Wireless M-BUS: An Attractive M2M Technology for 5G-Grade Home Automation

Pavel Masek[1], Krystof Zeman[1], Zenon Kuder[1], Jiri Hosek[1](✉),
Sergey Andreev[2], Radek Fujdiak[1], and Franz Kropfl[3]

[1] Brno University of Technology, Technicka 3082/12, 61600 Brno, Czech Republic
`xmasek12@phd.feec.vutbr.cz`, `hosek@feec.vutbr.cz`
[2] Tampere University of Technology, 33720 Tampere, Finland
`sergey.andreev@tut.fi`
[3] Telekom Austria Group, Lassallestraße 9, 1020 Wien, Austria
`franz.kroepfl@telekomaustria.com`

Abstract. The aggressive introduction of new smart devices for households is considered today as one of the most challenging issues in the Internet of Things (IoT) world. According to the wide variety of radio technologies used for communication between smart devices, there is a growing need to answer the question of which communication standard can be used to drive communication in smart homes and intelligent buildings as part of the emerging 5G ecosystem. To this end, we provide in this paper a performance analysis of Wireless M-BUS communication protocol which has recently increased its popularity especially in smart-metering domain in Western Europe. First, the developed WM-BUS module in Network Simulator 3 (NS-3) is described. Further, we investigate in detail the obtained simulation results which are compared with the real data from Kamstrup smart metering devices. Especially, the attention is focused on the packet delivery ratio and interference between smart devices. In particular, we demonstrate that our constructed module provides adequate correlation between the results obtained from the simulation and those from real-world measurements.

Keywords: Home automation · 5G-grade · IoT · NS-3 · Packet delivery estimation · Smart metering · Wireless M-BUS (WM-BUS)

1 Introduction and Motivation

During the last few years, the Internet of Things (IoT) attracted an enormous interest practically from all sectors of industry. According to Cisco forecast, the Machine-to-Machine (M2M) connections will grow from 495 million in 2014 to more than 3 billion in 2019 [1]. Today, we can see the wide variety of smart devices (e.g., smart meters, sensors, actuators) coming on the market in waves and trying to bring intelligent behavior into today's households. The initial idea of smart homes was built on collecting information from small groups of devices (very likely only from one device) and providing this information to the end user.

B. Mandler et al. (Eds.) IoT 360° 2015, Part I, LNICST 169, pp. 144–156, 2016.
DOI: 10.1007/978-3-319-47063-4_13

Today, the smart devices become more intelligent and provide new functions for measuring (e.g., energy consumption and production measured by one device), reporting (sending data to energy provider) and creating statistics for end users. To fully meet the described vision, the communication networks need to be ready for this. Today, the 4G and beyond networks (Long Term Evolution, LTE) increasingly introduce Device-to-Device (D2D) communication capabilities. Nevertheless, the 4G was build with the goal to provide higher capacity, user data rates, improve spectrum usage and latency with respect to previous generations of cellular networks. However, in today's world, the IoT brings new challenges which cannot be solved solely by a single technology, but rather by the harmonized set of communication platforms, protocols and applications which all create the 5G vision [2]. The emerging 5G ecosystem as a bridge between a massive number of energy- and power-constrained smart objects deployed e.g. within a connected home and remote cloud-based applications will act as a key enabler for the IoT domain. Whereas, there is an undivided attention given by industry and academia to the 5G communication technologies, the deployment of home automation scenarios is somewhat lagging behind. Therefore, we target to bridge this gap by investigating of the promising communication candidates for connected home.

In the light of the above, there are currently multiple devices providing similar functionality independently from the communication technologies (IEEE 802.15.1, IEEE 802.15.4 (6LoWPAN, ZigBee), KNX, Wired/Wireless M-BUS) [3]. Therefore the question of aggregation the inputs from smart devices on their way to the remote servers is considered as highly demanded issue together with providing the unified approach for end users to manage data from different types of smart devices [4,5][1]. Currently, the effort to standardize the IoT frameworks, message structures and communication procedures is growing strong world-wide [6,7].

