Indoor PLC Solution

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Abstract

This article presents the results oriented to comparison of average channel characteristics as well as transmission rate or bit error rate (BER) versus frequency of carrier, power level, mode of radiation of high frequency signal or distance. The results have been achieved in the PLC laboratory at the Technical university of Kosice during the experimental phase of the project [1] supported by VSE (Eastern Slovak Energetic Company). The laboratory has been equipped by the Ascom company indoor PLC components.

1. Introduction

The idea behind using power lines as a medium for delivering more than just electric power dates back to the early 1920's. In those early days, high voltage cables were considered to be a possible alternative to installing expensive pilot wires, especially in remote areas where distances of a few hundred kilometres were not uncommon. The need for remote network monitoring and control may have been the driving force, but even then, voice circuits were under consideration.

2. The Power-Line as a Communication Channel

Estimating the powerline channel capacity

The bandwidth is proportional to the bit rate, thus a large bandwidth is needed in order to communicate with high bit rates. The ability to transfer data can be estimated for any channel with knowledge of the essential parameters used in Shannon's formula:

$$C = B.\log_2\left(1+\frac{S}{N}\right) \qquad (1)$$

C indicates the maximum data rate (in bits/s) for which a theoretically error-free transmission is possible. *C* normally cannot be achieved by technically realizable and also profitable systems in practice. The use of (1) is not immediately feasible for powerline channels, since the signal-to-noise is not constant within bandwidth B, but may vary substantially. Taking the frequency range from 10 to 20 MHz and signal-to-noise ratio of around 60 dB results in the following impressive value for channel capacity:

$$C \approx 200 Mbits/s .$$

Of course this channel does not represent a worst-case scenario [4]

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Radiation of the transmitted signal
When transmitting a signal on the power-line the signal is radiated in the air. One can think of the power-line as a huge antenna, receiving signals and transmitting signals. It is important that the signal radiated from the power-line does not interfere with other communication systems. When using the frequency interval 1-30 MHz for communication the radiation is extremely important because many other radio applications are assigned in this frequency interval. It is not appropriate for a system to interfere with, e.g., airplane navigation or broadcast systems. When the cables are below ground the radiation is small. Instead it is the radiation from the households that makes the major contribution. Wires inside households are not shielded and thus radiate heavily.

Impedance mismatches
Normally, at conventional communication, impedance matching is attempted, such as the use of 50-ohm cables and 50-ohm transceivers. The power-line network is not matched. The input (and output) impedance varies in time, with different loads and location. It can be as low as milliohms and as high as several thousands of Ohms and is especially low at the sub station.
Except the access impedance several other impedance mismatches might occur in the power-line channel. E.g., cable-boxes do not match the cables and hence the signal gets attenuated.

Signal-to-Noise-Ratio
A key parameter when estimating the performance of a communication system is the signal-to-noise power ratio, SNR.
The noise power on the power-line is a sum of many different disturbances. Loads connected to the grid, such as TV, computers and vacuum cleaners generate noise propagating over the power-line. Other communication systems might also disturb the communication, thus introducing noise at the receiver. The attenuation on the power-line has shown to be very high (up to 100 dB) and puts a restriction on the distance from the transmitter to the receiver.

The time-variant behavior of the grid
A problem with the power-line channel is the time-variance of the impairments. The noise level and the attenuation depend partly on the set of connected loads, which varies in time. A channel, which is time-variant, complicates the design of a communication system. At some time instants the communication might work well but at other times a strong noise source could be inherent on the channel, thus blocking the communication.
To solve this a possible solution is to let the communication system adapt to the channel. Extensive measurements [2] shown that the lower frequencies are less attenuated than the higher ones. As the distances in the public part of the power network are longer than within buildings, the lower frequencies have been assigned to the outdoor system, the higher ones to the indoor system.

3. Powerline Communication system

The Powerline Communications System must be optimized for the data transmission over existing power distribution networks, providing maximum throughput at a minimal power level [3]. The modulation design and the frequency assignments avoid interference from and to amateur radio and radio services.

Modulation and coding
The modulation matches the signal to the transmission channel. There are many possible modulation choices, each of which has specific advantages and disadvantages. We can distinguish roughly the following modulation families:

- Direct sequence spread spectrum modulation,
- Orthogonal frequency division multiplex (OFDM), and
- Narrow band modulations, of which GMSK is a variant.

