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Network Planning for Third-Generation Mobile Radio Systems

The success of UMTS relies not only on the development of a flexible air interface, efficient coding techniques, and handset technology; it is equally important to design a system that can support the underlying technology and to interface with other networks.

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*I*n recent years there has been a huge increase in the demand for wireless communications, and the number of wireless subscribers will continue to grow. Market research shows that up to 50 percent of communication terminals will become mobile by the year 2005 [1]. Currently, wireless communication consists of two main categories, cellular and cordless systems, which differ in terminal mobility management. Cellular systems such as the Global System for Mobile Communications (GSM) and Advanced Mobile Phone System (AMPS) provide radio coverage by high-power base stations that support both portable and vehicular-based units. Terminal mobility is supported by call handover between base stations within the network. The pan-European system GSM also supports inter-country roaming within the European community. On the other hand, cordless systems such as the second-generation cordless telephones (CT2) only offer limited coverage by personal base stations or low-power public base stations with no handover capability. Systems such as Telepoint in the United Kingdom only handle outgoing calls, while the Pointel system in France will support two-way calling capability. Future-generation mobile systems will see a convergence of the cellular and cordless systems into a single universal personal communications system where a single terminal can be used in a variety of environments. Moreover, simple speech terminals will evolve into sophisticated personal communicators that will combine telephone, pager, fax, answering machine, digital diary, and even full-motion video communications within a single unit.

In Europe, extensive research activities are underway to evaluate the market and technical requirements, as well as the physical implementation aspects, of the Universal Mobile Telecommunication System (UMTS) [1]. The aim of UMTS is to provide a multitude of communications services, ranging from speech communication and video telephony to high-data-rate file transfer up to 2 Mb/s with quality comparable to contemporary fixed networks. Extensive collaborative research activities sponsored by the Commission of the European Community (CEC) under the auspices of Research into Advanced Communications in Europe (RACE) have devoted many resources to the study of various aspects of UMTS. The Code Division Testbed (CODIT) and Advanced TDMA Mobile Access (ATDMA) projects investigate the relative merits of spread spectrum Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA), respectively. The RACE project's technology in smart antennas for universal advanced mobile intrastructure (TSUNAMI) is considering the benefits that adaptive antenna technololgy can bring to both air interface techniques, as well as developing appropriate conponent technologies. The mobile network (MONET) project studies the network management and security requirements of UMTS. The Mobile Audio-Visual Terminal (MAVT) project evaluates different source and channel coding techniques for low-bit-rate image and speech transmission for future mobile terminals. Apart from UMTS, the Mobile Broadband System (MBS) project investigates the requirement of high-bit-rate systems using millimeter-wave technology.

The success of UMTS relies not only on the development of a flexible air interface, efficient coding techniques, and handset technology; it is equally important to design a system that can support the underlying technology and to interface with other networks. Therefore, the proper design of the network, in order to provide sufficient capacity of high-quality coverage and efficient terminal mobility management, is of utmost importance. The Advanced Planning Methods and Tools for Third Generation Mobile Radio Network (PLATON) project studies the network planning aspects for UMTS. In this article, we discuss the requirements of the network planning tool for future mobile radio systems and how these requirements are met by the proposed PLATON planning methodology.

Service Requirements

*F*irst-generation analog and second-generation digital mobile radio systems are designed to support voice communication with limited data

Teleservice	Throughput (kb/s)	Target bit error rate
Telephony	8 - 32	10E-3
Teleconference	32	10E-3
Voice mail	32	10E-3
Program sound	128	10E-6
Video telephony	64	10E-7*
Video conference	384 - 768	10E-7*
Remote terminal	1.2 - 9.6	10E-6
User profile editing	1.2 - 9.6	10E-6
Telefax (group 4)	64	10E-6
Voiceband data	64	10E-6
Database access	2.4 - 768	10E-6
Message broadcast	2.4	10E-6
Unrestricted digital information	64 - 1920	10E-6
Navigation	2.4 - 64	10E-6
Location	2.4 - 64	10E-6

*The figure given is for high-quality video services.

