Infrastructure Optimization in a Transmission Network

Mary Luz Mouronte
Departamento de Ingeniería y Arquitecturas Telemáticas
Universidad Politécnica de Madrid
Madrid, Spain
mouronte.lopez@upm.com

***Abstract*—This paper presents an algorithm to optimize the number of necessary resources in a transmission network; this procedure could be executed by the operators during the maintenance and fulfillment tasks. It allows the reduction of the investment, improvement of the resource utilization and achievement of the high resilience. We have developed an experimental prototype and have executed it over different transmission networks saving resources up to a percentage of 30%.**

***Keywords*-Transmission network; Optimization**

I. Introduction

This paper shows a method to lower the usage of resources in a transmission network. The algorithm achieves significant savings.

A transmission network consists of end-to-end circuits strictly designed as ring, mesh, bus and other motifs connecting equipments with different link capacities (Mbps/Gbps). This network has several components:

- Regenerators or equipments carry out the regeneration of the signals.
- Terminal multiplexers combine the plesionchronous and synchronous input signals into higher bitrate signals. They are the network elements that originate and terminate the signals.
- **A**dd-**D**rop **M**ultiplexers (ADM)/**O**ptical **A**dd-**D**rop **M**ultiplexers (OADM) combine several lower-bandwidth streams of data into a single beam of light. An ADM also has the capability to add lower-bandwidth signals to an existing high-bandwidth data stream, and at the same time can extract or drop other low-bandwidth signals, removing them from the stream and redirecting them to some other network path.
- **D**igital **C**ross-**C**onnects/ **O**ptical **C**ross-**C**onnects exchange traffic between different fiber routes. The key difference between the DCC/OCC and the ADM/OADM is that the DCC/OCC provides a switching function, whereas the ADM/OADM performs a multiplexing function. The DCC/OCC moves traffic from one facility route to another.
- Cards:
  - Aggregate cards provide the line interface. They connect the ADM to the exchange via fibre optical cables.
  - Tributary cards collect customer traffic and pass them, via the common cards, to the aggregate cards. Tributary cards are used to provide interfaces to one or more lower speed devices.
  - Other types of cards.

Transmission networks are managed by means of **N**etwork **E**lement **M**anagers (NEMs), **S**ub**N**etwork **M**anagers (SNMs) and, in some cases, also by a **N**etwork **M**anagement **S**ystem (NMS).

Link connection, trails and others entities for the tansmission network are defined in [1]:

- A link connection is a transport entity provided by the client/server association. It is formed by a near-end adaptation function, a server trail and a far-end adaptation function between connection points.
- A trail is a transport entity in a server layer which is responsible for the integrity of the transfer of characteristic information from one or more client network layers and between server layer access points. It defines the association between access points in the same transport network layer. It is formed by combining a near-end trail termination function, a network connection and a far-end trail termination function.

The proposed algorithm reduces the usage of resources in a transmission network. The resource release is obtained by the optimization of:

- Port usage in tributary cards.
- Occupancy rate in trails. The aim is the reduction of the hop number in the trail from the origin to the destination point, by increasing the occupancy rate in link connections.
  The analysis is done independently over the different network layers. Additionally, when a protected trail is examined by the procedure, it is verified that no optimized trail is matched with the current backup trail.

This optimization method has been included as a software module in a NMS, which manages different vendors (Nortel, Alcatel-Lucent, Ericsson and Huawei) and technologies (**S**ynchronous **D**igital **H**ierarchy (SDH), Ethernet over SDH, **W**avelength **D**ivision **M**ultiplexing (WDM)). This fact verified the operation results.

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The rest of the paper is organized as follows: Section II details related works, Section III gives an overview about the transmission network, algorithm is described in Section IV, Section V summarizes the results of applying a prototype on a life transmission network, and Section VI describes the main conclusions.

II. Related works

There are several works on optimization in a network, for example:

In [2], refering to the traditional multicast IP network, authors describe a method based on ant colony algorithms to minimize unnecessary overhead while achieving the desired throughput in a multicast scenario. In this type of network, the intermediate nodes take care of replicating the packet to reach multiple receivers only when necessary, so it is difficult for the network to achieve the maximum transmission rate. However, not all intermediate nodes are required for network coding operations.

