

Personal Communications Networks Bridging the Gap Between Cellular and Cordless Phones

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Invited Paper

Today's cellular radiotelephone systems currently serve some 12 million subscribers but at average costs of \$70/month for service, cellular remains a business, not a consumer, service. On the other hand, cordless phones are already a consumer product in over 40% of U.S. households and annual sales of new cordless phones are already greater than sales of regular corded phones. Personal Communications Networks (PCN) providing Personal Communications Services (PCS) are designed to bridge the gap between expensive public cellular and private cordless services. In this paper we will explore PCN/PCS topics including: a definition of the service, identification of the underlying technologies, and discussion of tradeoffs between the technologies.

I. INTRODUCTION

Engineering starts where science stops and perhaps no field of interest illustrates this better than that of wireless personal communications services (PCS). In the case of PCS there are many challenging technical issues, but there are many more nontechnology choices driven by the interaction of technology with economics, politics, and market needs. PCS development is engineering at its best—the process of applying science in the face of complex tradeoffs to solve real-world needs. In this paper we will explore the definition of PCS, the underlying technologies, and the tradeoffs involved; using the U.S. situation as a real-world example of similar problems being faced around the world.

PCS is the next generation of mobile telephone service (MTS) and to understand PCS it is useful to review the history of MTS. The first recorded mobile radio services that provided interconnection to the switched telephone network was in 1946 when the FCC allocated six radio channels for the first *public correspondence system* in St. Louis [1]. During the 1950's and 1960's the service evolved into manual MTS services where mobile units called into operators who manually placed the calls. The major innovation was the introduction of 600/1500-Hz transitional signaling decoders so that mobile units could

mute their radios until the operator selectively alerted them of an incoming call by sending the correct signaling tones. These manual MTS services were provided in the 30–50-MHz VHF (low band) and the 150–174-MHz VHF (high band). The modulation type was narrow-band FM and a single high-power base station provided coverage of some 20–30-mi radius to several hundred mobiles per 20–30-kHz-wide radio channel.

In 1964 a new service was introduced called Improved Mobile Telephone Service (IMTS) [2]. The first-generation IMTS service (MJ) was provided in the 150–174-MHz VHF (high band). Like the prior manual MTS service, a high-power base station modulated with narrowband FM provided service from a single location per city. Unlike manual MTS, however, there were two important innovations:

- Both land-originated (outbound) and mobile-originated (inbound) calls were processed automatically without operator intervention
- On the order of 8 channels per major city were available with an automatic channel selection mechanism to afford the higher grade of service possible by trunking, or sharing, the channels

With only 8 channels per city, however, traffic theory leads to a limit on the order of 130 mobiles to insure a high grade of service given by a less than 2% chance of all channels being occupied during the busy hour period [3]. Because the demand for service exceeded the supply by many times, however, it was not unusual for IMTS systems to support over 400 mobiles with the result that grade of service was reduced to approximately a 40% chance of all channels being occupied during the busy hour period. The introduction of MK IMTS service a few years later at 450 MHz added on the order of 10 more channels to each major city but this additional resource was quickly occupied by the long waiting list of users.

It was not until 1983, after 20 years of delay due to politics, that today's analog cellular services were introduced to the U.S. on a commercial basis. The first Cellular systems

Manuscript received August 8, 1993; revised November 18, 1993.
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IEEE Log Number 9215561.

0018-9219/94\$04.00 © 1994 IEEE

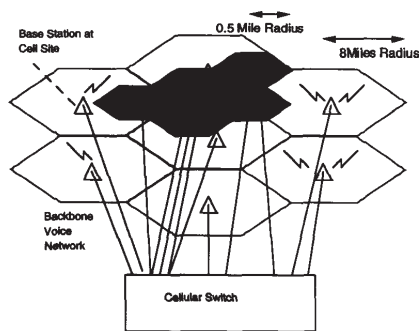


Fig. 1. Cellular AMPS high level architecture.

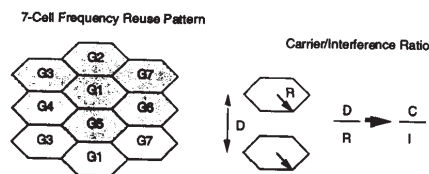


Fig. 2. Frequency reuse in cellular AMPS.

were built in Chicago and Baltimore and within a few years were serving tens of thousands of subscribers. The cellular analog standard in use in North America is called Advanced Mobile Phone Service (AMPS) and is fully documented by The Telecommunications Industry Association Standard 553. Figure 1 shows a high level view of the applicable cellular architecture.

