In-building cellular: Why it is a Wi-Fi alternative

Part 1 of this two-part series discusses the technical aspects of cellular coverage and the challenges of providing in-building coverage.

There has been plenty of buzz about the rapid evolution of 802.11-based networks for data services, and one of the hottest areas of development has been voice-over-WLAN technology. But cellular voice is an older and far more pervasive technology, and higher-speed cellular data services now offer users a viable alternative to Wi-Fi.

As a result, many large companies are now grappling with the issue of improving their indoor cellular coverage. This two-part article discusses the technical aspects of cellular coverage, the challenges of providing in-building coverage, and the various approaches to meeting those challenges. In this part, we'll focus on the technology and challenges.

Cellular phones and e-mail terminals have become essential equipment in enterprises, bringing into focus the challenge of providing adequate cellular coverage inside buildings. According to IDC (June, 2006), enterprise telecommunications managers now believe that more than 28 percent of their employees use their cell phones as their primary connection.

3G technologies such as UMTS/HSDPA and CDMA EV-DO are also growing rapidly: the GSM Association announced in June 2006 that the technology now connects 2 billion users worldwide, and projects that there will be some 700 million HSDPA users by 2010.

As device usage soars and applications expand, so does indoor use. In a 2005 study, Japan's NTT DoCoMo found that 70 percent of 3G wireless calls originate from within buildings. Now, many companies are finding that their indoor cellular coverage isn't adequate.

Transmission systems

Providing effective cellular coverage requires distributing the correct frequencies with sufficient signal strength and quality, which means overcoming signal loss (attenuation) and interference. This challenge is greater inside buildings because materials such as steel and concrete (as well as office furniture, equipment, and other objects) attenuate radio signals.

The technical attributes of the signal vary according to the transmission system being used. North American carriers currently employ several systems (GSM, UMTS, CDMA-1xRTT, CDMA-EV-DO, and iDEN) to provide coverage, using four frequency bands:

- Two iDEN bands, 806 to 824 MHz uplink and 851 MHz to 869 MHz downlink, as well as 896 to 901MHz uplink and 935 to 940MHz downlink.

- 850 MHz band used for GSM and CDMA, which ranges from 824 MHz to 849 MHz in uplink and 869 MHz to 894 MHz in downlink
- 1900 MHz frequency band, which ranges from 1850 MHz to 1910 MHz in uplink and 1930 MHz to 1990 MHz in downlink

Due to length considerations, we will confine our discussion to GSM, UMTS/HSDPA, and CDMA-1xRTT/CDMA EV-DO.

The primary goal of any radio system is to provide clear connections to all users who want them. The variables affecting coverage include signal strength, interference (which dictates the spacing and placement of antennas), and capacity (the number of simultaneous calls per cell).

The system will also need to support various data rates based on whether the application is voice or data. It is therefore useful to consider the strengths and weaknesses of cellular systems in terms of how they meet these requirements.

The Carrier to Interference-plus-Noise Ratio (CINR) is a primary measurement of signal effectiveness. The carrier is the desired signal, and the interference can either be noise or co-channel interference. (Co-channel interference is a particular problem when frequencies are reused at short distances).

In order for the receiver to be able to decode the signal, the signal must fall into an acceptable CINR range, which differs with the technology used (i.e., CDMA, GSM, etc.). CINR is expressed in decibels (dBs).

The minimum CINR depends on the kind of modulation (QPSK, QAM) and coding gain. In networks with a frequency reuse of one (same frequency in each cell), the signal characteristics must support so-called soft handoffs, which occur when a receiver is at the edge of a cell in an area where the signal strength from its current cell is almost equivalent to the signal strength from the adjacent cell using the same frequency. Soft handoff is possible if the CINR requirements are -5 dB or less, allowing the two different signals to vary a couple of dBs.

With these basics in mind, let's look at the differences between the predominant cellular technologies.

GSM

GSM uses a 200 KHz channel with eight timeslots per carrier. The timeslots can be used by a control channel (at least one is needed per cell), or by voice channels and the remaining data channels. To increase the capacity of a coverage cell, each cell can include multiple GSM carriers (= TRX).

However, GSM requires a CINR of +9 dB for the modulation and does not have any coding gain, so a soft-handoff will not work in cells, because the two signals from the base stations would violate the CINR requirement (causing too much interference), and the mobile device would not be able to detect these signals. This is why GSM uses different frequencies in order to get the necessary separation.

CDMA 1xRTT

CDMA 1xRTT uses a 1.25 MHz channel. Rather than using separate frequency carriers or different timeslots, it uses code division multiplexing to transmit multiple voice calls on a single carrier.

A CDMA carrier can typically handle 32-48 simultaneous voice calls. Since all mobile phones transmit simultaneously on the uplink (mobile to base station), each mobile device in a CDMA system has to transmit with the right output power in order to preserve the capacity of the cell. To facilitate signal-sharing, CDMA1xRTT uses a very sophisticated power control on the uplink.

