Implementation Options and Economics of Phased UMTS Deployment

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Abstract: **3GPP (Third Generation Partnership Project) is defining UMTS (Universal Mobile Telecommunication System) releases which span the transition from GSM/UMTS coexistence to All-IP UMTS networks. The deployment of an UMTS network depends, in the first place, on the intended service offerings and the release an operator chooses to start service with. Other key decisions influencing UMTS deployment relate to the timing of the functional enhancements and capacity increases along the economic life of the network. This paper gives an overview on the architectural and technical options for UMTS deployment. It also outlines the methodology underlying the business plan aimed at estimating the returns from investments in the UMTS infrastructure, thus helping to tune operators' strategies for UMTS deployment.**

Index Terms: **Third generation mobile systems, network architecture, operator policy, deployment options, deployment economics, business plan, sensitivity analysis.**

I. INTRODUCTION

3GPP (Third Generation Partnership Project) is defining UMTS releases which span the transition from GSM/UMTS coexistence to All-IP (i.e., end-to-end IP connectivity) UMTS network, [1]–[3].

An operator intending to offer UMTS services has to take the following strategic decisions impacting UMTS network deployment:

- The service offerings intended to be supported and their anticipated evolution;
- the "entry level" network, i.e., the UMTS release to start service with. This level may depend on whether the operator is an incumbent or a green field one;
- the timing of the functional enhancements. These may be related to the evolution from one UMTS release to another, and/or to the upgrading devised for the same release;
- the timing of the capacity increases. Schedules for provisioning capacity to meet demand growth may be synchronized with functional enhancements.
- the tariff policy and its evolution along the economic life of the UMTS network. This policy accounts, among others, for the erosion of the service costs with increased service penetration.

UMTS economics, similarly as with other systems, suggest that architecture/functional enhancements and capacity increases be considered in the perspective of optimizing the interventions on the network. As a result, strategies for a phased approach to cost-effective UMTS deployment play a key role in: i) Ensuring market share and profitability margins to UMTS operators, and ii) enabling a smooth introduction of new services and extension of the service coverage. To materialize and facilitate operator deployment plans, vendors provide their equipment with a high degree of flexibility and modularity in accommodating functional and capacity increase requirements.

This paper reviews key architecture and implementation options for UMTS deployment considering both the radio access and the core network. The paper also addresses the methodology underlying the business plan process for the economic analysis intended to guide operators' choices for UMTS deployment.

II. UMTS EVOLUTION PHASES

Release 1999 (Rel-99) of 3GPP UMTS specifications is essentially a consolidation of the underlying GSM specifications and the development of a new radio access network. With Rel-99, the foundations have been laid for future high-speed traffic transfer in both circuit switched and packet switched modes. In evolving Rel-99, it was moved away from a strict yearly schedule of releases, and the successive release has become known as Release 4 (Rel-4). Its specifications have been functionally frozen in early 2001. Release 5 (Rel-5) has been finalized in mid 2002, and work on Release 6 (Rel-6) is ongoing. Key features of Release 99 to Release 5 are summarized in Table 1.

One major change when passing from Rel-99/Rel-4 to Rel-5 consists in dropping the support of GSM in one operator's domain. This results in the discontinuity evidenced in Fig. 1 due to dropping of the circuit switched segment in the Radio Access Network (Iu-CS interface).

Since operators will choose different migration strategies from 2G to 3G systems, UMTS and GSM/GPRS interoperability across different administrative domains will have to be supported for some time even after widespread deployment of All-IP UMTS[1].

III. THE RADIO ACCESS NETWORK

The investments on the radio access network (RAN) typically range between half and two thirds of the total investments for the infrastructure of a mobile system. For this reason, and because a large part of the quality of service perceived by the end-user is impacted by the design and dimensioning of the radio access network, planning of UMTS terrestrial RAN (UTRAN) plays

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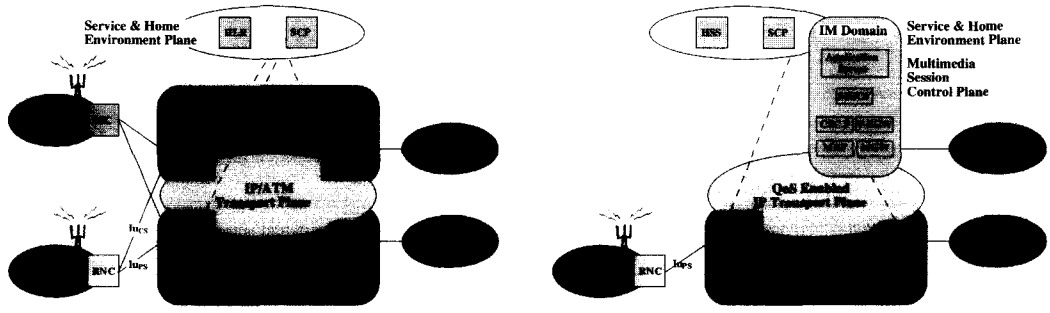
[1] Also, operators might choose different timing for implementing in their own domain Rel-99 to Rel-5 releases for the radio access and the core network.



(a) (b)

CSCF	Call State Control Function
GGSN	Gateway GPRS Support Node
HSS	Home Subscriber Server
MGCF	Media Gateway Control Function
MGW	Media Gateway function
MRF	Multimedia Resource Function
RNC	Radio Network Controller
SCP	Service Control Point
SGSN	Serving GPRS Support Node
T-SGW	Transport Signaling Gateway Function

Fig. 1. (a) UMTS Rel-99; (b) UMTS Rel-5.

Table 1. Phases of UMTS standard development in 3GPP (selection of features, Release-6 under development).

