MEDIUM AND LONG TERM EVOLUTION OF THE ITALIAN TOLL NETWORK

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This paper presents a pragmatic approach to define the main structural characteristics of the long-term toll network. Regarding the structural characteristics of the target network, the problem is here mainly addressed of investigating the economical and technical effects of the well established trend toward large-capacity switching systems. The paper addresses the evolution process of the toll network, where, beside the target network structure, other aspects must be carefully considered, like the mixed analog-digital configuration in the transient period, the rate of digitalization of local and toll nodes, the existing plant and operational constraints.

1. Introduction

During recent years a main part of network planning activities had been firstly focused on the strategies of introduction of digital switching systems, in order to assure an orderly and gradual modernization of the network, accounting for the complex problems posed by the existing analog infrastructures, the subscriber and traffic growth, the analog-digital interworking and the budget constraints. As many of those and other factors can widely vary over different countries, different policies of network digitalization have been adopted and are currently implemented. Even if this first phase of digitalization, tightly influenced by the dominant weight of the analog world, will still cover the remaining 80's and partly the early 90's, new planning issues are now emerging regarding the structural configuration of the digital networks at their ultimate stage. As in fact digital switching and transmission facilities reach a significant level both in size and territorial extent, the constraints of analog infrastructures will rapidly relax and the urge will soon arise to orient the network structures toward a "target network" optimized with respect to the cost profiles and performance characteristics of the digital technologies. This search for a target network is made complex not only by the traffic and new services forecast uncertainties and the rapidity of the technological changes, but also by the higher level of required performances in terms of quality of service, reliability and robustness.

These problems are in this paper addressed with reference to the Italian toll network, for which the main steps of the planned evolution during the 90's are presented. After outlining in Section 2 the present configuration, Section 3 shows the results of a cost-driven optimization study for the overall network structure in a long-term perspective. On this basis an evaluation of the transition problems is carried out in Section 4 and the network evolution steps are discussed.

2. Outline of the present network configuration

The Italian telecommunication network covers a territory of 300,000 sq.Km, serving at present about 18 million of subscribers with an outgoing
peak-hour traffic of about 25 mE/subscriber, one fourth of which being long-distance traffic. The network consists of 231 District (CD) subdivided into 20 Compartments.

The District area, representing the area of univocal numbering and identified by a proper area code, consists of several Sectors (the total number of Sectors is 1398) which in turn are subdivided into local areas with a global number of 11,000 local switches.

The national network, as depicted in fig. 1, stretches on 5 hierarchical levels and it can be considered as divided into two components:

- the district network which exhibits a double star structure connecting local offices with the Sector Centers and in turn these latter to the District Centers;
- the long-distance (or interdistrict) network which has a 3 level hierarchy connecting the 231 District Centers with the 20 Compartment Centers and in turn these latter with 2 High Centers.

As the toll network is concerned, the introduction of digital switching has already started by following the pragmatic approach of facing the most critical situations in terms of building exhaustion or obsolescence of the existing plants; moreover, the following two basic criteria have been followed:

- Top-down policy from Transit Centers to District ones;
- Overlay instead of complete replacement policy.

The massive digitalization of the district switching centers during the last two-three years gave the opportunity to modify sensibly the structure itself of the network in order to fully exploit all the digital capabilities. As matter of fact a previous study has been carried out on considering various target configurations of the toll network by reducing the number of District Centers. It is remarkable that in a fully digital network the correspondence between functional and hierarchical switching levels is disappearing, as digital exchanges are able to provide all the required functions only by software rearrangements, while expensive hardware implications would have been required by electromechanical switches.

That study showed that in a static optimization a sensible economical advantage could be achieved by grouping in a single toll center more neighbouring CD's. This principle has been applied now to the Italian toll network. Indeed the policy of introduction by overlaying digital systems to analog ones in the District centers has creating a duplication of nodes and hence a duplication of network: analog and digital. The traffic originating from the digital exchanges is grouped into 102 Superior District Centers (CDS) which represent the sources and destinations of the digital network. This digital network has a 2 level hierarchy on 102 CDS and 17 transit centers; the routing is hierarchical with alternate paths.

The scheme of the two networks (analog and digital) is depicted in fig. 2.

