# RTT TECHNOLOGY TOPIC
December 2004

# OFDM Performance and cost

In last month's Hot Topic, we looked at 3G cost and quality metrics. This month, we look at why the PHY (the radio physical layer) has to work harder year on year, why OFDM is becoming increasingly prevalent as a way of improving PHY performance and some of the 'hidden' costs implicit in getting OFDM to work at a practical level.

**THE PHY OVER THE PAST 100 YEARS**

Over the past 100 years there have been a number of clearly defined evolutionary changes in the way that radio spectrum (the radio physical layer/PHY) has been utilised.

Early radio transmissions used spark transmitters, inherently broad band devices. The invention of the valve and an understanding of oscillation techniques and tuned circuits meant that broad band spark transmitters were replaced with progressively narrower band (more power efficient) transmission systems.

The invention of the transistor in the 1950's enabled these narrow band radio techniques to be applied in portable transceivers, first in the VHF band and then at UHF frequencies. By the mid 1980's, radio systems were typically using 25 kHz, 12.5 kHz or 5 kHz channel spacing for voice and many of these systems are still in use today.

In the 1970's however, a general (world-wide) R and D consensus emerged that it would be more cost efficient to filter in the time domain rather than the frequency domain. In wireline communications, frequency division multiplexed circuits were replaced with time division multiplexed circuits.

In wireless, a similar transition occurred with channel spacing being relaxed to 200 kHz (GSM) or more recently the 5 MHz used in present UMTS radios. User to user selectivity in these systems is achieved either by using time slots (GSM and PDC) or orthogonal spreading codes (UMTS), ie time domain rather than frequency domain selectivity..

**THE WIDE AREA PHY AND TCP/IP PROTOCOL OVERHEADS**

There has been a debate as to the spectral efficiency of these systems. The need to support mobility (users moving at up to 500 km/h) and wide area coverage (Pico cells, microcells, macro cells) implies substantial signalling and channel coding overhead. In GSM for example, 62% of the channel bandwidth is taken up by signalling and channel coding. Supporting IP voice and/or video (IP MMS) will add significant **additional** loading to the PHY in terms of address and traffic shaping/prioritisation overhead.

## THE WIFI PHY, MAC AND SESSION MANAGEMENT OVERHEADS

In 802.11 a and g, QoS mechanisms (EDCF/EDCA/HCCA) substantially decrease MAC efficiency over and above higher layer IP address and signalling overhead. Even something as simple as SIP adds 7000 bytes of signalling load every time a session starts. These overheads translate directly into a need to achieve higher more efficient user data throughput.

The higher speeds are needed for new services such as simultaneous voice and video, the improvements in efficiency are needed to help reduce power drain in hand held devices.

CDMA could be used for these higher data rate applications (tens of megabits per second) but the chip rates needed become problematic and tend to introduce jitter.

Adding in an OFDM multiplex helps to slow down the symbol rate. Consider it as an additional step in the signal preparation process. In a sense it marks a U turn in that additional frequency filtering is implied and this implies a (dollar and power budget) cost in terms of TX/RX processor overhead. These costs are reasonably easy to quantify. The harder part is quantifying the 'hidden costs' incurred in making the OFDM multiplex work **well** in the poor signal to noise environment typically present in mobile communications.

## OFDM AND PHY PERFORMANCE

In OFDM, a wide band channel is sub divided into a number of narrow band frequency sub carriers. The purpose of the OFDM FFT is to get the symbol rate down and increase the symbol length so that it remains resilient to multipath interference.

## WIFI AS AN EXAMPLE

WiFi is an example. In 802.11 a and g, 17 MHz of occupied bandwidth is sub divided into fifty four 312.5 kHz channels. A 54 Mbps OFDM 802.11 a or g channel has a symbol length of 4 microseconds of which .8 microseconds is used as a guard period and 3.2 microseconds for data. As a comparison, a single carrier (non-OFDM) channel would have a symbol duration of 50 nanoseconds. Given that radio waves take .33 microseconds to travel 100 metres, it can be seen that a single carrier channel will be subject to intersymbol interference (ISI). An OFDM sub carrier will be (relatively) immune to ISI.

## DAB/DMB/DVB AS AN EXAMPLE

DAB/DMB is another example of OFDM being used to reduce the symbol rate. Here the requirement is different in that the distance from the transmitter to the receiver can be 10, 50 or even 100 kilometres or more rather than the 100 metres typical of a WiFi wireless LAN. This requires a longer guard interval to accommodate the longer delay spread on the channel. A longer guard interval requires a more complex FFT, for example 1.536 MHz channels divided into 1536 sub carriers produce a guard interval of .246 milliseconds compared to the .8 microseconds in 802.11 g and a.

DVB is another example with similar delay spread characteristics on the channel - an 8 MHz channel is subdivided into 8000 sub carriers (the so called 8K multiplex) giving a symbol time of 1 millisecond, a guard interval of 250 microseconds and a carrier distance of 1 kHz.

**THE COST OF OFDM**

However, although OFDM does great things at symbol level, it does introduce a number of performance and test and measurement challenges.

The signal has significant peak to average amplitude which needs to be captured and expressed statistically, the impact of clipping on signal integrity and burst errors has to be measured and analysed, the relatively closely spaced carriers (312.5 kHz in WiFi OFDM, 1 kHz in DVB) amplify the effects of non linearity and VCO instability, transmitter modulation accuracy is compromised by constellation error, centre frequency leakage and a lack of spectral flatness. Higher user data rates are achieved by using higher-level modulation techniques (64 level QAM for example) ie the high data rates are supported by a combination of OFDM techniques and higher level modulation. This in turn places stringent demands on modulation accuracy and demodulator performance. Designing a DAB or DVB broadcast transmitter to meet these requirements is reasonably straightforward (given that there are relatively large amounts of DC power available) but doing something similar in a handset (even at low RF transmit power) is rather more demanding.

