Digital Modulation Techniques Evaluation in Distribution Line Carrier system

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Abstract- In this paper, different methods of modulation technique applicable in data transferring system over distribution line carries (DLC) system is investigated. Two type of modulation –analogue and digital – is evaluated completely. Different digital techniques such as direct-sequence spread spectrum (DSSS), Frequency-hopping spread spectrum (FHSS), time-hopping spread spectrum (THSS), and chirp spread spectrum (CSS) have been analyzed. The results shows that because of electrical network nature, digital modulation techniques are more useful than analog modulation techniques such as Amplitude modulation (AM) and Angle modulation .
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Introduction

During the last decades, the usage of telecommunications systems has increased rapidly. Because of a permanent necessity for new telecommunications services and additional transmission capacities, there is also a need for the development of new telecommunications networks and transmission technologies. From the economic point of view, telecommunications promise big revenues, motivating large investments in this area. Therefore, there are a large number of communications enterprises that are building up high-speed networks, ensuring the realization of various telecommunications services that can be used worldwide.

The direct connection of the customers/subscribers is realized over the access networks, realizing access of a number of subscribers situated within a radius of several hundreds of meters. However, the costs for realization, installation and maintenance of the access networks are very high. It is usually calculated that about 50% of all network investments belongs to the access area. On the other hand, a longer time is needed for paying back the invested capital because of the relatively high costs of the access networks, calculated per connected subscriber. Therefore, the network providers try to realize the access network with possibly low costs.

After the deregulation of the telecommunications market in a large number of countries, the access networks are still the property of incumbent network providers (former monopolistic telephone companies). Because of this, the new network providers try to find a solution to offer their own access network. An alternative solution for the realization of the access networks is offered by the DLC technology using the power supply grids for communications. Thus, for the realization of the DLC networks, there is no need for the laying of new communications cables. Therefore, application of DLC in low-voltage supply networks seems to be a cost-effective solution for so-called "last mile" communications networks, belonging to the access area.

However, power supply networks are not designed for communications and they do not present a favorable transmission medium. Thus, the DLC transmission channel is characterized by a large and frequency-dependent attenuation, changing impedance and fading as well as unfavorable noise conditions. Various noise sources, acting from the supply network, due to different electric devices connected to the network, and from the network environment, can negatively influence a DLC system, causing disturbances in an error-free data transmission. On the other hand, to provide higher data rates, DLC networks have to operate in a frequency spectrum of up to 30 MHz, which is also used by various radio services. Unfortunately, a DLC network acts as an antenna producing electromagnetic radiation in its environment and disturbs other services operating in the same frequency range.

1. Modulation Techniques

Modulation is the process of varying a periodic waveform, i.e. a tone, in order to use that signal to convey a message.

1) Analog modulation methods

In analog modulation, the modulation is applied continuously in response to the analog information signal. A low-frequency message signal may be carried by an AM or FM radio wave. Common analog modulation techniques are:

- Amplitude modulation (AM)
  - ✓ Double-sideband modulation (DSB)
  - ✓ Single-sideband modulation (SSB, or SSB-AM),
  - ✓ Vestigial sideband modulation (VSB, or VSB-AM)
  - ✓ Quadrature amplitude modulation (QAM)
- Angle modulation
  - ✓ Frequency modulation (FM)
  - ✓ Phase modulation (PM)

2) Digital modulation methods

In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols.

The most common digital modulation techniques are:

- Phase-shift keying (PSK):
- Frequency-shift keying (FSK):
- Amplitude-shift keying (ASK)
- On-off keying (OOK), the most common ASK form
- Quadrature amplitude modulation (QAM) - a combination of PSK and ASK:
- Continuous phase modulation (CPM) methods:
- Orthogonal frequency division multiplexing (OFDM) modulation:
- Wavelet modulation
- Trellis coded modulation (TCM), also known as trellis modulation

3) Spread-spectrum modulation:

These techniques are methods by which energy generated in a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference and jamming, and to prevent detection.

Frequency-hopping spread spectrum (FHSS), direct-sequence spread spectrum (DSSS), time-hopping spread spectrum (THSS), chirp spread spectrum (CSS), and combinations of these techniques are forms of spread spectrum. Each of these techniques employs pseudorandom number sequences, created using pseudorandom number generators to determine and control the spreading pattern of the signal across the allotted bandwidth. Ultra-wideband (UWB) is another modulation technique that accomplishes the same purpose, based on transmitting short duration pulses. Wireless Ethernet standard IEEE 802.11 uses either FHSS or DSSS in its radio interface.

