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COST 231 in the European Telecommunications Environment

Eraldo Damosso, CSELT, Italy

With the emergence of second generation cellular mobile and cordless systems, the first steps have been taken towards a ubiquitous universal personal mobile communications network. Since 1988 Europe has conducted pre-normative UMTS research within the RACE programme, as well as in other European Community frameworks and in the context of national programmes, to explore technological options and to carry out basic research in collaboration with service providers, network operators and equipment manufacturers. However, the vision within the past RACE Mobile Projects and current ACTS Workplan developed under the 1994-98 4th Framework for European Research (as well as within the various standardisation bodies), is now one of total universality; universal in coverage and accessibility, but coupled with universal service provision in terms of scope, capability and availability. Personalised communication services over UMTS will exploit its bearer and teleservice capabilities: a wide variety of UMTS-supported services and applications are foreseen. Services include speech, video and data at various bit rates and these are expected to provide a wide range of user-group applications, including provision of interactivity. This will lead to a gradual blurring of distinctions that now exist between fixed and mobile services, in parallel with the development of the Intelligent Network(s). To enable UMTS to enter service successfully, clear technical guidelines have to be developed, regarding in particular the level of UMTS support of ATM (Asynchronous Transfer Mode) technology on IBC networks, the compatibility of UMTS and fixed-network architecture and intelligent functionality, the level of integration of the satellite components of UMTS, the multi-service convergence philosophy of the UMTS radio air-interface(s).

1.1 The evolutionary vision of mobile communications in Europe

While UMTS is a system to be deployed at the turn of the century, work towards defining 4th generation Mobile Broadband Systems (MBS), for use beyond 2005, is already necessary from now. It is indeed of strategic importance to meet the requirements for wireless communication with very high throughput and to develop the industrial capability to produce the necessary system components. Also essential is the investigation and definition of system aspects, radio access schemes, network management issues, integration with IBC, etc.

Although most basic and system technologies have been already developed for the implementation of wideband digital mobile networks and their inter-operability with the fixed network, what is still to be done for a true UMTS and MBS implementation may be in principle listed as follows:

- a full functional integration between mobile and fixed networks and a provision on mobile networks of all services which, more or less, are already available at the fixed level;
- a sound characterisation of the radio channel properties in the 2 GHz band;
- feasibility studies and development of new (universal) mobile terminals;
- basic studies for mobile broadband communication at millimetre waves, including propagation aspects, network architectures, RF and IF components, intelligent antennas and the integration with satellite networks;
- an exhaustive and well assessed test bed demonstration of UMTS/MBS facilities and capabilities;
- the definition of the relevant standards at a worldwide level.

The above vision embraces the inter-operability of fixed, mobile and mobile-satellite networks when supporting personal communications facilities. UMTS and MBS must, therefore, be locked into this convergence process towards access-independent, universal, personal communications. The European pre-eminence in digital mobile radio (Europe's world leading position in the implementation of digital mobile technologies is unquestionable) has made the Union a major actor in this field: Europe has historic strength in the domain, has technical competence, large home markets comprising sophisticated users, competent service providers, and equipment manufacturers competitive on a world-wide level. Unlike other countries, like US and Japan however, it suffers from a fragmentation of activity across the different Member States and its nationally based companies and organisations. Without a rationalisation of the efforts in this area it losing its position to the global competition; such a rationalisation should carefully take into due account the three kinds of economy which affect the policies and strategies of the major telecommunications players in the world market: scale, scope and integration.

"Economy of scale" is the classic advantage of mass production; "Economy of scope" reflects the additional benefit to the user of having the same service widely available; finally, the "Economy of integration" reflects the advantage of sharing facilities and the benefit for the user of combining services to meet specific needs. To do this, Europe's assets need to be fully mobilised to become effective in ensuring the exploitation of the three economies mentioned above and the whole process should hopefully be user oriented, in order to ensure that the technology development activities respond quickly to changes in economic and social conditions and to new scientific discoveries and breakthroughs.

Furthermore, mobility and the proliferation of either portable and laptop computers or Personal Digital Assistants (PDA), together with potential cost savings in avoiding the wiring or re-wiring of buildings, are driving forces for the introduction of wireless Local Area Networks (LANs), which can transfer data and share resources without physically connecting them. These have received most attention from equipment manufacturers because they represent two of the fastest-growing segments of the computer industry, LANs and mobile computing. Although in Europe the activities at ETSI are aiming towards the standardisation of a stand-alone wireless LAN, next generation mobile systems must consider a system integrated wireless LAN as one of its key functionalities. Such integration concept requires the design of high-performance pico-cells, capable to support the requirements for high-rate local data communication: important issues to be addressed are frequency allocation/selection, bandwidth efficient coding schemes, specification of medium access protocols and link control, as well as connectivity aspects related to the backbone wired or wireless communications networks. Different working environments (e.g. office, production line, storehouse) have different requirements, which concern security, range, health aspects, transmission rate, re-using of frequencies, cost, maintenance, penetration ability, etc. The status of WLANs is presently that they are mainly used for data distribution and specified to IEEE 802.11 standard for use in the North American ISM frequency band. Other standards are in preparation, e.g. ETSI RES-10, and there are several proprietary systems; specific characteristics include:

- limited transmission distance (20-100 m);
- high capacity local pico-cell for voice and data with high throughput;
- un-regulated and uncoordinated operation of multiple WLAN in the same service area;
- propagation and channel models (< 20 GHz, optical, LED);
- propagation and channel models (60 GHz, optical, laser);
- advanced baseband signal processing.

In the above context, Fig. 1.1 presents the schematic flow [1] of the evolution of current (or next) systems/services towards the third/fourth generation ones, highlighting the role of the Community, through RACE and ACTS works.

As a matter of fact, particular attention was paid in Europe in the recent past to radio aspects of third generation systems (for both narrow and broadband services), and related propagation issues (measurements and modelling techniques); in the process towards personal communications, a key topic is the selection of the access technique, due to its impact on several other system aspects: the two major competitors are (Advanced) TDMA and CDMA schemes, as known. Moreover, within the European Community, it is of strategic importance that the efforts pursued at a national level be complemented on a much larger scale by Community funded projects, aimed at the development not only of a Pan-European market, but also of world markets.

