Table A-1 shows a small sample of the technical parameters of nine systems based upon FDMA, TDMA or CDMA radio system technologies.[6] The variance in technical parameters between the cellular and cordless standards stems from the different characteristics of these services. Cordless handsets transmit over short distances, ranging from 30-meters indoors to 150-meters outdoors, at very low-power levels on the order of 10 mW. In addition, speech voice coders in the handset operate at much higher rates -- 32 kilobits per second (Kbps) versus 8 or 13 Kbps -- to improve service quality, lower equipment costs, and keep handset power requirements to a minimum (a lower speech rate requires more signal processing to reconstruct or transmit a voice channel in real time). Thus, the duplex channel size for a cordless system is much larger at over 100 kilohertz (KHz) than the cellular standard.

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[6]The cellular and cordless technologies listed in Table A-1 are:

1) Advanced mobile phone service (AMPS) is the current analog cellular standard in the United States. A Narrowband AMPS (N-AMPS) standard has been proposed which would expand network capacity by a factor of 3 by decreasing the duplex RF channel size to 20 KHz.
2) United States cellular interim standard (IS) 54 is set by the Telecommunications Industry Association (TIA) and uses the same carrier spacing as AMPS. IS-54 systems are being deployed this year in a few major cities.
3) The Groupe Special Mobile (GSM) standard for cellular service has been initiated by 15 European countries. Begun in 1987, the ambitious GSM standard was due to be introduced across Europe by July of 1991 but has encountered serious implementation delays. Many operators remain hopeful that they can start up GSM systems within the next two years. See Taylor, Jack T. "PCS in the U.S. and Europe." *IEEE Communications Magazine* June, 1992. 48-50.
4) QCDMA represents a spread spectrum system developed by Qualcomm, Inc. for PCS and cellular applications. See (Gilhousen, 1991).
5) RCMA represents a spread spectrum system developed by Rockwell International for PCS applications. See (Rockwell, 1992).
6) First generation Cordless Telephones (CT) are generally interoperable only with the type of base station bought with the telephone. United States systems employ narrowband frequency modulation (N-FM) with 10 channels.
7) CT2Plus is a second generation cordless telephone developed by Northern Telecom and Motorola that uses digital voice coding but the same FDMA techniques as CT. A CT-2 handset can initiate, but not receive, calls -- a service also called telepoint. CT2Plus would allow call handoff between cells at low speeds and includes a common air interface (CAI) standard which would allow all handsets and base stations to interoperate.
8) The Universal digital PCS (UD-PCS) system proposed by Bellcore enables a handset to operate with a network of base stations connected to the public switched network. See Bellcore (1990).
9) The digital European cordless telephone (DECT) standard is a third generation cordless system developed by Ericsson in Europe, mainly designed for in building uses, where handsets can both initiate and receive calls.

Parameter	AMPS	IS-54	GSM	QCDMA	RCDMA	CT	CT2Plus	UD-PCS	DECT
Radio Access Method	FDMA	TDMA /FDMA	TDMA /FDMA	CDMA/ FDMA	CDMA	N-FM	TDMA/ FDMA	TDMA/ FDMA	TDMA/ FDMA
RF Chan. Size	30KHz	30 KHz	200KHz	1.25MHz	40 MHz	20K	100	700 KHz	1.7 MHz
Chan. Rate	-	48 Kbps	270.8 K	10 or 32K	20 or 40K	-	72 Kbps	514 Kbps	1.1Mbps
Voice Chan. per RF Chan.	1	3	8	20-60 per sector	126	1	1	10	12
Duplex Voice Channel Size	60KHz	20 KHz	50 KHz	-	-	40K	100KHz	70 KHz	144KHz
Voice Bit Rate	-	8 Kbps	13 Kbps	8 - 32 K	16 Kbps	-	32 Kbps	32 Kbps	32 Kbps
Handset XMIT Power: Max/ Avg (mW)	600 /600	3000 /200	1000 /125	200 /6	100 /1	≤ 10	10 /5	100 /10	250 /10
Max. Cell Radius	> 32 Km	> 32 Km	32 Km	2.5 Km	450 meters	100 m.	100 meters	500 meters	500 meters

Sources: (Bellcore, 1990; Gilhousen, Jacobs, et al., 1991; Kucar, 1991; Rockwell, 1992). Both IS-54 and GSM standards anticipate twice the capacity within 5 years by halving the rate of each voice channel.

Table A-1. Comparison of Cellular and Cordless Radio System Parameters

At this early point in the development process, it is difficult to evaluate between TDMA and CDMA technologies. The complexity of equipment appears roughly comparable. The most significant difference is that users of a CDMA system all share the same channel, but are assigned a unique spreading code to minimize mutual interference, whereas a TDMA system designates a separate frequency and time slot to avoid interference.[7] Thus, mutual interference places a "soft" limit on the capacity of CDMA system -- whenever the number of users exceeds some ceiling, all the connections are maintained albeit at a lower quality level -- whereas the time slot size relative to the overall bandwidth places a "hard" limit on the capacity of a TDMA system which cannot be exceeded under any

[7]This property raises the possibility that a CDMA system could operate over the same range of frequencies as other spectrum users without causing significant harmful interference. Field tests have demonstrated that a CDMA system can operate in the same spectrum as microwave users, although precautions need to be exercised to minimize disruptive interference. See Schilling, Donald L. et al. "Broadband CDMA for Personal Communications Systems." *IEEE Communications Magazine* November 1991, p. 86-93; and Telesis Technologies Laboratory. *Experimental License Progress Report to the FCC.* February, 1992.

circumstances.[8] The improvement in cochannel interference tolerance of proposed digital systems reduces C/I objectives from current analog FM ratios of 18 dB to 9-13 dB for TDMA systems (Calhoun, 1988), and 5-8 dB for CDMA systems.

