Everywhere you imagine.

DCSK Technology vs. OFDM Concepts for PLC Smart Metering

By, Kevin Jones & Christos Aslanidis

March 2009

RENESAS
Everywhere you imagine.

Figures and Tables

Introduction

This article seeks to establish the keys factors to consider when selecting a suitable PLC technology for smart metering applications, to objectively evaluate established DCSK PLC technology versus proposed OFDM concepts and to conclude from a technical point of view which of these technologies is most suitable.

Definitions and Objectives

Environmental concerns, increasing demand and fears over the security of Europe's energy supply is causing massive technological and infrastructure investment from utility companies and European governments into smart metering networks. These networks provide many features such as on demand readings, remote tariff updates, connection/disconnection, "theft" monitoring and demand/load management. All of which require communication between meters and a data concentrator. For utility companies conveying this information is a challenge. The utility companies have many aspects to consider including network coverage, delay of information flow, amount of data transmitted etc. Power Line Communication (PLC), whilst providing some technical challenges, makes an obvious choice because the infrastructure is already present, it provides the lowest cost solution and is well proven with many massive deployments already existing.

There are defined standards for narrow band PLC systems as laid out by CENELEC, the European Committee for Electro Technical Standardization. CENELEC standard EN 50065 defines the signaling on low voltage electrical installations in the frequency range 3 kHz to 148.5 kHz, whereby the use of frequencies within the band 3 kHz to 95 kHz is restricted for use by electricity suppliers and their licensees and more commonly referred to as CENELEC A.

Furthermore there are a number of modulation schemes which can be used in PLC such as FSK, SFSK, DCSK, OFDM etc. and as with all technology, advancements are continuous. The selection of the right PLC technology will play an important part in ensuring reliable and cost effective network operation. Whilst Differential Code Shift Keying (DCSK) technology is considered the most robust PLC technology and has been deployed in many AMM installations already, there is increasing interest around Orthogonal Frequency Division Multiplexing (OFDM) as a preferred modulation for PLC. OFDM is already used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access. The primary reason for this interest seems to be that OFDM promises higher data rates with an adaptive mechanism to control the data rate according to the dynamic noise levels usually seen on the power lines. So what is the difference?

DCSK in Detail

DCSK is known for its extreme robustness and belongs to the family of spread spectrum modulation technologies. It can currently be offered as a truly interoperable solution with existing PHY and Data Link Layers being available from two suppliers, Yitran Communications Ltd. and Renesas Technology. DCSK is also an open standard as specified by HomePlug and Echonet (in Japan) and has a roadmap to achieve higher data rates. In October 2008, Renesas announced that it will use Yitran's high speed PLC technology in its expanding family of narrowband PLC devices, with communications speeds of up to 150 kbps in FCC bands (up to 60 kbps for CENELEC A). The technology is also compliant with different frequency band regulations such as CENELEC, FCC and ARIB with backward compatibility to ensure interoperability with established installations. It will be uniquely available as an interoperable solution from at least two semiconductor vendors from its launch. This device will reduce the system cost of a DCSK based solution further due to high system integration (integrated power amplifier).

Spread spectrum modulation is a technique in which a signal is transmitted on a bandwidth considerably larger than the frequency content of the original information. Spread spectrum modulations provide many advantages; they are less susceptible to narrowband and burst noises, able to work when the signal level is lower than the noise level (negative SNR). A graph showing the bit error rates of various SNR values for DCSK is shown in Figure 1. They are also less susceptible to multi-path fading, signals arriving via different routes, and impedance modulation. These properties explain why the military have used spread spectrum for many years and why DCSK is considered the most robust modulation technique for PLC. DSCK is already chosen by industry initiatives such as HomePlug Command and Control and Echonet. This waveform spreading produces a modulation with a constant envelope (same amplitude signal across the range of transmitted frequencies) which reduces the Peak-to-Average Ratio (PAR) and requires less linear power amplifiers. This helps produce a cheaper less power consuming solution which generates less heat. Using frequencies away from the transmission limits reduces the need for high order filters which also reduces the total cost of the solution.

