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Application of CDMA Technology to Wireless Local Loop Service

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Abstract

This paper is a tutorial overview of CDMA technology. The paper also discusses how CDMA technology is used in Wireless Local Loop (WLL) applications to satisfy demands quickly and efficiently. Wireless telephony has focused primarily on mobile applications until recently. The huge demand for telephone service, which has emerged in many parts of the world, coupled with the long lead times to install outside plant, has led to the application of wireless technology with fixed location wireless subscriber equipment. CDMA technology has proven to have a significant advantage over other wireless technologies, because of its large capacity and its superior economics. Examples are shown of an integrated subscriber station, a full feature subscriber station supporting voice, data and fax, and a concentrated subscriber system, all for WLL use. Economic comparisons are made with alternative technologies. The Globalstar LEO system is cited as an example to illustrate WLL services provided via satellite.

Keywords

CDMA, WLL, Wireless Local Loop, fixed wireless, wireless telephony, Integrated Subscriber Station, Concentrator Unit.

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Wireless Local Loop Demand

Wireless telephony has experienced explosive growth during the past 10 years, with the number of subscribers globally estimated at approximately 55 million persons in mid 1995. It is estimated that 45% of these are in North America. The vast majority of usage is for mobile applications. These 55 million users represent only about 1% of the total world population.

Various estimates forecast growth of wireless telephony usage during the next ten years to exceed 10% of world population, with more than half of the growth occurring in fixed applications, also known as "Wireless Local Loop (WLL)." Demand for basic telecommunication service in many developing regions far exceeds the ability of traditional wireline telephony to install outside plant. Long waiting times, and difficult terrain are only a few of the reasons why carriers are turning to WLL telephony as a fast, cost effective way to satisfy the demand. WLL technology is also less vulnerable. Service is not easily disrupted by cut cables. And, there is no copper to dig out of the ground and sell.

WLL technology is also much more flexible for changes. For example, shifts in population, and unexpected growth patterns are easier to accommodate. No new wire has to be laid. It may be necessary to adjust antenna patterns or to add a few additional BaseStation Transceiver Subsystems (BTS's). But this still costs substantially less than it would cost to make the appropriate changes with wireline technology, and less time and labor are required.

Distinguishing Between Wireless Local Loop and Mobile Telephony

From a technological perspective, the application of wireless telephony to fixed applications is very similar to mobile telephony. Configurations of Base Station Controllers (BSC) and BTS's are very similar. The major difference is that the subscriber equipment remains in a fixed location. This makes engineering of the wireless somewhat simpler, because it is not essential to plan for hand-off.

In most cases, WLL is intended to be a substitute for wireline telephony. As a result, the subscriber equipment is designed to have a similar look and feel to the normal telephone found in a residence or in a business office. For example, users should not have to stop to think whether they are using a wireline telephone or a wireless telephone. As a result, WLL subscriber equipment must generate dial tone, while a mobile phone has no such requirement. The WLL user does not have to press a "Send" key, to initiate the connection.

WLL subscriber units are designed to operate with normal 110/220 VAC power found in a home or office. For regions where there may be power interruptions, back up battery systems are normally added to a WLL phone to assure power throughout a day.

The same subscriber equipment employed by a mobile user could be used in a WLL network, and some operators will choose to deploy a mixed mobile/WLL network. In that case the network must be engineered for the volume of hand-offs required. WLL subscriber equipment could also be used as a mobile phone. But operators want to discourage users from doing so for two reasons: to protect higher tariffs charged to mobile users, and to minimize or eliminate hand-offs, and, in doing so, minimize network costs. To discourage the subscriber from carrying a WLL subscriber unit on his/her person or in his/her automobile, it is deliberately built to be bulkier and heavier than cellular equipment.

For fixed applications, three different kinds of WLL subscriber equipment can be identified. The simplest looks like a standard wireline home or office telephone with an antenna attached. Figure 1 shows an example of this kind of phone. For business application, a system is required which can accommodate voice, data, and fax. Figure 2, shows an example of this kind of system. It is desirable to be able to provide high quality WLL service to people in apartment buildings, without requiring separate antennas. This is accomplished with a concentrator unit, using a single antenna mounted outside the apartment complex, connecting through in-building wiring to the various apartments within the building. This is particularly valuable where a building has been pre-wired internally, but wireline connections to the building are not available. Figure 3 is an example of this kind of system.