The remaining CD analog centers will continue to route the traffic on the basis of 231 destinations through the analog network.

At the end of 1989 the situation of the switching centers (both terminal and transit) can be summarized as follows.

- 21 District Centers will be purely analog
- 150 District Centers will have one digital exchange overlaying the existing analog one
- 60 District centers will be fully digital.

Statistical data are also provided for transit centers and details can be found in table 1 where one can be seen that the analog traffic sources for the analog network are 181, while the digital sources are 225 and form the basis of the digital network. The two networks are designed with the aim to warrantee digital connectivity to the digital traffic by maintaining as far as possible the traffic on the relevant network and providing the necessary A/D conversions to the terminating point. To give an idea of the digital penetration the percentage of trunk circuits connected to at least one digital exchange is 50.65% while the percentage of fully digital trunk circuits
reaches 32%. As far as the switching trunks are concerned the total number is about 1 million about 25% of which being on digital exchanges. Even if the percentage of analog trunks is predominant, as far as the transit centers are concerned, the situation is completely reversed: in fact the digital penetration reaches 65.7% due mainly to the top-down strategy of introduction of digital technics.

3. Cost optimization of the network structure

Digital transmission on optical fibres is nowadays a reality that, in addition to the expected decreasing trend of laying and cable costs, leads to a cost structure of the transmission circuits sensibly different from the traditional copper facilities. In fact, the feasibility of very high bit-rate systems jointly with the low transmission-loss (longer repeater spacing and concentration of electronics in the transmission nodes) make lower and less sensitive to the length the marginal cost of the transmission circuits. As a consequence, we can easily expect an advantage of increasing the length on which information is transmitted before being concentrated or switched, and, equivalently, an economy can be envisaged in concentrating the switching and routing functions in a decreasing number of nodes far away from the traffic sources/destinations.

These considerations are strengthened by looking at the present technological evolution on the switching side, where processing and memory advances make feasible and cost competitive switching systems of increasing capacity in terms of both subscriber number and traffic amount. Regarding in particular the local switching, it is also to be stressed that the efficient exploiting of a large capacity system is allowed by the parallel trend toward a greater remotization of the line stages (LS), connected with the local group stage (LGS) via low-cost trunks and common-channel like signalling. This capability allows to introduce the concept of "switching area", taking the place of multi-exchange area (presently composed of several analog stand-alone switches), and without affecting the existing layout of the subscriber loop plant; a swiching area can thus cover a quite large territory under a single large-capacity LGS, where local and toll functions can also be economically merged.

Not less important are the structural modifications foreseeable in the toll network as due to the aforementioned technology and cost factors of both transmission and switching systems. Firstly, the large traffic and processing capacity of local LGS will allow to configure them as mixed local-toll nodes, also because many of these LGS's will have naturally the same locations of the toll nodes themselves; in large metropolitan areas the feasibility of mixed local-tandem nodes is offered too. Secondly, on considering that each LGS node conveys and routes a significant amount of traffic (all the traffic external to the its switching area), a great simplification can be achieved on the structure and the number of hierarchical levels in the toll network: it can be envisaged a unique level of large-capacity transit switches (TGS), while a rich mesh of LGS-LGS and LGS-TGS high-usage trunk groups could find economical justification and guarantee a sufficient number of routing choices.

Starting from these general considerations, the fundamental planning of target network structures has to answer the following basic questions:

- which is the optimal size of a switching area? and how many local LGS can consequently be foreseen accounting for the constraints of a real territory environments? and which is the role played by the cost ratios among network components?
- which hierarchy of the long-distance network matches with this local network configuration having LGS's as traffic sources/destinations? how many TGS and which routing scheme allow to minimize the network cost?

The cost comparison of the different network solutions allows to derive useful guidelines on the main characteristics of the target network in the district environment. To estimate over the whole territory the impact of different capacities of the LGS, a statistical approach has been followed.
starting from the analysis of a sample of 16 District networks, assuring a good representativeness of the whole network. On each district several alternatives of network structures are generated by a simple automatic procedure, that starting from the most peripheral nodes explores the topology graph, and by a sequential merging of adjacent nodes it is able to reach a suitable placing of the LGS's. This merging process is controlled by a variable threshold parameter representing the minimum number of subscriber lines that justifies the existence of a switching area. Three main cases will be discussed resulting from as many values of this threshold, i.e. $A = 10K$; $B = 20K$; $C = 40K$.

