Wireless Local Loop Radio Systems

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Abstract

Wireless local loop radio, is expected to become a widely accepted technology for rapid access to network infrastructure by remote locations. Characteristics of a wireless local loop system are partially different from those in the mobile cellular system and therefore their design and planning require different considerations. This paper provides first an overview of the wireless local loop systems and then discusses the important design aspects such as the necessary fade margin to achieve a given availability, level crossing rate and average fade duration.

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I. Introduction

The technological developments in the wireless cellular area in recent years have provided opportunities for cost-effective service offering through deployment of the wireless local loop (WLL). Wireless local loop (WLL) uses radio signals as a substitute for copper to complete the “last mile” between the subscriber (premise) and the public switched telephone network (PSTN). Sometimes called radio in the local loop (RLL), such systems can be deployed as large fixed radio access (FRA) networks or as clusters of microcellular networks for low-mobility users.

Cellular systems aim at large coverage area of the base station (BS) and high user mobility. The penalty is the voice quality and relatively low data rate services with considerable delays. Cellular systems overlook the customers who may find the anytime, anywhere accessibility unaffordable or unnecessary but who want to use wireless phones in low-mobility environments like homes, offices, and shopping malls. The residential market which adopted cordless technology despite poor quality and limited range, and the success of the PHS (Personal HandyPhone System) in Japan show that a new market - the *low-mobility personal communications* - is going to emerge and deserves special consideration. WLL is one application of the low-mobility personal communications.

WLL is most often targeted towards rural areas or as a competing alternative to wired loops where wireline service is ubiquitous. Often, no subscriber mobility is assumed or it is limited to pedestrian type. WLL systems are disadvantageous as far as BS coverage area and user speeds. Their strength includes high-quality, low-delay voice and data capability. The expected quality of service (QoS) for WLL systems is very close to those provided by local exchange carriers (LEC). Thus, WLL systems represent a step in the process of service integration. Subscribers will benefit from seamless services (in-home, in-car, in-office, underground) and transparent features (wireline / wireless).

Basically, in WLL systems fixed subscribers will use directional antennas while pedestrian subscribers will use omni-directional antennas. In the following we will focus on fixed subscriber WLL systems. Because subscriber antennas are considered to be rooftop, propagation loss will be smaller than for wireless mobile. This will allow larger cells but will increase interference. Also, low mobility allows reduced carrier-to-interference (C/I) threshold as compared to C/I threshold values in mobile cellular networks. Thus, new cellular layouts with high frequency reuse factor are expected to be deployed.

Although a number of technologies can address the wireless local loop services, our focus here would primarily be on land-based radio and we will consider only digital WLL systems. The services in general may be voice, data, video, and multimedia. As the WLL provides an alternative to wireline access to network, the attributes of a fixed network subscriber will be most applicable. In other words, the Erlang traffic per WLL system subscriber is expected to be much higher than a mobile cellular terminal subscriber. Furthermore, no special handling of calls due to handoff would be required.

II. Available Technologies

As there are no definitive WLL standards, four categories of wireless technology are available for WLL implementation: analog cellular, digital cellular, PCN/PCS [1], and proprietary implementations. The appealing technologies for **high-tier WLL applications** include digital cellular, and PCN/PCS. Usually, high-tier WLL are intended for rural or sub-urban FRA. The **low-tier WLL systems** contemplate high capacity reduced-mobility urban applications. Preferred technology for low-tier WLL are PACS/PHS, and PWT/DECT, a division of PCS/PCN.

Different technologies will serve some applications better than others. Ultimately, the appropriate technology will depend on an array of application considerations, such as

- size and population density of the market (rural versus urban)
- service needs of the subscriber base (residential versus business; plain old telephone services (POTS) versus data access, etc.).

A. Cellular Radio

As a WLL platform, analog cellular has some limitations in regards to capacity and functionality. It is best suited for serving low-density to medium-density markets that don't require landline-type features. Analog cellular is expected to be used at least in short term and is forecast to account for 20% of the wireless local loop subscribers in the year 2000.

Digital cellular is expected to play an important role in providing WLL. It can support higher capacity subscriber than analog cellular, and it offers functionality that is better suited to emulate capabilities of advanced wireline networks. It is forecasted that approximately one-third of the installed WLLs will use digital cellular technology in the year 2000.

