CDMA vs TDMA

NOTE: During this discussion I will use the generic term "CDMA" to refer to the IS-95 standard. Technically speaking, CDMA is only a means to transmit bits of information, while IS-95 is a transmission protocol that employs CDMA. You may also hear the term "TDMA" used to refer generically to the IS-136 standard. Once again, TDMA is only a method of transmitting bits, while IS-136 is a protocol that happens to employ TDMA.

I spend quite a bit of time reading the messages that flow through the various PCS newsgroups and forums on the Internet, and if one thing is abundantly clear, it is that people don't seem to know the true differences between CDMA and TDMA. And who could blame them? There is so much hype surrounding these two competing technologies that it is difficult for a regular PCS subscriber to know who is telling the truth.

I personally am NOT an RF engineer, nor do I work for any of the cellular or PCS companies. It is however, my hobby to keep up with the latest developments in mobile communication (as this web site amply demonstrates). I would like to clear the air by interjecting my own spin on this debate. I hope that by the time you finish reading this editorial, you will have a better understanding of the true strengths and weaknesses of both technologies.

The Basics

Let's begin by learning what these two acronyms stand for. TDMA stands for "Time Division Multiple Access", while CDMA stands for "Code Division Multiple Access". Three of the four words in each acronym are identical, since each technology essentially achieves the same goal, but by using different methods. Each strives to better utilize the radio spectrum by allowing multiple users to share the same physical channel. You heard that right. More than one person can carry on a conversation on the same frequency without causing interference. This is the magic of digital technology.

Where the two competing technologies differ is in the manner in which users share the common resource. TDMA does it by chopping up the channel into sequential time slices. Each user of the channel takes turns transmitting and receiving in a round-robin fashion. In reality, only one person is actually using the channel at any given moment, but he or she only uses it for short bursts. He then gives up the channel momentarily to allow the other users to have their turn. This is very similar to how a computer with just one processor can seem to run multiple applications simultaneously.

CDMA on the hand really does let everyone transmit at the same time. Conventional wisdom would lead you to believe that this is simply not possible. Using conventional modulation techniques, it most certainly is impossible. What makes CDMA work is a special type of digital modulation called "Spread Spectrum". This form of modulation takes the user's stream of bits and splatters them across a very wide channel in a pseudo-random fashion. The "pseudo" part is very important here, since the receiver must be able to undo the randomization in order to collect the bits together in a coherent order.

If you are still having trouble understanding the differences though, perhaps this analogy will help you. This my own version of an excellent analogy provided by Qualcomm:

Imagine a room full of people, all trying to carry on one-on-one conversations. In TDMA each couple takes turns talking. They keep their turns short by saying only one sentence at a time. As there is never more than one person speaking in the room at any given moment, no one has to worry about being heard over the background din. In CDMA, each couple talk at the same time, but they all use a different language. Because none of the listeners understand any language other than that of the individual to whom they are listening, the background din doesn't cause any real problems.

Voice Encoding

At this point many people confuse two distinctly different issues involved in the transmission of digital audio. The first is the WAY in which the stream of bits is delivered from one end to the other. This part of the "air interface" is what makes one technology different from another. The second is the compression algorithm used to squeeze the audio into as small a stream of bits as possible.

This latter component is known at the "Voice Coder", or Vocoder for short. Another term commonly used is CODEC, which is a similar word to *modem*. It combines the terms "COder" and "DECoder". Although each technology has chosen their own unique CODECs, there is no rule saying that one transmission method needs to use a specific CODEC. People often lump a technology's transmission method with its CODEC as though they were single entities. We will discuss CODECs in greater detail later on in this article.

Voice encoding schemes differ slightly in their approach to the problem. Because of this, certain types of human voice work better with some CODECs than they do with others. The point to remember is that *all* PCS CODECs are compromises of some sort. Since human voices have such a fantastic range of pitch and tonal depth, one cannot expect any single compromise to handle each one equally well. This inability to cope with all types of voice at the same level does lead some people to choose one technology over another.

All of the PCS technologies try to minimize battery consumption during calls by keeping the transmission of *unnecessary data* to a minimum. The phone decides whether or not you are presently speaking, or if the sound it hears is just background noise. If the phone determines that there is no intelligent data to transmit, it blanks the audio and it reduces the transmitter duty cycle (in the case of TDMA) or the number of transmitted bits (in the case of CDMA).