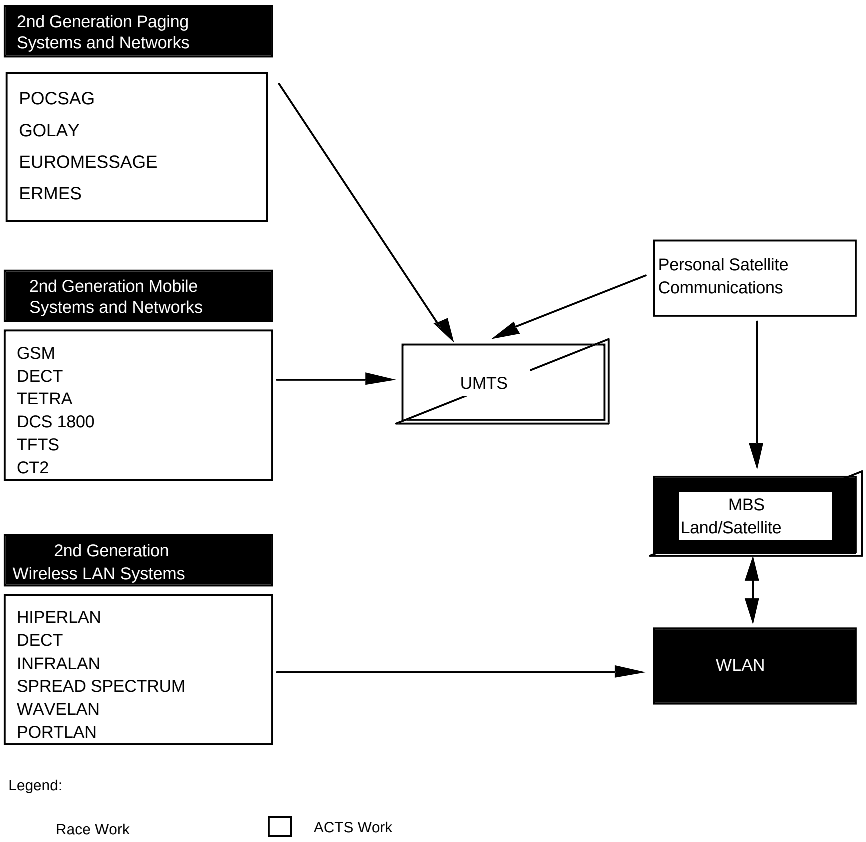


Fig. 1.1 - Evolution towards third/fourth generation systems with reference to RACE and ACTS programmes.

To these purposes, in 1992 two RACE (Research and technology development in Advanced Communications technologies in Europe) Projects have been set up by the European Community, e.g. CoDiT-UMTS (UMTS Code Division Testbed) and ATDMA (Advanced TDMA Mobile Access), to get optimised system architectures and compare their performance in a global environment. In addition, other RACE Mobile Projects were launched on related subjects, within the framework of the Mobile Project Line of the Community, namely: MONET (Mobile Network), MBS (Mobile Broadband System), MAVT (Mobile Audio Visual Terminal), SAINT (Satellite Integration in the Future Mobile Network), TSUNAMI (Technology in

Smart Antennas for Universal Advanced Mobile Infrastructure). Concurrent activities in the field of standardisation are in progress within ETSI (the European Telecommunications Standards Institute), to address third generation mobile systems and services under the label of UMTS, with a special focus on radio interfaces and network aspects, but worth noting are also the work of CEPT (Conference of European Postal and Telecommunications Administrations) and ERC/ERO (European Radiocommunications Committee /Office) regarding frequency allocations, the work of CENELEC (Comité Européen de Normalisation ÉLECtronique) on radiation health hazards and the activities of the GSM-MoU (Memorandum of Understanding), insofar as they may be a precursor to a UMTS-MoU.

It is expected that future requirements for personal communications will reach unprecedented levels, and the demand for a Personal Communications Space will require radically new, expanded and spectrum-efficient networks, infrastructures and equipment. As a consequence, the work of the new-born ACTS Projects will mainly focus on operational trials and on the technological aspects of integrated fixed and mobile broadband networks that have a direct bearing on the provision of enhanced personal communication services. Such trials should validate the wireless sub-system and network components in a variety of environments (office, residential, factory); they are expected to demonstrate cost/effective applications and services in the above environments, validate the integration and interworking of heterogeneous mobile networks and fixed network entities and, on the other, support for the radio connection through the various layers of the air-interfaces, proving their effectiveness. The ACTS Projects will also involve the development and proving of maintenance procedures, reliability testing and end-to-end quality-of-service management. The work will contribute to the development of common specifications and standards, as well as to the identification of new market opportunities and needs for changes in regulatory procedures and equipment specifications.

Such evolutionary scenario means that conformity, or at least compatibility, across network interfaces of all the necessary call, signalling and control procedures and protocols should be granted. It will also be necessary to conform to certain network functional arrangements and transmission requirements; in addition, the efficiency of the three technological platforms (UMTS, MBS, and WLANs) must also be proven in offering new opportunities for advanced mobile services. There is a need to establish the application feasibility of these services; a major issue in this context is continuity of services across different radio environments: in-building pico-cells, outdoor micro-cells, small and macro-cells, delivered by networks of widely differing capabilities. The technological feasibility of underlying mobile telecommunications technologies, for acceptable bearer capability, quality of service, general system fit-for-purpose, interworking and integration requirements, etc., should be identified through system oriented demonstrators taking place using UMTS, MBS and broadband Wireless LANs system platforms, in order to perform a fine tuning of the technologies themselves to achieve the desired functionality.

