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"Integration of New Telecommunication Technologies Via a Digital Radio Systems"

The Radio Project of Bologna University

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Integration of new telecommunication technologies via a digital radio systems

(The Radio Project of Bologna University)

S. d'Addona[†], S. Focardi[•], V. Ghini[††], G. Martoni[Φ], P. Mangani[††], G. Pau[††]

Abstract

Nowadays telecommunications are one of the main tools for scientific research; in the developing countries telecommunication network is often inadequate to the necessity of scientists, therefore, one of the key points for improving the social and economic progress of such countries is to build a telecommunication network that connects universities, schools, governmental organizations to similar organizations in foreign countries. In many countries it is not economic to build a "cabled" network, so digital radio system technologies are used as a carrier instead. In this paper we will report our experience about the design of a radio based network, and about the integration of new telecommunication technologies, such as ATM, with a radio based network. Our point of view is that of the network developer; therefore, we will not explain the radio principles in detail, rather we will discuss the network design principles with particular attention to the ATM technologies, and the ATM integration in a non ATM network. This paper will talk about a real ongoing project, partially realised by the University of Bologna.

From the point of view of the Telematic Networks designer.

We want to present a real example of integration of data-communicating technologies with digital Radio Links technologies, realizing a relatively cheap high speed WAN (Wide Area Network). Our point of view is that of the network designer, who aims at optimizing the network performance, respecting the needs of the radio transmission, and not vice versa. In other words, we are only users of the radio transmission channel, and we do not intend to improve (or develop new) radio links technologies; on the contrary, we only want to exploit existing equipments, available on the market.

Scenario

The development of the decentralization and the growth of the importance of the networks.
The birth of the "Progetto Radio" at the University of Bologna is mainly due to the following two causes: the increasing importance of communication networks in different productive fields and, in particular, in research; the strong effort of the University of Bologna in promoting the birth and the development of decentralized sites of the University, also supported by local political and economical institutions.
The University of Bologna counts today about 100,000 students; about 20,000 of them are enrolled in courses located in the decentralized sites of the Romagna territory (cities of Cesena, Forli', Rimini, Ravenna) and in the city of Reggio Emilia. In these sites the research activities are rapidly increasing, also thanks to the close connection with local factories; these activities, in addition to didactic and bureaucratic ones, are producing an intense data-exchange between the decentralized sites and the central University structures in Bologna.
Due to the internal organization of the University of Bologna and its intrinsic features, the more requested connections are between the central site in Bologna and the single decentralized sites in Romagna, rather than

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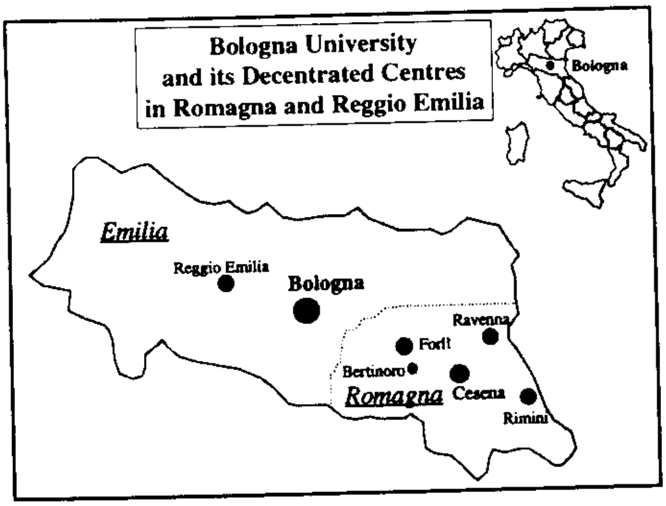
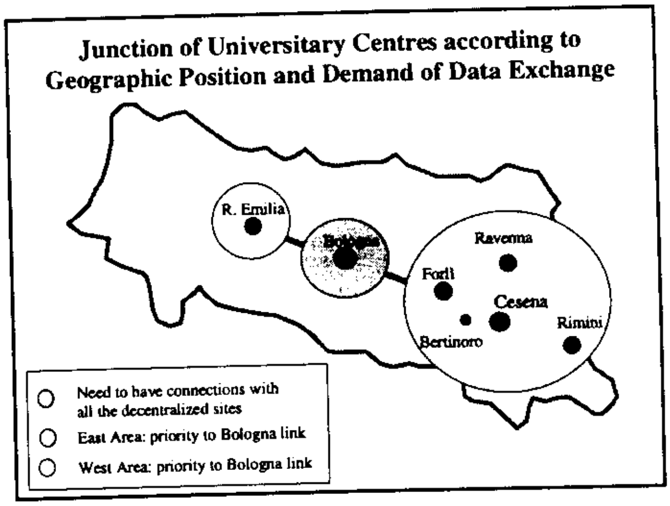
among the decentralized sites. Another particular requirement is that the sites in Cesena and Forli', where undergraduate programs in Computer Science and Engineering are located, need large bandwidth connections.

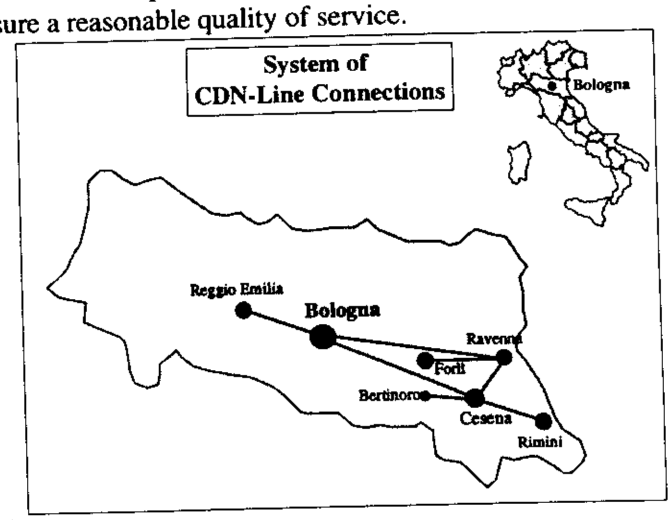




Current Status of the Network

The current connections with the decentralized sites are implemented through dedicated CDN lines, which unfortunately do not offer enough bandwidth to ensure a reasonable quality of service.

System of CDN Line Connections	
Line	**Bit-Rate**
Bologna - Reggio Emilia	64 Kbit/s
Bologna - Cesena	256 Kbit/s
Cesena - Rimini	64 Kbit/s
Bologna - Ravenna	128 Kbit/s
Ravenna - Forlì	64 Kbit/s
Cesena - Ravenna	64 Kbit/s
Cesena - Bertinoro	64 Kbit/s



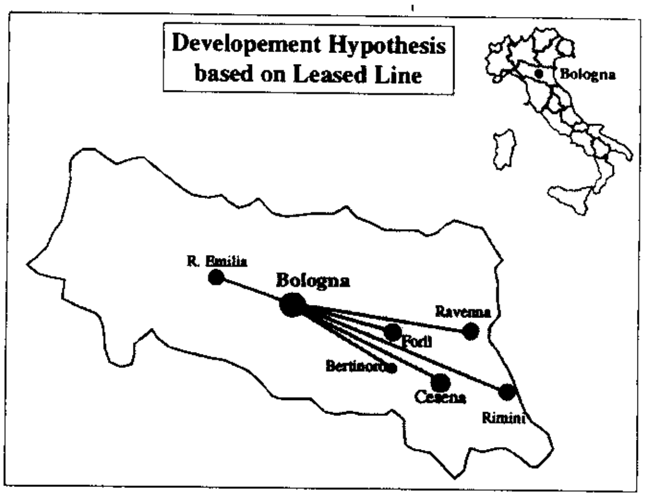
Network DEVELOPMENT

The main needs of the decentralized sites may be summarized as follows: speed increase of the connections, guarantee for high quality services, and integration and homogenization of the local networks of the decentralized sites with the network of the central site in Bologna. Due to its unability to meet these requirements, we had evaluated two different hypotetical development plans for the global network of the University of Bologna: one is based on the concept of Leased Line, while the other one on the concept of Radio Links.

Project 1: Network based on Leased Line

In 1995 the technical staff of the University of Bologna thought to develop the global network, organizing the connection as reported in the following diagram. The expected costs for this project were considered not attractive, also for the high operating outlay (compared with the imvestment outlay). In particular, about $ 0,7 millions per year were foreseen for payment of a license fee to the line provider.

CDN Line [illegible]	
[illegible]	[illegible]
Bologna - Reggio Emilia	256 Kbit/s
Bologna - Cesena	2048 Kbit/s
Bologna - Forlì	256 Kbit/s
Bologna - Ravenna	256 Kbit/s
Bologna - Bertinoro	256 Kbit/s
Bologna - Rimini	256 Kbit/s

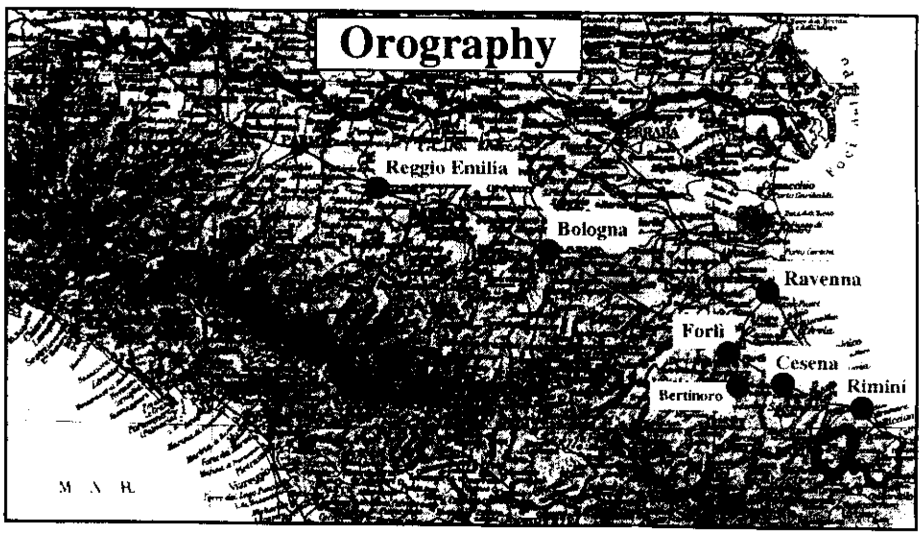


Project 2: Network based on Radio Links

The basic idea of this project is to integrate the network of the University with a system of private, digital, high-speed Radio Links connecting the central site with the sites in Romagna. The advantages of this proposal are manifold; in particular, the resulting network guarantees the required very high speed in communication, and high reliability and usability of the channel. From the point of view of the University, besides matching the technical requirements, this solution has these additional advantages: It reduces enormously the costs for the network management, even if at the price of increasing a bit the investement costs for the radio links; indeed, after the initial investment for buying the necessary equipment, the operating expense are minimal (e.g., periodic control of the equipment). Being the owner of the radio links, the University can keep under its own control the network, by forming technical personnel highly specialized in using and managing these new technologies (no need of an external provider of the line and/or of the service); As a final remark, we want to stress that the current choice of the Radio technologies does not preclude any possible future evolution of the network; after the overcoming of the Break Event Point and, possibly, some further years of usage, if the adopted technologies become outdated, then there will be no problem in either buying updated Radio technologies or in renting new telephone lines, depending on the future economical market conditions.

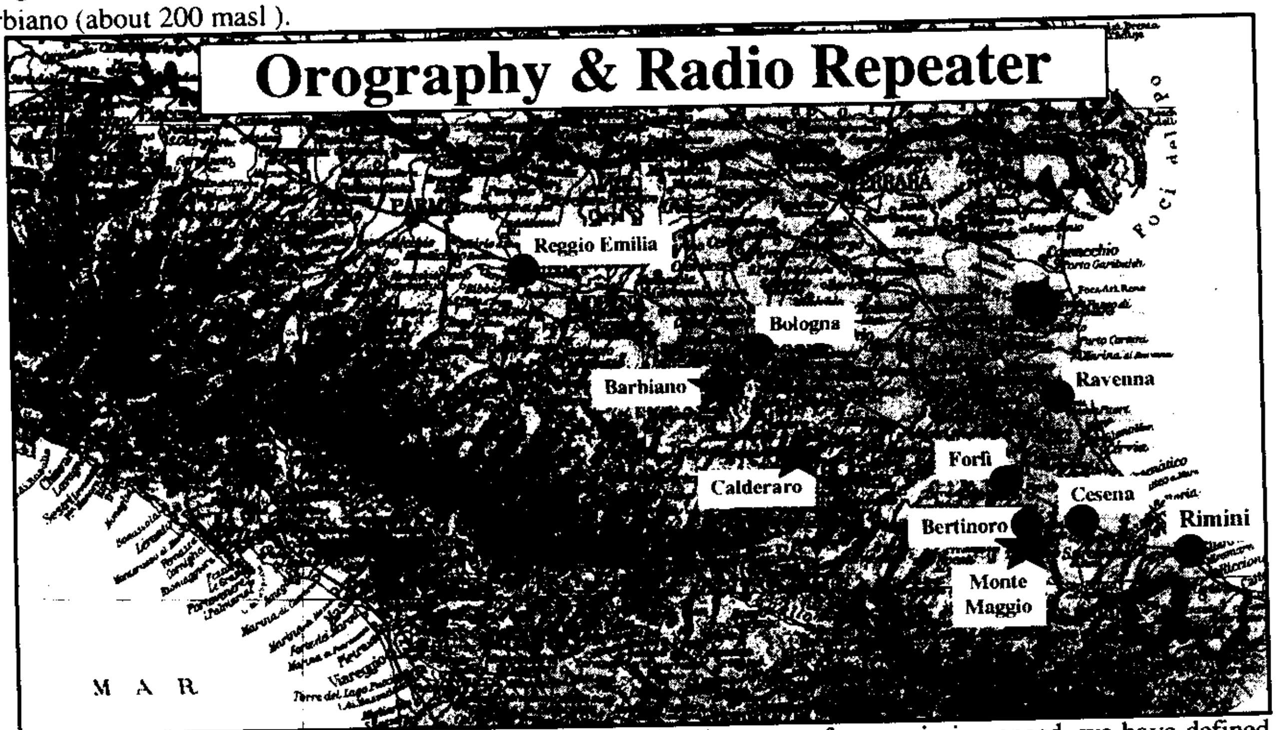
The study of the territory

The first studies were focussed on the evaluation of the logistic situation and, in particular, of the orography of the territory, in order to individuate the potential problems in setting up such connections. In fact, two major outcomes of these studies were the impossibility to directly connect Bologna with the territory of Romagna, and the consequent need of locating signal repeaters in the mountains.



