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On Backbone Structure For a Future Multipurpose Network

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Abstract—Telecommunications are evolving towards the unification of services and infrastructures. This unification must be achieved at the highest hierarchical level for a complete synergy of services. Therefore, one of the requirements is a multipurpose backbone network capable of supporting all the current and future services over the same infrastructure, offering high QoS levels. This paper analyzes different possibilities of a future backbone in order to find the best option among the studied ones. This option is a two level structure formed by the combination of N2R and Grid topologies which will achieve high performance levels.

Keywords— Backbone, QoS, Grid, N2R.

1. MOTIVATIONS

Synergy between the telecommunications and broadcast networks has been an issue for the main telecommunication providers around the world for the last years. Synergy involves not only the services merging but also the infrastructure behind them. Some telephony providers are an example, they offer mobile and fixed telephony services but without a total synergy since there are different backbone networks supporting each one of the services. The synergy requires that a single backbone network carries the traffic of all the different offered services by the provider. The high development of the data networks, mainly IP networks based, has allowed the different traditional services such as fixed telephony (IP telephony) or TV (IP TV) to be carried on data networks. The result has been the Triple Play providers, which offer fixed telephony, TV and data. Some of them look forward to the total synergy and they support all the services over the same backbone network, they are new or relatively new providers which did not have an infrastructure when they started to work. The traditional operators are in the opposite situation: owners of the telephony infrastructures, usually still use different backbone networks to offer telephony, TV and data. Therefore, the Triple Play providers form one of the first steps towards the synergy of telecommunications and broadcast networks.

Another important question is if the providers will move to the total synergy, why and when. Nowadays the providers have several types of networks: IP/MPLS, ATM, fixed telephony, mobile telephony, TV, etc. Hence, when an operator reaches the total synergy it will be capable of offering all the services over a single backbone network. The consequences will be a huge cost reduction due to the simpler design, planning,

development, implementation, management and maintenance tasks and a reduction of the resources employed in the network [1]. Therefore there are enough reasons to move towards the total synergy of services. But it will be a progressive adaptation since the providers have made huge investments on its current networks and they must keep them at least until they recover the investment. For instance, if we think of the recently deployed UMTS networks in some countries, it must be assumed that probably those operators which just installed the UMTS networks will not include the mobile telephony in a future single network either in a short or a medium term.

Hence, the future network will be a synergy between telecommunications and broadcast networks with a high QoS support. It will consist of several access networks using different technologies (Wireless, UMTS, Satellite, Radio, LANs...) which connect to an unique backbone network.

2. INTRODUCTION

This paper defines a potential future backbone structure which is able to merge the current and future telecommunications end to end and broadcast networks into a single network. The structure of the current backbone networks is divided into different hierarchical levels. The core of the network is usually formed by a mesh topology and the lower levels are formed by rings.

The proposed structure removes the hierarchy and proposes a flat topology at the physical level whereas it has two logical levels. The physical topology is a grid structure [2], introduced in Subsection 4-B.

From the logical point of view, the proposed scheme presents two levels. The lower level is a grid network whereas the higher level is an N2R [3], introduced in Subsection 4-A. The addition of a N2R over the grid reduces the path length compared to a flat logical structure. Average path and diameters lengths are performance parameters directly related to the delay on transmissions. The delay is one of the most critical parameters, specially for real time applications.

The proposed structure allows to easily define three independent (disjoint) paths between any pair of nodes of the backbone. This feature achieves a low probability of loss of connectivity between any pair of nodes offering a high availability.

The structure of the rest of the document is as follows. Section 3 treats the main challenges for the future backbone network. Section 4 introduces a brief summary about the main topologies involved in the proposed solution. In Section 5 the proposed backbone topology is defined more accurately. Section 6 analyzes a real case based on the proposed backbone topology. Finally, Section 7 exposes the conclusions extracted from this paper.

3. FUTURE CHALLENGES

The future backbones will be an evolution of the present data backbones. They will have to combine the best properties of all existing networks and technologies in order to create a standard system (in terms of equipment, routing, protocols, etc). The upcoming services are demanding high QoS levels, therefore, one the main issue to focus on is guaranteeing the challenging requirements of each of these services.