Figure 1. QCT-1000 CDMA Integrated Subscriber.

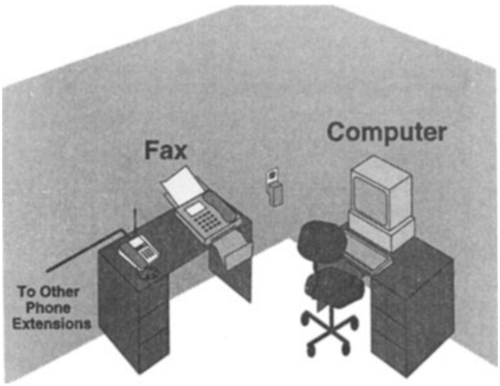

Figure 2. QCT-6000 CDMA Full -Feature Subscriber Station.

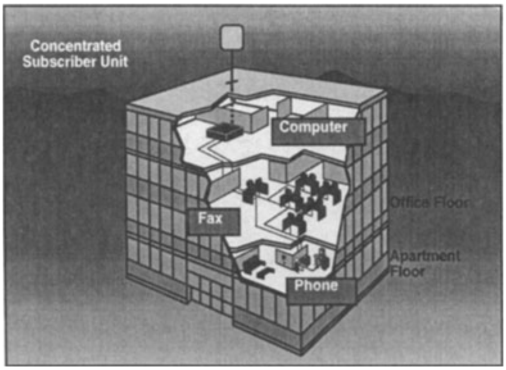

Figure 3. QCT-8000 CDMA Concentrated Subscriber System.

What is CDMA?

CDMA or Code Division Multiple Access is a spread spectrum method which allows multiple users to communicate with a network of base stations through a shared, interference-limited wireless channel by near-optimal utilization of available channel capacity. The CDMA Common Air Interface (IS-95A) has been defined to provide a standard air interface between subscriber station and base station vendors. IS-95A is an industry standard which was created by collaboration among equipment vendors, cellular carriers, and test equipment vendors. It defines modulation, coding, error correction and detection, message structure, messaging and call processing. The basic standard has been augmented by a Vocoder Service Option Standard (IS-96), Data and FAX Service Option (IS-99), and other service options and performance specifications.

Key Attributes of CDMA

CDMA is a spread spectrum technology. Standard analog wireless technology allocates a single frequency for each active user (channel). Time Division Multiple Access (TDMA) methods have been developed to improve the utilization of the spectrum, by dividing each frequency into multiple time slots (three, six or eight), and assigning the slots to different users. This has been likened to having a room full of people who take turns speaking. CDMA spreads all the conversations over a range of frequencies by multiplying each conversation by a unique digital signature. CDMA has been likened to having the same room full of people, with each pair of persons using a different language to speak to each other. As long as none of them speaks too loudly, and as long as there enough different languages, the capacity is only limited by the number of people who can fit into the room.

Some key attributes of CDMA include Power Control, Multipath advantages, Soft Hand-off, Higher Capacity, Variable Rate Vocoder, Universal Frequency Reuse, Improved Link Budget, and Privacy. These attributes are discussed in the following paragraphs. Soft Hand-off and Multipath advantages apply only to mobile usage of CDMA, while the Link Budget advantage applies primarily to mobile usage. However, because this paper is intended, in part, as a survey of CDMA, they are included here.

Power Control

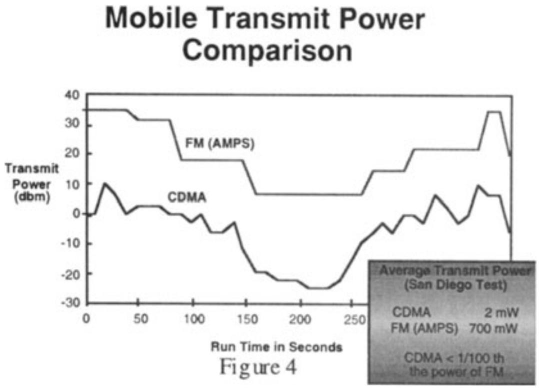

Figure 4

If one or a number of channels transmit with too much power, they will severely interfere with other channels. To prevent this, IS-95A specifies a sophisticated power control scheme. Power control is the dynamic adjustment of base station and subscriber station transmit power so as to maintain an acceptable level of system performance at the lowest possible radiated power level. Three different types of power control are defined for CDMA: Reverse Open Loop, Reverse Closed Loop and Forward Power Control.