Equally uncertain is the extent to which TDMA and CDMA approaches could increase network capacity relative to current cellular systems. Compared to cellular networks using AMPS, the IS-54 TDMA standard would increase the number of available channels by 3 to 6 times; CDMA systems are predicted to increase the available channels by 18 times (Gilhousen, Jacobs, et al., 1991), although this number must be treated only as an estimate until further field experience can be obtained.[9]

Because the uncertainty surrounding the costs of TDMA and CDMA equipment is sufficient to make any cost differentials between these two technolgies indistinguishable, cost estimates in the engineering cost model do not assume explicitly either a TDMA or CDMA radio access technology. Instead, given the 5-year time horizon of this study, the base case model assumes a radio access technology that offers more than twice the capacity relative to current cellular networks (*i.e.*, a duplex traffic channel size of 25 KHz and the same frequency reuse factor of N=7). By keeping the reuse factor unchanged, and the channel size relatively large, this base case allows the improvements made available by digital technology, such as lower C/I and power requirements, to be applied to improve service coverage and service quality.[10] The sensitivity analysis, however, does explore the impact of decreasing the frequency reuse

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[8]Of course, the network requires capacity and equipment for each subscriber connected to the network. Thus, the "hard" limit for a CDMA network may no longer be set by the spectrum available in the wireless link, but the capacity of the network switching and transmission equipment.

[9]The two factors which make the capacity of a CDMA system much larger than a AMPS system are an assumed frequency reuse pattern of N=1, which provides a seven-fold increase, and the use of digital speech interpolation (because speakers are active only 37.5 percent of the time during a call, these gaps in the call can be filled with blocks from another call). Making similar assumptions regarding the amount of time a speaker is active, Hughes claims their *extended* TDMA system provides 15 times the capacity of AMPS. See *Telecommunications Reports*, p. 23-24, May 25, 1992.

[10]Even though it is stated throughout this study that the PCS network offers "ubiquitous" coverage throughout the service area, a 100 percent level of service coverage is not practical due to propagation variations. Service coverage can be characterized as a probability distribution function based upon a particular link budget. For example, today's cellular systems usually try to cover 90 percent of an area in flat terrain and 75 percent of an area in hilly terrain assuming a C/I ratio of 18 dB (Lee, 1989). Thus, improved service coverage could be obtained by either increasing the link budget to illuminate weak spots in the coverage pattern or, alternatively, by choosing a dynamic power control scheme to compensate for some percentage of the variations in the power budget.

factor to N=1 consistent with the use of a CDMA radio access technology, and use of different channel sizes, and the impact on total costs due to variations in the cost of radio system components.

Network Signalling and Database Requirements

Beyond the hardware necessary to deliver PCS on a large scale, there are significant logical or network operations capabilities essential to the provision of PCS as well. A highly touted feature of PCS is "personal number" service where a telephone number would no longer be associated with the location of a telephone line or a mobile telephone, but instead with an individual subscriber.[11] To manage this mobility, a PCS network must be capable of routing incoming calls to the correct location, charge on the basis of the personal number, interconnect calls among different networks, and authenticate the user by personal number on a real time basis (CCIR, 1990b). It is anticipated that an important network management tool in this regard will be the user profile, a database record associated with each personal telephone number that profiles the subscriber's individual preferences and current location (Nguyen, Tam, et al., 1991).

Switch manufacturers and telephone companies have already started to develop the network intelligence required to manage mobile services. The vehicle for this functionality is the advanced intelligent network (AIN). PCS has been touted as one of the lead service drivers of this new technology (Homa and Harris, 1992). When a call is placed on the current telephone network, the switch establishes the connection according to the *call model* (embedded in the switching software) that defines what steps, or check points, are executed during the call. The AIN specifies a new call model with a new set of steps, or check points which depend upon external processors in the intelligent network to operate.

The network intelligence to interact with the call model can be located either locally, in the form of adjunct processors, or centrally in large intelligent network nodes. While it is premature to know how the network intelligence will be distributed throughout the network to offer PCS, preliminary studies suggest hierarchical approaches to mobility management are the most promising (Northern Telecom, 1992). In any event, the AIN will increase network signalling traffic, and personal number service -- whether offered in conjunction with PCS

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[11]Early versions of personal number service are now available to cellular and long distance subscribers. Currently, these services allow subscribers to automatically forward their calls to predetermined locations, or receive a lifetime number. See, for example, "Bell Atlantic Plans Service That Links Phone Numbers," *New York Times*, D7, March 17, 1992; see also AT&T News Release, April 28, 1992. Future personal number services anticipate a network capable of automatically tracking subscribers' locations through their handset and forwarding calls to any location, if desired.

or otherwise -- will engender even more signalling traffic.[12] The price for adding these enhanced features into the PCS network is a more complex call model, which will consume a commensurate increase in the real-time processing power of the switch (Homa and Harris, 1992). Without an advanced signalling network platform, however, the call set-up times for roamers throughout the PCS network will suffer greatly (Jabbari, 1992).

In calculating switching costs, the engineering cost model assumes a 50 percent increase in processing power at the switch relative to today's telephone switch is necessary to execute the AIN call model required for PCS. The model does not consider the costs of interoffice transport facilities and centralized intelligent nodes. Except at very low-penetration levels, the costs of these facilities are not likely to be significant on a per subscriber basis because this equipment can be shared among many users. For example, even if an intelligent node costs several million dollars, it is expected to support roughly 1-million subscribers at a cost of several dollars per subscriber.

Link Between Service Demand and Network Architecture

A clear understanding of PCS can only emerge from detailed knowledge of how consumers really want to use these new technologies. It is difficult to define or describe PCS because a clear description of these markets has yet to emerge. While it is obvious that the nature of the demand for mobility and portability will strongly influence network design, uncertainty regarding the characteristics of this demand make it difficult to select the network architecture best suited to deliver PCS.[13] This discussion examines how the characteristics of the demand for PCS could influence the design of the network infrastructure, and the relevant assumptions incorporated into the engineering cost model.