In [3], authors present an algorithm with two optimization modes in a network architecture with a three-layer IP/MPLS over SDH over WDM: in optimization mode 1, the service blocked in the upper layer can be transmitted to the lower layer by its idle resources; in optimization mode 2, authors regard the three-layer network as an integrated network and search route for each service in the integrated network.

In [4], the author's research addresses the problem of Routing and Wavelength Assignment (RWA) for survivable networks with the objective of optimizing the needed wavelength links and the number of optical/electrical devices.

The main differences between the aforementioned methods and the presented procedure are:

- It maximizes the tributary cards with zero occupation rate and the server trails with minimum number of hops for a specific occupation rate.
- It works in an multiprovider and multitechnology environment. In an operative environment, NEMs have analysis tools which optimize subnetworks within each manufacturer domain. However, networks are composed of different technologies and vendors. They have isolated management domains where it is not possible to analyze and optimize with a whole network vision.

III. Transmission Network

Transmission networks are increasingly demanding greater capacity and more effective communications to support telecommunications services.

Standards agencies define a set of International Telecommunication Union (ITU) recommendations. [1], [5],[6], [7], [8], [9], [10], and [14] are designed to build telecommunication networks that allow greater flexibility and interconnection capacity between different technologies and equipment manufacturers.

ITU-T recommendations define a transport network for different technologies. Currently, transmission networks are set up mainly with SDH and OTH (Optical Transport Hierarchy).

According to ITU-T definitions, transmission networks are divided into independent layers where each layer has a server-client relationship with the adjacent layers. Each layer is also divided to reflect the internal structure and enable its management.

On a physical level, these networks are set up by nodes and connections between them. The nodes consist of racks containing cards in charge of performing different tasks in the network.

- Tributary cards: they introduce the client signal into the network.
- Aggregate cards: they add client signals to a server signal which is transmitted to other nodes through a physical trail.
- Matrix: it cross-connects signals to drive their route. This matrix can be electrical (SDH, OTH electric layer) or optical (OTH electric layer).
- Control card: it is responsible for node control.
- Transponder: it receives client signals and adapts them to optical signals for the Optical Transport Network (OTN).
- Muxponder: it is a hybrid card, with tributary ports, aggregate ports and electric cross-connect capacity (they are common in OTN technology).
- Amplifiers, Filters: they adapt the signal to physical transmission media.

The SDH network structure is defined in the ITU-T recommendation G.783 (Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks) [1]. This document describes its layered structure and interfaces between different network layers.

- Physical layer SDH.
- RS: Regenerator Section layer.
- MS: Multiplex Section layer.
- HO: High Order trail layer.
- LO: Low Order trail layer.

The OTN network structure is defined in the ITU-T recommendation G.809/Y1331 (Interfaces for the Optical Transport Network (OTN)) [14]. This document describes the layered structure and interfaces among different network layers.

- OTS: Optical Transmission Section.
- OMS: Optical Multiplex Section.
- OCh: Optical Channel.
- OTU: Optical channel Transport Unit. There are different units (OTUk), where k can take values 1,2,3,4 and represents the signal speed: 2,5 Gb/s, 10 Gb/s, 40 Gb/s, 100 Gb/s.
- ODU: Optical channel Data Unit. There are different

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units (ODUk), where k can take values 0,1,2,3,4 and represents the signal speed: 1,2 Gb/s, 2,5 Gb/s, 10 Gb/s, 40 Gb/s, 100Gb/s. A lower level ODU can be multiplexed into a high level ODU using multiplexing TDM (Time Division Multiplex).
- OPU: Optical Payload Unit. Layer for adapting the client signal to the ODU channel payload. Like the OTU and ODU channels, there are different OPUk values depending on channel speed.

In their inception, networks are planned in order to optimize resources such as nodes, cards, ports and link connections. The aim is to reduce the infrastructure costs taking into account the forecast traffic growth due to the emergence of new services. Transmission networks are constituted as interconnected islands, each island belonging to a single vendor. Network design and planning is carried out over these management islands without an end to end vision over the whole network.

Network operation results in several processes which add, modify and remove services may cause a non optimal usage of elements such as:

- Tributary cards with low occupancy.
- Server trails with low occupancy.
- Network layers fragmentation that results in low efficiency trails.

The network operators need to manage the usage of resources by means of end to end optimization mechanisms, which will avoid the network capacity degradation. Our algorithm, which is included as a software module within NMS, can be a very useful tool.