A chirp signal (signal with sweeping frequency) starts and ends at different frequencies, for CENELEC A typically between 20-80 kHz, depending on the transmitted symbol. DCSK supports multiple transmission modes which correspond to the number of bits which are transmitted during each symbol period in standard mode there are 6 bits represented by each symbol. For example, if we consider the bit pattern 000000'b then over a fixed time period the frequency of transmission would spread from 20kHz to 40kHz, whereas the bit pattern 100000'b would be shifted according to a shift index and start at 30kHz and sweep up to 40kHz and then from 20kHz returning to 30kHz. A combination of 6 bits would then split the transmission into 64 different waveforms all starting at different frequencies but all transmitting over the same range of frequency. This is a major advantage of DCSK. PLC is renowned for its high noise, loads and impedances which can change within short periods of time and significantly more burst noises (a burst of noise at or around a particular frequency). Due to the spreading of the signal across a band of frequencies noise at any given frequency does not affect the signal. The reason for this is that the decoder can still decode the parts of the waveform which are not affected. For transmissions within the CENELEC A band the same waveform is also repeated in three transmission bands, 18-44 kHz, 38-63 kHz and 58-89 kHz which makes DCSK an extremely robust modulation. An example frequency spectrum of DCSK modulation is shown in Figure 2.

A DCSK receiver contains a correlator which employs a matched filter having a template of the chirp waveform which is used to detect the amount of rotation within the received signal for each symbol. This can be compared for all possible shift patterns, with the shift pattern which bears maximum correlation then decoded to yield the originally transmitted data. A DCSK modem transmitter also contains the following blocks:

- Encoder; responsible for error correction codeword generation.
- Interleaver; used in digital data transmission technology to protect the transmission against burst errors. These errors overwrite a lot of bits in a row, so a typical error correction scheme that expects errors to be more uniformly distributed can be overwhelmed. Interleaving is used to help stop this from happening.
- Preamble (synchronization sequence); a signal used to synchronize the transmission timing. Proper timing ensures that all systems are interpreting the start of the information transfer correctly. It can also contain information about the packet type used in the particular transmission, for example in DCSK the mode of transmission, number of bits per transmitted symbol.
- Digital Filter (shaping filter); internal to the DCSK modem and used to improve the spectral characteristics of the output signal, suppressing any signals generated outside the transmission band.
- Digital to Analogue Conversion (DAC).
- Power amplifier, the signal generated by the DAC is fed into a power amplifier such as a high current dual line driver IC to increase the amplitude of the waveform.
- Line Coupler; couples the amplified signal to the high voltage mains network.

OFDM in Detail

OFDM is a method of modulating a large number of sub-carriers in such a way that each sub-carrier is independent and does not interfere with neighboring carriers. Each carrier is classed as a data stream or channel which is modulated with a conventional modulation scheme, such as BPSK, QPSK or QAM, thus allowing for several parallel data streams. One of the main advantages of OFDM is that it is possible to change the modulation scheme used by the carriers, thus adapting the modulation to the noise currently experienced in the transmission medium and therefore increasing transmission speeds during less noisy periods. Another major advantage is that transmission sub-carriers within the OFDM waveform can be selected, meaning that known noise sources at or around one sub-carrier's frequency can be avoided by simply removing this sub-carrier. Hence a low bit rate transmission is converted in to a high bit rate transmission by transmitting different parts of the data on many different sub-carriers. The ability to adapt to severe channel conditions (by changing modulation or selecting sub-carriers), being robust against multi-path propagation, and offering high bit rates (in the range of 128kbps for "PRIME" specification), make OFDM an attractive choice for smart meters or smart grids. "PRIME" is a project that was launched in order to assess the idea, define and test a new OFDM PLC based solution.