The choice of the Radio Link Path

The best locations for the signal repeaters were realized to be in correspondence of the relay stations of the italian TV broadcasting corporation (RAI). In order to use these kinds of relay, to use the local power supply engines which guarantee the continuity and security of this kind of service, and, finally, to benefit of the know-how of the technical RAI personnel, we started a useful collaboration with RAI. For the connection between Bologna and the territory of Romagna, we used -- as signal repeaters -- the relay stations in Calderaro (about 600 masl), near Bologna, and Monte Maggio (about 300 masl); for the connection with Reggio Emilia only the relay station Barbiano (about 200 masl).

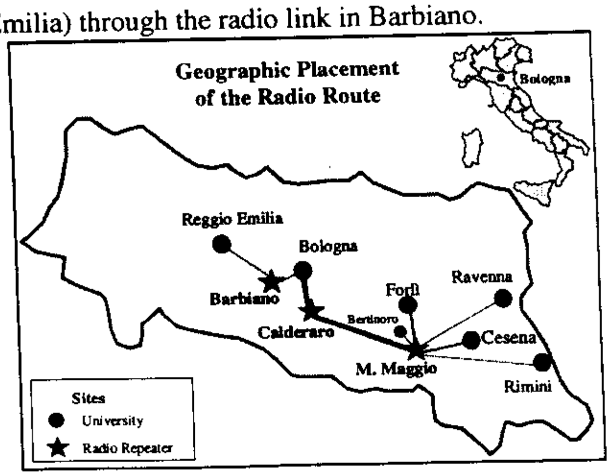


Once evaluated the needs of the university decentralized sites in terms of transmission speed, we have defined the connections between repeaters and terminal stations, in order to design the radio system in detail. In particular, we have proposed a very simple network topology with the aim at minimizing the number and the cost of the routing components; indeed, such pieces of equipment are usually rather expensive, are often source of transmission delay and may also be of uneasy configurability. In particular, those components working on the backbone are always very expensive, because they have to process very quickly a large amount of data.

So the network topology consists:

- in a backbone between Bologna and Monte Maggio through the radio link in Calderaro, and then, in a radial arrangement of connections from Monte Maggio to the singular seats in the Romagna territory;
- in a secondary path from Bologna to Coviolo (near Reggio Emilia) through the radio link in Barbiano.

Radio Link	Distance
Bologna - Calderaro	19 km
Calderaro - Monte Maggio	57 km
Monte Maggio - Cesena	8 km
Monte Maggio - Forlì	11 km
Monte Maggio - Ravenna	31 km
Monte Maggio - Rimini	36 km
Monte Maggio - Bertinoro	1 km
Bologna - Barbiano	4 km
Barbiano - Reggio Emilia	60 km



Criteria for choosing transmission frequencies

The choice of the transmission frequencies is bound by three main factors:

- the distance among the points to connect, in order to assure a transmission without errors;
- the transmission speed to use related to the laws in force in Italy, which impose a band-width for every range of frequencies consequently limiting the quantity of transportable data;
- the diameter of the aerials and of the bearing structures; this is the less important factor: aumenting the transmission frequency the diameter of the used aerials diminishes, and, consequently, the charge on the bearing structures which support these aerials diminishes too.

We have to select different frequency bands according to the damand for the transmission speed of each link. We can make therefore a choice only after a realization hypothesis. In the table there are summarized the frequency bands related to the two realization hypothesis of the Radio System.

Frequences in relation to Distance and Bit-Rate

Bit Rate \ distance	2 Mbit/s	2x2 Mbit/s	8 Mbit/s	34 Mbit/s
0-5 km	17 GHz		17 GHz	
5-15 km			17 GHz	14 GHz
15-60 km	2.3 GHz	2.3 GHz		8 GHz

Two different hypothesis: "Low Cost" vs. "Backbone ATM

Once fixed the transmission speeds, the localities to locate the radio links, the frequencies and the bands, we have studied two different hypothesis of practical realization of the Radio Project, characterized by different typologies of offered services and kind of cost:

- **"Low Cost"** hypothesis which minimize the investment realizing a subset of network features, corresponding to those offered by the traditional networks;
- **"Backbone ATM"** hypothesis which allow to support ATM, at least in the main university seats, providing all the services requested by the modern applications (i.e. asynchronous data management, connection with constant throughput or constant delay data exchange, etc.) and guaranteeing a major using flexibility, and a maximum evolution capability of the system through the homogenization with the global network of the University of Bologna.

Both these hypothesis present similar solutions to some common problems as those derived from the integration of digital radio links into the network.

Integration of digital radio links into the University of Bologna network

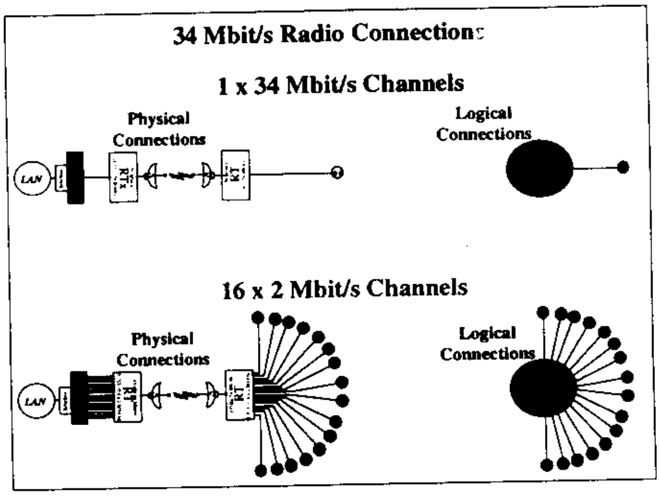
The choice for the radio, routing and interface equipments used in the Radio Project to set up the radio network is guided by three principles:

- to carry out the connections according to the expected speeds and frequencies;
- to interface the University of Bologna network (in Bologna as in the decentralized Seats), that is to use equipments whose electric interfaces correspond to the interfaces of the routers to connect;
- to reuse, as far as possible, the pre-existing equipments in the various Seats of the University of Bologna, rationalizing the use of resources.

The interfacing between the radio system and the pre-existing network opens a problem about the electric standards.

Indeed the commercial RTX equipments of the PHD hierarchy adopt only the electric standards defined in the ITU-T Recommendations G.703 for the speeds of 2048 Kbit/s (2 Mbit/s, named E1), 8448 Kbit/s (named E2), 34368 Kbit/s (named E3), all HDB3codified. The 8448 Kbit/s channel may be obtained admitting 4 flows each one of 2 Mbit/s, while the 34368 Kbit/s channel may be obtained admitting 16 flows each one of 2 Mbit/s.

This is the reason for which a router can be connected to an 34 Mbit/s RTX both as a 34 Mbit/s channel or as sixteen 2 Mbit/s channel, each of then directed toward different IP destinations. In the latter case the use of converters between the router and the RTX is requested.

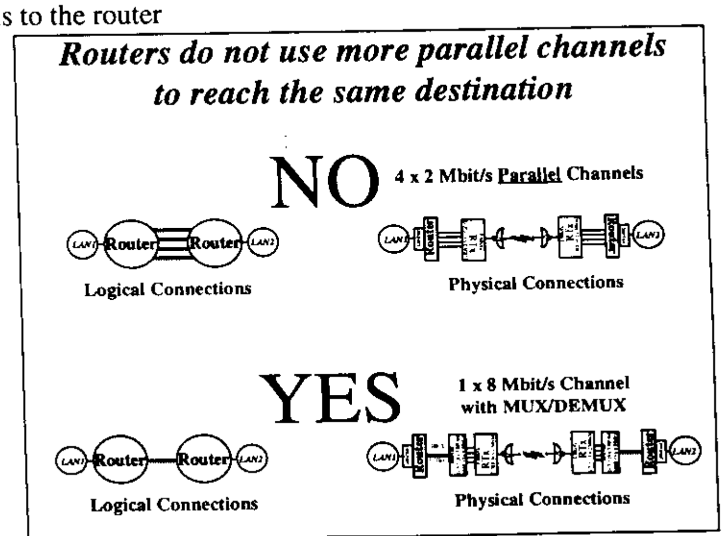


Contrary to the commercial RTX, the routers support several electrical interfaces, i.e. the 2048 (E1) and 34368 (E3) (only ATM) Kbit/s interfaces, the HSSI (High Speed Serial Interface) which supports from 2 to 52 Mbit/s, and the V35 which supports from 2 to 7 Mbit/s, but they don't support the 8448 Kbit/s interface described in G.703.

Moreover actually routers do not provide the possibility to use simultaneously more parallel channels to reach the same destination, balancing the load among these channels. In a more precise manner, there are some routers that do it, but the used algorithms are in general not standardised, and the only one standardised: OSPF (Open Shortest Path First) are not performing enough.
Because of the above described problem, the connection between a RTX of 8448 Kbit/s HDB3 and a router is difficult to execute; moreover it is not possible neither to enter directly with the flow of 8448 Kbit/s into the router because the suitable interface does not exist, neither to separate the 8448 Kbit/s flow into 4 flows, 2 Mbit/s either, because the router is not able to manage them (this kind of separation is possible only if the 4 flows are viewed by the router as bound to different IP address.
In order to exit from the router and enter into the RTX with a single E2 speed flow, seen by the router as a single channel, it is necessary:

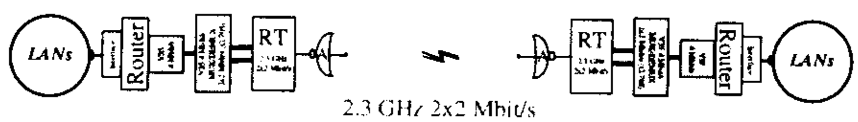
- to install on the router a HSSI card (High Speed Serial Interface) which manage the E2 speed (8 Mbit/s);
- to connect the router to an equipment similar to an inverted multiplexer, which convert the flow into 4 E1 speed channels (4x2 Mbit/s);
- to enter with these four channels into the transmitter.

This kind of connection may be useful if you want to realize an E2 speed radio channel, hiding the problems of re-routing on parallel channels to the router



In a similar manner, the connection between a 2x2048 Kbit/s HDB3 RTX and a router is difficult to execute; indeed it is not possible to enter directly into the router with two flows of 2048 Kbit/s each one, because the router is not able to manage them in an efficient manner. So it is necessary to unify two flows into a single one, following a standard accepted by the router, i. e. the V35 standard, diminishing the performance.

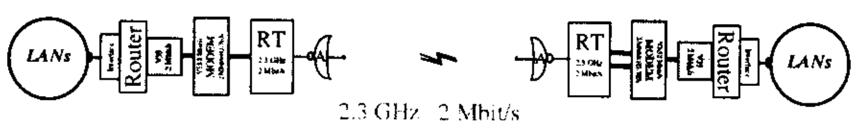
2x2 Mbit/s G.703 TO 4 Mbit/s V35 Conversion



The connection between a 34368 Kbit/s RTX and a router is possible instead, because the routers have got interfaces which accept this kind of size; in particular the ATM standard contemplate 34368 Kbit/s HDB3interfaces for connecting to the routers.

The situation is complicated by the need to re-use, if it is possible, the equipment located in the different seats of the University of Bologna, in order to economize on costs. For example, in the university seats in Reggio Emilia and Bertinoro, there are low cost routers on which it is no possible to install cards with a 2048 Kbit/s HDB3 (E1) interface for connecting to a 2048 Mbit/s RTX; however these routers have got V35 interfaces, so it is possible to use a 2 Mbit/s SAT20 modem between the V35 router interface and the 2Mbit/s G.703 HDB3 interface of the RTX which effects the necessary translation.

2 Mbit/s G.703 TO 2 Mbit/s V35 Conversion

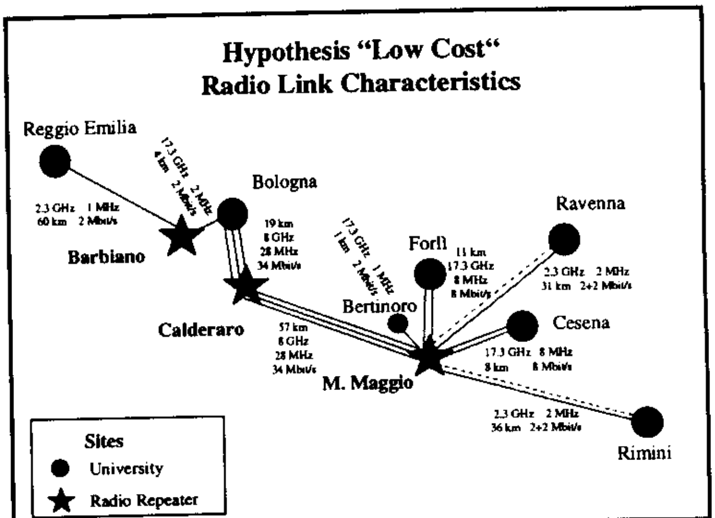


Hypothesis of "Low Cost" realization

This hypothesis was been formulated according to the initial needs of the University of Bologna. These needs are not comprehensive of the means for telephonic connections or for the data-exchange with a certain quality of the offered service, indeed the only one request was to have a simple connection able to transport a data flow, in a no too expensive manner.
Moreover connection internal to the town were no expected and requested transmission speed was lower than today; in particular the transmission speed in Cesena and Forlì was only 8 Mbit/s for each one. For this kind of scenario the network topology remains the same above mentioned, but the speed on the Radio Link is different. The high speed coming from Bologna is stopped in Monte Maggio, here it is divided into two lower speed Radio Link toward Cesena and Forlì. The connections with Rimini, Ravenna, Bertinoro e Reggio Emilia remain the same.