All the QoS characteristics related with the distribution properties can be classified in three groups: **Reliability**, **Performance** and **Security**. See Ref. [5]:

This paper only treats the first two groups, security is more related with the implementation of tools for the network than with the structure design.

The terms reliability, availability and fault tolerance are close related with the idea of a network with low probability of failure (loss of connectivity). The theoretical definition of availability as in [6] is:

Availability is the probability of the system being found in the operating state at some time t in the future given that the system started in the operating state at time $t=0$. Failures and down states occur but maintenance or repair actions always return the system to an operating state.

The standard availability required by the most of the telecommunications providers for optical fibre communications is five 9s (0,99999). This value in function of time and failures is 5.26 minutes per year outage [6].

There are two complementary methods to achieve a high availability for the different services.

The first one implies the use of reliable network elements rarely to fail and maintenance of the network. Equation (1) used to calculate the availability (or unavailability) of a system is in this case [6]:

$$A = \frac{MTTF}{MTTF + MFT} \quad (1)$$

The term *MTTF* (Mean time to fail) is the average time a component or system is operating with no failure. The standard unit for this variable is FIT, 1 failure per 10^9 hours. In function of years 1 FIT = 1 failure in 144155 years [6]. The term *MFT* (Mean fail time) also *MTTR* (Mean time to repair) is the time a component or a system is down due to its reparation. There must be a balanced relation between the two values (*MTTF* and *MFT*) for an optimal response of the network.

The second method is more related to the redundancy of the design; to have multiple choices of distribution gives a protection against possible failures. The possibility of having

alternative independent routes will reduce the probability of loss of connectivity between a pair of end systems. Hence, the designed structure must be capable of providing those different alternatives.

One of the most critical parameters at any kind of communication is the delay. If long delays exist the level of QoS of a network will be reduced and consequently affect especially the real time traffic. The delay on transmissions depends on many factors such as signal treatment by the equipment and saturation of the servers. Those factors are out of the structure design, but under the same conditions it is proved that the delay of transmissions is proportional to the number of hops (switches involved in the path) and not so affected by the physical distance between the nodes [4].

From the topological point of view the future backbone can be designed based on regular topologies. It offers several advantages, among them, the most important are two. First, it is possible to define and document well-known parameters and metrics (i.e. number of independent paths) which ease the network characterization. Besides, based on well-known metrics it is easy to compare different designs in a proper way. Second, based on regular topologies it is possible to define topological routing techniques which allow faster transmission, avoidance of complex network management tasks and reduction of packets overhead [8].

New, currently unknown, applications will appear, and some of them will be killer applications as peer-to-peer now or mobile telephony in the 90s. The future backbone must be designed capable of supporting and adapting itself to possible new killer applications.

In a nutshell, the future backbone must be designed to offer high reliability, high redundancy and also to provide a low delay. Regular topologies have the potential of easily fulfil these requirements.

4. TOPOLOGIES

This Section introduces the two topologies used to design the proposed future backbone, Grid and N2R.

A. N2R

The N2R network structure is a type of generalized Double Ring (DR) structure, it consists of two rings denoted inner ring and outer ring. Hence, the number of nodes in the N2R structure is any positive even integer larger or equal to 6. These rings each contain the same number of nodes (p). The inner ring links do not interconnect physically neighbor nodes. The links in the outer ring and the links interconnecting the two rings can be described in the same way as the DR structure, but links in the inner ring are interconnecting node I_i and node $I_{(i+q) \bmod p}$, where q is a positive integer. To avoid forming two separated networks in the inner ring, q must fulfil $\gcd(p, q) = 1$ (Greatest Common Divisor), also q is evaluated from 1 to $p/2$. See Ref. [3]. Fig. 1a illustrates an example of a scheme of this topology.

The N2R structure is used for the higher level of the backbone, selected among the different options (grid, double ring). In Section 5 all the procedure is explained in depth.

