Power Line Communication

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Abstract*- This thesis is about power-line communication over the low voltage grid, which has interested several researchers and utilities during the last decade, trying to achieve higher bit-rates and more reliable communication over the power lines. The main advantage with power-line communication is the use of an existing infrastructure. Wires exist to every household connected to the power-line network.*

This thesis starts with a general introduction to power-line communication. Then an existing application, communicating on a low-voltage grid, is investigated in order to obtain some knowledge of how the power line acts as a communication channel. We also expose this system with a load, consisting of a set of industrial machines, to study the change in communication channel quality. After these large-scale measurements we measure some channel characteristics in the same grid. Measurements of the noise level and the attenuation, up to 16 MHz, are reported.

The power-line communication channel can, in general, be modeled as having a time- varying frequency-dependent signal-to-noise ratio over the communication bandwidth. The effect of non-white Gaussian noise on different receiver structures is studied, one ideal and one sub-optimal, and the importance of diversity (in frequency) is illustrated when the set of transmitter waveforms is fixed. We investigate robust, low-complexity, modulation methods which are able to handle unknown phase and attenuation, which simplifies the implementation of the receiver.

Finally we describe a communication strategy that eventually could be used for information transfer over the power-line communication channel. In doing this we combine coding, frequency diversity and the use of sub-channels (similar to Orthogonal Frequency Division Multiplex). This is a flexible structure which can be upgraded and adapted to future needs.

I. INTRODUCTION

The communication flow of today is very high. Many applications are operating at high speed and a fixed connection is often preferred. If the power utilities could supply communication over the power-line to the costumers it could make a tremendous break- through in communications. Every household would be connected at any time and services being provided at real-time. Using the power-line as a communication medium could also be a cost-effective way compared to other systems because it uses an existing infrastructure, wires exists to every household connected to the power-line network.

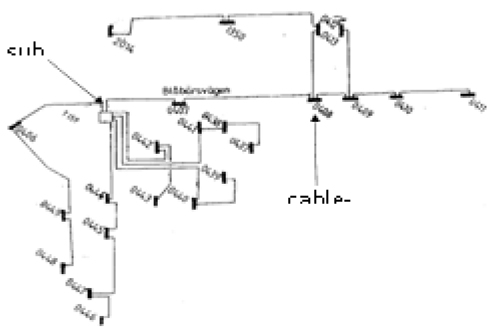
The deregulated market has forced the power utilities to explore new markets to find new business opportunities, which have increased the research in power-line communications the last decade. The research has initially been focused on providing services related to power distribution such as load control, meter reading, tariff control, remote control and smart homes. These value added services would open up new markets for the power utilities and hence increase the profit. The moderate demands of these applications make it easier to obtain reliable communication. Firstly, the information bit rate is low, secondly, they do not require real-time performance.

During the last years the use of Internet has increased. If it would be possible to supply this kind of network communication over the power-line, the utilities could also become communication providers, a rapidly growing market. On the contrary to power related applications, network communications require very high bit rates and in some cases real time responses are needed (such as video and TV). This complicates the design of a communication system but has been the focus of many researchers during the last years. Systems under trial exist today that claim a bit rate of 1 Mb/s, but most commercially available systems use low bit rates, about 10-100 kb/s, and provides low-demanding services such as meter reading.

The power-line was initially designed to distribute power in an efficient way, hence it is not adapted for communication and advanced communication methods are needed.

Today’s research is mainly focused on increasing the bit rate to support high-speed net- work applications.

This thesis is about communication on the power-line (on the low-voltage grid). Section 1.1 gives a general description of power line communications. Section 1.2 explains some preliminaries needed in digital communications and Section 1.3 describes the power-line channel, its characteristics, problems and limitations, and also serves as a survey of cur- rent research. Finally Section 1.4 gives an outline of the rest of this thesis. Other introductory descriptions on power-line communications are given in [14], [20], and [36]. Reference [36] also studies new business opportunities for the power utilities and reports research on coming technology.



Each low-voltage grid has one *substation*, which transforms the voltage into 400 V and delivers it to the connected households, via low voltage lines. Typically several *low-volt- age lines* are connected to the substation. Each low-voltage line consists of four wires, three phases and neutral. Coupled to the lines are *cable-boxes*, which are used to attach households to the grid.

This thesis is about communication on the low-voltage grid, communication between the substation and the households. Related issues are how to communicate inside a house- hold and how to communicate on the medium-voltage grid.

Many systems today use a topology with a central node (the substation) communicating with clients (the households). Al l communication is between the substation and the households and there is no communication between households. Because there is a physical connection between every two households it would also be possible to support this kind of communication. As an alternative, this communication could be routed through the substation.

The configuration with a central node and a set of clients may be compared with systems for mobile telephony, e.g., GSM [33]. In GSM a base station (central node) is connected to all mobile phones (clients) within a restricted area. Thus the network topology is not unusual, but used in practice.

Power line communication is based on electrical signals, carrying information, propagating over the power-line. A communication *channel* is defined as the physical path between two communication nodes on which the communication signal is propagated [1], [41]. In a low-voltage grid there is a lot of different channels, in fact the links between the substation and each household are all different channels with different characteristics and *qualities*. If the communication system supports communication between households all these links are also different channels.

The quality is estimated from how good the communication is on a channel. The quality is mostly a parameter of the *noise level* at the receiver and the *attenuation* of the electrical signal at different frequencies. The higher the noise level the harder it is to detect the received signal. If the signal gets attenuated on its way to the receiver it could also make the decision harder because the signal gets more hidden by the noise.