To reduce the negative impact of distribution line transmission medium, DLC systems have to apply efficient modulation, such as spread spectrum and Orthogonal Frequency Division Multiplexing (OFDM).

Two important topics have been studied to improve the DLC performance: The first is related to the line couplers for low and high voltage level lines [1], [2]. The second is related to the modulation techniques used for data transmission.

The choice of the modulation technique for a given communications system strongly depends on the nature and the characteristics of the medium on which it has to operate.

The power line channel presents hostile properties for communications signal transmission, such as noise, multi-path, strong channel selectivity. Besides the low realization costs, the modulation to be applied for a DLC system must also overcome these channel impairments.

For example, the modulation, to be a candidate for implementation in DLC system, must be able to overcome the nonlinear channel characteristics. This channel nonlinearity would make the demodulator very complex and very expensive, if not impossible, for data rates above 10 Mbps with single-carrier modulation. Therefore, the DLC modulation must overcome this problem without the need for a highly complicated equalization. Impedance mismatch on power lines results in echo signal causing delay spread, consisting in another challenge for the modulation technique, which must overcome this multi-path. The chosen modulation must offer a high flexibility in using and/or avoiding some given frequencies if these are strongly disturbed or are allocated to another service and therefore forbidden to be used for DLC signals.

In this paper we have focused on two modulation techniques that have shown good performances in other difficult environment and were therefore adopted for different systems with wide deployment. First, the Orthogonal Frequency Division Multiplexing (OFDM), which has been adopted for the European Digital Audio Broadcasting (DAB), the Digital Subscriber Line (DSL) technology, and so on. Second, the spread-spectrum modulation, which is widely used in wireless applications, offering an adequate modulation to be applied with a wide range of the multiple access schemes.

2. Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing is a special form of Multi-Carrier Modulation (MCM) with densely spaced sub carriers and overlapping spectra, as shown by the OFDM symbol representation in the frequency domain in figure 1.

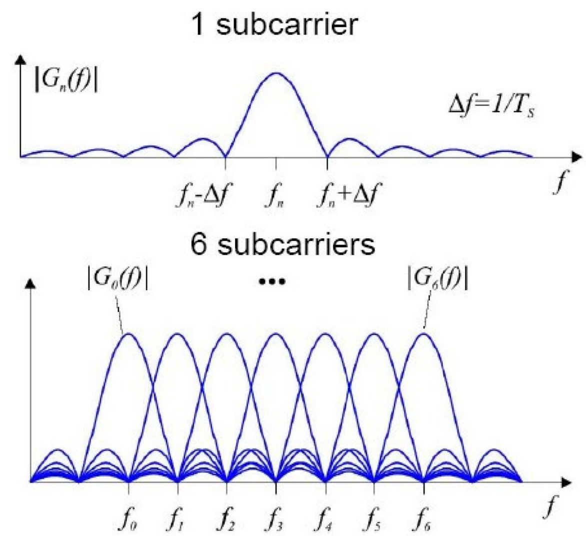

Figure 1. OFDM symbol presentation in the frequency domain

Compared to modulation methods such as Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK), OFDM transmits symbols that have relatively long time duration, but a narrow bandwidth. Usually, OFDM systems are designed so that each subcarrier is narrow enough to experience frequency-flat fading. This also allows the sub carriers to remain orthogonal when the signal is transmitted over a frequency-selective but time-invariant channel.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions. For example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate inter-symbol interference (ISI).

OFDM is used by power line devices to extend Ethernet connections to other rooms in a home through its power wiring. Adaptive modulation is particularly important with such a noisy channel as electrical wiring.

An OFDM carrier signal is the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of quadrature amplitude modulation (QAM) or phase-shift keying (PSK). This composite baseband signal is typically used to modulate a main RF carrier. A typical OFDM transmitter-receiver is shown below in figures 2 and 3.