1.2 System migration prerequisites

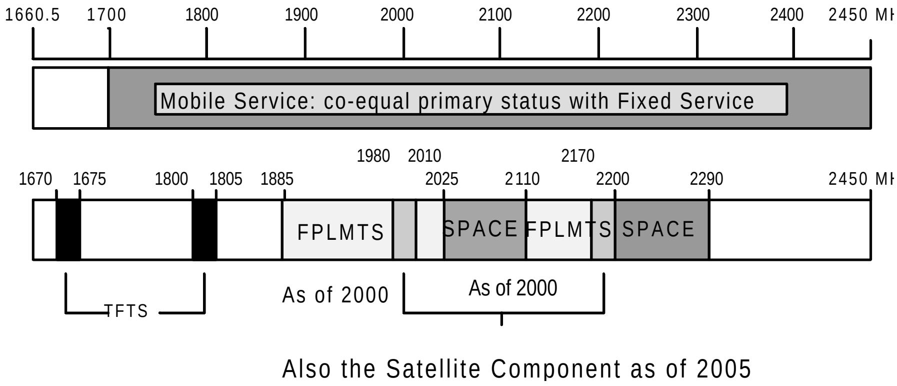
The above transition to third/fourth generation systems is fundamentally based on several prerequisites:

- Frequency Allocations and Spectrum Efficiency
- Enabling Technologies and Advanced Service Provision
- Terrestrial/Satellite Mobile Networks Integration
- Standardisation

1.2.1 Frequency Allocations and Spectrum Efficiency

The question of overcrowding in the frequency spectrum is an old one. As each year passes, new services and new users are demanding a share of this limited natural resource; the problem may be alleviated (and this is the case of mobile communications) through the adoption of new techniques enabling higher and higher frequencies to be brought into use, the utilisation of dual polarisation, directional or smart antennas, improved modulation methods, better filtering techniques and computer aided frequency planning. Nevertheless, demand for spectrum is still growing, leading to a rather strong congestion in some parts of it; taking into account any existing constraint (of technical, economical, social or political nature), both internationally recognised frequency allocation procedures and rules, and the subsequent work for maximising the spectral efficiency of the available resources appear to be essential. Frequency spectrum availability should no longer be an issue for mobile and personal communications, in a medium-term perspective at least, since the Final Acts of the 1992 World Administrative Radio Conference (WARC-92) extended the frequency bands allocated to a wide range of mobile terrestrial and mobile satellite services in the range below 3 GHz.

In most cases, the above services have been given the status of worldwide primary services (or at least on regional basis), with particular reference to FPLMTS (Future Public Land Mobile Telecommunication Systems) or IMT-2000 (International Mobile Telecommunications-2000, which is the recently suggested new name) [2]. WARC-92 decisions will present a variety of challenges in the design and definition of future services and systems and are schematically represented in Fig. 1.2 for the 1670-2450 MHz band: there is also much more room for future growth even at higher frequencies, because several existing fixed service bands above 4400 MHz have been allocated to the mobile service on a primary basis.



TFTS = *Terrestrial Flight Telephone System*

FPLMTS = *Future Public Land Mobile Telecommunication Systems*

SPACE = *Space Research, Space Operation, Earth Exploration Satellite Services*

Fig. 1.2 - WARC-92 Frequency Allocations to Mobile Services (1.6 - 2.5 GHz).

The most significant result was the promotion of mobile services to the co-equal primary status with fixed services in the above frequency range; this is in full agreement with the spirit of the 14 ECP (European Common Proposals) submitted by CEPT, after a formal agreement amongst 31 European administrations (including several eastern countries), reached after a consultation process led by ERC and ERO. The WARC-92 decisions in the mobile area may be summarised as follows:

- Allocation of a given frequency band (on a world-wide basis) to Personal Communications under the title of FPLMTS, with 230 MHz (including space segments) around 2 GHz;
- Allocation of additional spectrum for mobile satellite services (terrestrial, maritime, aeronautical) with up to 100 MHz for big LEO satellite services (Low Earth Orbiting) below 2 GHz and up to 10 MHz for little LEO, below 1 GHz
- Spectrum allocation to APC (Aeronautical Public Correspondence) systems, taking into account the different needs (and reservations) of Europe, US and Japan

The primary status condition will facilitate the implementation at a worldwide level of a number of European mobile systems, such as DECT, DCS@1800, ERMES, DSRR (Digital Short Range Radio), without significant constraints. Concurrently, the allocation of a given spectrum segment to FPLMTS (215 MHz for Europe, in the 1885-2025 and 2110-2200 MHz bands, in order to take into account the needs of already existing systems such as DECT and DCS@1800), will pave the way to the 3rd generation systems standardisation bodies (although with some limitations, due to the foreseen dates of entering into force). Furthermore, it will enable them to define specifications and develop the relevant technologies for personal communications on regional and international paths, including less populated and developing countries, where traditional communication structures do not grant an adequate coverage. On the other hand, it should be pointed out that at the same time demands for spectrum for other service applications and non-civil uses are changing and must also be carefully recognised: for example, it is estimated that over 30% of the spectrum range 30-960 MHz is typically currently allocated in Europe for governmental (and chiefly military) use (a similar proportion holds for the frequency range up to 3 GHz) [3]. Therefore, the problems of release/sharing of frequencies or of funding user migration on re-farming of frequencies are of crucial importance for a sound frequency spectrum management.

For Europe in particular, it is worth noting that, since from its inception, ERO activities have been directed to study the radio spectrum usage, promoting the DSI (Detailed Spectrum Investigation) programme [4 a,b], in co-operation with ECTEL (European Telecommunications and Professional Electronic Industry), whose main goal is to arrive at a well established Frequency Allocations Table for Europe by June 2008; the first phase, regarding the frequency range between 3400 MHz and 105 GHz was settled in 1993, while a second phase (29.7 to 960 MHz) is being concluded during 1995. This work should ensure administrations, industry, broadcasters, service providers, operators and users derive the maximum benefit from the frequency allocations decided at ITU level and is of course in full agreement with the EC policy (as outlined by the European Commission [3]), aimed at the introduction of a single market in which competitive supply opportunities exist, together with a technical harmonisation which ensures maximum compatibility and inter-operability of telecommunications through Europe.