In this paper we propose a scenario where smart devices perform data in a house together, see Fig. 1. The collected values of electricity (orange), water (blue), temperature and humidity (green), motion sensor (violet) are sent towards an aggregation point (purple) where the data is transmitted via the 5G-ready infrastructure to the remote cloud application, see Fig. 1. The wireless communication technologies for smart metering provide high installation flexibility and therefore can be easily retrofitted in today's households.

This leads us to the question on the choice of the suitable communication technology/standard providing the energy efficiency, short message format and support from the industry companies [8]. Following our previous works within this field [12] where we paid our attention especially to the development of universal smart home gateway [4,10,11], we selected the Wireless M-BUS [9] as a promising driver for communication between devices (direct communication (MTCD - MTCD) and communication from smart device to remote server (MTCD - MTCG)).

---

[1] The aggregation point for smart devices based on different communication technologies is often called Machine Type Communication Gateway (MTCG). The smart devices are then described as Machine Type Communication Devices (MTCDs).

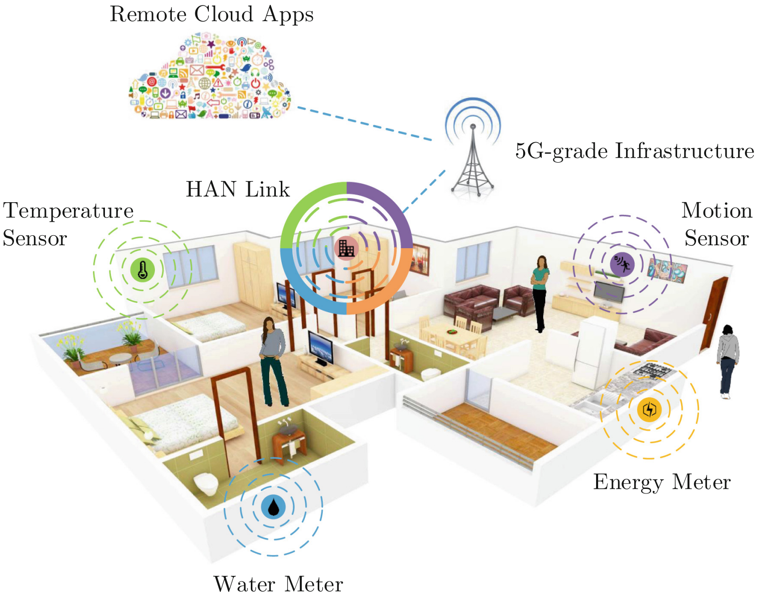


Fig. 1. In-house deployment of smart meters/sensors. (Color figure online)

Addressing the scenario where the key information about the electricity/water consumption is collected by the aggregation node, we provide the possibility for industry to assess behavior of WM-BUS devices and plan their deployment in dense urban areas with respect to the key metrics such as interference between installed devices, energy efficiency (battery life), active/idle time, transmission range and probability of successful data delivery. All these requirements were taken into account during the implementation of Wireless M-BUS into our simulation environment based on Network Simulator 3 (NS-3). We paid specific attention to utilization of the latest version of WM-BUS standard (following the requirements given in EN 13757-4:2005) and therefore our created module is able to deliver results where the data message follows the structure used in today's devices. As a verification of the obtained data from our module, we used the data set provided for us by Kamstrup [13] – one of the leading European companies in the smart grid communication domain.

2 Related Works

Most of the research activities during the recent several years were focused on the architecture and the key features/characteristics of selected wireless technologies considered for home automation and, more specifically, for smart metering [14,15]. We studied in detail published works which address the prominent wireless technologies in smart grids/smart homes with the aim to provide their performance evaluation.

Authors of [16] describe how to evaluate the wireless technologies for smart grid networks. However, recommendations from [16] cannot be used for evaluation in indoor environments due to the fact that authors paid attention to wide area networks in their research; further the effects of multipath propagation are not taken into account by this publication.

In [17], the unified metrics (PHY layer metric and MAC layer metric) of Home Automation Networks (HANs) are given. Especially, authors focused on IEEE 802.15.4, IEEE 802.11 and P1901 communication technologies and their functionality for smart grid applications.

