A Network Emulation Testbed for Complex Topologies of Wired M-Bus According to EN13757

Oliver Kehret, Manuel Schappacher, and Axel Sikora
Institute of Reliable Embedded Systems and Communications Electronics (ivESK), Offenburg University of Applied Sciences, Badstrasse 24, D 77652, Offenburg, Germany
Email: {oliver.kehret, manuel.schappacher, axel.sikora}@hs-offenburg.de

Abstract—The M-Bus protocol (EN13757) is in widespread use for metering applications within home area and neighborhood area networks, but lacks a strict specification. This may lead to incompatibilities in real-life installations and to problems in the deployment of new M-Bus networks. This paper presents the development of a novel testbed to emulate physical Metering Bus (M-Bus) networks with different topologies and to allow the flexible verification of real M-Bus devices in real-world scenarios. The testbed is designed to support device manufacturers and service technicians in test and analysis of their devices within a specific network before their installation. The testbed is fully programmable, allowing flexible changes of network topologies, cable lengths and types. It is easy to use, as only the master and the slaves devices have to be physically connected. This allows to autonomously perform multiple tests, including automated regression tests. The testbed is available to other researchers and developers. We invite companies and research institutions to use this M-Bus testbed to increase the common knowledge and real-world experience.

Index Terms—M-BUS, smart metering, bus emulation, wire emulation

I. INTRODUCTION

In smart metering the M-Bus protocol according to EN 13757 is widely used. However, the original standard was not complete and showed inconsistencies in real life installations. The letter and the lack of a solid test environment for M-Bus devices are root causes for failures during set up of M-Bus networks. Several sophisticated methods are known to predict and examine the behavior of new applications. Due to their flexibility, reproducibility and space-efficiency computer based simulations often are the method of choice. However, simulations have their limits, for instance if the behavior of the physical layer has to be predicted or real devices have to be involved. In cases with low quality requirements to the simulation of the physical layer, software-based, statistical models might be sufficient. However, the latter methods will fail to model parameters like transmission failure rate of a device. This is where a physical testbed [1] has it strengths. Physical testbeds are built to model the physical layer more precisely and to allow the connection of real devices. In comparison to a real test setup, physical testbeds are more space- and time-efficient and may be quickly reconfigured.

To provide the benefits of a testbed to M-Bus developers the authors developed a network emulation testbed for the wired M-Bus. As of today M-Bus device developers have no common criteria to test functionality of devices. Testing these different devices on the testbed helps to guarantee functionality as well as interoperability among different vendors and models.

The paper is organized as follows: Section two gives an overview of existing testbeds. In section three the wired M-Bus is described. Section four introduces the proposed M-bus network emulation testbed and in section five measurement results are shown. We finally summarize our proposal in section six.

II. STATE OF THE ART

Over time, a huge number of different testbeds have been created. Testbeds are usually highly specialized and tailored to satisfy the needs of their creators. However, most testbeds follow generic concepts and aims, which provide benefits for testbeds of different types. These are, beside others, reliable regression tests and the evaluation of applications in scenarios close to the real world.

In details, a testbed for automotive wireless transmission has to be constructed in another way rather than a testbed for wired industry communication. Thus the actual testbed implementations differ in many aspects. To the best of our knowledge, there is no testbed that fits to the requirements of the M-Bus physical layer. In particular, the voltages in M-Bus physical layer can reach up to 50 V. Also, the topologies of test M-Bus are extremely flexible, i.e. much more flexible than most of the other (better defined) network protocols.

As many testbeds are developed in R&D departments, it is anticipated that not all testbeds are publicly known. Therefore, the following overview is neither complete nor exclusive, but somehow represents the state of the art in testbed development.

- Automated physical testbed (APTB) was developed in the institute of Reliable Embedded Systems and Communication Electronics [2]. It supports wireless signal transmission, propagation, reception, and accurate measurements. In order to achieve this it
encapsulates wireless devices into shielded boxes and connects the antenna outputs to RF-waveguides. The waveguides are interconnected in a way that provides a controllable topology reconfiguration. Thus, AFTB enables both realistic and repeatable wireless experimentation.

