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WHAT IS OFDM?

By RON HRANAC

An unusual collaboration of authors produced what is likely the longest NCTA paper ever at The Cable Show 2012, held in Boston back in May. The paper, comprising some 185 pages, was written and presented by industry competitors John Chapman of Cisco, Mike Emmendorfer of ARRIS and Rob Howald of Motorola plus Shaul Shulman of Intel. What topic could possibly bring this diverse group of technologists together? The paper's title, Mission Is Possible: An Evolutionary Approach to Gigabit-Class DOCSIS, tells it all. The authors describe what could serve as the foundation for a future generation of Data Over Cable Service Interface Specification (DOCSIS) technology, supporting data rates as high as 5 gigabits per second (Gbps) to 10 Gbps in the downstream and 1 Gbps to 2 Gbps in the upstream.

The paper discusses various possible new forward and return frequency splits as well as upper frequency limits that go beyond today's 1002 MHz; new physical layer (PHY) technology would have to play a major part in achieving the previously mentioned lofty data rates. The authors propose something called orthogonal frequency division multiplexing (OFDM) in the downstream, and its upstream counterpart orthogonal frequency division multiple access (OFDMA). Helping to make modulation orders as dense as 4096-QAM (quadrature amplitude modulation) work reliably is a more sophisticated forward error correction (FEC) known as low density parity check (LDPC). (Quick side note: The concept of LDPC was introduced by Robert Gallager in his 1960 Ph.D. thesis but, because of encoder and decoder complexity, it wasn't practical to implement until relatively recently.)

A Closer Look

What the heck is OFDM? Grab a cup of coffee and follow along as I attempt to provide a 30,000-ft. explanation.

Cable networks have for decades used frequency division multiplexing (FDM) to allow the transmission of several RF signals through the same length of coaxial cable at the same time. Each RF signal is on a separate frequency or, more specifically, assigned to its own channel slot. National Television System Committee (NTSC) analog TV signals each occupy six megahertz of bandwidth, and each six-megahertz-wide chunk of spectrum is a channel. For instance, what we call Channel 2 occupies 54 MHz-60 MHz. Within each channel used for NTSC analog TV transmission, one will find an amplitude modulated (more specifically, vestigial sideband amplitude modulation or VSB-AM) visual carrier located 1.25 MHz above the lower channel edge, and a frequency modulated aural carrier 4.5 MHz above the visual carrier. A color subcarrier is located in between the visual and aural carriers, approximately 3.58 MHz above the visual carrier.

When the cable industry made the jump to digital transmission several years ago, the modulation of choice was QAM. Each downstream QAM signal – which is really a double-sideband, suppressed-carrier analog RF signal – occupies the same six megahertz of bandwidth as an analog TV signal. The current method of QAM transmission is known as single carrier QAM (SC-QAM); the latter is true even when DOCSIS 3.0 channel bonding is used. Each channel slot carries only one modulated carrier – a QAM signal – hence, the SC-QAM moniker. The entire data payload transmitted in the channel modulates just that one QAM signal.

Now imagine transmitting a large number of individual very-narrow-bandwidth QAM signals – hundreds or even thousands – within a given channel. A 6-megahertz-wide channel could, for example, contain up to 480 narrow QAM signals that are spaced only 12.5 kilohertz apart. Each of these narrow QAM signals, called a subcarrier, subchannel, or tone (I'll use subcarrier in the remainder of this article), carries a small percentage of the total payload at a very low data rate. The aggregate of all of the subcarriers' data rates comprises the total data payload. This variation of FDM is known as OFDM.

For improved spectral efficiency, the subcarriers actually overlap one another. This sounds counterintuitive, because one would be inclined to think that, if signals overlap each other, interference will occur. With OFDM, the subcarriers are mathematically orthogonal to – that is, distinguishable from – one another, which takes care of the interference concern. "Orthogonal" in this case means the subcarriers are independent such that there is no interaction between them despite the overlap in frequency. The concept is analogous to having zero inter-symbol interference (ISI) in the time domain.

Orthogonality is achieved by spacing the subcarriers at the reciprocal of the symbol period (T), also called symbol duration time. This spacing results in the sinc (sin x/x) frequency response curves of the subcarriers lining up so that the peak of one subcarrier's response curve falls on the first nulls of the lower and upper adjacent subcarriers' response curves. Orthogonal subcarriers each have exactly an integer number of cycles in the interval T.