Like IMTS, cellular employs narrowband analog FM modulation and also takes advantage of the trunking efficiencies of multiple channels automatically assigned from a shared pool. Unlike IMTS, cellular consists of multiple base stations of various sizes. Some of the key features of cellular MTS are as follows:

- Service is provided in the 800-MHz microwave L-band on 832 (initially the FCC allocated 666) pairs of channels spaced at 30 kHz. The channels are divided into two groups of 416 pairs and assigned to two competing cellular carriers per metro area.
- Early in the life of the new cellular system, when there are few subscribers and there is a desire to provide wide-area coverage, the base stations operate at power levels on the order of 30 W and transmit on tall towers on the order of 8-mi radius.
- In traditional cellular architectures, as traffic builds (initially in the heavily populated central city) the cell sizes are reduced to as small as 0.5-mi radius and power levels are correspondingly reduced to scale transmission range to the smaller cell size.
- Unlike IMTS, where it is only necessary to provide a small number of voice circuits between the base station and the mobile telephone switching office (MTSO or switch), in the case of cellular there is a need for an extensive, and expensive, backbone network of voice circuits to connect base stations to the switch.

The real magic of cellular comes from the concept of frequency reuse [4] as shown in Fig. 2.

Because the spectrum allocated to each cellular operator is limited to only 25 MHz, it is necessary to reuse channels in more than one cell site. To avoid interference, a common desired criterion is to keep the distance between cell sites with the same channel large enough so that the desired carrier to undesired interference ratio (C/I) is greater than 17 dB. For cell sizes of 0.5-mi radius (and larger) this can generally be achieved with a 7 cell reuse pattern shown in Fig. 2.

By these means cellular systems can serve on the order of 100–300 thousand subscribers per metro area with a high grade of service. However, even today's analog cellular systems are being challenged in major cities such as Los Angeles as subscribers exceed the original design limits of analog AMPS. For these reason new systems based upon low bit rate speech compression technology and efficient digital modulation, are being proposed that can increase capacity from 3–10 times the current limits of today's analog AMPS systems. Other approaches to provide higher capacity include exploration of reduction of cell sizes below the current 0.5 mile radius to what have been called *microcells*. As we shall soon show, the technologies of microcells and low bit rate coded digital speech are the same basic underlying technologies of PCS.

The drive to deploy PCS can be traced to the introduction of Telepoint Services based on the CT2 air interface in the UK [5]. As a result of the high visibility of the U.K. activity, and in response to petitions for rule-making, the FCC issued a notice of proposed rule making (NPRM) [6] to explore the reassignment of frequencies in the 2-GHz band from fixed point-to-point microwave users to new emerging mobile service technologies. In July 1992, the FCC released a tentative decision to set forth the rules to govern PCS in the U.S., and just recently the FCC has released a second report and order on the same subject [7]. While the final rules and regulations are still somewhat uncertain, the FCC second report and order provides some insight into the FCC's thinking for what they define as *broadband PCS*:

- There will be up to 7 PCS operators per market (versus cellular's limit of 2 operators per market) with some mix of operators serving one of 492 metro areas called a Basic Trading Area (BTA) and some operators being licensed for one of 51 larger regions called a Major Trading Area (MTA). The size of even a BTA is generally much larger than the size of today's cellular franchise.
- The license process will likely be by auction based upon a desire by the government to raise \$11 billion to offset the budget deficit.
- MTA PCS operators (2 operators/MTA) will get 30 MHz of spectrum each while BTA operators (5 operators/BTA) will get either 10 or 20 MHz each; as contrasted with the 25 MHz for today's cellular operator.

- The 1850–2200-MHz band is proposed to be divided into a 120-MHz portion for licensed service with an additional 20-MHz portion set aside for unlicensed short-range voice (1890–1900 MHz paired with 1920–1930 MHz) and 20 MHz more for data communications (1900–1920 MHz unpaired).
- The licensed band will be allocated in pairs with a 80-MHz offset between the pairs. There are two bands earmarked for assignment on an MTA basis from 1850–1880 MHz paired with 1930–1960 MHz. There are five additional bands earmarked for assignment on a BTA basis from 1880–1890 MHz paired with 1960–1970 MHz and from 2130–2150 MHz paired with 2180–2200 MHz.
- Base station powers will be limited to about 100-W effective isotropic radiated power (EIRP) and mobile to about 2-W EIRP.