The principles of operation are somewhat different to DCSK, and a typical OFDM modem transmitter contains the following blocks:

- Scrambler; performs data pre-whitening, which changes the probability of long sequences of '0's and '1's. This has a positive effect on forward error correction and also reduces the peak-to-average ratio of the waveform which in turn relaxes the linearity requirement of the power amplifier.
- Convolutional Encoder; a forward error correction scheme. By inserting extra data bits into the transmitted data the receiver can detect and correct errors in the received bit patterns.
- Interleaver; as for DCSK.
- Mapper; for each data sub-carrier the data bits are mapped to the corresponding constellation points for the modulation, BPSK, QPSK etc.
- Inverse Fast Fourier Transform; decomposes a sequence of values into components of different frequencies.
- Interpolation; a method of constructing new data points within the range of a discrete set of known data points.
- Digital to Analogue Conversion (DAC)
- Power amplifier; as for DCSK.
- Line Coupler; couples the amplified signal to the high voltage mains network.

Not all of the functional blocks are listed above but an example diagram of these is shown in Figure 3. From the description and block diagram it is clear that OFDM provides a complex solution. OFDM has also been proven and widely adopted in many applications.

There are however some downsides to OFDM technology. In general the total solution is much more expensive. As with most non-constant envelope modulations, OFDM has a higher PAR waveform. This actually requires a very (6 – 10 dB higher) linear power amplifier and therefore for similar power outputs, power amplifiers that are up to 4 times more capable to handle the peak envelope power are required. These larger power amplifiers are less efficient, consume more primary power, generate more heat and are more expensive. This in turn also requires a more expensive power supply. These linearity requirements also have a knock-on effect on the coupling circuit. The transformer used to couple the PLC signal to the high voltage network will require higher linear performance and therefore generally a more expensive transformer is required. Since OFDM is more complex there is also added cost for the processor or PLC modem. A high performance DSP is used for up-sampling, interpolation and viterbi decoding. The DAC is more complicated due to the aforementioned linearity which increases the silicon size, all of which requires an expensive device.

OFDM for PLC

Firstly, it should be noted that some of the disadvantages listed above are not necessarily valid for an OFDM solution for CENELEC A. Generally speaking OFDM solutions are spread across multiple bands of transmission frequencies whereas in CENELEC A the transmission is contained within one band 3 – 95 kHz. This means that a constant envelope waveform can be created and reduces the requirement for such linear amplifiers and coupling circuits.

Although OFDM has been adopted in many applications this is not so true for PLC. The CENELEC A band of transmission is renowned for its high noise, constantly varying loads and impedances and significantly more burst noise. These effects diminish the advantages of OFDM for at least two reasons; the high data rate modulations such as Quadrature Amplitude Modulation (QAM) require a clean environment and a higher signal to noise ratio, so immediately the data rate of the total system in a noisy environment is less than the theoretical. The other complication is the number of sub-carriers used; the more sub-carriers the higher the data rate. However the advantage of OFDM is its flexibility, so in a noisy environment certain sub-carriers will be removed from the communication which in turn will reduce the perceived data rate. To understand this it is necessary to look at how the carriers are selected.

If we consider the band 3 - 95 kHz, to reduce the requirement for high order filters frequencies near the limits should be avoided. Taking the band 30 – 80 kHz and having a sub-carrier spacing of around 500 Hz would allow 100 sub-carriers. If the modulation used is 8 PSK (3 bits per symbol) and symbol duration is 2ms this equates to 150 kbps raw data rate (ignoring pilot carriers). As mentioned if noise is present at a range of frequencies then sub-carriers with frequencies within the noise band can be removed. For example, consider noise around 30 – 40 kHz, thus reducing the number of sub-carriers to 80 and therefore the raw data rate reduces to approx. 120 kbps, if error correction (convolution code ½) is used then the data rate would be approx. 60 kbps. In general convolutional code would always be present. Table 1 shows an example of achievable raw data rates with different modulations based on 100 data sub-carriers. It shows that a 150 kbps raw data rate solution is reduced to 50 kbps when convolutional code is used and the modulation is DQPSK. A reduction in data rate could however be avoided using OFDM. In the above example (of reducing 100 sub-carriers to 80 due to noise at 30 – 40 kHz) the sub-carrier spacing could be reduced to 400 Hz and therefore there would still be 100 data sub-carriers located between 40 – 80 kHz. However, this would increase the FFT speed and therefore require more performance from the CPU, a higher performance DSP increases system cost.