Although GSM currently dominates mobile digital cellular and provides high-quality voice, there has been little activity in using GSM as a WLL platform. Being designed to handle international roaming, it carries a large amount of overhead that makes it unwieldy and costly for WLL applications. In spite of these limitations, it is likely that GSM WLL products will be developed over the next few years.

CDMA appears to be the standard best suited for WLL applications [6]. It offers higher capacity than the other digital standards, and relatively high-quality voice. The main disadvantage of CDMA is that it is only now beginning to be deployed on a wide scale.

B. PCS/PCN

PCS/PCN incorporates elements of digital cellular and cordless standards as well as newly developed RF protocols. PCS/PCN has been designed specifically to provide WLL by the public wireless operator. Its purpose is to offer low-mobility wireless services using low-power antennas and lightweight, inexpensive handsets. **PCS** (personal communications services) is a broad range of individualized telecommunications services (personal numbers, call completion regardless of location, call management that gives the called party greater control over incoming calls, and so on) that let people or devices communicate regardless of where they are. **PCN** is primarily seen as a city communications system with far lower range than cellular (low-tier system).

The candidate standards for the WLL portion of PCS/PCN are: CDMA, TDMA, GSM, PACS, omnipoint CDMA, PHS, and digital cordless.

C. Proprietary Implementation

These systems are considered proprietary because they are not available on the public wireless networks and are typically customized for a specific application. They generally do not provide mobility. Proprietary systems are, therefore, positioned to provide basic fixed wireless telephony in low-demand and medium-demand density applications.

III. Low-tier WLL

The major radio interfaces characteristics for the low tier WLL systems are listed in Table I. The tradeoffs in selecting the parameters are discussed below.

A. Radio Interfaces

Speech quality and frame length

The desired toll-quality for WLL voice communications is not only reached by using 32 kb/s ADPCM coders. Frame erasure lengths have an impact on the recovery time of speech quality. Longer system frame lengths lead to longer speech frame erasures, which in turn lead to slower recovery of speech quality for the ADPCM decoders. For 2.5 ms erasures, the decoded speech signal recovers to within 3 dB of the error-free signal (in terms of signal energy) within 5 ms after restoring correct transmission for 80 percent of burst errors. For 10 ms erasures, the 80^{th} percentile delay for recovery is 35 ms.

Frequency planning

For low-tier WLL systems automatic frequency assignment procedures are considered for selecting individual radio port (RP) frequency channels. Besides the well-known dynamic channel allocation (DCA) new techniques have been developed which combine the principal advantage of dynamic channel allocation with new capabilities. In particular, pre-engineering of a frequency plan would be unnecessary. Furthermore, a similar performance advantage as in the fixed frequency assignment, such as elimination of blind time slots for channel assignment, elimination of call blocking due to resource blocking, and faster call setup and handoff times, are gained.

Seamless Handoff

When mobility is supported, in order to offload the network and to assure robustness of the radio link by allowing *reconnection of calls* even when radio channels suddenly become poor, the subscriber unit (SU) determines when and to which RP to perform the handoff. The key to seamless handoff is the fact that the old link is maintained on one slot while the new link is set up on another time slot. When the last is established, the (new) RP requests the controller to make a seamless handoff.

Traffic engineering

When used for fixed WLL, Erlang B formula is used to determine system capacity. When the system allows mobility, special traffic engineering applies [1]. For PWT, a 10:1 weighting factor between a blocked handoff and a blocked call is applied to ensure that handoffs will not be blocked. This reduces the capacity of the system compared to fixed usage. For PACS, no attempt is made to distinguish blocked handoffs from blocked calls.

Duplex techniques

FDD-based systems do not require adjacent radio port coordination and result in a much lower bit rate through the RF channel, hence a simple receiver. On the other hand, TDD, with only one RF channel per call, allows an easier implementation for dynamic channel allocation.