II. DEFINITION OF PCS

There is no universally accepted definition for personal communications services. From the point of view of the FCC, a wide variety of alternate PCS visions have been proposed and seem to be accommodated in the tentative PCS rules:

A. Unlicensed Emerging Technology Service Alternatives

- *Cordless Phone*—both residential and office wireless PABX.
- *Wireless LAN's*—for short distance peer to peer or peer to master station data transmission connectivity within an office.
- *Data PCS*—for short distance peer to peer communications between machines in meeting rooms, work groups, such as laptop computers or personal digital assistants.

B. Licensed Emerging Technology Service Alternatives

- *Cellular at 2 GHz*—essentially the same as today's macrocellular 800-MHz system except up at 2 GHz.
- *Wireless Loop Replacement*—fixed, short distance links from microcells <1500 ft to voice telephone sets in a home or small business, wireless loops are designed to save costs of providing local exchange telephone service and not to provide mobility.
- *PCS*—a new wireless service with some highly differentiated attributes from today's cellular service.

The PCS features are key: Our view of PCS is that it is a consumer priced public network communications service designed mainly to support voice traffic but can (and likely will) also support medium speed data traffic. Further details regarding the features follow:

- *Management of Mobility*—the system supports the mobility of the user both as they roam from system to system between phone calls as well as supports handoffs between base stations within and between

Table 1 Attributes of Personal Communications Services (Source Arthur D. Little, Inc)

Service Attributes	Technology Attributes
• Features —Management of mobility —Convenience un use —Call management —Personal numbering • Performance —Wired voice quality —Low probability of blocking —Reliable and well-defined coverage —Light weight and small size —Long battery life —Secure against fraud and information interception —Spectral efficiency of ~ 100× that of cellular AMPS • Cost —Handset < \$175 —Service 25–35/month	• Microcell size 500–1500 ft radius • Digitally coded compressed voice • Intelligent network control • Frequency reuse

adjacent systems. The functions of mobility management include: handoff, location management, and registration for service while roaming.

- *Convenience in Use*—the phone is so light, convenient, and has such a long battery life that the phone is always with the user and available for use.
- *Call Management*—the user has control of all incoming phone calls and can decide which calls to take and which to refuse or divert to voice mail or third parties. Implicit in the idea of call management is that the handset provides the user with information regarding the caller and perhaps the nature of the call, or the equivalent function by having the user preset a set of rules regarding the processing of calls from specific callers.
- *Personal Numbering*—the calling number maps to the user no matter what location he is at, or even what equipment he may be using. This is as opposed to today's switched telephone network where the number refers to a specific physical terminal or aspecific terminal location and not a person.

While the PCN will likely include a significant portion of a wired network to connect to microcells, because PCS has mobility as a key feature the personal communications network (PCN) must be based on wireless transmission for the last leg of the link between some antenna and the subscriber handset. Further, because inexpensive handsets with long battery life are required, an outdoor coverage PCN must consist of several thousands of microcellular base stations of 500–1500-ft radius of coverage. PCS in the context of the family of other mobile communications services is shown below in Fig. 3.

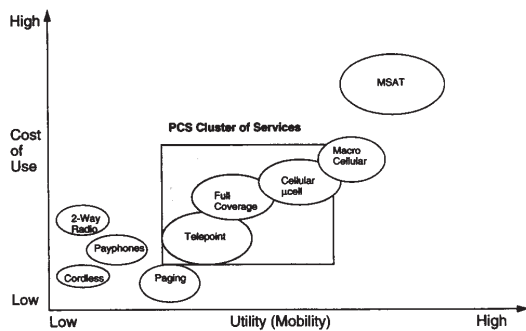


Fig. 3. PCS positioning in the mobile communications family of service.

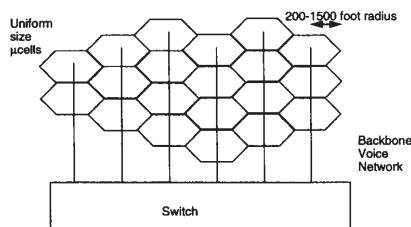


Fig. 4. Personal communications network logical architecture.