When allocations and assignments (by licensing authorities) have been performed, the question of effective usage of spectrum resources arises, in order to maximise the spectral efficiency of the service under examination. From a quite general standpoint, protection against potentially interfering services may be increased with a proper selection of the available system design parameters. In very general terms, the following measure may be used for quantifying the effective spectrum usage of a system [5]:

$$U = B \cdot S \cdot T \qquad (1.1)$$

where B is the frequency bandwidth, S the geometric space and T the time, all denied to other potential user of the same resources. The quantity S, in particular (usually an area) may be interpreted in some cases as a volume or as an angular sector around a point, whilst in other situation may lose one dimension, as in the case of the geostationary orbit. In case of mobile services, all the above quantities must be taken into account simultaneously and optimised for an effective spectrum management. Once the measure of the spectrum usage is known (according to the previous expression) the actual spectrum efficiency must be evaluated, since the spectrum usage U, by itself, tells nothing about the efficiency of use; again from a general point of view, a ratio between the information transferred within the system and the above measure U of the usage may be defined, according to the equation:

$$E = M / U \qquad (1.2)$$

where U has been previously discussed and M could be the system information transmission capacity (bit/s), the number of radio channels per unit length (or area), or even an equivalent macro-indicator, such as the service area size, the investment revenue, etc.

According to [5], considerable work is needed to transform such general concepts into calculated values for any particular service. In case of mobile communications the above measure may be specialised (irrespective of system characteristics), as:

$$\eta = (N \cdot B) / W \qquad (1.3)$$

in which N is the potential number of users that could be served with the expected quality, B is the bit-rate of a single digital signal and W the total available bandwidth for serving the territory. No matter which multiple access scheme is adopted (see Fig. 1.3 for a general schematic representation, with n transmitters and n receivers), one can conventionally introduce an equivalent bandwidth dedicated to a single channel, denoted by W_0; it is then possible to factorise in the following way:

$$\eta = \frac{B}{W_0} \cdot \frac{N}{W / W_0} = \frac{B}{W_0} \cdot \frac{N}{M} = \eta_f \cdot \eta_s \qquad (1.4)$$

where η_f is a measure of the frequency efficiency (depending on the mo-demodulation technique and coding), while η_s is a measure of the space efficiency, strongly depending on the channel reuse in the territory to be served and the modulation robustness to interference contributions (once the spatial filtering effects, due to both propagation losses and the possible use of directive antennas are taken into account). In practice, η_f and η_s are mutually dependent and what is important is just the combination of both; furthermore, according to the measure U of spectrum utilisation, a third term should be added to the above equation, to account for the time efficiency too (depending, for a fixed quality, on blocking probability and mean waiting time).

However, time efficiency, as previously defined, has a minor impact on global efficiency; without loosing generality, N may be then considered as the number of users simultaneously active on the territory (thanks to the cellular structure), while M is the number that each cell could accommodate, when completely isolated from one another.

Finally, in order to allow comparisons not depending on cell size, a normalised efficiency could be defined, as:

$$\eta_M = \frac{\eta}{N_c} \qquad (1.5)$$

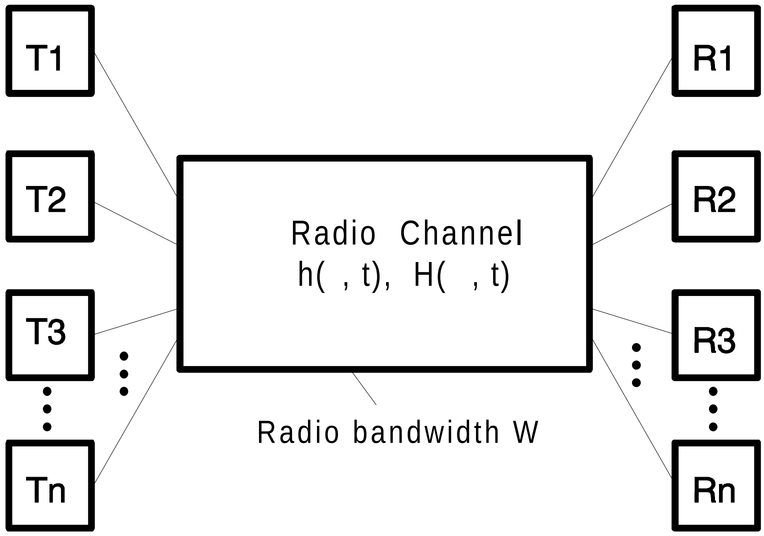


Fig. 1.3 - General scheme of a multiple access to radio channel within a cell.

where N_c is the number of cells required for an adequate coverage of the service area: according to the selected multiple access technique, the above quantity η_M will take different forms, depending on the orthogonality properties of the adopted scheme (and the related vulnerability to interferences). Further discussions of the relative advantages and drawbacks of different candidate solutions in terms of spectral efficiency are out of the scope of this introductory chapter and will be more extensively addressed afterwards.

1.2.2 Enabling Technologies and Advanced Service Provision

The adequacy of enabling technologies is self-evident from the existing hardware implementations which are widespread in use, and from the numerous articles and conference papers devoted to highlight technological developments aimed at future implementations, namely, smaller, lighter and more power efficient hand-held terminals.

Since new generation mobile communication systems should support over a seamless radio infrastructure not only the different service offerings of the second generation ones, but also a much wider range of broadband services (data, voice, video, multimedia), novel multiple-access techniques should be developed for example, together with associated coding and compression technologies, to meet the requirements for a reliable and secure transfer of very large volumes of information at speeds commensurate with those of fixed broadband networks. The overall objective is an improved efficiency of information transfer per unit bandwidth, of frequency re-use planning tools and related channel allocation techniques.

A major application of UMTS is in fact to support data communications for a range of bit rates up to 2 Mbit/s; furthermore, new information systems will be developed that will cover both mobile and fixed workstations. For mobile environments the service providers industry also requires standardised application interfaces: portable workstations are getting smaller and they are often equipped with communication interfaces for mobile and cordless systems. One trend is to integrate the portable computer and mobile telephone into a single unit; this requires adaptive terminal operation, capable to accommodate heterogeneous air-interface characteristics and to optimise the distribution of intelligence between fixed and mobile entities, in order to manage seamless migration among different radio environments. Taking into account the rapid developments occurring in the field of microelectronics, we can expect that the technology will enable the development of Intelligent Multimode Terminals that will provide a full range of service options in the future generations of mobile communication systems and be downwards compatible with current second generation systems too. Finally, as far as the terminals themselves are concerned, the objective is to achieve enhanced performance with reductions in size, weight and battery re-charge frequency.