With OFDM, the concept of a six-megahertz-wide channel no longer is necessary. The previously mentioned NCTA paper includes an example of a downstream OFDM channel's bandwidth being as wide as 192 megahertz, supporting some 15,200 subcarriers spaced 12.5 kilohertz apart. Along with the subcarriers are pilot tones for synchronization and other purposes. There are guard bands at each end of the 192-megahertz-wide channel, resulting in a useful bandwidth of 190 megahertz. The useful symbol duration time is 80 microseconds (µs), the reciprocal of which is the previously noted subcarrier spacing: 1/0.000080 second = 12,500 hertz. The total symbol duration time is 84.13 µs, which includes what are called guard interval samples and symbol shaping samples. Assuming 4096-QAM on each subcarrier, the 192-megahertz-wide channel supports 2.11 Gbps without FEC. Other example channel bandwidths discussed in the NCTA paper are 96 megahertz and 48 megahertz. All of these particular OFDM channel bandwidths are multiples of six and eight megahertz, which allows easier coexistence with today's North American and European channel plans. If the spectrum doesn't have enough room for a full OFDM channel, some of the subcarriers can be nulled, which effectively turns them off.

OFDM can be used for multiple access – say, as OFDMA in the upstream – by assigning different subcarriers to different users. OFDM also can be used in combination with such other multiple access schemes as time division multiple access (TDMA). In this case, the full channel would be assigned to one user at a time, and the multiple access achieved via time division. When combined with TDMA, OFDM can deliver a very high peak-data rate, which may be desirable for some applications.

Pros And Cons

Advantages of OFDM include the ability to adapt to such degraded channel conditions as severe micro-reflections without the need for complex adaptive equalization algorithms. One reason for the latter is that a very narrow bandwidth subcarrier typically experiences what is known as "flat fading" when micro-reflections affect channel response. This is in contrast to a SC-QAM signal that occupies the full channel bandwidth and is susceptible to amplitude ripple (standing waves) across that full bandwidth. Each OFDM subcarrier "sees" just a tiny portion of the ripple, which for the most part affects only the amplitude of the narrow subcarrier. Compensating for what amounts to little more than an amplitude variation among subcarriers simplifies the fix.

Likewise, the composite OFDM signal is more robust than SC-QAM in the presence of interference. For example, a narrowband ingressor like a pager transmitter's signal affects only a few subcarriers rather than taking out the full channel. Depending on the severity of the interference, FEC may be able to deal with it.

Alternatively, the OFDM transmitter simply can disable a few subcarriers to avoid narrowband interference on problem frequencies. Inter-symbol interference is generally less of a problem with OFDM because of the low data rate per subcarrier. As discussed earlier, the overlapping nature of OFDM's subcarrier transmission provides high spectral efficiency.

If information about the channel's condition is sent back to the transmitter by the receiver, then adaptive modulation, FEC and power allocation can be applied to all subcarriers, blocks of subcarriers or even individual subcarriers. In other words, some subcarriers in the channel can use higher orders of modulation than other subcarriers, some subcarriers can have more aggressive FEC, and the power of individual subcarriers can be varied – all on an as-conditions-warrant basis.

OFDM does have a few disadvantages: It is susceptible to frequency and clock errors, although the pilot carriers that accompany the subcarriers help to mitigate this by providing the receiver a means of synchronization. OFDM has a high peak-to-average power ratio (PAPR), but a spectrum full of SC-QAM signals does, too. While PAPR-reduction techniques are available for OFDM and OFDMA, they probably won't be necessary in a typical cable network. Some of OFDM's high spectral efficiency is reduced by the use of cyclic prefixes, which help to maintain subcarrier orthogonality.

Why Bother?

You may be wondering why one would even consider a new PHY for a possible future version of DOCSIS. After all, SC-QAM works well, and channel bonding can be used to significantly increase data throughput. The good news is that OFDM isn't some new-fangled technology without a proved history. It is used in Wi-Fi networks, worldwide interoperability for microwave access (WiMAX), long term evolution (LTE), digital audio broadcasting (DAB), ultra wideband (UWB) and Europe's digital video broadcasting (DVB). A variation of ODFM also is used in asymmetric digital subscriber line (ADSL) and very high-speed digital subscriber line (VDSL).

The previously discussed advantages bring a lot of signal transmission flexibility to the table. When OFDM is combined with more powerful FEC like LDPC, higher orders of modulation can be used – within the limits of the channel conditions, of course. Toss in new frequency splits and upper frequency limits, and all of this could help cable networks of the future support far higher data rates than are possible today with SC-QAM.

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