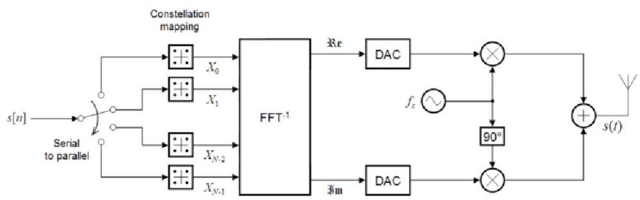

Figure 2. OFDM Transmitter

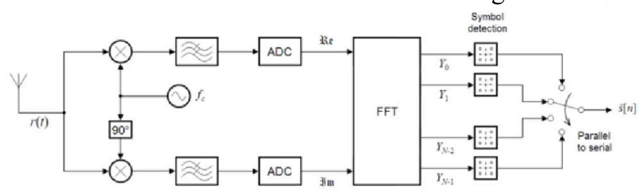

Figure 3. OFDM Receiver

The connection between transmitter and receiver is shown in figure 4.

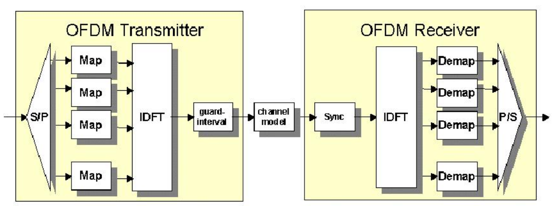

Figure 4. A connection between Transmitter and Receiver

The OFDM transmission scheme has the following key advantages[3]:

- Makes efficient use of the spectrum by allowing overlap
- By dividing the channel into narrowband flat fading subchannels, OFDM is more resistant to frequency selective fading than single carrier systems are.
- Eliminates ISI through use of a cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
- Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
- It is possible to use maximum likelihood decoding with reasonable complexity, as discussed in OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.
- In conjunction with differential modulation there is no need to implement a channel estimator.
- Is less sensitive to sample timing offsets than single carrier systems are.
- Provides good protection against co-channel interference and impulsive parasitic noise.

In terms of drawbacks OFDM has the following characteristics:

- The OFDM signal has a noise like amplitude with a very large dynamic range; therefore it requires RF power amplifiers with a high peak to average power ratio.
- It is more sensitive to carrier frequency offset and drift than single carrier systems are due to leakage of the DFT.

3. Spread-Spectrum Modulation

Spread spectrum is a type of modulation that spreads data to be transmitted across the entire available frequency band, in excess of the minimum bandwidth required to send the information.

Spread spectrum originates from military needs and finds most applications in secure communications environments; such is the case in the DLC environments. Its typical applications are the cordless telephones, wireless LANs, DLC systems and cable replacement systems such as Bluetooth. In some cases, there is no central control over the radio resources, and the systems have to operate even in the presence of strong interferences from other communication systems and other electrical and electronic devices. In this case, the jamming is not intentional, but the electromagnetic interferences may be strong enough to disturb the communication of the non-spread spectrum systems operating in the same spectrum.

The principle of the spread spectrum is illustrated in figure 5, where the original information signal, having a bandwidth B and duration TS, is converted through a pseudo-noise signal into a signal with a spectrum occupation W, with W>>B. For military applications, the SF is between 100 to 1000 and in the UMTS/W-CDMA system the SF lies between 4 and 256. This parameter is also known as "spreading gain" or "processing gain" and is defined by Eq. (1).

$$G = \frac{W}{B} = W.T_S \qquad (1)$$

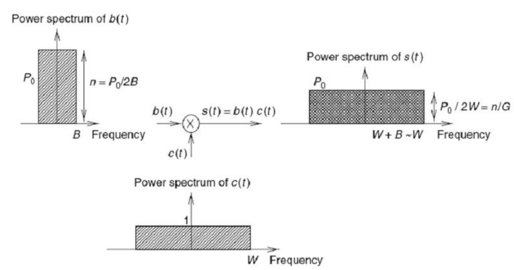

Figure 5. Principle of bandwidth spreading in DSSS

Among the several advantages of spread-spectrum technologies, one can mention the inherent transmission security, resistance to interference from other systems, redundancy, and resistance to multipath and fading effects. The common speed spread-spectrum techniques are Direct Sequence (DS), Frequency Hopping (FH), Time Hopping (TH), and the Multi-Carrier (MC). Of course, it is also possible to mix these spread-spectrum techniques to form hybrids that have the advantages of different techniques. We focus in this paragraph only on DS and HF. The DS is an averaging type system where the reduction of interference takes place because the interference can be averaged over a large time interval. The FH and TH systems are avoidance systems.

1) Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum (DSSS) is the most applied form of the spread spectrum in several communications systems. To spread the spectrum of the transmitted information signal, the DSSS modulates the data signal by a high rate pseudorandom sequence of phase modulated pulses before mixing the signal up to the carrier frequency of the transmission system which is shown in figure 6.

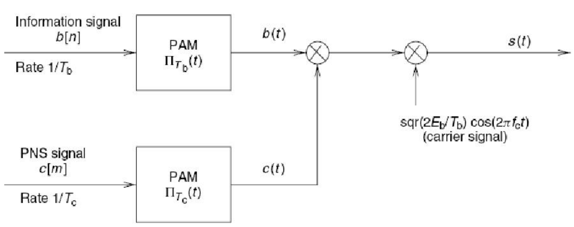

Figure 6. Synoptic scheme of a DSSS transmitter

2) Frequency Hopping Spread Spectrum

In a Frequency Hopping Spread-Spectrum system (FHSS) the signal frequency is constant for specified time duration, referred to as a time chip Tc. The transmission frequencies are then changed periodically which is shown in figures 7 and 8.

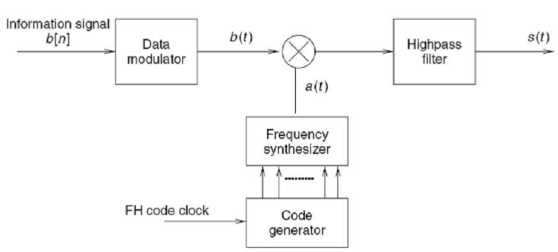

Figure 7. Transmitter for FHSS

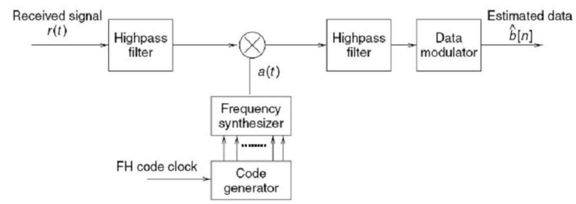

Figure 8. Receiver for FHSS

3) Comparison of DSSS and FHSS

The comparison can be achieved according to different evaluation parameters, such as the spectral density reduction, interference susceptibility, capacity, and so on. Furthermore, the choice of the suitable scheme according to the system needs is based on parameters that are linear or inversely dependent on each other. Both DSSS and FHSS reduce the average power spectral density of a signal. The way they do it is fundamentally different and has serious consequences for other users. For an optimal system realization, the objectives are to reduce both transmitted power and power spectral density, to keep them from interfering with other users in the band. DSSS spreads its energy by phase-chopping the signal so that it is continuous only for brief time intervals (or chip). Therefore, instead of having all the transmitted energy concentrated in the data bandwidth, it is spread out over the spreading bandwidth. The total power is the same, but the spectral density is lower. Of course, more channels are interfered with than before, but at a much lower level. Furthermore, if the spread signal comes in under the noise level of most other users, it will not be noticed. Traditional FHSS signals lower only their “average” power spectral density hopping over many channels. But during one hop, a FHSS signal appears to be a narrow band signal, with a higher power spectral density.

The interference susceptibility is another important parameter which allows the system to operate properly. In DSSS receivers, the de-spreading operation consists in multiplying the received signal by a local replica of the spreading code. This correlates with the desired signal to push it back to the data bandwidth, while spreading all other non-correlating signals. After the de-spread signal is filtered to the data bandwidth, most of the noise is outside this new narrower bandwidth and is rejected. This helps only with all types of narrowband and uncorrelated interference, and it has no advantage for wideband interference since spread noise is still noise and the percentage that falls within the data bandwidth is unchanged.

The FHSS signal is agile and does not spend much time on any one frequency. When it hits a frequency that has too much interference, the desired signal is lost. In a packet switched system, this results in a retransmission, usually over a clearer channel. In a fast enough FHSS system, the portion of lost signal may be recovered by using a FEC. Other parameters and comparisons of the DSSS and FHSS and also other methods are listed in Table 1, from which it becomes clear that the DSSS shows more advantages than the FHSS systems. A compared graph between DSSS and FHSS methods is shown in figures 9 and 10.