Another solution for smart homes and Energy Management System (EMS) is presented in [18,19]. Authors offer design and implementation instructions for an EMS based on ZigBee, but not covering the performance of the ZigBee network within the indoor environment.

Evaluation of the performance of wireless sensor networks in different electric power system environments is provided in [20]. Authors perform measurements in order to determine the link quality; the measurements consider to an exemplary chipset implementing the 2.4 GHz physical layer of IEEE 802.15.4. Obtained results show degradation of the link quality and the number of successfully transmitted packets.

In addition to previous research work, authors of [21,22] focus on the IEEE 802.15.4 data transmission in different channels. However, presented model is very simple and authors do not provide comparison between performance of different technologies. Regarding the interference within the 2.4 GHz ISM band, authors of [23] provide the performance evaluation of IEEE 802.15.4 under the IEEE 802.11 interference. Obtained results indicate the significant impact on the reliability of a ZigBee network from the side of IEEE 802.11, which is in line with the results published in [24,25]. Based on that, authors propose guidelines on how to deploy the ZigBee network in order to minimize the impact of harmful

Table 1. Comparison of the key parameters of WM-BUS and IEEE 802.15.4. As the main findings, two parameters can be highlighted – in case of WM-BUS, the transmission frequency 868 MHz offers large area coverage and together with using the n/a channel access (data is sent as broadcast; especially in T mode), WM-BUS represents possible candidate for transmitting measurement data from sensors/meters.

Standard	Data rate	Transmission frequency	Effective bandwidth	Transmission power	Channel access
Bluetooth LE	1024 kb/s	2,4 GHz	1 MHz	10 mW	n/a
IEEE 802.15.4 (Worldwide)	250 kb/s	2,4 GHz	2 MHz	20 mW	CSMA/CA
IEEE 802.15.4 (Europe)	20 kb/s	868 MHz	600 kHz	25 mW	CSMA/CA
WM-BUS S mode	16,384 kb/s	868 MHz	200 kHz	25 mW	LBT/n/a
WM-BUS T mode	66,67 kb/s	868 MHz	300 kHz	25 mW	n/a

interference. Additionally, authors performed simulations in order to analyze the impact of PHY parameters (simulations were restricted to AWGN channel only).

In the light of the above, we recognized that almost all relevant publications focus on the IEEE 802.15.4 (ZigBee, 6LoWPAN) radio technology. However, following the information in [4,11], we identified Wireless M-BUS as a preferred communication protocol used widely in today's smart meters and sensors, see Table 1 for comparison between WM-BUS and IEEE 802.15.4. Owning to the tight cooperation with the Kamstrup [13] we had a clear idea on the issues with deploying new smart devices in dense populated areas faced by industry companies. Therefore we believe that our work brings valuable insights on how to evaluate communication between unattended devices based on the Wireless M-BUS and helps to resolve possible issues during deployment of smart devices in real use cases.

3 WM-BUS Module in NS-3

In this work, we describe the extended WM-BUS module for simulation environment NS-3. In the first version of our module for NS-3, described in [26], we only paid our attention to implementation of the core/main principles of WM-BUS communication.

Following the fact that our first implementation did not cover the frame structures of WM-BUS data, we extended our cooperation with the industry companies offering metering devices with the aim to come up with the improved implementation suitable for comprehensive testing of real data frame exchange between WM-BUS devices in practical environment. Therefore in this section the most important features and functions, beyond the scope of the first implemented version, will be described together with the developed frame dropping algorithm.

3.1 WM-BUS Protocol and Network

The general idea of created module is to provide the tool for evaluation of WM-BUS communication between metering devices. To be able to cover all scenarios where WM-BUS can be deployed, we implemented all supported operation modes of WM-BUS communication protocols; the description of network structure is given in what follows.

The topology of Wireless M-BUS [9] network can differ depending on the level of automation required for the application. Today, in static configuration, a network can consist of three types of nodes: meters (transmission mode T or S), repeaters (mode R) and concentrators (mode C). Meters periodically send broadcast messages containing the current information about the measured values. These signals are received by the concentrator(s) where the data can be processed. Then, repeaters are used in situations where the signals from the meters are not successfully received on the side of concentrator. They can be configured to re-broadcast received signals from meters and thus extend the effective range of the concentrators with respect to those meters.