Release 1999	Release 4	Release 5
Services & system aspects		
• Services as available with GSM • Multimedia messaging	• Virtual Home Environment (VHE) and Open Service Architecture (OSA) evolution • Location Services (LCS) in Circuit Switched and Packet Switched domains	• Development/ Selection of a Multi-Rate Wideband Speech Codec (50Hz-7kHz) for Wideband Speech Telephony in multiple radio environments • IP-based multimedia services
3G radio access		
• Completely new Radio Access Network (UTRAN), built 'from scratch' • Different base technology compared to GSM: Wideband CDMA instead of TDMA	• New TDD mode (1,28 Mcps) for narrowband application	• Intra-domain Connection of RAN Nodes to Multiple Core Network Nodes • Evolution of UTRAN transport: support of IP and radio bearers for efficient IP-based multimedia services
Core network		
• EDGE • GPRS • GSM-UMTS interworking • OSA	• Enabling Bearer Independent CS Architecture	• Provisioning of IP-Based Multimedia Services (SIP Call Control protocol) • Intra Domain Connection of RAN Nodes to Multiple CN Nodes • Reliable end-to-end QoS for Packet Switched domain

a central role in UMTS deployment[2]. As a matter of fact, the number and distribution of Node Bs determine the allocation of RNCs and, to a large extent, the transport infrastructure of the radio access network.

[2]In the following, UTRAN and RAN will be used interchangeably.

A. RAN Planning

Planning a CDMA-based system like UMTS is a two-stage process. Initially the cell coverage is determined in isolation with reference to typical operation environments (i.e., dense urban, urban, suburban and rural) and relevant average traffic, propagation and interference conditions – cell dimensioning, [4]. This enables an initial identification of the number and location of Node Bs to meet the service coverage and radio interface oriented QoS requirements by stated traffic loading – start of the RAN planning. Subsequently, the actual traffic and interference conditions under the intended coverage of any single cell in any particular operation environment over the entire service area are used to fine-tune the cell dimensioning, thus determining the exact cell coverage pattern and possibly leading to a revision of the Node Bs distribution. Finally, the allocation of clusters of Node Bs to RNCs so as to meet cost-effectiveness targets completes the RAN planning.

In interference-limited CDMA systems, great care has to be given to modeling the traffic load in the radio interface, both in terms of source activity and instantaneous bitrate. The combination of the signal energy associated with the traffic sources simultaneously active determines the interference level in the cell and, effectively, the cell traffic handling capacity.

B. The Transport Infrastructure

Different solutions are possible for implementing the transport infrastructure in the radio access network, i.e., the combination of topology, transport techniques and media for interconnecting Node Bs and RNCs aimed at achieving efficiency in handling the traffic flows. These solutions depend on various factors, ranging from the constraints represented by already existing infrastructure to the target layout and capabilities of the mature UMTS network.

The network elements in the RAN are designed to be upgradeable and adaptive to support the features of the various UMTS releases. In order to handle the traffic flows more efficiently, the UTRAN transport network is generally subdivided

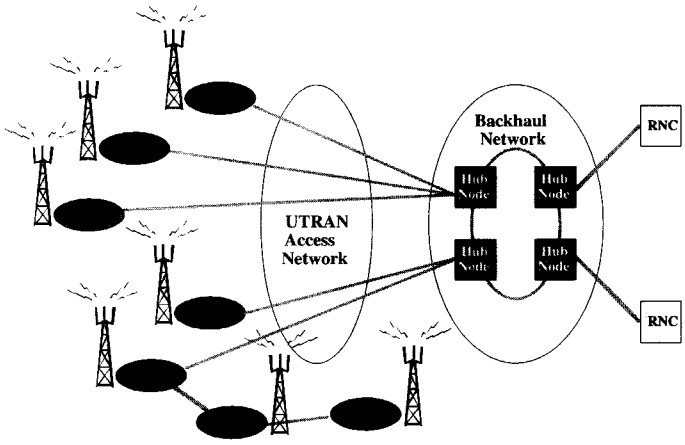


Fig. 2. Reference architecture for UTRAN transport solutions.

into two parts (Fig. 2). The first consists of the links between the Node Bs and so-called "aggregation nodes" (hub nodes), the second (backhaul network) connects the aggregation nodes with the RNCs. This architecture capitalizes on the multiplexing gain effect and the flexibility in rearranging Node Bs-to-RNCs relationship. This allows reducing the overall cost of the transport infrastructure of the access network and to accommodate changing traffic and/or service conditions over the time.

C. Key Options

Several realizations of the UTRAN transport architecture are possible by combining the options available for the physical media and the transport technique on one side - such as low capacity microwave (PDH), high capacity microwave or optical links (SDH STM-1/STM-4), ATM, LMDS, xDSL, leased lines - and the topologies (e.g., tandem, ring, star) for each of the two cascaded arrangements on the other side. These realization possibilities are based on decisions which have strategic and economic motivations, such as:

- Choosing the network topology depending on whether GSM legacy networks are present (incumbent operators) or not (green field operators);
- allocating Node Bs to RNCs based on traffic loading considerations; and,
- evaluating the total expense for the use of the media based on the cost and/or in-place availability of fiber, copper, microwave licenses or leased lines.

IV. THE CORE NETWORK

The UMTS Core Network is based on the evolution of the current GSM architecture, starting with UMTS Rel-99, which retains the main features of circuit domain for voice applications and packet domain for data applications - as found in today's GPRS networks. In UMTS Rel-4, a "next generation" architecture for the circuit domain is introduced, [5]. This architecture which enables bearer-independent call control and features separation between control and switching layer, bases on new components such as the Mobile Switching Center servers (MSC servers) and Media Gateways (MGW). UMTS Rel-5 consists essentially in the introduction of the Internet Multimedia (IM) concept involving enhanced capabilities and new components in the Core Network intended to provide QoS guarantee and operator-controlled IP connection handling. This would allow operators to offer veritable multimedia services, such as voice combined with pictures, videos, web augmented calls, etc.

