Load Profile and Communication Channel Characteristics of the Low Voltage Grid

Lars Selander, Lund University, Sweden
Tonny I. Mortensen, NESA A/S, Denmark
Göran Lindell, Lund University, Sweden

Summary:

Communication over the power line has become an opportunity for the power distributors to implement new services. As the applications evolve, the requirements on the communication system is increased. To be able to design high performance communication system, an increased knowledge of the power line as a communication channel is necessary.

The focus of this project has been to study the properties/behavior of the power line channel by observing an existing system used on the low voltage grid. With statistics collected from the running communication system the quality of the communication channels has been estimated. The results are based on communication between a central computer and 59 households, i.e. 59 different communication channels. The communication is made up of so-called transactions (a control-flow consisting of a request and a reply). The collected data make it possible to calculate an estimate of the quality of the communication channels.

A time-variant behavior of the channel quality and a seasonal behavior has been found. The 59 communication channels are subject to different impairments and large variations in channel quality has been observed. The quality of specific communication channels varies within a small interval around an average quality level, which has been found to depend on the signal's path in the grid.

Loads connected to the low voltage grid interfere with the communication in several ways. A study of the energy usage delivered to the grid in relation to the quality of the channels indicates that a high energy consumption have a tendency to decrease the channel quality.

To investigate the influence of a specific load on the quality of the communication channels, a set of industrial machines was connected to the grid at several locations. When the load was connected to the sub station where all the communication passes through, the quality of the communication channels were significantly decreased. When the load was located further away on one of the out-going low voltage lines large quality reductions were only found in the area surrounding the location where it was connected.
Load Profile and Communication Channel Characteristics of the Low Voltage Grid

Lars Selander, M.Sc.CSE, Lund University, Department of Information Technology, Telecommunication Theory Group, Lund, Sweden, e-mail: lars.selander@it.lth.se

Tonny I. Mortensen, M.Sc.EE, NESA A/S, Commercial Department, Copenhagen, Denmark, e-mail: trt@nesa.dk.

Göran Lindell, Associate Professor, Lund University, Department of Information Technology, Telecommunication Theory Group, Lund, Sweden, e-mail: goran.lindell@it.lth.se
Abstract

Communication over the power line has become an opportunity for the power distributors to implement new services both for the utilities and for their customers. As the applications evolve, the requirements on the communication system is increased. An efficient communication system should be designed with respect to the characteristics of the power line communication channel and hence, a knowledge of these characteristics is valuable. In this paper, the properties/behavior of the power line communication channel is studied by observing an existing system used on the low voltage grid in a typical application (meter reading). Here we focus on large-scale variations of the channel, e.g. how its quality depends on different time-windows, distances and loads. This study is based on collected data representing communication with 59 households, i.e. 59 communication channels are considered. To investigate the influence of a specific load on the quality of the communication channels, a moveable load was connected to several locations in the grid. Large variations in the quality between the individual communication channels have been found. Furthermore, a period of high energy consumption in the grid, typically mornings and evenings, have a tendency to decrease the quality of the communication channels.

1 Introduction

The interest in power line communication has increased during the last decade. Several systems using the power line as a communication medium have been put on the market. Most of these systems are primarily intended for meter reading but some also add other services. Possible services are:

- Monitoring Systems
- Tariff Reading
- Load Distribution
- Security Systems
- Alarm Systems
- Network Communication

Most of the services intended for power distributors do not require high bit rate communication. Meter reading e.g. has very low such requirements and the data does not need to be collected immediately. Some of the new services require more out of the communication system. Alarms e.g. must with high probability arrive at the alarm central within a specified time-interval.

If the power line will be used for applications external to power distribution, then the requirements are even harder in general. Possible such services are e-mail, telephony and Internet applications. These applications require high bit rate communication.

The intention with this project was to study the properties/behavior of the communication channel by observing an existing system used on the low voltage grid in a typical application. Here we focus on large-scale variations of the communication channel, e.g. how its quality depends on different time-windows, distances and loads.