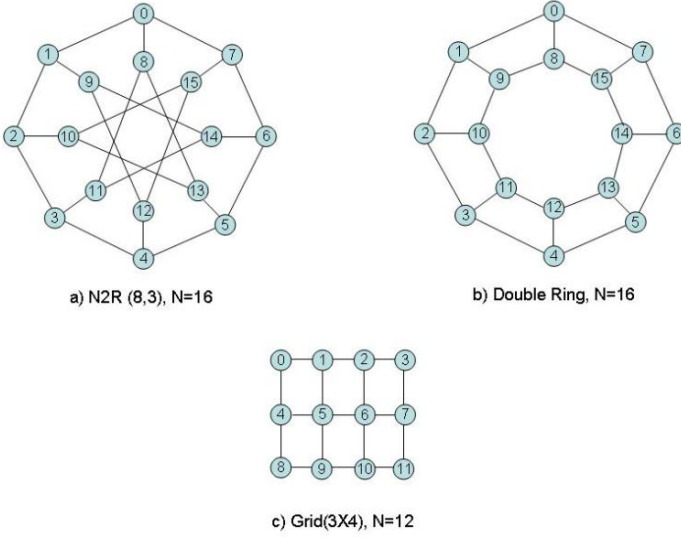


Figure 1. N2R, Double Ring and Grid Structures

B. Grid

Let dim_x and dim_y be positive integers. They define a regular grid structure S with node set N and line set L as follows. Every node in N is associated with 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 with a node. Furthermore, no two nodes are associated to the same pair of coordinates. Consequently, 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 notation. The lines of the regular mesh is given as follows: Two nodes (x_u, y_u) and (x_v, y_v) are connected by a line if and only if $|x_u - x_v| + |y_u - y_v| = 1$. For further information about grid it is recommended to read [2]. See Fig.1c

5. BACKBONE NETWORK STRUCTURE PROPOSAL

The current backbone networks are traditionally composed by several levels of rings which merge in a core mesh network. Due to the use of rings the structures do not have a high level of redundancy and reliability. These rings are double rings where the traffic flows in opposite directions. Then if one of the rings fails part of its traffic must be added to the other ring and it must be distributed in only one of the directions increasing the average distance between each pair of nodes [7].

The proposed backbone structure is not divided in a secondary physical level (the rings) and a primary level (the mesh network). It has only one physical level which is a grid($N \times M$) network.

Furthermore, from the logical point of view the proposed backbone topology has two levels. The lower level is a grid($N \times M$) network and the higher level topology is a N2R(p, q). This two levels structure allows to define three independent paths between each pair of nodes, whereas in the current topologies only two independent paths can be defined due to the use of the traditional rings.

The way the transmissions are established is to use both levels when the distance is shorter than the distance using only the lower level. Therefore, it is expected that geographically close nodes will be connected using just the grid and the opposite with further away nodes.

A failure analysis is required in order to prove the feasibility of the proposed design since, as commented above, fault tolerance is one of the main challenge of the future backbone. This analysis treats the availability of the paths to connections transmissions between any pair of nodes.

6. CASE OF STUDY

The real scenario analyzed proposes a backbone network capable to unify the services at the highest hierarchical level for the continental territory on Spain. It is the combination of N2R (11,4) at the higher level with a grid (12X12) at the lower level. The main aspect to focus on in the design of the backbone is the high availability with no significant influence on the delay of the transmissions by having too long distances (QoS).

A. Analysis

The purpose of this section is to expose some values and performance characteristics of the different possibilities to design a backbone network based on regular topologies. The best option will be analyzed to determine the feasibility of applying it for backbone structure that fulfils the requirements (introduced in Section 3) of a multipurpose backbone network.

The procedure to perform this analysis is divided in two steps. First, the higher level topology is decided and then, the combination of the two levels is analyzed giving values of for important parameters as availability or average distance.

Higher Level:

The first analysis is to decide which topology has the shortest paths distances at the higher level. It is assumed that the topology with the shortest paths is the one that will give the best results when the complete network is analyzed.

The number of nodes estimated which are needed to cover the whole area and population of the country is 22. This value is taken from previous analysis over the same territory [4] and [9].