III. PCN TECHNOLOGY

While the FCC has allowed for a variety of uses of the 2-GHz emerging technologies band, for the purpose of the remainder of this paper we will use PCS to refer only to the cluster of services identified in Fig. 3. To support PCS's key mobility feature and the other attributes of small size and low cost, the personal communications network (PCN) supporting PCS must allow for long battery life, inexpensive handsets; and yet the network must provide for high voice quality and well-defined zones of coverage. While there are several alternative PCN architectures which might support PCS, they all share one important common feature: The distance from the base station antenna and the handset must be short—on the order of 500–1500 ft. The coverage cell of a single antenna is much smaller than the 0.5-mi radius macrocell common in today's analog cellular AMPS systems. For this reason, the small cells needed in a PCN have been named microcells. While a major metro-area macrocellular system might have a few hundred macrocells of varying size (from 0.5- to 8.0-mi radius), a microcellular PCN might have several thousand cells of uniform size. A logical architecture for a PCN is shown in Fig. 4 below. We use the term logical architecture to distinguish Fig. 4 from physical architecture alternatives that we will describe shortly (i.e., a star network is implied in Fig. 4 but the backbone network could be a bus or some hybrid form).

The implications of this are profound:

- With several thousand of cells, the backbone network to interconnect the cell sites now becomes a much more extensive system whose cost needs to be minimized.

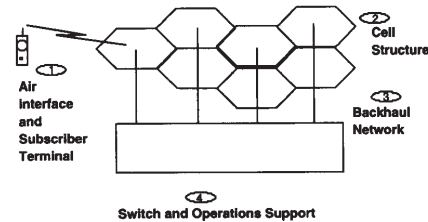


Fig. 5. Physical components of a PCN architecture.

- With microcell sites spaced as close as every 500 ft, the physical size of the hardware at each cell site must be small and the antenna structure needs to be environmentally friendly.
- Unlike macrocellular systems which can start with a small number of large cell sites to reduce the initial cost of building a system, a microcellular-based PCN must have nearly all the cost of the cell sites deployed on the first day of service; even when there are a small number of customers.

To mitigate the costs of a PCN and deal with the concerns of eyeball pollution, several interesting architectures have been developed. These architecture alternatives will be described with respect to the four components of the architecture identified in Fig. 5 below.

The components of the architecture and their impact on the service and network cost are as follows:

A. Air Interface and Subscriber Terminal

The air interface refers to those aspects of the system responsible for the link between the subscribers terminal/handset and the base-station receiver and transmitter. The major elements of the air interface include:

- Frequency Band—in the U.S. it is likely to be at 2 GHz for new emerging technology services and at 800 MHz for those cellular systems which evolve toward microcells to support the PCS vision.
- Channelization—the bandwidth allocated to each channel and the spacing, including any guardband, between each channel.
- Duplex Method—either Time-Domain Duplex (TDD) or Frequency-Domain Duplex (FDD). In the case of TDD, both receive and transmit of the handset and base station occur on the same frequency, ping-pong alternating in time. FDD, on the other hand, uses one frequency for mobile to base and another frequency for base to mobile.
- Channel Modulation—in the case of PCS, we assume that all systems employ digital transmission of the digitally coded representation of speech. In this case the channel modulation describes the number of bits of information per symbol sent and the means used to represent the symbol. Simple binary modulation methods such as FSK have a low cost, and low power drain to implement but will require more bandwidth (in hertz per bit) than complex channel modulation schemes such as QPSK.

Table 2 Examples of Alternative PCN Air Interfaces Compared to Analog Cellular AMPS (Source [8], [9])

	Analog Cellular AMPS	IS-54 New Cellular	CT2	UDPCS	PHP	QCDMA
Average RF power	600–3000 mW	600–3000 mW	5 mW	10 mW	10 mW	8 mW
Peak RF power	600–3000 mW	600–3000 mW	10 mW	100 mW	80 mW	200 mW
Duplex method	FDD	FDD	TDD	FDD	TDD	FDD
Access method	FDMA	FDMA/TDMA	FDMA	FDMA/TDMA	FDMA/TDMA	FDMA/CDMA
Voice circuits per RF channel	1	3	1	10	4	420
Channel spacing	30 kHz	30 kHz	100 kHz	300 kHz	300 kHz	1.25 MHz
Channel data rate	N.A.					
Speech coder	none	8 kb/s VSELP	32 kb/s ADPCM	32 kb/s ADPCM	32 kb/s ADPCM	variable 3.2 kb/s average
Channel coder	none	$\pi/4$ DQPSK	GFSK	$\pi/4$ QPSK	$\pi/4$ DQPSK	QPSK

