Technologies on the Horizon

This month marks the start of "Technologies on the Horizon," a new feature for *IEEE Communications Magazine.* The purpose of the column is to provide an introduction to and informative discussion on selected new technologies in communications applications, their potentials and limits, and current issues that are critical to the successful application of new communications technologies.

As appropriate, "Technologies on the Horizon" will present contributions from one or two exponents of a leading-edge technology. Where possible, contributors will be selected whose views will help inform readers of *Communications Magazine* who are not specialists in the chosen area about the range of opinions and approaches in a given technical field.

Anyone familiar with atmospheric optics may recall several phenomena that distort images seen by an observer of objects that are near the horizon. The desert mirage and flattened sun are just two of the better-known atmospheric distortions resulting from temperature-dependent refraction of light in the atmosphere. In general, such effects are greatest for objects close to the horizon; they are also increased by unusual temperature distributions between the object and observer.

Recognizing that technologies close to the horizon are occasionally subject to a similar wide range of perceptions (or misperceptions) as they are viewed through the rarefied atmosphere of technical journals, monographs, and trade publications aimed at specialists, the column editor will seek to create a lively forum for technical exchanges that will help readers understand the backgrounds and promising applications of, and potential impediments to, the successful use of new technologies.

This month's column features a contribution by Raymond Steele of the Department of Electronics and Computer Science at the University of Southampton, England, on present plans for Personal Communication Networks (PCNs) in Great Britain. Professor Steele's comments here are adapted from his recent keynote address at the Second National Seminar and Workshop on Wireless Personal Communications (Wireless '90) in Calgary.

PCNs are networks that allow mass communications between users who are, in general, mobile. They represent a significant extension of the capabilities of today's cellular mobile telephone networks with much smaller cells and far lower station power requirements. The article below examines the relationship between PCNs and current cellular networks, and explores technical approaches that will promote widespread PCN availability.

The column editor welcomes comments, suggestions, alternative views, and other contributions to ongoing public discussion of technologies that are on or just over the horizon. Correspondence should be sent to:

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Deploying Personal Communication Networks

Raymond Steele

There is worldwide research and development activity in digital mobile communications today. In the U.S., the 30 kHz bands in cellular mobile telephone systems will be able to support three Time-Division Multiple Access (TDMA) channels at the burst rate of 48 kb/s. Europe is dynamic and ambitious in cellular radio. There is the pan-European TDMA Group Speciale Mobile (GSM) system at 270 kb/s; the Digital European Cordless Telephone (DECT), which operates in a ping-pong mode at 1,152 kb/s; the European Radio MEssaging System (ERMES) at 6 kb/s; the Cordless Telephone system (CT2) and its phone-point, or telepoint, service, which transmits at 72 kb/s; and so forth [1]. All of these systems are Personal Communication Networks (PCNs), although people often like to consider that a PCN is something more, namely, a network that provides mass communications where most mobile stations are handheld.

We are concerned here with PCNs. As Britain is currently attempting to deploy them, we will commence by describing the background there in PCNs. We will then move on to consider alternative types of PCNs that will satisfy criteria to be described.

The PCN Situation in Britain

In 1989 the government announced that new two-way PCNs would be established. Mercury Communications Ltd. would be given a license in order for it to compete with its powerful rival British Telecom, which has a major stake in the mobile phone company, Cellnet. The two cellular operators, Cellnet and Racal Vodafone, were barred from applying for a PCN license. The ministry (informed by the Department of Trade and Industry, or DTI) said that the PCN license holders should operate to a common technical standard to encourage competition. It also decided that the standard should be either the pan-European GSM or DECT. The PCN cells were to be "small," and the operators would be required to link their Base Stations (BSs) using radio (38 GHz). Links to the Public Switched Telephone Network/Integrated Services Digital Network (PSTN/ISDN) would be provided by British Telecom or Mercury Communications. A number of consortia applied for PCN licenses, and three were granted.