IV. Algorithm

Our optimization procedure uses the following input information relating to the network structure, which is obtained from NMS:

- The trails that support other low order layer trails, the available capacity in them and the equipments where they end.
- Ports:
  - The tributary ports that perform termination function on low order trails in SDH or WDM equipments.
  - Aggregated ports or line ports.
- Cards.
- Layer trails to analyze:
  - Client layer trails with source and destination points in the same node, in order to group traffic and to release resources in cards with tributary ports.
  - Server layer trails aiming to look up alternative trails which allow reducing the hop number and releasing resources in the transmission media and in cards with aggregated ports.
- The algorithm also receives the occupancy rate in each server layer, which is established by the operator.

Once the information is stored, the procedure performs the two following analysis:

- *Analysis type 1. Method for tributary card optimization in a exchange office*: It calculates the tributary card occupancy rate and redistributes the input ports in the cards with low occupation in other busier cards, thus some cards are released.
  The details of tributary card optimization procedure are outlined in Fig 1. The following parameters are estimated:
  - OR_{Ci}: Occupation rate of tributary card Ci
  $$OR_{Ci} = \frac{TotalOfBusyPortsInCi}{TotalOfPortsInCi} \tag{1}$$
  - M : Number of tributary cards where $OR_{Ci} = 0$.
  - Goal to achieve or maximum M value ($Max[M]$).
- *Analysis type 2. Method for trail optimization*:
  - It groups the client trails with the same origin and destination and analyzes the server trails in each group:
    * The server trail with the least number of hops between source and destination points is searched applying the Bellman-Ford algorithm [15], [16].
    * If these server trails have not reached the maximum occupancy rate set by the operator (who can reserve resources for future network deployments), the client trails are set-up in them. When the maximum occupancy rate is reached, the procedure looks up the next shortest server trail. The process is repeated for all client trails with the same origin and destination.
  - By reducing the server trail size, it is possible to release resources which will be available for setting up other client trails.

  The details for the server trail optimizing procedure in each layer are outlined in Fig 2. This procedure is applied on each server layer recursively until specified by the operator. The following parameters are estimated:
  - G : Set of server trails with the same origin and destination.
  - OR_j: Occupation rate of j, where j : is the server trail j.
  $$OR_j = \frac{TotalOfBusyLinkConnectionsInj}{TotalOfLinkConnectionsInj} \tag{2}$$
  - E : Set of server trails in G with the least number of hops and where occupation rate is $= ID$, ID is the occupation rate for server trails set by the operator.
  - Goal to achieve or maximum E value ($Max[E]$).

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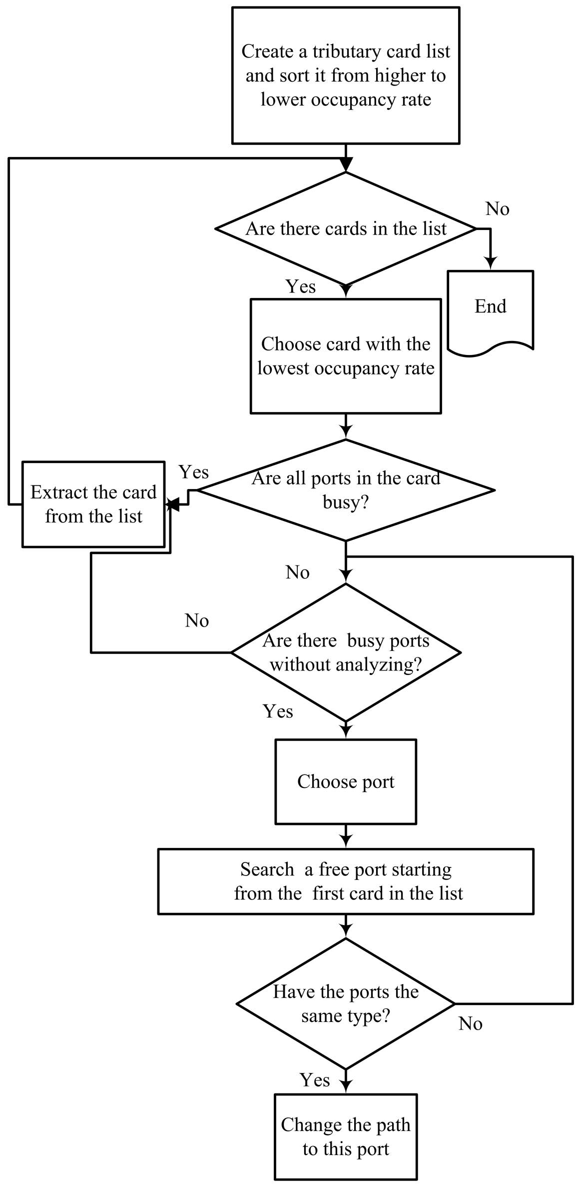

Figure. 1 Procedure for tributary cards optimization.