The enabling technology domain also includes new adaptive (smart) antennas: use of adaptive directional antennas in the context of mobile communications (for base-stations, mobile terminal environments and furthermore indoor and outdoor applications) has been receiving growing attention. Novel developments in fact promise improved frequency re-use, higher protection against interferences, and better overall system capacity, together with a decrease in implementation costs. Coupling these techniques to, and optimised with, sophisticated digital signal processing technology will allow an adaptive, flexible and power efficient transceiver system.

A specific category of user is the personal roamer, operating in developing as well as in developed countries: to provide telecommunication services to these categories of users will require the internetworking and service support of fixed and mobile satellite or terrestrial systems that support narrow and broadband services. Individual requirements may demand handover between terrestrial and satellite systems with terminal equipment capable of accessing both: certain international organisations and large multinational corporations in fact need fixed, temporary fixed and mobile communications and often such organisations operate in developing countries with no telecommunications infrastructure. It is indeed of strategic importance to meet the requirements for wireless communication with very high throughput and to develop the industrial capability to produce the necessary system components: even more, in order to achieve the required high bit rates (up to 155 Mbit/s), it is necessary to consider high frequency spectrum resources. In this context, research to determine the optimum spectrum allocation (either in the K- or Ka-band, or in the 60 GHz region, where two sub-bands at 62-63 GHz and 65-66 GHz have been identified) is needed. MBS-like systems will provide novel multi-media and video mobile telecommunication applications, including applications appropriate to wireless, office, broadband systems.

1.2.3 Terrestrial/Satellite Mobile Networks Integration

In recent years there has been significant evidence that personal communications will evolve as hybrid fixed/mobile/satellite networks: system concepts have been developed to cater to specific markets, but conventional satellite designs appear not to be able to provide economical service to hand-held terminals, thus different concepts have emerged. Specifically, geosynchronous orbit satellites (GSO) operating at the Ka-band (20-40 GHz) or low earth orbit (LEO) and highly elliptical orbit (HEO) are contenders to provide the order of magnitude increase in communication capacity required for operation of extremely small terminals used in mobile communication networks. Congestion in currently used frequency bands and the demand for small earth stations is bringing EHF satellite communications to the point of economical viability, even if signal deteriorations due to hydrometeors and vegetation/building blocking phenomena are major drawbacks. In this perspective, the satellite component of MBS, as with UMTS, has to be carefully investigated: in principle, satellites in all the above mentioned different orbits are capable of offering operation to hand-held terminals, but with varying degrees of propagation delays and associated satellite and ground network complexity. The selection of a particular orbit will be a trade-off of these parameters. Compared with cellular systems, the satellite component of UMTS/MBS will be limited by the number of users it can support; there may also be limitations in the range of services it can economically offer to customers. However, they will have significant role to play due to the ability to serve economically very large areas: this should enable them to complement terrestrial UMTS/MBS with global roaming, and possibly to support introduction of some services ahead of a terrestrial infrastructure. Satellite components may also provide fixed links from one UMTS/MBS network, say in a developing country, to the Intelligent Network (IN) of developed countries (interconnection of UMTS/MBS islands); this may help the roll-out of the IN or provide economy where traffic is low. Another important application in this area is the use of a local satellite gateway where direct access to the space segment with the personal communicators is not feasible.

Relevant to the work in this area are the developments taking place in the world, under different schemes and constellations, such as IRIDIUM, GLOBALSTAR, INMARSAT P21, ESA-ARTES, etc. In this framework, the European RACE SAINT project and COST Action 227 (Integrated Space/Terrestrial Mobile Networks), both aiming at evaluating and identifying the requirements for integrating satellites into future personal mobile telecommunications are of paramount importance. This process of Fixed, Mobile & Satellite Network Integration will involve fundamental investigation of the essential network architectures, networking principles, functionality disposition, signalling and control procedures, together with protocols and terminal located functionality, that leads to the definition of efficient and economic network architectures which are mutually compatible: the essential functional, transmission and operating characteristics of each network must be recognised and accommodated by the linked networks.

1.2.4 Standardisation

Standardisation seems to be the area of slowest progress: while there is general agreement that global standards are in everybody's interest for the inter-operability of regional telecommunication networks of various kind in order to provide the customer with new universally accepted and available services, some difficulties still seem to exist in the co-operation between regional and international bodies. It may be worthwhile noting that ISDN standardisation has required approximately 15 years and the ATM standard is under development by about 5 years; this in spite of the fact that, on average, telecommunications have developed up to now more than 50% of all existing standards in all possible activity fields at a world-wide level. Standardisation needs a spontaneous consensus from all interested parties, nobody excluded, in some cases on very specific solutions: current procedures (and the relevant structures of specification bodies) appear to be rather cumbersome and no longer adequate to the actual objectives and market requirements, which are the unique real independent variable of the global system. A lack of a suitable and timely answer from the standardisation world would probably lead to pragmatic approaches, such as de facto world-wide standards (INTERNET is a significant example), built up on the ground of market requirements, technology availability and large multi-national companies willing, aimed at actual proprietary solutions, without any a priori agreement.

In this respect, recent initiatives taking place in Japan, North America and within the European Community indicate that to meet the challenges of globalisation and international competition, very significant effort must be devoted to the development of personal telecommunications networks, products and services. In Europe, the European Telecommunications Standards Institute (ETSI) established an "ad-hoc" Group on Universal Mobile Telecommunications System, now SMG5 (Subgroup 5 of the "Special Mobile Group"), which focused on the critical points to be studied for systems suitable for providing personal communications services to people on the move. The main goal of the Group is the definition of the services that can be potentially delivered by radio, with particular reference to access and terminal mobility aspects. This work has a very close relationship with concurrent ITU-R specification activities on FPLMTS [6] and ITU-T studies on UPT (Universal Personal Telecommunications), which is a service concept, aiming at the provision of a full personal mobility. Other regional standardisation bodies are currently active in the same field: the T1 Committee in US and TTC in Japan are two major examples, together with other organisations from Korea (TTA), Australia (ATSC) and Canada (TSACC) [7].