Table I Radio Interfaces

	DECT	***PWT-E***	***PHS***	***PACS (licensed)***
Modulation	0.5 GFSK α=0.5; Gaussian	π/4-DQPSK	π/4-DQPSK α=0.5; SQRT raised cosine	π/4-QPSK
RF channel separation	1.728 MHz	1.25 - PWT 1 MHz - PWT-E	300 kHz	300 kHz
Channel rate (Kbps)	1152	1152	384	384
Duplex technique	TDD	TDD	TDD	FDD 1850-1910 uplink 1930-1990 down
Voice coding	32 kb/s ADPCM	32 kb/s ADPCM	32 kb/s ADPCM	32 kb/s ADPCM
Time Slots per Frame	24 TS	24 TS	8 TS	8 TS
Traffic CH per RF	12	12	3	7
Frame duration	10 ms	10 ms	5	2.5 ms
Handset power (peak / average) mW	250 /	90 /	/ 10	200 / 25
Cell size (urban/rural)	150m/1-2km	150m/	/ 5 km	300 - 500m/
Frequency planning	DCA	DCA	DCA	QSAFA
Subscriber mobility	pedestrian (<10 km/h)	pedestrian (<10 km/h)	Pedestrian (<10 km/h)	basic SU <50 km/h enhanced SU < 100km/h

B. PWT/DECT

DECT is a *radio interface standard* developed mainly for indoor applications. PWT and PWT-E are DECT-based standards developed by the TIA in the United States for unlicensed and licensed PCS applications, respectively [2]. In order to efficiently utilize the bands in the USA, the PWT modulation was modified to π/4-QPSK.

DECT and PWT were originally designed as a radio system interface between a fixed part (FP) and a portable part (PP). The radio system will be used in conjunction with a wireline network (Figure 1). The interface between the two parts of the whole system is left as a vendor-implemented solution. There may be a local network (PBX or LAN) between the PWT radio system and the wireline network.

The FP is generically understood to have three major entities with specific functions:

- Radio fixed port (RFP) - terminates the air interface protocol
- Central system - provides a cluster controller functionality managing a number of RFPs
- Interworking unit (IWU) - provides all the necessary function for the PWT/DECT radio system to interwork with the attached wireline network; that can be: the public switched telephone network (PSTN), ISDN, and the packet-switched public data network (PSPDN)

The DECT/PWT standards define neither these components nor the interfaces between them. Because the RFP terminates the air interface protocol, any changes in any layer may require modifications of these units.

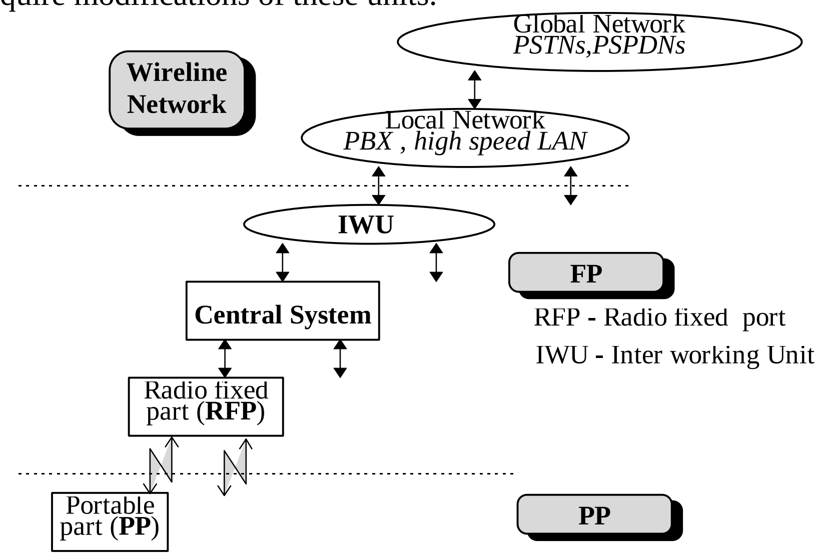


Figure 1 **PWT-E reference architecture**

The basic characteristics of the air interface are presented in table I. The data rate for voice transmission is 32kb/s using adaptive differential pulse code modulation (ADPCM). Variable bit rate (VBR) data communications are possible by using multiple time slots or by skipping time slots.

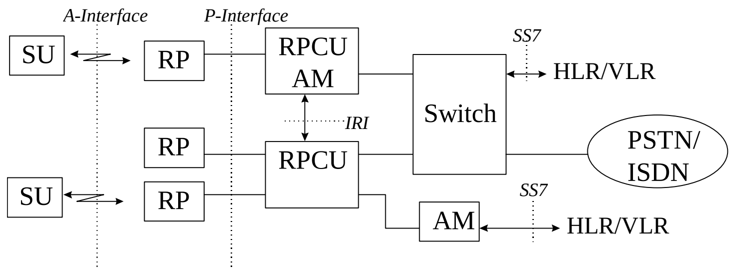
The size of the cell covered by an RFP is rather small, less than 150m for urban applications and 1-2 km for rural applications. For rural applications the coverage can be extended by using repeaters at the expense of capacity. Each RFP uses one RF channel with 12 traffic channels which can handle 5.9 Erlangs of fixed traffic at 1 percent blocking.