It is well-known from communication theory that any practical communication system will have communication problems if the signal-to-noise ratio at the receiver drops below a certain level, see [1]. This can of course happen also in the power line communication channel as a result of channel impairments, e.g. signal attenuation, signal degradation and noise sources along the signal path.

In order to obtain quantitative results, parameters related to the quality of the communication channel are estimated. The most frequently used parameter in this paper is an estimate of the probability that re-transmissions of so-called transactions are made. This parameter is used as an indicator of the quality of the communication channel, since a re-transmission is made when the receiver is unable to make a reliable decision, which in turn normally is due to channel impairments. Hence, a low value on the probability of re-transmissions indicates a "good" communication channel.

It should be observed that the estimated probability above do not measure the reliability in the final decisions produced by the communication system. In general, a very high reliability in the final decisions can be obtained with communication systems using re-transmissions. However, in this paper focus is on the quality of the communication channel, and that is the reason why we estimate parameters that reflect how often channel impairments result in re-transmissions.

The Integrated Distribution Automation and Management (IDAM) system is developed in cooperation between IBM and Sydkraft. This system was chosen because it is in use within the project and it has been tested on several locations in different environments. Furthermore it is fully implemented and commercially available. The actual implementation used in this paper is located in Ronneby, Sweden.
The purpose of this project was not to evaluate the IDAM system but rather to extract information from IDAM that can be used to estimate the quality of the power line as a communication channel.

The disposition of this paper is as follows:

• The IDAM system, section 2.
• The overall performance of the communication channels, section 3.
• The performance of the communication channels at various locations in the low voltage grid, section 4.
• The relation between the load profile and the quality of the communication channels, section 5.
• The influence of a load on the quality of the communication channels, section 6.

This paper ends with a discussion and conclusion section, section 7.

2 The IDAM System

The backbone of IDAM is its possibility to support meter reading but it is also designed to support other services such as alarm systems. The structure of IDAM, according to the developers, is designed to be an open-system architecture and easily extendable to both producer and consumer specific applications. IDAM is also described in [2], [3] and [4].

IDAM consists of three major parts. The Multi Function Node (MFN), the Concentrator & Communication Node (CCN) and the Operation and Management System (OMS). Figure 1 shows how the parts are connected in a typical system.

![Image of IDAM system](image)

Figure 1. The different parts of the IDAM system and how they are connected.

The MFN is a unit that is installed in each household either as an integrated or separated part of the meter. It reads the meter value each hour and stores it in a memory. The memory can store up to 40 days of meter values.

The CCN manages all MFNs in an area, e.g. a low voltage grid, and it is responsible for collecting their meter values. Typically, the CCN is installed in a sub station and it consists of an ordinary PC.

An OMS manage a set of CCNs. The meter values collected by the CCN are stored in the OMS where they can be accessed and analyzed.

2.1 The Implementation in Patorp

Figure 2 shows a map of the low voltage grid in Patorp where the experiments have been carried out. The area consists of about 70 households and is supported by the sub station T159. The households are connected to the low voltage grid via cable-boxes also shown in Figure 2. The markers placed on some of the low voltage lines means that the connection is off. More information concerning this grid can be found in [2].

In Patorp a MFN is installed in each household. The MFN is connected to the low voltage grid and to the meter, which in most cases is placed outside the house.

The CCN is installed in the sub station T159 and it is connected to the OMS via an optical fibre. The OMS is placed inside a house known as Villa Wega a couple of kilometers from Patorp.

The results in this paper are based on the 59 households that regularly deliver meter values to the IDAM system.
2.2 The Communication in IDAM

The communication between the CCN and the MFNs is in all cases over the power line. Every hour the CCN polls each MFN in order to get the meter values. To control the MFNs, and to read the meter values, a series of transactions are needed. A transaction is defined as the combined sequence of a request by the CCN followed by a reply, with some data, from a MFN. For every transaction, the communication system, on which IDAM is built (see section 2.3), is invoked. If a transaction fails then IDAM is notified and the CCN tries again until the transaction is succeeded. All communication is between the CCN and the MFNs. No communication is going on between the households in the area.