The recent reorganisation of ITU will undoubtedly stimulate progressively closer co-ordination between the various standardisation efforts. In fact, tight relationships among the various regional bodies dealing with third generation systems are warmly supported: this is reflected in a recent draft new ITU Opinion [8] which urges the ITU to make every effort to persuade regional and national authorities to support the Radiocommunication Sector in an explicit manner in its development of Recommendations on FPLMTS and strongly encourage regional organisations to work together towards a single world-wide standard: the co-ordination of the regional bodies within world-wide standardisation mechanisms is a first positive answer. Their grouping formerly in the Interregional Telecommunications Standards Conference (ITSC) and now around its successor, the Global Standards Collaboration (GSC), should result into an effective and efficient supervision of standards-making management, by means of voluntary exchange of information among their members, thus complementing ITU international activities, minimising the potential risks of overlap and/or duplication of work, and, on the whole, increasingly shaping the world of telecommunications. Accordingly, there is a need to continue, if not accelerate, contributions from any interested institution to standardisation bodies on all aspects regarding UMTS.

1.3 Medium/long-term Action perspectives

In the particular field of mobile radio (or personal communications), the above co-operative approach will facilitate the implementation of a smooth transition from the second generation (not compatible) systems to the universal third generation one: COST 231 most ambitious aim was to act as a focal point within such a process.

1.3.1 Objectives and Participation

The objectives of the Project were, among others [9], to identify the characteristics of third generation mobile and personal radio systems currently under specification, and to provide design methods and coverage models for their implementation: this involves studies on digital transmission techniques. Propagation studies were concurrently carried on in the UHF band for modelling and simulation of the transmission channel, and establishing prediction methods for attenuation (shadowing, penetration losses, etc.) and multipath effects in large, small and indoor cells. For the long-term period, communications systems for broadband services (i.e., services requiring a capacity greater than that of the basic ISDN services) have been studied, which involve a large spectrum of new telecom technologies at millimetre wave and infrared bands. Then, COST 231 research programme covered a wide spectrum of land mobile communications aspects, with a major emphasis on personal communications systems that in the near future will provide voice and data communications through small, cheap, handportable radio terminals.

Participating Countries and Entities. Currently, 20 signatory Countries participate at the M.C. meetings: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom. COST 231 M.C. meets three times a year, usually on invitation by Administrations, Research Institutes or Universities; more than 80 people usually attend the meetings, from some 70 participating entities (Research Institutes, PTTs, Manufacturers, Universities), as listed in Annex 1.

1.3.2 Liaisons with European research and specification bodies

The COST 231 Project started on 6 April 1989 [10] and, formerly scheduled to expire on April 1993, was extended to 5 April 1996, with a three year extension, aimed on one hand to fully support ETSI in its standardisation activities of UMTS, on the other to investigate, for the long-term period, communications systems for broadband services, as well as the relevant propagation characteristics in the appropriate frequency bands (from high microwaves to millimetre waves), taking into account channel limitations and impairments.

Accordingly, COST 231 work in this stimulating context can be envisaged to complement the research activities carried out within international and regional bodies and, by definition, had a synergistic relationship with both ETSI standardisation activities on UMTS and ITU studies on FPLMTS and UPT.

As a matter of fact, in addition to the relationships with most RACE Projects, a number of liaisons with several regional or international bodies (ITU-R SG3, ITU-R TG8/1, ETSI-SMG2, ETSI-SMG5, ETSI-RES02, ETSI-RES03, ETSI-RES10, UK Technical Working Party on Mobile Propagation, UK LINK CDMA Project, URSI) were established by COST Action 231, and were fostered through exchange of documents and participation to meetings: "ad-hoc" rapporteurs are appointed.

1.3.3 Action activities

According to the objectives, the major goals were to identify the characteristics of radio systems and provide design methods and coverage models for their implementation [11]. Propagation studies have been carried on for modelling and establishing prediction methods for attenuation (shadowing, penetration losses, etc.) and multipath effects in large, small and indoor cells. For the medium-long-term period, most items concerning future mobile and personal telecommunication systems were examined: narrowband and wideband techniques, coding and access schemes, prediction methods for micro- and pico-cellular applications. COST 231, due to its nature and commitment to basic researches, had the freedom to consider and compare several promising alternatives, in addition to those addressed for example by RACE Projects, with particular reference to broadband services and related technological problems.

The work has been split into three main areas, allocated to three working groups:

- WG1 - Radio System Aspects
- WG2 - UHF Propagation
- WG3 - Broadband Applications

WG1 focused its work on system options and techniques for future third generation standards; the work of WG1 was seen to complement the various RACE Projects, and also to provide significant results for the ETSI SMG5 Group. Particularly important are the contributions looking at multiple access techniques (CDMA, TDMA, etc.), and the work in new modulation and coding techniques. Three types of CDMA systems were examined in detail, namely DS-CDMA, FH-CDMA, Hybrid SFH/DS-CDMA, together with related problems of interference suppression, spectrum sharing and integrated voice/data services.

WG2 covered the mobile channel characteristics at frequencies between 900 MHz and 3 GHz. Particular attention was given to outdoor measurements and modelling (macro and micro-cells), by developing both statistical and electromagnetic prediction methods, taking into account the effects of system parameters, such as base station antenna height and directivity, site location and environment. Increasingly, the emphasis has been on outdoor short-range, indoor propagation and building penetration, in the perspective of finding suitable planning tools for micro- and pico-cellular environments.

WG3 dealt with both propagation (at microwave and mm-waves) and system aspects. The group concentrated on high data rate (>10 Mbit/s) short range communication in the indoor environment, both from a theoretical (modelling and simulation) and experimental standpoint, using millimetre wave radio frequencies (>30 GHz) where there is adequate bandwidth available. Attention has also been paid to outdoor environments and infrared wavelengths, with particular reference to High Performance Radio Local Area Networks (HIPERLAN), considering typical classes of application. Attention was also given to the safety aspects for both millimetre wave and infrared radiation and to study the performance of possible system configurations for wireless optical systems (and relevant constraints).

1.4 Outline of the Contents

According to previous statements, this book covers two main broad areas, respectively dealing with systems for narrowband/wideband communications operating at around 2 GHz, and systems for broadband communications operating at high microwave and millimetre wave bands. Such division appears to be as the most appropriate one, taking into account the potential solutions envisaged for the future [12].