In Reverse Open Loop power control, the subscriber station adjusts its transmit level based on received signal strength from the BTS. This allows the subscriber station to react to large path loss fluctuations such as shadowing. The response is relatively slow-typically on the order of 30 msec.

In Reverse Closed Loop power control, the Base Station commands a subscriber station to adjust its transmit level to maintain a signal to noise ratio which will not interfere with other subscriber stations. This is accomplished by a single control bit which is sent to each subscriber station 800 times per second. For example, a subscriber station which is close to the base station will be commanded to reduce its power to the minimum level, while a far away station may be commanded to go to maximum power.

Forward Power Control maintains a grade of service for the entire coverage area from a base station. The base station adjusts its transmit level based on frame error rate reports received from all of its active subscriber stations. The transmit power is adjusted approximately one time per second, which allows each subscriber station time to collect enough frames so that it can calculate a meaningful Frame Error Rate. The base station transmit power will only increase when the subscriber station frame error rate exceeds a set level. Otherwise, the power will decrease slowly.

All of this has an immediate impact on the life of the batteries in the subscriber equipment. CDMA subscriber station transmit power is typically less than 1% of an FM (AMPS) subscriber station's transmit power. In a comparative test conducted in San Diego, the CDMA subscriber station transmit power was 2 mW, while FM (AMPS) subscriber station transmit power was 700 mW (See Figure 4). An analog subscriber station typically has a one half to one hour talk time and eight hours of standby time. CDMA cellular subscriber stations, on the other hand, have talk times of 3 to 5 hours, and standby times on the order of 50 hours to 3 days. A CDMA WLL subscriber station can operate on battery power much longer than either an analog or a TDMA WLL subscriber station, typically 8 hours.

CDMA's Multipath Advantage and Soft Hand-off

A CDMA subscriber station continually processes the three strongest signals received, using 3 rake receivers. These signals are phase shifted and coherently added together to produce a stronger signal. As a result, multipath is actually an advantage with CDMA. Multipath fading is a problem experienced with both FM analog systems and with TDMA systems, including D-AMPS and GSM. But with CDMA, multipath fading is eliminated.

It should be noted that the CDMA multipath advantage further reduces power requirements. In urban applications of CDMA WLL, multipath reflections from nearby buildings will reduce power requirements of the subscriber unit and make it easier to install. Reflections from vehicles passing near the home or office which introduce annoying noise with other wireless technologies become an advantage with CDMA systems.

IS-95A specifies that the three rake receivers in the subscriber unit are always processing the three strongest received signals, while a fourth rake receiver is searching for the strongest current path. In WLL applications, these signals may be the direct signal and two multipaths. In mobile applications, there will be two signals from two different Base Stations as the receiver nears a cell boundary. This is the enabler for another significant advantage enjoyed by CDMA: Soft Hand-off.

With previous technologies, the base station instructs the old transmitter to drop the call as the receiver nears the cell boundary. It then issues instructions to a new transmitter to establish a call with the receiver. It is during the few microseconds between dropping of the old call and establishing the new call, that calls are most frequently dropped, especially when "ping-ponging" occurs. With soft hand-off, the subscriber station begins communicating with the new transmitter, BEFORE communication with the old transmitter is dropped. The result is that dropped calls are virtually eliminated in CDMA. Figure 5 compares the advantage of soft hand-off over hard hand-off using the analogy of a trapeze artist being "handed off" in mid air.