So far, this paper has advanced the notion that virtually all wireless applications fall into a broadly defined category of PCS. Indeed, potential wireless

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[12]One way the network can track users' locations is by monitoring handset locations and storing this information in a large database. This approach has been applied in the development of the TIA IS-41 standard which is derived from the GSM standard. This approach maintains two network registers. The home location register (HLR) holds billing validation and subscriber profiles; the visitor location register (VLR) holds the local records of roaming subscribers. If a subscriber moves to a "visited" location, the "visited" location updates the "home" location database through signalling between the handset and network. When a call is placed to the roaming subscriber, the network queries the HLR for the current customer location, which routes the call to the appropriate VLR for completion. See (Jabbari, 1992; Nguyen, 1991).

[13]A number of the experimental PCS licenses granted by the FCC are marketing trials which seek to learn the strength of consumer preferences for different service functionalities such as mobility and handset portability. For example, see "GTE launches nation's largest PCS customer trial," GTE Press Release on August 25, 1992.

services span a diverse set of applications including voice, voice messaging, electronic mail, facsimile, data transmission, paging, dispatch, archive and inventory information, to name but a few. Yet each application generates different signalling and network capacity requirements. Mobile voice service requires a two-way circuit of sufficient bandwidth, and constant network management throughout the call. In contrast, a paging service only needs a one-way connection of very brief duration, and data services can tolerate substantial delay in transmissions. Consequently, a network optimized to deliver voice service will be very different than one optimized for paging, data, or other wireless applications. This connection between network architecture and network services underscores the importance of clearly defining the network services incorporated into the engineering cost model, since costs can be expected to vary widely with different sets of services.

This study assumes the primary objective of the PCS network is to deliver voice services (*i.e.*, establish two-way interactive channels) using small portable handsets. Three observations suggest this level of functionality is appropriate:

- The demand for wireless voice service is already well-founded as demonstrated by current cellular and cordless markets. In contrast, the mass-market appeal for other wireless services, with the exception of paging, remains speculative.
- The lack of wide-spread, small, lightweight handsets with a large coverage area in today's market suggests a market opportunity for this service. To be sure, this window is a temporary one, in recognition of the rapid progress made by manufacturers in producing lighter and smaller cellular portables.
- A digital network providing voice service has the capability to carry the great majority of other wireless services (although whether it is the most efficient means of distribution is an another question).

Where economies of scope prove to exist between different wireless services will determine the eventual mix of PCS offered over a single network. Again, this paper makes no assumptions regarding what this mix of services may evolve to be, only that voice services using low-power handsets will be driving the deployment of PCS networks in the subscriber loop.[14] Indeed, PCS providers

[14]Because digital signals are more easily combined than their analog counterparts, high expectations of service integration often accompany deployments of digital technology. Thus it is not surprising to find that GSM has been described as a "mobile ISDN" standard because of its digital format, the large number of services it can provide (e.g. facsimile, paging), and the dedicated signalling channel. Historically, many of these expectations have proved to be premature, mainly because the broadest common denominator is often not the most efficient means of distribution. For example, even though the concept is nearly a decade old, the roll-out of a narrowband ISDN has yet to reach most consumers in the United States. Likewise, deployment of broadband ISDN has been slowed by the lack of economies of scope between narrowband and broadband services (Reed, 1991, Chapter 5).

probably will try to integrate other complementary applications with their voice service. The presumption, however, is that the demand for these complementary services will not be great enough to change the network architecture in a manner more suited to the particular characteristics of these services.

Subscriber Location and Velocity

A key question is the immediate circumstances under which consumers are likely to use wireless services. Two important service attributes in this regard are the subscriber location -- whether the call takes place indoors or outdoors -- and the velocity of the subscriber during the call.

Subscriber Location

Whether a PCS network will be designed to offer services to subscribers located both inside homes, apartments, or offices and outdoors is a question with major implications for network design. PCS providers may view the portable indoor communications as an attractive market to enter.[15] Moreover, if the cost is reasonable, consumers are likely to have a strong preference for one handset that can be used in all these environments.

To operate indoors through an outdoor base station, however, PCS handsets would need sufficient power to overcome path loss through the walls of homes. The penetration losses that occur as radio signals travel through ceilings and walls average 20 dB for large buildings (Cox, Arnold, et al., 1987). Thus, a PCS network optimized for outdoor calls will provide much lower circuit quality for most indoor calls.[16] Designing a PCS system to offer both indoor and outdoor coverage will therefore increase system costs. For instance, a system for indoor and outdoor coverage would require smaller cell sizes, higher radiated power levels, larger antennas, or more efficient radio access and modulation techniques.

The question, then, is whether PCS systems which provide coverage over a wide area can viably offer indoor services in light of the alternative wireless services available. In particular, a PCS system offering indoor coverage from outdoor microcells will be competing with cordless telephones using the existing telephone network. The profusion of cordless telephones -- over 30 percent of U.S. households now own one -- demonstrates the popularity of the inexpensive low-

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[15]One study estimates that cordless residential telephony will account for 33 percent of the PCS market share in 1995, while high-speed hand-off and walking hand-off services will account for 13 percent and 8 percent of the market share, respectively. See Clifford Bean, "Outlook for Wireless Personal Communications in the United States," Eastern Communications Forum, Rye Brook, NY, 1992.

[16]Cox, et al. offer a simple model to demonstrate that "if indoor users are served on a system originally designed to give good service to 90 percent of the outdoor users at some chosen radius, then only 16 percent of the in-building users will receive that same service. (In practice, many of the call attempts from in-building units will fail, so that the probability of good service (given that it was possible to start the call at all) will be higher.)" See Appendix in (Cox, et al., 1987).

power handsets in households. Even supposing that a PCS system could provide an equivalent quality of indoor coverage, an advantage of cordless service could be the apparent lack of "air-time" charges for use of the spectrum. Today, consumers enjoy the benefits of cordless service at no incremental costs above their regular telephone rates. Against this benchmark, PCS systems will need to offer an indoor cordless service at a cost comparable to normal telephone rates plus "free" air-time charges.[17] These formidable technical and economic factors will influence how PCS providers will introduce their services. Within these constraints, two strategies for providing indoor and outdoor service over one handset can be imagined.

