networks. The prerequisite is a careful planning of the placement and linking of the base stations in the radio-based networks to avoid dependencies on allocated channels in the wired networks.

A promising complementary approach is to apply structuring principles beyond the level of ring network topologies. For economical and practical reasons, a WAN today only has the possibility for providing a very limited set of physically independent paths, except in the highest network hierarchy. Analysis of reasonably large geographical areas has demonstrated that the next generation global infrastructure can be expanded far beyond the present economical and practical limit where only tree structures have been affordable. The prerequisite is careful planning of the foreseen FTTH, regarding it not only as a last mile enterprise, but also as an essential part of an overall high quality infrastructure [6].

3 Structured Mesh networks

To avoid the complexity in the meshed networks in general, an approach based on vertex symmetric graph structures is presented, demonstrating that rather large structures can be handled with a realistic computational effort.

The overall end-to-end user communication patterns are a combination of an almost unlimited set of point-to-point, point-to-multipoint and multipoint-to-multipoint relations.

Seen from a logical point of view, this corresponds to a fully connected graph and the exercise is to map this into a suitable graph with lower connectivity.

In order to provide higher reliability the potential number of independent path connecting a node with any other node plays an important role. In practice, the upper limit is 3-4 independent paths.

The classical routing algorithms are able to find a shortest path between any two nodes in a connected graph of even relatively large size. The problem of finding two or more independent paths is at least an order of magnitude higher.

In this paper, we will only consider a metric based on number of hops, as the focus is on structural properties. Two approaches and considerations will be presented. The first is based on a maximum spanning tree approach, in order to minimize the path lengths; the second is based on vertex symmetric graph structures, in order to obtain global properties.

3.1 Spanning tree

In the first approach we look at a generic maximum spanning tree, *SPT(d;N),* for graphs with nodal degree *d* and order N. The reason for this approach is that it is a very efficient way to make an optimal distribution design out from a specific node.

Furthermore, it leads to a design able to ensure low upper bounds for the maximum distance even in the case of a degraded network with *d-1* lines out of order.

The maximum number of nodes, *N*, covered, with a maximum of *h* hops from the root, is:

$$N = (d*(d-1)^{h}-2)/(d-2);\ d>2$$

The spanning tree can be regarded as a set of *d* root interconnected sub-trees each with *d-1* branches and leaving a freedom in interconnecting the nodes with distance *h* from the root to *d-1* other nodes with the same distance (Figure 1).