• The Open Access Research Testbed for Next-Generation Wireless Networks (ORBIT) aims to provide a flexible and modular facility to support research for next-generation wireless networks [3]. Due to its open APIs, components and packages may be developed easily by the community.

• In [4] H. A. Andrade and et al. proposed a new approach for a reconﬁgurable testbed for time-sensitive cyber-physical systems. Therefore, in this testbed, time should be used as correctness metric rather than performance metric.

• The project “Seamless Aeronautical networking through integration of Data-Links, Radios, and Antennas” (SANDRA) deﬁned and validated a new reference aeronautical communication architecture. The development of a testbed was a central aspect of the project [5]. This testbed focuses on a joint resource management of integrated routers and integrated modular radio as well as on a network mobility, and security [6].

• In Fort Bragg, North Carolina a team of researchers has developed a testbed to explore and evolve distributed command, control, and communications (C3) concepts by means of emerging information and telecommunications technologies [7]. It supports evaluation of adaptive packet-switched communications, disturbed databases, and computer operating systems targeted at the 21st century U.S. military communications architecture.

• Guo et al. in [8] presented an experimental ultra-wideband (UWB) real-time testbed, which was developed to explore advanced radio technologies, ranging, and physical layer security. The basic design consists of transmitter and a receiver at each side, that can be expanded easily to multi transmitter or receiver designs.

• A software radio testbed for orthogonal frequency-division multiplexing (OFDM) WLAN was developed at Georgia Institute of Technology [9]. For high ﬂexibility, it’s mainly software based and supports ﬁeld programmable gate array (FPGA) integration.

• To enhance quality of education on industrial networks a team from University of Catania, Italy, built a testbed for experiencing with industrial communication networks [10]. Students may experience both wired and wireless networks by means of a single setup. Usage of the testbed is encouraged due to its remote nature, which provides students the possibility to use it from their PCs at home.

• Replacing cables with wireless nodes has been proposed to reduce wiring effort and costs. The UWB is reasonable candidate for the wireless in-car communication. To test and evaluate UWB wireless nodes in in-car communication an Intra-Vehicle Ultra-Wideband communication testbed has been developed [11].

• AutoPlug [12] is a testbed developed to diagnose, test and update automotive Electronic Controller Units (ECU). To explore the feasibility for remote code updates. Therefore it is assembled of several different ECUs that are connected via the industry standard controller area network (CAN) bus [13].

III. THE WIRED M-BUS

Introduced in the 80’s, the Meter-Bus or M-Bus is a well-established ﬁeld bus connecting various types of metering devices [14]. It allows service companies to connect to several types of meters e.g. gas, electricity, heat and water meters, in apartments and commercial buildings whereas the M-Bus protocol supports simultaneous connection for hundreds of devices. The major technical standard for application in Europe is EN 13757 [15]. However, this standard has some ambiguities, which directly relate to deployment problems with M-Bus networks. To address the latter and to have a common basis for both developing M-Bus devices and setting up M-Bus networks, several companies founded the work group 4 (WG4) in the Open Metering Systems (OMS) group [16]. These institutions aim to deﬁne a new revision of the basic standard. One of the goals WG4 is to deﬁne solid rules, giving the designers of M-Bus networks strong and reliable guidelines [17].

A. The M-Bus in the ISO-OSI Reference Model

M-Bus follows the basic concept of the ISO-OSI Reference Model. It covers layers one, two and seven, since it supports star topologies, only [18]. An additional cross-connected Management Layer allows the administration of the lower layer from the higher layers, which normally is not allowed in ISO-OSI Reference Model (cf. Fig. 1). However, this approach helps to easily change parameters like baud rate from the application or the application layer.