The result of each transaction, whether it has failed or not, is noted in a logfile for further processing. This logfile can be used to retrieve information about the communication performance. The information used in this paper is the following:

\[ e_i, \text{ the number of failed transactions to household } i \]
\[ N_i, \text{ the number of total transactions to household } i \]

New values are obtained for each hour. If the communication is error-free, \( N_i \) is typically two and \( e_i \) is zero per hour.

All estimated results related to communication performance in this paper have been calculated with the parameters above.

The collected meter values are stored in a file in the OMS. These values have been used to study the effect of the loads on the communication performance, see section 5.

2.3 The Communication Technique

The IDAM system is built upon LonWorks provided by Echelon, see [5]. LonWorks is a general purpose network technology that is in wide use in different industry applications. LonWorks supports communication over a wide range of different channels e.g. cable-tv, radio channels and, as of interest for the utility distributors, the power line. An advantage of using LonWorks is that it supports many different channels and the only thing that differs between the implementations is the transceiver used. LonWorks includes some elementary control flow and before IDAM is notified that a transaction has failed a fixed number of re-transmissions has already occurred. A description of the protocol used by LonWorks is found in [6].

IDAM uses the PLT-30 transceiver, see [7]. It communicates in the frequency band 9-95 kHz. This is the frequency bandwidth set up by the CENELEC EN50065 standard exclusively for utilities, the so-called A-Band. The bit rate used is 2 kb/s and the communication technique used is Spread-Spectrum. The number of information bits in a transaction is in the range of 80-240 bits.
3 Estimated Overall Performance of the Communication Channels

In Patorp the CCN communicates with 59 MFNs which are geographically spread. Hence, this means that 59 communication channels are present in the area, and the quality of these channels can be very different. In this section, the overall (average) performance of these communication channels is estimated and discussed.

With the information given in the logfiles, an estimate, $P_i$, of the probability for re-transmission of a transaction between the CCN and household number i (MFN number i), can be obtained as:

$$P_i = \frac{e_i}{N_i} \quad (1)$$

Since this parameter also is an estimate of the probability of rejection of an individual transaction at the CCN due to channel impairments, it could also be viewed as an estimate of the "channel error" probability. However, to avoid confusion with established terminology we prefer to refer to $P_i$ as an estimated channel impairment indicator to household i.

To be able to follow how the quality of the communication channels changes over time (large-scale variations), new estimates are calculated for each hour (normally). Though the available statistical data is limited, the obtained quantitative results can be used as an indication of how the quality of the communication channels depends on different time-windows, distances and loads.

3.1 The Average Performance of the Channels

The average, $P$, of the channel impairment indicators, $P_i$, is a measure of the overall average quality of the K (=59) communication channels in the area during an hour and is obtained as:

$$P = \frac{1}{K} \sum_{i=1}^{K} P_i \quad (2)$$

Figure 3 shows $P$ for Monday to Sunday a week in February and a week in May. A week in March is also shown in Figure 8 together with the so-called load profile.
Figure 3. Average of all estimated channel impairment indicators, $P$, for each hour (0-23) during a week in February (the points marked with asterisks) and a week in May (the points marked with circles).

Figure 3 and Figure 8 show that the average value is around 0.10-0.15. This means that if the same amount of transactions are sent to each house, then about 10-15% of the transactions fail on the average. It is also seen in the figures that a peak often occurs during the morning and in the evening. The impairments seem to be especially high around 8 pm. Figure 3 and Figure 8 indicate that the impairments vary with time. It is also seen that the three weeks show some similarities between corresponding days.

Figure 4. The collected data of the parameter $P$ in February (a) and May (b). Shown is, for each hour (0-23) during respective month, the median (crosses) and the minimum and the maximum values. The three largest and three smallest values are plotted with dots in the graphs.