The three cases studied are:

- N2R (11,4): The value of $q=4$ is chosen since it is the best configuration for a N2R for 22 nodes, shortest average distances [10].
- Grid : The hierarchical grid has already been studied [8], therefore it is interesting to test the feasibility of this structural design for this backbone network. Unfortunately there is not a regular square grid structure that fits the 22 nodes required at the top level, (11X2) will not be realistic. Hence, the grid (4X5) is chosen and 2 nodes are added at one of the sides.
- Double Ring (22 nodes). Fig. 1b illustrates an example of this topology.

Table 1 presents the results of the three topologies in terms of, average distance of the first, second and third independent

paths. Also, Table 1 shows the maximum value of the sum of the three independent paths.

| | N2R | Grid | DR |
|---------------|------|------|------|
| 1st Path | 1,31 | 2,24 | 1,6 |
| 2nd Path | 1,91 | 3,13 | 2,51 |
| 3rd Path | 2,7 | 4,3 | 3,83 |
| Total | 5,92 | 9,67 | 7,94 |
| Max. distance | 11 | 20 | 19 |

Table 1. Higher Level Average and Maximum Distances

The best case for the higher level in terms of average distances is the N2R (under the conditions of the example). Therefore, the complete path analysis will be performed using this topology.

Combination of lower and higher level:

It might seem obvious that the paths will be shorter using a hierarchical design than using a flat structure. In order to prove this affirmation the next analysis compares the results of the two level topology proposed and the flat logical structure of a grid (12X12), 144 nodes.

Table 2 shows the average distance of the first, second and third path of the two different cases and the improvement achieved by having a two levels structure.

| | Grid | Grid+N2R | Improvement |
|----------|-------|----------|-------------|
| 1st Path | 8,2 | 6 | 27,8% |
| 2nd Path | 8,3 | 6,16 | 25,8% |
| 3rd Path | 10,09 | 7,85 | 23% |
| Total | 26,59 | 20,01 | 24,8% |

Table 2. Average Path Distance

A flat backbone performance can be improved by adding another level above. The improvement, in this case, of the final average distance is about 25%. One of the consequences of reducing these paths is the increment of probability of failure (since the physical links of the N2R are longer). Hence, if the availability of the chosen option is below the standard requirements, the design will not be feasible.

The probability of loss of connectivity calculated is based on physical cuts of the fibre, possible hardware failures of the nodes (switches) or amplifiers and average distances of the different paths. To be able to give a value to compare with the standard limit of availability required which is of five 9s (0,99999) specific hardware is used. The MTTF (Mean Time To Failure) and the MFT (mean failure time) may vary for the different options of optical switches and amplifiers. These specific values and models are represented in Table 3. The procedure and values are taken from [11]- [13].

| Element | MTTF (FIT) | MFT (H) |
|------------------------------|------------|---------|
| Fibre | 500 /Km | 14,4 |
| Erbium Doped Fibre Amplifier | 2850 | 2 |
| Cross-Connect Switch | 502 | 6 |

Table 3. MTTF and MFT values

Table 4 shows the average length of the links and the average number of amplifiers per link.

| | Grid | N2R |
|------------------|-------|-------|
| Avg Km. per link | 133,5 | 406,5 |
| Number of Amps. | 1 | 5 |

Table 4. Average distance and Number of amplifiers per link

Based on the values from Tables 3-4, Table 5 presents the results of the availability of each components at each level.

| | Grid | N2R |
|--------------|-----------|-----------|
| Link (Fibre) | 0,99904 | 0,9971 |
| Amplifier | 0,9999943 | 0,9999943 |
| Node | 0,9999960 | 0,9999960 |

Table 5. Availability

Some of the components will have no significant influence on the system's availability due to their high reliability. In any case, the analysis is realized using all the components. In order to calculate the total value of the availability of the system, the information about the path distances and nodes at each level in the first, second and third path is necessary. These values are represented at the Table 6. There is an average of 1,31 hops per path corresponding to the links between levels not consider which have influence on the delay but not on the availability.