Setting Aside Spectrum for Indoor Cordless Applications. The PCS operator could set aside a portion of its spectrum for indoor cordless services. When indoors, the handset automatically senses the presence of a private base station and acts like a cordless telephone. The cost of indoor calls would be reflected in the monthly bill for telephone service. When outdoors, the subscriber is linked using the same handset to a network of macrocells or microcells optimized for outdoor coverage. A PCS provider could coordinate these services by distributing its own private cordless base stations for residential use in conjunction with its outdoor wireless services. One advantage of this approach is that it allows the PCS provider to integrate indoor and outdoor service features into a seamless package that is completely transparent to the user. A PCS provider could also assure the quality of its indoor service because it has full control to manage the interference within its exclusive spectrum assignment.

Using a Common Allocation for Cordless Applications. Instead of setting aside a portion of its spectrum allocation, the PCS provider could use a spectrum allocation available for unlicensed cordless telephone applications, such as the allocations near 49 MHz or 915 MHz in the United States. In addition, the FCC has proposed allocating 20 MHz out of the 2 GHz emerging technologies band for unlicensed applications such as indoor cordless telephone (FCC, 1992a). The PCS provider would still be able to offer customers indoor and outdoor coverage over a single handset, although it would forfeit the ability to manage the quality of the indoor service over the unlicensed spectrum allocation. The PCS provider also might be constrained by a more limited set of features available in the cordless phone mode.

Whether these two options or other approaches eventually gain the most acceptance cannot be predicted at this time. In this paper, all cost calculations assume PCS providers set aside 1 MHz of their spectrum allocation for indoor cordless service. This approach appears to minimize infrastructure costs while

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[17]There is a cost to the use of the spectrum for cordless service -- measured by the highest amount that would be paid by another application for the use of this spectrum. Because the spectrum used for cordless services is not licensed to one supplier, there is no charge for using the spectrum in spite of the opportunity costs for using these frequencies in this fashion. Conversely, subscribers may opt to pay more for indoor services from a PCS network to avoid crowded conditions on the cordless frequencies.

still providing ubiquitous, easy-to-use service on one handset. While technology advances and more innovative approaches to spectrum management will increase the availability of spectrum, the overriding objective at the outset of deployment will be to minimize infrastructure costs, and designing a wide area microcell network to provide toll quality indoor service does not serve this goal.

Subscriber Velocity

The degree of mobility most frequently requested by subscribers also could hold substantial implications for the design of the PCS network. Whether walking down the street or driving on a highway, subscribers need the same network functionalities but at different speeds. Specifically, the processing speed and volume of network signalling and control functions increase directly with the velocity of the subscriber and inversely with the average cell size. As noted earlier, the extent to which these factors will determine the network architecture remains highly uncertain, and depends in large part upon the costs of network complexity and the power requirements of the handsets.

The model incorporates estimates which assume aggressive reductions in the costs of network handoff, power control, and signalling using microcells. Within this environment of significant uncertainty, however, these assumptions might be overly optimistic for the smaller-sized microcells considered in the model. As a result, the sensitivity analysis examines the sensitivity of network costs to this factor.

Usage Characteristics

Another highly uncertain factor is the rate at which consumers might opt to sign-up for new PCS. Fueled by the explosive growth of cellular and cordless services, a number of marketing studies forecast large markets for PCS featuring lightweight handsets. For example, a US West marketing study predicts 21 percent of the population would subscribe to PCS assuming a low-cost handset with adequate capabilities (US West, 1991). The model in this paper estimates network costs under static assumptions regarding subscriber penetration and usage levels. The analysis makes no assumptions regarding the price elasticity of PCS, or cross-price elasticities between PCS and other wireless services that could ultimately influence the strategy of network evolution.

The same traffic engineering principles applied to calculate the size of cellular or telephone networks can be used to determine the necessary capacity of a PCS network. The expected level of subscriber traffic during the peak usage hour determines system capacity. But unlike traditional telephony, high usage of PCS during the peak hour also translates into a need for more spectrum, or more efficient radio transmission links. Additional capacity to accommodate growth is acquired by lowering the spectrum reuse factor, cell splitting, or by improving the radio access technology. Thus, as usage increases, either the number of cells or the complexity of equipment, or both, must also increase.

The expected number of customers and the average offered traffic per subscriber in the peak usage hour are key parameters in the engineering cost model. Telephone networks enjoy near universal penetration of households with

a typical residence generating 0.1 erlangs per line during an average busy-hour.[18] In 1991, cellular telephone services had roughly 9-million subscribers who offer an average of 0.02 - 0.03 erlangs of traffic during the average peak hour. Because the diffusion rate of PCS will be highly uncertain, this value is treated as a parameter in the cost models. The model assumes as a base case that each PCS subscriber generates 0.03 erlangs of mobile traffic on average during the peak hour and that there are an average of two subscribers per household. The sensitivity analysis examines how costs vary with levels of offered traffic by subscribers.

Planning for Network Evolution

Over time the demand for wireless services will vary depending upon new growth, introduction of new services, or other changes in patterns of consumer choices. The dynamic nature of demand translates into the need for a network infrastructure which can be flexibly modified to efficiently accommodate new patterns of usage. *Network evolution* is the process through which planners change the network architecture in order to satisfy new patterns of demand or incorporate new technologies into the network. To remain commercially viable, PCS network architectures should have the capability to evolve to reflect the growth in wireless service demands and technological innovations.