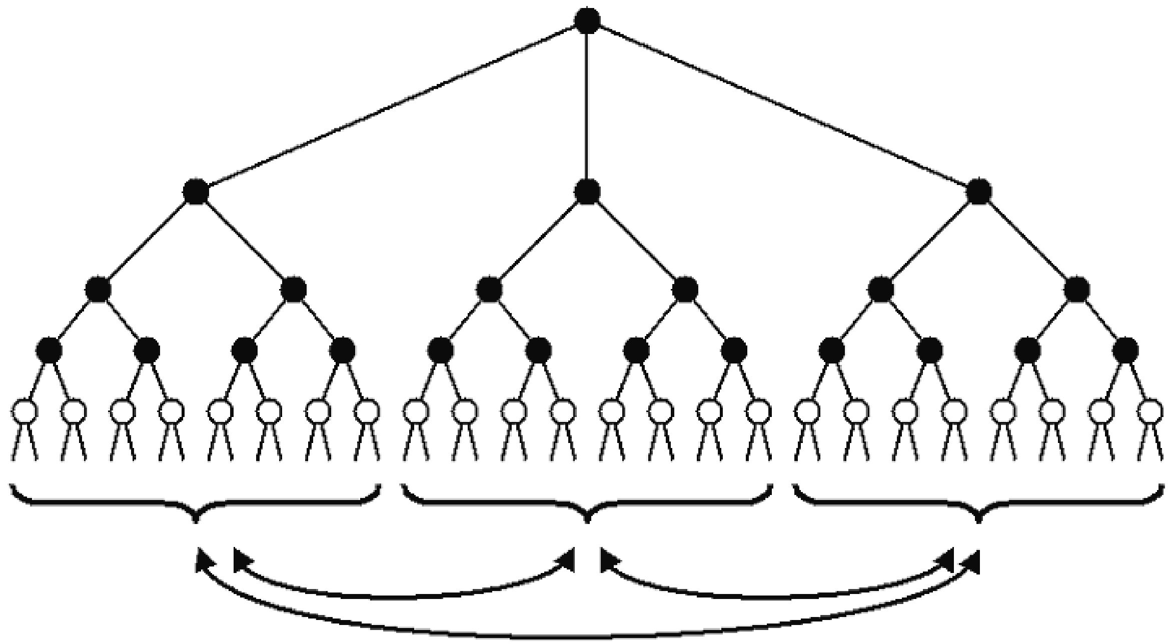

Figure 1 *The balanced SPT(3,46) with a height h = 4*

Interconnecting the leaf nodes in one sub-tree with leaf nodes in distinct sub-trees ensures that from the root there will be *d* independent paths to any leaf node. The shortest path to such a node has the length *h*, and the other *d-1* paths will have the length *h+1*. It is easy to se that there also exist *d* independent paths from the root to any other nodes in the spanning tree. One is the shortest path with the length *h'* corresponding to the actual position in the spanning tree. The remaining *d-1* paths have a length of *2*h-h'+1*, leaving a worst case of *2*h.*

The design so far only assures SQoS parameters for the root node relations to any other node, but without any guarantee of obtaining the same set of parameters for other nodes in the graph. In general, it is not possible to find a design for a complete maximum spanning tree providing this SQoS property on a global base. Thus in order to obtain global SQoS, a group of vertex symmetric graphs will be highlighted.

3.2 Vertex symmetric graphs

A vertex symmetric graph is a graph which looks the same viewed from any node. In networks based on these structures, we can utilise the symmetric properties and simplify the routing scheme. In this paper focus will be on a family of vertex symmetric graphs *N2R(p;q;r)*, based on interconnected rings.

3.3 N2R(p;q;r)

The *N2R(p;q;r)* family is based on two rings of order p, interconnected in accordance with the following scheme (Figure 2):

Nodes: $\{N_1[i] \cup N_2[i]\}$
Lines: $\{L_{11}[i] \cup L_{22}[i] \cup L_{12}[i]\}$
$L_{11}[i]$: *Line* $(N_1[i], N_1[i+q \bmod p])$ *(inner ring)*
$L_{22}[i]$: *Line* $(N_2[i], N_2[i+r \bmod p])$ *(outer ring)*
$L_{12}[i]$: *Line* $(N_1[i], N_2[i])$

$0 \le i < p$; *p, q and r* are integers without common prime factors; $p>2$;
$1 \le q < p/2$; $1 \le r < p/2$.

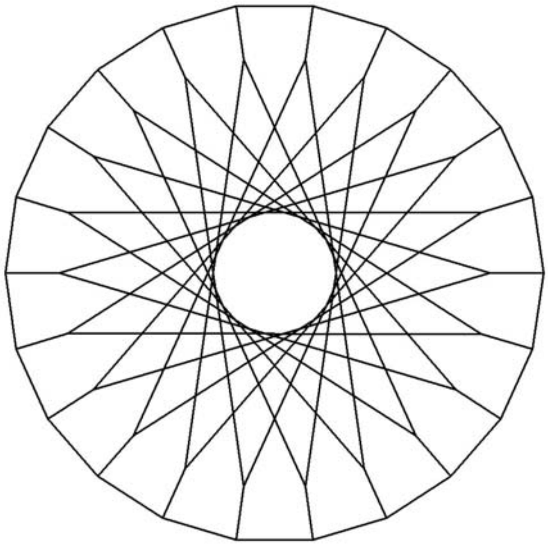

Figure 2 *N2R(22;9;1)*

Some properties of *N2R(p;q;r):*

N2R(p;q;r) is a subset of vertex symmetric degree-3 graphs;
N2R(p;1;1) correspond to the classical double ring architecture;
N2R(5;2;1) correspond to the Petersen graph;
$N2R(p;x;y) \equiv N2R(p;y;x)$;
$\forall x \exists z \mid N2R(p;x;y) \equiv N2R(p;1;z)$.

The *N2R(p;q;r)* family allows for the provisioning of a simple routing scheme, with global knowledge of distances and independent paths across the network and therefore also a predictable and specified base for delay and reliability calculations. The highest SQoS level to be provided on a global scale in *N2R(p;q;r)* is a triple set of dedicated independent paths between any two nodes with a predictable upper and lower limit for the distance variations between the 3 paths.

4 Simulations

A complete analysis has been conducted of *N2R(p;q;r)* for *p≤500* and selected values of *p* up to1000, calculating the distance metrics.

The number of variants of *N2R(p;q;r)* has been calculated for all values of *p* up to 5000 (Figure 3) and an estimate of the calculation time for all values of p up to 1000 on a standard PC is presented (Figure 4).