1.4.1 Narrowband & Wideband Communications

Mobile system planning is a very broad process that is related to technical aspects on one hand and economic aspects on the other hand. Consequently, there are two main research areas: Simulation Tools and System Planning. Simulation Tools allow to evaluate the performance of a system and to optimise the parameters to meet the specified service or application requirements; the simulation of a system or of a sub-system is based on techniques capable to describe both the systems and the environment, and take into account channel models, mobility models, traffic models, service and application models, etc. As to the second area, System Planning is a specific structured methodology to plan entire communication systems: rather than to consider technical details, as it is the previous case, it deals with economic aspects and overall performance, reliability, efficiency, capacity capability and acceptance aspects for specified services and applications. COST 231 mainly focused on the first area, with particular reference to the identification of the propagation channel properties and relevant software and hardware simulation techniques: this is reflected in the contents of Chapter 2 (Radio Channel Characterisation). In fact, to characterise a mobile radio channel and establish prediction methods, the first step is to measure it with sufficient accuracy. Third generation of digital cellular systems will have a larger bandwidth than current systems and will be operated in various environments. As a consequence, the investigation of propagation phenomena needs channel sounders able to measure the frequency selective behaviour of the channel by means of either the impulse response or the transfer function in at least the system bandwidth, and to cope with different constraints according to the environment, in terms of maximum excess delay, time resolution, etc. Of course, usual field strength measurements are still needed for path-loss modelling and planning purposes, but the techniques are rather well known; therefore, wideband measurements were given a special attention. Furthermore, measurements of the Direction-of-Arrival (DOA) of multipath components are also a relatively new feature which is important in order to validate prediction methods based on ray tracing (or, more generally, ray-optical methods) and to find good physical models, capable of describing propagation effects like diffraction and scattering by buildings and street corners. Chapter 2, again, concentrates on all the above topics.

In Chapter 3 (Antennas and Antenna Diversity) COST 231 studies on antennas for both base stations and portable terminals are included, and diversity techniques (including combining strategies) are examined, with a discussion of the improvements achievable using macro- or micro-diversity techniques. A particular attention is given to low-absorption (and reduced health hazards) hand-portable applications, together with the investigation of antennas configuration, as well; this would allow to identify the implementation of small-sized equipment and to optimise the relevant link performance. Finally, the advantages of using directive and adaptive (smart) antennas are addressed, stressing the significant achievable improvements, in comparison with antenna systems currently in use, based on either fixed pattern antennas or single space-diversity switching techniques.

In the field of propagation, prediction methods and related data base management were investigated, considering outdoor large cells, outdoor small cells, outdoor micro-cells (short range applications), in-building pico-cells and outdoor/indoor propagation (including penetration losses and attenuation phenomena due to internal walls, floors and ceilings). Overlaid and three-dimensional cellular coverage structures were also examined, including suitable modelling of the wave propagation and application examples (coverage structure for large and small indoor areas, multi-storey buildings, etc.). In fact, in order to evaluate the performance of a system and to optimise the relevant parameters by means of a simulation tool, a sound knowledge is required of the various propagation mechanisms and of the specific approach to be adopted for a given environment. Chapter 4 (Propagation Prediction Models) addresses such issues, together with models for coverage of special environments, such as tunnels: this is particularly important for communication services with trains. Working with terrestrial cellular networks (using a common standard) would provide the railroad operator and passenger with means of communicating across state boundaries. Tunnels require ad hoc coverage solutions, but at the frequencies envisaged for UMTS operation the ratio of tunnel cross-section and wavelength encourages natural wave propagation within the tunnel, with considerable cost savings, by using antenna systems instead of leaky feeders. In addition, the velocity of some trains exceeds the presently specified capabilities of cellular networks; therefore, the effect of high speed (in combination with the environmental conditions of rail tracks, cuttings, tunnels, etc.) on the reliability of digital transmission was subject of investigation.

In order to identify the most suitable radio access methods for the future Universal Mobile Telecommunications System, advanced transmission techniques must be studied. Continuing studies on modulation methods, multiple access, adaptive channel equalisation, coding, diversity techniques, etc. have been carried out, considering the need for adapting the bit rates to service requirements and channel conditions. Radio Subsystem Aspects Group started its activities examining the performance of 2nd generation systems; a special attention, as described in Chapter 5 (GSM and DECT Systems), was paid to DECT: one good example has been the performance assessment of DECT in different reference scenarios, in the presence of significant delay spreads. Also GSM radio-link performance under selective frequency propagation conditions was investigated, and improvement by using either frequency hopping or antenna diversity was addressed, as well.

Increasingly the emphasis has been on system options and techniques for 3rd generation standards; a special attention was devoted to study Advanced Radio Interface Techniques and Performance (Chapter 6). As far as multiple access techniques are concerned, researches were directed towards Advanced TDMA methods and several Spread Spectrum and CDMA schemes, such as Direct Sequence (DS) CDMA, Frequency Hopping (FH) CDMA, Hybrid Slow Frequency Hopping/Direct Sequence CDMA Systems, CDMA with interference suppression. Concurrently, Chapter 6 present COST 231 studies in the field of coding, modulation and equalisation: a number of equalisers are examined, with particular reference to Viterbi Equalisation with Non-Coherent Modulation, Joint Equalisation, Impulse Response Estimation, Block Decision Feedback Equalisation. Recently, there has been much progress in the research of fast algorithms applicable for adaptive equalisers and echo cancellors: COST 231 work concentrated also on massively parallel structures and VLSI simulation of fast parallel adaptive echo cancellors based on FIR filtering. Finally, Medium Access Control (MAC) protocols and (dynamic) channel allocation strategies are discussed, together with handover capabilities, allowable cell size, maximum mobile speed, roaming capabilities, coexistence with other systems sharing the same frequency bands.

Potential Radio Interface Subsystems for UMTS are examined in Chapter 7; specific different approaches are discussed in detail (Advanced TDMA, DS-CDMA, CTDMA and JD-CDMA), and the relevant performance and spectrum efficiencies assessed for the candidate solutions. Hybrid systems, in particular, appear to be attractive, because they can combine the advantages of both direct sequence and frequency hopping systems, while avoiding some of their disadvantages. Moreover, such systems offer the possibility to increase the system capacity and may also use shorter spread spectrum code sequences and hopping patterns, thus reducing the overall acquisition time. On the other hand, a drawback of hybrid systems is the increased complexity in their transmitters and receivers: a careful investigation on these topics was carried out. Furthermore, since interference in CDMA could be a limiting feature unless optimum power control is guaranteed, if the impact of imperfect power control has to be reduced adequate CDMA system capacity can only be obtained by applying methods of interference suppression. Such methods can be subdivided into interference cancellation (IC) and joint detection (JD). Both are examined: the potential of the latter, in particular, seems to be very promising and is analysed in a section of Chapter 7.