Moreover connection internal to the town were no expected and requested transmission speed was lower than today; in particular the transmission speed in Cesena and Forlì was only 8 Mbit/s for each one. For this kind of scenario the high speed Radio Link coming from Bologna is stopped in Monte Maggio, here it is divided into two lower speed Radio Link toward Cesena and Forlì.

Lower speeds connections to Rimini, Ravenna, Bertinoro and Reggio Emilia are expexted.



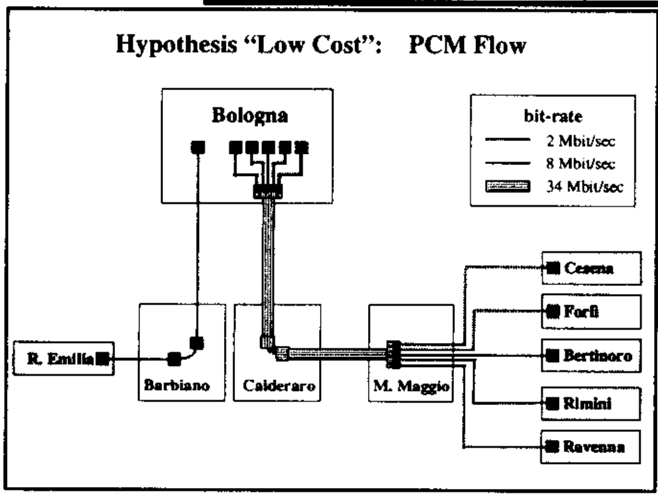
Hypothesis "Low Cost" Radio Link Characteristics					
Radio Link	Capacity (Mbit/s)	Distance (km)	Frequency (GHz)	Band Width (MHz)	Modulation
Bologna - Calderaro	34	19	8	28	PCM-QPSK
Calderaro - M. Maggio	34	57	8	28	PCM-QPSK
M. Maggio - Cesena	8	8	17.3	8	PCM-QPSK
M. Maggio - Forlì	8	11	17.3	8	PCM-QPSK
M. Maggio - Ravenna	2 (+2 unused)	31	2.3	2	PCM-16QAM
M. Maggio - Rimini	2 (+2 unused)	36	2.3	2	PCM-16QAM
M. Maggio - Bertinoro	2	1	17.3	2	PCM-QPSK
Bologna - Barbiano	2	4	17.3	2	PCM-QPSK
Barbiano - Reggio Emilia	2	60	2.3	1	PCM-16QAM

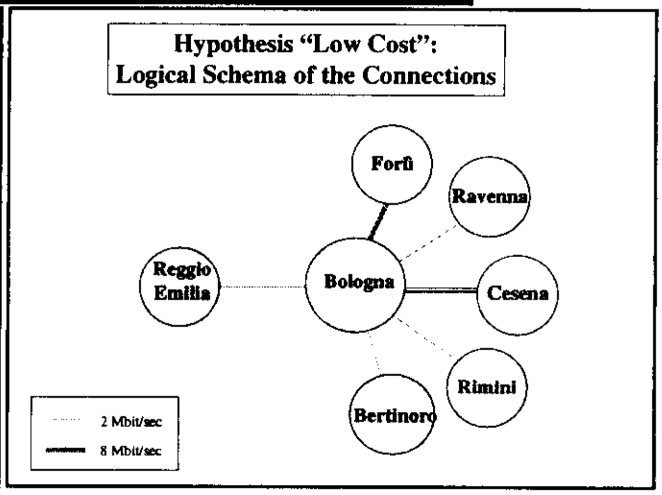
Data flow and Routing in the Low Cost Hypothesis

The aim of the "Low Cost" hypothesis is to permit the use of a series of PCM flows directed from Bologna to the decentralized Seats without the interposition of no equipment for outing, in order to simple the data transmission and to minimize the costs.
The schema of the flows shows as all the channels directed toward the Romagna territory are unified through a multiplexer in a single 34 Mbit/s channel, even if this channel is really used only as a 22 Mbit/s channel.

The routing of the frames which pass on the Radio network is totally executed in Bologna and in the terminal Seats; that is that there is no intelligence on the Repeaters, but only a static connection of channels. A Router in Bologna would see every connection toward each decentralized seat as a direct link, separated by the others, characterized by a typical speed of transmission, as illustrated in the logic schema, below.

PCM Flow Characteristics		
PCM Flow	Capacity (Mbit/s)	Occupation of 2 Mbit/s flows on the Backbone
Bologna - Cesena	8	4
Bologna - Forlì	8	4
Bologna - Rimini	2	1
Bologna - Ravenna	2	1
Bologna - Bertinoro	2	1
Bologna - Reggio Emilia	2	1





Disposition of the equipment in the "Low Cost" Hypothesis

The Radio system structure is designed to realize connections according with the expected speeds and frequencies, guarantying the continuity of the service, to integrate the existing network (in Bologna as in the decentralized seats), to re-use the equipment already used in the various seats.

All the radio connections, except the Monte Maggio-Bertinoro one, are executed with (1+1) ISO RTX, completed by a service channel, that is an automatic backup to be used in case of fault of the main RTX.

The structure of the system is influenced by three main problems, described below.

The transmitter in Bologna accepts only a 34 Mbit/s flow or 16 2 Mbit/s flows.

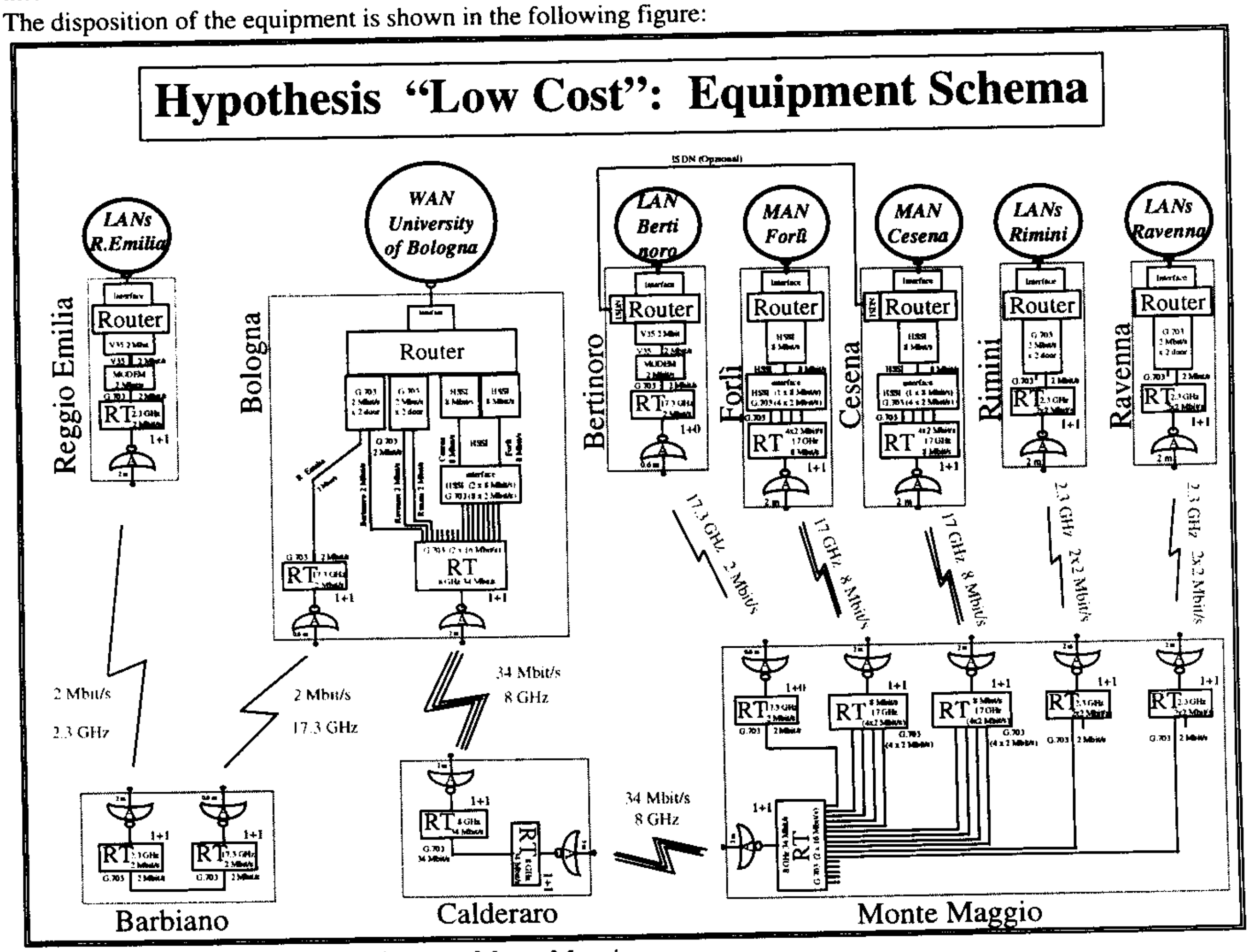
Because of in Monte Maggio there is no routing activity, but only a static connection of physical channels, the re-routing of the frames must be executed in Bologna. So the router must have a different interface for every university seat, that is a point of destination (Cesena, Forlì, Rimini, Ravenna, Bertinoro e Reggio Emilia).

The router doesn't manage the contemporary use of more than one parallel channels toward a single destination point, so the router must have one and only one interface for every destination point.

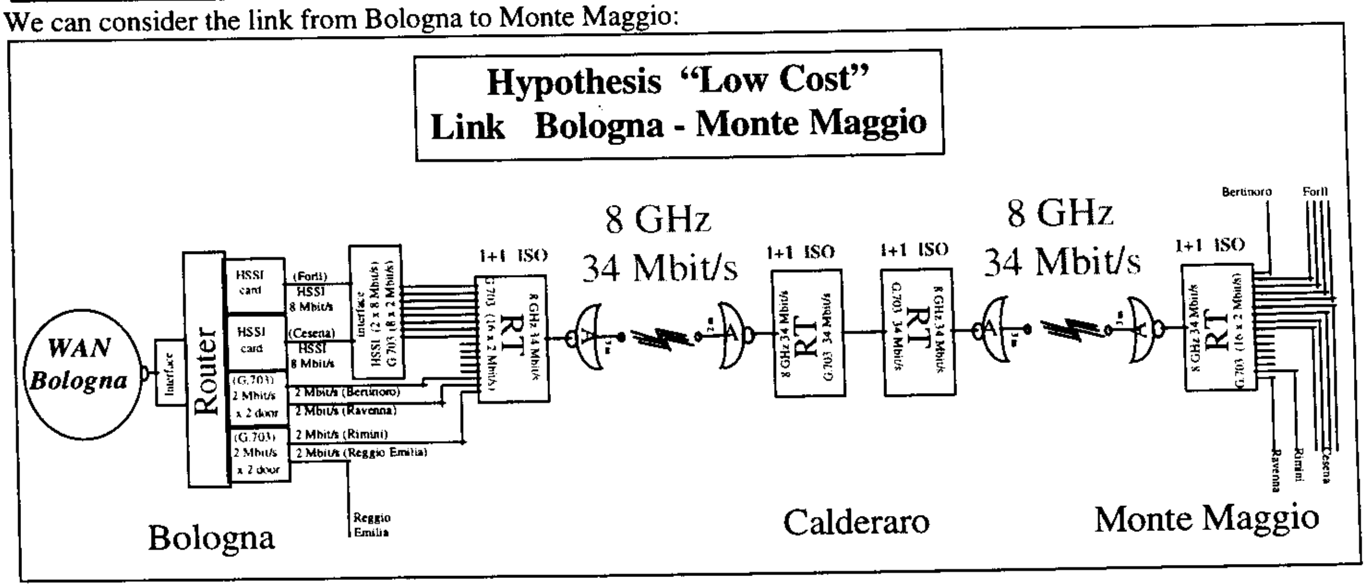
In short, for every university seat of destination the router must have a separate interface, and the data-flow which exit from the router must be devided into 2 Mbit/s flows before entering into the transmitter.