The application of each threshold to the 16 Districts and the extrapolation to the whole territory using the weight coefficients of the sample networks lead to the structural characteristics summarized in fig. 3. For the three cases A, B and C fig.3 indicates the estimated total number of switching areas, i.e. of the LGS's with colocated SL's, and as well the total number of local offices served by remote LS's; the structural characteristics of the switching areas are also described in terms of average distances (LGS-remote LS and LS-concentrators) and of percent distribution of subscriber lines per class of office. Regarding the average size of the switching areas in terms of subscriber lines, the values of 20.5K, 40.4K and 74.3K have been obtained for the case A, B and C respectively.

A secondo step of this analysis is concerned with the economical comparison among these three network alternatives in terms of parametric costs:

- $CTR = \text{transmission cost, evaluated as a function of the distance } d \text{ by an } a + b.d \text{ model;}$
- $CTK = \text{trunk terminations cost, with differentiated values for trunks internal and external to the switching areas; }$
- $CGS = \text{GS first cost including software: }$

Note that the cost of the SL subscriber lines, though being about the 70% of overall switching and transmission cost, has not been here considered, as it represents a costant amount independent from the network structure.

The result of fig. 4 clearly shows that sensible savings in the range of 20%-30% of the switching cost $CGS + CTK$ can be obtained when average sizes of the switching areas greater 40K are reached (compare B and C with A), while a very slight penalty is incurred on the transmission side. This behaviour has been also fully confirmed by several sensitivity analyses. The motivation for that relies on the fact that larger switching areas at a same time reduce the number of LGS's, improve the efficiency of the trunk groups and avoid double switching of an increasing fraction of traffic. Moreover, it is worth noting that the major part of these economical benefits is get only passing from the alternative A to B, while rapidly decreasing advantages can be expected by furtherly increasing the size of the switching areas.

Based on these results the actual planning of the territory leads to 516 switching areas. As far as the long-distance network interconnecting the 516 LGS, is considered the classical hierarchical routing scheme has been compared with a non-hierarchical routing among the TGS's and also a variable number of TGS from 2 to 102 has been considered.

Fig. 5 shows the cost comparison of these alternatives and leads to the following conclusions:

- the optimal number of TGS is in the range 16 - 20: note that the increase in network cost, for a greater number of TGS is due essentially to switching, while for a number of TGS smaller than the optimum, the impairments are a consequence of transmission disoptimisation.
- A non hierarchical routing scheme among the TGS's, besides the slight economical advantage (compare curves A and B), can offer additional performance benefits with respect to flexibility versus non coincident peak traffic and network management capabilities.
4. Choices and steps in the evolution period

In the medium term period (1989 - 1995) the strategy for the evolution of the network towards a target network is now discussed.

Firstly, it must be noted that the present massive introduction of LGS's in the local areas will lead to the availability of about 240 LGS's by the 1990 and of about 390 LGS's by the 1995, with a percentage of originated long distance traffic passing from the 30% to the 52% at the same dates. That means that by the middle 90's the digital local network rapidly becomes quite near to the target structure on 516 LGS's; this fact calls for reconsidering the role of the present CDS policy, whose optimality is tightly related to the exigence of grouping the long-distance traffic originated by sparcely distributed local digital switches (without applying the concept of switching area).

As far as the long-distance traffic routing is concerned, for the toll traffic outgoing from the LGS's two alternatives have been exploited:
- to group the traffic to the own CDS,
- to link the LGS to the own TGS by a final trunk group.

The former solution would increase the digital network based on CDS, delaying, in the same time, the birth of the target network. As a consequence, at the end of the period (1995) the digital switching trunks of the CDS's would become more than twice the 1989 situation. A large part of the digital exchanges actually in operation has not a capability necessary to face with this request, and therefore this fact would call for a replacement or an overlapping of these exchanges. Moreover, an oversizing of the CDS switches would occur without an efficient reusing in the coming target network.

The second solution, which has been adopted, implies the presence in the network of all the transit group stages from the beginning.