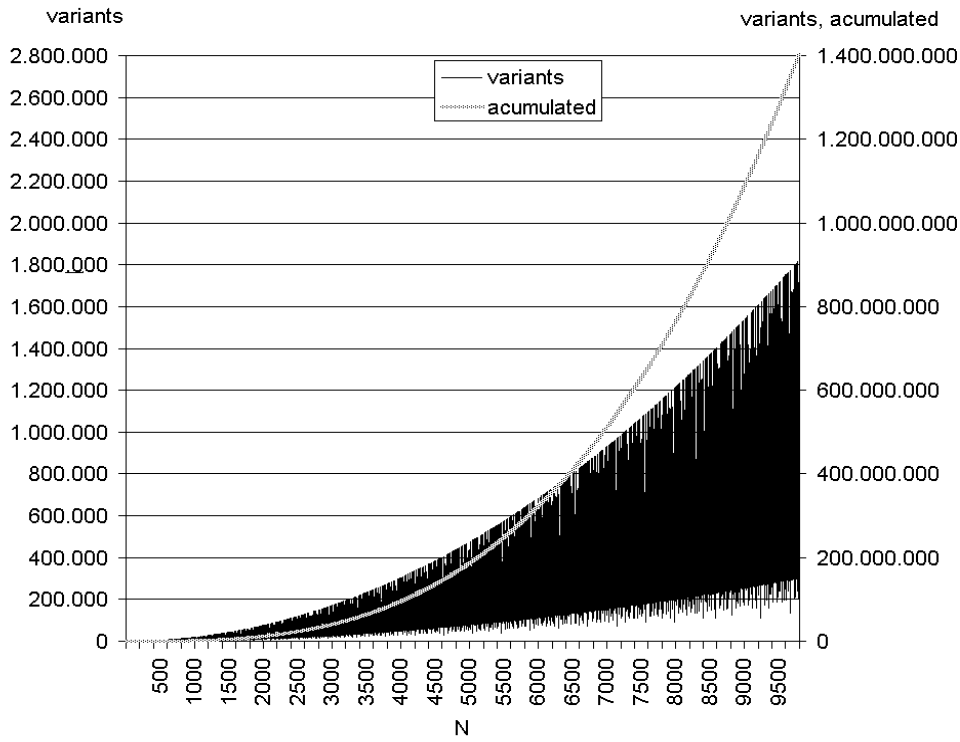

Figure 3 *Number of variants in N2R(p;q;r)*

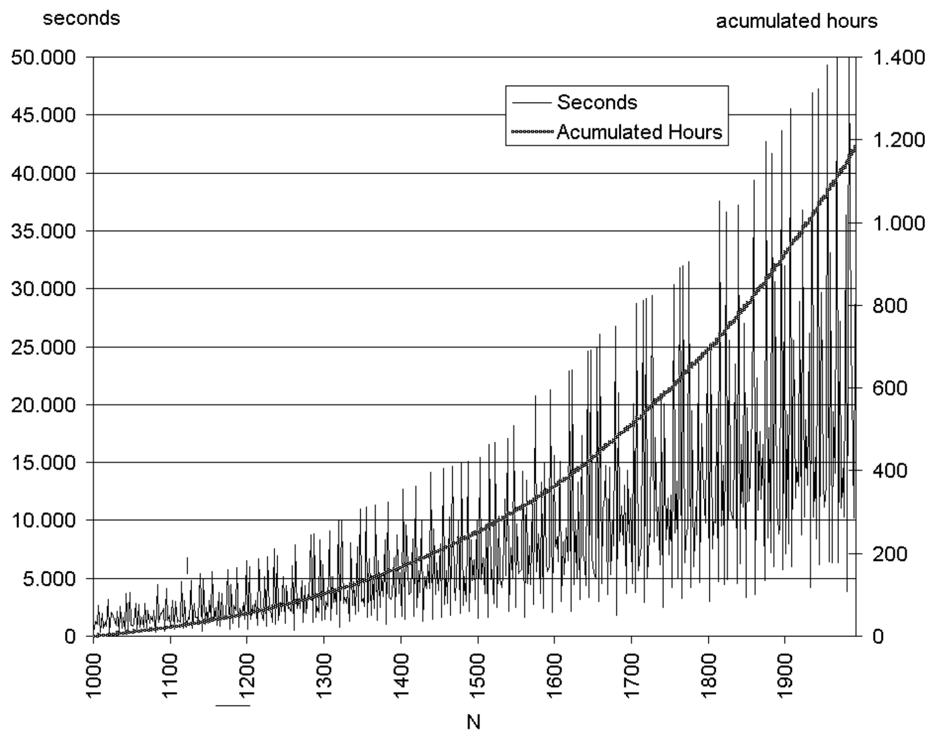

Figure 4 *Calculation time N2R(p;q;r)*

For each *p*, the *AvgNOH* (Average Number of Hops) and the diameter have been calculated for all variants. An example can be seen in (Figure 5). In this presentation, only the shortest path of the potential three independent paths is taken into account in the *AvgNOH* calculation.