C. PACS

PACS is a total system standard (i.e., radio interface and associated network infrastructure) developed in the USA for licensed PCS applications. For the unlicensed applications two versions are available: PACS-UA which actually includes PHS, and PACS-UB. PACS uses FDD for the licensed version and TDD for the unlicensed versions [3].

PACS design was considered from the beginning to support WLL with additional capabilities to provide mobility, such as roaming. It relies on the public network switches' ISDN and AIN capabilities to provide basic voice switching and also transport signaling messages.

The generic reference architecture for PACS is presented in Figure 2. Some PACS' entities have names and functions similar to the GSM counterparts. The RPs function largely as RF modems; layer 2 and 3 messages are passed transparently between the RPCU and SU. Thus, service upgrades do not require visits to RP sites.



RP: Radio port
RPCU: Radio Port Control Unit
AM: Access Manager
IRI: Inter RPCU Interface

Figure 2 The generic PACS architecture

The air interface characteristics are synthesized in Table I. PACS uses TDMA on the up-link and TDM on the down-link. Time slot 5 is reserved to support a 16 kb/s system broadcast channel (SBC). Three logical channels are installed on SBC. They provide the basic functions for signaling, paging and access (table II).

The frame delay in PACS is about 5 ms, thus negating the need for an echo canceller circuit in the radio equipment. The PWT and other radio technologies usually require an echo canceller.

The PACS protocol supports switching to alternate channels when one RP is busy. No attempt is made to distinguish blocked handoff from blocked calls. Thus, Erlang B tables at 1 percent blocking can be used to determine the capacity of the system.

Table II Logical channels installed on PACS SBC

	Channel name	*Function*
AC	Alerting CH.	Paging
SIC	System Information CH.	Broadcast system information such as identities, timers and protocols constants
PRC	Priority request CH	Request emergency calls

The automated frequency assignment in PACS is called *quasi-static autonomous frequency assignment* (QSAFA). The QSAFA process is controlled by the RPCU for its associated RP transceivers. It is a self-regulating means of selecting individual RP frequency channel pairs without a centralized frequency coordination between different RPs.

The QSAFA process is initiated by the radio port control unit (RPCU) for its associated RP transceivers. For each subordinate RP, the RPCU sends a command to turn off its transmitter, tune to the downlink frequency band, and scan all possible downlink frequencies. The selected RP reports the signal power of the frequencies back to the

RPCU. Based on this report, the RP is instructed to tune its transmitter on the frequency with the lowest receive signal and turn on.

The QSAFA is repeated by all radio ports, one at a time, until no ports request a change in their assigned frequency for two consecutive cycles or until a threshold number of iterations is reached. Because the downlink transmitter must be turned off briefly during the assignment procedure, the measurement should be conducted during low-traffic hours. Simulation studies have indicated that for 256 ports using 16 frequency pairs, the assignments can always be stabilized within fewer than five iterations.

D. PACS / PWT-E comparison

PWT-E has lower radio coverage than PACS; thus, in areas that are coverage-limited, a PACS solution requires fewer radio ports than PWT-E. In areas where the system is capacity limited, fewer PWT-E radio ports are needed, but more radio exchanges will be necessary than for PACS. A PACS versus PWT-E radio systems comparison in a high-density (Miami) and in a moderate-density (Jacksonville) geographic area is provided in reference [4]

IV. RF design issues for high-tier WLL networks

A. WLL propagation environment

Basically, *WLL provides fixed to fixed radio links placed at a high spot in a nonobstructive environment*. A line of sight (LOS) condition is not necessary for such systems. Many differences against mobile radio links stem from this basic consideration.

- *The signal propagation is close to that in the free space.*

One major outcome of this propagation scenario is the demand to increase the number of tiers considered in the interference analysis. By mistake, many engineers consider the old two-tier model when computing the carrier to interference ratio (CIR) for a specific cellular layout. That is applicable only in mobile environments where, due to ground reflection, the path loss is around 40 dB/decade. In a fixed WLL environment where the signal propagation is close to free space, a two-tier cell structure will prove too optimistic.