Not all applicants initially advocated GSM or DECT. Some used notions to be found in the deliberations of International Consultative Committee for Radio (CCIR) Inter-Working Party (IWP) 8/13, while others were conscious that the PCN should utilize some of the special radio properties to be found in the small cells (i.e., microcells). However, once the choice of GSM was a valid option, it was inevitable that it would be adopted, particularly as the specification for DECT was far from completion. Firstly, the mobile radio community had spent years writing the GSM specification, and it was the system they had come to understand. Furthermore, many of them were busy implementing the GSM system for service throughout Europe in the early 1990s. For the equipment manufacturers, the

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advent of the PCN was an opportunity for them to realize profits on equipment that had been designed and developed for the pan-European GSM. The new license holders saw it as a means of competing with the two existing cellular operators, as both would have the GSM system, but the incumbents would not have nearly as much bandwidth as the PCN operators and therefore would not be able to support as many users. However, Cellnet and Vodafone do have the advantage of an existing client base.

So the PCN in Britain will be a modified version of the pan-European GSM system. Modifications to the GSM specification will be carried out under the auspices of the European Telecommunications Standards Institute (ETSI) and are expected to be finalized by the end of 1990. The ETSI standard for the PCN will be called Digital Cellular System (DCS) 1800 [2]. The 1800 is associated with the frequency of operation in MHz. The actual band will be from 1,710 to 1,880 MHz, providing 75 MHz duplex bands with a 20 MHz spacing. The DCS 1800 will use GSM network interfaces and architecture, and the main modifications are expected to facilitate low-power handheld portables operating over relatively small cells. The adoption of the GSM standard, albeit in a modified form, will mean that the DCS 1800 will use second-generation technologies. It will therefore sit between second- and third-generation systems. The cell sizes will be smaller than in the pan-European GSM, but they will still be relatively large, with radii probably up to 6 km in rural areas and of the order of 750 m in urban centers. Microcells whose overall dimensions will normally exceed 400 m will be used and may provide only handover from a microcell to its overlaying macrocell. Because the DCS 1800 will be obliged to operate in relatively large cells, many of the complex, power-hungry circuits associated with the pan-European GSM network will probably be retained. There are those who consider that Britain is not so much getting novel PCN systems with inexpensive and wide-ranging services, but essentially a second GSM pan-European system, albeit with an increase in the level of competition.

No doubt this approach of deploying a modified pan-European GSM network is sensible to many people, but it may be a lost opportunity. Let us consider why the pan-European GSM is so complex [1]. The system is designed to operate in cells that span approximately 1 to 30 km. By selecting TDMA, the transmission and reception of signals occur at different times, and only one BS transceiver is required for eight users. Unfortunately, a Mobile Station (MS) transmits in a burst mode at 270 kb/s, and for the large size of cells used in the pan-European systems, a host of techniques must be employed to contain the Bit Error Rate (BER) within acceptable limits. A complex Regularly Pulse-Excited linear predictive coder with Long-Term Prediction (RPE-LTP) is used, and this causes many of the encoded speech bits to be sensitive to transmission errors. Forward Error Correction (FEC) coding must be used, followed by bit-interleaving. Frequency Hopping (FH) of interleaved FEC-coded blocks of data is mandatory from MS to BS and is essential to assist stationary MSs in a deep fade. The receiver needs adaptive Viterbi equalization whose metrics can be used to assist the FEC decoding and the muting of the output speech if the BER is very high. The control structure is exceedingly complex, probably 100 times greater than that of CT2. The overall delay is required to be less than 90 ms.

The pan-European GSM system has to be complex if it is to operate in large cells. This complexity will be reflected in the cost of equipment and the cost of making a connection. Because GSM BSs will be relatively expensive, their deployment in very small cells (<200 m) will be prohibitive, at least in the short term. The modified GSM, namely DCS 1800, will deploy similar BSs. No doubt they will be less expensive than the pan-European version and, as many will be deployed, the cost per BS will be less due to the economies of scale. Nevertheless, they will not be inexpensive, and this will make the service provider think carefully before deploying BSs in microcellular clusters.