1.4.2 Broadband Communications

The communication landscape of the future will be characterised on one side by a heterogeneous set of networks, including B-ISDN, N-ISDN, usual telephone lines, wireless techniques (including radio in the local loop), and LAN-standards. Wireless voice/data transmission in particular has become an important factor in communication techniques and it is used to develop a new generation of Wireless LANs: as known, the use of the radio transmission technology for LANs will provide an alternative to the cabling of offices and industrial plants. In this scenario, HIPERLAN could play a dominant role: WG3 activities to support ETSI Committee RES-10 in developing a standard for a HIgh PErformance Radio LAN are worth noting. HIPERLAN, which has been recently assigned spectrum by CEPT/ERC in the 5 GHz and 17 GHz bands for specific use (even if on a non-protected from and non-interference to basis), plans to distinguish itself from earlier spread spectrum products by the large bandwidth (with a target of about 20 Mbit/s) and its time-bounded service capability (aimed at multimedia applications). Furthermore, HIPERLAN should also be able to support ad hoc networking of highly portable PCs, (such as laptops, note-books, pen-books), including full-scale Personal Intelligent Communicators (PICs) and Personal Digital Assistants (PADs) [13], as a result of the technological merger of mobile telecommunications, computer technology and consumer electronics. Functionally these personal communicators are a combination of a portable computer and a cellular telephone thereby giving the user the facilities of data transmission, fax, electronic mail, paging, voice telephony as well as the capability to organise and manipulate information (agenda/scheduler). In Fig. 1.4 a feasible timeline evolution is reported, as excerpted from [1], in terms of potential deliverable services (from voice to multimedia), and related transmission rates.

Accordingly, the majority of HIPERLAN applications are envisaged to be extensions of wired LANs, providing transport of asynchronous data and real time voice and image streams, granting access facilities to public networks with efficient internetworking, and allowing multiple networks co-existence without the need of frequency planning and co-ordination.

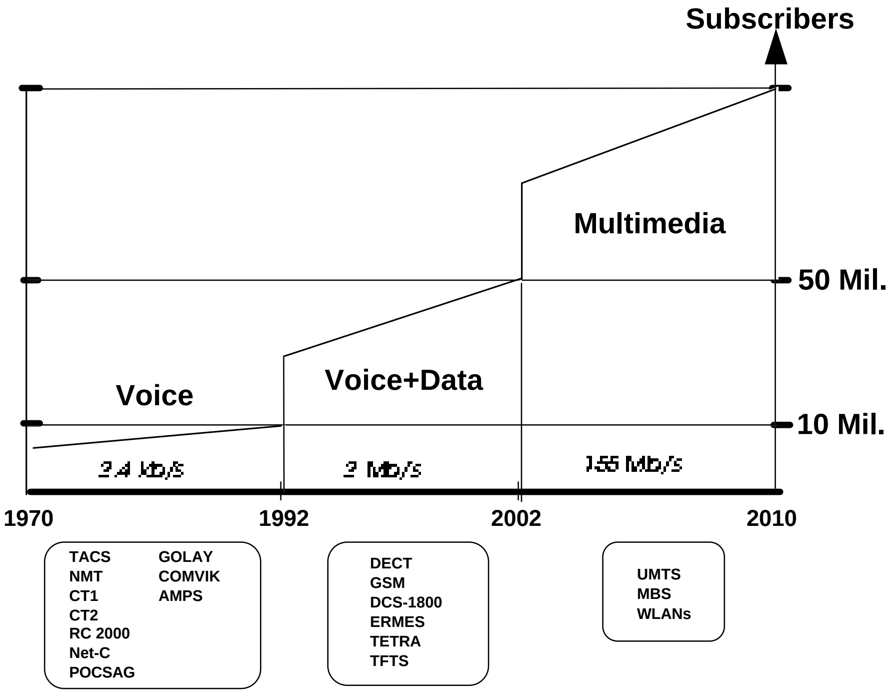


Fig. 1.4 - Evolution timeline towards personal communications and multimedia services.

Of course, HIPERLAN will provide mobility (at least for pedestrian or indoor vehicle speeds), and security (comparable to that of traditional LANs), preventing eavesdropping and ensuring protection against unwanted data injection. Different environments (office, production, storehouse) have different requirements, which concern security, range, health aspects, transmission rate, re-using of frequencies, cost, maintenance, penetration ability, etc. In this respect, the studies on broadband communications carried out in COST Action 231 were directed towards systems operating in the quasi-millimetre band, although this does not rule out considerations of other bands (IR, Infrared) in the light of any future developments, taking also into account the similarities between IR and mm-wave systems at the physical level. Both system aspects and propagation studies in the radio-frequency and optical field have been dealt with, considering communications within buildings with one cell per room, taking advantage of the natural (atmospheric) and man-made shielding effects, cellular coverage of indoor areas (office and industrial buildings) with indoor base stations, coverage of indoor areas from external base stations, communications from inside a building to a mobile outside, local-area broadband radio networks and outdoor millimetre-wave cellular coverage. The studies concentrated on material characterisation, modulation schemes, non-ideal receivers (especially carrier recovery), to include the effects of co-channel interference and evaluate the application of DS-CDMA and frequency hopping techniques. Transmission performance evaluation, using both simulations and field trials, covered several aspects, such as outage probability evaluation, analytical models for frequency selective channel, adaptive equalisation, OFDM systems and CDMA systems, and dynamic channel allocation. All the above topics are considered in Chapter 8 (Broadband Communications); in the same chapter a variety of medium access control protocols, with a particular attention to the HIPERLAN features are discussed. Analytical models for multipath fading, shadowing, near-far-effect in the mm-wave communication systems to evaluate network performance are then examined, together with the study of suitable protocols for high data rate and for voice and data integration.

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