- High-gain directional antennae can be installed for RPs and subscriber units. This can improve signal and reduce interference.
- The multipath fading is expected to be very weak.
- No handoff is necessary since subscribers (houses) are assigned to fixed RPs.
- No continuous power control is necessary. It can easily be done at call connection. For CDMA technology, adjustments are required when a new user joins or an existing user leaves the system.

B. Fade margin

As for any radio link, the communication channel has a multipath structure [5]. Signals come from different second sources surrounding the receiver. Basically, because either the radio port and subscriber unit antennas are located far above ground (roof top) the mobility of vehicles or pedestrians will have a negligible contribution on the received signal. Movement in the subscriber antenna surrounding clutter will be the main contributor to the received signal strength fluctuation. Thus, the only explanation to the time fluctuation of the signal comes from foliage and atmospheric layers movement. The last one may be neglected for short distance links (<20 km). In the absence of the wind, the received power will be constant over long periods of time. During windy weather, one expects a change of the channel attenuation in time; the speed of change being related with the wind speed. The maximum Doppler shift f_D of the received signal relates the signal fluctuation with the speed v of moving objects in the surrounding clutter that modify the propagation channel structure: $f_D=v/\lambda$, where λ is the carrier wavelength.

Availability is an important parameter when designing WLL links. In a wide sense, *availability* is defined as the probability of the event {*received power* ***x*** *greater than threshold w*}, where the threshold *w* represents the signal power below which the communication quality (for instance the bit error rate (BER)) is unacceptably low. Instead of using the absolute threshold *w* which depends on the average power, the *fade margin* (FM) is considered (Figure 3).

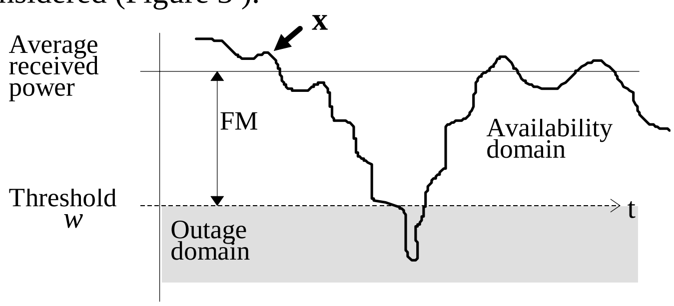


Figure 3. Signal power **x** and Fade Margin

The fade margin (in dB) indicates how much below the average power the threshold *w* is

$$FM(\text{dB}) = -10 \cdot \log_{10} \frac{\text{threshold}}{\text{average received power}} \quad \textbf{(4)}$$

The fade margin is related to the required link availability. As a rule of thumb, the higher the required availability the higher the fade margin and consequently the costs to deploy the WLL network.

Due to coding, interleaving, and slow frequency hopping, communication may survive fades with duration larger than the bit period. Thus, not all fades should be considered when evaluating the channel availability. The composed event {*instantaneous received power below power threshold* **AND** *fade duration grater than duration threshold*} defines availability in the strict sense. Obviously, for the same threshold power and availability, the wide definition will produce a larger fade margin than the strict definition.

Two kinds of probability density functions (pdf) are commonly used to characterize the received envelope statistics in a multipath channel: Rayleigh and Rice. For Rayleigh channels, the received signal power is uniformly spread between paths. For such a channel, the availability (wide sense) is given by

$$\text{Availability} = \mathrm{P}\{\mathbf{x}_{dB} > FM_{dB}\} = \exp\left(-10^{-FM_{dB}/10}\right) \quad \textbf{(1)}$$

With Ricean fading, the received signal exhibits two components: a constant signal and a time-variable signal resulting from multipath field. The Ricean environment has distinctive advantages when compared against the Rayleigh environment. Because fades are shallow, reduced fade margins will be required. Also, the reduced power fluctuation allows for lower carrier to interference design thresholds.