A. Switching and Routing

The network elements that comprise the switching and routing functionality of the UMTS Core Network differ significantly from one UMTS release to another. In Rel-99 the key network elements are the Mobile Switching Center (MSC), the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). In Rel-4, as anticipated, the key switching and routing network elements are the MSC servers and the Media Gateways (MGW).

In Rel-5 the introduction of the Internet Multimedia Services (IMS), through the "All IP" network, should be a key success factor for operators enabling the provisioning of veritable differentiated value-added services. The main functional components of this architecture are CSCF, MGCF, T-SGW, and MRF, that with the support of the media gateways, will enable interoperability between communication networks, based on various technologies, protocols and devices. Functions and capabilities of key core network elements of different UMTS releases are summarized in Table 2.

B. The Transport Infrastructure

The transport architecture of the UMTS Core Network depends on the utilization strategy chosen by the operator. The SGSN and/or GGSN nodes can be co-located in the same site or distributed in different sites, as well as the management and charging network elements. According to the number of RNCs, SGSNs in the existing transmission transport network and the expected traffic, different network topologies are possible. The chosen topology will have a great impact on the efficiency, reliability, cost, flexibility and scalability of the UMTS network. In case of operation centers distributed regionally, Fig. 3 shows an example where an UMTS Core Network transport can be used to federate all the UMTS network elements around the same network infrastructure.

C. Key Options

In principle, the interfaces between a variety of network elements could be supported by a common infrastructure based on IP/MPLS/ATM, depending on which 3GPP release the operator is willing to deploy. This applies notably to:

- The network elements of the terrestrial radio access network (and especially the RNC via the Iu-PS, Iu-CS and Iur interface);
- the network elements of the circuit switched domain of the core network (and especially the MSC (or the MSC server) via the Iu-CS interface);
- the network of the packet switched domain of the UMTS

Table 2. UMTS Core Network switching and routing elements, and UMTS releases.

	Element	Notes
Rel-99	MSC	Is connected simultaneously to both the UTRAN and the BSS and has to provide a direct internal handover between these two radio access networks.
	SGSN	Interworks with the UTRAN and the UMTS User Equipment (UMTS UE). The SGSN is responsible for radio assignment, taking into account the UE requests, the user subscription profile and the available resources; it is also responsible for the security functions, such as authentication, charging and interception.
	GGSN	Allows the interworking between the GPRS access network and the external IP Packet Data Networks (PDN) such as Internet Service Providers (ISPs), Corporate Networks or the public Internet.
Rel-4	MSC servers	Implement the control and mobility management of a 3G mobile network with packet transport in the circuit-switched domain. They interface the UTRAN and the fixed network (PSTN) and enable mobile users to gain access to the 2G features of today mobile networks as well as 3G Rel-99.
	MGW	Can be classified in two families, the Access Gateways (AGW) and the Trunking Gateways (TGW). The AGW is located on the border of the UMTS core network to the RNC, performing functions like bearer conversions for the user plane, simple routing, insertion of tone announcement, anchor point when selected at the beginning of the call by the anchor MSC server. The TGW is located on the border of the MTS core network to the PSTN/ISDN and performs functions such as circuit-switched voice to packet-based voice stream and vice versa, transcoding the PCM voice packets according to a UMTS specific coding mechanism.
Rel-5	CSCF, MGCF, T-SGW and MRF	Will enable inter-operability between communication networks, based on various technologies, protocols and devices. In particular, CSCF (Call State Control Function) is used for routing and user database processing related to mobile originated and terminated calls. MGCF (Media Gateway Control Function) is the PSTN/PLMN termination point for a defined network. T-SGW (transport Signaling Gateway Function) maps PSTN/PLMN <-> IP signaling and transport level address. MRF (Media Resource Function) handles multiparty/multimedia control actions.