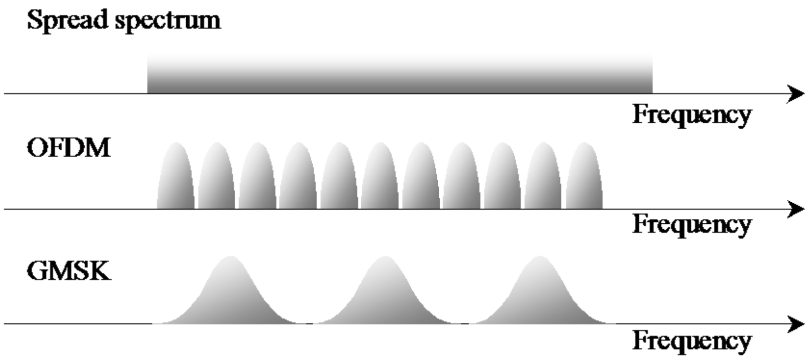

Figure 1. Modulation techniques for PLC systems

The spread spectrum modulation technique is widely used in military applications. It provides a very low power spectral density by spreading the signal power over a very wide frequency band. This type of modulation requires, therefore, a very large bandwidth to transmit several megabits per second. As the available bandwidth is limited, see the discussion on attenuation above, this technique is ideal to transmit lower data rates on the power cables.

Orthogonal Frequency Division Multiplex (OFDM) consists of a large number of narrow band carriers arranged side-by-side. This modulation easily adapts to varying channel characteristics, as interfered carriers can be left out, naturally with a corresponding penalty in the throughput. The disadvantage of OFDM is its need for a highly linear power amplifier, to avoid interference in higher frequency bands due to harmonics of the carriers. Such harmonics are generated in the non-linearities of the transmit power amplifier and are an important interference issue in all modulations with time-varying signal envelopes.

Gaussian Minimum Shift Keying (GMSK) is a special type of narrow band modulation. GMSK transmits the data in the carrier phase resulting in a constant envelope signal. This allows less complex amplifiers to be used without producing harmonic disturbances. As the data rate of the modulated signal is over two megabits per second. The GMSK signal is robust against narrow band interference, typical in the short wave radio band. GMSK results in a Gaussian spectrum shape, hence its name.

Powerline frequency bands

Large data rates require wide bands to transmit the signal over the power distribution. The Ascom powerline system is using frequencies between 1.6 and 30 MHz. Multiple carriers are managed dynamically to obtain the best overall system throughput.

The powerline system is simultaneously using up to more carriers in the outdoor system and more carriers in the indoor system. The outdoor system is normally operated in the frequency range of 1,6 to 13 MHz, the indoor system in the range 15 to 30 MHz. The choice of the carrier frequencies is based on extensive measurements and frequency planning within the short wave radio band and is in line with the work in progress in CENELEC. The following aspects have been taken into account for the choice:

- Coexistence with important existing broadcast and amateur radio bands.
- Assigning the lower frequencies, which travel further on power distribution, to the outdoor system.
- Providing sufficient separation between the simultaneously operating outdoor and indoor systems to avoid interference.

Standardization activities

Rules and regulations for the use of the frequency band 1.6 to 30 MHz are in preparation. At the time being the situation is as follows.

In CENELEC the European standard prEN59013 has been drafted for national approval defining the coexistence between access- and in-house PLC as follows:

- Frequency multiplex division will be used.

- The frequencies from 1,6 MHz to 12,7 MHz are allocated for PLC access and the frequencies from 14,35 to 30 MHz are for use by indoor PLC.
- The guard band between the two PLC applications ranges from 12,7 to 14,35 MHz

Radiated emissions

Using high frequencies in wire based broadband communication networks raises the question on how much radiation can be accepted in order not to disturb existing (short wave) radio services. Currently there are three relevant national [2] documents defining radiation limits by regulators:

4. PLC Services

In order for a PLC service to satisfy a significant proportion of today's communications requirements in the residential and small business sectors, there are a minimum set of services that a customer expects. A successful PLC system must be capable of initiating and/or supporting these services. Services, which might be considered fall into the following key categories:

Baseline set of PLC services

1. Telephony (Voice, Operator services, Facsimile transmission)
2. Telemetry and utility-related services (Customer and security service, Power utility related services)
3. Data services (IP data services)

Expanding the set of PLC services

1. Urban GSM network extension
2. Security Applications
3. Fast Internet access
4. "Smart" in-home, energy, and building management services

5. The Ascom Powerline Communication system

The Ascom powerline communications system is using GMSK, a robust modulation with a good performance. The coding adds redundancy to the data before transmission to enable the automatic correction of transmission errors at the receiver. Each one of the carriers described in the section above is using identical modulation, similar coding, and data rate. For this reason we restrict this discussion to a single carrier. The multi-carrier Ascom GMSK system can be considered as a broad band OFDM system.

The Ascom PLC system consists of simultaneously operating outdoor and indoor systems. The outdoor system covers the public part of the low voltage power distribution from the transformer to the house access point. The outdoor system is connected to the communication backbone at the transformer station. The indoor system extends the communication from the house access point to every socket in the private area of a building. It covers the private area of the power distribution. The outdoor Adapter connects the outdoor with the indoor system.

PLC products

The Ascom PLC system consists of a small number of plug-and-play products to build up powerful system solutions. The Ascom PLC devices are equipped with industry standard interfaces for easy integration into the communications world, be it towards the customer or the backbone. Presently the Ascom PLC system consists of the following devices:

- **Outdoor Master APM-45o**, controlling the outdoor system and interconnecting a Power Cell to the backbone network.
- **Outdoor Adapter APA-45o**, providing a direct user access to the outdoor system. This unit is used for a simple Internet access of a single family home where no indoor PLC networking is required.

- □**Outdoor Access Point APM-45ap**, is the bridge between the outdoor system and a single indoor system.
- □**Indoor Adapter APA-45i**, is the user modem to connect to an indoor system.

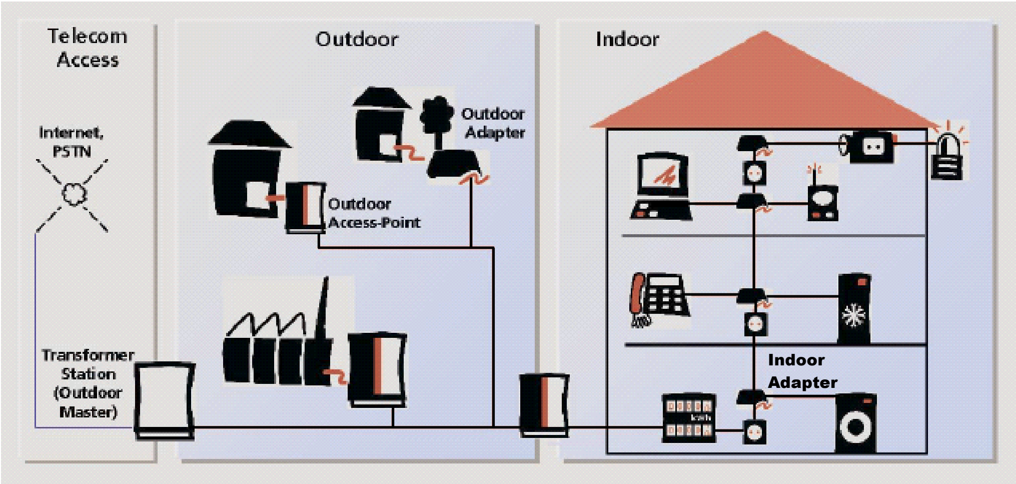

Figure 2. Complementing outdoor and indoor systems for maximum coverage

Coexistence with existing short wave services

The frequency band between 1,6 and 30 MHz is used by a variety of services like long range radio broadcasts, radio amateurs, ship to shore radio, etc.