For a Ricean channel, the probability distribution function of the received envelope is

$$f_{\mathbf{R}\text{ice}}(x) = \frac{x}{\sigma^2} \cdot e^{-\frac{x^2+m^2}{2\sigma^2}} \cdot I_o\left(\frac{x \cdot m}{\sigma^2}\right), \quad x \geq 0 \quad \textbf{(2)}$$

where m is the amplitude of the constant signal, σ^2 is the average power of the time-variable signal resulting from the scattered paths, and *I(0)* is the modified Bessel function of the first kind and order zero. Ricean distributions differentiate according to the *Ricean factor K*

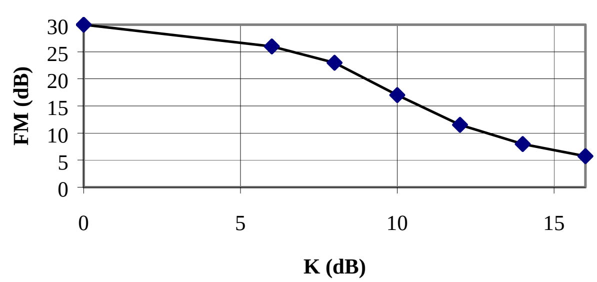
$$K[dB] = 10 \cdot \log_{10} \frac{m^2}{\sigma^2} \quad \textbf{(3)}$$

When K=0 the channel is Rayleigh, whereas if K is infinite the channel is Gaussian. We define the fade margin relative to the average received power $\sigma^2+m^2/2$

$$FM[dB] = -10 \cdot \log_{10} \frac{r^2}{2\sigma^2 + m^2} \quad \textbf{(4)}$$

Figure 4 represents the fade margin as a function of K *for a 99.9% availability*.

Figure 4 Fade margin for Ricean channels and 99.9% availability



For example, when the subscriber antenna has a 20 dB gain and a lot of trees surround the antenna, we may presume K=10. According to the graph above, for K=8 dB a fade margin of 20 dB will guaranty a 99.9% availability. In WLL design, each market should be classified according to the K factor.

C. Level crossing rate and average fade duration

Two characteristics of a multipath channel are typically needed to design the communication system: the A*verage Fade Duration t(r)* and the *Level Crossing Rate N(r)*. Both of them are functions of the level *r* which is related to the power *w* through the equation $w=r^2$. The Level Crossing Rate is the expected rate at which the signal envelope crosses a specified signal level *r* in the positive direction. The average duration of a fade below the level *r* is given by the average fade duration. The Level Crossing Rate and Average Fade Duration are simple to evaluate for the Rayleigh fading case, but much more complex for the Ricean fading.

The received envelope pdf for a Rayleigh channel is given by equation (5).

$$f_{\mathbf{R}ayleigh}(x) = \frac{x}{\sigma^2} \cdot e^{-\frac{x^2}{2\sigma^2}}, x \geq 0 \quad \textbf{(5)}$$

where σ^2 represents the average received power. Typically, the shallower the fade the more frequently it is likely to occur. The crossing rate at level *r* is given by equation (6).

$$N(r) = \sqrt{2\pi} \cdot f_D \cdot \frac{r}{\sqrt{2\sigma^2}} \cdot e^{-\frac{r^2}{2\sigma^2}} \quad \textbf{(6)}$$

Thus, in a *T* second interval, the average number of fades below *r* is given by $T \times N(r)$. The average duration of a fade below the level *r*, is given by equation (7).

$$t(r) = \frac{e^{\rho^2} - 1}{\sqrt{2\pi} \cdot f_D \cdot \rho} \quad \textbf{(7)}$$

where $\rho = r / \sqrt{2\sigma^2}$, and f_D is the maximum Doppler shift. In a WLL system with fixed subscriber antennas, if movement in the antenna's surrounding is limited to 0.17 m/s, the maximum Doppler shift is 2 Hz at 3.5 GHz carrier frequency.

Table III. Availability, level-crossing rate, and average fade duration as a function of level *r*

		Normalized to f_D	
r [dB]	*Availability* [%]	$N(r)/f_D$ *Level crossing rate*	$t(r) \times f_D$ *Average fade duration*
-30	99.90	0.079	0.013
-20	99.00	0.248	0.040
-10	90.48	0.717	0.133
0	36.79	0.922	0.685
5	4.23	0.189	5.076

We note from Table 3 that for a fade margin of 30 dB, the availability is 99.9%. For the same fade margin, the average fade duration for a Doppler shift of 2 Hz is 6.5 ms. Considering a 4- minute call at the same Doppler shift, the average number of fades encountered during a call is 38 (or consequently an average of one fade every 6.3 seconds). Figure 5 shows a plot of the Availability versus Fade Margin. Figures 6 and 7 show normalized Level Crossing Rate and Average Fade Duration vs. the Fade Margin, respectively.