In a real system the sub-carrier spacing is generally fixed so there is a maximum number of sub-carriers (not all of these must be used in the transmitted frame). There are also a set number of predefined headers with information about which sub-carriers exist and which modulation is used. This means the designer must decide how many sub-carriers there are and where these are located in frequency space. The PLC environment must be evaluated in detail to select the sub-carriers which will be removed in noisy periods. A crude example might be that noise is found between 30 – 50 kHz during the morning and between 70 – 80 kHz in the evening then headers can be formed indicating transmissions which avoid sub-carriers in these ranges. Any transmission which is not decipherable by the receiver (noise level too high for modulation chosen or burst noise at sub-carrier frequency) must be re-transmitted and this has a severe impact on the effective data rate. The system must either use the same more robust modulation and smaller number of sub-carriers continuously or continually search for the optimum modulation. This is fine for large data transfer applications such as WiFi whereby once the transmission is selected the system transfers a large block of data, but it is not ideal for small data transfers such as AMM. In a noisy environment increasing the robustness negates the major advantage of a promised higher data rate.

RENESAS
Everywhere you imagine.

Existing OFDM Solutions for PLC

It is also important to consider existing OFDM based PLC solutions. Previously it was mentioned that an advantage of OFDM was being able to select the modulation used (a higher data rate modulation can be used at times when there is less noise on the network). However, just because the signal is classed as OFDM does not mean that the modulation is flexible. It simply means that it is spaced such that carriers are orthogonal.

A solution currently exists which makes use of flexible modulation and allows the user to select BPSK, QPSK, 8-PSK and 16-PSK. This offers a maximum data rate of 78.6 kbps using a maximum of 48 data sub-carriers from 24 – 93 kHz. Using such high frequencies means that the transmission filters must be of a high order (more expensive) to sufficiently reduce out of band signals. The solution, as provided, is not compatible to CENELEC A. To obtain the maximum data rate, 78.6 kbps, 16-PSK modulation must be used on all 48 data sub-carriers. This is the maximum physical data rate so if error correction is used then application data rate is reduced. In tests, the maximum robustness of this solution (using 16-PSK as the modulation) was achieved using 24 carriers from 24-93 kHz, making the maximum PHY bit rate 38.4 kbps. However to achieve the maximum attenuation of 60 dB, error correction was enabled (FEC ½) which meant the actual application layer data rate was just over 3 kbps. With DCSK modulation, error free transmission at 2.5 kbps is achieved at over 90 dB attenuation.

Although any number of phases may be used to construct a PSK constellation, 8-PSK is usually considered the highest suitable to deploy in OFDM systems. With more than 8 phases the error-rate becomes too high and there are better though more complex modulations available such as QAM.

As outlined above, there are many different types of OFDM systems for PLC, using different modulations and different sub-carriers. More and more utility companies are looking for interoperable solutions and standard protocols. Although OFDM is flexible and the algorithms executed in flexible DSPs, these different types are not interoperable - unless interoperability is specified at the beginning. A system which utilizes BPSK-only modulation cannot suddenly demodulate 16-PSK modulated waveforms. It may be possible to change the firmware within the DSP but 16-PSK requires a higher performance DSP so this must already be present. The sub-carriers used for the modulation must also be agreed and the amplifiers, coupling circuits and filters must be chosen to match, more than likely requiring modifications to the hardware design.

DCSK or OFDM

Comparing the two solutions is extremely difficult. The promise of such high data rates is enticing but the noise level must be sufficiently low to achieve these not forgetting that these are reduced with error correction techniques. The idea of PLC is not new, nor is OFDM as a technique so why do products not exist today with the promised data rates. Anyone implementing or designing such smart grid systems must ask themselves if these data rates are achievable in a real PLC installation. If they are, is the cost of these expensive systems viable? It is clear that DCSK is a much lower cost one chip solution which has been tested around the world against available technology and always ranked number one in performance and reliability.

Already proven as a dual source, interoperable and open standard solution now with a roadmap to much higher data rates must make this a truly competitive alternative. With time constraints on the roll-out of such smart metering networks, do designers have time to wait for a robust, interoperable OFDM solution?