■ **Table 1.** *A subset of proposed teleservices for third-generation Universal Mobile Telecommunications Service (UMTS)* [2].

communication capabilities. Third-generation systems, such as UMTS, aim to offer a wide variety of communication services as illustrated in Table 1. Most of the listed services are wireless extensions of ISDN, while services such as navigation and location information are mobile-specific. Wireless network users will expect quality of service (QOS) similar to that provided by contemporary fixed networks such as ISDN. However, it is unrealistic for the wireless network to emulate the performance of ISDN in the physical link layer due to the unpredictable variation of the radio propagation environment and the inherent terminal mobility in a wireless network. Service providers will use higher-layer protocols such as powerful forward error correction and digital speech interpolation techniques, so that the perceived QOS matches that of the fixed network. As shown in Table 1, objective quality measures such as bit error rate (BER) and data throughput vary considerably with the type of teleservice. For example, a BER of 10^{-3} is adequate for speech telephony but is insufficient for video transmission due to the high compression video coding algorithm, which is more susceptible to transmission errors. An intelligent network planning tool for UMTS should hide the low-level design from the system planners and allow them to specify services supported and the associated quality requirements, rather than low-level parameters such as the signal-to-interference ratio requirement. The planning tool will then map the physical characteristics of the propagation environment to subjective quality assessments through a set of sophisticated algorithms.

Capacity Requirements

As a result of the multitude of teleservices offered in different operating scenarios, the teletraffic density generated will depend on the environment, the mix of terminal types, and the terminal density. Teletraffic density will vary substantially in the case of high-bit-rate services provided in business areas, whereas basic services such as speech and video telephony will be offered in all UMTS environments. Currently, system capacity is described as Erlang-per-square-kilometer, which indicates the number of simultaneous telephone calls that can be supported. Since different services require different transmission rates that can vary up to two orders of magnitude (as seen in Table 1), the traffic capacity required can no longer be specified by a single unit based on speech telephony. The equivalent telephone Erlangs (ETE) per square kilometer has been proposed to characterize the traffic density where the capacity is specified as the equivalent number of telephone calls [1]. Therefore, the traffic capacity represented by this unit will depend on the transmission rate of the basic telephony service. Assuming the basic telephone call transmits at 8 kb/s, a video telephone call requires 8 ETE while a 2-Mb/s service requires 256 ETE. However, the basic rate of telephone calls and other services may change during the lifetime of UMTS when more advanced data encoding techniques are developed, thus it is best to minimize the dependency of the traffic capacity representation on the transmission rate of a telephone call. An alternative is to use the transmission rate as the unit of the traffic capacity while maintaining the teleservice information. Therefore, the traffic can be represented as megabits-per second-per-square-kilometer ($Mb/s/km^2$), which is calculated from the transmission rate of different teleservices and the density of different terminal types in an environment. For indoor environments, the unit can be modified to Mb/s-per-floor. Regardless of the unit used to specify the traffic capacity, it is essential to retain information on the terminal type and density to aid planning.

Mobility and Call Handover

Future-generation wireless systems will support true mobility in which a single terminal can be used regardless of the environment, provided that the infrastructure necessary to support the particular service exists. Terminal mobility is a distinct feature of wireless communications that offers advantages over a fixed network. Careful system planning is essential in order to ensure the continuation of the call and to maintain quality when the mobile terminal moves. The degree of mobility depends on the operational environment as shown in Fig. 1. For example, domestic dwellings will be served by a personal base station to which access is restricted to authorized users. This can be considered as an enhancement of the current cordless telephone, but with a common radio interface that is compatible with UMTS. The personal base station connects either directly to the public land telephone network or to the public UMTS via an external radio port that relays the data to a public base station. Radio coverage is confined within a certain radius (50 m, for example) around the base

