Wireless Personal Communication Networks

By David J. Goodman

To optics and photonics experts, the status of wireless communications will seem strange. There is a shortage of technology to satisfy a substantial public demand. Photonic communication, in common with other information services, progresses in an orderly fashion from science to technology to standards to products to services. Then there is a search for applications, which eventually emerge. And finally there are revenues and rewards to the virtuous. I recall a phone call from the AT&T press office, while I was at Bell Labs. The caller wanted to explain to a non-technical audience the significance of multi-gigabit transmission. I calculated that you could send all of Shakespeare, the Encyclopedia Britannica, and the Bible in a few milliseconds. The caller thanked me for the impressive illustration. Neither of us reflected much on whether anyone really wants to do that.

Information Is Personal

By contrast, Dick Tracy, Star Trek, and others long ago prepared the public for *personal communications*. However, industry and governments paid little attention until they were confronted by a massive outpouring of demand. For the past decade, the public has shown dramatically that people want their information to be personal. The action in computing in the 1980s was in *personal computers*. My WINLAB colleagues, Melissa Gelfman and Philomena Genatempo, and I all have Macintoshes in our adjacent offices. However, the three computers look and sound and feel different—truly personal. By 1990, it wasn't enough to have this reflection of my personality on my desk. I needed a laptop. I want my information to be personal and I want it to be part of me, not part of my home or my office. Similarly, in entertainment, *personal stereos* are indispensable items for almost everyone.

In communications, two of the hot items of the 1980s were cellular phones and cordless telephones. Both of these products in 1992 are quite different from what they were when they arrived on the scene about eight years ago. In developing cellular technology, the aim of AT&T was to put into my car the equivalent of my home or office phone. Just as the instrument on my desk is part of the office and the one attached to the wall in my kitchen is part of the house, the cellular phone was part of the car. The cordless phone was something to use when I couldn't conveniently get to the phone on the wall in the kitchen; for example, when I was in the backyard or in the basement. In the early days, my callers would immediately recognize something strange when I answered the cordless phone. More times than not, I went to the kitchen and transferred the call to the wall telephone.

In the past few years, cordless and cellular phones have changed a lot. Now people take cellular phones with them when they leave their cars. Perhaps, in crowded cities, they don't use them in cars at all. Even though there is a big price premium for lightweight portable phones, half of the cellular phones purchased today are in this category. And like PCs, they are personal. Most have automatic dialers and programmable directories for up to 100 names and phone numbers. On the cordless side, we all threw away our original sets and bought, at elevated prices, telephones that sound good. Just as most people buy up-market personal stereos with high fidelity sound, the biggest share of the cordless phone market falls to expensive products with good sound quality. Now I use my cordless phone instead of the the one on the wall. It truly is personal. Depending on who I am speaking with, I take the phone to a different part of the house.

My cordless and cellular phones improve my life but in different ways. I like the cordless phone because it is small and light. (It weighs 100 grams and fits into any pocket.) It costs me no more to use than my ordinary telephone and I don't worry too much about keeping its battery charged. The one drawback is that I cannot use it when I leave home. When I am on the move, the cellular phone is excellent. I can use it almost everywhere. However, the service is extremely expensive, and the battery needs recharging after 40 minutes of conversation. As an engineer reflecting on the complementary advantages of cordless and cellular phones, I think about a new type of communication that will merge their merits. Figure 1 shows cellular and cordless telephony converging to a single mode of wireless access to the public telephone network.

Personal Communications Service (PCS) is the nomenclature for the next major step in this convergence. Unlike cellular and cordless telephony, there is no precise definition

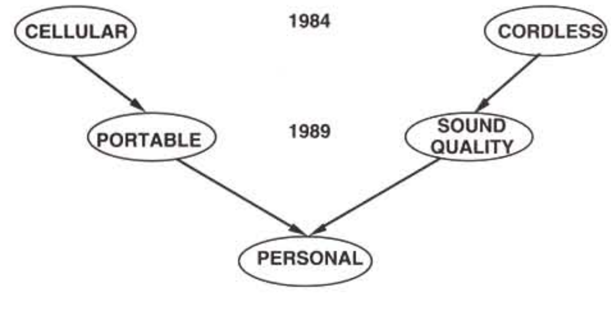


FIGURE 1: CELLULAR AND CORDLESS COMMUNICATIONS MAY ONE DAY MERGE INTO A UNIFIED PERSONAL COMMUNICATIONS SERVICE.