When the audio is blanked, your caller would suddenly find themselves listening to "dead air", and this may cause them to think the call has dropped.

To avoid this psychological problem, many service providers insert what is known as "Comfort Noise" during the blanked periods. Comfort Noise is synthesized white noise that tries to mimic the volume and structure of the real background noise. This fake background noise assures the caller that the connection is alive and well.

However, in newer CODECs such as EVRC (used exclusively on CDMA systems), background noise is generally suppressed even while the user is talking. This piece of magic makes it sound as though the cell phone user is *not* in a noisy environment at all. Under these conditions, Comfort Noise is neither necessary, nor desirable. You can read my article on EVRC by clicking here.

CDMA

Now that we have a rudimentary understanding of the two technologies, let's try and examine what advantages they provide. We'll begin with CDMA, since this new technology has created the greatest "buzz" in the mobile communications industry.

One of the terms you'll hear in conjunction with CDMA is "Soft Handoff". A handoff occurs in ***any*** cellular system when your call switches from one cell site to another as you travel. In all other technologies, this handoff occurs when the network informs your phone of the new channel to which it must switch. The phone then stops receiving and transmitting on the old channel, and commences transmitting and receiving on the new channel. It goes without saying that this is known as a "Hard Handoff".

In CDMA however, every site are on the SAME frequency. In order to begin listening to a new site, the phone only needs to change the pseudo-random sequence it uses to decode the desired data from the jumble of bits sent for everyone else. While a call is in progress, the network chooses two or more alternate sites that it feels are handoff candidates. It simultaneously broadcasts a copy of your call on each of these sites. Your phone can then pick and choose between the different sources for your call, and move between them whenever it feels like it. It can even combine the data received from two or more different sites to ease the transition from one to the other.

This arrangement therefore puts the phone in almost complete control of the handoff process. Such an arrangement should ensure that there is always a new site primed and ready to take over the call at a moment's notice. In theory, this should put an end to dropped calls and audio interruptions during the handoff process. In practice it works quite well, but dropped calls are still a fact of life in a mobile environment. However, CDMA rarely drops a call due to a failed handoff.

A big problem facing CDMA systems is *channel pollution*. This occurs when signals from too many base stations are present at the subscriber's phone, but none are dominant. When this situation occurs, audio quality degrades rapidly, even when signal seem otherwise very strong. Pollution occurs frequently in densely populated urban environments where service providers must build many sites in close proximity. Channel pollution can also result from massive multipath problems caused by many tall buildings. Taming pollution is a tuning and system design issue. It is up to the service provider to reduce this phenomenon as much as possible.

In defense of CDMA however, I should point out that the new ***EVRC*** CODEC is far more robust than either of the earlier CODECs. Because of its increased robustness, it provides much more consistent audio in the face of high frame error rates. EVRC is an 8 kilobit CODEC that provides audio quality that is *almost as good* to the older 13 kilobit CODEC. Since CDMA consumes only as much of the "ether" as a user takes, switching everyone to an 8 kilobit CODEC was an inevitable move.

Don't confuse EVRC with the old (and unlamented) 8 kilobit CODEC implemented in the early days of CDMA deployment. That CODEC was simply awful, and very few good things could be said about it. EVRC is a far more advanced compression algorithm that cleans up many of the stability problems inherent in the two older CODECs. The sound reproduction is *slightly* muddier than the 13 kilobit CODEC, but the improvement in stability makes up for this.

Supporters often cite ***capacity*** as one CDMA's biggest assets. Virtually no one disagrees that CDMA has a very high "spectral efficiency". It can accommodate more users per MHz of bandwidth than any other technology. What experts do not agree upon is by *how much*. Unlike other technologies, in which the capacity is fixed and easily computed, CDMA has what is known as "Soft Capacity". You can *always* add just one more caller to a CDMA channel, but once you get past a certain point, you begin to pollute the channel such that it becomes difficult to retrieve an error-free data stream for *any* of the participants.

The ultimate capacity of a system is therefore dependent upon where you draw the line. How much degradation is a carrier willing to subject their subscribers to before they admit that they have run out of *useable* capacity? Even if someone does set a standard error rate at which these calculations are made, it does not mean that you personally will find the service particularly acceptable at that error rate.