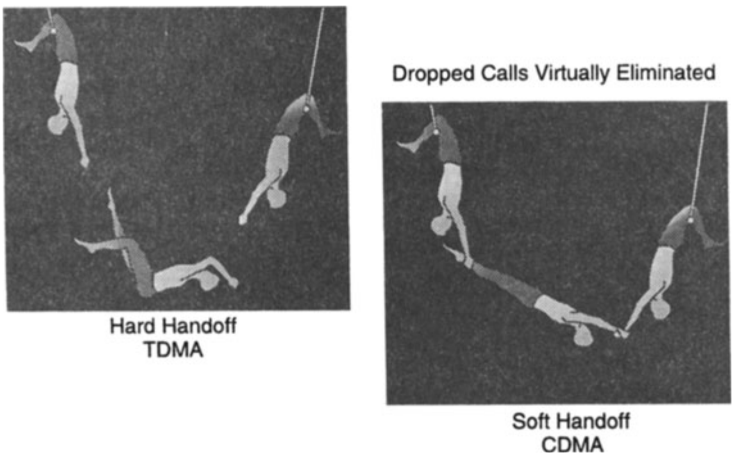

Figure 5. Hard vs. Soft Hand-off

For pure WLL applications, subscriber stations are fixed, so hand-off is not required. However, many CDMA networks will carry a mix of cellular traffic and fixed station traffic on the same system, extending the capability of a network. No additional equipment is required for a mixed WLL/mobile network, but engineering must take into account that some stations are fixed, while other stations will be mobile. The ability to mix fixed and mobile traffic on one system, will further improve the economics of WLL application, because a higher tariff can be charged by operators for cellular usage of the network, than for the WLL applications. This can provide an important subsidy to the WLL application.

Variable Rate Vocoder

Significant efficiency in CDMA channel capacity is achieved through the use of a variable rate vocoder. The IS-96 vocoder varies the transmission rate based on speech activity, using a Code Excited Linear Predictive (CELP) algorithm. The vocoder takes 64 kb/s digital voice, and encodes it at data rates of either 8 or 13 kb/s. In particular, most silent intervals are removed in this encoding process. As a result, the actual voice rate can drop as low as 1 kb/s for the 8 kb/s encoder, with an average rate under 4 kb/s. The reduction in transmission rate also reduces interference, further increasing system capacity, and further improving the economic advantage of CDMA for WLL applications. Details of the CELP algorithm and the encoding process can be found in IS-96.

IS-96 permits "dim and burst" interleaving of signaling or other secondary traffic with voice, allowing mixed primary/secondary traffic in each frame. The vocoder can also bridge frame erasures. Strong error correction and detection ensures the frames sent to the vocoder have a high probability of being correct.

Use of the CDMA vocoder optimizes capacity while maintaining high voice quality. Results of tests of the QUALCOMM 13 kb/s version of CELP conducted by AT&T Holmdel laboratories have shown that the 13 kb/s vocoder produces speech that is nearly wireline quality. The MOS for 64 kb/s voice was 4.06, while the MOS for QCELP-13 was 4.02. Scores for AMPS and GSM are typically in the range of 3.0 to 3.5. Voice quality of CDMA wireless systems using 13 kb/s encoding in the vocoder is basically indistinguishable from wireline systems. This makes CDMA particularly well suited for WLL applications.

Universal Frequency Reuse and CDMA Capacity

One of the most significant advantages of CDMA, for WLL, cellular and PCS applications is in the area of frequency reuse. Narrowband systems (AMPS, D-AMPS, GSM) cannot reuse frequencies in adjacent service areas because of sensitivity to interference. Frequency reuse planning to meet requirements for the signal to interference ratio severely limits spectral efficiency. Typical frequency reuse for narrowband systems is 7 (or 21, for 3 sector cells).

CDMA has universal frequency reuse. Frequency reuse planning is completely eliminated with CDMA. Interference is "pooled" among all users, by the nature of spread spectrum technology. All users experience interference from all others. In a cellular environment, approximately 2/3 of the interference arises from within a users "own" cell, and 1/3 from neighbor cells. Interference for WLL applications is further reduced through the use of directional subscriber antennas. Because of universal frequency reuse there is no reuse planning with CDMA. Instead network designers can concentrate on network capacity and coverage planning.