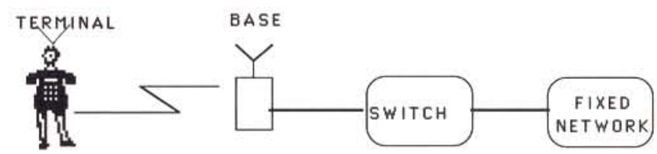


FIGURE 2: WIRELESS ACCESS TO A FIXED INFORMATION NETWORK.

of PCS. In fact the definition, as well as several other issues, are subjects of intense debate. There are four major questions:

- What exactly is PCS?
- What part of the electromagnetic spectrum will it occupy?
- Which organizations will be allowed to provide PCS?
- Which technologies are best suited to PCS?

My purpose in this article is to discuss technology, so I will not address the second and third questions. The following general answer to the first one will be sufficient, I hope, to put the technology questions into context:

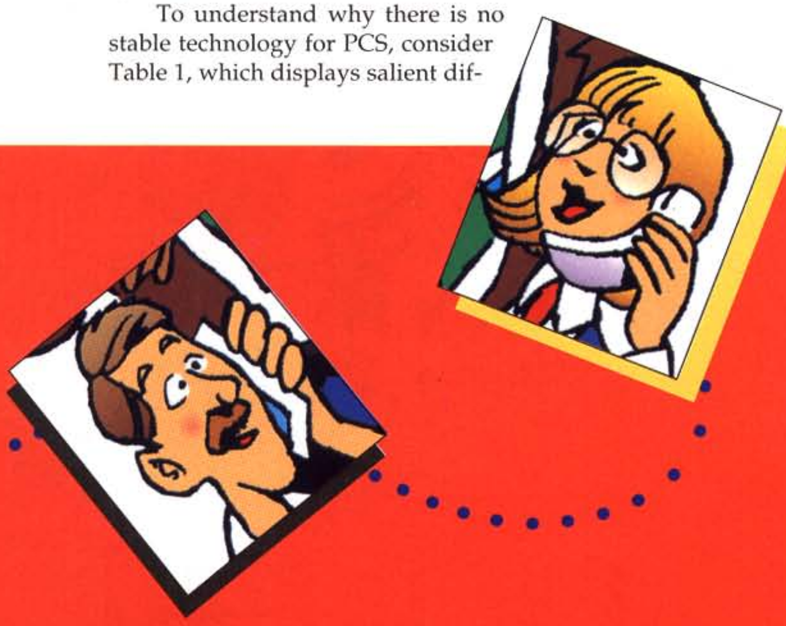
> *With Personal Communications Services, people moving at pedestrian speeds in public places will be able to make and receive phone calls using lightweight wireless instruments. The equipment and service will cost less than cellular and appeal to a mass market.*

Technology Challenges

Figure 2 shows three devices that are necessary for wireless access to fixed information networks. The *terminal*, with its own power supply, is the user interface. It uses free-space electromagnetic radiation to exchange signals with a fixed *base station*. The base-to-terminal transmission medium for PCS will be microwave radio channels at carrier frequencies in the range 1-3 GHz. While some PCS frequency assignments are in place in Europe, the United States still awaits government decisions on spectrum allocation. (Infrared signals, which do not require spectrum licensing, may be used for certain indoor, high bandwidth communications.) The *switch* in Figure 2 connects the wireless information network to the fixed information service.

Each wireless communication system has its own way of moving information among the network elements in Figure 2. In addition to user information, it is necessary to transfer significant amounts of system control information. This control information allows the network to manage its resources, most notably its wireless communication channels. It helps the network adjust itself to the changing locations of the terminals.

To understand why there is no stable technology for PCS, consider Table 1, which displays salient differences between wireless access techniques and conventional telephony. In each case, wireless access is more demanding than fixed access and we need new technology to bridge the gap. One of the most contentious issues is *multiple access to the transmission medium*. This problem does not arise in fixed telephone networks because each subscriber has dedicated facilities (usually a pair of wires) for communicating with the system. However, in a wireless network, the signals moving to and from all terminals get mixed together in the air. How should we design the signals so that they can be separated from each other at terminals and base stations?



