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CDMA vs. OFDM in Broadband Wireless Access

The Fundamental Characteristics of OFDM Make It Ideally Suited for Broadband Data

By Victor Shtrom

More and more service providers are conducting trials of non-line-of-sight (NLOS) second-generation broadband wireless technologies. Service providers are deploying the equipment as well. As this takes place, it's become apparent that two competing technology camps exist — one based on code division multiple access (CDMA) and another based on orthogonal frequency division multiplexing (OFDM).

This article provides an in-depth look at the pros and cons of CDMA and OFDM/TDMA multiple access technologies.

Emergence of Voice Technology

CDMA was a groundbreaking technology, originally designed for simultaneously supporting many low-data-rate voice users. Using vocoders, acceptable voice-quality speech transmission can be achieved at well under 13 kbps.

As an example, IS-95 CDMA supports many low-voice-rate users by "chipping," or equivalently spreading, the narrowband voice signal into 128 times that, or 1,228,800 chips per second occupying 1.25 MHz. The resulting gain is around 21 dB. CDMA relies on this bandwidth spreading for both multiple access as well as coverage gains — the higher the spreading factor, the larger the cell area that can be covered. CDMA therefore achieves multiple access at the expense of the required extra RF channel bandwidth.

Since CDMA requires much higher RF bandwidth to deliver the same user data rates as non-CDMA technologies, it can claim spectrum reuse of one. With a spectrum reuse of one, all of the cells can operate on the same RF frequency. In fact, CDMA was designed such that everyone interferes with everyone else.

Figures 1 and **2** illustrate how CDMA achieves multiple access using code-derived spreading sequences.

At the receiver side of a CDMA link, the received waveform is multiplied by the same sequence that was used to spread the user data. This despreads the received signal, and the original data are then recovered. In theory, the spreading code sets are specifically designed such that if a code belonging to another subscriber is used to despread the received signal, the resulting output is zero. In reality, a portion of the signal does not get cancelled out (because codes are not perfectly orthogonal), so each user adds noise to all other users. In this manner, the loudest user sets the noise floor for everyone else. Therefore, CDMA requires tight power control to keep all users at the same level at the base station receiver.

Broadband CDMA Extensions

In order to deliver true broadband data rates, CDMA must either increase the RF bandwidth (for example, 3xRTT CDMA requires 5 MHz — more than three times the RF bandwidth of 1xRTT due to guard bands) or effectively aggregate several low-data-rate code channels to deliver the required rates. A combination of both of these approaches is usually used. Aggregating channels comes at the expense of the CDMA "spreading gain." Since this spreading gain is one of the major factors in determining the cell radius for CDMA, increased data rates come at the expense of reduced cell radius, or equivalently, diminished coverage.

With CDMA, cell radius can also decrease as the number of users grows (see **Figure 3**). Each new user slowly degrades the overall performance. As the number of users increases, so does the noise floor of all/each users. The users at the edge of the cell try to increase their transmit power to stay above the growing noise floor. At some point, they will no longer be able to keep up. In effect, the cell shrinks because only the users who are closer to the base station will have enough power to close the link. This results in the well-documented "cell breathing" effect, meaning there is an inherent tradeoff between CDMA coverage and capacity. The less capacity the cell needs to support, the larger the cell can be and vice versa.

This means that CDMA will do very well during the field trial phase, since it is very difficult to heavily load a trial system. To fairly evaluate a CDMA system, not only must the cell of interest be fully loaded but also all of the adjacent cells. For accurate evaluation, there should be six cells adjacent to the center cell for a total of seven trial cells.

Some vendors have synchronous CDMA implementations, which lower the multiuser interference. In theory, synchronization lowers interference by time-aligning the chip boundaries of all users. In practice, however, synchronous CDMA can only be realized for intracell users, and only if no significant multipath is present. Multipath destroys synchronicity because the reflections from buildings and other topographic obstacles travel different distances en route to the receiver and thus arrive out of sync. It is also not possible to synchronize intercell users because the differing time-of-flight delays depend on user location. Even if all of the cell sites' chip boundaries are synchronized to each other, users would still see asynchronous signals due to the different path lengths signals travel. That is, users cannot all be equidistant from all of the interfering base stations.