**OFDM PERFORMANCE IMPAIRMENTS**

Typical impairments include time domain impairments (signal timing problems caused by transmit rise times) and time, frequency, amplitude and phase inaccuracies caused by non-linear PA's, VCO instability and/or carrier instability. Problems with modulation quality either show up as an error vector at sub carrier level or at symbol level and are typically caused by PA non linearity, signal clipping, signal filtering or just simple straight forward phase noise.

Impairments and inaccuracies, including timing errors in the modulator and subsequent distortions introduced by amplification and filtering translate into error vectors. Error vectors translate into bit error rates and burst errors at the physical layer, which translate into frame errors at the MAC layer and packet loss at the transport layer which in turn absorb network bandwidth and radio bandwidth and power.

**OFDM and UWB**

OFDM is a 'favoured option' for handling bit rates from a few tens of megabits up to at present just over 100 Mbps (the various turbocharged versions of 802.11 b and g).

The higher throughput rates are achieved by the combination of OFDM and higher level modulation but this makes the radio system inherently sensitive to a poor radio channel which makes it difficult to achieve anything remotely approaching the headline data rates in anything other than near perfect channel conditions.

At which point we start to look at Ultra Wideband techniques. In our September Hot Topic (BLUWB) we pointed out that as CMOS geometries have decreased, it has become practical to build low cost pulse train generators and detectors with the bandwidth dictated by the rise time of the IC process. Thus today it is feasible to produce nanosecond length pulses (occupying one GHz of instantaneous bandwidth). There is no modulation as such as effectively the transmission is a burst of noise. This is the basis of the Motorola/Freescale DS UWB chip set - a combination of direct sequence coding and (simple) pulse modulation.

TI and Intel have however promoted an alternative 'multi-band' option, based on an OFDM multiplex with a 528 MHz lower band and 528 MHz upper band split into multiple OFDM sub carriers.

Although the Freescale approach has many benefits,(low cost, good power efficiency and the ability to scale to higher bit rates as rise times reduce eg 800 Mbps and above), the MultiBand option is presently being persuasively promoted on the basis of having a tighter spectral mask.

OFDM is therefore presently deployed in WiFi, DAB, DMB, DVB and proposed for UWB radio systems. It is also used for digital AM broadcasting in the sub 30 MHz bands (with 4.5 to 20 kHz channel spacing) and is a strong contender for fourth generation cellular systems. Note that these systems are sometimes described as COFDM -coded OFDM, to indicate that the system has coding added to correct for residual ISI errors caused by overlapping sub-carriers.

It has to be said however that all of these OFDM systems tend to promise rather more than they actually deliver. DVB is a present example in that receive sensitivity is really not as good as it could or should be, and why the headline data rates printed on the packaging of an 802.11 g access point bear little or no relation to the real life throughputs likely to be achieved.

**SUMMARY.**

OFDM transceiver design is relatively complex and involves relatively expensive test and development programmes, and presently expensive conformance, performance and manufacturing tests. Applications such as WiFi voice and WiFI video place significant additional demands on PHY performance in terms of RX sensitivity and TX efficiency and are hard to realise in present implementations. (The MAC and IP overheads hit the Eb/No link budget just where it hurts).

The DS UWB system promoted by Motorola/Freescale is persuasive in that it achieves high data rates by using short pulse durations rather than a complex FFT and/or high order modulation techniques. This means the PHY can be realised at low cost and with relatively simple test procedures. Concerns (real or imaginary) are however being expressed as to the impact of the DS-UWB PHY on proximate radio systems, with the multiband OFDM proposal presently gaining ground on the basis of a more tightly managed spectral mask.

## PHY PERFORMANCE AT A PRICE

The increasing ubiquity of OFDM in radio systems deployed from long wave up to 10 GHz and above provides a robust mechanism for achieving high data rates across a multipath channel. The FFT multiplex/demultiplex is however computationally expensive and present OFDM transceivers offer disappointing performance in terms of modulation accuracy, receive sensitivity (demodulator performance) and power efficiency. For example, although 802.11-g chip sets are promoted as being power efficient on the basis of watts per megabyte transferred, they are in practice comparatively inefficient due to implementation issues (modulator/demodulator performance). Poor modulator/demodulator performance translates into high bit error rates and burst errors that translate into retries and retransmissions or packet loss. These losses have to be added to the MAC and network/transport layer overheads ie the power efficiency per user byte is far lower than the headline data rates suggest. Efforts to improve fundamental OFDM performance (modulator/demodulator performance) are presently proving expensive both in terms of R and D effort and test and measurement overhead.

As you would expect, PHY performance gain using OFDM comes with a dollar and power budget price tag.

## About RTT Technology Topics

RTT Technology Topics reflect areas of research that we are presently working on.

We aim to introduce new terminology and new ideas to clarify present and future technology and business issues.

Do pass these Technology Topics on to your colleagues, encourage them to join our Push List and respond with comments.

## Contact RTT

RTT, the Shosteck Group and The Mobile World are presently working on a number of research and forecasting projects in the cellular, two way radio, satellite and broadcasting industry.

If you would like more information on this work then please contact

geoff@rttonline.com

00 44 208 744 3163