Figures and Tables

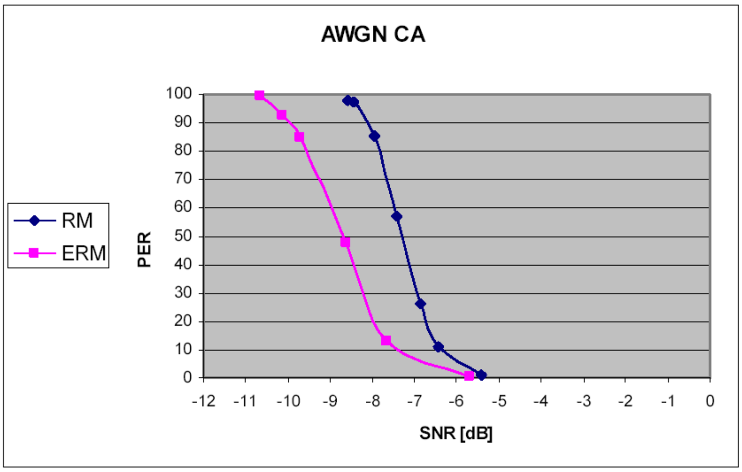

Figure 1
Graph showing the bit error rate verses the signal to noise ratio of DSCK for CENELEC A using Gaussian white noise.

Figure 2
Example, frequency spectrum of DCSK modulation for CENELEC A.

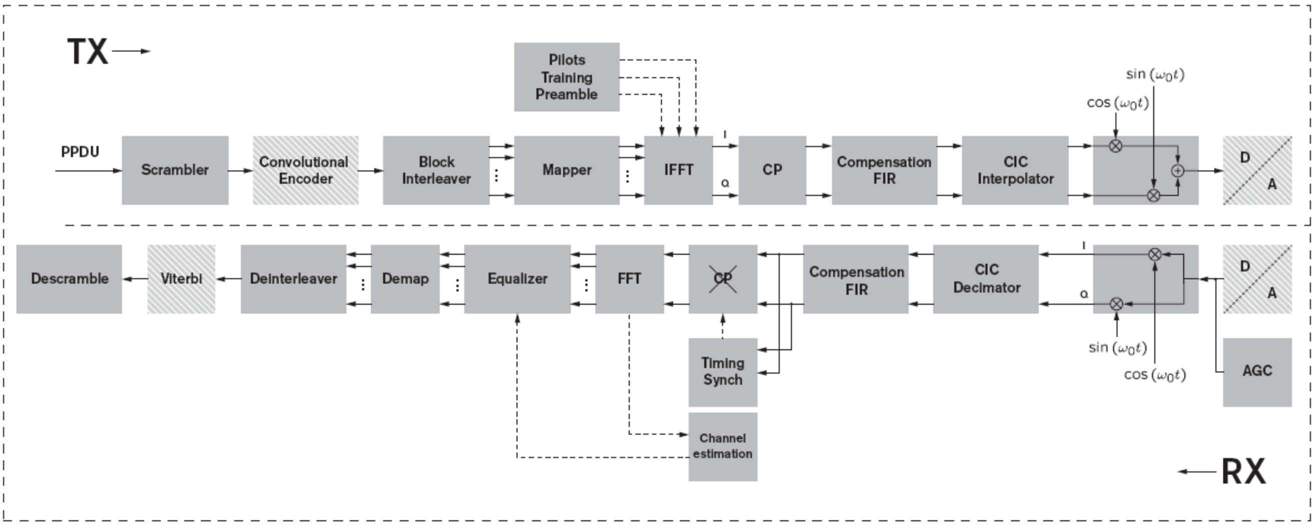

Figure 3
Block diagram showing the functional blocks of an OFDM transmitter and receiver.

	DBPSK		QPSK		8-PSK	
Convolutional Code (1/2)	On	Off	On	Off	On	Off
Effective bits per sub-carrier	0.5	1	1	2	1.5	3
Information bits per symbol	50	100	100	200	150	300
Raw Data Rate (approx.) kbps	25	50	50	100	75	150

Table 1
Table showing approximate raw data bit rates for an OFDM solution containing 100 data sub-carriers and a symbol duration of 2 ms.