A speculative commentary on the future

The Evolution of Personal Communications

RAYMOND STEELE

The term *personal communications* is not well defined, as are the related terms personal communications networks (PCN) and personal communications systems (PCS). PCN and PCS appear to synonymous, with the Europeans preferring the former and the Americans the latter nomenclature. However, usage of PCN/PCS varies widely. To some it is public communications where the communicator is personally owned, while others would argue that PCN does not yet exist, and the first one will be the global mobile network planned for beginning of the next century.

We are concerned here with examining how we might evolve from the current chaotic scene in mobile radio communications to the global network known in Europe as the universal mobile telecommunication system (UMTS), and by the ITU as the future public land mobile telecommunications system (FPLMTS). A pre-requisite for our discussion is a brief statement of the current scene followed by list of the cardinal goals of UMTS. From this framework we may speculate on evolutionary routes.

The Current Scene

The mobile communications scene of today is an international bazaar, with a wide variety of equipment on offer to provide different types of networks. In recent times many national telecommunications companies are, or have been, deregulated, only to be partially re-regulated to give newly formed competing companies a chance to establish themselves. Some mobile companies are closed user groups, able to exist without requiring the services of the large public switch telephone networks (PSTNs) or integrated service digital networks (ISDNs), while many mobile networks are forced to use the PSTN/ISDN and pay charges which inevitably are passed on to the mobile subscriber. The deregulating process may yield financial benefits to the consumer due to the competitive pressure on price tariffs, but they also introduce technical solutions that are more expensive, sub-optimum, and may even delay the realization of the universal mobile telecommunications system (UMTS).

The current mobile scene is composed of many disconnected systems. Table 1 shows a compilation of some of them [1-5]. There are first generation analog cellular, second generation digital cellular, analog and digital cordless, long-standing analog private mobile radio (PMR) and the latest digital PMR systems, a range of wireless LANs, existing satellite networks for land, sea and air mobiles, a group of proposed digital mobile satellite networks, entrenched and new paging systems, terrestrial flight telecommunication systems (TFTS), and so on. Space does not allow us to describe these systems. We may note that the analog cellular systems are conceptually similar, although incompatible, and based on FDMA, while the digital cellular employ either TDMA or CDMA. Cellular systems use frequency division duplex (FDD). Following the analog cordless telecommunications (CT) the digital CT2 is FDMA using time division duplex (TDD), while the digital European cordless telecommunications (DECT) system uses time division multiple access (TDMA) with TDD. Wireless LANs will be a complement to, and not a replacement for, fixed LANs.

Aims of UMTS/FPLMTS

Although UMTS and FPLMTS are sponsored by different organizations their goals are fundamentally the same. UMTS is powered by the European RACE program, and a sub-committee of the European Telecommunications Standards Institute (ETSI), called SMG5, is tasked with defining the UMTS standards. The primary aims of UMTS is global coverage for speech and low-to-medium bit rate services, with the provision of high bit rate services over limited coverage areas. To achieve these aims the air interfaces need to be defined; functions, signaling systems and architecture to support the fixed part of the UMTS network is required; integration with the PSTN/ISDN in terms of the intelligent network (IN) and universal personal telecommunications (UPT) needs quantifying; the ability to be ISDN-compatible; to be technologically independent; to have end-to-end encryption; to accommodate a range of cells from microcells to satellite cells, and so forth. The spectrum allocated is 230 MHz in the 1.885 to 2.200 GHz band. The services may be sub-divided into dialogue (eg., speech, fax, low resolution video telephony), messaging (eg., paging voice and e-mail), informational retrieval (eg., voice, music, data). The bit rates for these services vary from 1 kb/s to 2 Mb/s. UMTS/ FPLMTS is scheduled to come into operation at the beginning of the 21st century.

The Virtues of Evolution

Many of the digital systems in Table 1 have yet to be installed in any significant numbers. They are all stand-alone systems and only a few are moderately compatible. They range from satellite, PMR, and cellular to CT. The global PCN will embrace all these types of networks. However, will this global PCN evolve from existing second generation mobile networks, and if so, from which ones? Slow evolution has the virtue of allowing each new service to be commercially established before the next one is introduced. Evolution would also facilitate the steady improvement to the existing networks, avoiding the massive investment required to deploy a new network over a relatively short time scale. Thus evolution would allow operators to maintain or increase profitability during the evolutionary phase, while providing more services.

