SmallCAN - A Reliable, Low-Power and Low-Cost Distributed Embedded System for Energy Efficient Building Automation

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***Abstract*—In this paper we propose a new reliable, low-power and low-cost platform for a building automation system, BAS, which is suitable to be used as a single platform for all appliances of a building. Furthermore today's platforms for building automation do not focus on low-energy consumption of the platform itself. The costs are also quite high and the installation has limited flexibility and needs extensive planning. The proposed platform features low-power consumption, has a reliable wired structure which is flexible, simply structured and can easily be extended. The low-power and low-cost approach targets the wide spreading of smart buildings to maximize global energy saving and to easily interface with a future smart grid. The SmallCAN platform has shown during evaluation in our demonstrator that it is able to fullfil all identified requirements of a modern building automation system.**

***Index Terms*—low-power; low-cost; building automation; embedded systems; smart grid; platform;**

I. INTRODUCTION

Nowadays up to 40 % of the overall european energy consumption is used by buildings [1]. Since resources in general and energy in particular are limited, different measures are researched to lower the total energy consumption of buildings.

Today's buildings are containing many energy consuming appliances like air conditioning, heating, lighting, fire detectors, burglar alarm etc. and also energy generating appliances start to enter the building sector for example solar panels or small combined heat and power units. Usually every single appliance is controlled separately. For example heatings often use a dedicated temperature sensor measuring the outside temperature and the temperature in the living room to control the heating.

The logic separation of appliances does not take advantage of a comprehensive control of all appliances regarding efficient energy usage. A trivial example would be to make the data of burglar alarm sensors available to the heating. The heating would then be able to check whether there are any open windows before starting to try raising the room temperature.

One can think about many other examples how the logic coupling of separate appliances of a building may boost the energy efficiency of the particular building. Consequently it is an obvious approach to use only one platform which controls every appliance of the building. This single platform would be aware of all the available data of the building and can control the building appliances as energy efficient as possible.

Furthermore a single platform will be able to easily provide comprehensive energy usage or energy generation data in real-time to the smart grid. A fast and broad reaction upon data provided by the smart grid is also an advantage of a single platform.

Another important parameter of a platform for building automation is often overseen: the energy consumption of the platform itself. Many of the current platforms are not energy efficient and do not scale well with respect to their own energy comsumption. Additionally the overall cost of the available platforms is quite high.

Therefore we propose a new platform for a building automations system which is able to control all appliances of a building by providing a reliable communication network, has a low power consumption and is designed of cheap standard components.

We will begin with identifying the needed requirements of a platform for building automation in the following section. In section III we will compare current platforms for building automation the identified requirements. Based on this comparison and the requirements identified in section II we propose a new platform which fulfils all of the mentioned requirements in sections IV to VII. We will then describe a demonstrator that we built to evaluate the new platform in section VIII. After that we finish with our conclusion.

II. REQUIREMENTS

A platform for building automation which should be used to control all appliances of a building and provide/receive data to/from a smart grid has to fulfil several requirements to be beneficial for the energy efficiency and the general usability of the building. Several different platforms have been developed and/or proposed so far addressing the control of building appliances. A comprehensive and detailed overview of current platforms can be found in [2].

One of the main requirements of a single platform which may be used for all possible appliances is high reliability.

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This is needed to ensure a safe and secure operation over several decades without causing dangerous conditions in case of errors. Furthermore appliances like burglar alarm systems or fire detectors rely on a reliable communication network.

Another important requirement is a low power consumption. The power consumption of the platform has to be as low as possible to guarantee maximum energy savings without spending to much energy in operating the platform itself. Otherwise buildings equipped with a building automation system may consume more energy in total, because operating the system uses more energy than it saves by efficient control of the building's appliances. This does also depend on the size of the building and the number of installed appliances, because a platform may scale bad with respect to power consumption. Therefore the overall energy consumption of a platform becomes a main factor for its success.