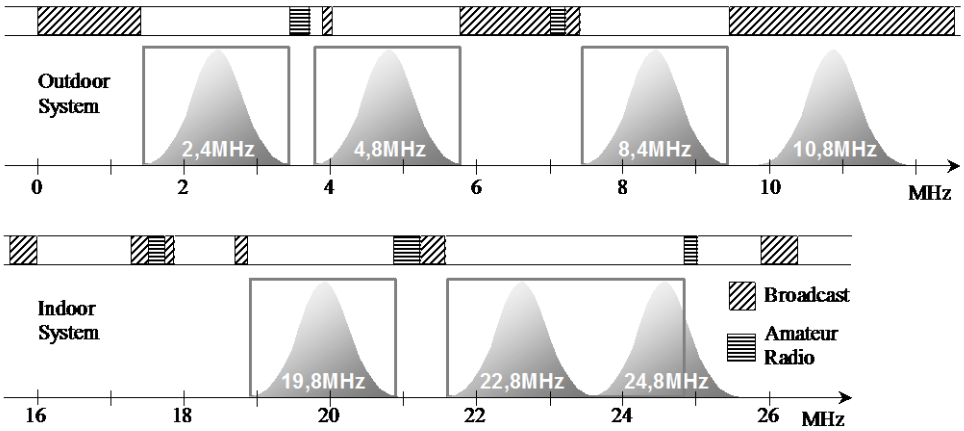

Figure 3. Coexistence with other short wave services.

Ascom has taken care to avoid bands of important short wave services within the same band, as shown in Fig. 3. Splitting the signal into the individual carriers enables Ascom to shift the carriers, or even deactivate one of them totally, should there be a local interference. Through system parameters the carrier center frequencies can be shifted in steps of 0,6 MHz.

The Ascom PLC system employs powerful forward error correction coding. This allows the correction of transmission errors at the receiving side. A rate 1/2 code is used, implying that the transmitted data is doubled in the PLC transmission, i.e. for every data bit the PLC system sends 2 bits over the channel. Experience has shown, that the PLC channel is often of excellent quality for stations close to the master. In these cases it is not necessary to use the FEC coding. In this case the channel capacity for the user can be doubled. The Ascom PLC devices automatically monitor the channel quality. If it is high enough, the FEC is disabled. Should the quality drop, the FEC automatically switched on again.

The carriers are operated at the same time. Each carrier can be considered as an independent communication link. Each carrier provides a user data rate between 750 and 1500 kbits/sec. The higher data rate can be achieved on high quality links. On these links the system

automatically disables the forward error correction (FEC) coding and uses the total resulting bandwidth for the user data. FEC is required on weaker links. These are normally all links between the master and the slaves at the fringe of the coverage area.
The Ascom PLC system automatically minimizes the radiation. All PLC slaves use a variable transmitting power up to a parameterized maximum value. Slaves close to the master can maintain an excellent connection with very low transmit levels. The Ascom PLC slaves automatically adjust their transmitting power to the minimum required transmit level to maintain a high quality link. This feature minimizes the overall system radiation.

Sharing capacity

The Ascom PLC system dynamically allocates channel capacity to the users based on their instantaneous demand. Each one of the carriers, as described above, transmits data between the transmitting and the receiving stations. This PLC channel is shared by all stations in a single PLC system consisting of a master (*outdoor master* -OM, resp. *indoor master*-IM) and its associated slaves (*outdoor access point*-OAP, resp. *indoor adapter*-IA). The master, depending on the traffic requirements of the slaves, allocates the access to the channel. The data stream of each carrier is divided into frames and frames are divided into slots. The channel is used in a half duplex mode. Each of the slots can carry traffic in one direction, either downlink from master to slave(s), or uplink from slave to master. There is no peer-to-peer communication in the Ascom PLC system.

Demanding capacity

A slave can demand communications capacity in two ways. If the slave has already slots assigned, then it piggy-backs the demand for further capacity onto a regular data transmission. If the slave has not yet, or no longer slots assigned, then it transmits its demand for capacity in one of the regularly appearing multiple access slots.
The data traffic transported by the Ascom PLC system can be grouped into real-time and non-real-time traffic. Real time traffic, like voice and video conferencing, demands an immediate transmission of the data with little delay, while non-real time traffic, like file transfer, can easily cope with delay and delay variations. Applications producing real time traffic are normally using the UDP (User Datagram Protocol) transmission protocol, which is optimized for fast, unacknowledged transmission of the data packets. File transfers are normally using the TCP (Transmission Control Protocol) protocol.

System management

The Ascom PLC system contains all necessary features to facilitate the integration into an automated management and supervision system. All Ascom PLC devices are manageable via DHCP (Dynamic Host Configuration Protocol) and SNMP (Simple Network Management Protocol). This allows the integration into standard network management systems, providing an effective system and traffic monitoring and fast error location with established tools.