One of the advantages in CDMA is the so-called coding gain, which means the information is transmitted over a longer period. The link budget is increased by the coding gain and the CINR requirement is reduced. For voice and low data rates, CINR is negative, so a soft handoff is possible.

For a spreading factor of 128, the coding gain is 21 dB, so if the CINR was +9 dB before spreading, the CINR is -12 dB after spreading. (The spreading factor is the ratio of the chips (CDMA = 1.2288 MChips/s) to baseband information rate.)

CDMA EV-DO

CDMA EV-DO also uses a 1.25 MHz channel and is often used as the second CDMA carrier in CDMA systems. Since EV-DO does not provide circuit voice capability, it is optimized for data and works nicely with CDMA 1xRTT. Downlink speeds can reach up to an impressive 2.4 Mbps, but as a consequence, CDMA EV-DO requires a better signal than CDMA 1xRTT: the link budget is reduced and the CINR requirement is increased.

In fact, data rates of more than 153 Kbps require a CINR greater than "5 dB, and therefore require frequency planning similar to that in GSM (in which adjacent cells use different frequencies). Using the highest data rate of 2.4 Mbps requires a higher CINR than for GSM voice. As a result, soft-handoff for high data rates is not possible with CDMA EV-DO. However, since EV-DO is a data-optimized channel, it can easily carry VoIP traffic instead.

UMTS/HSDPA

UMTS/HSDPA uses a 5 MHz channel. It combines voice and data channels. For circuit voice it is similar to CDMA 1xRTT, and for fast data it is similar to CDMA EV-DO. However, it uses a 5 MHz channel and can therefore carry more traffic. Typical voice capacity in UMTS/HSDPA is 32-170 simultaneous calls per carrier. The highest data rate of 10.7 Mbps requires the same CINR as for the EV-DO 2.4 Mbps speed.

To put these differences in perspective, Figure 1 shows the differences in coverage areas and subscriber capacities of cells using GSM, CDMA 1xRTT, and UMTS. The assumed usage scenario is a dense office environment (150 square feet per subscriber) with medium user traffic (40 mErl, where an Erlang represents the total traffic volume of one hour, or 3600 seconds).

The area listed below represents the area where the base station would be 100 percent loaded. The number of antennas represents how many antennas are needed to cover this area assuming 20,000 square feet per antenna for voice coverage.

Technology	Channel	TCH	Erlang	Subscribers	Area [sq. ft.]	# Antennas
GSM	1 TRX	7	2.50	63	9,375	1.00
CDMA	1xRTT	35	24.64	616	92,400	5.00
UMTS	HSDPA	70	56.11	1,403	210,413	11.00

Figure 1: *Typical Coverage and subscriber capacities for GSM, CDMA, and UMTS.*

Coverage and Interference Challenges

As mentioned previously, coverage and interference are two of the main factors affecting the quality of cellular service. The challenges of providing in-building coverage become even more difficult as providers roll out 3G data services such as EV-DO and HSDPA, because path loss attenuation increases with the frequency of the signal, particularly with respect to free space attenuation (objects typically attenuate signals at a more constant rate).

The 1900 MHz frequency band has higher attenuation than the 850 MHz band, so some mobile operators use the lower frequency band to get better coverage. (As a guideline, doubling the frequency reduces the link budget by 6 dB.)

Since the receiver in the base station or terminal needs a "cleaner" signal (equal or better CINR) for high data rates, it also requires a stronger signal because noise can be considered as an interferer. Higher frequencies attenuate more quickly, so if the protocol requires a 6 dB higher CINR ratio, for example, it reduces the maximum allowable path loss by at least 6 dB.

A 6 dB decrease of path loss is the equivalent of reducing the cell area by 50 percent. This has a significant consequence for high speed data rates since it requires a stronger signal (lower maximum path loss) as well as a better signal (higher CINR requirements).

The data in Figures 2, 3, and 4 show the CINR requirements for GSM, CDMA, and UMTS. As we have seen, the higher the data rate, the more stringent the requirements.

GSM CINR Requirements	
Protocol	**CINR**
Voice	9 dB
GPRS-CS1-19.05kb/s	9 dB
GPRS-CS2-13.4kb/s	13 dB
GPRS-CS3-15.6kb/s	15 dB
GPRS-CS4-21.4kb/s	23 dB
EDGE-MCS1-18.8kb/s	9.5 dB
EDGE-MCS2-11.2kb/s	12 dB
EDGE-MCS3-14.8kb/s	16.5 dB
EDGE-MCS4-17.6kb/s	21.5 dB
EDGE-MCS5-22.4kb/s	14.5 dB
EDGE-MCS6-29.6kb/s	17 dB
EDGE-MCS7-44.8kb/s	23.5 dB
EDGE-MCS8-54.4kb/s	29 dB
EDGE-MCS9-59.2kb/s	32 dB

Figure 2: *GSM CINR requirements.*

Note in Figure 2 that the difference in quality for the minimum and maximum protocol is about 23 dB, which means the maximum path loss is reduced by 23 dB. As a consequence, the area of a cell using high data-rate radios is about 6.2 percent as large as it would be for a cell using low data-rate radios, and the cell radius drops to about 25 percent of what it would be for a cell with low data rate radios.