Link Budget

Other technologies require link budget margin for fading, cell boundary service, and handoff. CDMA's Rake receiver technology and soft handoff largely eliminate the need for link budget margin to compensate for these effects. The advantage over GSM is approximately 10-14 dB in mobile applications. In WLL applications CDMA's adaptive power control adjusts the per-user Eb/N0 to the lower values permitted by stationary subscriber stations, further improving the link budget by 3-4 dB. In both mobile and WLL applications the interference averaging property of CDMA permit cells to add capacity in proportion to the sectorization, in marked contrast to narrowband technologies. All these link budget advantages translate directly into larger coverage areas, fewer cell sites, lower capital investment, faster deployment, and lower operating and maintenance costs.

Privacy and Protection

Wireline telecommunications users want and expect some level of privacy in their communications. AMPS is completely open to any eavesdropper, making it unsuitable for WLL applications. It is more difficult to eavesdrop on TDMA technologies, such as GSM and D-AMPS. It is most difficult to eavesdrop on CDMA technology, because of the nature of the spread spectrum technology. Just one of the two keys used to spread each conversation is 31 bits long, making it very difficult and calculation intensive to try to extract an individual signal which has been spread over a 1.25 MHz CDMA channel. This complexity will make any equipment to "eavesdrop" on a CDMA conversation much more expensive than equipment to pick out an unscrambled TDMA channel. Like TDMA, CDMA can be made even more secure by adding encryption.

Capacity Advantages of CDMA for WLL Applications

Table 1 compares capacity for 5 different wireless technologies: AMPS (Advanced Mobile Phone Service), GSM (Global Standard for Mobile Communication), D-AMPS (Digital AMPS), E-TDMA (Extended Time Division Multiple Access), and CDMA. The table deliberately uses a worst case for CDMA, assuming a single sector CDMA cell, while the other technologies are depicted with multiple sector cells. The results of extensive testing plus actual experience with commercial operation, have shown that the air link can support up to 45 simultaneous calls per sector per 1.25 MHz CDMA band. Table 1 converts all technologies to a standard "channels" per 10 MHz, and then shows the amount of traffic supported, assuming 1% blocking. CDMA has approximately 10 times the traffic capacity of GSM, and 5 times the capacity of D-AMPS, assuming a **single** cell sector. CDMA can be operated with nine sectors per cell, and such a cell will support 302.4 Erlangs, at 1% blocking! The much greater capacity of CDMA has a strong positive impact in the WLL economic comparisons discussed below.

Table 1

CDMA Capacity Comparison-Summary

Technolog	Sector Frequency Reuse	FDM Spacing	Traffic Channels/ FDM	Channels/ 10 MHz	Erlangs/ 10 MHz 1% Bl.
AMPS	21	30 kHz	1	15	8.1
GSM	9	200 kHz	8	44	32.5
D-AMPS	12	30 kHz	3	83	68.2
E-TDMA	12	30 kHz	6	166	146.9
CDMA	1	1.25 MHz	45	360	336.0

Table 2 gives quantitative proof of the advantages of CDMA for WLL applications. The table shows another comparison of CDMA with E-TDMA, TDMA (Time Division Multiple Access per EIA/TIA IS-54), GSM and AMPS. This comparison has been made for a typical light urban region extending 25 km in radius (approximately 2000 m^2). A 10 MHz spectrum license (5 MHz in each direction) has been assumed. And this scenario has been developed for 100,000 subscribers at 0.1 Erlang per subscriber with 2% blocking. An even distribution of subscriber stations throughout the region has been assumed for this analysis.

The CDMA system is assumed to be a network of contiguous radio cells providing complete coverage of an urban service area. The system provides customers a wide range of services and facilities, both voice and non-voice, which are compatible with those offered by wireline networks.

Channel Bandwidth in the first row of Table 2 is standard for each of the different technologies - 1.25 MHz for CDMA, 30 Khz for AMPS, TDMA, and E-TDMA, and 200 Khz for GSM. The next row in the table shows the number of channels of these bandwidths which will fit in the 5 MHz (each way) spectrum allocation. Frequency reuse reduces the effective number of channels available, except for CDMA. Since CDMA has universal frequency reuse, the effective number of CDMA channels remains 3/1 = 3. For AMPS, there is a reuse factor of 21 with 3-sector cells. This reduces the effective number of channels from 167 actual channels to 167/21 = 7.95. Similar calculations are shown for the other technologies.