A mobile communicator that can communicate from anywhere at any speed may be desirable, but can only be achieved in a bulky, heavy, expensive form and supported by an incredibly expensive infrastructure. A realistic alternative is to design a range of handheld communicators, which vary from the simple calculator or wristwatch size of negligible cost for offices and inner cities to the expensive, bulky size for use in mountainous areas. Many parts of the world are densely populated, enabling small cells to be used. For example, in Britain PCN systems should eventually operate with no cell in excess of 2 km, even in rural areas. If the operators deem this to be uneconomical, let the other systems, like the pan-European GSM system or Total Access Communication System (TACS), provide the service. We note that most people are supplied with electricity in their homes, and this provision is a far greater achievement than we ask of our communication service providers.

Low-Complexity PCNs

Given limited spectrum allocation, the most effective way to achieve high user densities is by deploying microcells [3] [4]. For ground coverage, e.g., streets and parks, two-dimensional microcells will be used, whereas three-dimensional microcells will be deployed in office environments. The number of microcells per cluster may be much higher than with current cells. The microcells may be as small as an office in a building or as large as a 1 km segment of a highway. The antennas radiate from locations relatively close to the MSs, for example, from ceilings in buildings or from lampposts in the streets. The power levels are low, less than 100 mW, down to the microwatt level. Battery power is significantly conserved and biological risks greatly curtailed. The small size of the cells results in Rician rather than Rayleigh fading, and this dramatically reduces the operating channel Signal-to-Noise Ratio (SNR) and renders the system significantly more robust to cochannel interference. The excess delay spread is decreased to the point where equalization is unnecessary, unless the bit rate is significantly above 1 Mb/s. FH is still advisable, but its gains may be far less as it becomes more difficult to hop farther than the coherence bandwidth when the excess delay spreads become very small. However, space diversity becomes feasible for transmission in the 2 GHz band.

If a primary objective of the PCN is to convey toll-quality speech, simple codecs using Adaptive Differential Pulse-Code Modulation (ADPCM), like the ones in DECT and CT2, can be used, because microcells can support a much higher bit rate than conventional cells. Operating at 32 kb/s, they are much simpler than RPE-LTP GSM codecs, have negligible delay, and cope with much higher BERs for a given speech quality. Although 32 kb/s Adaptive Delta Modulation (ADM) does not have speech quality quite as good as ADPCM, it often has a much better speech quality over the coverage area when used in mobile communications. This is because it is not subjected to errors caused by loss of word synchronization. Indeed, with ADPCM an entire packet may be corrupted due to synchronization failure. This is not a problem with ADM, which has a further advantage of requiring only a sixth of the battery power consumption.

On the assumption that the transmitted bit rate is low enough (say, <500 kb/s) that the channel does not have more than one significant fading path, then not only are equalizers avoided, but channel coding as well. However, channel coding may be desirable to assist in handovers. Given small enough cells, the PCN is essentially a Cordless Telephone (CT) type of system. It therefore follows that if DECT was rolled out, i.e., deployed outside the office environment, we would obtain a PCN.

Let us not focus on any specified system, such as DECT. Instead we will consider the simplest arrangement, namely: TDMA; a low-cost, low-power-consuming speech codec, like ADM; a Bose-Chaudhuri-Hocquenguem (BCH) codec (if required); and a Non- Coherent Frequency Shift Keying (NC-FSK) modem. In general, the control of mobile radio cellular systems is complex, absorbing significant power and space. The GSM control is particularly elaborate, and even the Common Air Interface (CAI) of CT2 is nontrivial. However, is the control process innately complex, or do we exacerbate the problem by having separate control channels? With a bit rate at a lower premium in microcells, can we sacrifice bit rate for lower control complexity by using the TDMA packets to convey both data and control information, and decrease the decisions made by the handheld portable and increase those made by the network? By decreasing the complexity of the control circuitry, along with the deployment of ADM and NC-FSK, the handheld portable could be small and light, with a minuscule power consumption compared to that of conventional handhelds. Its cost would be so low it could be sold in department stores. The BSs would be significantly less complex than those used in GSM or in Advanced Mobile Phone Service (AMPS) and TACS. They would be simple TDMA transceivers operating at low power with inexpensive microstrip combiners. The BSs would be linked together and to the Mobile Switching Centers (MSCs) by optical Local Area Networks (LANs) in buildings, and by optical or radio LANs in the streets. The BSs would be of shoebox to coffee-cup size.