One attractive aspect of cellular design is that the network can evolve to accommodate new traffic demands through the process of cell splitting. Cell splitting permits a strategy of network evolution which begins with a few, large-sized cells when there are a small number of subscribers and progresses to a large number of microcells in those areas where traffic growth warrants the additional investment in network capacity. Service quality will place a lower bound on the number of large cells initially deployed in the network. In particular, low-power handsets could constrain the maximum cell size available for a given level of service quality. Once an acceptable service coverage region is achieved, the amount of spectrum available and the rate of growth will determine the number of new cells created by cell splitting.

The cost model assumes a system that is initially designed to provide coverage throughout the entire service area. As noted above, the penetration level of PCS subscribers is a model parameter. This usage level and the size of the spectrum allocation determine both the network capacity and number of cells needed in the network. For a given spectrum allocation size, the model calculates the largest microcell size possible for a given level of usage. Thus, the model calculates the long-run average costs of building the PCS network assuming smaller cell sizes are needed as the subscription levels rise. The output is a matrix of values with the spectrum allocation size and subscriber penetration parameters as indexes.

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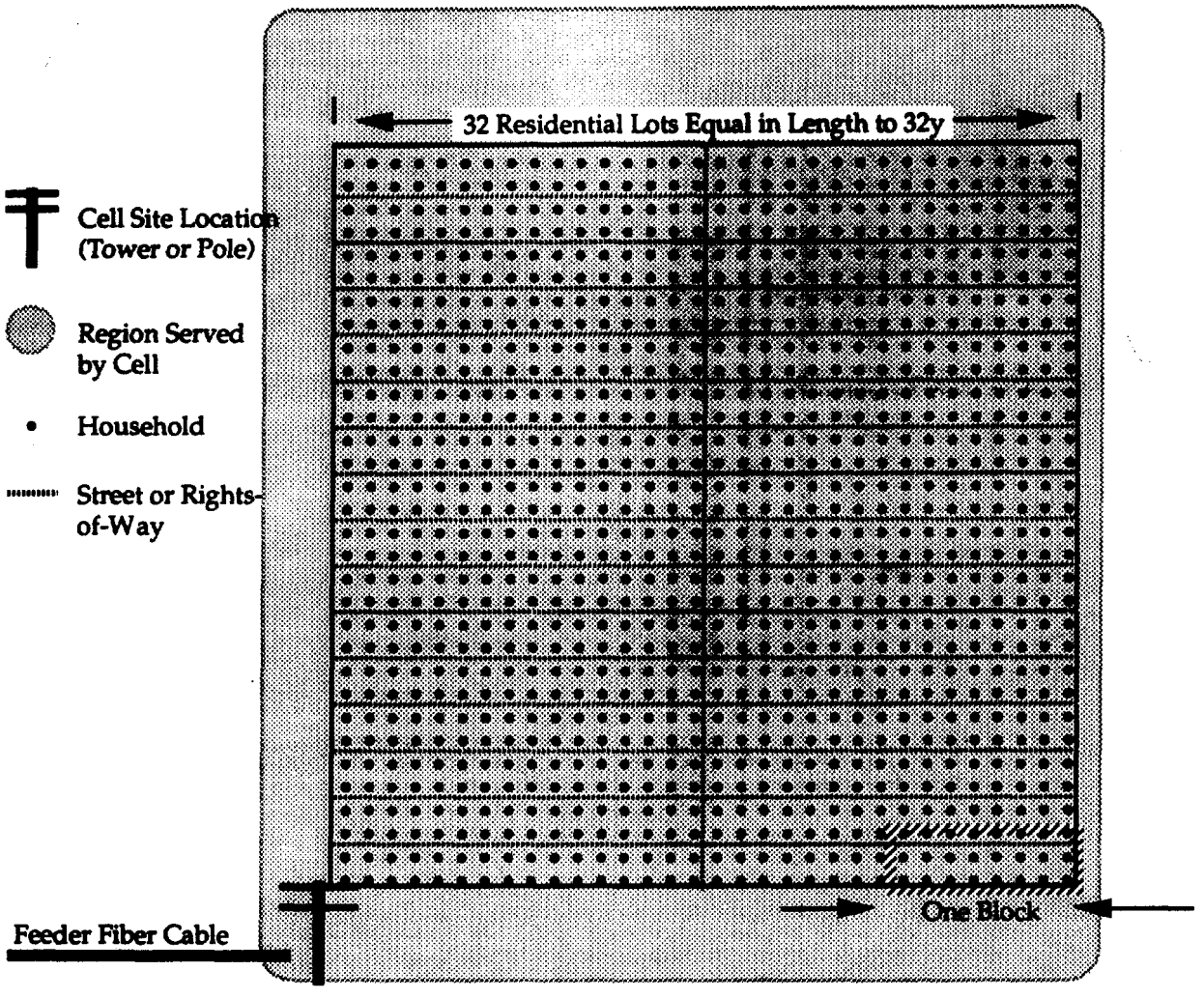
[18]Erlangs are the unit used to measure the traffic load on telecommunications systems. Erlangs can be viewed as the ratio of the time that an individual circuit is busy.