We can consider a generic data-flow from Bologna to a University Seat in Romagna: this flow exits from an electric interface of the router in Bologna, and a particular equipment separates it into a certain number of 2048 Kbit/s flows; these flows enter separately into the transmitter, and here they are unified in a 34 Mbit/s flow and they are sent from Bologna to Monte Maggio; in Monte Maggio RTX the 34 Mbit/s flow exits newly separated

into the 2048 Kbit/s flows which separatly enter into a transmitter in order to be sent to the final destination; in the final destination a specific equipment unifies them constituting again the original data flow which enter in an interface of the router.
The disposition of the equipment is shown in the following figure:

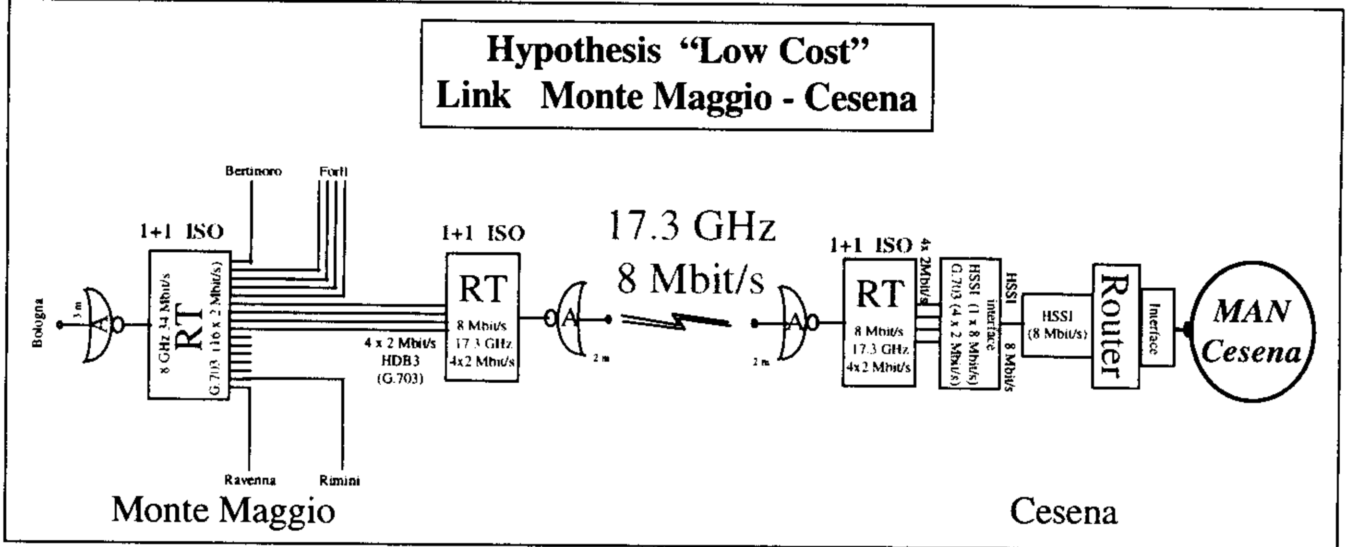


We can consider the link from Bologna to Monte Maggio:



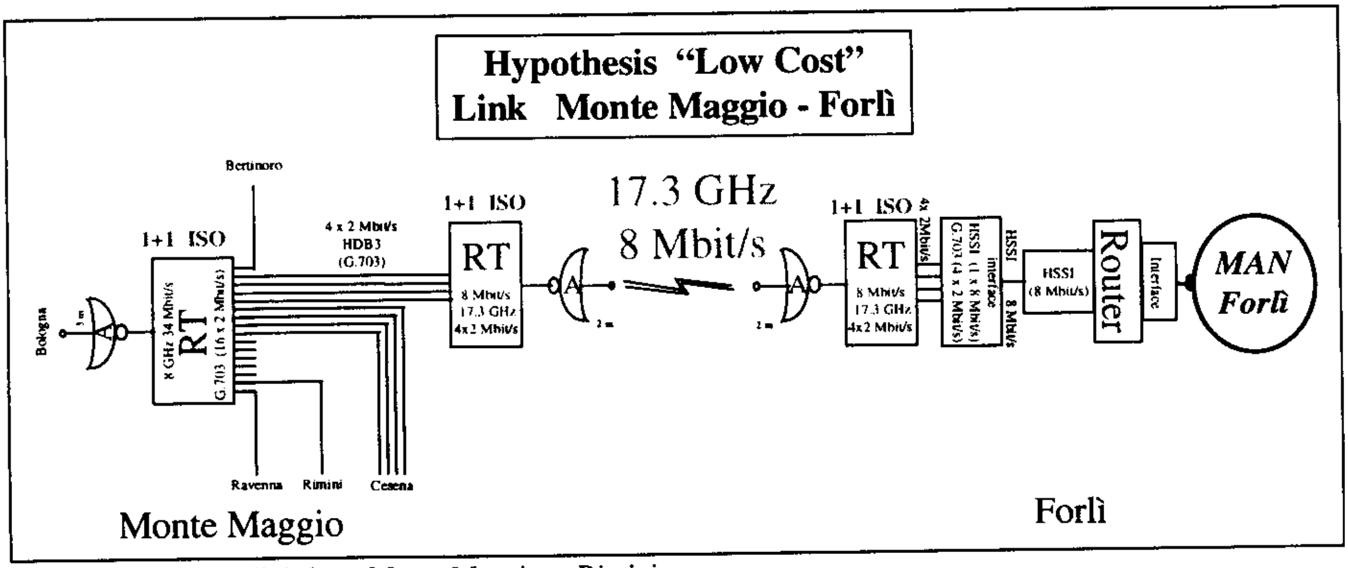
A multiplexer is connected at the HSSI interface of the router, this multiplexer separates the data-flows toward Cesena and Forlì into four 2Mbit/s flows. These flows enter separately into the transmitter, and here they are unified with the other three 2 Mbit/s data-flows (directed to Rimini, Ravenna and Bertinoro) in a 34 Mbit/s flow and then they are sent to Calderaro ; in Calderaro the 34 Mbit/s data-flow pass without variations in the receiver and in the transmitter, and then it is sent to Monte Maggio. In Monte Maggio the 34 Mbit/s flow is newly separated into the original 2 Mbit/s flows, which, according to their own final destination point, are sent (via hardware) to the correct specific transmitter in order to be sent to the correct specific university seat of destination (if there are more than one flow with the same destination, they are unified in a single data-flow before to be transmitted).

We can consider the link from Monte Maggio to Cesena:

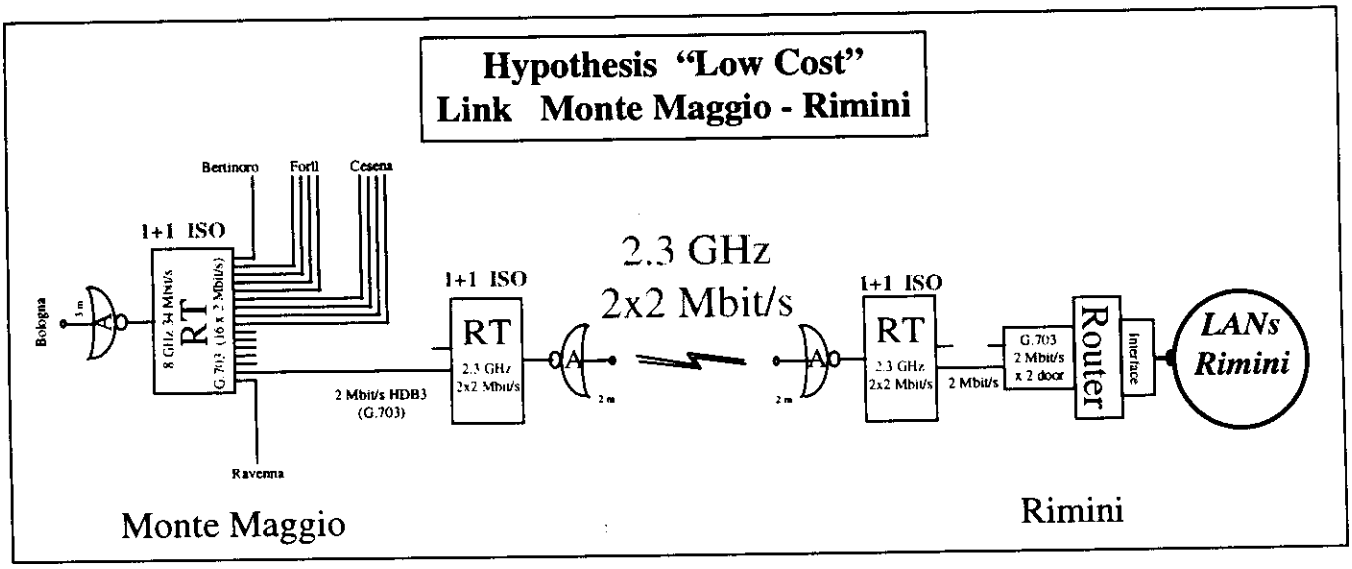


The 8 Mbit/s flow coming from Bologna to Cesena, enters into the specific transmitter of Monte Maggio to Cesena already separated into four HDB3 (G.703) 2 Mbit/s flows; here is unified in a unique 8 Mbit/s flow, and it is transmitted to Cesena at the frequency of 17.3 GHz. In Cesena the receiver separates the flow again into the original four flows which enter into a de-multiplexer undergoing a conversion of size in 8 Mbit/s in order to be sent to the HSSI interface of the router. Using the de-multiplexer we are able to resolve the problem of entering into the transmitter with four 2 Mbit/s flows, and the problem of exiting from the router through a single interface, on the other side the de-multiplexer comports some additional COSTS.

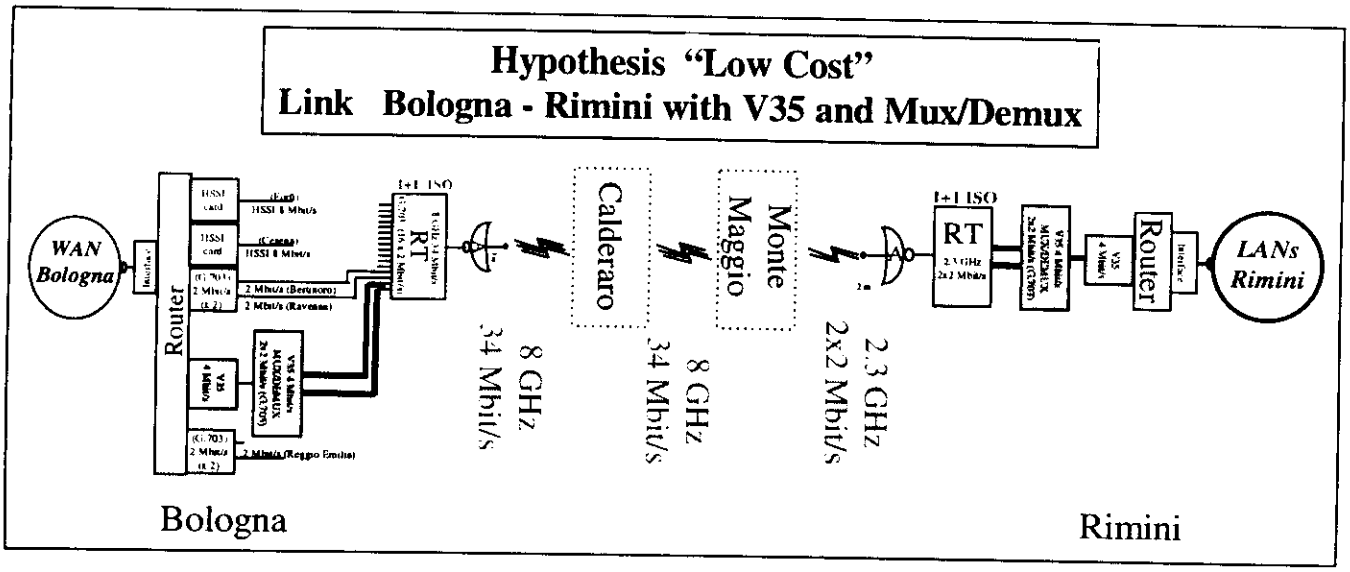
The link from Monte Maggio to Forlì is identical to the link from Monte Maggio to Cesena.



We can consider the link from Monte Maggio to Rimini:
The single 2 Mbit/s HDB3 (G.703), coming from Bologna to Monte Maggio, enters into the apposite transmitter without conversions; here it is transmitted to Rimini at the frequency of 2.3 GHz, where it enters in the router again without conversions.

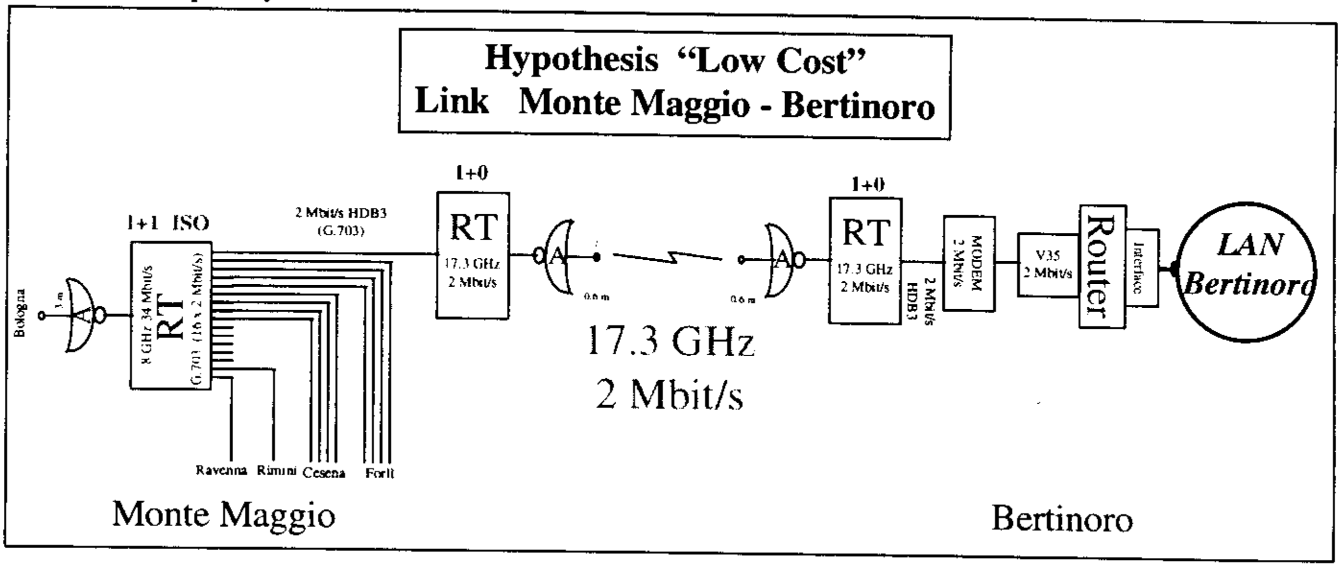


We can notice that the band expected for this link, would permit to transport two 2 Mbit/s flows, but the second isn't used because the router in Rimini isn't able to manage two different interfaces. In order to exploit both the interfaces for the flows in the two directions (from Rimini to Bologna and from Bologna to Rimini) we would add two multiplexer/demultiplexer (one in Bologna and one in Rimini) and two V35 interfaces (one on the router in Bologna and one on the router in Rimini).