Simple TDMA systems operating at burst bit rates <500 kb/s, with the bit rate allocated to the channels as required, will be able to provide a range of services. Cyclic Redundancy Codes (CRC) with Automatic Repeat Request (ARQ) will facilitate reliable computer data transmissions, although the simple organization of the system will not effectively support video services. Our optimism for this simple system is based on our experimental transmissions of 300 kb/s at 900 MHz and 1.15 Mb/s at 1.8 GHz.

High-Complexity PCNs

A wide range of services requires high bit rates on demand. As argued above, for a limited spectrum this means microcellular structures. Although the delay spreads become small in microcells, they are significant if the bit rate is large. Once again, all the problems associated with large cells occur as the ratio of the transmitted bit rate to the excess path delay becomes sufficiently large that even microcells become dispersive. One way to combat the problem is to reduce the symbol rate (and thereby the dispersion) by using multilevel modulation. For example, if the data rate is 8 Mb/s, it can be transmitted by 16-level Quadrature Amplitude Modulation (QAM) at 2 MBd. For microcells of moderate size (e.g., 300 m), we have effectively removed Intersymbol Interference (ISI) at 2 MBd, and our communicator is transmitting multilevel signals over a single Rician fading path. The problem is still far from simple. The receiver must be able to overcome the large gyrations and amplitude variations of the I and Q components of the received signal as it goes in and out of fades.

Research into QAM [5] has shown that novel QAM system arrangements will allow 4.8 kb/s Codebook Excited Linear Predictive (CELP) coded speech to be transmitted with the aid of channel coding over Rayleigh fading channels at only 1.2 kBd, provided the channel SNR > 26 dB. Operation at megabit rates can be accommodated [5] in microcells where single path Rayleigh fading occurs, and where the transmissions are at 2 GHz to pedestrian mobiles. Although the Europeans ruled out the CD900 system (which utilized TDMA with spectrum spreading) for their GSM standard, we may expect this type of complex system, and others, such as those using Code-Division Multiple Access (CDMA) and multilevel modulation with equalization, to be introduced to combat channel dispersion as the symbol rate is increased.

Adaptable Transceivers

For a given bit rate, the ease of communications depends on the channel. As the channel worsens from Gaussian to Rician to Rayleigh to dispersive, the complexity of the link to provide an acceptable performance increases from a simple modem to a receiver having adaptive equalization and much more. For a given complexity of equipment, the bit rate can be decreased as the MS roams farther from the BS while maintaining the same BER. By controlling the bit rate in this way, we avoid the onset of dispersion. When the MS is able to operate at relatively high channel SNRs, multilevel modulation can be used; whereas when the channel SNR is low, the modulator can discard its higher levels. QAM can therefore be used as an embedded modulator, adapting the number of its levels to suit the channel conditions.

In a similar way, speech and image codecs need to have embedded properties [5] such that the essential information is sent on the primary codec, while supplementary information that significantly enhances the recovered audio or image quality is conveyed by the outer codecs. Similar arguments apply for channel coding, ranging from no channel coding when conditions are good to increasingly powerful FEC as conditions deteriorate. When transmission delays are not important, e.g., during computer file transfers, error detection with ARQ is used. We observe that for an optimum link the source codec, channel codec, interleaver, and modem need to have embedded characteristics.

Complex PCNs may communicate using different bands. Each band will handle traffic at different rates and different BERs. We anticipate higher propagation frequencies being used in office environments than in rural areas. Television conferencing will operate at much higher bit rates and require higher-integrity channels than slow-scan television transmissions used for surveillance. In making a call connection, the user will be required to select the service required, and the network will assign the band to be used together with the type of transceiver configuration.