Wireless network users will expect quality of service similar to that provided by contemporary fixed networks such as ISDN.
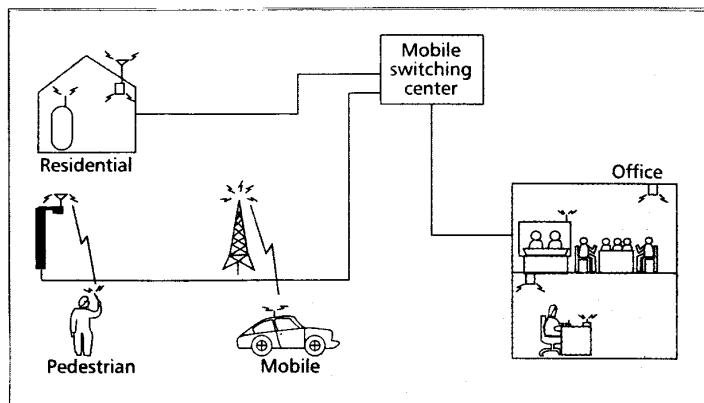
■ Figure 1. *Universal mobile telecommunications system's operational scenario.*

station, and handover capability will not be supported between personal base stations.

Next in the system hierarchy is the customer premises network (CPN) that consists of a network of low-power base stations that provide coverage in a business environment. This can be considered as a wireless extension to the private branch exchange (PBX). Due to the large amount of traffic generated in a business environment, the wireless CPN connects to the mobile switching center (MSC) via an optical fiber link or a dedicated radio link so as to minimize the signaling burden on the public UMTS air interface. The provision of a wireless CPN allows the telephone to be associated with a person rather than attached to a desk. As a result, terminal mobility should be supported by allowing handover between different base stations within the same CPN.

The public UMTS network will support full mobility by efficient call handover between public base stations. Moreover, handover between personal base stations and the business CPN to a public network will be provided by intelligent mobility management by transferring the call that originates from an indoor network to an outdoor public network and vice versa without the user's notice.

A UMTS network must provide transparent handover between base stations by minimizing the probability of call disconnection due to handover failure. Current analog and second-generation digital systems, such as GSM, require handover failure probability of less than one percent. To improve the handover success rate, and to maintain high service quality when the mobile terminal enters the transition region between the coverage area of two cell sites, macroscopic diversity (which maintains a communication link between the mobile terminal and multiple base stations) has been proposed. This is known as soft handover in a direct sequence code division multiple access (DS-CDMA) system [3]. In TDMA, such as the Digital European Cordless Telephone (DECT), base station diversity is implemented as seamless handover where the network continuously switches between base stations that give better communication quality when the mobile enters the transition region. The provision of soft handover not only affects terminal mobility and service quality, it has a direct impact on the system capacity. However, there is a fundamental difference in the impact of soft handover on the overall system capacity for a DS-CDMA and a TDMA system that must be considered when designing the corresponding network.

For a spectrum spreading technique such as the DS-CDMA, every additional user attached to the system will look like additional noise as far as other users are concerned. Therefore, there is a graceful degradation in the system's performance when more users are added to the system. Intuitively, the uplink (mobile-to-base) capacity can be improved by reducing the transmission power of mobile terminals while the reduction of base station transmission power enhances the downlink (base-to-mobile) capacity. Soft handover achieves this capacity enhancement by exploiting the diversity gain obtained from multiple communication links that in turn reduces the transmission power required to maintain an acceptable service quality. Preliminary study showed that the system capacity for the DS-CDMA uplink can be improved by 16 percent when 50 percent of the mobile users operated in soft handover mode that resulted in a reduction of the average transmit power by 1 dB due to diversity gain [4]. Furthermore, the make-before-break characteristics of soft handover greatly enhance the user's perceived quality by reducing the handover failure probability.

Future TDMA systems will use some form of dynamic channel allocation as opposed to a fixed frequency plan to improve spectrum utilization. To implement soft handover or seamless handover capability, multiple time slots (possibly on different frequencies) must be available. Therefore, the overall system capacity will be reduced when soft handover is implemented for a TDMA system.

Regardless of the multiple access techniques used by UMTS, the implementation of soft handover increases the signaling load over the fixed network and the radio interface since data are being sent and processed by multiple base stations. Network planning that supports soft handover must optimize the tradeoff between service quality and network signaling load.