Figure 4 shows all the estimated values of $P$ during February and May. The figure shows that the minimum values occur during the night and in the morning and the maximum values during the day and in the evening. It is also seen that the quality of the communication channels are better in May than in February. This indicates a seasonal behavior of the channel quality. The median values are about the same but the maximum values in February are higher.

### 3.2 The Number of Households Experiencing at least one Re-transmission

The number of transactions initiated to each household in IDAM is in general not the same because the amount of re-transmissions depends on the quality of the communication channel. A different measure of how well the communication works is to count the number of households having a non-zero value, $e$. Note that these results are only valid as long as only the meter reading system is in use. If the number of transactions increase (e.g. new applications), the number of houses experiencing re-transmissions will of course increase.
Figure 5 shows the number of households experiencing at least one re-transmission each hour (hence $e_i \neq 0$). It is seen that this is the case for about 10-15 MFNs each hour. This is about 20% of the total number of MFNs. Note that a peak occurs at 1 pm because the IDAM system during this period initiates at least five transactions to each household instead of the usual two transactions. As in Figure 4, it is seen that the quality of the communication channels are better in May than in February.

![Graphs showing number of households experiencing re-transmissions in February and May](image)

Figure 5. The number of households experiencing re-transmissions in February (a) and May (b). Shown is, for each hour (0-23) during respective month, the median (crosses) and the minimum and the maximum values. The three largest and three smallest values are plotted with dots in the graphs.

### 3.3 The Overall Re-Transmission Probability

Because IDAM does re-transmissions to households corresponding to low-quality channels one might believe that the information is collected by just doing a few re-transmissions. The fact is that a lot of re-transmissions are in general needed to collect all the data. Each hour the CCN initiates two transactions to each MFN (except at 1 pm when five transactions are initiated). If all households would function error free only 118 transactions per hour would be needed (except at 1 pm when 295 transactions would be needed). The overall estimated re-transmission probability, $P_{CCN}$, is estimated as:

$$P_{CCN} = \frac{\sum_{i=1}^{K} e_i}{\sum_{i=1}^{K} N_i}$$

From the logfiles it is found that roughly 70% of the total number of transactions are rejected ($P_{CCN} = 0.7$). The reason for this is that the main part of the communication is directed to households corresponding to low-quality communication channels. By studying the logfiles it is also seen that some households sometimes are addressed about 70 times per hour while some houses are almost never the target of a re-transmission. Hence, this indicates a significant spread in quality among the 59 communication channels. Section 4 will go further into this subject.

### 4 Channel performance associated with specific cable-boxes in the grid

It is seen in Figure 2 that the studied low voltage grid consists of six low voltage cables connected to the substation T159. Furthermore, a number of cable-boxes are connected to each cable (3, 4, 2, 2, 3 and 9 respectively). To each cable-box, a number of households are connected (typically 4 households per cable-box). The low voltage lines going through the cable-boxes 444 and 407 connects 16 respective about 20 houses. The others lines have at most 12 households connected.

In this section we are interested in the quality of the communication channels associated with a specific cable-box. To get quantitative results for a specific cable-box, we calculate $P_{cb}$, similar to equ. (2), as the average value of the estimated channel impairment indicators to the corresponding households. As an example; assume that four households are connected to a specific cable-box and that the corresponding channel impairment indicators are $P_a$, $P_b$, $P_c$, and $P_d$ respectively. The parameter $P_{cb}$ for that specific cable-box is then defined as $P_{cb}=(P_a+P_b+P_c+P_d)/4$.

Figure 6 shows one graph for each low voltage line. Each graph shows the average channel impairment indicator for each of the cable-boxes connected to the corresponding low voltage line. The cable-boxes are sorted after increasing distance to the sub station. Estimates are shown for a week in February and the parameter $P_{cb}$ above is averaged during a day, denoted $P_{cb,av}$. 
Figure 6. The average of the channel impairment indicators associated with each cable-box in the grid (24-hour average). Each graph shows the cable-boxes associated with each of the six low voltage lines connected to sub station T159. The bar to the left corresponds to Monday and the bar to the right corresponds to Sunday.