TDMA

Let's move away from CDMA now and have a look at TDMA. Before we can go any further though, I should note that there are actually three different *flavors* of TDMA in the PCS market. Each of these technologies implements TDMA in a slightly different way. The most complex implementation is, without a doubt, GSM. It overlays the basic TDMA principles with many innovations that reduce the potential problems inherent in the system.

To reduce the effects of co-channel interference, multipath, and fading, the GSM network ***can*** use something known as [Frequency Hopping](). This means that your call literally jumps from one channel to another at fairly short intervals. By doing this, the likelihood of a given RF problem is randomized, and the effects are far less noticeable to the end user. Frequency Hopping is always available, but not mandated. This means that your GSM provider may or may not use it.

IS-136 is another form for TDMA, and it is this implementation that people generically refer to as TDMA. I personally wish they wouldn't do this, since it confuses the issue. It makes it sound as though IS-136 is the *only* TDMA technology. Naming conventions aside, IS-136 is probably the crudest implementation of TDMA. It will suffer from various maladies far more easily than GSM, but it does have one unique feature that compensate for its crudeness. It is the only technology that integrates with existing analog systems. While CDMA can provide handoffs from digital to analog, there is no way to send the call back to digital. In IS-136 you can go both ways at any time.

iDEN is a proprietary Motorola technology that no other company seems to participate in. Only Motorola makes iDEN phones, and only Motorola makes iDEN infrastructure equipment. Perhaps the company guards its technology on purpose. iDEN performs reasonably well, but its chosen CODEC is not quite as good as those on GSM or CDMA. In my experience, the quality of iDEN depends a lot on which iDEN phone you use. Some of Motorola's later models (such as the i85, i80, and i90) have improved things markedly.

Each of the three TDMA technologies uses a different CODEC. GSM sports a CODEC called EFR (short for Enhanced Full Rate). This CODEC is arguable the best sounding one available in the PCS world. IS-136 used to sound horrible, but in the fall of 1997 they replaced their old CODEC with a new one. This new CODEC sounds much better than the old, but it doesn't quite match the GSM and CDMA entries.

TDMA systems still rely on the switch to determine when to perform a handoff. Unlike the old analog system however, the switch does not do this in a vacuum. The TDMA handset constantly monitors the signals coming from other sites, and it reports this information to the switch without the caller being aware of it. The switch then uses this information to make better handoff choices at more appropriate times.

Perhaps the most annoying aspect of TDMA system to some people is the obviousness of handoffs. Some people don't tend to hear them, and I can only envy those individuals. Those of us who are sensitive to the slight interruptions caused by handoffs will probably find GSM the most frustrating. It's handoffs are by far the most messy. When handoffs occur infrequently (such as when we are stationary or in areas with few sites), they really don't present a problem at all. However, when they occur very frequently (while travelling in an area with a huge number of sites) they can become annoying.

Spectral Efficiency

Channel capacity in a TDMA system is fixed and indisputable. Each channel carries a finite number of "slots", and you can *never* accommodate a new caller once each of those slots is filled. Spectral efficiency varies from one technology to another, but computing a precise number is still a contentious issue. For example, GSM provides 8 slots in a channel 200 kHz wide, while IS-136 provides 3 slots in a channel only 30 kHz wide. GSM therefore consumes 25 kHz per user, while IS-136 consumes only 10 kHz per user.

One would be sorely tempted to proclaim that IS-136 has 2.5 times the capacity of GSM. In a one-cell system this is certainly true, but once we start deploying multiple cells and channel reuse, the situation becomes more complex. Due to GSM's better error management and frequency hopping, the interference of a co-channel site is greatly reduced. This allows frequencies to be reused more frequently without a degradation in the overall quality of the service.

Capacity is measured in "calls per cell per MHz". An IS-136 system using N=7 reuse (this means you have 7 different sets of frequencies to spread out around town) the figure is 7.0 (which is an unfortunate coincidence, as there is no direct relationship to the N=7 value). In GSM we get figures of 5.0 for N=4 and 6.6 for N=3. It was hoped that IS-136 could use tighter reuse than N=7, but its inability to cope with interference made this impossible.

Computing this figure for CDMA requires that certain assumptions are made. Formulas have been devised, and using very *optimistic* assumptions, CDMA can provide a whopping 45 users per cell per MHz. However, when using more *pessimistic* (and perhaps more realistic) assumptions, the value is 12. That still gives CDMA an almost 2:1 advantage over the TDMA competition.