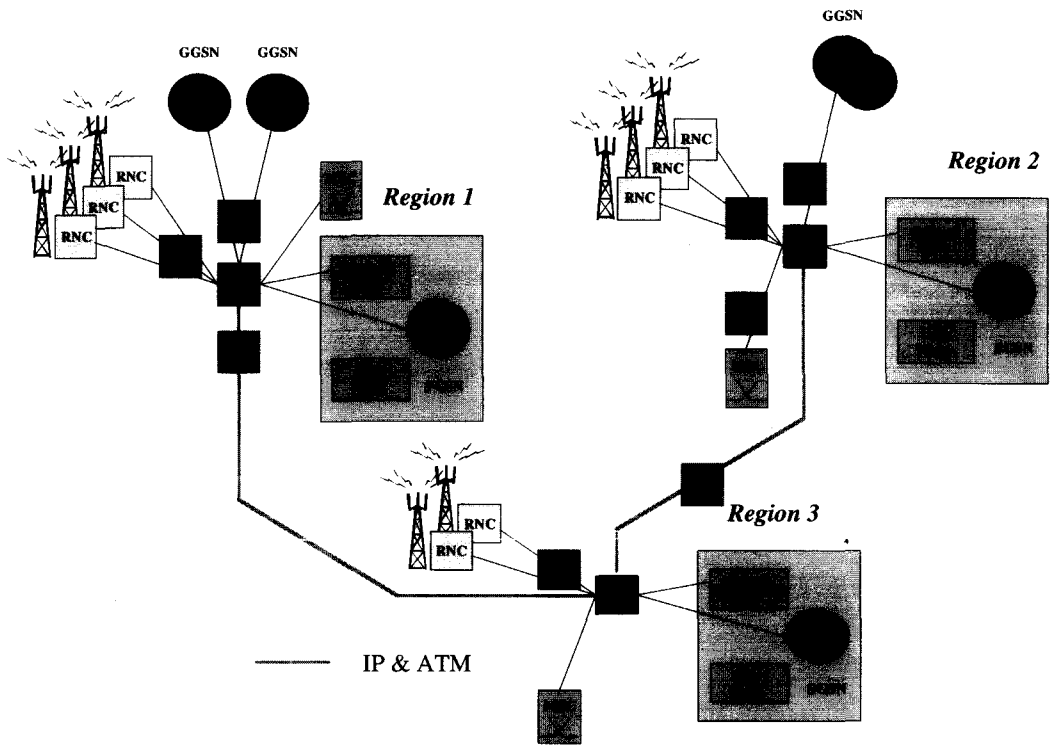


Fig. 3. A possible architecture for UMTS core network transport.

core network (and especially the GGSN via the Gn interface);

- the media gateway (MGW) and the border gateway (BGW).

SDH/DWDM could be used as underlying physical transport solution. This solution is most suitable when a large number

of RNC, MSC and GSN have to be interconnected, enabling the Iur interface to be supported between RNCs. When the Core Network elements are centralized and co-located in the same site a LAN configuration is recommended, based on Fast Ethernet or Gigabit Ethernet, offering reasonable bandwidth and simple management at low cost.

The key factors that will drive the Core Network evolution are, again, a matter of strategic decision to be taken by the operators in the UMTS scene, whether incumbent or green field ones. In any case, the factors that will influence the Core Network implementation include:

- The availability of the different types of UMTS terminals;
- the introduction of multimedia services as early as possible;
- the advancement of UMTS standards with respect to IP Multimedia aspects;
- the replacement of first-release 3G terminals; and,
- the speed of UMTS market growth.

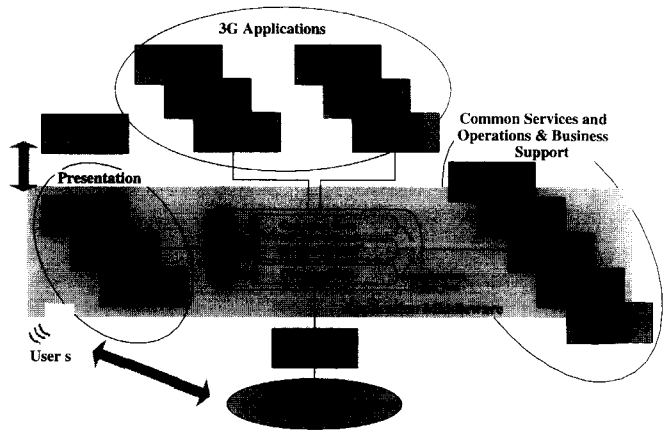
V. THE SERVICE AND APPLICATION PLATFORM

One major objective with 3G systems and Personal Communications is is to provide the customers a service environment from which the subscribed service profile can be accessed and operated independently of the actual network or terminal equipment the user happens to be associated with (Virtual Home Environment, VHE). This objective is combined with the desire to make available a service provisioning environment that is independent as much as possible of the network infrastructure.

To make service creation and provision independent of the underlying network infrastructure, UMTS adopts OSA (Open Service Architecture), [6]. This allows, in principle, that service enhancements are decoupled from the UMTS network infrastructure (and releases). Another benefit with OSA is the high degree of flexibility in configuring services and applications (whether oriented to the end-users or to network operators). OSA makes systematic use of the "server" concept, i.e., elements specialized for performing (set of) tasks which, combined with those of other servers, activate network functionality to run an application having user or operator significance.

Servers are organized into "application" or "service capability" layers, depending on whether they are associated with the application logic or the breakdown of the application into modules to be used as building blocks for a variety of applications. Finally, other types of servers deal as the linkage for the activation of the functionality of network elements responsible for running the applications. Fig. 4 shows the functional architecture of the service platform.

Two broad categories of services relate to those with end-user significance (ranging from voice, messaging and localization based services, to content presentation support, i.e., multimedia portal), and those associated with operation, administration and maintenance (e.g., operations system support and billing). As indicated in Fig. 4, applications relying on the same support platform are grouped together. The functional architecture is complemented with "Application Open Bus" dealing as the communication pipe where data (customer data, service requests



GW Gateway SCS Service Capability Server

Fig. 4. Functional architecture of the Service Platform.

and charging data) are exchanged between the platforms for the necessary interactions between the applications.

A. Services and Applications

The service capabilities included in the category having end-user significance range from traditional application support (voice, messaging, and localization) to presentation of content applications and payment solutions. Specifically:

- 3G applications cover a broad range of possibilities, with different support of network capabilities. As an example, some applications relate to network capabilities provided by IN or CAMEL service environment, and unified messaging. Location based mechanisms also fall in this group. Other applications cover Audio/Video streaming, infotainment and gaming capabilities. These applications rely on capabilities such as rating, charging and, when financial institutions are concerned, payment solutions;
- presentation capabilities are built on a multi terminal portal and provide profile management for terminals and users. They also provide a syndication mechanism allowing end-user preference to be transferred to content provider to access focused, instant information.

As relates applications with operator significance, Common Services and Operation and Business Support is central to management information systems and manages user and service identification and authentication. Management information system capabilities are provided by a Back-office Operations support, combining tools for network-, fault-, QoS- and fraud management as well as service provisioning. Front-office Business support provides tools for customer care, billing, and charging gateway. Payment server, as a specific instance of payment solution, is associated with this grouping.