In the cellular arena alone, there are three entirely different approaches advocated for meeting the needs of the immediate future. These approaches are based on frequency division, time division, and code division—all established technologies in other application areas. The remarkable thing about wireless communications is that technical experts cannot agree on basic scientific issues related to the relative merits of the three approaches. Issues of similar importance, such as the advantages and disadvantages of coherent communications, are settled by the photonic community long before there is an urgent need to put something into the field.

I will draw your attention to one other item in the table—*network configuration*—and discuss in some depth its impact on technical alternatives. Rearranging a fixed network is an awkward matter, especially when the end user is involved. A few months ago, WINLAB consolidated itself in a single building at Rutgers. All of us moved there from other places, and in spite of four weeks' advance notice to New Jersey Bell and AT&T, it took over a week to get all the phones working properly in our new home. The campus Ethernet did much

	WIRELESS ACCESS	FIXED ACCESS
Terminal-to-network channel	time-varying poor at times	constant high quality
Access to transmission medium	shared with other terminals	dedicated to one terminal
Privacy, security	vulnerable: signals radiated in the air	wiretapping requires special measures
Bandwidth allocation	determined by government policy	determined by economics
Network access authorization	burden on network	burden on subscriber
Network configuration	changes frequently during calls	rarely changes
Electric power supply	contained in telephone	in premises or network

Table 1: Wireless networks raise issues that do not arise in most fixed networks.

better. Everything was operational in only two days. Now consider the cellular network in any city. Every second, several subscribers disconnect themselves from one point of entry to the network (base station) and establish a connection through another one. This happens automatically and imperceptibly to the human user, even if that person has a call in progress at the time.

This impressive feat is coordinated by the computers that control the switches in Figure 3. In some places, these computers are hard pressed to keep track of the changing locations of terminals. In the busiest cellular systems—in New York and Los Angeles, for example—there are about 200,000 subscribers and 100 base stations. Networks are organized hierarchically, as in Figure 3, with network control concentrated in the switches. The busiest switches today control about 60 base stations each. The communication links between the base stations and the switches represent a significant fraction of the cost of operating the network. Usually these links are copper wires or fixed microwave facilities. As systems grow, optical fibers will be major candidates for performing this task. However, it is not clear which fiber plant is best suited to the job. Is it the one owned by the local telephone company? Is it a cable television backbone? Or is the best solution to be found in a special purpose network installed only for personal communications?

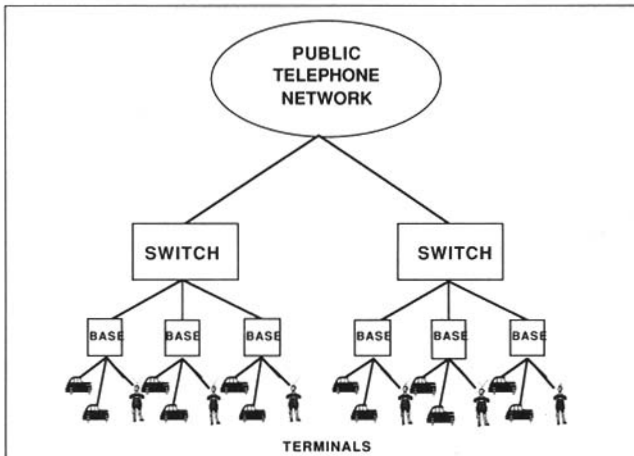


Figure 3: Hierarchical structure of cellular networks. Control is concentrated in the switches.

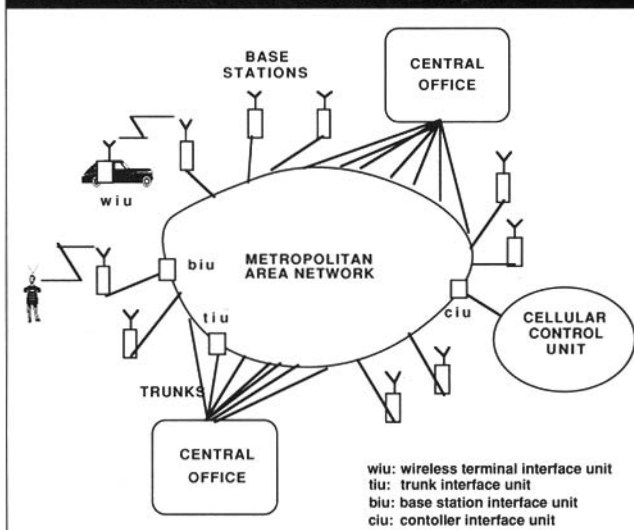


Figure 4: Control of the cellular packet switch takes place in interface units distributed on the metropolitan area network.