Evolution does occur naturally and continuously at the local level as equipment suppliers improve their products, operators enhance their managerial skills, and service providers add new services. The evolution we are concerned with here is the evolution imposed by international standards bodies. These bodies are often technologically rather than market driven. They concern themselves with elegant and commercially viable engineering improvements to the current state-of-the-art. They are often unaware or may appear indifferent to the aspirations of the public. Like it or not the global PCN will arise from technocrats.

Factors Affecting Evolution to UMTS

The public perceive mobile phones as a luxury item, that calls are relatively expensive and often of poorer quality than those of the fixed network, and that there may be biological hazards. Persuading people to buy more complex products will require technological improvements, a decrease in user equipment costs, lower tariffs, and creative marketing of new services. Then there are a number of critical technologies. These include improvements in batteries and integrated circuit devices, introduction of flat screens and voice recognition and speaker verification systems, end-to-end encryption, IN to support UMTS, introduction of multicellular, multimode interfaces, and widescale deployment of special purpose optical supporting networks. It is also imperative that the second generation networks are a financial success. Without this success UMTS is likely to be significantly retarded. Some existing networks are of a brickwall nature, being incapable of significant development. We note that development is synonymous with evolution in this context. Others are capable of much development, and possibly the network that will evolve the most is the global system of mobile telecommunications (GSM), as developments are planned for both its radio interface and its network. Evolutionary aspects of existing networks may have considerable influence on UMTS. However, if these existing networks have fundamental weaknesses UMTS should abandon them at the outset.

Evolution of GSM

The most complex of all the second generation systems is GSM, having an advanced radio system and supporting fixed network. GSM supports eight users in a TDMA format on each radio carrier. The TDMA carriers are FDMA multiplexed. GSM has many advanced features to combat fast fading, such as FEC coding, bit interleaving, channel sounding and equalization, power control, and voice activity detection. Currently we have GSM, phase 1, and because of the introduction of DCS 1800, this is now referred to as GSM 900. DCS 1800 is itself an evolution of GSM, where the operation band is at 1800 rather than 900 MHz. There are a number of marginal differences between GSM 900 and DCS 1800, the most important of which is that the transmitted power levels of DCS 1800 are lower to promote the deployment of small cells. Phase 2 GSM 900 will have lower bit rate speech codecs and with their new FEC codecs will enable 16 mobile channels per carrier. This doubling of users per carrier will not change the bandwidth occupancy of each carrier, but it will significantly increase system capacity. Phase 2 will also add data services, fax, and supplementary services. The specifications of both GSM 900 and DCS 1800 will merge to allow both systems to provide coverage in microcells and in large cells. Macrocells will overlay microcellular clusters. It is envisaged that slow moving mobiles will use microcells, faster mobiles will use the macrocells. The mobile will be able to identify itself as fast moving and do fewer cell handovers and location updates. The handover algorithms will be modified to allow for the small distances between a mobile and its microcellular BS by simplifying the mobile's timing advance procedure.

The supplementary services of call-forwarding and call-barring will be extended to conference calls, call-waiting indication, mobile PABX. GSM 900 will support improved short messaging, computer data, and video phones. Vehicle speeds

Analog cellular	Nordic mobile telephone Advanced mobile phone service Total access communications system NETZ C, D Nippon advanced mobile telephone system
Digital cellular	GSM Digital communication system at 1800 MHz IS-54 (D-AMPS) IS-95 (Qualcomm CDMA) Japanese digital cellular Terrestrial flight telecommunication system
Cordless communications (CT)	Analog domestic cordless telecommunications (CT) Improved CTI Common air interface CT 2 system Digital CT at 900 MHz Digital European CT
Wireless LAN	European Telecommunication Standards Institute categories 1, 2, 3 ALTAIR (proprietary wireless LAN)
Private mobile radio (PMR)	Analog 12.5 kHz/FM Trans-European trunked radio Digital short range radio
Mobile satellite	Aeronautical in-flight Land: EUTELTRACS, PRODAT Maritime: Inmarsat A, B, C Proposed: IRIDIUM, GLOBALSTAR, ODYSSEY CONSTELLATION ELLIPSAT
Paging	Many entrenched systems European radio message system

■ **Table 1.** *Some existing or soon to be deployed mobile radio systems.*

of up to 500 km/hr are anticipated and the system will be adapted to cope with the high Doppler speeds that will occur. We note that there is no intention to have a GSM phase 3; instead all changes after phase 2 will be referred to as phase 2+, a term that implies continual refinement or evolution.