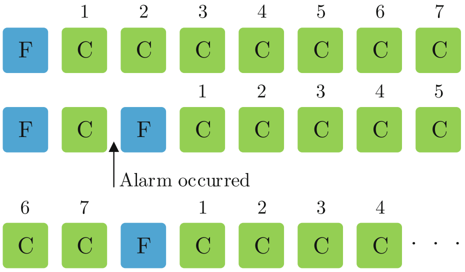
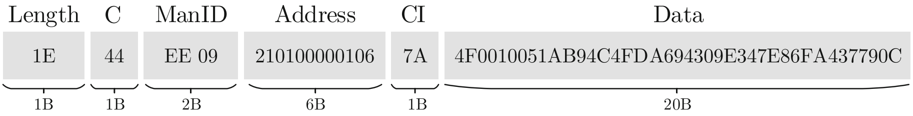


Fig. 2. Diagram of full (F)/compact (C) frame sequence with the alarm event.



Length	C	ManID	Address	CI	Data
1E	44	EE 09	210100000106	7A	4F0010051AB94C4FDA694309E347E86FA437790C
1B	1B	2B	6B	1B	20B

Fig. 3. Implemented WM-BUS frame structure for water meter.

To decrease the amount of redundant data sent after the connection between meters and concentrator(s) is established, real meters (e.g. Kamstrup Multical 21, Multical 402 and Multical 602) [27] implement two types of frames: full and compact. Data in the compact frames cannot be decoded in case that the full frame has not been previously received from a meter. Under normal conditions, a meter sends full frame followed by 7 compact frames and the cycle is repeated. Otherwise, in case that alarm occurs at the meter, the cycle is restarted immediately and a full frame is sent followed by 7 compact frames, see Fig. 2.

Frame Structure was implemented following our cooperation with the Czech and Austrian telecom and smart metering companies offering their temperature/water/electricity meters. Therefore we are able to simulate data traffic with the real frame structures (with and without the AES 128 encryption). The example of implemented frame structure (31B) for water meter is shown in Fig. 3.

All described features, defined in [9], were taken into account and implemented, see Sect. 3.2.

3.2 Implementation

The implementation of Wireless M-BUS communication protocol is based on simple Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) protocol for NS-3 introduced in [28]. This module (initially provided for NS-3.13) was modified in order to adhere to the requirements for WM-BUS given in [9]; the channel access method Listen-Before-Talk (LBT) is used in special cases in mode S. In most cases data is send via broadcast (mode T and S). A summary of constructed classes used in our module is depicted in Fig. 4; we introduce here

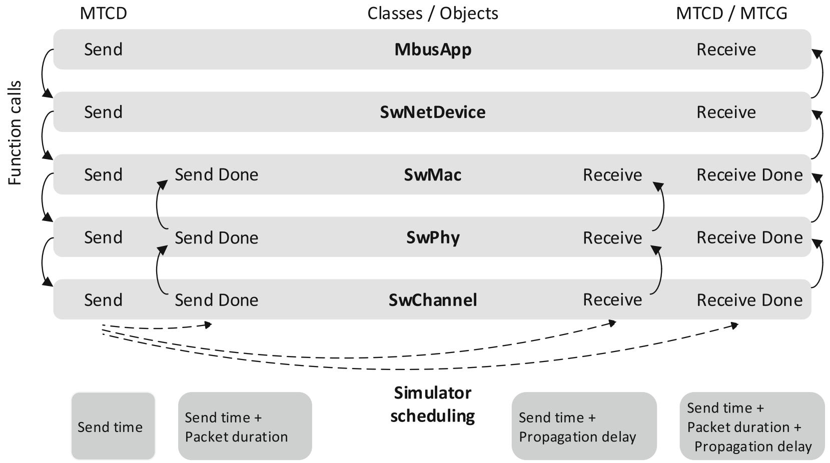


Fig. 4. Created classes for WM-BUS module.