The overall cost of the platform, including component and installation cost is last but not least important to make the platform affordable for everyone to maximize the global energy saving by installing a building automation system in every building. Therefore a platform for building automation is in general cost sensitive.

In the next section current platforms for building automation will be compared against the identified requirements.

III. DIFFERENTIATION OF CURRENT BUILDING AUTOMATION SYSTEMS

The reliability of the used communication network is the main requirement for a platform which should be used for all appliances of a building. Recent research has proven that wireless systems do not fulfil this requirement since they tend to be easily disturbed. Especially the often used IEEE802.15.4 Standard mainly used in wireless sensor networks for building automations systems suffers heavily from IEEE802.11 data communication resulting in a packet loss rate of up to $100\ \%$, [3], [4], [5], [6]. However, the ease of installation and the flexibility make a wireless network an interesting option for appliances which do not require high reliability of the communication network like light switches or temperature sensors.

Power-line communication is another option, if the focus lies on ease of installation, especially for retro-fitting buildings, but power-line communication can be interrupted by devices without or defect noise suppression or by other devices injecting noise into the low-voltage grid like light dimmers or microwave ovens for example, [7], [8]. Up to $78\ \%$ packet loss was observed in low-thoughput power-line channels under adverse circumstances and even in optimal configuration there was still a remaining packet loss of $15\ \%$, [9]. Therefore power-line communication is similar to the wireless approach with respect to reliability of the communication network.

Platforms fulfilling the reliability requirement by using dedicated data-lines for a reliable communication network can be divided in platforms, which power the nodes over bus, also known as linkpower, and platforms where each node is powered by a separate power supply. The power consumption, which was identified as another important requirement, differs between these two principles. Platforms powering each node separately suffer from the fact that each node has to generate its own low voltage supply including the inherent power loss of the respective power supply. This leads to maximum power consumption per node of 4.6 W [10].

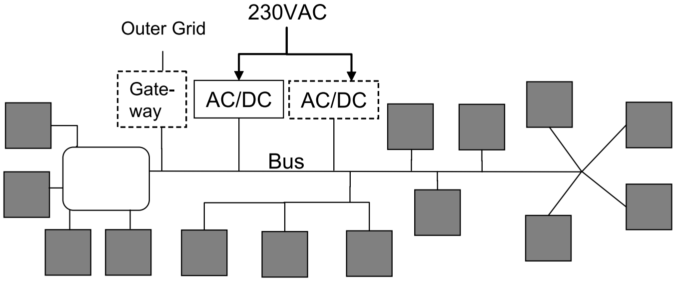

Fig. 1. SmallCAN System

Linkpowered platforms use one or more central power supplies which supply all nodes. This approach leads to a lower power consumption compared to separately powered nodes, because the power supply standby losses only occur once and not at every node. The operational losses can be further reduced by the use of a highly efficient and reliable power supply. Furthermore there is an inherent need to design energy efficient nodes to be able to supply as many nodes as possible. Typical nodes of such a platform for example are supplied by one central $24-30$ V power supply and consume about 0.6 W each [11], [12].

Other existing approaches such as I2C or one-wire bus are not designed for use in harsh building environment, not dealing with potential differences, voltage losses on long lines, auxiliary power for arbitrary sensors and actuators and high efficient throughput.

The different platforms also cause different installation costs. Direct digital control-based platforms for example usually require a star topology instead of an easier to install bus topology which raises the installation cost compared to systems using bus topologies. Platforms allowing a completely free topology cause the lowest installation costs, if only dedicated wiring platforms are considered, since no detailled planning is needed and the shortest path between two adjacent nodes can always be taken.

In the next section we will propose and describe a new reliable, low-power and cost-sensitive system for building automation, called SmallCAN, since no current platform for building automation fulfils all requirements satisfyingly.