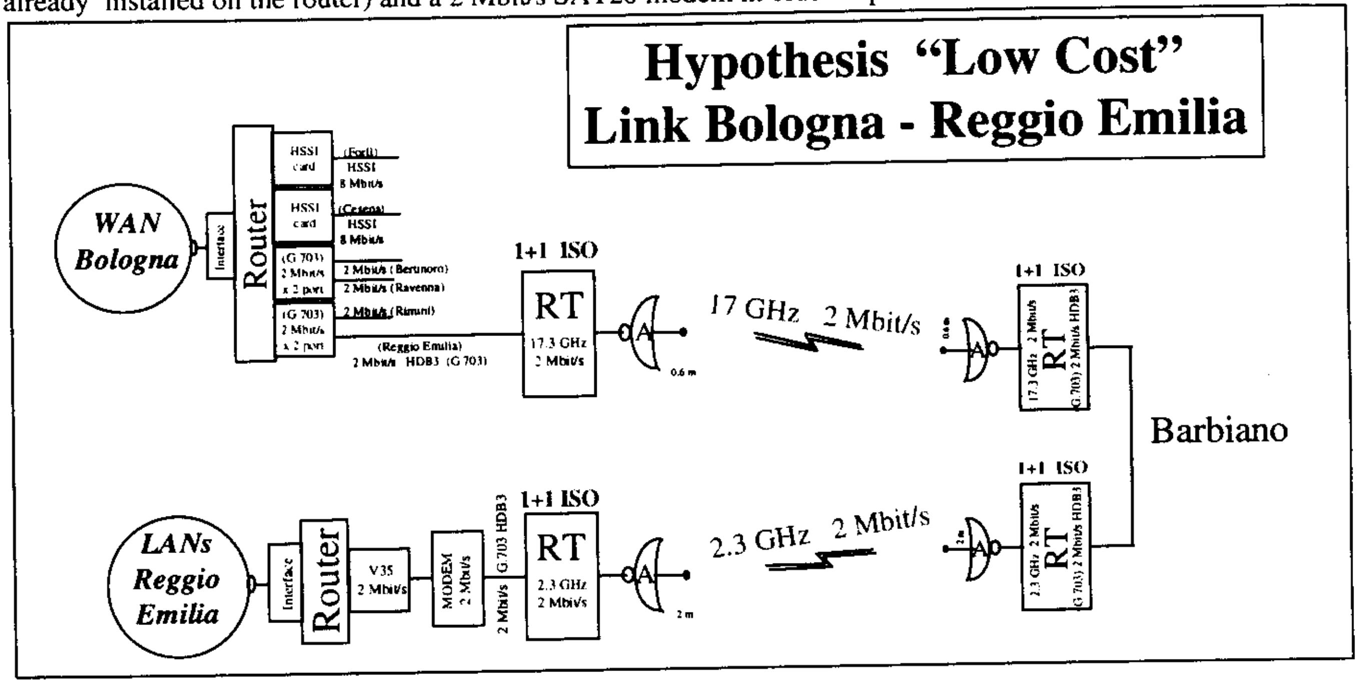
Considering this architecture, we can consider a V35 interface on the router in Rimini for a 4 Mbit/s flow, which enters in a multiplexer dividing the flow into two HDB3 2 Mbit/s flows. These two flows enter separately into the transmitter, through which they are sent to Bologna. Here another multiplexer unify the two flows in the original one which finally enters in the V35 interface of the router.

The link from Monte Maggio to Ravenna is identical to the link from Monte Maggio to Rimini.
We can consider the link from Monte Maggio to Bertinoro:
For this link the RTX are in 1+0 configuration. The transmission frequency is 17.3; the band expected permit to transport only one 2 Mbit/s flow. Moreover in Bertinoro there is a low cost router on which it is not possible to install 2048 Kbit/s HDB3 (E1) cards, with the result that we have to use a 2 Mbit/s V35 interface (that is already installed on the router) and a 2 Mbit/s SAT20 modem, which transform the flow into a 2048 Kbit/s HDB3 flow that can be accepted by the transmitter.



We can consider the link from Bologna to Reggio Emilia with a repeater in Barbiano.
As Barbiano is near to Bologna, a 17.3 GHz frequency is sufficient in order to use little aerials. There are no routing problem because only one 2 Mbit/s is expected on this link. In Barbiano the signal coming from Bologna is repeated on a different frequency. As in Bertinoro, also in Reggio Emilia there is a low cost router on which it is

not possible to install 2048 Kbit/s HDB3 (E1) cards. So also here we have to use a 2 Mbit/s V35 interface (that is already installed on the router) and a 2 Mbit/s SAT20 modem in order to pass the flow to the transmitter.



Main features of the "Low Cost" Hypothesis

Main positive features:

- the reasonable cost (about $ 1,2 millions).
- the use of transparent channels, that are channels usable without knowing the technology which realizes it;
- the definition of a Fault Tollerance system thanks to the use of 1+1 ISO RTX;
- the possibility to evolve the system also to realize telephony (this only with the static allocation of the band). This evolution is realizable inserting some multiplexers between the RTX and the router (in the university seats) in order to extract a (static) flow , with a expensive cost.

Main negative features:

- the static managment of the band;
- the impossibility to provide data-exchange with a specific quality for the services, as in ATM networks;
- the impossibility to communicate between Bologna and the territory of Romagna, but also among the seats in Romagna themselves, in case of fault on the backbone. The connection with Reggio Emilia is not involved by an eventual fault of the backbone, and, on the other end, also an eventual fault of the connection with Reggio Emilia doesn't cause problems to the backbone.

Conclusions about the realization of thr "Low Cost" hypothesis.

This hypothesis has been rejected in spite of the "Backbone ATM" one which, though with a higher cost, it guarantees a range of services of higher quality, a bigger scalability and flexibility of the system and the possibility of an evolution towards an homogeneous and global ATM management of the Atheneum network.

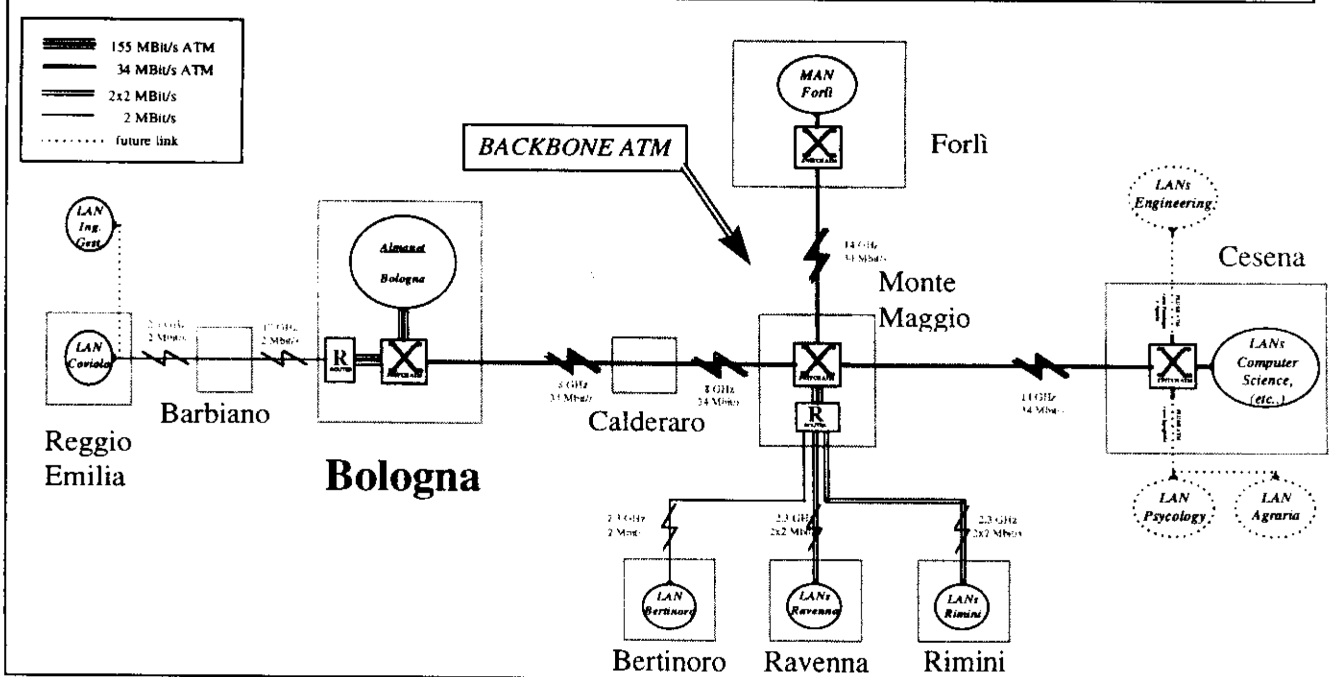
Hypothesis of "Backbone ATM" realization

This hypothesis has been projected to meet the actual needs of University activities. These needs have been focused during the phase of projectation. The hypothesis has been thought in details by University itself and is now being realized.

New needs of Bologna University.
In towns where a plan of connection between some universitary locations was already in project, there is the need to link some extra universitary centres. In Cesena, in particular, the location of the Course of Informatic Science, which was already to enter the connection, has been joined in the plan by the decentralized locations of Engeneering, Psychology and Agriculture. Besides, in order to connect also a decentralized location of Engeneering, the link bit-rate with Forlì has been increased. Finally, it has been acknowledged the undenieble advantage, from the point of view both of performance and flexibility, of managing dynamically the range of links. We also have considered the possibility of tele-didactics and the video-conferencing.
The telephony management is not required, but, in the "Backbone ATM" hypothesis, the system is easily developeble, to allow the standing by of telephony inside the University. In the "Backbone ATM" hypothesis, the telephony could be immediately realized between the locations of Bologna, Cesena and Forlì, exploiting the potential of the ATM link. The joining of the locations of Rimini, Ravenna, Reggio Emilia and Bertinoro in the telephony project would mean some modifications only slightly more complex.

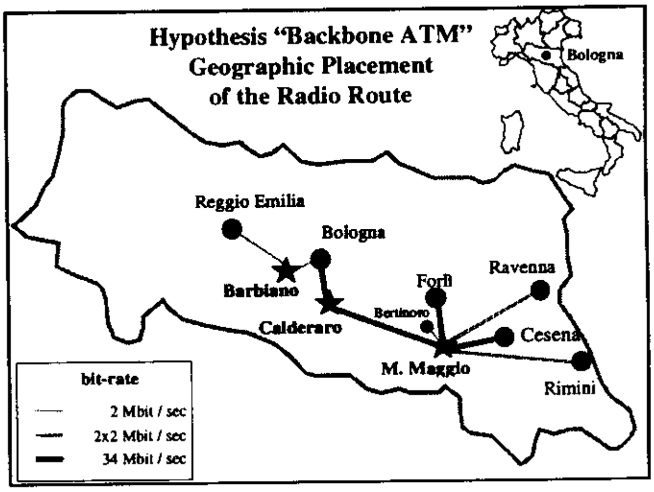
Basic idea of the "Backbone ATM" hypothesis.
The new hypothesis characteristic is that it realizes a "Backbone ATM" with 34 Mbit/s between Bologna and Montemaggio, which devides itself in two further radio link ATM, working at 34 Mbit/s towards Cesena and Forlì. Besides, from Monte Maggio, by adding a router, three not-ATM radio link depart at lower speed towards Ravenna, Rimini and Bertinoro.