The Influence of GSM on Other Systems

Representatives of equipment manufacturing companies pollinate standard bodies. Having influenced the design of GSM 900 and produced the equipment to deploy the system, they modified GSM 900 to formulated DCS 1800. Having a grasp on TDMA, they influenced IS-54 (which became D-AMPS). Turning their attention to cordless telecommunications (CTs) for office and telepoint applications resulted in ETSI standardising the digital European CT (DECT) which has enhanced TDMA features. Each TDMA carrier supports 12 channels but instead of using FDD it employs TDD. A number of slots rather than a single slot per carrier can be assigned to wideband users, and it can also configure its radio interface so that most of the uplink and downlink slots can be used for transmission of data in one direction. Dynamic channel allocation (DCA) can also be used. Here clusters of BSs are given the same set of frequencies and time slots and under network control can assign them in such a way that the capacity is increased compared to earlier fixed channel assignment methods.

The multiple access method has a significant influence on the spectral efficiency, and there is much research in progress to enhance the different multiple access techniques.

Evolution of Multiple Access Methods

While the capacity of the fixed component of the mobile network is not a fundamental problem, maximizing the capacity of the radio part of the network has not yet been attained. All mobile radio systems are interference-limited, as the precious allocated radio spectrum must be continually reused. Spectral efficiency of mobile radio systems is defined in terms of Erlangs/MHz/km^2, and systems that can cope with cochannel interference with few or single cell clusters will have a higher spectral efficiency than systems that have a large number of cells per cluster. The multiple access method does have a significant influence on the spectral efficiency, and there is much research in progress to enhance the different multiple access techniques.

A discourse on evolutionary issues in PCN must therefore be concerned with the evolution of multiple access methods. We need to identify the basic features of an access method when it is obfuscated by numerous enhancements. Then we must ask ourselves if these basic features will seriously limit the performance, no matter how inventive we are. Research should then be directed to those multiple access methods that innately have good performances.

It will be recalled that all first generation mobile systems use frequency division multiple access (FDMA). Using large cells and therefore high transmission powers, the BS equipment is bulky, and one transceiver is required per channel. These features persuaded second generation designers to avoid many of these problems by opting for time division multiple access (TDMA), where a new set of difficulties relating to signal processing could be handled. We note that two of the contending systems for GSM did employ hybrid multiple access methods that involved TDMA with spectral spreading [6, 7]. Following the specification of the TDMA cellular radio interfaces, code division multiple access (CDMA) interfaces were designed. Presented with three basic multiple access options we need to identify if there is a role for all of these multiple access methods in UMTS, or is there a clear long term winner. Let us now examine the evolutionary steps that have occurred, and speculate as to what might happen.

TDMA Evolution

In the section on GSM's influence on other systems, the evolution of TDMA that has occurred in DECT was mentioned. Another embellishment is packet reservation multiple access (PRMA), which comes to mobile radio from earlier systems concerned with packet transmissions, such as those involving ALHOA techniques. Basically PRMA enables more users to be supported than there are time slots [8]. It achieves this by exploiting the statistics of an ensemble of users. For example, in voice communications users who are not currently speaking vacate their channels for those who are. Essentially PRMA exploits the condition that at any given instant a substantial number of users are not talking. As there are more users than channels there will be times when not enough channels are available when the quality of some channels becomes severely degraded.

In fixed channel assignment (FCA) systems the graph of signal-to-interference ratio (SIR) versus the number of cells per cluster M is a slowly increasing monotonic function with M. This means that to improve the SIR to meet radio link requirements may necessitate a significant increase in M that results in a substantial decrease in capacity. It is because of the shape of this curve that the theoretical minimum cluster size in both TDMA (and in FDMA) is not realized in practice. Cluster size has no meaning in DCA, as all the BSs can have the complete set of TDMA carriers. By not requiring frequency planning, DCA may have an important role to play in UMTS where three-dimensional microcells having very irregular volumes will be deployed. DCA will require accurate and rapid power control together with fast handover algorithms to enable the mobile to escape from high cochannel conditions. New protocols will be required, as well as distributed network intelligence to support spectrally efficient DCA.