- **Channel Coding**—this refers to the overheads added to the transmitted bit stream to reduce (i.e., improve) the bit error rate. The channel coding means generally involve some combination of forward error correction and interleaving of data. Complex channel coding methods can greatly improve communications link margin but can add cost, reduce battery life of the handset, and add undesirable time delays in the speech path.
- **Source Coding**—this aspect of the air interface refers to the means to digitally encode the speech. Source coding can employ simple, low power drain methods such as PCM or ADPCM or highly complex vocoders such as linear predictive coding methods. While complex vocoders can lead to lower bit rates, and higher spectral efficiency, they generally reduce the speech quality both in terms of naturalness, intelligibility, and in time delay.
- **Multiplex and Access Method**—the means used allow several users to share the allocated bandwidth. These methods include single or hybrid combinations of frequency-domain multiple access (FDMA), time-domain multiple access (TDMA), code division multiple access (CDMA) using spread spectrum modulation.
- **Power Control**—this refers to the capability of the air interface to adjust the transmitter power level continuously, or in steps, to that needed to insure adequate transmission quality. Systems with power control will be more complex, but can reduce the dynamic range requirements of the receiver, provide for longer average battery life of the handset, and allow automatic adaptation for excess losses in the transmission path.

To understand the tradeoffs between each of the Table 2 air interfaces, each will be compared to the analog AMPS baseline.

Analog AMPS—Today's cellular systems employ analog FM modulation and can provide an excellent voice channel when close to the base station. However, channel quality will suffer when the mobile is near the range limit (at the edge of a cell). The analog FM system allows for low signal processing cost and battery drain, but the relatively large transmitter power creates two problems: 1) A high battery drain when transmitting, and 2) A need for the base station equipment to operate in a wide dynamic range.

IS-54 AMPS—Both the TDMA-based IS-54 and the QCDMA-based IS-95 are proposed to replace analog AMPS. The major goal here is to increase subscriber capacity and not to realize the vision of low-cost, long-battery-life PCS. However, both air interface standards have been suggested as candidates for PCS at 2 GHz. IS-54 increases the number of voice circuits/RF channel from the AMPS number of one voice circuit to three voice circuits per RF channel. However, this increase in spectral efficiency comes at a cost: the low bit rate speech coder and the DQPSK channel modulator add signal processing cost and a heavy load on the limited battery life. The speech coder also adds a noticeable impairment in terms of loss of naturalness and time delay due to signal processing. In addition, the IS-54 standard still calls for a high transmitter power not compatible with long battery life and small cell size.

CT-2—This air interface standard was first developed for use in the U.K.'s telepoint system and a CT-2 variant is the basis for PCS now licensed in Canada. CT-2 differs from analog AMPS in that (like IS-54) it employs digitally coded speech. However, unlike IS-54, CT-2 uses only modest ADPCM speech compression at 32 kb/s versus the IS-54

highly compressed 8 kb/s. A simple binary FSK channel modulator also keeps down signal processing cost and battery drain. The use of time-domain duplex (TDD) allows for operation on a single channel which reduces handset cost and facilitates interference management. Unlike both analog AMPS and IS-54, the CT-2 air interface uses a fixed low power of 10-mW peak (5-mW average). The impact of the CT-2 choices are low battery drain inexpensive handsets but at the price of low spectral efficiency (one voice circuit per 100-kHz channel) and at the further cost of a large number of base stations to provide high-quality coverage at such a low transmitter power level of 10 mW.