Hypothesis "Backbone ATM": Radio Link and Routing Equipment



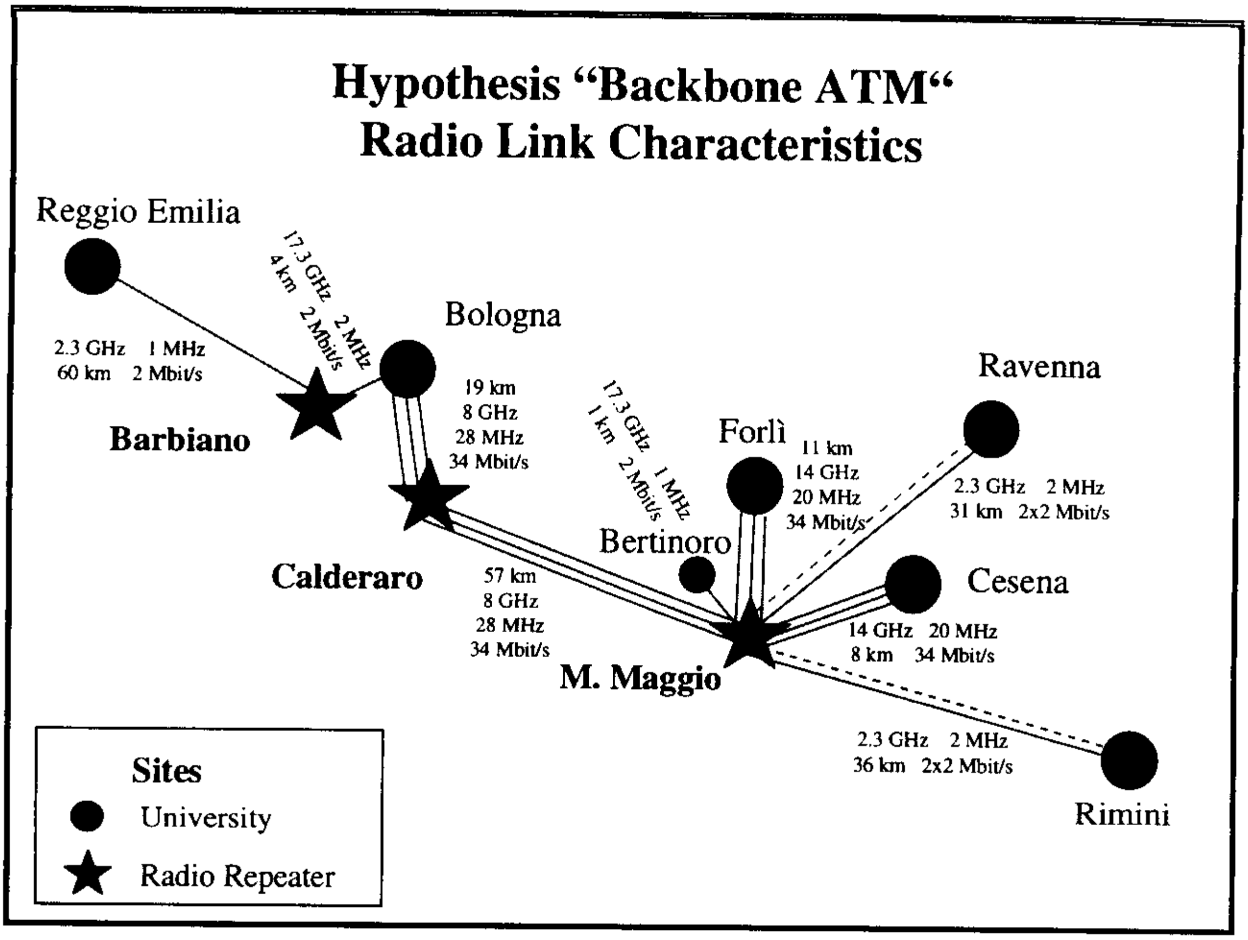
Radio Link and dimensioning of the bit-rate speed in the "Backbone ATM" hypothesis.
In this way, the topology of the connection is the same of the "Low Cost" hypothesis, but, in the radio link from Monte Maggio to Cesena and Forlì, the speed is higher.

Hypothesys "Backbone ATM" Choice of the Radio Link		
Radio Link	[illegible]	[illegible]
Bologna - Calderaro	34 Mbit/s	19 km
Calderaro - Monte Maggio	34 Mbit/s	57 km
Monte Maggio - Cesena	34 Mbit/s	8 km
Monte Maggio - Forlì	34 Mbit/s	11 km
Monte Maggio - Ravenna	2x2 Mbit/s	31 km
Monte Maggio - Rimini	2x2 Mbit/s	36 km
Monte Maggio - Bertinoro	2 Mbit/s	1 km
Bologna - Barbiano	2 Mbit/s	4 km
Barbiano - Reggio Emilia	2 Mbit/s	60 km



Choice of transmission frequences.
In the case of certain radio link short enough, for example Monte Maggio-Cesena and Monte Maggio-Forlì, which require a 34 Mbit/s flow of data, it is posssible to realize a link without mistakes by using frequences at about 14 GHz. For these frequences the Minister of PP:TT provides channels wide enough.
In the case of other radio link, particulary the ones of the Backbone --from Bologna to Calderaro and from Calderaro to Montemaggio-- the long distance calls for low enough frequences. Thus, it has been opted, as to the radio link Bologna-Calderaro and Calderaro-Monte Maggio, for a 28 MHz band, in the range of frequences of 8 GHz, which allows to realize the required 34 Mbit/s flow.
For the long radio link (till 60 Km), in which a transmission speed of 2Mbit/s was enough (widenable to 2x2Mbit/s), it has been opted for a 2.3 GHz frequence, which is low enough to allow the covering of long distances as well; besides, on this frequeces, the Ministery of PP.TT allows the use of a sufficient band.
In the case of short radio link (till 5 Km), for which a transmission speed of 2Mbit/s is enough, it has been opted for the 17.3 GHz frequence, which allows the use of smaller parables and decreases the charge on structures.
The characteristic parametres of the radio link are summmed up in the following scheme.

Hypothesys "Backbone ATM" Radio Link Characteristics					
Radio Link	Capacity (Mbit/s)	Distance (km)	Frequences (GHz)	Band Width (MHz)	Modulation
Bologna - Calderaro	34	19	8	28	PCM-QPSK
Calderaro - M. Maggio	34	57	8	28	PCM-QPSK
M. Maggio - Cesena	34	8	14	20	PCM-16QAM
M. Maggio - Forlì	34	11	14	20	PCM-16QAM
M. Maggio - Ravenna	2x2	31	2.3	2	PCM-16QAM
M. Maggio - Rimini	2x2	36	2.3	2	PCM-16QAM
M. Maggio - Bertinoro	2	1	17.3	2	PCM-QPSK
Bologna - Barbiano	2	4	17.3	2	PCM-QPSK
Barbiano - Reggio Emilia	2	60	2.3	1	PCM-16QAM



An informal approach to ATM technology.

The ATM connection organizes the data change with connection-oriented modalities, by making use of information flows that are structured in cells of constant dimensions (53 byte). The ATM connection is organized like a set of Hosts, in which applications are settled, and of Switches, which select the data routes through the connections. Two contiguous Switches have a set of physical channels, which the data transmission can take place through. In order to send datas from a Host A to a Hosty B, you have to follow a certain route _R,_ running along a sequence of physical channels among the the Switches. You say that the route is mapped with the physical channells of the connections.

Everytime a data change have to take place between two Hosts, ATM provides an identificator ID to that communication, choose a route through the Switches and communicates to the involved Switches which physical channels that communication will be bound to follow. Thus, it can be said that ATM books those resources that will be employed in that communication. Every pack of information (cell) being transported in ATM brings on itself the identificator ID of the communication which it belongs to. In such a way, every Switches is able to sort out the datas of different communications and sends all the datas of the same communication through a chosen physical channel. In other words, the ATM organization keeps an open channell for each communication. Such a channel occupies the passing band only when the datas are presently going through; otherwise, the band is available to other channels.

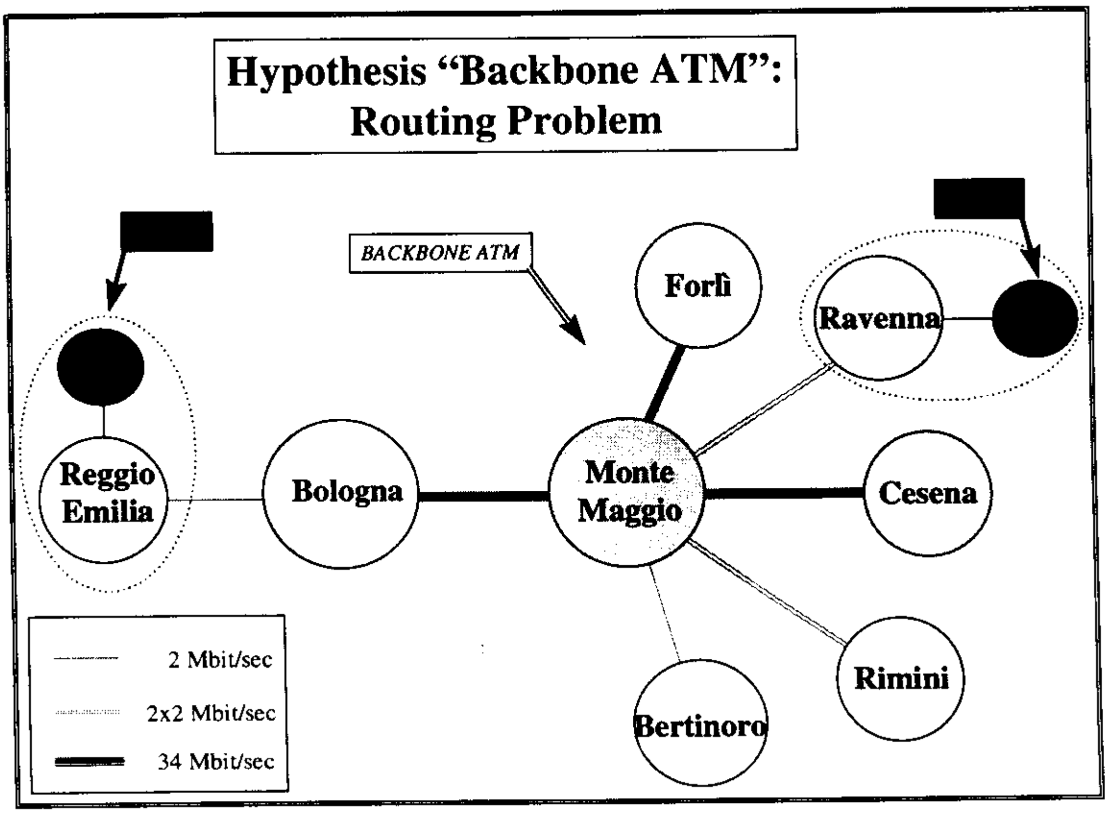
ATM can associate a certain service quality (QoS) to each communication:

- **Guaranteed QoS**: the avarage quantity of transmissed datas in the unit of time, that's to say the throughput, is constant;
- **Predictable QoS**: the delay variation ranges within a foresaid intervall;

- **Available bit-rate QoS**: the throughghput is not guaranteed, nor a costant maximum delay is. The connection does nothing but a service as good as possible, in relation to the real traffic situation.

Accordingly to the quality required for the communication, ATM manages for the Switches to deal datas in the proper way, so that the required quality is guaranteed.

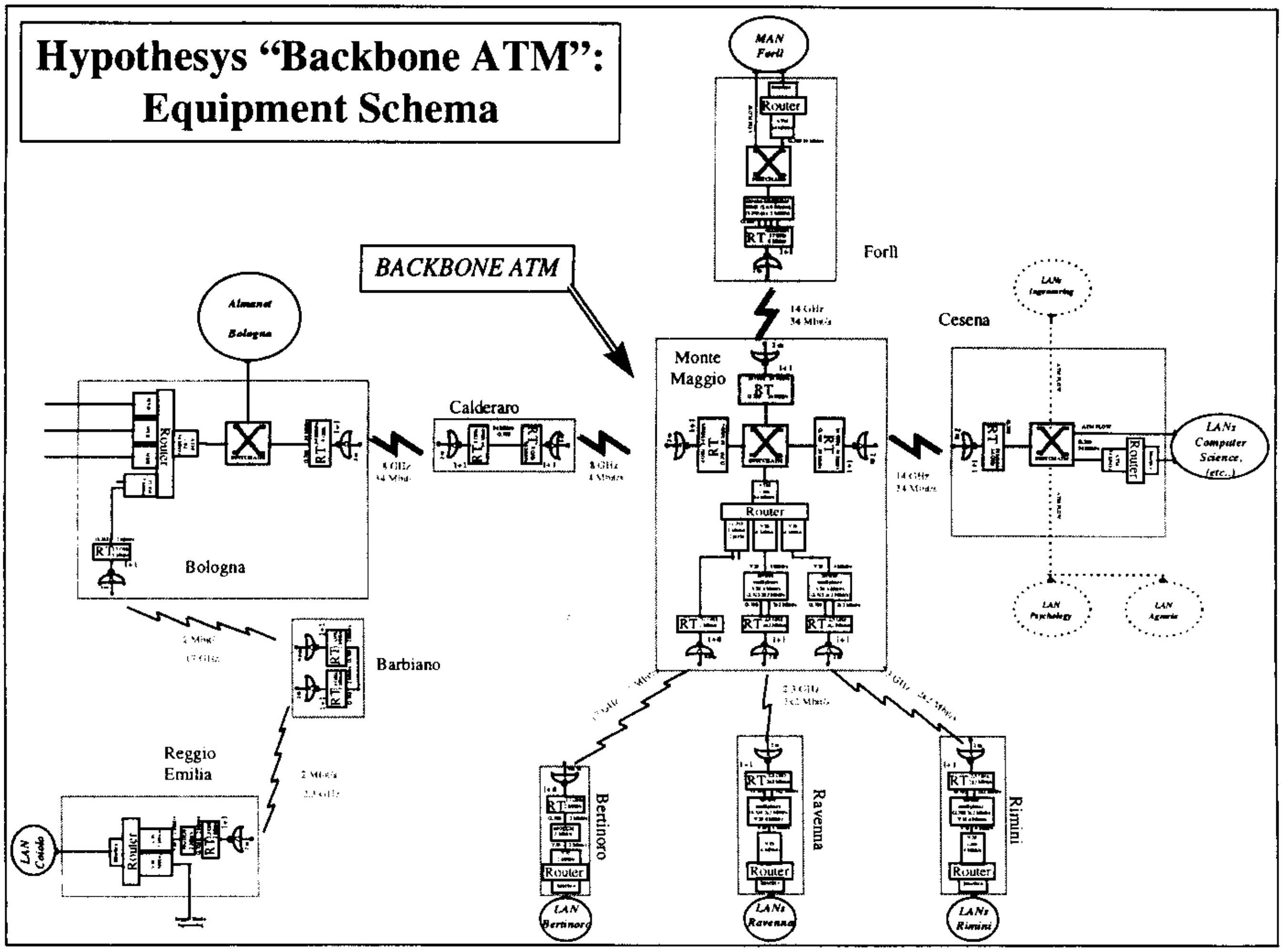
The routing in the "Backbone ATM" hypothesis.
The routing of the cells passing through radio connection is being managed in correspondence of repeater bridge of M. Maggio, which, thus, play the role of central point of routing for all the cells to and from the land of Romagna. ATM is a backbone technology so if one machine connected to a fast ethernet that is at one side of the backbone wants to talk to another machine (also connected to the fast eternet) on the other side of the backbone the routing is a problem. The main difficulty is the MAC address resolution,this is because the LAN tecnologies are generally meant for a shared medium with a natural broadcast mechanism ATM instead is a point-to-point or point-to-multipoint connection oriented technology, over which broadcast is hard to implement. The problem is how to use ATM without rewriting the network applications? The ATM forum and the IETF (Internet Engineering Task Force) are proposing each it's own standard, so there are many manufacturers that have be implemented either, but presently there isn't a complete standardization in this area.