It is well documented that in IS-95 CDMA, other cells account for about 60 percent of the interference relative to the interference coming from within the cell.

OFDM: Reliable Data Technology

OFDM is not new. It was originally patented in 1970. Moore's Law has driven down the cost of the signal processing chips, paving the way to viable OFDM-based commercial communications systems.

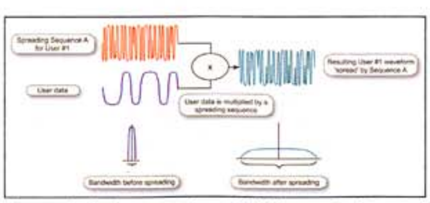

Figure 1. At the transmitter, CDMA spreads the bandwidth of user data with code spreading sequences (different codes are used for different users).

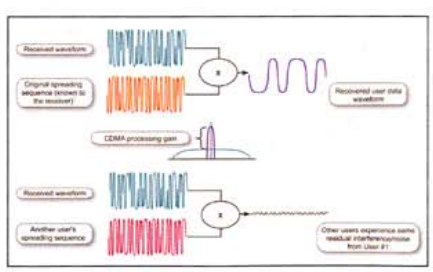

Figure 2. At the receiver, CDMA despreads user data using the same code that was used in the transmitter. Residual noise remains when another user's code is used to despread the data. The overall noise floor thus changes with loading.

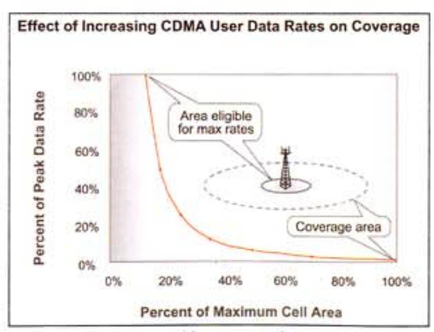

Figure 3. Only about 13 percent of the total cell area is eligible for the highest data rate based on UMTS CDMA's four to 256 spreading factors (40 dB per decade path-loss coefficient was used for the graph).

OFDM takes a broadband data pipe and distributes it among many parallel bins, the exact number being a function of the Fast Fourier Transform (FFT) size (see **Figure 4** on page 21). These bins are then modulated by the inverse FFT (IFFT). This signal, containing a bank of narrow-band carriers, is then upconverted to an RF frequency, amplified and then launched out of the antenna(s). The receiver then demodulates the signal via the FFT. In this fashion, the data are protected from multipath-induced frequency selective fading. If a subcarrier experiences a fade, the data lost are only a small portion of the aggregate data pipe. Since the transmitted data of all communications systems contains forward error correction (FEC) bits, the missing pieces can subsequently be recovered. In fact, this is the mechanism by which OFDM obtains its frequency diversity gains.

Another way to look at the same phenomenon is to notice that multipath causes the echoes from previous data symbols to arrive on top of the current symbol. This phenomenon is termed inter-symbol interference (ISI). Since OFDM sends the data in parallel over many subcarriers, each subcarrier's data rate is a fraction of the aggregate. A lower data rate means longer symbol duration. Longer symbol duration makes OFDM much less susceptible to ISI and therefore less susceptible to multipath.

CDMA systems can also obtain a measure of multipath diversity by using rake receivers and/or equalizers. CDMA rake receivers use "fingers" to lock onto each multipath signal. The outputs of the fingers are then coherently combined, resulting in multipath protection. The rake receivers are fairly complex, and so the number of these fingers is limited. IS-95 usually uses a four-finger rake. Keep in mind that these fingers are also involved in soft handoff, as well as pilot search (pilots are used for synchronization and other control purposes). Out of the four fingers, one is always searching for pilots and others are shared between soft handoff and multipath. So, an IS-95 four-finger rake cannot handle more than a couple of the most significant multipaths. The processing complexity for rake receivers and equalizers grows very quickly with broadband user data rates and bandwidth. Beyond a certain user bandwidth, OFDM processing is much more economical.

OFDM Standards

OFDM is therefore very well suited for broadband data transmission. In fact, a great majority of the new broadband standards have chosen OFDM variants for their physical layer. DSL equipment vendors chose discrete multi-tone (DMT) for broadband delivery, and DMT is essentially just another variant of OFDM.

