System and Process Modelling for Design, Management and Performance Evaluation of Present and Future Mobile Networks

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The evolutionary path of mobile communications at the beginning of the new Century is characterised by:

- some significant steps forward of the radio access technology
- an extensive integration between the Mobile and the Intenet solutions
- a variety of new services, rapidly approaching a multimedia context scenario.

These evolutionary trends are widely affecting the Dimensioning, Planning and Performance evaluation paradigms that have driven until now the network and service construction of wireless systems. In this respect, the most important aspects to be reviewed seem to be: the Cellular planning and the Core Network dimensioning tasks, together with the Radio Resource Management schemes that are to be adopted in conjunction with the emerging Service Development and Control capabilities.

On the other hand, service requirements and technological solutions are more and more affecting each other in a closed loop process, and this is making increasingly difficult to establish compact evaluation models, able to bridle the non predictable behaviour of these phenomena. In spite of the above complexity trend, entangling both Telecommunication and Information Technology contexts, modelling techniques remains the strongest tool for system representation and process evaluation aims, provided that they can be continuously checked with the experience of the real world.

Starting from the **mobile service** side, indubitably, forthcoming applications show completely new requirements with respect to those offered in the second-generation context. Mobile services are evolving from a classical voice-centric attitude towards an increasing penetration of data services. This reflects the convergence trend between telecommunications and information technology worlds. Accordingly, the variety of requested capacity (bit rate) is rapidly widening, as well as the connectivity needs: point-to-multipoint and asymmetrical connections will co-exist either in a single system (UMTS) or, more likely, over a limited number of access segments (e.g. UMTS and W-LAN solutions).

Not only traffic streams are bearing different capacity and connectivity requirements. Since they are mostly induced by the penetration of *Web – based* services, the related traffic sources obey completely new statistical laws in terms of call arrival process, session times and capacity request process. This poses several modelling problems in terms of traffic representation. Nevertheless, most of the techniques used to model the B-ISDN loading environment can hopefully be used in the mobile context as well.

Each specific service is of course requiring that a specific set of QoS levels are guaranteed by the underlying network (e.g. session dropping probability, packet transfer delay, delay distribution). The related performance levels are to be reached in situations where the same set of resources is shared between different traffic sources, operating in an interference-dependent environment.

In both GPRS and UMTS cases, for example, packet channels are shared with the circuit-switched ones. Several degrees of freedom are then offered to the operator to define the sharing level between the two kinds of resources (e.g. permanent or temporary allocation of resources to the packet flows).

These kinds of topics are characterising the **radio performance evaluation** of the addressed systems. In this respect, it has to be noted that GPRS sharing and dimensioning choices can be defined cell by cell, while for the W-CDMA case, they are much more inter-related through the so called *interference-sensitive* behaviour of the latter system. Simultaneous presence of voice and data (circuit and packet traffic) is in general requiring that models based on queuing theory are adopted.

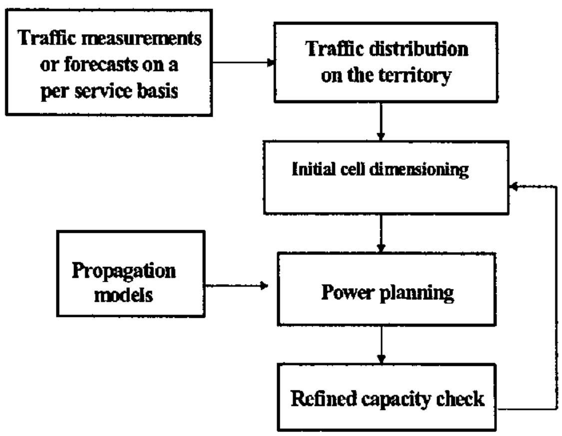
At the **cellular planning** level, the technological development of the radio access is raising significantly new problems. As for the GSM case, in the early stages of its path, it will be essential for UMTS to guarantee sufficient radio coverage on the territory, where the prominent objective is searching new sites to host base stations. In a second stage, customers increase and quality will emerge as key issues. Networks become capacity-limited, rather than coverage-limited, and advanced cellular structures need to be deployed to satisfy the service demand.

Second generation mobile systems, are typically planned through three basic steps:

- traffic analysis and forecasts (this drives the radio station positioning)
- radio coverage and cell dimensioning process (setting size and capacity of each cell)
- frequency plan, which defines the carriers to be assigned to each cell in order to fit the cell capacity by minimising at the same time the overall interference patterns (the cost function driving the minimisation process embodies both the worst C/I and the number of carriers showing a C/I below a given threshold).