![Fig. 1. The four layers specified in the M-Bus protocol. The ones shown in light grey are that from ISO-OSI model. Layers with names in gray are not used in the protocol. In dark grey the additional Management Layer is shown.](image-url)
B. Physical Layer and Link Layer

On the physical layer (PHY) the M-Bus master modulates the bus voltage to communicate with slaves and the slaves modulate their current consumption to reply to the master.

The M-Bus operates at a voltage level of $U_\text{mark}$ in idle state and $U_\text{space}$, which is at least 12 V below $U_\text{mark}$ for data transmission. A minimum voltage of 12 V is needed for $U_\text{space}$, to ensure continuous remote powering of all slaves. $U_\text{mark}$ can be at a voltage level between 21 V and 42 V. A logical one is represented by $U_\text{mark}$ and a logical zero is represented by $U_\text{space}$. The voltage step between $U_\text{mark}$ and $U_\text{space}$ is chosen to have an adequate signal-to-noise ratio in master to slave transmission [15].

The M-Bus specification defines the unit load ($N\cdot U_\text{mark}$) as the maximum mark state current of 1.5 mA. An M-Bus slave is a constant current sink, with an idle current of $N\cdot U_\text{mark}$, with $N$ as an integer value of the range one to four. That current powers the transceiver IC in the slave and optionally the slave itself. To be independent on wiring resistances and immune against induced voltages signals slave transmit signals to master via constant current.

![Bus Voltage at Repeater](image)

Fig. 2. The basic operation of the M-Bus physical layer. The upper graph shows the bus voltage at repeater and the bottom side graphs shows the current consumption of a slave. The master modulates the bus voltage to communicate with a slave. This doesn’t affect the current consumption on the bus. However, if a slave modulates its current consumption to transmit to the master, the bus voltage swings.

Moreover, slaves are polarity-independent to reduce installation errors. Protective resistors at the input of each slave transceiver prevent overvoltages. In addition, precautions limit the current of a defect slave to 100 mA.

Of course, the current modulation of the slave has an influence on the bus voltage $U_\text{mark}$. That results in a small voltage drop, which can be seen in Fig. 2. The latter depends on the resistance of a transmission line and the internal resistance of a master. Since the internal resistance of the master is not specified in the standard the drop can’t be predicted. Typical resistance values are in the range of 1 $\Omega$ to 68 $\Omega$. Thus, voltage drop is typically between 7 mV and 1.1 V measured peak-to-peak.

At the link layer (DLL) a minimum baud rate of 300 Baud is required. The basic standard defines the optional support of baud rates up to 38400 Baud. However, baud rates above 9600 Baud are neither recommended, nor widely used due to the characteristics of the physical layer [19].

IV. THE NETWORK EMULATION TESTBED FOR THE M-BUS

A network emulator gives the possibility to dynamically vary the parameters of a network without having real physical channels. This allows to change physical topologies without manual interaction. Fig. 3 depicts that from a user perspective. The emulator operates as a black box with several devices connected to it. It mainly concentrates on the provisioning of bus oriented topologies, as they are the only relevant setups for M-Bus in practice.

Therefore, the M-Bus network emulation testbed supports testing of various different M-Bus topologies, including the cases shown in reference [20]. These cases describe six examples of how an M-Bus topology can look like in real-world scenarios. Recommendations about wire lengths, wire diameter, and number of bus devices depending on bus speed are given, for small domestic installations (Type A) as well as for widespread installations for whole apartment blocks (Type D).

The design of the M-Bus testbed follows a modular structure to combine extensibility and flexibility. The M-Bus testbed consist of two parts, the main and the peripheral boards. Both boards are built on 19” PCB and fit into 19” racks [21]. One main board and up to 32 peripheral boards can be connected by a single backplane. The main board controls the testbed. It receives the commands from the user and sends them to the peripheral boards. On each peripheral board, 146 relays are mounted to emulate the different topologies and transmission line lengths. These relays are controlled by 13 STM32F0x0 microcontrollers. In the following the important concepts and parts are described in depth.