The evolution of TDMA will continue and we may speculate on its inherent limitations. TDMA implies that users' transmissions are bursty rather than continuous, and that a time frame structure prevails. Consequently the transmission rate is much higher than the source date rate, so that in the future when users' data rates become very high the burst rate may become unacceptably excessive. Further, and perhaps ultimately the most significant limitation, is that the frame structure means that TDMA signals may cause serious interference with non-radio systems.

FDMA Evolution

The first generation mobile radio systems use FDMA. The development of these systems continues and it is interesting to note that systems like TACS have fax and data services, whereas GSM 900, Phase 1, does not. The innate weakness of these analog systems is their inability to provide affordable security. But what of the evolution of FDMA. By using digital FDMA the security can become the same as for TDMA. In FDMA users are assigned a specific frequency band for the duration of their call. One development of FDMA is to arrange for a user's data to be simultaneously carried on a number of different frequency channels. This can combat frequency selective fading, and is particularly appropriate for wideband signals. Frequency hopping of FDMA channels may be used, where a mobile's transmissions is continuous, but in a different frequency band during each hop. PRMA may also be applied to FDMA where more than one user may share an FDMA channel according to activity of the users' data sources.

As previously mentioned, it was equipment factors that prompted the move from FDMA to TDMA. However, most of the teletraffic carried in UMTS will be from microcells in streets and buildings. As this can be accomplished using low power levels, and due to the likely advancements in technology, FDMA equipment can be small and lightweight. Another innate virtue of FDMA is that the data rate is essentially the same as the multiplexed rate. Consequently for the highest bearer rates in UMTS, FDMA can be implemented without the signal processing complexity required in TDMA and CDMA systems. We also note that FDMA is an enabling multiple access method, as both TDMA and CDMA multiplex their carriers using FDMA.

CDMA Evolution

The roots of CDMA are in military communications, as it was conceived for covert communications with a relatively strong immunity to enemy jamming. By representing each data symbol by a code whose elements are called chips, the CDMA signal spans a wide band of frequencies and is a noise-like time signal. An important feature of CDMA is that the jamming noise is decreased by the processing gain, the ratio of the symbol duration to the chip duration.

CDMA was not seriously considered for cellular communications because it was perceived to have three fundamental weaknesses. These were the necessity to give each user a unique code, the ability to synchronize the network at the chip time, and the tight power control to ensure that the received power from all the mobiles at the base station was the same to within a small error. These weaknesses were all overcome by Qualcomm. Their system is now the second U.S. digital cellular standard, IS-95.

Qualcomm's activities in CDMA have had a profound catalytic effect as witnessed by the current world wide explosion of research in CDMA and the new CDMA systems that are being offered. We may expect to see variable rate CDMA, with high chip rates being used in microcells and lower chip rates in larger cells. Interference cancellation techniques will be enhanced to significantly increase capacity, macrodiversity will be deployed, co-existence with other CDMA services using the same frequency band will be provided, and so forth. CDMA does not seem to have the serious innate deficiencies of TDMA, except that if services require very high bit rates, the demands on the technology to generate much higher chip rates may be prohibitive. The spectral efficiency of CDMA versus an efficient DCA system needs to be resolved. CDMA would get my vote with its innate robustness to interference.

Network Evolution

At the present time mobile communication networks are minuscule compared to PSTN/ISDN networks that handle vast volumes of traffic, with their trunk transmission rates many orders greater than mobile rates. PSTN/ISDN operators have their own evolutionary agenda. It involves establishing an intelligent network (IN) in which functions, such as call diversion, call holding, multimedia facilities, etc., that are often limited to PBXs, will be stored in a central location accessible from the PSTN/ISDN. A flexible hardware architecture enables the stored functions to be realised via separate software modules. New features and new services only require new software modules to be introduced.