The graphs show that most cable-boxes are associated with relatively good channels, while some have significantly worse performance. An important question is why this behavior occurs. Known facts is that the low voltage lines corresponding to graph (a) and (f) serves more houses than the other four and the distance of these low voltage lines is also longer than the others.

Figure 7. The average of the channel impairment indicators associated with each cable-box in the grid (24-hour average). (a) for a week in February. (b) shows all estimated values for February. Shown is for each cable-box during February, the median for each cable-box (shown with crosses), the minimum and maximum values (shown with lines) and the three largest and the three smallest values (plotted with dots).

Figure 7a shows the same as Figure 6, but now the cable-boxes are sorted after the distance to the sub station. It shows that, in general, a high level of channel impairments can be expected at large communication distances. This is reasonable, since a larger distance normally imply a larger signal attenuation and/or degradation. However, the figure also shows that some cable-boxes, e.g. 437, function well despite the long distance. The problem is therefore not only the distance but rather the combined effect of distance, signal attenuation, signal degradation and interference level at the receiver.

In Figure 6 it is seen that the performance associated with a certain cable-box is about the same each day, i.e. it varies around an average level. Figure 7b shows all collected data in February. The figure indicates that the quality of the channels, in average, are within a rather small interval. This figure also indicates that impairments exists that make the channel quality vary around an average level. Cable-box 437 is an exception, the collected data shows that it is only a couple of samples that has a value significantly above 0.10 and these values are sequenced in time. Some impairment existed during a period of a couple of days that disturbed these receivers.

5 Load Profile

In this paper a load is defined as a device connected to the low voltage grid. A load interferes with the power line communication in different ways. The interference caused by the load can disturb the receiver, and the input impedance of the load can alter the signal attenuation/degradation of the channel.
The collected meter data gives the so-called load profile, which is equivalent to the energy used in the Patorp area. By comparing the load profile with the average of the estimated channel impairment indicators it is possible to study the influence of the load on the quality of the communication channels.

### 5.1 Load profile and Communication Channel Impairments

Since the meter values are only read on an hourly basis it is not possible to make reliable conclusions for a single household. The reason is that communication to a specific household is only in progress during a short time, just enough to collect the meter data, and these data says little about the load during the (short) time interval when the household was accessed.

Figure 8 shows the average of the estimated channel impairment indicators, $P$, together with the load profile of the area for a week in March.

*Figure 8. The average of all channel impairment indicators, $P$, and the load profile during a week in March. The load profile is shown with bars and the parameter $P$ as a line.*
The figure shows that peaks in the load profile occur in the morning and in the evening. During the weekend the morning peak is delayed. The behavior shown is typical in a low voltage grid consisting of only households.

It is also seen that in many cases when the energy usage is high the quality of the communication channels is low. This is as expected because when the energy usage is high, more devices are connected to the grid and hence more possible sources of impairments exist.

The relation between the two parameters is not linear because the dependence between the energy usage of a device and its impairment on the channel is not linear. Therefore the quality of the channels can be low even though the energy usage is low.

6 The Influence of a Load on the Quality of the Communication Channels

As the previous section indicates, the various loads connected to the power line can decrease the quality of the communication channels. However based on the collected data it can not be said how strong this influence is. To investigate this further a moveable load was transported to Patorp. This load is designed by NESA A/S and consists of a set of industrial machines mounted within a container.

More specifically, the moveable load consists of a 65-kVA voltage source inverter, which drives a 40 kW induction motor, which drives a 48-kVA synchronous generator. The generator supplies power to some 45-kW heaters. A 35-kVA welding unit is also housed within the container. Information regarding the harmonic noise introduced in the power line by this load can be found in [2]. The energy usage of the load when all devices are active is roughly 68 kWh per hour. This can be compared with the total energy usage per hour shown in Figure 8.