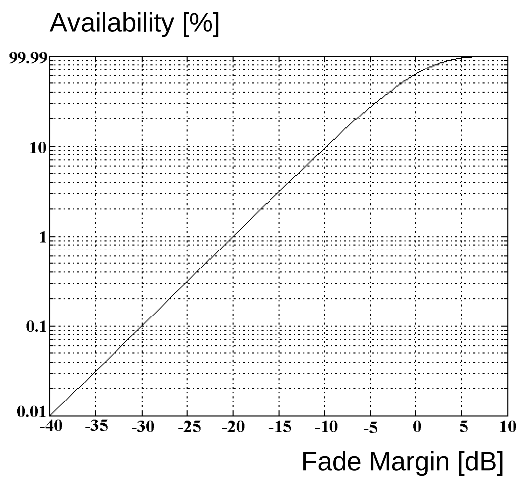


Figure 5..**Availability as a function of fade margin**

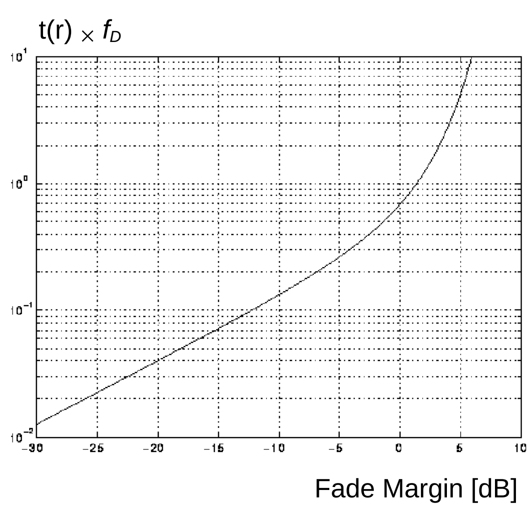


Figure 6 Normalized Average Fade Duration vs. Fade margin.

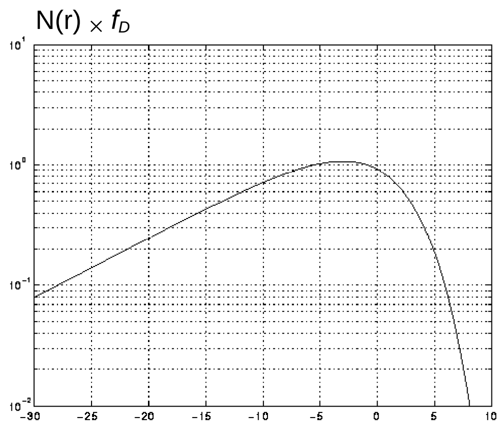


Figure 7 **Normalized Level Crossing Rate vs. Fade margin**

There are several factors that come into play in determining the required Fade Margin, and consequently, the Level Crossing Rate and Average Duration of Fades. For instance, one could cite antenna height, gain, and pattern. Another aspect would be the density of foliage. A Rayleigh distribution of the received signal envelope describes a worst case scenario. Factors such as those previously mentioned might however contribute to yield a Ricean distribution of the received signal envelope.

D. Interference computation in a WLL environment

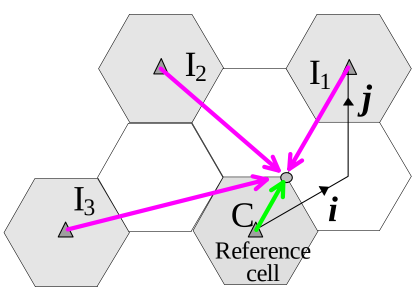


Figure 8 Hexagonal cellular layout with parameters (*i,j*)

A typical homogeneous hexagonal cellular layout is depicted in Figure 8. Cells have the same radius *R*. The gray cells in Figure 8 represent a reference cell and some of its co-channel neighbors: cells that use the same set of frequency. The co-channel cells in the Figure are located on the first tier. In addition to the useful signal *C*, users within the reference cell will receive unwanted (interfering) signals I_1, I_2, I_3 , on the same frequency, from co-channel cells. The ratio of the useful to the total interfering power defines the so-called carrier-to-interference ratio (CIR). The highest the CIR the better the communication quality.