Planning Methodology

*W*e have discussed the requirements and factors affecting the design of a planning tool and identified that the planning of a UMTS network will concentrate on the service quality, system capacity, and mobility issues. The question remains how to implement the UMTS concept to an operational system by efficient network planning. It is a well-accepted fact that system capacity can be improved by using smaller cells and the reuse of frequency channels in a geographically ordered fashion. The high quality and capacity required by a UMTS network can only be provided by utilizing different cell structures according to the operational environment [5]. Cell structures to support UMTS range from conventional macrocells to indoor picocells. Typical characteristics for UMTS cell structures are shown in Table 2, and an operational scenario of the mixed-cell architecture is shown in Fig. 2. In particular, microcell with low transmission power will be widely deployed in urban areas while other cell structures are used according to the environment to provide ubiquitous coverage. The need to provide an underlying network to support a microcellular-based system presents a

challenging task to the network planner [6]. We anticipate that the cost of base station equipment for microcells will be significantly reduced due to the elimination of costly high power amplifiers and the economies of scale in microcell base station equipment manufacturing. Nevertheless, the system's cost will still play a determining role in the design of the network infrastructure since more microcellular base stations are needed to provide adequate radio coverage.

Mixed-cell architectures tailor the various cell sizes and shapes to the environment, expected terminal characteristics, density, and mobility. Microcells with a radius less than 1,000 meters will be used extensively to provide coverage in urban districts. Microcell base stations will be mounted on lamp posts or on buildings where electric supply is readily available. Due to the low elevation of microcell antennas compared with the surrounding buildings, the so-called waveguide or canyon street effect will provide better radio coverage when a line-of-sight component exists between the base station and the mobile terminal. Furthermore, surrounding buildings act as barriers that limit signal spillage and interference to other streets, thus improving frequency reuse efficiency. For high user-density areas such as airport terminals and shopping malls, picocells with coverage of tens of meters will be used. To facilitate efficient handover when the vehicle-based user crosses microcells at high speed, these calls will be handled by umbrella cells (or overlay macrocells) whose coverage areas contain several to tens of microcells.

The aforementioned discussion suggests that the planning of third-generation UMTS is more complicated than the design of current speech-oriented, macrocell-based mobile radio systems, and thus requires a more advanced and intelligent network planning tool. Existing network planning tools are basically a "prediction tool," where the system planner specifies the cell site (base station) locations and the planning tool predicts the
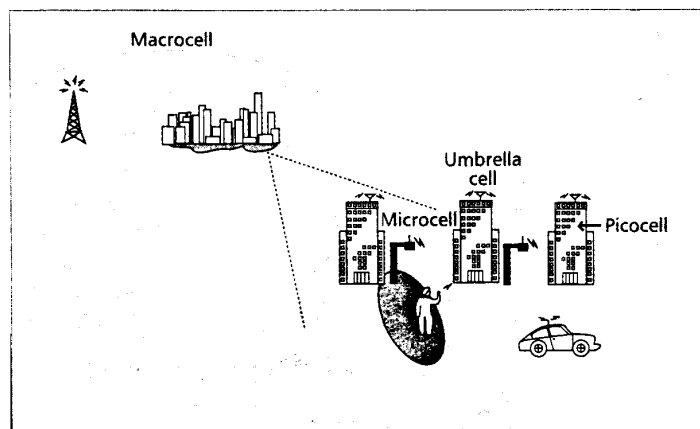

■ Figure 2. *Mixed-cell architecture for UMTS.*

signal strength, coverage area, and interference level according to some established propagation models such as the Hata-Okumura model for macrocells and Walfisch-Ikegami model for microcells [7]. Based on the information obtained, the planning tool may also produce other objective measures, such as bit error rate, outage probability, call blocking probability, etc. This approach works well for systems where the primary service is speech transmission. As more sophisticated services (each with different quality and traffic requirements) are proposed for next-generation wireless communications systems, the simple signal level and bit error rate prediction may not be adequate.