IV. SMALLCAN SYSTEM OVERVIEW

We propose a system meeting the requirement for high availability and reliability by using dedicated wiring for data transmission together with a reliable communication protocol. Furthermore the topology of the wired bus medium is not restricted and completely decentralized to lower costs for planning and installation. The low-power requirement is met by powering all bus components with a single extra-low voltage power supply over the bus line. This reduces the losses which usually occur if every bus component needs to supply itself. We also developed a sophisticated busnode layout with respect to power consumption to be able to deal with the restricted amount of power provided by the single power supply. To also satisfy the cost sensitiveness we use as many unified parts as possible in an exemplary implementation to proof that a cheap mass production of all system components is possible.

Thus we present a new distributed embedded system for the control of building appliances which is able to completely satisfy all of the identified requirements by implementing the above named design decisions. The system which we present in this paper is called SmallCAN, because the communication protocol is mainly derived from the CAN specification, [13]. Our system consists of:

- low-power bus-devices, which are build of a unified busnode and a function-specific device adapter
- dedicated bus wiring for communication and power supply of the bus-devices
- a central power supply
- an optional gateway interfacing the SmallCAN to smart grids or the internet for remote control

The bus-devices usually contain sensors, actuators or both and are used to operate the building appliances forming different applications such as room temperature or lighting control for example. The topology of the dedicated bus wiring connecting and supplying the bus nodes is completely free, see fig (1). Only one central power supply, backup power supply possible, is used to power all bus-devices via the bus.

The following sections will describe in-depth the SmallCAN system starting with the communication network.

V. COMMUNICATION

A. Physical Layer

The *SmallCAN communication network* uses a dedicated star quad cable for data transmission and power supply. Two wires are used for data transmission consisting of the data line itself and the associated ground wire. The dataline is driven to $23\ \mathrm{V}$ by the central power supply unit. $23\ \mathrm{V}$ is the idle level of the dataline which also complies to the recessive state of the bus. The busnodes are able to drive the voltage level of the dataline low with a single transistor. The low-level corresponds to the dominant state of the bus. With respect to the binary-physical-allocation the high-voltage-level, recessive state corresponds to 0 and the low-voltage-level, dominant state corresponds to 1. The used datarate is $9.6\ \mathrm{kbit/s}$. Several measures, described in the next subssection, have been taken to allow for an efficient system operation by reducing the required telegram and data rate. The comparatively low datarate allows for a long busline without the need of termination resistors or restricted stub lengths, because the datarate enables the voltage-level to settle before the next bit is transmitted. Therefore the bus lines can be arranged in a completely free topology. This hierarchy free topology enables adding nodes easily to an existing system. The physical layer is designed to operate up to $1000\ \mathrm{nodes}$ with an overall bus length of $1000\ \mathrm{m}$.

The remaining two wires of the dedicated star quad cable are used for the $30\ \mathrm{V}$ power supply of the busnodes. Due to the low-power design of the busnodes all nodes can be powered by the bus through a single power supply. This power supply is a high quality mains adapter regardless of high costs, because this is only needed once per system or segment. This central power supply should be highly efficient to ensure a low overall system power consumption. The availability of the system can be further improved by the optional use of a second redundant mains adapter to prevent this central unit from being a single point of failure. It is also possible to use battery buffering to be protected against mains flicker or temporal mains shutdown.

To maintain our target of a low-cost system, we decided to not galvanically insulate data and power supply ground which would otherwise lead to a higher component count and therefore to higher cost.

B. Protocol

The implemented multi-master *communication protocol* uses CSMA/CA for medium access which guarantees a very efficient use of the medium's datarate. It uses short telegrams with a fixed length. This fixed length can easily be handled in software by the busnodes. This is needed to achieve a simple software implementation of the protocol.

The developed protocol is in general very similar to the widely-known CAN specification which is used mainly in automotive environments[14]. SmallCAN inherits most of the properties of CAN to reach the same reliability. Therefore it is also easily possible to port the system to using a normal CAN-Bus, if needed.