Fig 3 shows a network situation where the algorithm can be applied:

- Equipments: A, B, C, D, E
- Cards:
  - Equipment A: 2 cards with 2 tributary ports, and 2 cards with 2 aggregated ports.
  - Equipment B: 2 cards with 2 tributary ports, and 2 cards with 2 tributary ports.
  - Equipment C: 2 cards with 2 tributary ports, and 2 cards with 2 aggregated ports.
  - Equipment D: 2 cards with 2 tributary ports and 2 cards with 2 aggregated ports.
  - Equipment E: 2 cards with 2 tributary ports and 2

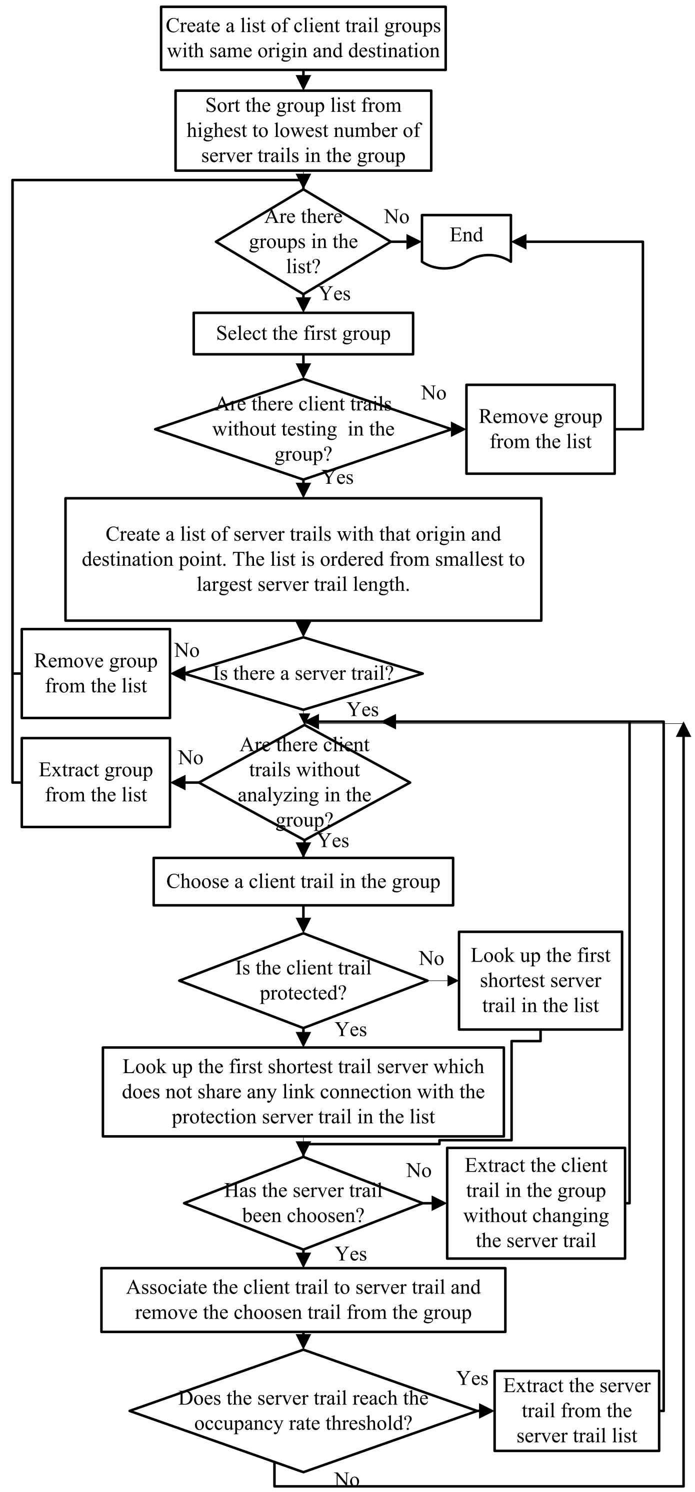

Figure. 2 Procedure for server path optimization.

cards with 2 aggregated ports.