A. The Testbed Main Board

The main board is the hub to the M-Bus master devices as well as to the user inputs. The central part is a Raspberry Pi B2 with Raspbian Operating System (OS), as these components are powerful, easily extensible and well-known. Thus, a developer may adapt new features with minimum efforts.

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A Structured Query Language (SQL) database is implemented on Raspberry Pi using the SQLite library. SQLite is well established and, especially targeted at Internet of Things (IoT) devices, and provides interfaces for a rich set of different programming languages. Therefore, users are able to access the database with self-written software modules. The database holds all information about the emulator and allows users to change, the testbed configuration by modifying database table entries. The latter is done directly by means of the phpscript phpLiteAdmin, controlled by a preinstalled Apache HTTP Server, or by a GUI. The advanced GUI based solution, which controls the script, enhances usability and lowers skill requirements for the user.

A daemon process running on the Raspberry Pi polls changes in the database and alters the configuration of the testbed. Therefore, the General Purpose Input Output (GPIO)-pins of the main board transmits signals via I²C interface to microcontrollers located on peripheral boards. To access GPIO-pins and interfaces on the Raspberry Pi, the bcm2835 library is used.

### B. The Peripheral Board and Backplane

The peripheral board is the most complex part of the testbed. It comprises two blocks: one routes the signals from the backplane and another emulates the actual transmission line, to which the M-Bus slaves also are connected. Each peripheral board allows the connection of up to eight M-Bus slaves, grouped into two units called clusters.

The backplane provides means to connect the main board to several peripheral boards.

### C. Transmission Line Emulation

The transmission line emulation has two inputs from the signal selection part and two outputs to the backplane. A maximum of eight M-Bus slaves may connect to the transmission line.

In this subsection an abstract model to ease the understanding of the emulator is described. Its major parts are segments, the Junction Point (JP), and the Device Port (DP). A segment is an abstraction for a piece of wire. However, we specify four different types of a segment. Neutral segments are shown by a dashed line. They have negligible resistance and capacity like a PCB track. Table I includes all possible segment types. They represent combinations of self-constructed digital resistors and digital capacitors.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Segment Type</th>
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<tbody>
<tr>
<td></td>
<td>Neutral Segment (NS)</td>
</tr>
<tr>
<td></td>
<td>Short Route Segment (SRS)</td>
</tr>
<tr>
<td></td>
<td>Long Route Segment (LRS)</td>
</tr>
<tr>
<td></td>
<td>Device Segment (DS)</td>
</tr>
</tbody>
</table>

JP s are kind of complex wiring. In drawings, JPs with no switchable functionality, being hard-wired in the physical testbed, are surrounded with a circle.

CPs are used to mark a connection between a segment and a JP. It should be noted that CPs do not have a physical representation and therefore are used for illustrative purpose only. To mark points to connect an M-Bus slave the DP is introduced.

![Fig. 4. The M-Bus emulators’ transmission line in abstract notation. All possible topologies may be derived by removing unnecessary parts. To switch between Point Mode and Split Mode the NS between the two central JPs have to be activated and the right LRS isn’t connected in point mode. The four NS connected to the output JP represent the special functions. Both short NS in the middle are representing the Pass Middle Point special function. The NS connecting the JPs at both ends is used for Loop-back Mode and the NS connecting cluster ends with the output JP are used with no special function active.](image_url)

Fig. 4 shows the structure of the transmission line in abstract notation. Removal of unnecessary parts provides a possibility to form paths and by this control a final topology.

### D. Topology Modes and Special Functions

In order to make the emulator more flexible, two topology modes and three special functions are available.

The emulator may operate in a so called split or point topology mode. In split topology, both clusters of a peripheral board are totally independent. Each cluster has its own entry and exit point to connect with other clusters. On the entry point the input bus signal may be applied and on the exit point the output bus signal may be tapped. In point mode the clusters are sharing a common entry point and thus both clusters are connected. There are,
however, two exit points like in split mode. In this mode the second LRS is out of operation and can’t be used to emulate a longer transmission line.