The IN conceptual model has four planes of abstraction. The service plane describes services and service features from a users perspective. The global plane has serviceindependent building blocks (SIBs), which are units of service functionality. SIBs when combined with service logic in the global plane are able to realize services and service features on the service plane. Below the global plane is the distributed function plane. This plane has units of network functionality called functional entities (FEs) and the information flow between FEs is called a relationship. A sequence of FE actions (FEA) and the resulting relationships will realise a SIB on the global plane. The bottom plane is the physical plane. The potential physical systems, called physical entities (PEs) and their interfaces describe different physical architectures that can be realised. FEs on the distributed plane are physically realised on the physical plane, while relationships on the distributed plane are mapped on the physical plane as physical interfaces [9].

IN is evolving from the existing PSTN/ISDN. Each set of IN capabilities is called a capability set (CS) and each IN CS is to be evolutionary toward the goal of service creation, management, interaction and processing; and network management and interworking. Only IN CS-l currently exists.

The roots of CDMA are in miliary communications as it was conceived as for covert communications with a relatively strong immunity to enemy jamming.

The services will include freephone, UPT, virtual private network (VPN), and IN CS-l will support flexible routing, user interaction and charging. IN CS-l is concerned with actions at the initiation and termination of calls, not actions during calls. There are 14 SIBs.

Now let us turn our attention to IN for mobile networks. All fixed network IN features are required by mobiles, plus IN functions relating to subscriber service mobility and call management. Current mobile networks have these features and could develop their own INs. With many different service providers and mobile network operators, plus the numerous national PSTN/ISDN networks, we could have a myriad of INs needing to be themselves networked. This scenario is at variance with the PSTN/ISDN IN, which has a single centralized location for all software and data bases. Mobile communications in microcellular environments will require large information flows of location updating, which implies distributed data bases. Along with distributed data bases is distributed control due to the numerous handovers during a call.

Some mobile networks will grow and offer all the services of the current PSTN/ISDN, while some PSTN/ISDN will develop wireless local loop access. Each may have its own IN with gateways between INs. The evolution of IN in the fixed network has a momentum of its own. Nevertheless, given the size of the problems the IN deployment may be slow, and UMTS is likely to develop its own independent IN if it is to be deployed according to its time scales.

IS-95 does have a greater capacity than GSM, but unlike GSM it is only designed to the base station controller (BSC) level in GSM architecture. However, a full network design of IS-95 is imminent as operators are in the process deploying this system.

Evolutionary Routes

Route 1

GSM, Phase 2+ will continue to develop and will be doing so by the turn of the century when deployment of UMTS is scheduled to start. By then GSM may be widespread with an effective IN in place. Its radio interface will have been honed, and microcells and many advance features and services required by UMTS will exist in GSM. As a consequence, GSM may have prevented DECT and CT2 from developing, as GSM will operate in CT environments and, equipped with FEC codecs and equalizers, it will not have difficulties with dispersive channels. GSM will be a combined cellular and CT network. An alternative is that GSM operators will use DECT equipment coverage in both CT and cellular environments. Further, GSM may develop to accommodate closed user groups and seriously compete with second generation digital private mobile ratio (PMR).

If GSM develops in this way with mobiles able to log on to either GSM 900 or its sister DCS 1800, then how much more will GSM have to develop to satisfy the goals of UMTS. Firstly, it must become a global standard. This requires all countries to adopt it and in particular for the USA to do so. While it is unlikely that GSM 900 will be deployed in the United States, DCS 1800 may be introduced as a PCS network. Armed with a dual GSM 900/DCS 1800 portable, a user would then be able to communicate from anywhere in the world. While GSM 900 Phase 2+ will be able to support many UMTS services, it cannot provide a significant number of them, particularly those requiring high bit rates, such as 2 mb/s.

We conclude by considering that GSM will be deployed over most of the world, will have many UMTS features, but that cannot evolve into the UMTS standard because of its relatively low TDMA rate.

Route 2

UMTS is driven in Europe by ETSI committee SMG5. Technical information is provided by the RACE II program dealing with mobile communications. Other inputs come from academic and industrial organizations. Some members of SMG5 sit on the ITU committee designing FPLMTS, along with other international representatives. The result is that the SMG5 and ITU committees have essentially common goals. That is why the term UMTS has also been used to mean, in the final outcome, FPLMTS.