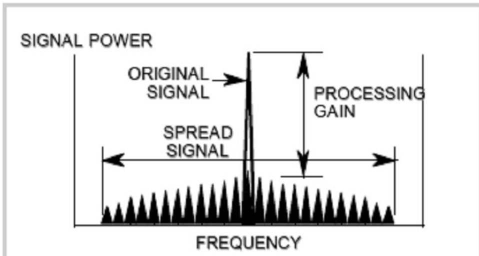

Figure 9. Direct Sequence

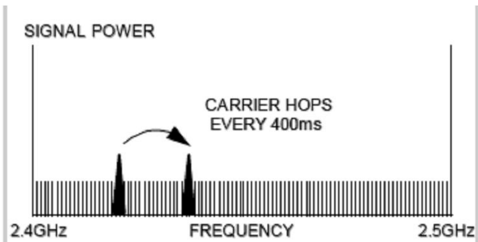

Figure 10. Frequency Hopping

4. Choice of Modulation Scheme for DLC Systems

Several investigations have been carried out to find suitable OFDM implementations for DLC networks. In order to avoid hard degradation of OFDM signal over the transmission channel, which is caused by the frequency-selective fading, a method for sub-carriers power control consists of controlling the transmission power of each subcarrier of OFDM signal in order to maximize the average SNR of each subcarrier of the received signal. This controlling is so flexible that the total transmitted power is not increased. Further improvement of such controlling is possible by spreading the parallel sub-streams at the output of the serial-to-parallel converter output. An OFDM system which subdivides the original information into three parallel data groups, where each group is mapped either according to BPSK or QPSK and coded according to Reed–Solomon code or convolution code, is also investigated in [KuriHa03]. Performances of OFDM system were also investigated under different noise scenarios, especially under the impulsive noise, which is considered the dominating noise in PLC environment.

Spread-spectrum modulation techniques, with direct sequence or frequency hopping, were investigated to be implemented in DLC physical layer. An “iterative detection algorithm” for M-ary spread-spectrum system over a noisy channel is investigated and this shows a remarkable improvement of the detection performance for M-ary systems. However, the main drawback of the spread-spectrum technique is the relative lower realizable bit rate, in comparison with OFDM systems. This makes any decision about the modulation to be adopted for a DLC system more difficult. The main advantage of the spread spectrum is its electromagnetic compatibility, by the radiation of weak electromagnetic fields in the environment.

Table 1) Comparison of the advantages and drawbacks of various methods

	Advantages	Disadvantages
DSSS	▪ Reduced with processing gain ▪ Continuous spread of the transmitted signal Continuous and broadband transmission ▪ Narrowband interference ▪ No timing constraints in high data rates ▪ Self-synchronization ▪ Simple frequency planning ▪ Good interference rejection	▪ In higher data rates If a station is jammed, it is jammed until the jammer goes away ▪ Complex baseband processing ▪ Medium bit rates (up to 11Mbps)
FHSS	▪ Reduced with processing gain ▪ Hopping makes transmission on usable channels possible ▪ Simple analog limiter/discriminator receiver ▪ Simple frequency planning ▪ Good interference rejection ▪ Low-power, low-cost radios	▪ Only the average power of the transmitted signal is spread, ▪ Discontinuous and narrowband Transmission ▪ Narrowband interference in the same interference is not reduced ▪ Many channel need to search for synchronization ▪ Low bit rates
OFDM	▪ Mitigates multipath	▪ High complexity and deployment costs ▪ Guard bands reduce efficiency ▪ Frequency offsets require accurate AFC ▪ Synchronization is difficult ▪ High peak-to-average power ratio requires PA back-off
Single-Carrier QPSK / QAM	▪ High bit rates, proven technology Efficient, dynamic capacity allocation for bursty sources.	▪ Susceptible to multipath interference (needs an equalizer) ▪ Susceptible to interference (needs interference avoidance technique)

5. Conclusion

In this paper we investigate on several different methods for modulation technique used in data transfer over power lines. As it is shown, because of nature of environment in electrical network, it is useful to use digital modulation techniques such as DSSS, FHSS or OFDM.

Conclusion the proper choice of direct sequence or frequency hopping as a spread spectrum technique depends on the actual environment in which the system will be deployed. If there are narrowband interferers of moderate level, then a DSSS system that will completely reject them may be designable. Should there be any large interfering signals, then a DSSS link may completely fail while FHSS is likely to continue operating, even though the interference is not completely rejected.

6. Acknowledgment

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