The moveable load was connected to various places in the low voltage grid in order to investigate how it affected the quality of the communication channels. It was placed in the sub station to see how it affected all channels, and in cable-boxes to see the influence on specific communication channels. Because the IDAM system uses one hour to access all households it was necessary to let the load be on during at least an entire hour without interruption.

6.1 The Influence of the Load when Connected to the Sub Station.

The moveable load was first connected to the sub station T159. By doing this it was made sure that the load influenced every message sent (received) from (at) the CCN.

![Figure 9. Average of all estimated channel impairment indicators, P. (a) shows P on March the 19th when the load was connected to the sub station. (b) shows P on March the 27th when the load was connected to cable-box 447.](image)

Figure 9a shows the results from one of the experiments made, the value of P for Thursday March the 19th. This day the moveable load was active between 10-12 am and 2-4 pm. It is seen in Figure 9a that the channel impairments increased considerably when the load was active. P increased from 15% to 35-40%. It was also found that the number of houses requiring at least one re-transmission increased from about 10 to roughly 30 households when the load was active.

The results in section 3 indicate that no high peaks, like those in Figure 9a appear in the normal case when the moveable load is absent.
6.2 The influence of the load when connected to a cable-box

To further investigate the influence of the load on the channel quality, the moveable load was moved to different locations in the grid.

An experiment was made on March the 27th. During this experiment the load was connected to cable-box 447, see Figure 2. This cable-box is located 220 meters from the sub station. The corresponding low voltage line, on which it is connected, serves 16 houses connected to four cable-boxes. First, the load was active for one hour at a time, between 8-9 am, 10-11 am and 12 am - 1 pm. Thereafter the load was active between 2-12 pm. All the machines were active during the whole experiment except the welding unit which only was in use between 10-11 am and 12 am - 1 pm.

Figure 9b shows the value of $P$ (see equation (2)) for March the 27th. This figure shows that at this location the moveable load did not degrade the channel quality as much as when it was located at the sub station. The average of the channel impairment indicators increased from 15% to 20-25%. One reason is that the distance to the load from the sub station is far so many communication channels are less affected by the load. Only 25% of the households are connected to this low voltage line so assuming the load does not cause too much interference in the other low voltage lines the value of $P$ should be lower.

Figure 10 shows the average of the channel impairment indicators associated with each of the cable-boxes (Pcb) connected to the same low voltage line as cable-box 447. The black bars correspond to March the 27th and the white bars to March the 13th. Figure 10 shows the average of the channel impairment indicators associated with each of the cable-boxes (Pcb) connected to the same low voltage line as cable-box 447. Samples are shown for March the 27th and the Friday two weeks before, when the load was not connected. The figure indicates that when the load was active a severe degradation of channel quality occurred to households connected to the cable-box where the load was connected.

Cable-box 446 is placed after cable-box 447 with respect to the sub station and it also represents low-quality channels. As Figure 10 shows this cable-box was a low-quality channel even when the load was not connected. The channels associated with cable-boxes located closer to the sub station were also affected by the load. Peaks are shown for cable-box 445 at times when the load was active. A study of cable-boxes 442 and 443, which belong to another low-voltage line, shows that they are very little affected.

Even when the load was not active one heater was on warming the container. This can explain why Pcb seems to be higher even when the load was not active.

7 Discussion and Conclusions

In this paper, focus is on the quality of the communication channels in a specific low voltage grid. By processing collected data, obtained from a running meter reading system (IDAM) operating in the low
voltage grid, estimates of channel impairment parameters are obtained. Hence, the IDAM system is not evaluated here, rather it is used to extract information that can be used for (large-scale) channel quality estimation. This study is based on collected data representing communication with 59 households (hence, 59 communication channels are considered), and the low voltage grid is located in Ronneby, Sweden.

The overall average quality of the communication channels fluctuates more or less randomly for each hour within a day, and also for each day within a week. However, the average quality seems to vary around a level that corresponds to a re-transmission probability roughly equal to 0.15. By comparing the results for February and for May, it is seen that less variations is obtained for May which indicates a seasonal behavior of the channel quality.