IS-95 does have a greater capacity than GSM, but unlike GSM it is only designed to the base station controller (BSC) level in GSM architecture. However, a full network design of IS-95 is imminent as operators are in the process deploying this system. If IS-95 significantly evolves (Qualcomm has an evolved CDMA at 1.7 GHz with higher bit rate services compared to IS-95), and the GSM fixed network meets UMTS criteria, then an up-graded IS-95 radio interface operating with the GSM, Phase 2+ fixed network might be able to provide more UMTS services than a GSM Phase 2+ system. However, this arrangement would not satisfy the goals of UMTS. It is important to note that evolved GSM network with an evolved IS-95 radio interface would provide strong competition to a fledgling UMTS network, and may slow the introduction of an effective UMTS service.

Route 3

This route is different because it does not adhere to the simple notion that one type of radio interface will suffice. The objectives for UMTS are relatively modest, except in one aspect, i.e., the global dimension. If we consider that UMTS should be an evolving network, then we need to design into UMTS the flexibility to continually introduce more services and high data rate links. We need to think in terms of a plethora of cell types to cover our global environment: picocells (few meters), nanocells (up to 10 m), nodalcells (10 to 200 m), microcells (10 to 400 m for pedestrians, 300 m to 2 km for vehicles), minicells (500 m to 3 km), macrocells (up to 5 km), large cells (5 to > 35 km), megacells (20 to 100 km) and satellite cells (> 500 km). Currently cellular radio employs minicells and above, while CT uses microcells and below.

UMTS will have the complete range of cells. Cochannel interference in macrocells and in street microcells depends on the size of buildings, whereas in CTs it is dependent on office construction, furniture and people. It is interference that effects cluster size and forces TDMA and FDMA to work with cluster sizes that exceed unity. CDMA can operate with single cell clusters. However, in city streets the buildings may significantly shield the cochannel propagation and TDMA with DCA may be a viable option. For nodalcells or megacells, we advocate FDMA due to the high data rates. Suffice to say that the optimum multiple access method is dependent on the type of cell and service, and that a rigid radio interface would be suboptimum in some situations. This leads to the notion of a radio interface where the network selects the type of multiple access to enhance performance. From this concept we propose that other radio link elements, such as source codec, FEC codec, and modulation be modified under system control. The UMTS terminal is now seen to have an adaptive structure. It will adapt to different channel conditions, teletraffic loading, and required service. We call this terminal an intelligent multimode terminal (IMT) [10].

The IMT is able to operate in a multicellular environment, although some IMTs may be designed to operate in a limited range of cell types, e.g., megacells and satellite cells. Base stations will emit radio beacons and the IMT may receive a number of these beacons, each uniquely coded. The IMT selects the beacon associated with the smallest cell as the smaller the cell the wider the range of services, particularly high bit rate services, it can support. Each type of cell, e.g., a microcell, has a specific default set of radio-link sub-systems for logging on to the base station. Authentication and registration ensues.

Each sub-system in the IMT is programmable under software control from its management entity (ME). When the user dials up a service the ME using the default sub-systems arranges for the IMT to establish a call for the required service. Once the service has been granted, and the call connected, the BS informs the ME in the IMT of the type of multiple access, modulation, FEC coding that is required. The BS makes this decision in conjunction with network control, which knows what the other adjacent cells are doing in terms of local area teletraffic levels and estimated cochannel levels. As the call proceeds, the IMT receiver determines the quality of the downlink radio channel, while the BS measures the quality of the uplink channel. The channel quality information, together with information related to local teletraffic loading and cochannel levels at the BS, are used to fine tune the radio link subsystems.

Evolution from second generation to this global high capacity multicellular network with IN, UPT, fluid radio interfaces, and a wide range of services can be done in stages. The generic forms of second generation mobile systems such as cellular, CT, and PMR are identified, and a set of stage 1 UMTS systems is conceived. For CTs there is m-UMTS; for cellular, M-UMTS; and for PMR, P-UMTS. Each ( )-UMTS can emulate the second generation network with which it is associated, but more, it can provide enhanced services that are expected of a UMTS working in that specific environment. It is observed that ( )-UMTS terminal has a flexible radio interface, but not the IMT mentioned above. This method provides evolution to Stage I with backward compatibility to its second generation system.