The number of Voice Calls per Sector comes from actual experience with testing and commercial operation. The number of voice calls which each sector can accommodate across the 5 MHz spectrum allocation is the product of the effective number of channels and the number of voice calls per sector per channel. This is then converted to Erlangs per sector with a 2% blocking factor for all of the technologies being compared.

Because of universal frequency reuse, CDMA is able to gain from use of 9 sectors per cell. This has proven to be practical in testing. Because of frequency reuse limitations, the other technologies do not gain from going to nine sectors per cell, so they have been kept at the more normal 3-sector cells. The row labeled "Erlangs per cell" is the product of Erlangs per sector and sectors per cell.

Table 2. CDMA Capacity Comparison-Detail

5 MHz (each way) Spectrum Allocation					
MEASUREMENT	CDMA	E-TDMA	TDMA (IS-54)	GSM	AMPS
Channel Bandwidth	1.25 Mhz	0.03 MHz	0.03 MHz	0.20 MHz	0.03 MHz
Number of Channels	3†	167 *	167 *	25 *	167 *
Frequency Re-use	1,1	7,21	7,21	3,9 **	7,21
Effective Channels	3/1=3	167/21 =7.95	167/21 =7.95	25/9= 2.8	167/21 =7.95
Voice Calls per Sector per Channel	45	12	3	7.25	1
Voice Calls per Sector across 5 MHz Allocation	135	7.95X12 =95.4	7.95 X 3 = 23.8	2.8X7.25 = 20.0	7.95 X 1 =7.95
Erlangs per Sector (2% blocking)	122 E	83.6 E	16.4 E	13.2 E	3.6 E
Sectors per Cell	9 ***	3 ***	3 ***	3 ***	3 ***
Erlangs per Cell	1098 E	250.8 E	49.2 E	39.6 E	10.8 E
Total Number of Cells (for 10,000 E)	10	40	200	250	925
Erlangs per Cell per MHz	219.6 E	50.16 E	9.84 E	7.92 E	2.16 E

† Even after taking guard band requirements into consideration, only 4.3 out of the total 5 MHz is being used. An additional 700 kHz remains unused in this illustration.

* Most optimistic case for E-TDMA, TDMA, GSM, and AMPS--guard band is not considered for these 4 alternatives.

** GSM's advertised reuse frequency factor of 3.9 is used for comparison, although 4.12 is GSM best case.

*** For E-TDMA, TDMA and GSM, implementing a 9-sector cell configuration generates no additional advantage. For CDMA, upgrading from three to nine sectors per cell approximately triples the capacity.

The next to last row shows the number of cells required to carry 10,000 Erlangs of traffic, computed by dividing 10,000 Erlangs by "Erlangs per Cell". The result is startling! GSM requires 25 times as many cells as CDMA to carry 10,000 Erlangs, while AMPS requires 92 times as many cells. Fewer cells for CDMA translates directly into less up front costs, because less equipment is required, less land is needed for cell sites, and implementation of the system is quicker. Far fewer connections to the Public Switched Telephone Network are required. This significant reduction in the number of backhauls means dramatic cost reductions. The cost of deploying many more cell sites with the other technologies is a significant economic advantage for CDMA applications of WLL. And CDMA has higher voice quality than the other technologies.

The final row in the table is computed by dividing "Erlangs per Cell" by "5" (the spectrum allocation) to yield "Erlangs per Cell per MHz" = a measure of spectral efficiency. The CDMA spectral efficiency of 219.6 Erlangs per Cell is four times greater than the most optimistic estimates for E-TDMA, and 90 times that of AMPS for fixed WLL applications. It is clear from this illustration that CDMA spectral efficiency is more than adequate to accommodate major urban settings with limited spectral availability. Other WLL technologies are not capable of meeting those requirements.

CDMA WLL/Wireline Financial Comparison

Detailed financial comparisons of CDMA WLL with other technologies, show a substantial advantage for CDMA. Table 3 gives a financial comparison of CDMA with wireline, a hybrid wireline/wireless network (wireline in urban area, wireless in suburbs and rural areas), and DECT, using eight different metrics. This is based on an economic study of Gujarat, India, a region with a population of 44 million people, and a current penetration of slightly more than two existing telephones per one hundred people. The study was based on a sophisticated economic model developed by a consulting firm independent of any manufacturer of wireless or wireline equipment.