A SmallCAN telegram consists of a unique $2\ \mathrm{byte}$ address which identifies the sender of the information and implies the priority. This is followed by 2 bytes containing payload and one CRC-byte for protection against transmission errors. The termination is done by positive or negative acknowledgement flags respectively and an inter-frame space to separate the telegrams. Each of the address, payload and CRC-bytes is accompanied by separate start and stop bits to allow for resynchronization of the receiving busnodes. These start and stop bits are also a replacement for bitstuffing which is used in CAN. Therefore frame errors can be recognized by missing or wrong positioned start or stop bits respectively.

This telegram structure leads to a constant and short telegram length of $69\ \mathrm{bit}$ including the minimum inter-frame space of $11\ \mathrm{bit}$. Every single data value is packed into the payload of only one telegram leading to low latencies with respect to measurement value or command transmission.

C. Communication Network Properties

The *availability* of the communication network is high due to the use of a dedicated, wired communication medium. The central, high reliable power supply powers all nodes via the bus wire. An additional power supply can be installed to compensate down times of the main power supply. These power supplies can also be backed up by a USV to protect the system against local mains breakdowns.

The high *reliability* is also based on the wired communication and the CRC protection against transmission errors. The CRC allows the detection of corrupted data and the needed telegram acknowledgement bits make it possible to signal data corruption or loss by the receiving busnode, [15].

A wired communication network generally comes with low error rates and a continuous availability thus enabling low latencies. In combination with the CSMA/CA medium access, timing guarantees can be calculated for all running applications by doing a formal system analysis, [16]. Therefore applications with mixed criticality may also run on this system.

The wired connection with integrated powering of the nodes also enables easy *maintainability* because the status of every node can be polled every time. The bus integrated power supply has an advantage compared to battery powered or energy harvesting devices, because it allows the use of sensors and actuators without the restriction for extremely low-power operation between actions. Thus high sampling rates of sensors for example as well as safety and security related functions which require fast condition monitoring are possible.

The *robustness* of the system follows from the conceptual design being an independent system. For example there is no personal computer needed to operate the system which would be an unforeseeable maintenance factor.

The *network performance* is a result of a predictable timing behaviour. Retransmissions in case of communication errors are the main reason for timing problems in the system. The low bus latency during medium access - implied by a short data telegram length and supported by a lightweight fast software implementation - in combination with the low error rate on the wired medium reduces timing problems and supports mixed criticality as described above. The data rate of $9.6\,\mathrm{kbit/s}$ may seem low, but the efficient protocol leads to an effective telegram rate of up to $140\,\mathrm{telegrams/s}$. In BAS the telegram rate is more important than the sheer data rate since the transmitted data or commands usually fit into one telegram, making the data rate a negligible parameter compared to the telegram rate. Different measures may be taken to further reduce the required telegram rate for the respective applications and therefore use the available telegram rate more efficiently. Common measures include: Event driven message transmission, send-on-delta with sophisticated jitter suppression, traffic shaping and discarding outdated data prior to transmission.

The following sections will further describe the structure of the bus-devices regarding hard- and software.

VI. BUS-DEVICE

A. Hardware

A *bus-device* consists of two parts, a unified busnode and a function-specific device adapter. The current busnode operates with $20\,\mathrm{V}$ to $30\,\mathrm{V}$. The average power consumption of the bus-node itself is $0.060\,\mathrm{W}$, the average power consumption of a complete bus-device including sensors, relays or other small actuator elements is $0.080\,\mathrm{W}$. A busnode contains nearly all of the electronic parts and the complete software for bus communication and the device functionality. The device adapter only implements a few components needed for the specialised bus-device function, for example to interface a special kind of sensor etc. The layout for a device-adapter can be deviated from a set of templates and therefore usually requires only small design efforts. At this stage the overall power consumption of every bus-device has to be limited and optimized by appropriate circuit design and power management for the sensors and actuators. For cost and reliability reasons the bus-devices use as few electronic components as possible. A significant amount of effort have been put into the optimization of the *busnode* with respect to power, cost and size. Only standard components are used which are available in high quantities for low prizes. The central part of the *busnode* is a PIC16F88-microcontroller which was chosen for its low-power consumption and its predictable structure with respect to timing. The only other active parts are a crystal and a voltage regulator. The bus driver circuit consists only of a MOSFET transistor and a resistive voltage divider.