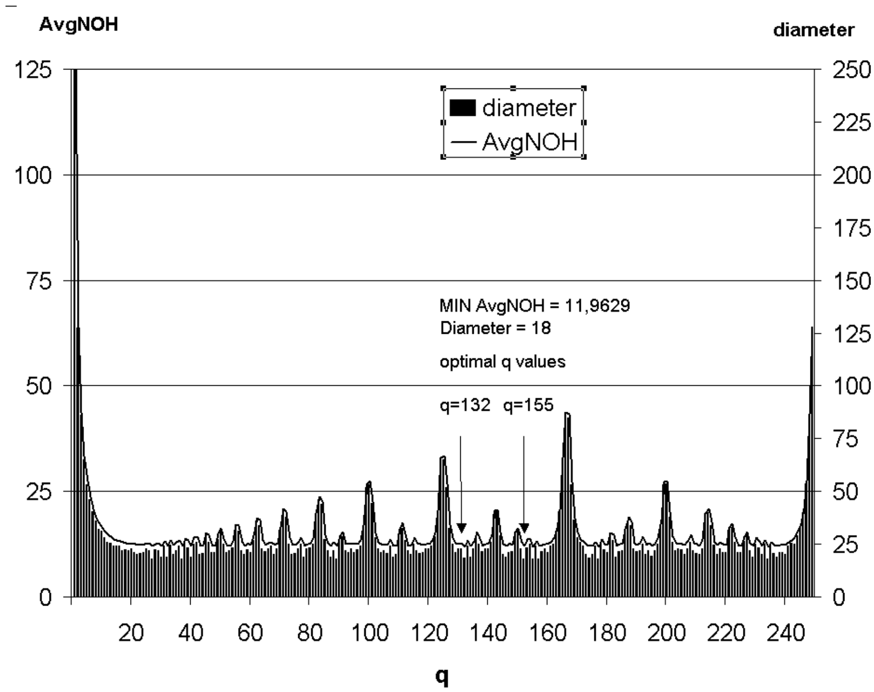

Figure 5 *Diameter and Average number of Hops in N2R(499;q;1)*

In order to have an absolute reference value for an efficiency measure, *eff*, for *N2R(p;q;r)* the *AvgNOHmax SPT(3,N)* was calculated for the corresponding balanced spanning trees (Figure 6).

