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 be 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 competitors 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 I 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 telecommunication (CT) the digital CT2 is FDMA using time division duplex (TDD), while the digital European cordless telecommunication (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 SMGS, 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 kbps to 2 Mbps. 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 I 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 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 multichannel, multimode interfaces, and widespread 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. These 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 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

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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 DAMPS). 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.

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/km², 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). Use of 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 ALHLOA 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 cell 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 rate, so that in the future when users' data rates become very high the burst rate may become unacceptably exces-
sive. Further, and perhaps ultimately the most significant limitation, is that the frame structure means that FDMA 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 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 rate in UMTS, FDMA can be implemented without 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 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 worldwide explosion of interest 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 service-independent 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-1 currently exists.
The services will include freephone, UPT, virtual private network (VPN), and IN CS-1 will support flexible routing, user interaction and charging. IN CS-1 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.

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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.

**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 advanced codes 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 radio (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 2Mbit/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 survive. 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 (300 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
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 databases, personalized mobility profiles, rapid introduction of new services, and the ability to interwork with other networks.

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

Biography
Reynold Steele was born in 1956. He received a B.Sc. in electrical engineering from Durham University, England, in 1979 and Ph.D. and D.Sc. degrees from Loughborough University of Technology, England, in 1985 and 1983, respectively. Before attaining his B.Sc., he was an indentee of addiceta radio engineer. After R & D posts with E. C. C. C. C. and Radex, and M. D. C. M. he joined the lecture staff of 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 consultant to the Acoustics Research Department at Bell Laboratories in the United States, and in 1979 he joined the company's Communications Methods Research Laboratory. 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 which he retains. From 1983 to 1986, he was a non-executive director of M. S. S. Research and Technology and from 1983 to 1985, 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 Telecommunications Manager, a fellow of the Royal Academy of Engineering, and a fellow of the IEA in the UK.