For the network planning tool to keep up with the advancement of UMTS, the design of an efficient planning tool should be flexible and intelligent in order to aid the human network planner by automating the lower levels of the design process. These include estimating the traffic density requirements from the terrain and building databases,

Cell type	Range (m)	Transmission power (W)	Antenna height (m)	Comments
Macrocell	> 1,000	1 - 10	> 30	Macrocells are used in conventional cellular radio systems. The coverage is maximized to reduce the system's infrastructure cost. Macrocells will be used to provide coverage for areas with low terminal density in UMTS.
Microcell	< 1,000	0.1 - 1	< 10	Microcells will be widely deployed in UMTS to provide ubiquitous coverage, mainly in urban areas. Compact base station units will be mounted on lamp posts and surrounding buildings.
Picocell	5 - 30	0.01 - 0.1	Ceiling	Picocells are used to provide services for areas with high terminal density and are usually deployed for indoor areas.
Umbrella cell	> 1,000	1 - 10	> 30	Umbrella cells are used to maintain continuous coverage and to assist handover for mobile terminals that traverse through microcells in high-speed.
Highway cell	100-1,000	< 1	< 10	Highway cells are used to provide coverage for sections of road using compact base station units with directional antennas that tailor the radiation pattern for the environment.

■ Table 2. *Cell structures to support UMTS.*
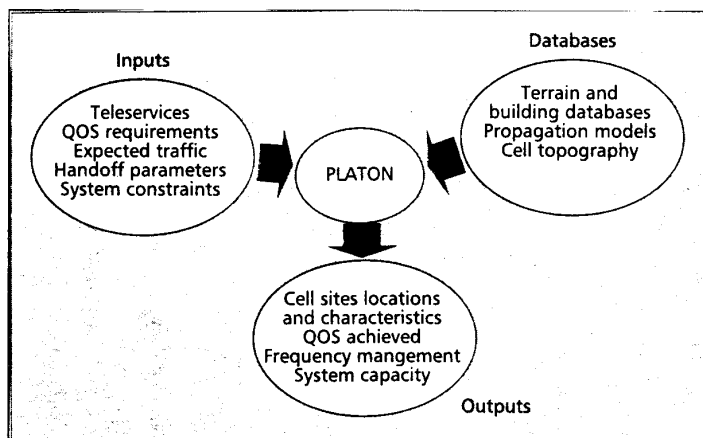
■ Figure 3. *Proposed PLATON planning tool.*

assigning appropriate cell structures to fit the environment, and mapping of subjective quality such as mean opinion score of speech transmission to physical parameters (e.g., bit error rate, carrier-to-interference requirements, etc.). Consequently, the network planner will specify higher-level design parameters, such as the user's perceived service quality, and fine tune the estimates given by the planning tool. Also, the proposed PLATON planning tool attempts to take a radical approach to planning by employing "synthesis" techniques. The deployment of the synthesis technique enables the system planner to perform forward planning that produces a radio network layout based on the high-level parameters specified by the system planner and other stored information such as digital maps and propagation models. Associated with the network layout are parameters such as cell site characteristics, i.e., base station transmission power, frequency allocation, achieved system capacity, service quality, and estimate of the system installation cost. A simplified block diagram of the proposed PLATON planning tool is shown in Fig. 3.

The PLATON tool operates on a set of input parameters that describe the quality objectives of the desired system and some pre-defined rules. It is unlikely that the system can be designed without any constraints. Therefore, the support of network evolution is essential to the planning tool. One of the most important constraints is the physical location of the base station site. For example, UMTS may operate on base station sites occupied by existing systems in order to minimize the construction cost and to avoid the cost of acquiring real estate, especially in downtown business areas. To support the network evolution path, the planning tool will reconfigure the existing network by adding and moving base stations in order to optimize the performance objectives.

Although we anticipate that the planning tool will primarily be used for forward planning, it will also incorporate features to allow more conventional reverse planning where the performance of an existing network is evaluated given the location of cell sites. This feature is essential not only to provide performance evaluation of an existing system, it also provides a means to validate the forward planning proposed by the planning tool. By providing both forward and reverse planning capability within a single tool as depicted in Fig. 4, network planning can be optimized by going through the iterative cycle of modification of cell site characteristics and evaluation of system performance in order to achieve the required performance objective.

The forward and reverse planning operates by mapping the physical parameters to the high-level user's perceived quality by a hierarchical approach in direction shown in Fig. 5. At each layer of the hierarchy, the system performance is measured by different parameters. The lowest level evaluates the channel propagation characteristics such as path loss, channel delay spread, fading statistics through propagation models, and terrain database. The deployment of microcells with base station antennas mounted below the average rooftop causes the propagation condition to be more site-specific. These areas are also more likely to experience high traffic capacity and require high-quality services where careful planning is most critical. Therefore, site-specific propagation models that adapt to changes in the environment are required.