The shift parameters *i, j* [7] of the cellular layout are used in order to find the co-channel cells of each reference cell. Starting from the cell selected as a reference, the nearest co-channel cells are found as follows: Move *i* cells along any chain of hexagons; turn counter-clockwise 60 degrees; move *j* cells along the chain that lies on this new heading. The distance to the nearest co-channel cell is denoted by *D*. The cluster size, that is the number of adjacent cells using distinctive frequency subset, is given by $N=i^2+ij+i^2$.

We assume the average received signal strength at any point decays as a power of the distance of separation *d* between a transmitter and receiver.

$$P_r = P_0\left(\frac{d}{d_0}\right)^{-\gamma} \qquad \textbf{(8)}$$

P_0 is the power received at a close-in reference point (in the far field region of the transmitting antenna) at distance d_0. The *path loss exponent* γ is assumed to be the same throughout the coverage area. Considering only the first tier, the carrier-to-interference ratio (CIR) for different cluster sizes *N* and γ are presented in table IV.

Table IV Carrier to interference ratio for different cluster sizes and path loss exponent γ

	γ=2	γ=3	γ=4
N=3	1.24	5.36	9.24
N=4	2.64	7.57	12.35
N=7		11.38	18
N=12		12.55	20

Due to the usage of narrow beam antennas at the subscriber premises, the multipath is greatly reduced, thus making it possible to lower the design requirement for CIR. Table V lists possible requirements for different high-tier technology contenders. To identify the minimum cluster size (*N*) for a particular propagation environment, the design CIR for IS-136 and GSM (table V) will be compared to figures in table IV. For example, when γ=3, considering only the first tier (which is very optimistic), the cluster size must be N=12 and N>12 for GSM and IS-136, respectively. This is unacceptably large. The usage of sectored antennas (antennas with a radiation pattern less than 360 degree in the azimuthal plane) for the RPs and directional antennas for the subscriber unit represent one solution to this issue.

Table V Design CIR for high-tier technologies

	IS-95		IS-136		GSM	
	Mobile	WLL	Mobile	WLL	Mobile	WLL
Design C/I			18dB	14dB	12dB	12dB
Design Eb/No	7dB	6dB				

Table VI shows the layout specific CIR, when the RPs use 120 degree sector antennas and subscriber antenna's beamwidths are 13-, 30-, and 45 degrees. This time, 6 co-channel tiers are considered for a cellular layout with a cluster size *N*=4. Figures indicated in the table represent the lowest CIR inside the cell without considering the back lobe of the antennas.

Table VI Worst CIR for N=4 and 6 tiers

	C/I Forward Link		
γ	13 degree	30 degree	45 degree
2	10.32	9.22	8.79
3	17.09	16.55	16.28
4	23.54	23.30	23.15

Thus, using 45 degree antennas, a GSM-based WLL system may be deployed for $\gamma=3$. For $\gamma\approx2$, narrower beamwidth subscriber antennas have to be considered. The same conclusion is true for IS-136 with its 14 dB CIR design threshold. IS-136 based design will require narrower beamwidth subscriber antennas than the GSM-based design.

In an actual network design, a software is run considering actual RP and SU antennas radiation pattern (including the back lobes), terrain, and buildings in order to accurately identify the C/I within each cell.

V. Conclusions

We have discussed the main characteristics of a wireless local loop system from radio design and planning aspect and have addressed the differences between such systems and mobile cellular. Low-tier and high-tier technologies are available to be deployed for WLL systems. High-tier solutions are based on high-mobility second generation cellular technologies (e.g., GSM, IS-136, IS-95). They are attractive for high coverage fixed WLL systems. Low-tier systems like DECT/PWT and PACS/PHS represent an option for the new *low-mobility personal communications* market.

Two issues will determine how quickly WLL will be deployed in the developed markets: cost and bandwidth. WLL deployment cost must be balanced with the potential for *lower access fees*. Because they are less expensive to implement, PACS and PWT-E should enable providers to offer customers usage rates less than a few cents per minute. In contrast, today's high-mobility services can cost up to a dollar per minute during peak periods.

As PACS and PWT-E equipment rolls out, spectrum licensees may decide to deploy low-mobility technologies as a differentiating strategy. With sound marketing and prudent economics, these licensees may be bigger winners than their high-mobility counterparts.

VI. References

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