In Stage II m-UMTS and M-UMTS merge to give m/M-UMTS. This evolution merges CT and cellular radio LANs in offices, while supporting a wide range of services. If cellular and CT networks have already merged by the time of Stage I, then m/M would be introduced without recourse to the independent stages m and M. Once the satellite and megacellular systems are in place, S-UMTS is formed. Now there are three intermediate stage networks: m/M- UMTS, P-UMTS and S-UMTS, all with the same architecture and compatible protocols. These networks are then forged together to yield UMTS.

In Stage III the adaptation of the UMTS network yields the full IMT. The network becomes an adaptive one with flexible architecture, distributive data bases, personalized mobility profiles, rapid introduction of new services, and the ability to interwork with other networks.

If we consider that UMTS should be an evolving network, then we need to design into UMTS the flexibility to continually introduce more services and high data rate links.

Acknowledgements

This article is itself an evolution. Starting from a report for the European Commission, to whom much thanks are given, it continued from the keynote lectures at Wireless '93 in Calgary and the International Symposium of Personal Communications, in Nanjing, China, October 1993, to this present discourse.

References

[1] R. Steele, Mobile Radio Communications, (London: Pentech Press, 1992).
[2] M. Mouly and M-B Pautet, The GSM System for Mobile Communications, Published by authors, 1992.
[3] W. Tuttlebee, Cordless Communications in Europe, (London: Springer-Verlag, 1990).
[4] Proc. Fifth Nordic Seminar on Digital mobile radio communications, DMRV, Helsinki, Dec., 1992.
[5] PCS: The Second Generation, special issue of *IEEE Communications Magazine*, vol. 30, no. 12, Dec. 1992.
[6] W-H. Lam and R. Steele, 'The Error Performance of CD900-like Cellular Mobile Radio Systems,' *IEEE Trans. on Veh. Tech.*, vol. 40, no. 4, Nov. 1991, pp. 671-685.
[7] D. G. Appleby, *et al.*, 'The Proposed Multiple Access Methods for the Pan-European Mobile Radio System,' IEE Colloquium, London, Digest No. 1986/95, Oct. 1986, pp. 1/1-1/26.
[8] D. J. Goodman and S.X. Wei, 'Efficiency of Packet Reservation Multiple Access,' *IEEE Trans. on Veh. Tech.*, vol. 40, no. 1, Feb. 1991, pp. 170-176.
[9] J. M. Duran and J. Visser, "International Standards for Intelligent Networks," *IEEE Commun. Mag.*, vol. 1, no. 2, Feb. 1992, pp 27-32.
[10] R. Steele and J. E. B. Williams, "Third generation PCN and the intelligent multimode mobile portable," *IEE Elec. & Commun. Eng. J.*, vol. 5, no. 3, June 1993, pp. 147-156.

Biography

RAYMOND STEELE [SM '80] received a B.Sc. in electrical engineering from Durham University, England, in 1959 and Ph.D. and D.Sc. degrees from Loughborough University of Technology, England, in 1975 and 1983, respectively. Before attaining his B.Sc., he was an indentured aprentice radio engineer. After R & D posts with E.K. Cole, Cossor Radar and Electronics, and Marconi, he joined the lecturing staff at the Royal Naval College. He moved to Loughborough University in 1968 where he lectured and directed a research group in digital encoding of speech and picture signals. During the summers of 1975, 1977, and 1978 he was a consultant to the Acoustics Research Department at Bell Laboratories in the United States, and in 1979 he joined the company's Communications Methods Research Department, Crawford Hill Laboratory. He returned to England in 1983 to become professor of communications in the Department of Electronics and Computer Science at the University of Southampton, a post he retains. From 1983 to 1986, he was a non-executive director of Plessey Research alnd Technology and from 1983 to 1989, a consultant to British Telecom Research Laboratories. In 1986, he formed Multiple Access Communications Ltd., a company concerned with digital mobile radio systems. He is a senior technical editor of *IEEE Communications Magazine*, a Fellow of the Royal Academy of Engineering, and a Fellow of the IEE in the United Kingdom.