Multiple measures have been taken to protect the nodes and the bus in case of errors, such as over-voltage protection, short circuit protection, and shut-off of the physical bus driver.

Primary common and cheap sensors and actuators are used to be integrated in device adapters (e.g. relays, humidity sensors, text displays). Sometimes it is necessary to interface modules and third party devices even though they are more expensive and less power efficient. This is done by standardized interfaces, such as RS232 or an ”0-10V” analog interface. Devices of other domain specific bus systems are interfaced as well to avoid the need for parallel bus cabling, especially for new installations. The local integration of such domain specific bus systems is done by a so called gateway device adapter, e.g. for DALI, MBUS and MP-BUS. These gateway device adapters are build similar to the normal bus-devices including their low complexity and power consumption. Standalone devices without dedicated bus connections have also to be controlled by specialized device adapters, e.g. gas heaters or electric meters. Because of the many possibilities of easy direct *interfacing* on device level, it is possible to use the presented system as a universal and holistic solution for all appliances of a building.

B. Software

The *software structure* consists run time kernel, an interface to local user functions and the user functions itself. The OS handles the bus communication protocol and standard functions such as I/O port operations and diagnostic functions. The implemented OS has a small code base and is well tested. The system also allows user functions which are in-system programmable over the bus. These user functions can be divided into two groups: hardware-related, hr, and non-hardware-related, nhr, functions. The hr function is used to control the hardware connected to the busnode or device adapter. The nhr function can be used to implement logic functions without being allowed to access hardware, for example a controller coordinating the access to window blinds and window openers. Each busnode may contain one hr and one nhr function. The user functions are connected to the OS by an interface which routes all calls of the OS to the user functions.

C. Bus-Device Properties

A high availability of the hardware is reached by a robust design and the reliability of the components itself. The number of the used electronic parts was kept as low as possible to reduce the probability of hardware failures. Furthermore extra circuits to monitor power stages, etc, enable an online surveillance of the hardware status to support fast response times in case of severe hardware failures. Thus defective busnodes can be easily located and exchanged fast.

The OS was kept as simple and small as possible. It was tested under several different conditions and for a longer time period to make sure it works reliable.

The *costs* of the bus-device are low because of the few standard components and the small design effort for new device-adapters. Especially the unified busnode uses a small pcb which can be assembled by common SMEs.

As mentioned before the average power consumption of only 0.080 W per bus-device is at least an order of magnitude lower compared to the systems which are currently state of the art and also fulfil the reliability requirements.

It is now possible to derive the system properties from the detailled descriptions of the system components. This will be done in the following section.

VII. SYSTEM PROPERTIES

By combining the described communication network with the bus-devices and the central power supply we get a system with the following general attributes:

- Highly available, because of the dedicated, wired communication network and the high availability of the bus-devices
- High reliability, because of the used robust protocol and thoroughly designed bus-devices
- Low-cost, since unified bus-nodes are used with a low component count and low part prizes
- Low-power, because of the central high efficient power supply and the careful considered part choice and layout of the bus-devices

The *robustness* of the system follows from the conceptual design of an independent system. The multi-master communication, the redundant power supply and the absence of a central controlling unit avoids a single point of failure. Especially there is no personal computer involved which would be an unpredictable maintenance factor. The high signal amplitudes were chosen to avoid problems with interferences. All signals leaving or entering the bus-devices are protected against damage by over-voltage etc.