| | Grid | N2R |
|---------------|------|------|
| 1st Avg Hops | 3,49 | 1,2 |
| 2nd Avg Hops | 3,5 | 1,35 |
| 3rd Avg Hops | 4,53 | 2,01 |
| 1st Avg Nodes | 4,49 | 2,2 |
| 2nd Avg Nodes | 4,5 | 2,35 |
| 3rd Avg Nodes | 5,53 | 3,01 |

Table 6. Average Number of Hops

The availability of a path is calculated by Formula (2) where M is the number of different kinds of elements involved (in this case is 3: fibre links, amplifiers and switches) and N_i is the number of elements of the path (in this case: 3 fibre links, 4 switches and 7 amplifiers).

$$A_{path} = \prod_{i=1}^{i=M} A_{elementi}^{N_i} \quad (2)$$

The total availability is calculated by Formula (3):

$$A_T = 1 - \prod_{i=1}^{i=3} (1 - A_{pathi}) \quad (3)$$

The result, presented in Table 7, it presents the average availability considering 1, 2 and 3 independent paths between any pair of nodes. For further information about how the availability is calculated it is recommended to read [6].

Availability vs Investment:

| | Availability |
|----------------|--------------|
| 1 Path | 0,9919 |
| 2 Paths | 0,999934 |
| 3 Paths | 0,99999972 |

Table 7. Availability Theoretical Values

The investment necessary to deploy a network is always a restricting factor. Therefore, the fact of having an availability extremely high could not be a worthy plan in the real world; it might seem unnecessary. To plan and develop a network requires a high investment, but what is not usually considered, a priori, on the budgets is the cost of remodeling the network when the design is not capable of supporting upcoming killer applications or high demanded QoS. Hence, a preventive design, in the long term, could be economically more efficient. Thus, it is feasible to design a network with better characteristics than the required at the moment of the implementation or the expected requirements for a short and medium term.

As an example, the proposed planning of the studied case is to build first a structure as the traditional backbones. A core network, which will be the N2R connected to regional rings, interconnected at the grid level by a national ring. The difference is that the planning is taking into account that more links will be added. Those links forming the rings, at the conclusion of the network they will become a part of the grid structure. Therefore, this dynamic construction, with a previous plan, will not have dramatic impact on the investments planned.

To build a third independent path (versus the traditional backbones with just two independent paths) could seem like a higher investment on the civilian constructions, the highest investment for a FO infrastructure project, but it is not always true. The evolution of the future networks is in the direction of a complete fibre optic infrastructure, from the core network to the user. Considering this affirmation it will be necessary to dig up most of the roads of the area to install the fibre [7].

Hence, with a good planning and agreements among all the infrastructure companies working at a certain area, the digging and ducts installation investments can be shared. The investment of adding fibre at the time that the ducts are placed is much lower than to dig up again where there is already another hierarchical level installation [9].

In terms of fibre, it could seem as if the amount of fibre needed would be higher. The next few lines demonstrate that it is not necessarily true. The comparison of the cases of two and three independent paths illustrates this idea.

In the case of two independent paths there is a possibility of protection against one of the two paths failure. Assuming balanced traffic (the traffic between two nodes is equally split among the all independent paths) in case of a failure, the other path would have to support the total traffic between the two nodes for a 100 % of redundancy. Tables 8 and 9 present the amount of capacity needed at the two cases (2 independent paths and 3 independent paths) for a 100% of redundancy in

the case of one path failure (X is the value of the capacity needed to support the traffic between two nodes).

| | Regular capacity | Protection capacity | Total |
|-----------------|------------------|---------------------|-------|
| 1st Path | X/2 | X/2 | X |
| 2nd Path | X/2 | X/2 | X |
| Total | X | X | 2*X |

Table 8. Capacity Required for Two Independent Paths 100% Redundancy

| | Regular capacity | Protection capacity | Total |
|-----------------|------------------|---------------------|-------|
| 1st Path | X/3 | X/6 | X/2 |
| 2nd Path | X/3 | X/6 | X/2 |
| 3rd Path | X/3 | X/6 | X/2 |
| Total | X | X/2 | 3*X/2 |