The IEEE 802.11a wireless LAN standard relies on OFDM, as do the European Telecommunications Standard Institute (ETSI) DAB and the ETSI BRAN HiperLAN2 standards. There is also another OFDM-based standard primarily for broadband video delivery, namely the European DVB-T. The Multimedia Mobile Access Communications Systems (MMAC) in Japan has also adopted OFDM for high-speed wireless access (HiSWANa — a HiperLAN/2 derivative) and ultra-high-speed wireless

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Broadband Wireless Basics

In all data networks, multiple access is achieved by orthogonality, or independence, in any of the following domains:

- *Frequency – Users on frequency 'A' are separated from users on frequency 'B' by filtering;*
- *Time, via Time Division Multiple Access (TDMA) – users are assigned transmissions at different time slots;*
- *Space – Users at different locations within the cell are separated by forming beams in each user's direction;*
- *Codes, via CDMA – Users are all on the same frequency, and the multiple access is done through codes.*

It is much more likely, however, that multiple access is achieved by a combination of some or all of the above approaches.

CDMA vs. OFDM

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LAN (CSMA — wireless Ethernet, an 802.11 derivative).

OFDM Technologies

OFDM's subcarriers make it very conducive to other technologies, such as multiple-input-multiple-output (MIMO) antenna implementations, as well as multiple access (OFDMA) implementations. For MIMO, OFDM greatly simplifies the processing. Otherwise, complex time-frequency equalizers would be required.

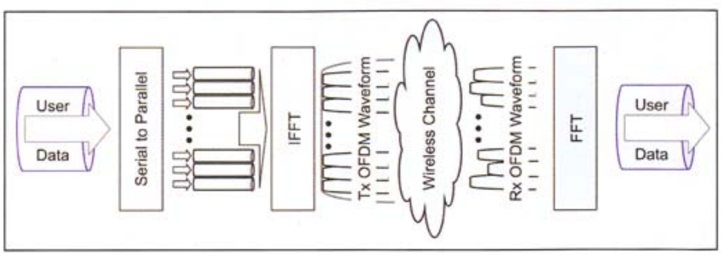

Figure 4. In OFDM a broadband pipe is divided up into many (size of the Fast Fourier Transform) parallel narrowband orthogonal carriers. This helps to mitigate frequency selective fading.

MIMO is very important to NLOS operation because it provides spatial diversity in addition to OFDM's frequency diversity. An example of spatial diversity is when a cell phone starts to fade, degrading the conversation quality. In that case, we instinctively move. By moving, we sample a different location in space where there is no multipath fade, and therefore provide spatial diversity. Yet another example of the same phenomenon occurs when you are stopped at a stop sign or a traffic light and the radio sometimes fades. Inching forward, even a small distance, quickly improves reception quality. Spatial diversity is always present, whereas frequency diversity is related to the delay spread. High availability NLOS operation requires many orders of diversity in space and frequency.

OFDM's subcarriers can also be aggregated into subgroups and assigned to different users. This permits two-dimensional scheduling of subscribers into both time and frequency slots. Allowing more scheduling opportunities minimizes latency.

There is also a link budget-related benefit from OFDMA. Since each user's OFDMA transmissions occur on a subset of the total subcarriers, receivers have narrower front ends allowing less noise in. Less noise with the same signal results in improved signal-to-noise ratios, and therefore improved coverage.

OFDM for BWA Communications

CDMA was a revolutionary technology for voice delivery, since it was specifically designed for the multiple access of many narrowband users. However, modifying and extending CDMA for use in multimegabit broadband applications forces this technology out of its sweet spot, and the price to pay is coverage and capacity.

By contrast, OFDM's fundamental characteristics make it ideally suited for broadband data delivery. OFDM's applicability to MIMO and OFDMA makes it the revolutionary technology for NLOS wireless broadband communications.

About the Author: *Victor Shtrom has 10 years' experience with smart antenna technologies for wireless cellular voice and data systems. Currently, he is the senior technical marketing manager at Iospan Wireless. He can be reached at vshtrom@iospanwireless.com.*

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