Disposition of the equipment in the "Backbone ATM" hypothesis.

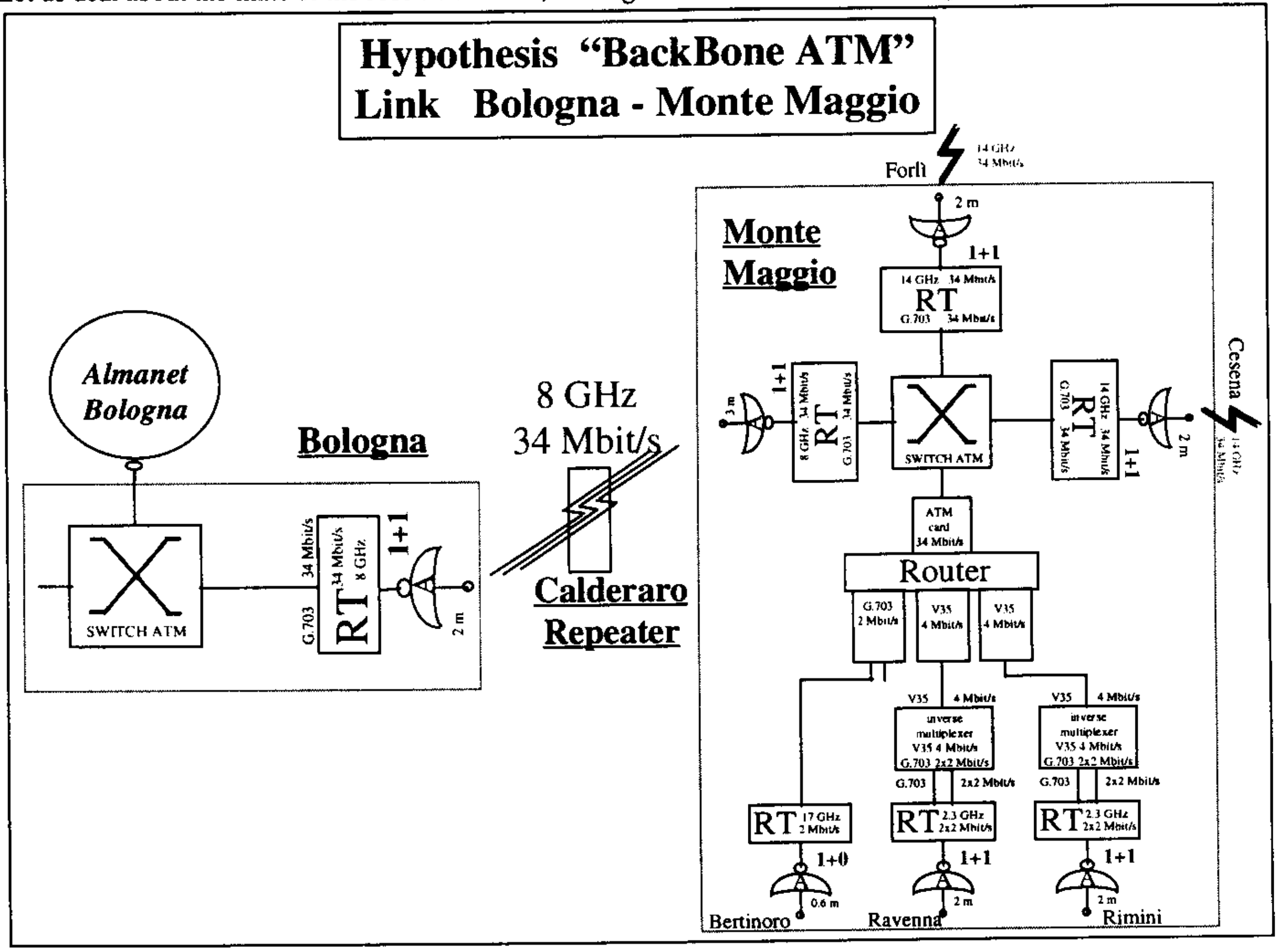
The whole of the radio connections, apart from the radio link M.Maggio-Bertinoro, is being realized with RTX 1+1 ISO (isofrequence reserve) terminals, including service channels.
Let us deal about the basic characteristic of the system:

- In Bologna there is an ATM Switch with a 34 Mbit/s door, directly connected to a 34 Mbit/s transmitter directed towards Romagna. This Switch sorts out the cells to and from Romagna. All the datas to Romagna pass through the Switch, then they are directed into a unique 34 Mbit/s flow and, finally, they are sent.
- At Montemaggio is provided the routing of the cells. For that, there are an ATM Switch, for the flows supperted in ATM, among Bologna, Cesena and Forlì, and a router, for the flows not supported in ATM, to Rimini, Ravenna and Bertinoro.
- The router of Monte Maggio cannot make different parallel channels work simultaneously towards the same destination. That's why you cannot go out with more than a door towards the same destination. Thus, for each of the final destination (Rimini, Ravenna Bertinoro) have to exist one and only one door of the router. As to the connection towards Rimini and Ravenna (2x2 Mbit/s), the unique flow going out of the router has to be split in two flows, each at 2 Mbit/s, before getting into the transmitter.



In particular, it must be pointed at the Backbone in ATM technology between Bologna and Monte Maggio. It devides and follows towards Cesena and Forlì, constituting a high-speed backbone between Bologna and Monte Maggio.

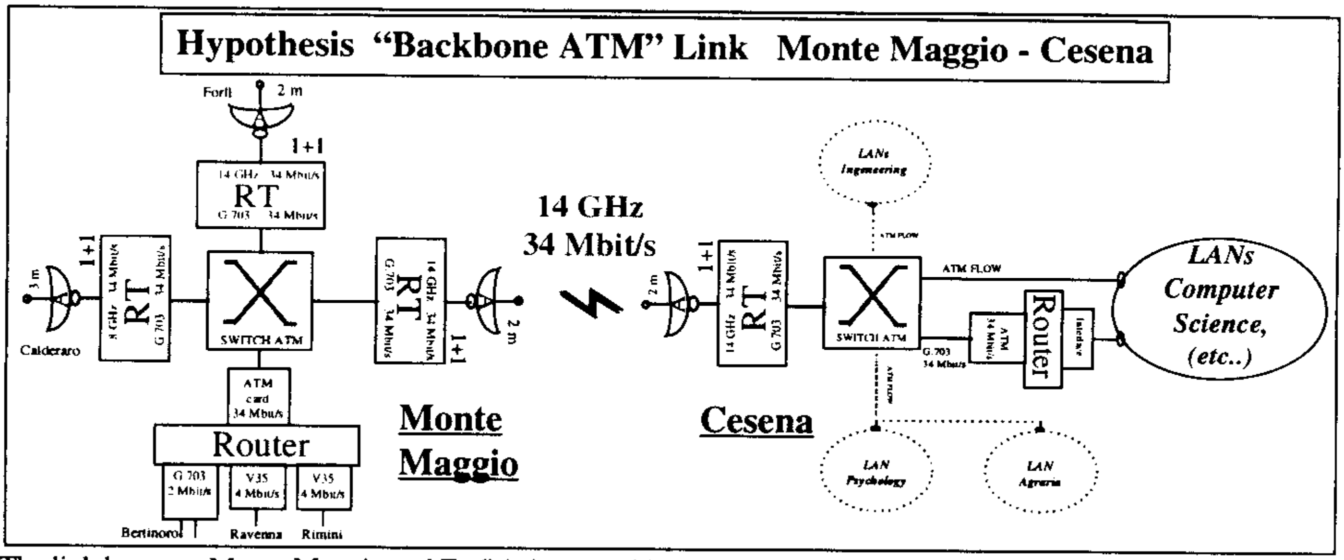
Let us deal about the links of the ATM backbone, starting from the one between Bologna and Monte Maggio.



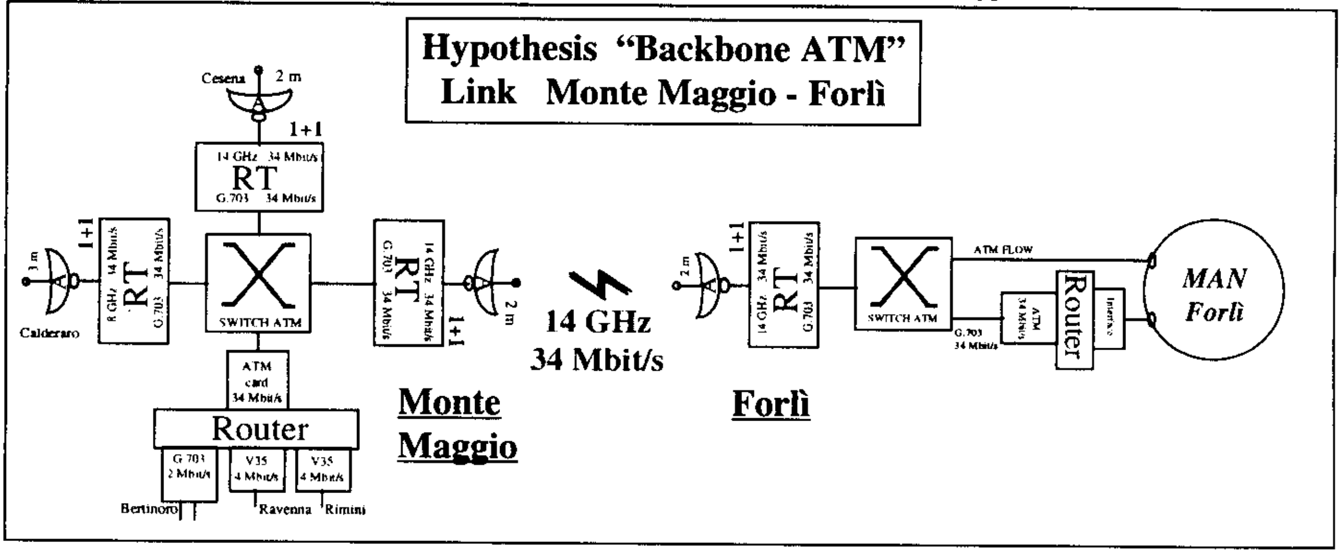
The datas directed to Romagna go out of the Switch in Bologna, from an ATM door, by means of a 34 Mbit/s flow that is directly sent towards Monte Maggio, without any further directioning. In fact, at Calderaro the 34 Mbit/s flow goes through the receiver to the transmitter without variation, and then it is sent towards Monte Maggio. Over there the flow (the ATM cells) is processed by the Switch. If the datas are to be sent to Cesena or Forlì, you have to stay in ATM technology, and the datas just follows to the right transmitter. On the contrary, if the datas are directed to Rimini or Ravenna or Bertinoro, you have to put aside the ATM technnology and let the flow go into a router that sorts out the datas. Thus, at this point, the management of the band is dynamic.

Let us deal with the link between Monte Maggio and Cesena.

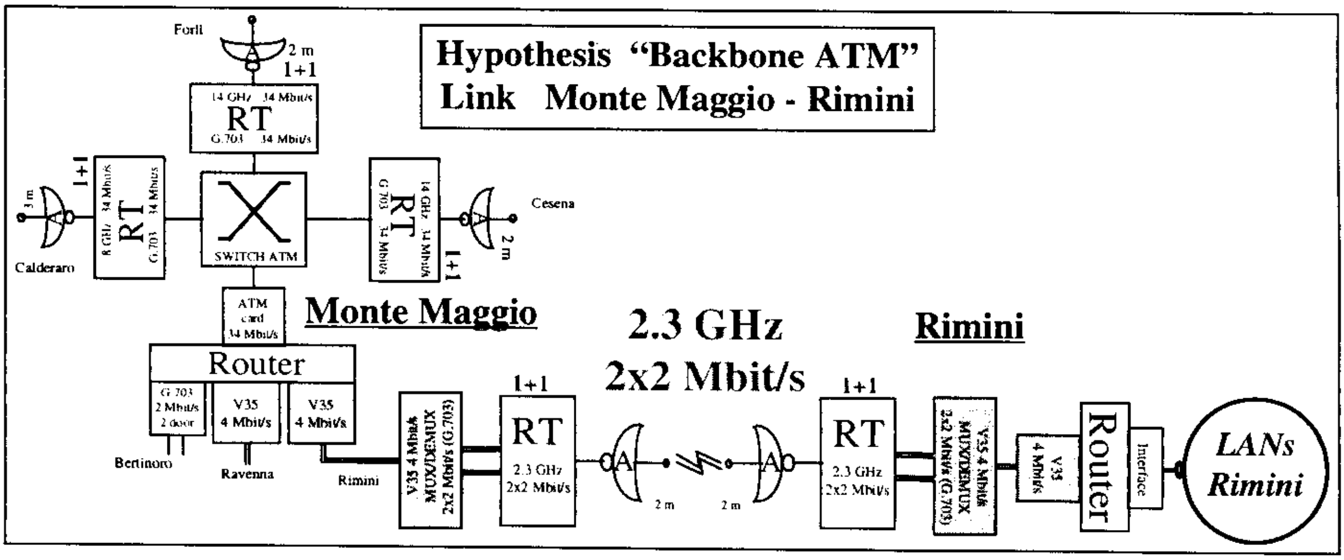
This link is simple as to both the radio transmission and the networking, because it consists of a unique 34 Mbit/s flow (G.703 HDB3) realized on a 14 GHz frequence; such a link conveys an ATM flow which, at Cesena, will be devided into an ATM part and a "not-ATM" part. The last one is sent to the router, which will correctly handle the directioning. Thus, at Cesena will be available two kinds of flows: the flows, that's to say the services, in ATM technology, and the classic IP flows.