UDPCS—Universal Digital PCS was proposed by Bellcore as a wireless loop replacement but is being considered for mobile services as well. UDPCS provides the same high voice quality of the 32-kb/s CT-2 air interface, but uses QPSK and time-domain multiple access (TDMA) to allow a much higher spectral efficiency than CT-2. The result is 10 voice circuits in a 300-kHz RF channel. A second less obvious impact of the 10-channel multiplex is a significant cost reduction in the base-station hardware. This cost reduction is due to the RF base station cost being more sensitive to the number of RF channels than to the cost of signal processing for the 10-channel multiplexing. While UDPCS maintains the high voice quality demanded by the PCS systems concept, it adds extra cost to the subscriber's handset, uses more battery resources, and does no better in spectral efficiency than analog AMPS.

PHP—Personal Handy Phone was developed by DDI (Japan) for mainly private use at home. However, PHP is also designed to support a public network PCS service as well. In terms of performance and complexity, PHP is positioned between CT-2 and UDPCS.

QCMDA—Qualcomm Code Division Multiple Access is the only example shown using spread-spectrum modulation to increase spectral efficiency. The claims for QCMDA include an increase in spectral efficiency above analog AMPS on the order of 10 times. The version of QCMDA is that proposed for PCS at 2 GHz. A higher power version is proposed for 800 MHz next-generation cellular. While the focus of QCMDA is upon the spread-spectrum modulation, there are a number of favorable attributes of the system that are not due to spread spectrum but are enabled by the use of spread spectrum. Because spread spectrum allows automatic allocation of bandwidth on demand, a variable rate speech coder can be employed. Therefore, on the average, a lower bit rate can be used without a reduction in voice quality. Spread spectrum also allows the use of a rake receiver to take advantage of multipath to increase signal quality, rather than suffer the fading effects of multipath with narrow-band TDMA signals. Finally, CDMA allows for soft handoffs between cell sites when the handset is in motion. The CDMA claims are based upon the need to control all handset power to very narrow tolerances. There continues to be some concern that this may cause operational problems in fully loaded systems. Furthermore, the CDMA signal processing adds cost and battery drain. Perhaps the greatest benefit of CDMA may be in the

increase in the communications range for a transmitter power level comparable to a TDMA system. This increase is due to the reduction in fade margin due to the rake processing to overcome multipath.

Examination of the PCS air interfaces reveals there is no current winner, but only a series of tradeoffs. If one is true to the PCS vision of high voice quality, low-cost handset, and long battery life; then the IS-54 choice can probably be ruled out.

B. Cell Structure

The cell structure shown in Fig. 5 refers to size of cells, whether the cell size is fixed or variable in size, the allocation of channels between cells and design rules relative to frequency reuse. The major difference between PCS at 2 GHz and today's 800-MHz cellular is likely to be in the cell structure. While cellular has variable cell sizes, up to 8-mi radius, PCS will likely need very small cells sizes on the order of 500–1500 ft. The PCS vision requires long battery life and high capacity, the long battery life limits transmitter power and therefore communications range. The high capacity also forces small cell size to limit the number of subscribers per base station to allow a large system capacity. These small cells have been termed microcells and the term microcellular is often used to refer to systems supporting PCS.

A typical PCS network would use uniform microcells with a high degree of frequency reuse. The size of the cell is determined to a first order by the transmitter power, the nature of propagation loss between the base-station antenna and the handset, and the desired quality of coverage objective. In this respect PCS will likely differ from cellular in all three aspects.

- Transmitter power—the handset power will likely be in the 10- to 100-mW range to keep battery drain low.
- The propagation loss in cellular is generally given by the plane earth model while in the case of microcells a more complex model is generally used where there is a transition from free space loss to a higher loss exponent on the order of plane earth [10]. In addition, in PCS there is assumed to be a large excess fixed loss above that of the distance-sensitive term. The fixed loss is assumed to be due to urban clutter in the path between the microcell base-station antenna and the handset.
- The quality of coverage objective in PCS is generally assumed to be much higher than in cellular. A typical cellular design objective is to be above minimum levels 90% of the locations. In the case of PCS, however, the assumption is that consumer users will require in excess of 95% of the locations.

The net impact of lower power, a high propagation loss, and a high coverage quality objective lead to coverage on the order of 500–1500 ft depending upon the specific air interface [11].

While the drawing in Fig. 5 implies full coverage of the designated service area by microcells, there is an alternate cell structure that uses only spot coverage.