B. Key Options

From a user perspective, the services intended to be offered by UMTS networks can be grouped into six major categories, i.e., Mobile Intranet/Extranet Access; Mobile Internet Access; Lo-

Table 3. UMTS service categories with end user significance.

Service category	Market segment	Charateristics
Mobile Intranet/ Extranet Access	Business	Provides secure mobile access to corporate Local Area Networks and Virtual Private Network.
Mobile Internet Access	Business, consumer	Offers mobile access to full fixed ISP services with near-wireline transmission quality and functionality. Includes full Web access to the Internet as well as file transfer and electronic mail.
Location Based Services	Business, consumer	Enables users or machines to find other parties, vehicles, resources, services or machines. It also enables others to find users to identify their own location via terminal or vehicle identification.
Rich Voice	Business, consumer	Real time and two way. It provides advanced voice capabilities, such as VoIP, voice-activated net access, while still offering traditional mobile voice features (e.g., operator services, directory assisted roaming). It will include mobile videophone and multimedia communications.
Customized Infotainment	Consumer	Provides access to personalized content anywhere, anytime via structure-access mechanisms based on mobile portals.
Multimedia Messaging Service	Consumer	Offers real-time multimedia messaging like SMS with multimedia contents, e.g., sounds, video, etc.

cation Based Services; Rich Voice; Customized Infotainment; Multimedia Messaging Service. The characteristics of these categories are summarized in Table 3 with respect to the potential market segment and ignoring the technological details for their implementation.

VI. UMTS ECONOMICS

A key step in the process of finalizing the UMTS deployment strategy is represented by the economic evaluation of the revenues expected from the investments over the economic life of the system, including the license acquisition costs [7], [8]. This evaluation bases on the (cost of the) options described earlier on and also on the assumptions about the evolution of demand and service penetration as well as tariff trends and policies.

In the following, the methodology for carrying out such an evaluation is illustrated. A key metric in the evaluation is the NPV (Net Present Value) understood as the net present value of the network, i.e., cumulative discounted cashflow generated to date. On a less formal level, this metric is indicative of the profitability of a business, as appreciated at Year 0, over a span of N years - N ranging from 1 to the economic life of the system. To simplify the description, numerical aspects for the various parameters characterizing the UMTS deployment are introduced in the following. However, it is to be stressed that figures have only indicative value and that conclusions based on NPV analysis are critically dependent on the assumptions underlying the parameter choice.

A. Business Plan Outline

To implement a financial model where all of the described aspects are properly taken into account, specially designed tools are normally used, e.g., [9]. This implies a sequence of steps to go through to associate values to the input parameters and to acquire the network engineering rules. Running the model generates the technical and financial outputs driven by geographical data and service demand. The implementation of a financial model is normally conceived so that further information on specific aspects may be obtained by increasing the level of detail in the description of the network infrastructure and/or network components. Examples of this modeling approach as applied to UMTS can be found in [10].

The economic evaluation comprises the following logical phases:

a) the year traffic demand[3] over the considered period is estimated. This, in turn, involves several steps, i.e.,
   - estimation of the potential user population
   - estimation of the service penetration considering dimensions such as: service class (i.e., bitrate of circuit switched and packet switched services), operation environment (i.e., dense urban, urban, suburban, rural), user age class, etc.
   - estimation of the activity factor per service type and class;
b) the radio access network is planned on a year basis considering the increase in the traffic demand, point a) above, and the resulting need for incremental additions of network infrastructure (Node Bs and RNCs) to meet capacity requirements. This stage considers that different operation environments are differently covered from a service point of view, both in time and as target coverage, with dense urban environments receiving priority;
c) the core network is also planned on a year basis considering the impact of traffic demand under points a) and b) above. As part of this planning, re-engineering of SGSNs and GGSNs is also accounted for, see section IV.A (Switching and Routing). This includes both HW and SW upgrading, i.e., processing power increase as well as architecture and functional enhancements due to implementation of successive UMTS releases. This stage considers that packet switching equipment will, as a tendency, substitute circuit switching equipment;
d) a revenue structure for each service is assumed. This structure considers both the charges on the end-user and the balance between costs and revenues associated with possible agreements with third parties involved in the service support (e.g., content providers, brokers, etc). The service revenue is then subjected to a "price erosion" along the economic life of the system. This erosion depends mainly on the general trend of telecommunication service tariffs, and the operator's policy for attracting and/or preserving the customer base and face competition;
e) the NPV computation is carried out and, based on the analysis of the results, refinements of the UMTS deployment strategy may be considered.

[3] As for capacity planning, the traffic demand results from the superposition of the demands related to the individual services. These may have different trends and, in general, different start-up times. In the following, unless stated otherwise, "demand" will indicate the superposition of the demands for the individual services.

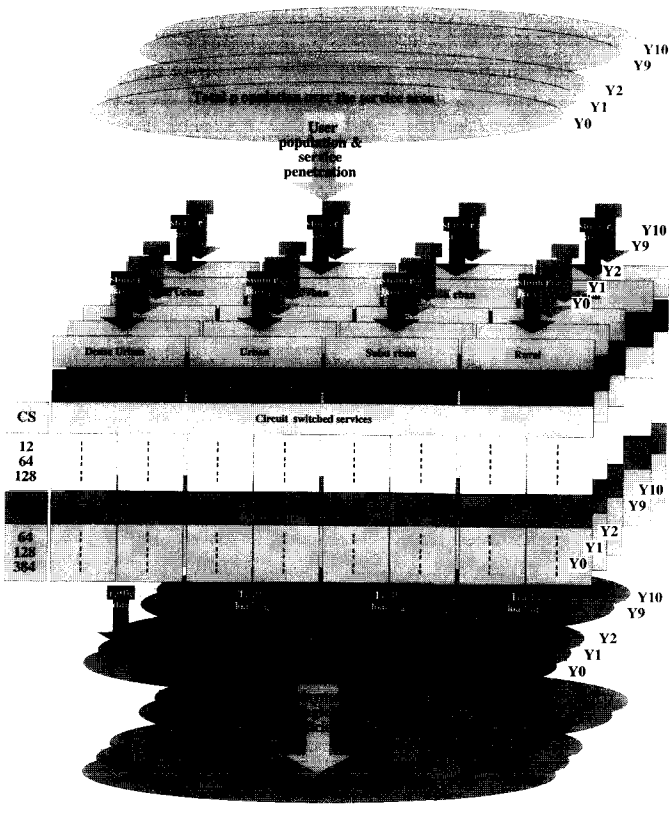


Fig. 5. RAN planning and UMTS deployment over the economic life of the system.