Fig. 2. Demonstrator: Future Workspace

The *installation costs* are split into the initial installation of the wiring and the costs for later system extensions by adding new bus-devices. The free topology allows the freedom to install and expand the system at any time without any detailled planning. Especially there is no need to route dedicated cables between sensors and actuators, e.g. between light switches and lights, because all nodes are wired in the same manner. However the dedicated wiring makes retro-fitting of an existing building uncomfortable compared to systems using wireless or power-line communication.

In summary the overall system costs are quite low compared to the currently available systems. Furthermore the operation costs are kept low, because of the energy efficient design of the system itself. Talking about several decades of operation the energy consumption itself becomes one of the main factors for the overall costs.

The busnodes offer sufficient *performance* for intelligent distributed controls. This enables a full exploitation of the energy saving potential by enabling easy to configure rules and functions as well as more complex algorithms.

The *energy consumption* of the overall system is the sum of the used bus-devices, the loss on the communication lines and the loss at the high efficient main power supply. For a common system in a family home a simple system may contain 25 bus-devices up to 250 bus-devices in total for a high-comfort system covering all possible applicances. Inclusive all sensors and actuators, excluding the 230 V devices like lights, motors, etc., the simple system will need about 2.5 W. The high-comfort system will only need about 20 W.

In the next section we describe a demonstrator which is used to evaluate the presented system, before we conclude in the last section.

VIII. DEMONSTRATOR

To be able to test and evaluate the above presented Small-CAN system we decided to build a demonstrator. Therefore we became partner of a local architectural research project in Braunschweig called future:workspace [17].

The aim of this project is to transform a floor of a tower building belonging to TU Braunschweig into the perfect workspace of the future. This includes the energy efficient use

Fig. 3. Wirings looms and single wire

of several building appliances like air conditioning, heating, lighting, etc. Therefore we installed our SmallCAN system in one of the four offices of the future:workspace. About $100\ \mathrm{m}$ of bus-line and 93 $\mathrm{busnodes}$ were installed in total. The installed system consists of many sensors for room and outside temperature, temperatures inside the heating and air conditioning subsystems, humidity, brightness, windspeed, noiselevel, etc and also switches and other possibilities to interact with the system like LC-Displays for example. Furthermore several nodes controlling actuators of the appliances were installed like window blinds and electric window openers, lighting control, power socket relays, waterpumps, etc.

The other three offices of the future:workspace were equipped with a state of the art DDC system using Ethernet for communication between the busnodes. All four offices were configured to reach the same range of functions so that both systems can be directly compared in a real application environment.

Some advantages of the SmallCAN system were observed immediately. The star-topology wiring loom of the DDC system showed to be more complex and space-occupying compared to the single bus-line of SmallCAN, see fig 3. *Material usage* is an important factor in terms of environment protection and economical handling of materials. Additionally the fire load and cable conduits do affect the overall costs. Furthermore the overall power-consumption of the SmallCAN system is only $9\ \mathrm{W}$ including an optional ARM-based Linux-gateway for remote control over internet. The power consumption of the DDC system is currently monitored. The SmallCAN shows an average telegram rate of $8\ \mathrm{telegrams/s}$ in the current configuration which corresponds to an average busload of $5.7\ \%$ for a system consisting of 93 $\mathrm{busnodes}$ of the possible 1000 $\mathrm{busnodes}$. Since the implemented control algorithms are way above average in the demonstrator, this shows that the choice of a low-datarate communication medium together with an efficient protocol and measures to keep the telegram rate low is working well. Further measurements to characterize SmallCAN like monitoring the packet loss rate and the busload with varying control algorithms are currently conducted and will be used to further improve the current platform or its successor. Smart power sockets, based on the SmallCAN platform, being able to measure and control the power usage of 230 Volt devices will be added in future to further increase the potential energy savings.