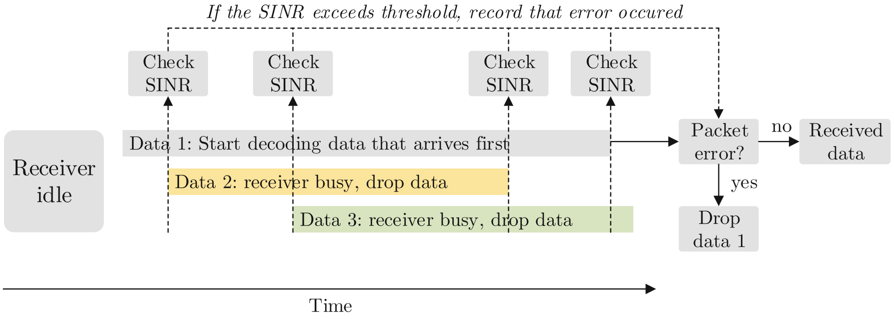


Fig. 5. Implemented frame dropping algorithm.

the completely new internal logic for communication inside the module allowing to implement all features given in [9][2].

When a frame is acquired during the simulation, its received signal strength is compared with the sensitivity of the receiver/concentrator. If this value is above the set threshold[3], the frame is recorded and the state of the receiver is set to busy. Whenever any other message arrives, the Signal-to-Interference-plus-Noise Ratio (SINR) is calculated at the beginning and at the end of the reception; to check if the SINR of the frame being decoded remained higher than the required value. In case the SINR becomes too low at any point, an internal variable is set to indicate a packet error. The state of the variable is read after the reception of the desired packet and the packet is dropped in case there was an error; this behavior is illustrated in Fig. 5.

---

[2] Description of proposed module structure is given in our previous work [26].

[3] For the purpose of our work, the threshold was set to −100 dBm.

The SINR is calculated in Eq. 1 as a ratio of the received desired signal power $P_{rx,desired}$ and the sum of all other signals $P_{rx,other}$ at the given receiver/concentrator and configurable noise floor, in linear values.

$$SINR_{db} = 10\log_{10}\left(\frac{P_{rx,desired}}{N + \sum P_{rx,other}}\right). \tag{1}$$

4 Performance Evaluation of Characteristic Scenarios

To increase the importance of the considered simulation scenarios and also to assess their performance, a set of measured data from real smart meters deployed by Kamstrup [13] was used[4]. In this section we paid our attention to two simulation scenarios. First, the results for the average number of delivered packets between concentrator-meter is given; this scenario contains the generic data structure and only the length defined in [9] is accounted for. Second, the probability of successfully received data frames has been recorded where the real data structure for water, electricity, humidity and temperature meters/sensors is considered.

The purpose of dividing the results into two sections follows from the need to have successfully calibrated module which can be used further for industry-grade simulation.

4.1 Model Calibration

All performed simulations were completed with the aim of the proper calibration of our created module in NS-3 in relation to the real-world measurements. The created scenario, potentially interesting for industry, is discussed later in this Sect. 4.2.

We performed two sets of simulation experiments as shown in Fig. 6. In the first experiment, the measured signal levels were used as the input data for simulation. In the second experiment, the signal levels were estimated by a log-distance propagation model [29] in 2 which was configured to match with common indoor environment in residential buildings:

$$PL(d) = PL\left(d_0 + 10n\log(\frac{d}{d_0})\right) + X_\sigma. \tag{2}$$

The $PL(d)$ represents the path loss at the distance d, $PL(d_0) = 31.22\,\text{dB}$ and represents the theoretical free-space path loss at the reference distance $d_0 = 1\,\text{m}$. Path loss exponent is taken as $n = 2.97$ [29]. Further, σ [dB] is a zero mean Gaussian random variable which represents the local shadowing that is assumed to be log-normally distributed; the standard deviation is set as $\sigma = 3\,\text{dB}$ and was added to the measured values in the first experiment to model random fluctuations of the signal strength.

---

[4] The tool for downloading the real data from meters was developed in parallel with this research work; the geographical positions of meters, repeaters and concentrators, as well as signal levels and packet delivery (data hit) rates for each pair (concentrator-meter) were obtained and processed.