The link between Monte Maggio and Forlì is in everything similar to the Monte Maggio-Cesena one.

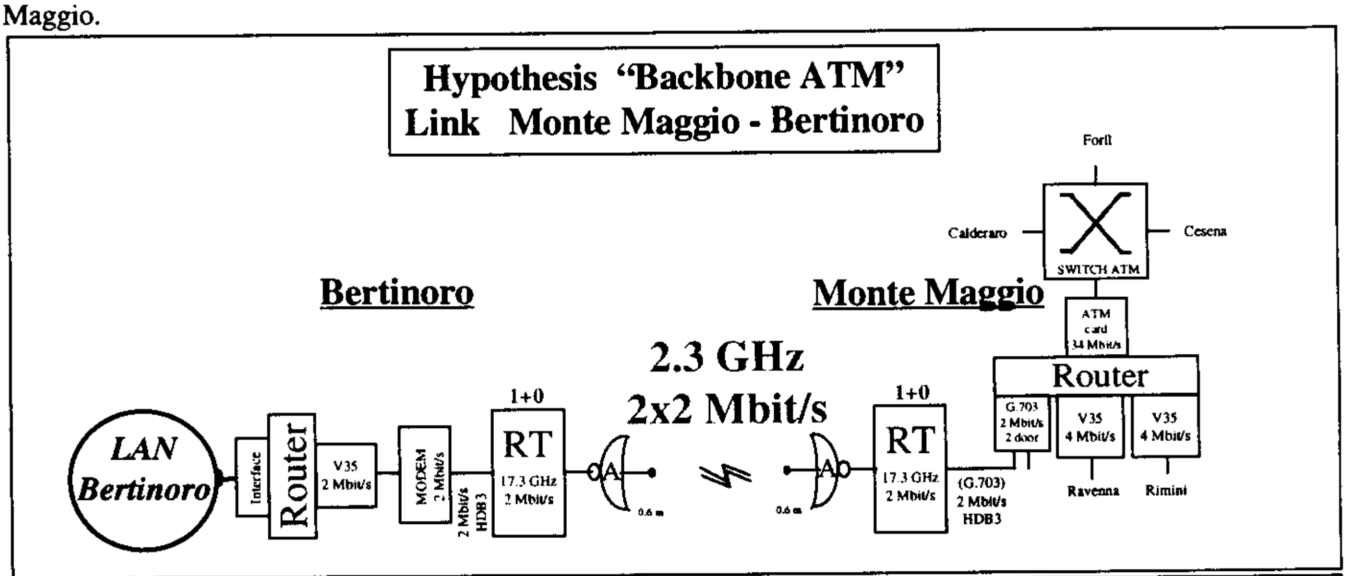


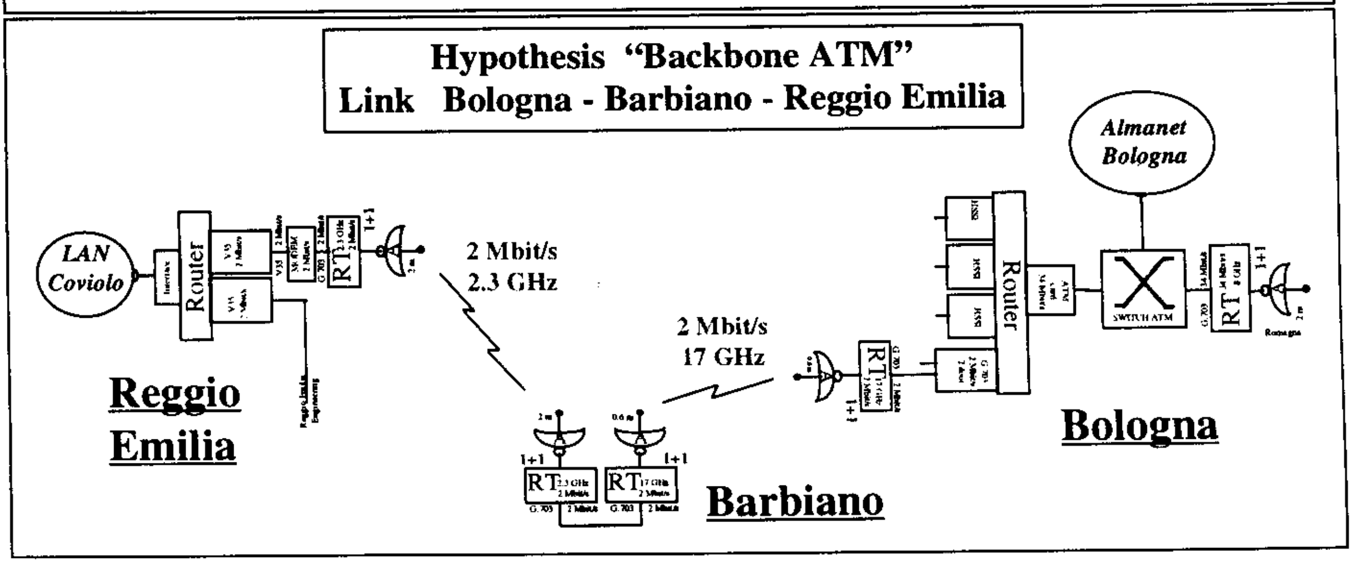
Let us deal with the "not-ATM" links.



In the respect of the "Low Cost" hypothesis, the bit-rate of the links towards Rimini and Ravenna has been increased, exploiting in full the available band. This has been possible by means of two V35 doors in the router of Monte Maggio. From each doors a flow goes out of the 4Mbit/s type, directed towards Rimini or Ravenna; each V35 door is connected to an inverse multiplexer which devides the going out flow into two 2 Mbit/s G.703 HDB3 flows. These will get to the transmitter to Rimini or Ravenna. Analogously, in Rimini (or Ravenna), immediately after the receiver, there is an inverse multiplexer and a V35 door on the router, in order to realize the inverse process.

Let us, finally, deal with the link settled between Monte Maggio and Bertinoro, and the link between Bologna and Reggio Emilia, with repeater in Barbiano. Such links do not undergo any variation, that's to say, they are kept like in the "Low Cost" hypothesis, apart from the presence of the two ATM Switches in Bologna and at Monte Maggio.





Main characteristic of the realization of the "Backbone ATM" hypothesis.

Main positive characteristics:

- Transparent channel, that's to say a channel exploitable like any other data line, where it is unnecessary to know the technology in use;

- Simplification of many interface problems between radio system and networkings;
- Fault Tollerance System, by means of the required transmitters with technology 1+1 isofrequence;
- Data changes among the Romagna universitary locations, already managed in Monte Maggio, instead of Bologna;
- In case of Fault on the Backbone, obviously, communication between Bologna and Romagna becomes impossible, but communication among the locations in Romagna are left well available;
- Possibility of developement of the connections, in order to provide support to the telephony with a dynamic management of the band. For the locations reached in ATM, the extension is a little bit much complex but possible;
- Dynamic management of the Band, for both datas and, possibly, telephony.
- Availability of advanced services (QoS, Quality of Service), provided by ATM, as to the locations reached in ATM, like:
  - demand of constant throughput ;
  - demand of a constant maximum delay;
  - no particular demand of quality service;
- Possibility of configuration of the Virtual Lan, for an advanced management of the net by the system administrators.

Main negative characteristics:

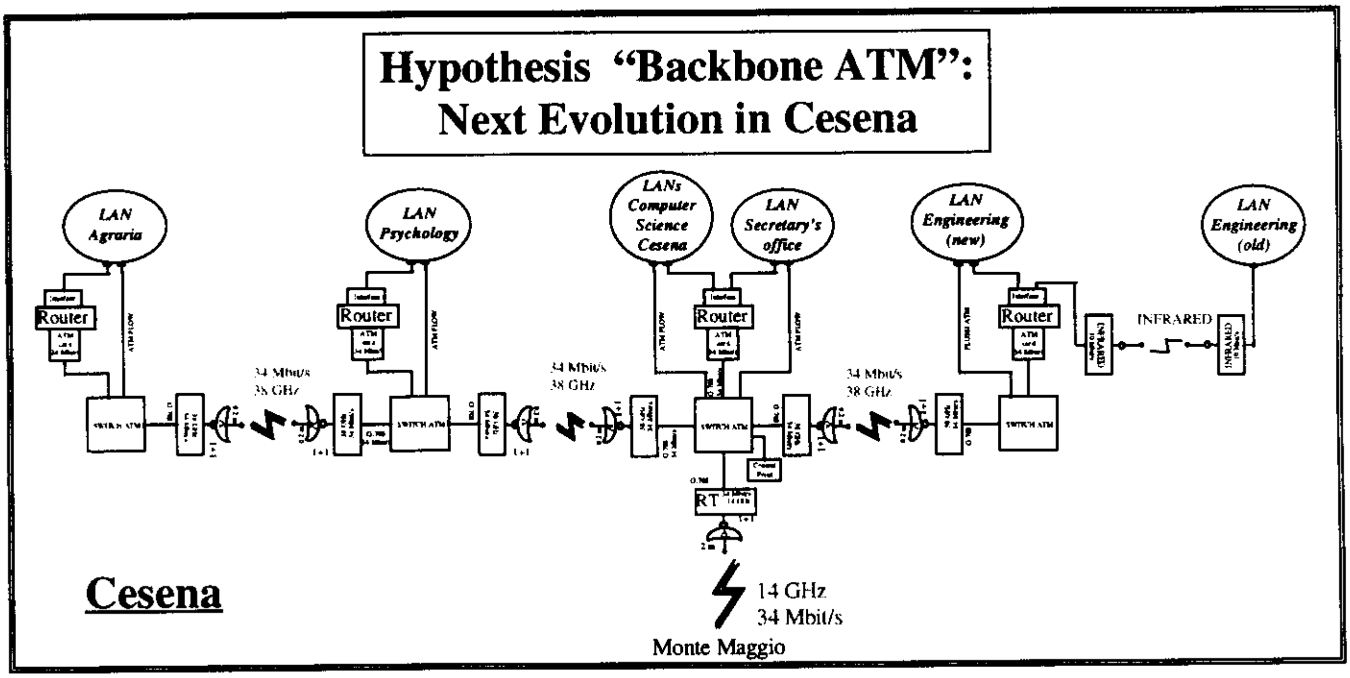
- Basically the higher costs, about $ 1,5 millions;
- Configuration of the routing much complex; the integration of connections in ATM and classic IP connections have to provide services of higher quality and keep the compatibility with the previous system; a wrong management of the routing lessens the global performance.

Conclusions about the realization of the "Backbone ATM" hypothesis.
This hypothesis has been chosen by the University of Bologna to realize practically its own net of connections with the decentrated universitary locations, because, though with a higher cost, it guarantees a range of services of higher quality, a bigger scalability and flexibility of the system and the possibility of an evolution towards an homogeneous and global ATM management of the Atheneum network.
At the moment (26/02/1997), the procedure of bid is taking place to establish which enterprise will be allowed to build the radio system.

Next Development

Actually we are studing some hypothesis for the future development of the radio system. In particolar they regard:

- the **topologic extension** of the ATM network in Cesena in order to connect via radio Computer Science to the Faculty of Psychology and the department of *Agraria* and the Faculty of Engeneering ; this hypothesis is in an **advanced** phase of development.



- the future resolution of the problem of supporting telephony also in the seats in Ravenna, Rimini, Reggio Emilia and Bertinoro ; in particolar we want to introduce equipment (cell-path) which support ATM technology also for low speeds (2 Mbit/s).

Technical Specification Definition.

Writing the technical specification of a complex radio network is an arduos work that takes a lot of time. The main difficult is to estabilish a compromise between quality/performance of the system and the allocated budget; one should specify, with more precision, how well does the new system integrates into the existent network.
The first thing is to have a precise idea of what features of the network are a must. The technical specification definition must describe in particular the technical charateristic of the system and it must also specify the kind of tests the systems must pass succesfully.
As an example the rain fading in the country where the radio will be installed should be considered to guarantee that the unavailability of the system will not exced a given amount of minutes/year. The typical elements that should be inserted into a technical specification are the amount of unavailability/year, the BER, the enviroment conditions and so on. As an example one of the test that is tipycally required is the "climatic room" test. One transceiver is located in a temperature controlled chamber and a second transceiver is located outside. The two are connected by means of variable attenuator. The chamber's temperature is cycled from cold to hot several times beetwen the limits of temperature and humidity of the specifications,and the performance of the syste is continuosly measured for a minimum of 24 hour that can be extended to 192 hours in some cases. Particular attention must be given to the interfacing of the communication equipment with the existing network.

Very often incompatibility between the interfaces will require to spend 100 in a system thath cost 100, or the lack precision in the tecnical specification that the equipment must meet result in system availability of only one day per year.
The writing of the techinal specification of our project required 4 mounth of full time work by a team of 7 person full time work, and the result covered 400 pages.