IX. CONCLUSION

The first test results of the presented SmallCAN system are promising and the system seems to fulfil all proposed requirements. It was proven that a platform for building automation which provides all necessary functions can be built with an exceptionally low-energy usage and without sacrificing system cost. Furthermore, due to the holistic approach to control every building appliance with one platform, comprehensive data can be sent and received to/from a smart grid. Future work will contain a more detailed comparison and analysis of the energy efficiency of the SmallCAN system and other BAS. Currently a model of the timing behaviour of the unified bus-nodes and the whole system is being build to be able to investigate the SmallCAN system by methods of formal analysis. Also porting the system to a more recent processor architecture is planned.

REFERENCES

[1] *DIRECTIVE 2002/91/EC*, Official Journal of the European Communities, The European Parliament Std., 01 2003. [Online]. Available: http://www.eebd.org/filelibrary/docs/Directive_English_Version.pdf

[2] W. Kastner, G. Neugschwandtner, S. Soucek, and H. Newmann, “Communication systems for building automation and control,” *Proceedings of the IEEE*, vol. 93, no. 6, pp. 1178 –1203, jun. 2005.

[3] A. Sikora and V. Groza, “Coexistence of ieee802.15.4 with other systems in the 2.4 ghz-ism-band,” vol. 3, may. 2005, pp. 1786 –1791.

[4] S. Pollin, I. Tan, B. Hodge, C. Chun, and A. Bahai, “Harmful coexistence between 802.15.4 and 802.11: A measurement-based study,” may. 2008, pp. 1 –6.

[5] M. Petrova, L. Wu, P. Mahonen, and J. Riihijarvi, “Interference measurements on performance degradation between colocated ieee 802.11g/n and ieee 802.15.4 networks,” apr. 2007, pp. 93 –93.

[6] M. Z. n. Zamalloa and B. Krishnamachari, “An analysis of unreliability and asymmetry in low-power wireless links,” *ACM Trans. Sen. Netw.*, vol. 3, June 2007. [Online]. Available: http://doi.acm.org/10.1145/1240226.1240227

[7] S. Bolognani, L. Peretti, L. Sgarbossa, and M. Zigliotto, “Improvements in power line communication reliability for electric drives by random pwm techniques,” in *IEEE Industrial Electronics, IECON 2006 - 32nd Annual Conference on*, 2006, pp. 2307 –2312.

[8] F. Canete, J. Cortes, L. Diez, and J. Entrambasaguas, “Modeling and evaluation of the indoor power line transmission medium,” *Communications Magazine, IEEE*, vol. 41, no. 4, pp. 41 – 47, 2003.

[9] Y.-J. Lin and H. Latchman, “On the effects of maximum transmission unit in power line communication networks,” in *Power Line Communications and Its Applications, 2007. ISPLC ’07. IEEE International Symposium on*, 2007, pp. 511 –516.

[10] *Busch-Powernet EIB Jalousie-/Serienaktor 6972 AG-102*, Busch-Jaeger Elektro GmbH, 2010.

[11] *HS485 D*, ELV AG, 2010.

[12] Siemens, *KNX bus*, 2010.

[13] *ISO 11898*, ISO Std.

[14] *CAN Specification Version 2.0b*, Robert Bosch GmbH Std.

[15] J. Wolf and R. I. Blakeney, “An exact evaluation of the probability of undetected error for certain shortened binary crc codes,” in *21st Century Military Communications - What’s Possible?*, vol. 1, October 1988, pp. 287 – 292.

[16] R. Henia, A. Hamann, M. Jersak, R. Racu, K. Richter, and R. Ernst, “System level performance analysis - the symta/s approach,” *IEE Proceedings Computers and Digital Techniques*, vol. 152(2), pp. 148–166, 2005.

[17] C. Bremer, “future:workspace - moderne arbeitswelt an der tu braunschweig,” *xia intelligente architektur, Zeitschrift für Architektur und Technik*, vol. 60, pp. 48–51, 2007.