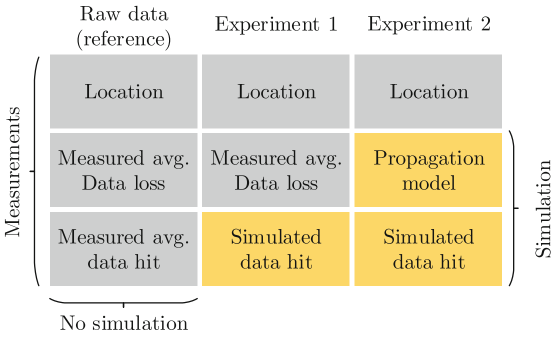
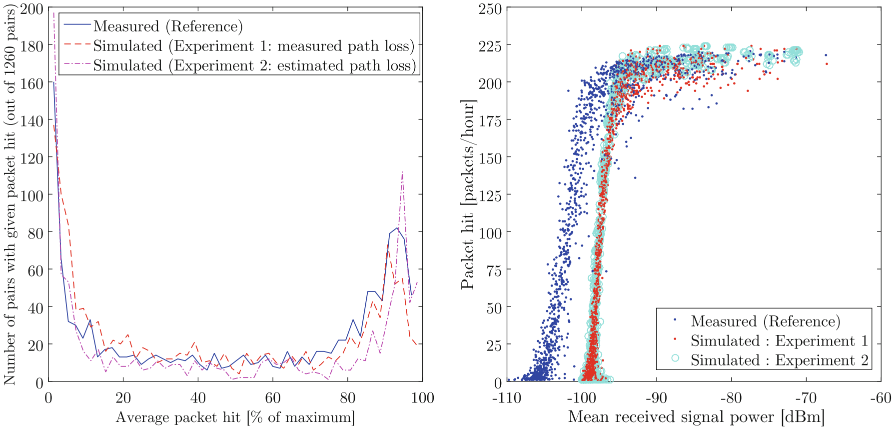


Fig. 6. Overview of the performed simulations in first scenario.



(a) Number of concentrator-meter pairs being in a given hit rate range.

(b) Data hit vs. path loss from all measurements.

Fig. 7. Model calibration.

The measured values of data hit (packet delivery rates for each pair (meter-concentrator)) were used as a reference (test data set) for the simulated values in both experiments. Figure 7(a) illustrates the number of concentrator-meter pairs which reached a given packet delivery ratio.

Figure 7(b) represents the dependence between the average number of data hits and the average received signal strength. Each point in the graph corresponds to one concentrator-meter pair. Further, the dispersion of measured data can be observed; based on these results the created module provides excellent correlation in range -100 dBm to -70 dBm. On the other hand, the discrepancy at the lower values can be seen. This behavior is caused by the frame dropping algorithm; the logic will be modified in our future works to better recognize the signals in range -100 dBm to -110 dBm.

4.2 Calibrated Simulation Scenario

Based on the results obtained in Sect. 4.1, we created an optimized scenario in Network Simulator 3 (NS-3) [30], where dozens of different smart devices (water meters, electricity meters, temperature sensors) communicate with the concentrator. Devices are distinguished by using different formats of WM-BUS message (length and structure) which was implemented exactly as in real devices, see Sect. 3.2.

Owning to good correlation of the constructed module, see Sect. 4.1, the presented simulation results provide an appropriate first-order picture for deployment of smart devices in real environment. In Fig. 8, the probability of successful reception (on the side of concentrator device) of data sent by meters is shown (blue line).

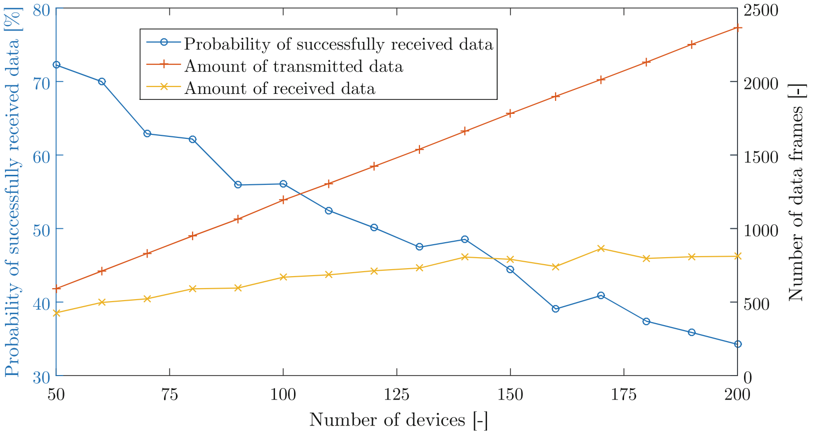


Fig. 8. Probability of successfully received data on the side of concentrator. Following the fact that nature of data transmission is based on broadcast, it could be expected that the collision rate will increase with the higher number of metering devices. (Color figure online)