Appendix B. Cable Layouts of PCS Networks



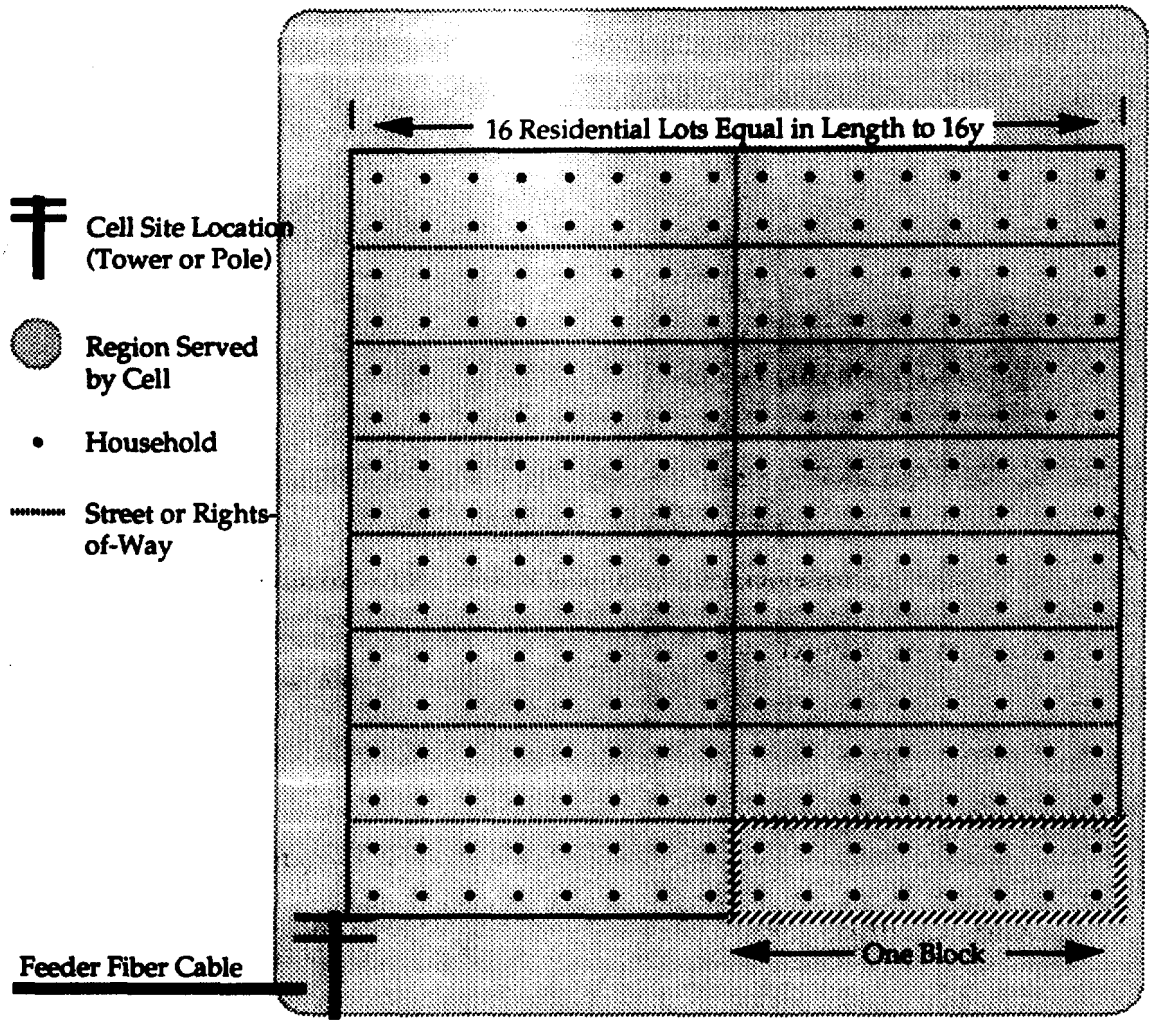
Calculations of Cable Length and Path Distance for PUS Network Using 1600-meters Microcells Throughout the Serving Area of 1024 Households

Number of Cell Sites = 1 per 4096 Households

Length of Distribution Cable and Path = 0

Radius of Cell = $32(\sqrt{2})y$

Figure B-1. PCS Architecture with 1600-meters Microcell



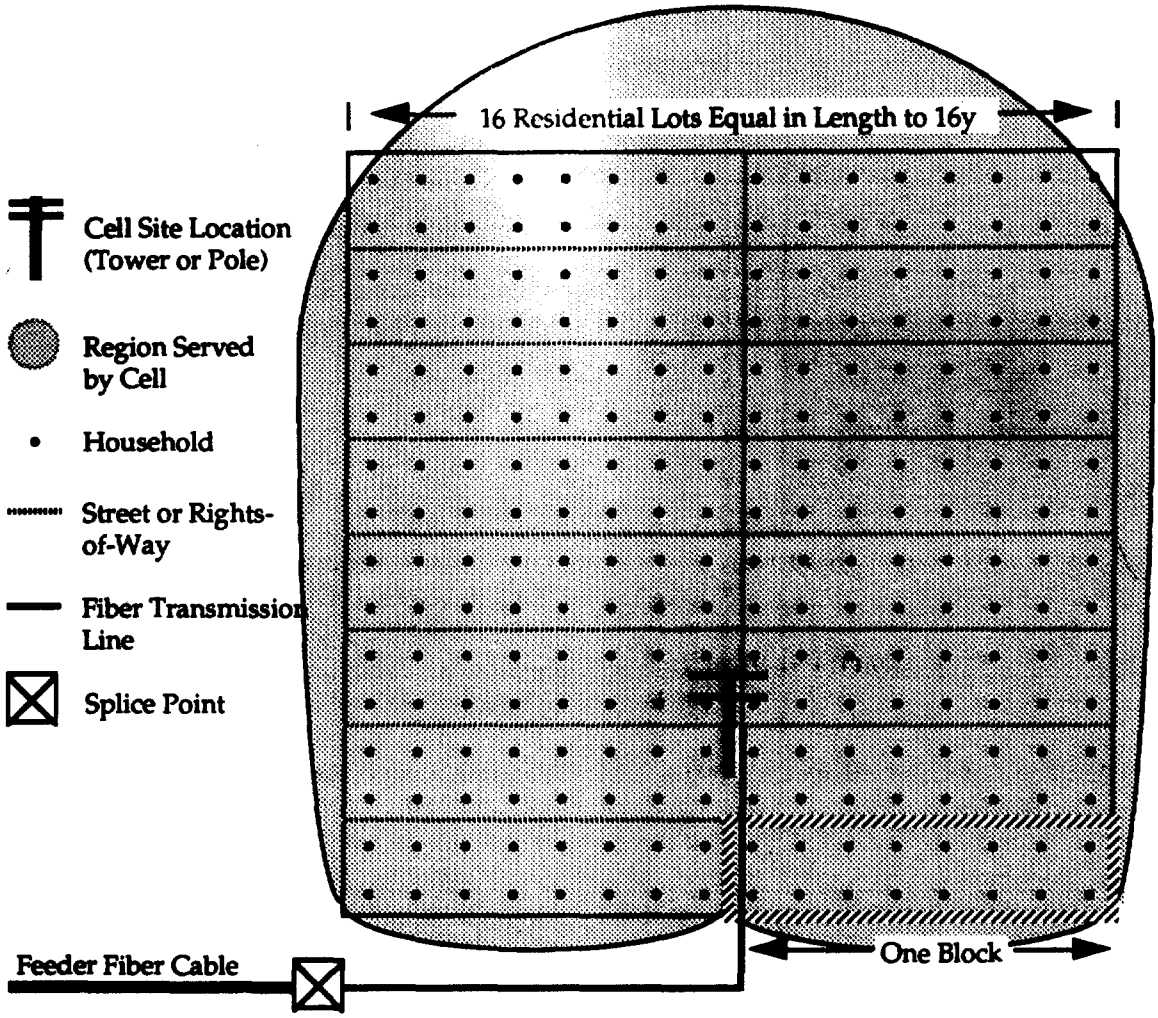
Calculations of Cable Length and Path Distance PCS Network Using 800-meters Microcells Throughout the Serving Area of 1024 Households