- Physical trails: A-B, A-E, B-C, B-D, B-E, C-D, C-E, D-E
- Client trails: A-B, A-B-C,A-E-B-C, B-D, E-B-C, E-B-

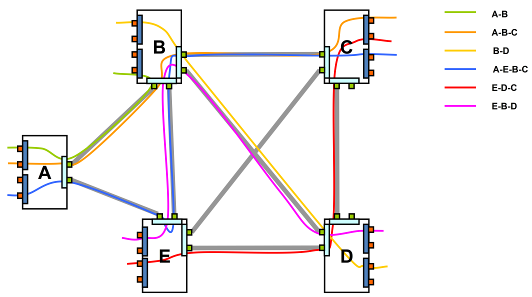

Figure. 3 Network situation to be optimized.

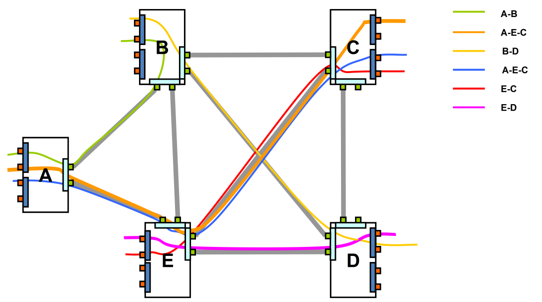

Figure. 4 Optimized network by means of our algorithm.

D

Fig 4 shows the obtained results. 3 cards are released by grouping ports in cards (6 cards were used previously) and 3 physical trails (only one was available before) are emptied by restoration of client trails.

V. RESULTS

An experimental prototype aimed to test and validate the optimization improvement in a network has been prepared.

Our optimization method is developed in PL/SQL and C++ language. These programs are included as a module in a NMS of a Telecommunication Operator where they interact with its inventory to obtain and update the network information. The programs are executed in the NMS by the operator when maintenance or fulfillment tasks are carried out.

We also implemented the necessary programs to compare with Shortest trail First (SPF) and Constrained Shortest trail First (CSPF) algorithms.

The NMS is a unified network management solution which provides end to end view and homogenous functions across different vendors. Furthermore, it executes all business processes related to the transmission network and its services: network fullfilment, circuit provisioning, network supervision and performance monitoring. This NMS manages SDH, Ethernet over SDH and WDM networks.

The NMS is a system constructed around a standards based network model, supported by an ORACLE DBMS, with a business logic layer that allows interaction with the core applications through a CORBA bus. The NMS works as a centralized system, with a primary machine of 16 CPUs, another one of 4 for the mediation with the plant and three more for users access.

In our validation test, 30 large networks (more than one province), 50 mid-size networks (provinces) and 125 small networks (provincial subdivisions) were evaluated. The networks had different topologies: point-to-point links, rings (single and dual), fully connected meshes, and the following characteristics:

- Big size network (average values): equipments: 20,248; circuits: 11,233; trails: 22,538; cards: 328,443; ports: 523,277 (tributary ports: 446,741; aggregate ports: 76,536).
- Medium size network (average values): equipments: 4,193; circuits: 5,274; trails: 16,064; cards: 90,343; ports: 118,427 (tributary ports: 108,806; aggregate ports: 10,341).
- Small size network (average values): equipments: 3,237; circuits: 1,233; trails: 1,823; cards: 11,243; ports: 15,456 (tributary ports: 9,235; aggregate ports: 6,221).

VI. CONCLUSIONS

In this research, we show a method to check and improve the element usage in the trails with an entire network vision (multi-provider and multi-technology environment); up to now the telecommunication operators just have tools to optimize subnetworks within each manufacturer domain. Besides, the algorithm obtains good results in an operative environment.

The two previous features are the principal novelty in our algorithm, which offers the following benefits:

- Significant resource savings by releasing cards with tributary ports, delivering link connections and redistributing trails.
- Higher quality deployment due to redistribution of resources. Setup, modification and removal operations do not usually take into account the whole network (with several vendors and technologies), so they do not use resources that could be employed with a different allocation.
- Resilience improvement. Minor resources to support a specific traffic demand are necessary (i.e. there is lower error probability in the network).

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