Due to the well-defined boundaries of microcell propagation, ray tracing has emerged as an accurate technique for propagation prediction. Recently developed ray tracing tools [8, 9] enable channel characteristics such as path loss, power delay profiles, fast fading, and root mean square delay spread to be determined by analyzing the signal arriving at the mobile terminal from the base station via wall reflections, corner diffraction, diffuse wall scattering, and over rooftop diffraction. System performance parameters such as bit error rate and outage probability are then evaluated based on the radio interface techniques employed and the ray tracing results, thus giving the performance of the data link layer. Progressively, the PLATON tool translates the objective parameters into a subjective performance indication of the communication link layer according to higher-level protocol specifications such as error control algorithm, multiple access techniques, etc. Therefore, the built-in mapping between intrinsic propagation parameters and higher-level quality parameters hides the system planner from the low-level system design.

Owing to the hierarchical mapping from phys-
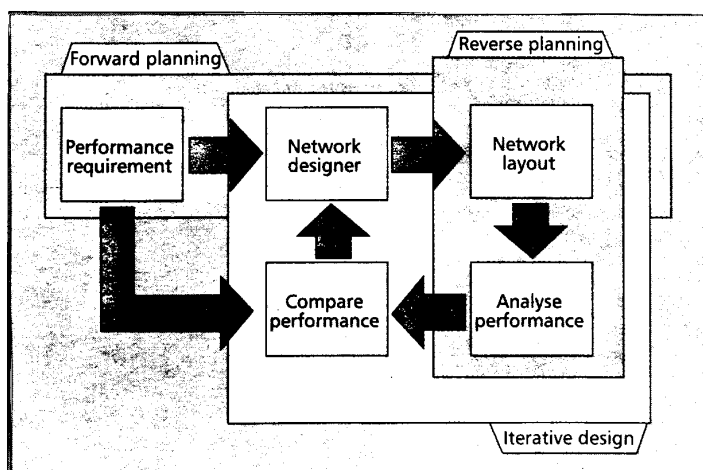
■ Figure 4. *The PLATON planning methodology.*
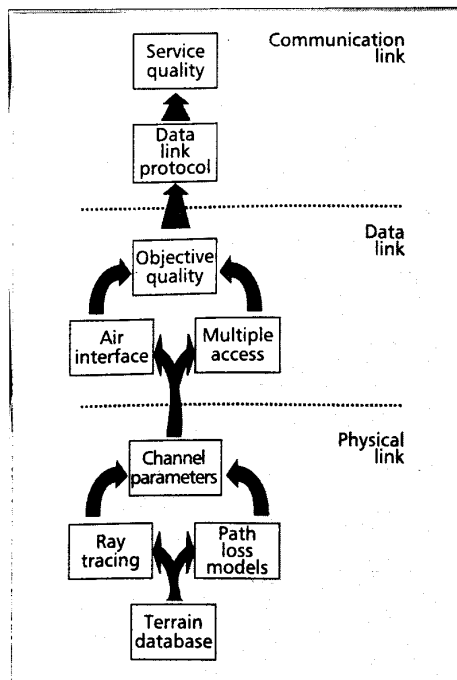
■ Figure 5. *Mapping of low-level physical link performance to high-level user's perceived service quality.*

ical quantities to the user's perceived quality, we must maintain the accuracy of our prediction from the lowest level. A digital map that provides detailed terrain data can be integrated into the planning tool to enhance the precision of propagation prediction. The accuracy of ray tracing can be improved by having the knowledge of the physical properties of building materials such as reflection coefficient and penetration loss [10]. Further up in the mapping path, performance of the data link and the communication link layers can be evaluated by extensive computer simulation, hardware testbed, and field trials. Therefore, we must have a thorough understanding of the performance of various entities of UMTS and provide sufficient accuracy in different layers of the planning process in order to devise an integrated planning tool for future mobile radio systems.

Discussion

The success of third-generation UMTS relies on intelligent network planning to achieve the superior service quality, high capacity, and efficient management of terminal mobility. Intelligent radio network planning tools assist system planners by automating low-level design, such as estimating capacity requirements, and matching channel propagation characteristics to the environment, while the operator specifies high-level design objectives such as user's perceived system performance and overall design strategies. The PLATON planning tool meets these requirements by providing both forward and reverse planning within a single tool where system design is opti-

mized by iteratively going through the design and analysis cycle.