In-building Coverage

Now let's deal with another issue involving CDMA and TDMA. In-building coverage is something that many people talk about, but few people properly understand. Although CDMA has a slight edge in this department, due to a marginally greater tolerance for weak signals, all the technologies fair about the same. This is because the few dB advantage CDMA has is often "used up" when the provider detunes the sites to take advantage of this *process gain*.

So, while a CDMA phone might be able to produce a reasonable call with a signal level of -106 dBm, whereas a GSM phone might need -99 dBm to provide the same level of service, does this mean that CDMA networks will always have a 7 dB advantage? If all things were equal, then yes, but they aren't equal. As I mentioned earlier, channel pollution is a big issue with CDMA networks, and to keep channel pollution to a minimum in urban environments a CDMA provider needs to keep site overlap to a minimum.

Subsequently, a CDMA network engineer will use that 7 dB advantage to *his advantage* by de-tuning the network accordingly. This means that CDMA users will frequently see markedly lower signal levels indoors than a GSM user will, but in the end it all works out about the same.

Buildings come in many configurations, but the most important aspect to their construction is the materials used. Steel frame buildings, or those with metal siding, shield their interiors more thoroughly than buildings made of wood. Large window openings allow signals to penetrate more deeply into buildings, unless the windows have metallic tint on them. Malls with glass roofs will generally provide better service than fully enclosed ones. More important than the type of building however is the proximity of the nearest site. When a site is located just outside of a building it can penetrate just about any building material. When a site is much further away however, the signals have a much harder time of getting past the walls of a structure

When it comes to distance, remember that signals are subject to the "distance squared law". This means that signals decrease by the square of the distance. A site at 0.25 kilometers away will have 4 times the signal strength of a site at 0.50 kilometers away, and 16 times that of a site 1.0 kilometers away. Distance squared however is the rate of signal reduction in ***free space***. Recent studies have shown that terrestrial communications are usually subject to rates as high as "Distance cubed", or even "Distance to the 4th". If the latter is true, then a site 1.0 kilometers away will actually be 256 times weaker than a site 0.25 kilometers away.

In-building penetration is therefore less a technology issue than it is an implementation issue. Service providers who have sites close to the buildings you commonly visit will inevitably look better those who don't. Never use someone else's in-building experiences unless you expect to go in the same buildings as they do. You cannot make useful generalizations about in-building coverage based upon one person's experience.

CDMA does have one peculiarity concerning in-building penetration that does not affect TDMA. When the number of users on a channel goes up, the general level of signal pollution goes up in tandem. To compensate for this the CDMA system directs each phone to transmit with slightly more power. However, if a phone is already at its limit (such as might be the case inside a building) it cannot do anything to "keep up with the pack". This condition is known as "the shrinking coverage phenomenon" or "site breathing". During slow periods of the day you might find coverage inside a specific building quite good. During rush hour however, you might find it exceedingly poor (or non-existent).

Some Final Observations

CDMA really comes into its element when you are out in the countryside with few sites covering large expanses of land. Under these conditions CDMA provides extremely stable audio with few frame errors to mess things up. This is because Channel Pollution is almost non-existent in these situations. Under similar conditions TDMA suffers too readily from interference and it will often blank the audio. Many people who use CDMA systems in sparsely populated areas have given this technology extremely high marks.

TDMA systems also have great difficulties in open regions just outside densely populated areas. In this situation your phone is exposed to signals coming from countless sites in the densely populated areas, but there are no dominant signals from a close-by site. CDMA can suffer under these conditions too (due to channel pollution), but not quite so badly. Valleys don't present a big problem for TDMA, but high ground is a killer. You can experience choppiness in the audio even when your signal indicator is reading 2 or 3 bars.

So in the end, can we really proclaim a winner in the CDMA vs TDMA war? For the time being I think not. Perhaps in the future when newer technologies built around wider bandwidth CDMA technologies come into existence the issue will warrant another look. By that time, even GSM will have moved to CDMA as its air interface of choice, but don't let that fool you into believing that they think the current TDMA air interface is inadequate for its purpose. Future standards are being built around high speed data.

If you are presently in the market for a new phone, my advise to you is to ignore the hype surrounding the technologies and look at service provider instead. Judge each with an eye to price, phone choice, coverage, and reputation. Technology should play a very small roll in your choice. If you follow this advice, you'll probably be much happier with the phone and service you inevitably wind up with.