Number of Cell Sites = 1

Length of Distribution Cable and Path = 0

Cell Radius = $16(\sqrt{2})y$

Figure B-2. PCS Architecture with 800-meters Microcells



Calculations of Cable Length and Path Distance for PCS Network Using 400-meters Microcells Throughout the Serving Area of 1024 Households

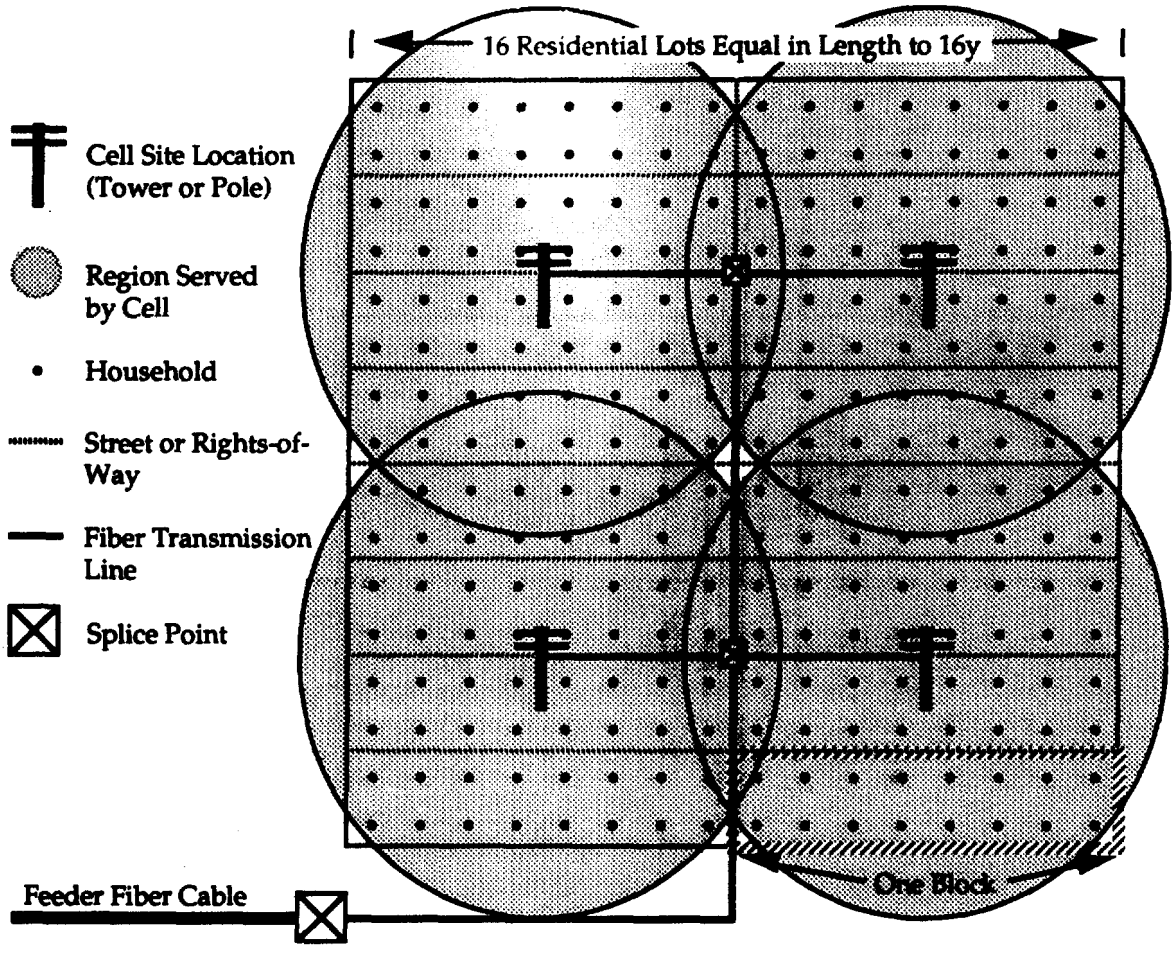
Number of Cell Sites = 4

Length of Fiber Cable = 4*{4y+8y} = 48y (plus 12 streetwidths and 5% overhead)