The number of metering devices was gradually increasing during the simulation from 50 to 200 nodes with the step of 10 devices. All nodes were deployed within the area of 100×100 m following random distribution pattern with the minimal inter-distance 1.5 m (internal Kamstrup logic). Devices were sending measured data periodically; in practice, the transmission interval is defined by each vendor independently, but for our research we set transmission intervals as follows: water (30 s), electricity (60 s), temperature (300 s); all intervals were set exactly as in real scenarios for employed devices.

5 Summary and Conclusions

In this work, we analyzed the emerging concept of smart devices providing the information on utility consumption and production in urban locations with particular focus on indoor environment. Our constructed simulation module developed in NS-3 tool is open source and available for download on GitHub [31]. We believe that it might be considered as a powerful tool to estimate the ratio of successfully received data in case of using Wireless M-BUS communication protocol between meters and concentrator(s) which can serve as an initial evaluation (e.g. number of repeaters; devices in mode R) of planned deployments of metering devices.

To achieve this functionality, the calibration data provided by the Kamstrup company served as a test data set. As a consequence, the proposed module is able to predict the general trend of hit rate (successfully received data from meter on the concentrator side) in the real deployment. After the calibration of the created module has been completed, we also constructed optimized scenario which gives answer to the question on the probability of successfully received data from meters at the side of central point (concentrator). This scenario is very popular today e.g., in households and neighborhoods and therefore we believe that our proposed solution can serve as a valuable simulation tool for planning the real deployment of smart meters/sensors within the maturing 5G ecosystem.

Acknowledgment. Research described in this paper was financed by the National Sustainability Program under grant LO1401. For the research, infrastructure of the SIX Center was used.

We would like to thank to Kamstrup [13] for access to measured data and insight into the protocol and its real-life usage.

References

1. Cisco Visual Networking Index, Global mobile data traffic forecast update, 2014–2019, White Paper, February 2015
2. Condoluci, M., Dohler, M., Araniti, G., Molinaro, A., Zheng, K.: Toward 5G densenets: architectural advances for effective machine-type communications over femtocells. IEEE Commun. Mag. **53**(1), 134–141 (2015). doi:10.1109/MCOM.2015.7010526
3. Niyato, D., Xiao, L., Wang, P.: Machine-to-machine communications for home energy management system in smart grid. IEEE Commun. Mag. **49**(4), 53–59 (2011)
4. Masek, P., Hosek, J., Kovac, D., Kropfl, F.: M2M gateway: the centerpiece of future home. In: 2014 6th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT). St. Petersburg, Russia, pp. 286–293 (2014). ISBN: 978-1-4799-5290-8
5. Di Fazio, A.R., Erseghe, T., Ghiani, E., Murroni, M., Siano, P., Silvestro, F.: Integration of renewable energy sources, energy storage systems, and electrical vehicles with smart power distribution networks. J. Ambient Intell. Hum. Comput. **4**(6), 663–671 (2013)
6. AllSeen Alliance. https://allseenalliance.org/
7. Home Gateway initiative (HGi). http://www.homegatewayinitiative.org/
8. Home Gateway initiative (HGi), Requirements for wireless home area networks(WHANS) supporting smart home services. http://bit.ly/1JlAFIC