By-pass mode (cf. Fig. 5) may be used to by-pass a signal directly from one card to another, without affecting the original signal. This might be useful to simulate structures with remote M-Bus slaves being far away from each other, e.g. being in different buildings.

To create tree topologies, the Pass Middle Point special function can be used. In that mode the signal is passed directly to the entry point of one central exit point. Pass Middle Point may be used in point mode exclusively.

To create a longer transmission a line loop-back mode may be used. The loop-back connects the two cluster exit points together. Loop-back mode is restricted to split mode only, to prevent a short circuit. One entry point operates as entry and the other as exit point.

E. Signal Selection

To be capable of emulating all required topologies the backplane provides five different inputs to a testbed backplane. These inputs are transmitted to two different sides called A and B. Namely the signals are,

- Masterline
- By-passed Signal A
- By-passed Signal B
- Signal A
- Signal B

Masterline is the signal transmitted from the main board. Thus, the original masterline signal is available one each peripheral board. By-passed signal A and B are the signals from the previous card by-passed over the transmission line emulation path and thus not modified. Signal A and B are the signal from previous card at the regular transmission line output. Signal selection process is best described with a multiplexer per side which has five inputs and a single output, (cf. Fig. 6). The single output one each multiplexer is split into two outputs, so that in total four outputs are provided by signal selection: the two input signals for the transmission line and the two by-passed signals for the next card.

F. Adjustable Resistor and Capacitor

Adjustable Resistors, so called R-Cells, are used to emulate the wires’ electrical resistance. To ensure both adjustability and precise resistance values, R-Cells are designed using a common resistor that is by-passed or not by a switch (cf. Fig. 7). The state of the R-Cell is changed by means of relays.

The adjustable capacitors in the emulator are called C-Cells. Much like the R-Cells, the adjustability is achieved by means of a switch, which is operated by a relay. However, the C-Cell is more complex (cf. Fig. 8). An additional resistor $R_{unload}$ is needed to ensure safe discharge of the capacitor.

G. Segments

To emulate transmission lines of different lengths, elements with adjustable resistance and capacity value are needed. Furthermore, these elements should not have any additional influence on the line.

![Fig. 6. Schematic of the peripheral board signal selection.](image)

![Fig. 7. The R-Cell schematic in the M-Bus emulator. The switch may be used to by-pass the resistance.](image)

![Fig. 8. The M-Bus emulator C-Cell. The capacity C may be switched between ground and high voltage level or ground to ground. The resistance $R_{unload}$ guarantees slow unload of a loaded capacity.](image)
The transmission line elements are called segments, see Table I. A segment compromises an adjustable resistor, an adjustable capacitor, and a by-pass (cf. Fig. 5).

Short Route Segments (SRSs) are capable to emulate resistance from 0 Ω to 15.04 Ω gradually. The capacity ranges from 0 F to 30.170 nF.

Long Route Segments (LRSs) are capable to emulate resistance from 0 Ω to 31.120Ω gradually. The capacity ranges from 0 F to 131.170 nF.

Each Route Segment can be bypassed to minimize its influence in deactivated state.

Device Segments (DSs) connect either with an optional route segment or with a bus device to the emulator. Basically, DSs are modeled similar to short route segments, having a connection to a jack on one side and to the emulator on the other. Because the DS has only one capacity and one resistance level, it is possible to switch it on or off, only.

H. Relays

Tune-in different resistance and capacity values is reached by means of relays [22]. On the emulator we choose low latching relays storing their state to be energy efficient [22]. The used type is NEC/TOKINs’ EE2-3TNUX [23] series using Double Pole Double Throw (DPDT) technology to reduce internal resistance as much as possible. Initial contact resistance is less than 75 mΩ. During Operation a single relay needs about 140 mW of electrical power. In total 146 relays are mounted on a peripheral board (cf. Fig. 9). Thus, four peripheral boards can be connected in parallel.