The phases comprising the business plan are summarized in Fig. 5. Due to the many parameters on which the business plan may depend, a sensitivity analysis on the impact of critical parameters (such as demand estimation uncertainty ranges, slope in the service price erosion, etc), normally complements the business plan exercise[4].

B. Service Penetration and Demand Scenarios

The service demand and traffic scenarios are input to the dimensioning and planning process, and ultimately to the economic considerations of the business plan. The service and traffic scenarios are derived through a combination of data regarding, among others, demography, social aspects, service coverage areas, prospected acceptance of service offerings, traffic source activity and bitrate of offered services.

Processing the data, quite naturally, starts with identifying the service area and the overall population insisting on it (see Fig. 5). From the overall population, the potential customer population is identified as the one confined within specified age limits. Further, assuming a stated percentage for the population service coverage, the final customer base population is derived. From this, by assuming stated percentages of the service area for dense urban, urban, suburban and rural operation environment, and also assuming that the share of business and consumer customers are specific to each operation environment, the user population can be classified according to the joint criteria of operation environment and subscription type. Finally, assuming that the service penetration for circuit and packet switched services are also specific to the operation environment and subscription type, it is possible to derive the actual user population subscribed to UMTS services. This population is now assumed evenly distributed over the service area for the purposes of estimating the offered traffic and, hence, carrying out the RAN planning. To this end, an activity factor specific to each service class is introduced and the overall traffic offered estimated, see Fig. 5. The mapping of offered traffic into the RAN planning is addressed in Section III-A (RAN Planning).

To obtain the evolution of the RAN planning, the above exercise is repeated for each year along the economic life of the system, as indicated in Fig. 5. This involves updating of the overall population and adjusting all other input data having a dependence on time, such as the service penetration. Normally, the number and location of Node Bs and RNCs for year N+1 correspond to those for year N plus the ones due to the increase in the customer base from year N to year N+1. In other words, no rearrangement of the radio network infrastructure in place at any time is normally considered.

C. A Possible UMTS Evolution Path

Obviously, the UMTS deployment scenarios may span over a wide range of options [11]. For illustrative purposes, in the following it is considered the case where UMTS Rel-99 is introduced starting from Y0 and Rel-5 is introduced starting from Year 3. Moreover, capacity upgrading will be systematically performed along the economic life of the system (assumed 10 years). Qualifying decisions to resolve key options for the business plan, including the service offering, are assumed as indicated in Table 4 ("reference scenario"). Other typical input and output data for the business plan analysis are as indicated in Table 5.

The NPV derived from the business plan for the reference scenario is shown in Fig. 6. The figure indicates that returns from investments start somewhat later than the half of the assumed economic life. Until then, profit gains are offset by substantial investments necessary for the service start-up. Once returns begin, an almost steadily increasing trend for the rest of the economic life is exhibited.

D. Sensitivity Analysis and Service Offering Policy

As anticipated, several parameters having a bearing on the economic aspects of UMTS deployment - and hence NPV - are either inherently affected by estimation inaccuracy or may vary depending on operator choices which, in turn, may vary in time in response to changing market and business conditions. To account for the impact of some of these factors, an example of sensitivity analysis is performed here. In the example, four aspects for which ranges in values of relevant parameters, or different disposition thereof, are considered (Table 6):

- traffic demand;
- service penetration;

[4]In addition to accounting for uncertainty margins, the business plan may be made more sophisticated by including additional aspects having a bearing on costs and revenues, such as promotional actions and tariffs, co-location of 2G/3G radio infrastructure, risk and benefit sharing following agreements with service/content providers and/or brokers, and so on.

Table 4. Example of deployment strategy and options to materialize an UMTS evolution path - Reference scenario.

Note - Entries associated with categories RAN, Core Network and service market segments, represent investment share within each category; entries in column "Y4 to Y10" relate to year 10.

	Year 0	Year 3	Year 4 to Year 10
	Rel-99	from Rel-99 to Rel-5	capacity increases [5]
Radio Access Network			
•Node Bs	55 %	55 %	60 %
•RNCs	30 %	35 %	30 %
•UTRAN transport infrastructure	15 %	10 %	10 %
Core Network			
•MSCs & MSC servers	50 %	0 %	0 %
•SGSNs & GGSNs	35 %	60 %	65 %
•MGWs	0 %	10 %	10 %
•CSCFs, MGCFs, TSGWs, MRFs	0 %	20 %	15 %
•Core Network transport infrastructure	15 %	10 %	10 %
	Year 0	**Year 3**	**Year 4 to Year 10**
Service Market Segment			
•Business	65 %	60 %	50 %
•Consumer	35 %	40 %	50 %
Tariffs	3 % yearly reduction over the whole economic life cycle		

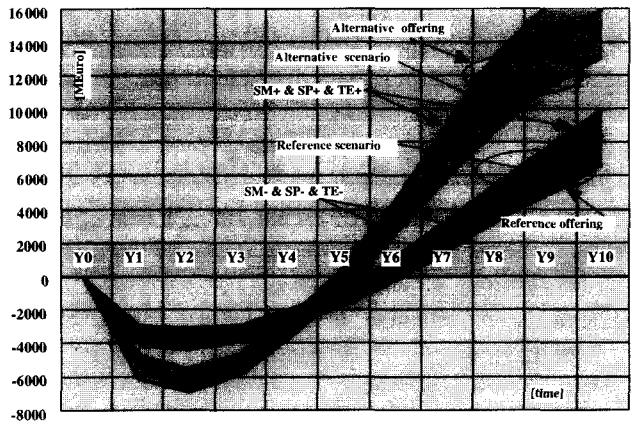


Fig. 6. Net Present Value of example UMTS business plans.