While the radio coverage step can rely on consolidated propagation prediction models (e.g. Okumura, Deygout, Ray tracing), the frequency plan step presents high combinatorial complexity and its solution is typically assigned to a mixture of algorithmic-empirical approaches (e.g. neural network, genetic processes).

Once the frequency has been completed, a feedback action could be invoked if the reached interference conditions remain too high: either cells or antenna positioning should be revised. In particular, when packet services are introduced, hierarchical cell structures are adopted, to cope with the need for a higher availability of radio resources. The assignment of hierarchy thresholds (driving the access conditions) makes the frequency assignment topic even more complex.



- the traffic distribution is performed on a per service basis
- the initial cell dimensioning relies on simple analytical formulas, performing a rough evaluation of the cell capacity and an estimate of the base station density
- the power planning step invokes radio propagation models and optimises the power layout until link budget and capacity limits are reached
- a refined capacity check is needed to verify the previous planning choices.

It is well known that UMTS adopts a wide-band CDMA access. Although a CDMA network does not need any frequency plan (all mobiles use the same bandwidth), a variety of new problems, still tied to interference, shall be solved. The W-CDMA cellular planning process is then leading to a completely new approach, as summarised in the figure below.

It can be seen that, differently from the second-generation case, the W-CDMA planning approach cannot rely on the separation between radio coverage and frequency allocation steps. In fact, cell size and interference conditions are fully embedded within the same process, which defines the service availability areas in function of the actual system status and interference conditions (*cell breathing*).

The evolution towards third generation system not only is suggesting new engineering topics at the radio planning level: the **core network planning** is itself undergoing completely new arrangements that modify both planning approaches and underlying performance modelling schemes. GPRS represents an important step in the mobile core network evolution, mostly because it is based on IP protocols. Indeed, recent developments in the IETF tend to make possible an entirely IP-based real-time mobile telephony and multimedia service.

In such a context, some areas where convergence between classic mobile communications and the IP world could emerge, are easily envisaged.

- Internet protocol suite is becoming a determining element for user data applications, often the only choice available.
- IP mobility procedures (evolution of Mobile IP and micro-mobility schemes) may provide mobility across data networks and also inside wireless LANs. Classic mobility management schemes will continue to play a central role in the access segment and will probably rely on IP for the transport of signalling messages (UMTS Release 2000).
- In the future, IP call control (e.g. SIP, H.323) could provide the basis for a common approach to call and session management of multimedia calls.
- Current IP is not well suited for QoS requirements for delay sensitive services. Evolution of IP to allow for service guarantees even in large-scale networks is required, through the provision of multiple service categories (DiffServ and edge buffering/shaping) and resource reservation (IntServ and RSVP).

Incremental evolutionary steps from the current GPRS architecture should enable to achieve the UMTS vision in the planned time scales and provide the opportunity of convergence with the evolution of IP services as standardised in the IETF, so that UMTS operator will blend the roles of ISP and classic GSM/Mobile operator at the same time.

The UMTS access network will be linked to both circuit switched domain and packet switched domains. UMTS core network equipments could as well support a Wireless LAN access adopting a Broadband Radio Access Network technology. In addition, during the early stages of the UMTS development, some fixed network technologies will emerge with Voice over IP gateways, gatekeeper and signalling gateways, enabling IP telephony nodes to interact with PSTN and SS7 nodes, with security and IP mobility servers.

Central to the operation of mobile networks are the functions of mobility management, enabling the correct establishment of communications to/from users. Mobility management functions cross many *layers* of a wireless network: radio access, security, quality of service management, usage policing, data routing.

New **service development and control** techniques will support third generation mobile operators in offering a wide variety of services. The adoption of models based on a client/server concept is establishing a unique way to create innovative services for mobile networks, independently from the underlying transport arrangements. This kind of service solution can be obtained by decoupling network capabilities from service and application layers through Application Programming Interfaces (APIs) that create a single application environment. Specific support modules ensure the separation between the application functions and the network features. This scheme makes service definition and control transparent with respect to the network then making easier the innovation on the service side.