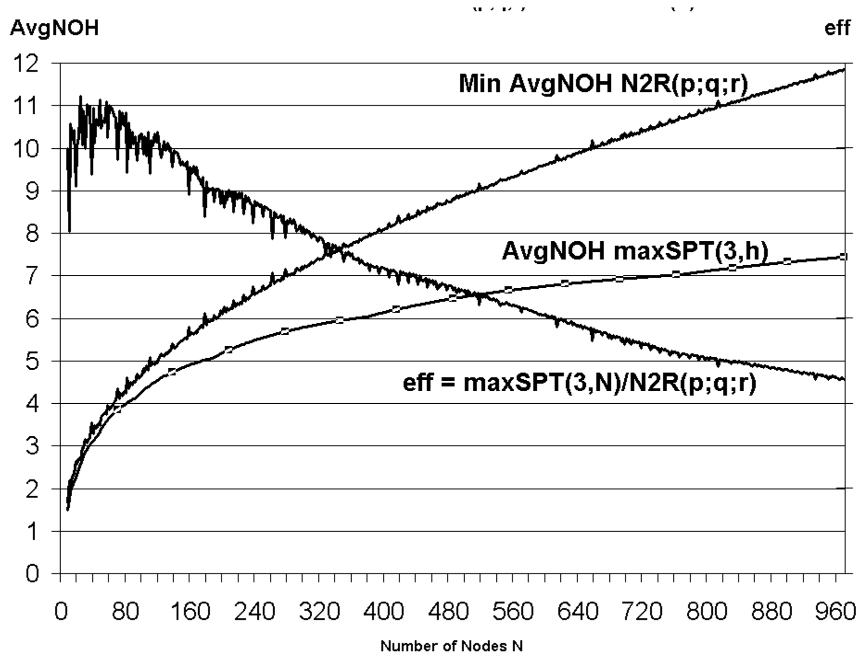

Figure 6 *Network efficiency in N2R(p;q;r)*

5 Results

The analysis and simulation of the *N2R(p;q;r)* family documents that this group represents an interesting potential base for networks with global SQoS. The efficiency with respect to *AvgNOH* is not far from the theoretical maximum for even relatively large meshed networks with the same size and order. For networks of order up to 100 the efficiency is over 90%. For networks of order up to 300 the efficiency is over 80%. The variation of the efficiency is relatively high within the variants for a given order (Figure 6).

With proper choice of parameters, considerably better results can be obtained compared to the actual practice based on rings, double rings or other types of structural approaches like the honeycomb networks [7], when the comparison is done for static structures of the same order. With a careful mapping into the physical environment this property can almost directly carry over into the economy of implementing the network.

The difficulties in general with the *N2R (p;q;r)* family are with respect to scalability, and hierarchical structures. In general it is not possible to add a limited number of nodes to an existing configuration without a complete rearrangement of the lines.

6 R&D initiatives

As part of a Danish national program [2] for promoting a modern IT based society, an initiative has been taken to analyse and design a new access network architecture in the local municipalities of the North Denmark region (6000 km^2 and 600.000 inhabitants) taking advantage of the opportunities in the situation. The outcome is a strategic long-term development plan for the area. An important element in the plan is a new fibre optical WAN access network with FTTH, carrying an identified set of virtual networks reflecting the variety of SQoS demands of a common infrastructure.

A detailed analysis of networks with a high SQoS potential is provided, in order to investigate the viability of a systematic approach for a specific representative area [8]. As a special case, the Swedish model [1] is analysed based on a logical square structure with local recursive refinements.

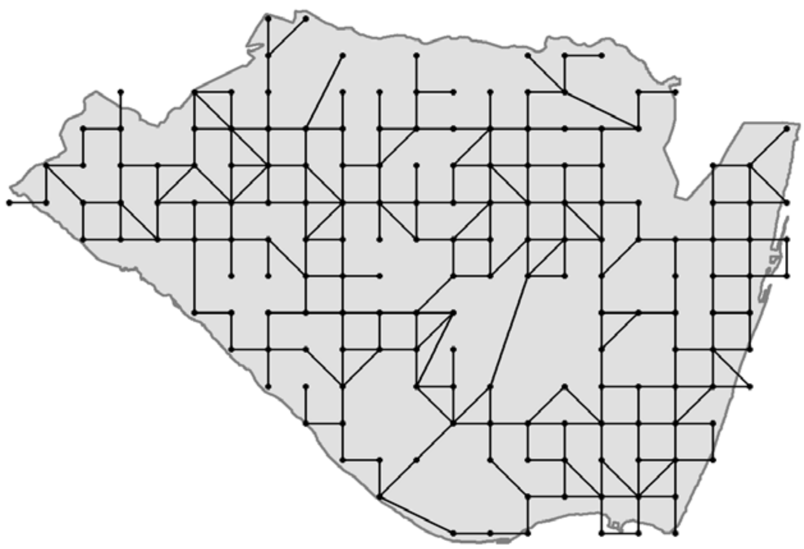

Figure 7 *Analysis of the municipality of Hals after a modified Swedish model*

Ongoing research in the SQoS group at Aalborg University investigates routing in networks with global structural properties; this includes simplified distributed routing schemes for best effort traffic and efficient routing schemes for multiple independent paths, as well as hierarchical topologies and limits-to-growth problems.

7 Concluding remarks

The introduction of the SQoS concept points to new systematic approaches in order to create support for dependent applications with high-reliability service demands. Seen from a real-time networking perspective this kind of design makes it possible to provide much better estimates of critical parameters.

A similar structural approach has already been taken in the area of high performance distributed computer architecture, and some results from this area can be transferred into the networking field [7], [9].

A key focus point in the next period should be the MAN environment, the component in the global infrastructure today with lowest actual SQoS potential. The need for a complete re-implementation with fibre optical technology, complemented with new wireless technology creates a historical chance to establish a complete end to end improved global infrastructure with an overall high SQoS potential. The density of branching points in the new fibre optical structures will increase from an average of app. 0,04 to 1 per sq km. By careful planning it will leave room for an extremely low cost, complementary set of lines in the WAN back-bones.

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