The study showed that a wireline network to serve 5.6 million subscribers by the tenth year of service in the Gujarat region would require $1.2 billion of financing, compared to only $667 million for an operator using CDMA WLL.

The investment (capital) required per subscriber is less for CDMA WLL than for any of the other scenarios. This comparison is even more dramatic when the cost of the handset is considered separately. CDMA WLL operators will enjoy faster price declines than those that choose wireline, because CDMA technology is newer. Steep cost reductions from high volumes of CDMA component production, coupled with learning curve cost savings as the technology matures, will allow equipment manufacturers to lower prices quickly. Since handsets make up nearly 50% of the total capital expense for CDMA WLL, the high volumes required will have a particularly large impact on overall capital expense.

The model calculated revenue on the basis of subscriber usage and the tariff structure in India. This was then used to calculate operating expense as a per cent of revenue. CDMA WLL has the lowest operating expense as a per cent of revenue.

Table 3. Financial Metrics for Wireline, Hybrid, DECT, and CDMA WLL

Parameter	Wireline	Hybrid	DECT	CDMA WLL
Peak financing requirement	$1,202 M	$708 M	$1,225 M	$667 M
Internal rate of return*	10%	33%	22%	37%
Net present value per POP**	$6.26/POP	$25.45/POP	$20.41/POP	$29.27/POP
Total net present value**	$277 M	$1,125 M	$902 M	$1,294 M
Life cycle cost: (OpEx + CapEx)/sub	$1,495	$1,104	$1,183	$1,017
Operating expense as a % of revenue - Yr. 5	39%	28%	27%	24%
Capital per subscriber - Yr. 5	$838	$700	$959	$717
Capital per subscriber - Yr. 5 Without Handset	$812	$440	$617	$368

* Internal rate of return is based on ten years' cash flow. ** Net present value is based on 20% discount rate using ten years' cash flow plus eight times terminal year cash flow discounted to Year 1.

WLL Services Provided by Satellite

There are a number of regions of the world where population is very sparse, and it is not economical to deploy either a wireline network or a fixed cellular Wireless Local Loop network. One of the options becoming available is to provide telephone service via LEO satellite. Ideally, the handset used for satellite service will be a multi-mode phone which can roam to cellular operation when the user moves from a region covered only by satellite to a region where cellular coverage is available and economical. A system offering such a capability for CDMA and GSM is currently under development by Globalstar. Details of Globalstar are beyond the scope of this paper.

Summary

CDMA has many technological advantages, including lower power, higher capacity, better frequency reuse, and better link budget. CDMA's multipath advantage and soft hand-off are important for mixed WLL/cellular systems. And CDMA is inherently more private than other wireless technologies. These technological advantages translate into strong economic advantages. CDMA WLL provides outstanding reliability, rapid deployment, flexibility, and it is less expensive to deploy, operate and upgrade. All of these advantages make CDMA the telecommunications technology of choice for local loop operators providing voice and data services in developing regions.

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Dr. Ronald P. Uhlig - Biography

Dr. Ronald P. Uhlig is currently Vice President, International Marketing, with Qualcomm, Inc., San Diego, California He was with Northern Telecom, Richardson, Texas from 1984-1995 in a variety of positions including Director, Intelligent Network Solutions, Director, Asia/Pacific Strategic Marketing, and Director, Network Consulting. He was with Bell-Northern Research, Ottawa, Canada from 1978-1884. Prior employers include the U.S. National Bureau of Standards, Brookhaven National Laboratory, and the US Army Material Command.

He is currently President, International Council for Computer Communication (ICCC), and has held a number of other ICCC offices, including Secretary General. From 1986-1991, he was Chairman, IFIP TC-6 (International Federation for Information Processing Technical Committee on Communication Systems). From 1979-1985 he chaired WG 6.5, the Working Group on Electronic Messaging of IFIP TC-6.

He has given numerous lectures, seminars, papers and courses on every continent on a wide range of topics including office automation, voice and data communication protocols, electronic mail, digital switching, global networks, wireless communication systems, and intelligent networks.

He holds a B.Sc. in Physics from the Massachusetts Institute of Technology and a Ph.D. in Physics from the University of Maryland.