Table 9. Capacity Required for Three Independent Paths 100% Redundancy

The values obtained in Tables 8 and 9 are valid for any network structure. The result for this specific case of study, applying the real link distances, is presented in Table 10 as values of fibre placement.

| | Km of fibre |
|--------------------|-------------|
| 2 Paths | 1967,6*X |
| 3 Paths | 1673*X |
| Improvement | 14% |

Table 10. Fibre Improvement

In case of three independent paths the fibre needed to provide a 100% of redundancy against the failure of one path is 14% less. Hence, if the rest of the fibre is used for a protection against the failure of two of the three paths the result is that the redundancy obtained is 58 % (8% more fibre at each of the paths). That extra capacity can be used for the high-priority traffic when two of the three paths are unavailable.

The conclusion of using three independent paths instead of two is that there is some kind of protection against two paths failure between a pair of nodes using exactly the same amount of fibre as to get fully redundancy against one path failure.

B. Simulation

The procedure of this simulation is to randomly generate cuts in the fibre and hardware failures. The simulation was iterated 1000 times for the different scenarios: one, two and three independent paths. Table 11 shows the availability, MTTF and MFT values for one, two and three independent paths .

| | Availability | MTTF (Y) | MTF (H) |
|----------------|--------------|----------|---------|
| 1 Path | 0,9989 | 0,22 | 13,04 |
| 2 Paths | 0,999929 | 16,15 | 6,68 |
| 3 Paths | 0,99999965 | 661,5 | 5,77 |

Table 11. Availability Simulation

FAILURE PERCENTAGE

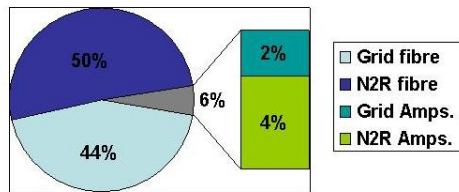


Figure 2. Failure Percentages



Figure 3. Availability VS. MFT

Fig 2 illustrates the percentages of the different causes of failure. The values for the switch failures are not considered in this graphic since they represent less of 1 % of the total failures.

The main influence on the availability of the system is the fibre failures. For this study a *MTF* for the fibre was obtained from [13] to provide a numeric solution. The value of the *MTF* depends on factors such as the budget for the maintenance or the relief of the area. Therefore, Fig. 3 illustrates the results for varying the value of the *MTF* of the fibre, from 1 hour to 24 hours, under the same conditions of switches and amplifiers failures.

7. CONCLUSION

The telecommunications and broadcast networks are evolving to the total synergy that in the long term will result in a unique multipurpose network. This evolution involves several aspects and this paper is focused on one of the main points: the definition of a future multipurpose backbone structure.

Firstly, this paper analyzes the main requirements of the future backbone which are summarized into three points: High topological availability, existence of independent paths as short as possible and regular topology. It is very important to have a small number of parameters to determine the feasibility of a certain topology in a simple way. Furthermore, they should be context-independent allowing to compare different topologies from an objective point of view in order to decide which one is the best option. Obviously, this work is a first step, and in the future analysis new parameters can be found, they could complement or substitute the parameters used.

In addition, this paper introduces and analyzes a new backbone proposal which fulfils the defined parameters. It

is a two level structure with a Grid and N2R topologies, in the lower and higher level respectively. This topology is applied to a real scenario, a national multipurpose fibre optic backbone for Spain. Based on this scenario, the proposed backbone structure is compared to other topologies. Several analytical and experimental analysis evaluating the availability, the average and maximum length of the paths in number of hops and fibre optic length are performed. It fulfils the five 9s operators criterion related with the availability and permits, compared to a flat solution, a reduction of 25% in the average path length. Also under the same conditions to implement a third path saves around the 14% of the investment in fibre.

Finally, some considerations about the impact of the proposed solution in the budget have been studied. The paper suggests that a strong investment in the short term will reduce the investment in the future. This investment model allows to deal with unexpected situations and upcoming killer applications.

This paper is a first step towards a long term objective, the definition of a multipurpose backbone structure for future networks. Much work is still to be done, but after the conclusions obtained there are some orienting results which allow to follow a possible direction.

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