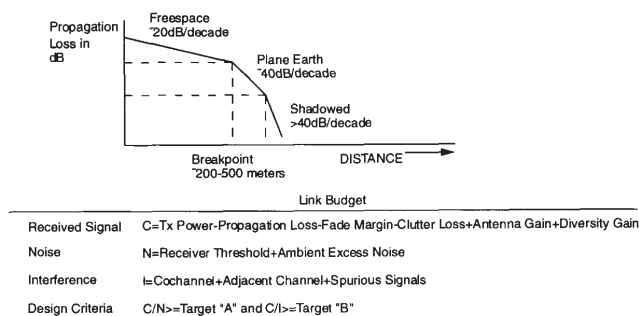


Fig. 6. PCS microcell propagation model.

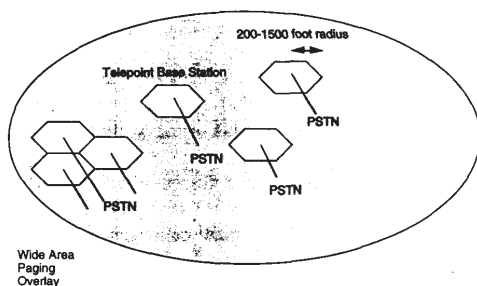


Fig. 7. Telepoint cell structure.

In this Telepoint architecture, the cells are of the same radius as other PCS networks, but the cell clusters and single cells need not provide full coverage. An optional wide-area paging system can provide full coverage alerting of incoming calls but calls can only be returned when within the range of a particular telepoint cell or cell cluster. Such a system can reduce the microcell count as well as the backhaul network demands. This can result in much lower costs. In the case of Fig. 7 above, the back-haul network is shown to be a direct connection to the public switched telephone network (PSTN) at the microcell.

C. Back-Haul Network

One of the consequences of the Fig. 5 microcell cell structure is a large number of microcells. This places great demands on an extensive back-haul network to link the microcells together. There are several architectural variations here as well. Perhaps the most important choice is the nature of the signal being carried over the back-haul network. Two extreme choices include RF transport and voice circuit transport. These options are shown in Fig. 8.

The remote and distributed antenna option uses the backbone fiber or coaxial-cable system to carry RF signals to base stations which are located at some significant distance away, perhaps all at a single centralized location. The other extreme is to locate the base stations at each microcell antenna site and then use the back-haul network

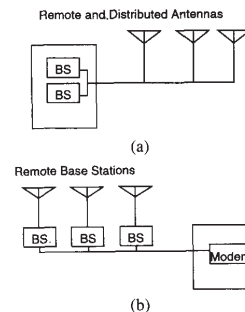


Fig. 8. Back-haul network options. (a) Remote and distributed antennas. (b) Remote base stations.

to carry voice circuits to a centralized switch. There are options in between where some elements of the base station may be at the microcell and other elements at the opposite end of the back-haul network.

In the implementation of PCS, it is quite likely that existing telephone or cable TV outside plant can be used to reduce the costs of implementation of these networks. Cable TV networks would offer the advantage of supporting either RF or voice circuit transport.

D. Switch and Operations Support

While the most simple system would place few demands on a switch beyond that of a conventional wired network switch, the PCS service concept demands a high degree of intelligence to support mobility, call management, personal numbering, in addition to an expected number of additional value-added services (e.g., voice mail). While not required, it is also likely that a number of operations support systems will be integrated into, or closely coupled to the switch. Operations support requirements for PCS include the same basic billing, test, and maintenance functions required by the wired network; however, PCS places a number of special demands on operations support that go beyond the needs of the public switched wired network. For example, billing is likely to be quite complex as rates may vary as a function of location, degree of mobility,

value-added features invoked, and settlements between connecting carriers. Maintenance and test is likely to be quite complex as the network will likely consist of a complex hybrid of distributed intelligence and a mix of wired and wireless transmission paths. Finally, operations support is complicated by a likely need to allow mass market sales and distribution channels to have access to new account activation and number provisioning.

IV. SUMMARY AND CONCLUSION

PCS has been shown to involve a large number of choices, each with technical, economic, and regulatory tradeoffs and a need to make these choices in the face of an uncertain set of customer demands. While there is no clear *winning* architecture, the tradeoffs are clear. Consumers are ready for PCS services, the benefits to society in increasing both our productivity and pleasure await the FCC's release of spectrum and a regulatory framework. As system operators begin to build PCS networks consumers will vote with their dollars and select the *right architecture*.

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