Research Issues

Another major concern for researchers into future networks is the ability of controllers to manage networks that are orders of magnitude more complex than the ones we have now. The added complexity will arise from a tenfold increase in the number of system users. To accommodate this growth within a limited radio spectrum allocation, it will be necessary to have many thousands of base stations in a metropolitan area. The same physical channels will be in use simultaneously in dozens of base stations, all separated just far enough to avoid damaging mutual interference. This *channel reuse* is the heart and soul of cellular communications.

Now, the highest density networks have base stations separated by about 2 km. To meet future demand, this spacing will have to come down to the order of 200 m outdoors and even less inside crowded business premises. Within these *microcells* and *picocells*, network rearrangements will take place thousands of times more frequently than they do in present cellular systems. To manage the volume of changes, it may be necessary to adopt a network architecture radically different from the hierarchical one of Figure 3.

Figure 3 reminds me of air traffic control. A controller at the airport tells each plane when it can take off and exactly which altitude and direction it can adopt. The plane can change course only under command of the controller. When the plane leaves one control area, the controller hands the flight off to a controller in another area by telling the pilot to tune to another radio channel. This procedure closely parallels the *handoff* operation of cellular systems. When it moves to a new location, the cellular phone receives a command to tune to a new radio channel. One problem with our air traffic control system is limited capacity. The same technology could never cope with the volume of traffic we have on our roads. The control of automobile traffic is widely distributed, with each vehicle making decisions based on internal knowledge of where it wants to go and on observation of local conditions.

In Personal Communications, the analogous distributed control appears in the architecture of a *Cellular Packet Switch* illustrated in Figure 4. Here all base stations in a service area and all connections to the fixed network appear on the same fiber optic metropolitan area network. Instead of information streams on dedicated radio resources of a circuit switched system, the Cellular Packet Switch assembles information in short bursts, called packets. Each packet carries its own source and destination addresses in addition to user information or network control information. These addresses enable the packets to reach their destinations without the intervention of a central controller. Instead, network control is distributed among hundreds of metropolitan area network interface units, each associated with a base station or a port to the fixed information service. Packets share, on a statistical basis, the transmission resources of the metropolitan area network.

With this architecture, when a terminal moves to a new cell, it observes the local environment and makes its own decision to use a specific base station and radio channel. When the terminal starts sending information to the new base station, the interface units on the metropolitan area network recognize the change in location and re-route outgoing information accordingly. Each interface unit caters to the needs of one phone call. This eliminates the threat to hierarchical systems posed by a flood of location changes that in a short time overwhelm the processing capacity of a central controller.

In addition to the network elements shown in Figures 2-4, advanced wireless networks will employ specialized databases to manage subscriber access to the network and to keep track of everyone's location. There will also be several software-intensive devices for systems operations, administration and maintenance. With the Cellular Packet Switch, the databases and other devices will appear as clients and servers all connected through the metropolitan area network. Current research is focused on several network control topics, including a new network operating system, referred to as *WIN*OS*, that will manage all of the network elements, even as they grow, shrink, and change location. Other research topics include the apportioning of control tasks among the various network elements in a manner that maximizes reliability and efficiency.

It Takes a Lot of Wires to be Wireless

Future personal communication networks will liberate humans from their tethers to information services. Paradoxically, we need an intricate "wired" network infrastructure to make this happen. This infrastructure will deliver not only telephony to a large number of densely spaced terminals, but also a wide variety of other information services. Escalating requirements will call for advances in the infrastructure. Astute deployment of photonic communication technologies will be essential to the success of Personal Communications Services and other wireless networks.

The optics and photonics communications community has created impressive technology for other applications, such as undersea communications and television distribution. The coming years will call for inventions matched to the far ranging needs of the next century's wireless information networks.

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