PCN Roll-Out

An approach to deploying a PCN is to start with the minimal number of BSs to service the initial number of users over a wide geographical area. This approach means the cells are relatively large, and that at the outset the MSs must be able to transmit at relatively high power levels, which in turn implies relatively bulky mobile equipment. Another implication is that although fewer BSs are used at start-up, the larger cells within which they operate may render the cost per channel higher than for BSs operating in very small cells. The worst situation is when the PCN is required to give national or wide-area coverage at start-up. If this requirement is imposed on the service provider, the design of the PCN has a high probability of being far below optimum at start-up.

However, given that the network commences in this way, it can subsequently use the initial wide-area start-up cells as overlaying macrocells, with embedded tessellated microcells [4]. The macrocells are now employed to assist MSs that cannot be adequately serviced by the lower-powered microcellular BS. As the MSs are required to power-up only occasionally to communicate with macrocell BSs, they can be much smaller, as in general they consume far less power.

As a consequence, the network starts up with relatively high power requirements, resulting in relatively complex BSs and MSs. The second-generation PCNs have lower power requirements, simpler BSs, and smaller and inexpensive MSs. Later overlay phases include BSs and MSs that can operate at higher bit rates, provide more sophisticated services, and communicate in different frequency bands, as described earlier.

An alternative scenario is to allow the service provider to expand his business due to market forces, rather than at the dictates of government planners. The provider should deploy clusters of microcells with oversailing macrocells at the outset in areas of dense teletraffic demand, e.g., the commercial districts in major cities. The BSs would be small, simple, and inexpensive. They would be linked by an optical or radio LAN to the MSC, which would house the first layer of significant network intelligence. The MSs would be little more than a modem with speech and channel coding, as discussed before. Thus, people in the offices and streets of commercial districts would have a service that operates up to, say, 1 Mb/s, enabling them to carry a lightweight handheld portable that would need to be recharged relatively rarely. As the cost of equipment and calls would be low, the user demand for the service would rapidly grow and, with it, the ability to expand the PCN to adjacent neighborhoods. We may anticipate that this approach will be taken by the cordless telephone operators.

By starting up a system in this way, the coverage is confined to areas with intense teletraffic demand, and users who require mobile communications outside of these areas will need a conventional cellular phone unless they are prepared to delay calls until they arrive in another PCN zone. However, this inconvenience may be very acceptable if the majority of their calls are made in the low-cost-per-call PCN areas.

The PCN roll-out continues with inexpensive mobile communications being applied to areas with successively lower teletraffic demand, with microcells never exceeding 2 km. In a country like the U.K., this will give virtually national coverage. While this roll-out is in progress, the second generation of PCNs will commence in the inner cities and will slowly spread to other areas in the manner employed in the first phase. By this means, waves of new and more complex PCNs, for those who want them, are overlaid to provide enhanced services in a commercially viable way.

Discussion

There is no universally accepted definition of a PCN. For some it is a conventional cellular network but with smaller cells, designed mainly for pedestrians. Others view it as a cordless telephone network with enhanced facilities, which has broken out from its building confines into the rest of the environment. Those who have the long view regard PCNs as "Star Trek" communications without the "beam me up" facility. There is general agreement that PCNs will need to cope with unprecedented volumes of traffic whose density is far less geographically and time predictable than that in the current networks. The PCNs will be required to accommodate ISDN and, furthermore, to cope with new developments in ISDN and the increasing range of services it will provide.

Given the many systems already under development and to be deployed (e.g., GSM, DECT, CT2, and DCS 1800), there is a strong temptation to make these systems compatible via CAIs, BS design and deployment, and so forth, and then design advanced PCN systems that are compatible with these networks. An alternative approach is to identify the direction in which we expect the PCNs to develop and design an embryonic network that can be systematically developed. The notion is to nest a sequence of PCNs of increasing complexity. We initially deploy a low-cost PCN using microcellular systems that are market-driven, as described by the second scenario in the previous section. As the network coverage extends and enhanced services operating at higher bit rates are provided, the initial network is comfortably embedded and acts as the core for the enhanced PCN. The problems of incompatibility are avoided, as the CAI also has embedded properties. It is only recently that we have produced the engineer who straddles the subjects of fixed networks and radio communications, and it is perhaps here that most of the research should be focused if we are to develop PCNs that do not continually require the discarding of older versions.

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Biography

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