Large variations in the quality between the individual communication channels have also been found. Especially, for the considered low voltage grid, low-quality communication channels have been found along two, of the six, lines leaving the transformer. A low-quality communication channel is normally the result of the combined effect of channel impairments such as signal attenuation, signal degradation and interference level at the receiver. However, based on the collected data, we are not able to decide which is the dominating impairment. This will be a subject for further studies/measurements. From the results it is also seen that there is a clear tendency that the quality of a specific communication channel varies randomly around an “average quality level”, which in turn depends on the channel’s path in the grid.

It is well-known that re-transmission methods can be used to improve the reliability in digital communication systems, and it is especially suitable in applications where real-time operation is not a critical issue and where the information bit rate is low (e.g. meter reading systems). A consequence of low-quality communication channels is that the main part of the communication is over these channels, since many re-transmissions are in general necessary to obtain reliability. The IDAM system is designed for collecting meter values and it uses a re-transmission method for this purpose. Hence, it takes some time until all the 59 meter values are collected. However, this time-delay is not critical in the current application.

The loads connected to the low voltage grid can have a serious impact on the communication performance. In general a load can introduce several effects; it can e.g. change the attenuation and/or the degradation of the information carrying signals. Furthermore, a load can also introduce interfering signals. A general problem is that the set of active loads in a given time interval is random. Despite these difficulties it is interesting to study the level of channel impairments in relation to the amount of energy delivered to the grid (the so-called load profile). From the observed data it is hard to draw any definitive conclusions. However, a period of high energy consumption (typically mornings and evenings) in the grid have a tendency to decrease the channel quality. It is also observed that the quality of the channels can be low at nights, though the energy consumption is low. An explanation might be that the loads in this case generate severe interfering signals.

To investigate the influence of a specific load on the quality of the communication channels, a moveable load consisting of a set of industrial machines was connected to several locations in the grid. When the load was connected at the central communication node which was located at the sub station, all communication channels where directly influenced by the load, and the average channel impairment parameter increased significantly from roughly 0.15 to 0.40. When the load was connected at a cable-box, 220 m from the sub station, the corresponding parameter increased to roughly 0.25. This is reasonable since the negative effects of the load will be most noticeable on the communication channels which are close to the load. Hence, channels corresponding to other low voltage lines is much less affected. However, households (i.e. channels) very close to the load experienced a dramatic decrease in channel quality.

The investigations reported in this paper can be characterized as an attempt to get an overview of some communication properties of the low voltage grid. Though additional specific (small-scale) measurements have to be made, it is already clear that advanced communication methods must be used in forthcoming applications requiring high information bit rates. Key parameters are the available bandwidth and the signal-to-noise ratio at the receiver. Several well-known communication methods are possible candidates for future use in power line applications. Examples are OFDM-type methods, GMSK-type methods, and methods based on spread-spectrum techniques. For a given application, parameters that will influence the choice of communication method are; the characteristics of the communication channel, the required information bit rate and the required level of robustness.

8 Acknowledgements

Parts of this work was supported by the Swedish National Board for Industrial and Technical Development and by Elforsk (supported by Sveriges Elleverantörer, Stiftelsen Ronneby Soft Center, Telia, EnerSearch, NESA A/S, IVO OY). We would also like to acknowledge Hans Ottosson, head of Enersearch (see [8]), who initiated this project.
We would like to acknowledge Ronneby Energi and Steen Munk at NESA A/S for helping us with the moveable load. We would also like to thank Mats Bäckström at Bextroem Automation AB for help with the IDAM system.

We would like to thank Marko Krejic and Richard Krejstrup at Högskolan Karlskrona/Ronneby for their time, help and advice during the whole project.

We would also like to thank Anders Holtsberg and Tobias Rydén at Lund University for valuable discussions concerning the statistical analysis and evaluation of the collected data.

9 References

Lars Selander is a Ph. D. student at Lund University, Lund.

He received the M. Sc. Degree in 1997 from Lund University, Lund.

His primary interests are coding, digital modulation methods, detection principles and power line communications.