Length of Path = 4*4y + 2*8y = 32y (plus 10 streetwidths)

Cell Radius = 8(√2)y

Figure B-3. PCS Architecture with 400-meters Microcells



Calculations of Cable Length and Path Distance for a PCS Network Using 200-meters Microcells Throughout the Serving Area of 1024 Households

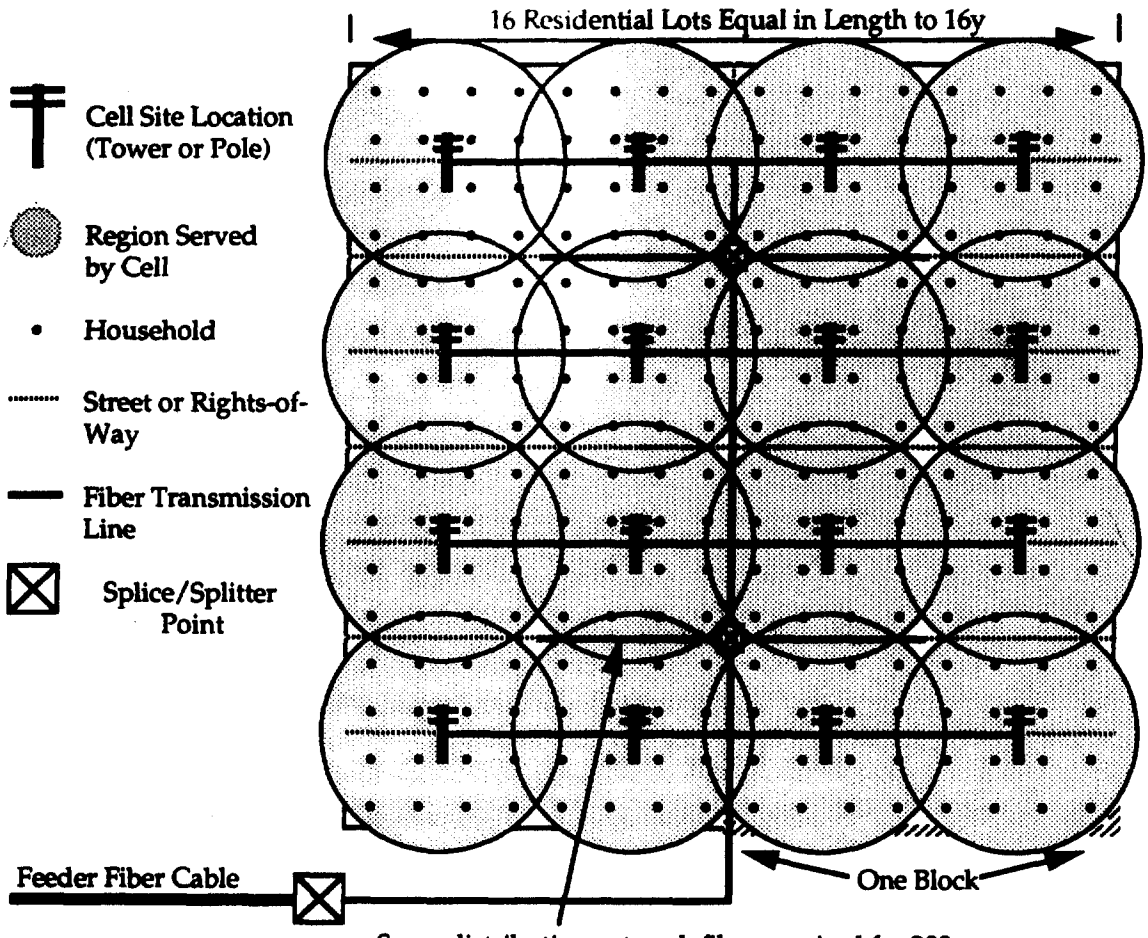
Number of Cell Sites = 4*4 = 16

Length of 4-Fiber Cable = 4*{12y+8y+2*8y} = 144y (plus 36 streetwidths and 5% overhead)

Length of Fiber Path = 2*8y+4*{12y+2*8y} = 128y (plus 34 streetwidths)

Cell Radius = 4(√2)y

Figure B-4. PCS Architecture with 200-meters Microcells



Some distribution network fiber required for 200-meters microcells is not used after cell splitting to 100-meters microcells.

Calculations of Cable Length and Path Distance for PCS Network Using 100-meters Microcells Throughout the Serving Area of 1024 Households

Number of Cell Sites = 4*16 = 64

Length of 4-Fiber Cable = 4*{12y+8y+2*8y+4*12y+2*4y} = 368y (plus 60 streetwidths and 5% overhead factor)

Length of Fiber Path = 2*8y+4*{14y+2*8y+4*12y} = 328y (plus 54 streetwidths)

Cell Radius = 2(√2)y

Figure B-5. PCS Architecture with 100-meters Microcells

Appendix C. Summary of Cost Model Base Case Assumptions

Parameter	Base Case Assumption	Comments
Average Offered Traffic	0.03 Erlangs/Subscriber	Assumes 2 call attempts per busy-hour; sensitivity analysis considers range between 0.01 - 0.12 erlangs per subscriber.
Subscribers per Household	2	
Radio Channel Size	25 KHz	Full-Duplex. Sensitivity analysis considers a range between 20 - 70 KHz.
Spectrum Reuse Factor	7	Sensitivity analysis considers a range between 1 -16.
Indoor Cordless Set-Aside	1 MHz	Amount of spectrum out of block size dedicated for indoor cordless applications.
Cell Sizes	100-meters to 1.6 Km.	Cell size depends upon amount of offered traffic.
Allocation Size	25 MHz	Model considers range between 1 - 40 MHz.
Grade of Service	1 percent	Network design assumes a 1 percent blocking probability using Erlang B formula.
Housing Density	88 homes per mile	

Table C-1. Base Case Assumptions for Cost Model

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