- tariff erosion;
- service offering.

In particular, the different disposition of the service offering with respect to the reference scenario reflects the assumption of a more aggressive attitude in planning investments related to services. The underlying assumption here is that of a greater share

[5]As for capacity upgrading in the core network, it is assumed that switching and processing requirements are totally conditioned by the upgrading in the radio access network.

Table 5. Sample of input and output data for UMTS business plan.

Input Data
Tariffs: • Estimation of tariffs, erosion along the years
Cost of equipment (tangible): • Cost of equipment for each resource, cost erosion
Cost of frequency and SW (intangible): • cost of frequency auction • cost of SW license
Running Costs: • Maintenance, installation as a percentage of CAPEX per resource • Administration, provisioning as a function of the number of subscribers. • Staff personnel for network design, radio coverage as a function of Node B • Sales and after sale personnel as a function of subscribers
Output Data
Resources required • estimation of resources (UTRAN, core network) for accommodating the customer base
Revenues • Revenues per service, per subscriber
CAPEX, and OPEX • Estimation of the CAPEX per resource, network • Estimation of the OPEX per resource, network • Depreciation and Amortization per resource **NPV and IRR**

Table 6. UMTS business plan - Parameter variations and alternative scenario for sensitivity analysis.

Deviation from assumed service mix	SM+ =>Y3: +10%, Y10: +25%; SM- => Y3: -10%, Y10: -25%		
Deviation from assumed service penetration	SP+ =>Y3: +10%, Y10: +25%; SP- => Y3: -10%, Y10: -25%		
Yearly deviation from tariff erosion	TE+ => +10%; TE- => -10%		
Alternative scenario	**Year 0**	**Year 3**	**Year 4 to Year 10**
Service Market Segment			
•Business	65 %	60 %	50 %
•Consumer	35 %	40 %	50 %

of additional services which are at a profound deviation from legacy GSM/GPRS ones, such as Mobile Internet Access and Multimedia Messaging Service. The result of the combination of the ranges is shown in Fig. 6. As it is evident, the impact of a different scenario for the service offering has a major impact on the NPV. This would indicate that by the same evolution of the customer population and overall traffic demand, a service offering aware of the increasing penetration of Mobile Internet Access and Multimedia Messaging Service categories would pay in terms of returns, in spite of a greater financial exposure in the initial period of the economic life of the system.

The impact of the other parameters subject to variations (traffic demand, service penetration and tariff erosion) is practically the same, in relative terms, whether they are associated with the reference or the alternative scenario. In summary, out of the four factors considered in the sensitivity analysis, the disposition of the service offering appears to have a major impact on the NPV

and hence on the deployment strategy - at least for the range of variations considered here.

Since NPV analysis is dependent on complex relationship and mutual dependence between technical and economical aspects of UMTS deployment, the indicative value of the exercise of Fig. 6 has to be restated. For completeness, it is worth noting that NPV benefits from the virtuous reaction within the loop "service offering - service penetration - QoS," if this is properly fed and controlled; moreover, key factors impacting NPV include the cost of the access links in the RAN, the savings resulting from co-siting of 2G and 3G infrastructure, and the cost of money.

VII. CONCLUSION

Deploying an UMTS network is a process where strategic, market and economic decisions play a fundamental role in planning investments for phased functional and capacity enhancements along the economic life of the network.

In planning investments, a balance has to be striven between actions decided in the early stages of the network deployment - which have normally long-lasting effects in terms of both shaping the network infrastructure and capital recovery - and actions which may be deferred - which are normally taken in response to changing market trends and/or conditions, and whose economic profitability has to be measured within relatively short time frames. Whatever deployment policy is chosen (also depending on whether the operator is an incumbent or a green field one), a significant margin of flexibility for adjusting the deployment plan has to be factored from the outset. Although this is advisable for any network deployment plan, this is especially important in the case of 3G systems for which the market opportunities for new, qualifying service categories have to be verified in the field. At the technical level, the adaptivity and modularity of future-proof equipment design guarantee this flexibility - be it radio access or core network infrastructure, or service platforms.

This paper has tried to indicate the options which are open for an UMTS deployment, together with the methodology used for assessing the economic viability of - and returns from - related investments.

VIII. APPENDIX – DEFINITIONS AND ACRONYMS

CAPEX	Capital Expenditure: The annual expenditure on new resources, resulting from Intangible Expenditure (on resources such as capitalized license fees, ...) and Tangible Expenditure (on resources such as equipment, ..)
Cashflow	(before financing): The amount of cash coming into the business during the year, after investment.
IRR	Internal Rate of Return, (Zero Terminal Value): The internal rate of return for the network, i.e. the discount rate (if any) which gives a zero Net Present Value.
NPV	Net Present Value (at x%): The net present value of the network, i.e. cumulative discounted cashflow generated to date, making no allowance for the terminal value of the network. Calculated from the Cashflow and a fixed discount rate of x%.
OPEX	Operational Expenses: All non-capitalized costs of operating the network, also known as Running Costs.