6. Experiments and results

The Ascom indoor system was tested in configuration with one APM45 as master and three APA45i as slaves. The average transmission rate was accepted as the main criterion of the transmission system ability. The average transmission rate was evaluated as ratio of total number of bits and time interval that was needed for their transmission. A firmware PLCCAM was used for measurement and setting of parameters.
In our experiments the blocks of bytes (64000 bytes) cyclically transmitted over 80 or 16 seconds were used. The block of data was generated with PLCCAM running on PC used for management of system components. During the experiments the changes of average transmission rate were monitored by influence of changes of the following parameters:

- number of carriers,
- signal coupling to the power distribution,

- transmitting power of master,
- noise source,
- distance between master and slave

Number of carriers

The indoor system can simultaneously use up to 3 carriers (2 MHz bandwidth for each). The default carrier positions are 19,8 MHz, 22,8 MHz and 25,2 MHz. The master can choose these carriers automatically or operator can restrict them. In our experiments we work without restriction, with restriction of carrier at 19,8 MHz and with restriction of carriers at 19,8 MHz and 22,8 MHz. The average transmission rate changed from 820 to 830 kbps. We could observe that the changes have been very small.

Signal coupling to the power distribution

The RF signal can be radiated between two from three phase wires. Software PLCCAM allows to setup one of three possibilities of coupling (P1-P2, P1-P3, P2-P3) direct in the master. It was observed by the selection of this parameter that the average transfer rate doesn't show expressive changes although variances of receiving power were remarkable. The configuration and conditions of the measurement were the same ones as in the previous case. There were permitted all three carrier and auto power relationships adjustment.

Transmitting power of master

If the transmission power of master was chosen as an optional parameter only one carrier (22,8 MHz) was used. There were changes of transmission power from –36 dBm to +20dBm. The results are shown in tab.1.

Master Tx Gain [dBm]	Slave Tx Level [dBm]	Slave Rx Level [dBm]	Noise Level [dBm]	CER [%]	**Average Transmission Rate** [kbps]
-36	181,25	-100	-70	0	736
-30	181,25	-100,3	-69,25	0	736
-24	143,25	-99,3	-69,75	0	736
-18	85,75	-94	-69,5	0	736
-16	180,75	-92,3	-68,75	0	736
-10	173,75	-86	-69,25	0	736
2	15	-74	-69,5	0	832
8	20	-73	-69,75	0	864
14	15	-62,3	-69,25	0	832
20	20	-62,5	-62,8	0	800

Tab. 1. Transmitting power vs. Average Trasmission Rate

Noise source

The main aim of this experiment was to verify the influence of conventional noise sources on the average transmission rate as well as a typical noise sources radiated in the frequency band occupied by ASCOM Power Line system. There were analyzed four situations:

1. without wittingly connected noise source,
2. with fluorescent lamp plugged in the same double socket as the adapter (slave),
3. with vacuum cleaner plugged in the same double socket as the adapter (slave),
4. in the same double socket as the adapter (slave) was connected one of two adapters from CORINEX (using OFDM modulation method in this frequency band)

The remarkable drop of taverage transmission rate (from 830 to 780kbps) was measured under the influence of perturbance of vacuum cleaner. During contemporary operation of two different PLC systems (at the same wires) the average transmission rate of ASCOM PLC system has fallen on 680 kbps whereas the second one (Corinex) has not been able to operate.

Distance between master and slave

The distance between Master and Slave has changed after these manners:

1. master and slave are located in the same room,
2. master and slave are located in the different rooms on the same floor,
3. master and slave are located in the rooms on the different floors,
4. master and slave are located in the farthest rooms of building (6 floors, over 100m)

Differences of the average transmission rate have been very small or no ones.

7. Conclusion

Presented results have shown that the average transmission rate, which is the most important parameter to appreciate transmission system, has shown very small deviations even if some parameters were changed dramatically (distance, transmission power). The reasoning of this deduction results from the cohesion of parameters and possibility of auto-controlling by master for which the transmission quality is the main criterion. The transmission quality is achieved by automatic selection of power level and frequency of carriers of variant components as well as by adaptive arrangement of the error-correcting code and robust GMSK modulation.

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