Acknowledgments

References

[1] CEC/RACE Industrial Consortium, "IBC Common Functional Specifications: Mobile Network Subsystems," RACE D730, issue B, Dec. 1991.
[2] CEC/RACE deliverable R2007/ATT/B1/DS/P/06/b0, "Quality of Service Requirements," Nov. 1992.
[3] Qualcomm, Inc., "An Overview of the Application of Code Division Multiple Access (CDMA) to Digital Cellular Systems and Personal Cellular Networks," document number: EX60-10010, May 1992.
[4] J. C. S. Cheung, S. C. Swales, and M. A. Beach, "On the Impact of Soft Handoff on a Direct Sequence Code Division Multiple Access Capacity," Centre for Communications Research Internal Report, PLA-TON/UOB/037/WPD2/07/93, issue 1, July 1993.
[5] R. Steele, "Toward a High-Capacity Digital Cellular Mobile Radio System," IEE Proc., vol. 132, pt. F, no. 5, Aug. 1985, pp. 405-415.
[6] L. J. Greenstein, et al., "Microcell in Personal Communications Systems," IEEE Commun. Mag., vol. 30, no. 12, Dec. 1992, pp. 76-88.
[7] CEC/RACE Deliverable R2020/EBN/PS/DS/003/b1, "Draft Propagation Model," June 1992.
[8] W.T. Webb, "Sizing up the Microcell for Radio Communications," IEE Electronics and Commun. Eng. Jour., June 1993, pp. 133-140.
[9] A. R. Nix, H. R. Anderson, and J. P. McGeehan, "Estimating Wideband Bit Error Rates Using Pilot Tone Envelope Fading Statistics," 4th International Symposium on Personal and Mobile Radio Communications, Yokohama, Japan, Sept. 8-11, 1993.
[10] S. G. Chard, M. A. Beach, and P. Syverson, "Material Characterisation," Centre for Communications Internal Report, PLATON/ UOB/035/WPD2/07/93, issue 1, July 1993.

Biographies

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MARK A. BEACH graduated from the University of York in 1983 with a degree in electronic engineering. After an initial period with the GEC Hirst Research Laboratories, he joined the department of electrical and electronic engineering at the University of Bristol as a postgraduate student. He then received his Ph.D. in 1989 for his work on adaptive antennas for multiple spread spectrum signal sources. Post-doctoral research at Bristol included work regarding the application of adaptive antenna techniques in mobile cellular networks for which the research team received the IEEE Neal Shepherd award in 1990. Since August 1990, he has been engaged as a member of the lecturing staff at Bristol and heads the CDMA and wideband propagation research activities within the Centre for Communications Research, Bristol, United Kingdom. He currently holds the UK DTI/SERC LINK grant concerning the evaluation of CDMA techniques for UMTS, and is the project manager of both the EC RACEII PLATON (R2007) and ESPRITIII LAURA (7359) projects, as well as other closely related radio-based research activities.

JOSEPH P. McGEEHAN obtained the degrees of B.Eng. and Ph.D. in electrical and electronic engineering from the University of Liverpool in 1967 and 1971, respectively. In 1970, he was appointed senior scientist at the Allan Clark Research Centre, Plessey Company, Ltd., where he was responsible for R & Dof two- and three-terminal Gunn Effect Devices and their application to high-speed logic, teclecommunications and radar systems. In 1972 he became a member of the academic staff of the school of electrical and engineering at the University of Bath and initiated research in the area of SSB (subsequently linear modulation) for mobile radio. In 1984 he was appointed chair of communications engineering at the University of Bristol. He is a recipient of the IEE Proceedings Mountbatten Premium, the IEEE Transactions Neal Shepard award, and other awards in recognition of his research contribution to radiocommunications. He is a Fellow of the IEE, a Fellow of the Royal Society of Arts and Commerce, and serves on numerous national and international committees concerned with mobile communications. In July 1994, he was elected a Fellow of the Royal Academy of Engineering.

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