2G	Second Generation
3G	Third Generation
ATM	Asynchronous Transfer Mode
CAMEL	Customized Application for Mobile network Enhanced Logic
CDMA	Code Division Multiple Access
CS	Circuit Switching
DWDM	Dense Wavelength Division Multiplexing
EDGE	Enhanced Data Rates for GSM Evolution
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
HW	Hardware
IN	Intelligent Network
IP	Internet Protocol
LAN	Local Area Network
LMDS	Local Multipoint Distribution Services
MPLS	Multi Protocol Label Switching
PDH	Plesiochronous Digital Hierarchy
PLMN	Public Land Mobile Network
PS	Packet Switching
PSTN	Public Switched Telephone Network
QoS	Quality of Service
SDH	Synchronous Digital Hierarchy
STM-x	Synchronous Transfer Module - x
SW	Software
TDMA	Time Division Multiple Access
TTD	Time Division Duplexing
xDSL	(any) Digital Subscriber Line System

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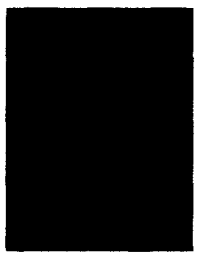
Davide Grillo received his Doctor degree in Statistics from the University of Rome, Italy, in 1965. From 1965 to 2000, he was with Fondazione Ugo Bordoni, Rome, where he was leader of Traffic Theory and Performance Evaluation Group and manager, Personal Communications. He is currently a to Alcatel Italia on advanced mobile systems and related standardization activity.

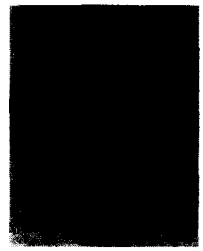
He was a visiting scientist and a consultant at the Siemens Central Laboratory, Munich, Germany, the Department of Information Technology at the University of Dortmund, Germany, and the IBM Research Laboratory in Zurich, Switzerland. He has been involved in several research areas, including telephone network operation and control; switching exchange architecture; packet switching networks; LAN/MAN architecture, interconnection and control; and resource allocation strategies in the radio subsystem of mobile networks. He has extensively published in those fields contributing to conferences, journals, books, and technical reports. He has promoted and was a Guest Editor of special issues of various journals, including the IEEE Journal on Selected Areas in Communications and IEEE Personal Communications.

He has been an active member of Study Group 2 of ITU-T for questions on traffic engineering of telephone networks and ISDN. Currently, he is Rapporteur for Performance Objectives and coordinator for the development of the E.750 series of Recommendations on traffic engineering for personal communications in ITU-T, and Liaison Rapporteur between ITU-D studies on strategies for migration of mobile networks to IMT-2000 and beyond and ITU-R WP 8F and ITU-T SSG. He has also been actively involved in TG 8/1 (IMT-2000) of ITU-R, where he has been acting as a liaison Rapporteur to ITU-T Study Group 2. He is a Technical Editor of IEEE Personal Communications and International Division Editor, Wireless Communications, of Journal of Communications and Networks.

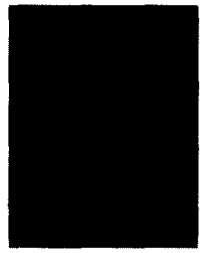


Maurizio Montagna graduated in Electronic Engineering at the University of Pavia in 1981. After a period as a researcher in microwave technologies at University of Pavia, he joined Alcatel-Italia (formerly, ITT-FACE) in 1982 where until 1985 he was active in the design of digital switching systems. From 1986 to 1990 he was in the Technical Direction of Alcatel Italia where he was involved in key areas of telecommunications and information technology, initially with responsibilities in network planning and subsequently in the coordination of the international standardization activity.

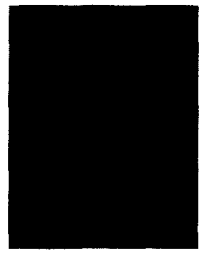
In 1991 he became responsible for the research activity on Next Generation Mobile Communication systems, including 3G systems. In this capacity, he participated in several EU research projects. In 1995 he moved to the Strategy and Development department of Alcatel Italia where he was responsible for market research in Italy and in the Mediterranean area. In 1998 he became responsible for the New Operators market. Since 2000 he has been coordinating the Alcatel Italia UMTS Task Force. Currently he is Director of Mobile Sales in Italy.



Franco Alfano graduated in Electronic Engineering at the University of Geonoa in 1996. During 1997 he was active as a researcher at the University of Genoa developing architectures for the support of image compression for video-telephony. In 1998 he joined Alcatel R&D where he was responsible for the development of Next Generation Multiservice Nodes for 3G transport applications. In 2000 he moved to a dedicated UMTS Task Force in Alcatel, with responsibility for Core Network & Next Generation Architectures, and where he was also involved in 3GPP standardization activities. Currently he is managing the Sales of Core Network products for the Italian mobile operators.



Antonio Colombo received his Degree in Telecommunication Engineering from Hensemberger Institute in Monza in 1970. From 1970 to 1991 he was with Telettra Laboratories where he participated in the design and development of TV radio transmitters, signaling interfaces, space-division electronic switching exchanges, CCITT #7 Common Channel Signaling, Central Processing for digital switching exchanges, HW for 450 MHz mobile systems. During this period he was also involved in the planning of public and private mobile systems. Since 1992 he is with Alcatel Italia where he had responsibility in the design and implementation of the private mobile system TETRA and in the preparation of techno-economic projects relating to the HFC networks (Socrate) and LMDS and DECT radio access systems. Currently he is involved in the technical promotion of XDSL, LMDS systems and in the business analysis of telecommunication solutions.



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