9. EN 13757-4:2005: Communication systems for meters and remote reading of meters- Part 4: Wireless meter readout (Radio meter reading for operation in the 868 MHz to 870 MHz SRD band)
10. Hosek, J., Masek, P., Ries, M., Kovac, D., Bartl, M., Kropfl, F.: Use case study on embedded systems serving as smart home gateways. In: Recent Advances in Circuits, Systems, Automatic Control. Budapest: EUROPMENT, pp. 310–315 (2013). ISBN: 978-960-474-349-0
11. Hosek, J., Masek, P., Kovac, D., Ries, M., Kropfl, F.: Universal smart energy communication platform. In: 2014 International Conference on Intelligent Green Building, Smart Grid (IGBSG), pp. 1–4. IEEE, Taipei (2014). ISBN: 9781467361217
12. Austria Telekom Group. http://www.telekomaustria.com/
13. Kamstrup. https://www.kamstrup.com/en-uk/
14. Gomez, C., Paradells, J.: Wireless home automation networks: a survey of architectures and technologies. IEEE Commun. Mag. **48**(6), 92–101 (2010). IEEE
15. Ferrari, G., Medagliani, P., Di Piazza, S., Martalo, M.: Wireless sensor networks: performance analysis in indoor scenarios. EURASIP J. Wirel. Commun. Netw. **2007**, 41–55 (2007)
16. Souryal, M., Gentile, C., Griffith, D., Cypher, D., Golmie, N.: A methodology to evaluate wireless technologies for the smart grid. In: Proceedings of the 1st IEEE International Conference on Smart Grid Communications (SmartGridComm), October 2010
17. Godfrey, T., Rodine, C.: Unified metrics for management of smart grid home area networks. In: Proceedings of the IEEE International Conference on Communications (ICC), May 2010
18. Han, D.-M., Lim, J.-H.: Design and implementation of smart home energy management systems based on ZigBee. IEEE Trans. Consum. Electron. **56**(3), 1417–1425 (2010)
19. Gill, K., Yang, S.-H., Yao, F., Lu, X.: A ZigBee-based home automation system. IEEE Trans. Consum. Electron. **55**(2), 422–430 (2009)
20. Gungor, V.C., Lu, B., Hancke, G.P.: Opportunities and challenges of wireless sensor networks in smart grid. IEEE Trans. Ind. Electron. **57**(10), 3557–3564 (2010)
21. Fang, S., Berber, S., Swain, A., Rehman, S.U.: A study on DSSS transceivers using OQPSK modulation by IEEE 802.15.4 in AWGN and flat Rayleigh fading channels. In: Proceedings of the TENCON 2010–2010 IEEE Region 10 Conference
22. Fang, S., Berber, S., Swain, A.K.: Energy consumption evaluations of cluster-based sensor nodes with IEEE 802.15.4 transceiver in flat Rayleigh fading channel. In: Proceedings of the Wireless Communications & Signal Process (2009)
23. Yi, P., Iwayemi, A., Zhou, C.: Developing ZigBee deployment guideline under WiFi interference for smart grid applications. IEEE Trans. Smart Grid **2**(1), 110–120 (2011)
24. Shuaib, K., Alsnuaimi, M., Boulmalf, M., Jawhar, I., Sallabi, F., Lakas, A.: Performance evaluation of IEEE 802.15.4: experimental and simulation results. J. Commun. **2**(4), 29–37 (2007)
25. Chowdhury, K.R., Akyildiz, I.F.: Interferer classification, channel selection and transmission adaptation for wireless sensor networks. In: Proceedings of the IEEE International Conference on Communications (ICC), June 2009
26. Kuder, Z., Jacobsen, R.-M.: Feasibility of wireless M-Bus protocol simulation. Elektrorevue **3**(3), 57–63 (2012)
27. Kamstrup, Mulical 21 Data Sheet. http://kamstrup.com/media/16541/file.pdf
28. Junseok, K.: Simple CSMA/CA Protocol for NS-3, 17 Oct 2011. http://www2.engr.arizona.edu/junseok/simple_wireless.html

29. Andersen, J.-B., Rappaport, T.-S., Yoshida, S.: Propagation measurements and models for wireless communications channels. IEEE Commun. Mag. **33**(1), 42–49 (1995)
30. Network Simulator 3: Discrete-event network simulator. http://www.nsnam.org
31. GitHub, Wireless M-BUS module for NS-3. https://github.com/xmasek12/WM-BUS-module-NS-3