On the power-line the noise is generated from all loads connected to the grid. Also broadcast radio interferes with the communication. The attenuation is a parameter of the physical length of the channel and impedance mismatches in the grid. The power-line is often considered a harsh environment because of the time-variant characteristics of the noise and the attenuation, but this is also the case in most communication systems and only limits the performance that can be achieved. Advanced communication systems exists today, designed to overcome the problems with such channels as, e.g., GSM. The characteristics of the power-line channel are further described in Section 1.3.

This thesis is focused on the research on the power-line as a communication channel. The objective is to come up with advanced digital communication methods to support higher bit rates and more reliable communication on the low-voltage grid. To understand the problem field some preliminaries are needed from digital communications. This is the subject of the next section.

II. METHODOLOGY

For this project we developed a high level idea and then worked down hierarchically to develop the individual pieces. The idea is simple – support communication through power lines by two parties. In Figure 1 we show the typical scenario of the Meter Man being used. We envision a system, where the consumer would go to Meter Man’s interface and choose to increase or decrease his power consumption level, and Meter Man would send a signal to the electric company advising them of the change in demand. Overall, this implementation would be perfect for the distribution of power between two electric grids so that power outages could be avoided. For example, let us consider the case of a large car manufacturer that will be increasing output by 40% for five days. This would mean that the company would be using more power than usually expected. This increased usage would cause extra load on the power grid. Now, if several other manufacturers had similar demands then we would be in trouble.

However, if the power company knew of the increased demand, then they could compensate for the extra demand ahead of time by ensuring that enough power is available.

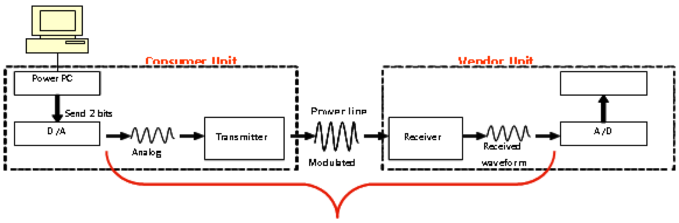
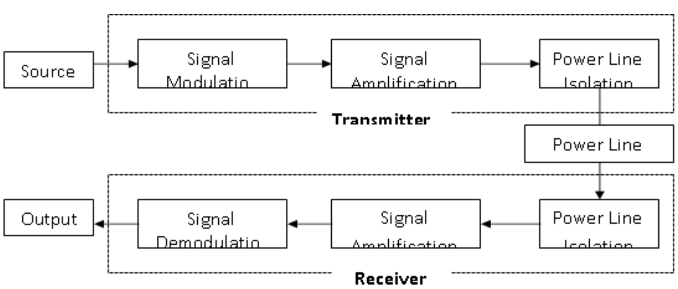


figure5: System Block Diagram

III. CIRCUIT DESIGN

The Power Line communication system we developed contains two major components: the transmitter and the receiver. The transmitter is responsible for sending the signal to the power line. It includes the following stages: the signal modulation stage, the signal amplification stage, and the power line interface stage. The receiver is responsible for receiving the modulated signal from the power line and recovering it to the original message signal. It includes the following stages: the interface with the power line, the signal amplification stage, and the signal demodulation stage. The block diagram of the system is shown in figure.



Two filters were implemented for the demodulation circuit. The first filter was designed to band pass the modulated signal which has a frequency range from 65 kHz to 75 kHz as discussed before. It is used to filter out any low or super high frequency noises from the power line. The schematic and simulation result are shown in Figure 12 and Figure 13respectively.

second filter is a low pass filter which is implemented to filter out the high frequency noise generated by the demodulation circuit. So the message signal, which has a frequency ranging from 500 Hz to 5 kHz, can be produced.

Since power lines are designed to send power, they are not optimized as transmission medium for data. Power lines typically have high amounts of noise, which causes signal distortion. This signal distortion increases the bit error rate (BER). The BER is defined as the ratio of incorrect bits demodulated by the receiver to the number of total bits received.

Furthermore, power line signals are also subject to high amounts of attenuation. These factors are the primary reasons why power lines have not been adopted for mainstream data delivery.

To overcome these shortcomings of the power line, we can employ various methods to decrease the BER. The current prototype uses FSK to modulate the message signal. All existing modulation techniques have deteriorated performance under the presence of interference, but there exist techniques that have slightly better performance than FSK in noise. A technique called BPSK (Binary Phase Shift Keying) has better performance than FSK under noise

IV. CONCLUSSION

Society's demand for power will continue to grow as new technologies are invented. This is a reality of living in an industrialized age. However, the same technologies that are created to make our lives more comfortable, convenient, and safe can sometimes cause traumatic results. Our power suppliers are given the burden of supplying us with a constant power supply, but this burden can not always bemet.

We proposed the idea of a device that would allow communication between the power suppliers and their large industrial clients in the hope that the communication would lower the probability of power failures. The interesting feature about the device is that it communicates solely through the power lines. This is an implementation of data transmission through power lines. A successful implementation of this type of technology would open the door to new data services that could also be provided through the power lines.

The implementation of the device, named Meter Man, began with the design of a transmitter and receiver circuit. The circuit would need to be able to receive data, modulate it, and then interface with the power line. We successfully created such a circuit using an FSK modulating chip and power amplifiers. The receiver was also built using a FSK demodulating chip and power amplifiers to interface with the circuit. The final step was to build filters that would allow us to retrieve the original message.

Although we encountered several problems on the way, we were able to successfully design, simulate, and implement the transmitter and receiver circuits. The test data was discussed earlier in section 3.

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