I. Emulated Wires

In this state M-Bus testbed is capable to emulate wires of the type NYM-3x1.5mm²[24] and J-Y(ST)Y2x2x0.8mm² [25]. Other types and lengths may be possible as well, but have to be checked in particular case. According to manufacturer, cables of type NYM-3x1.5mm² have 12.1 Ohm/km resistance and 105 nF/km capacity [26]. As a result the segments could emulate the following lengths in steps of ten meters each:
- SRS 0 m to 300 m
- LRS 0 m to 300 m
- DS 0 m to 10 m

V. Results

The emulated transmission line has a series of uncertainties that can’t be numbered. The elements used like relays and the PCB are having their own parasitic resistance and capacity. This leads to some offset. Furthermore the resistors and capacitors used have some deviation caused by manufacturing. Thus, it has to be proved on a real testbed that the values differ in an acceptable range.

Therefore, the following tests have been conducted. Testbed has been operated in split mode with no special function active. At start all segments are turned to 0 Ω and 0 F. All measurements have been performed both over main board and peripheral board and over the peripheral board only. Resistance and capacity have been measured with the multimeter and the time constant τ [27] with the oscilloscope. The oscilloscope features an additional signal generator, which was used to generate a step signal with a frequency of 800 Hz and a voltage step of 3 V. After the measurement a SRS has been turned to maximum resistance and capacity and the measurement has been repeated. Finally, also the LRS are turned to maximum value.

The more resistors and capacitors are used deviation increases slightly, see Table II. However, maximum deviation of τ is in the orders of microseconds, which is acceptable for the given use case.

VI. Conclusion and Outlook

This paper presents a novel testbed for the test and the evaluation of wired M-Bus networks and devices, which was developed at the authors’ institute. One of the development objectives was flexibility; thus the testbed is capable to flexibly cover the most important topologies used in today’s M-Bus installations without any adaptation of the underlying hardware setup. First measurement results confirm the correct operation of the emulator and its control interface. The deviations of resistance and capacity values are in an acceptable range for M-Bus applications compared to installations using real wires.
The next steps of the project will cover the development of a web based user interface and extended tests with real devices under real network scenarios.

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**Oliver Kehret**, holds a M. Sc. Degree from Offenburg University of Applied Sciences. He is currently with the Institute of Reliable Embedded Systems and Communications Electronics (iVESK), University of Applied Sciences Offenburg, Germany. His research interest includes network communication, and network security for resource constrained devices.
Manuel Schappacher, studied Computer Engineering at the University of Applied Sciences Furtwangen and received his Dipl.-Inform. Degree in April 2009. After that, he continued to work as project engineer at Steinbeis Innovation Center Embedded Design and Networking (sizedn) mainly in the field of embedded wireless and wired communication, including simulation of networking protocols. Since 2014 works with the Institute of Reliable Embedded Systems and Communications Electronics (ivESK) at University of Applied Sciences Offenburg.

Axel Sikora, holds a diploma of Electrical Engineering and a diploma of Business Administration, both from Aachen Technical University. He has done a Ph.D. in Electrical Engineering at the Fraunhofer Institute of Microelectronics Circuits and Systems, Duisburg, with a thesis on SOI-Technologies. After positions in the telecommunications and semiconductor industry, he became a professor at the Baden-Wuerttemberg Cooperative State University Loerrach in 1999. In 2011, he joined Offenburg University of Applied Sciences, where he leads the Institute for Reliable Embedded Systems and Communications Electronics (ivESK). Since 2016, he is also deputy member of the board at Hahn-Schickard Association of Applied Research. His major interest is in the field of efficient, energy-aware, safe and secure algorithms and protocols for wired and wireless embedded communication. In 2002 he founded the Steinbeis Transfer Center Embedded Design and Networking for professional protocol and platform developments, which was successfully spun off as STACKFORCE GmbH in 2014. Dr. Sikora is author, co-author, editor and co-editor of several textbooks and numerous papers in the field of embedded design and wireless and wired networking, and head and member of manifold steering and program committees of international scientific conferences, including ICSGCE.