Figure 3 shows the required CINR for different data rates with CDMA EV-DO. The CINR values include the coding gain.

PROTOCOL PARAMETERS		
Service		**CINR**
DL: 38400		-11.5
DL: 76800		-9.2
DL: 153600		-6.5
DL: 307200		-3.5
DL: 614400		-0.5
DL: 921600		2.2
DL: 1228800		4
DL: 1843200		8
DL: 2457600		10.3

Figure 3: *CDMA EV-DO CINR requirements.*

Above 153 kbps, the signal requires a CINR greater than -5 dB and therefore would require frequency planning. Note the difference in CINR for the minimum protocol and maximum is about 22 dB, which means the maximum path loss is reduced by 22 dB.

As a consequence, the cell area of a cell using high data rate radios is about 7 percent of what it would be for a cell using low data rate radios, and the cell radius drops to about 26 percent of what it would be for a cell using low data rate radios.

Figure 4 shows the required CINR for different UMTS/HSPDA data rates. The CINR values include the coding gain.

PROTOCOL PARAMETERS		
Service		**CINR**
DL: 120k (QP-1/4-1)		-14.5
DL: 240k (QP-1/2-1)		-10
DL: 360k (QP-3/4-1)		-7
DL: 480k (QA-1/2-1)		-5
DL: 720k (QA-3/4-1)		-0.5
DL: 1.8M (QP-1/4-15)		-2
DL: 3.6M (QP-1/2-15)		1
DL: 5.3M (QP-3/4-15)		4.5
DL: 7.2M (QA-1/2-15)		6
DL: 10.7M (QA-3/4-15)		10.5

Figure 4: *HSDPA/UMTS CINR requirements.*

Above 480 Kbps, the signal requires a CINR greater than -5 dB and therefore would require frequency planning. Note the difference in CINR for the minimum and maximum protocol is about 25 dB, which means the maximum path loss is reduced by 25 dB. As a consequence, the area of a high data rate cell is about 4.8 percent of what it would be in a cell using low data rate radios, and the cell radius drops to about 22 percent of what it would be for a cell using low data rate radios.

Figure 5 summarizes the effect of lower path loss on cell radius and cell area for a typical indoor installation.

dB loss	Percent radius	Percent area	dB loss	Percent radius	Percent area
0	100	100	16	38%	14%
1	94%	89%	17	36%	13%
2	89%	78%	18	34%	11%
3	83%	70%	19	32%	10%
4	78%	62%	20	30%	8.9%
5	74%	55%	21	28%	7.8%
6	70%	48%	22	26%	7.0%
7	65%	43%	23	25%	6.2%
8	62%	38%	24	23%	5.5%
9	58%	34%	25	22%	4.8%
10	55%	30%			
11	51%	26%			
12	48%	23%			
13	45%	21%			
14	43%	18%			
15	40%	16%			

Figure 5: *Effect of path loss on radius and cell area.*

If a network is designed for voice and low data rates, the antennas are farther apart and the interference is less of an issue. As a consequence, only small portions of the network will be able to offer high speed data. These high data rate areas can be as small as 5 percent of the voice area.

However, if the network is designed for high data rates, the antennas will be much closer together (up to 20 times more antennas). Interference is still an issue for an outdoor network. Frequency separation in CDMA or UMTS networks would be needed to achieve the required quality of the signals. For an indoor network, the interference level can be significantly reduced by using a DAS system. Therefore DAS systems may not require frequency separation.

In-building Technology

Essentially, an in-building system replicates the same type of coverage in an outdoor (macro) area in the more challenging indoor environment, where steel, concrete, furniture and equipment attenuate the signal much more quickly. This is accomplished with a distributed antenna system (DAS) that propagates the signal. There are two parts to the deployment process:

- Operators bring the cellular signal to the building, either by deploying a base station (BTS) in the building's equipment room or by adding a rooftop antenna and then placing a repeater in the equipment room. (Most DAS are now being deployed with dedicated base stations because the cost of smaller BTS continues to decline, and BTS provide dedicated capacity.)

- Operators and/or the building owner install a DAS to distribute the signals from the repeater or BTS throughout the building.

The BTS technology used for in-building coverage is the same as it is for macro cells, although the units are typically smaller. However, there are three types of DAS in use: passive, active, and hybrid. Each type of DAS has unique performance characteristics that impact the system's ability to provide in-building coverage.