The feasibility of the target network formerly described, calls for the availability of:
- local group stages with a maximum capacity of 80,000 subscribers;
- transit exchanges with a maximum capacity of 30,000 - 40,000 trunks.

Considerations about reliability and management problems have suggested to review the results coming from the optimization study as far as the number of transit group stages is concerned. In fact the experience, even short, of the management of the digital exchanges has showed that the probability of partial or total "down" is not negligible.

To the former considerations these others can be added:
- The grouping in average of 25 - 32 LGS into a single TGS would implies difficulties of management nature; moreover, possible splitting of final choice trunk-group on 2 or more TGS, for reliability reasons, could double the LGS's linked to a single TGS;
- a capacity of 30,000 - 40,000 switching trunks per TGS seems, for the time being, not yet feasible.

In conclusion the number of TGS has been increased to a value of 47.

The penality in term of investments with respect to the optimal solution is 8%. The location of TGS have been chosen according to the transmission topology and also according to the density og LGS's present in the area. At present 21 of the exiting transit exchanges already have the capability to support also the requested TGS functions.

In the period '89 - '95 the digitalization process of the network will proceed very fast compatibly with the financial resources. The percentage of traffic originating from all digital toll sources (CDS+LGS) will move from 41% to 75%. This is basically due to the radiation of 53 obsolete analog exchanges and the introduction of 390 LGS's.

In order to complete the study of the long-distance network evolution, two network dimensioning have been carried out, one referred to the 1992 intermediate year and the other to 1995 final year.

The network dimensioning has been performed considering three layers of network differing on the type of origin of traffic and namely:
an analog network whose sources are the electromechanical exchanges which still remain in the CD centers and address the traffic to all 231 District areas;
- a digital network whose sources and destinations are the 102 CDS centers which group the traffic originating from the stand-alone local digital exchanges.
- a second digital network whose sources are the LGS's handling only the traffic of the relevant switching areas.

The main scheme of the three networks is depicted in fig. 6.

While the analog and digital CDS networks use a hierarchical structure with alternate routing of the type depicted in fig. 1, the network based on LGS is initially based only on final trunk groups linking the LGS's to the own TGS, without any high-usage trunk groups LGS-LGS or LGS-TGS. Indeed the average originating traffic at the end of the period (1995) is only 220 erl/LGS and this amount, considering the number of LGS's and the modulus (30) of PCM transmission, is not sufficient to justify on the average any direct high-usage trunk groups.

The transit level of the analog network is formed by 20 transit centers. The number of the transit centers for the digital CDS network is reduced to 17 and at least one digital switch is in operation in every center. As already said, the transit level of the digital LGS network consists of 47 TGS switches.

The results of the network dimensioning and the long-term parametric evaluation are showed in the figure 7 which presents the percent trend of the total switching trunks subdivided per network layer.

It can be noted that the analog layer disappears in '98, while the digital CDS layer will survive until the first years, after 2000, when the target network reaches the complete coverage.

The detailed dimensioning results have been also used for the actual planning, center by center, of the timing of the interventions and of the required capacity of the digital exchanges.

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FIG. 5 CHARACTERISTICS OF THE SWITCHING AREAS IN THE THREE STRUCTURES A), B), C).

A = HIERARCHICAL NETWORK  
B = NON HIERARCHICAL NETWORK

FIG. 6 SCHEME OF THE NETWORKS WITH THE INTRODUCTION OF LSG AND TSG.

FIG. 7 TREND OF SWITCHING TRUNKS

FIG. 8 COST COMPARISON AMONG THE SAME ALTERNATIVES OF FIG. 5 (EXCLUDING COST OF LINE STAGES)

TABLE 1 TYPE AND NUMBER OF SWITCHING CENTERS

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<thead>
<tr>
<th></th>
<th>ANALOG</th>
<th>ANALOG+DIGITAL</th>
<th>DIGITAL</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>CENTERS NUMBER</td>
<td>SWITCHES NUMBER</td>
<td>CENTERS NUMBER</td>
</tr>
<tr>
<td>CC</td>
<td>3</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>CD</td>
<td>21</td>
<td>21</td>
<td>150</td>
</tr>
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