On the other hand, mobile operators must be able to cope with the increasing market demand by exploiting the full potentials offered by the new techniques. These goals can be pursued by means of suitable marketing and pricing policies, capable of matching/tracking in a flexible way the market forecasts:

- pricing policies based on offered service
- segmentation on customer behaviour (e.g., based on time and service access frequency)
- geographical segmentation of the market, based on call origin and destination.

In any case, the attitude to increase the service definition pace, enlarges dramatically the role of **radio resource management** policies to be adopted in third generation systems.

Some of them are anticipated in system like the GPRS. For instance, if GPRS data channels are permanently allocated, packets are typically undergoing a delay-based management policy, to be applied to any new transaction within the defined packet dimensioning thresholds. On the contrary, if a temporary allocation is used, it is possible to allocate GPRS services over the available time slots. Usually, the number of slots allocated to GPRS is set on the basis of traffic evaluations. Accordingly, a circuit-switched pre-emption policy is normally foreseen: a time slot temporary assigned to GPRS users can be released if no other time slot is available for an incoming circuit-switched call.

If no acceptance policy were adopted in the above conditions, a complete sharing of the resources would introduce a significant discrimination (in terms of call blocking and call dropping probability) between the different bit rate connections (i.e. between the different service classes) sharing the same pool of radio resources.

In the UMTS system, radio resource control and acceptance policies are even more meaningful. This is due to: the UMTS interference-sensitive behaviour; the variety of service requirements; the handover and macrodiversity mechanisms. In UMTS, the Radio Resource Management (RRM) policies will really determine the optimal working conditions of the radio access segment under performance constraints. The main objective of the radio resource management in a CDMA system is to minimise the overall power transmitted by mobiles (with particular reference to the uplink). It is then necessary to connect each user (cell selection/reselection procedure) to the base station that requires less power.

Differently from the GSM case, the power transmitted by the mobile terminal in a CDMA system, depends on the path loss as well as on the base station load. If a particular CDMA cell is heavily loaded, it would be critical to force a mobile terminal to operate with a different base station (as per the 'direct retry' mechanism in GSM): this would in fact imply a higher transmitted power that would further increase the interference level of the 'best choice' base station, thus leading to major problems for all the terminals connected to the best choice base station.

In addition to the interference limits in the uplink, the downlink is usually constrained by the maximum power that can be transmitted by the base station, as well as by the availability of the assigned orthogonal codes.

The optimal use of orthogonal codes in the down links will assume particular importance when Web Browsing services are extensively offered in the UMTS context. Under these conditions, a typical code management problem consists in trading-off the number of codes used to open new packet sessions and the number of codes used to carry the real data traffic on the down link. This means balancing the number of transactions governed by the system in a given instant versus the transport capability that the system can offer to each transaction.

This general overview has the only purpose of listing the emerging performance evaluation and modelling topics tied to the evolution of mobile communication. This should help in understanding the basic role that Research and Development activities in the field of planning and performance evaluation can play, in a direct relationship with the emerging service development perspectives and the growing network optimisation needs.

Biography

Dr. Cesare Mossotto was born in Torino, Italy, in 1940. He achieved a full-honours degree in Electronic Engineering at the Polytechnic of Torino in 1964. At present, he is Director General of Telecom Italia Lab (TILAB) the innovation company of TELECOM Italia Group, created recently to combine the Venture Capital and Innovation Business Unit with the R&D laboratories of CSELT. From 1988 to 2001, he has been Director General of CSELT, and, before, from 1983 to 1988 he has been responsible for R&D at SIP, now merged into Telecom Italia.

During his professional career, started in 1964 at CSELT and continued at Telecom Italia, Mr. Mossotto took part in a number of studies and developments concerning traffic theory, digital switching, dedicated data networks, value added services. Between 1967 and 1984 he was particularly active in standardization bodies, such as CCITT and CEPT, on common-channel signaling system and ISDN. From 1991 to 1995, he held the Chairmanship of the Strategic Advisory Group of Eureka Project 625 "Video-Audio Digital Interactive System – VADIS", which was instrumental to affirming digital video technologies based on MPEG2 in Europe. From 1994 to 1997 he was President of the Steering Board of the Telecommunications Information Networking Architecture (TINA) Consortium, fostering the convergence of intelligent network and distributed processing. On several occasions he has also acted as advisor to the European Commission, having been also member of IST Advisory Group (ISTAG) from 1998 to 2000.

Mr. Mossotto is a member of the Board of Directors and of Scientific and Technical Committees within several companies and institutions.

He is the author of some 100 papers in technical journals and conferences.