

Original article

## Secured wired BPL voice transmission system

Grzegorz Debita<sup>1\*</sup> , Przemysław Falkowski-Gilski<sup>2</sup> , Marcin Habrych<sup>3</sup> ,  
Bogdan Miedziński<sup>3</sup> , Jan Wandzio<sup>4</sup> , Przemysław Jedlikowski<sup>5</sup> 

<sup>1</sup> Faculty of Management,

General Tadeusz Kościuszko Military University of Land Forces, Wrocław, Poland,

e-mail: grzegorz.debita@awl.edu.pl

<sup>2</sup> Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology, Poland,

e-mail: przemyslaw.falkowski@eti.pg.edu.pl

<sup>3</sup> Faculty of Electrical Engineering, Wrocław University of Science and Technology, Poland,

e-mail: marcin.habrych@pwr.edu.pl; bogdan.miedziński@pwr.edu.pl

<sup>4</sup> KGHM Polska Miedź S.A., Lubin, Poland,

e-mail: j.wandzio@kghm.pl

<sup>5</sup> Faculty of Electronics, Wrocław University of Science and Technology, Poland,

e-mail: przemyslaw.jedlikowski@pwr.edu.pl

### INFORMATION

#### Article history:

Submitted: 29 October 2019

Accepted: 18 June 2020

Published: 15 December 2020

### ABSTRACT

Designing a secured voice transmission system is not a trivial task. Wired media, thanks to their reliability and resistance to mechanical damage, seem an ideal solution. The BPL (Broadband over Power Line) cable is resistant to electricity stoppage and partial damage of phase conductors, ensuring continuity of transmission in case of an emergency. It seems an appropriate tool for delivering critical data, mostly clear and understandable voice messages. This paper describes such a system that was designed and evaluated in real-time operating conditions. It involved a two-way transmission of speech samples in American English and Polish. The efficiency of the designed solution was evaluated in the subjective study on a group of 15 people.

### KEYWORDS

BPL (Broadband over Power Line), security, signal processing, voice transmission, wired medium

\* Corresponding author



© 2020 by Author(s). This is an open access article under the Creative Commons Attribution International License (CC BY). <http://creativecommons.org/licenses/by/4.0/>

## Introduction

Communication continuity and its appropriate quality in today's life are of major importance. However, they become key factors in any emergency. It applies, among other things, to mine disasters, when voice contact with injured personnel is required. The situation is similar in the case of black-outs and/or military threats, including the electric energy stoppage.

Therefore, in such cases, the use of PLC (Power Line Communication) technology in medium voltage cable networks, for image and/or voice transmission purposes, seems to be a justified solution. The cable networks in mines are laid underground, as are the urban networks in tunnels. They are robust and resistant to mechanical damage and can be effectively used as a transmission medium under the energy stoppage, even in the case of conductor interruption. To demonstrate the validity and usefulness of this idea, authors carried out a series of tests for a selected fragment of a 6 kV mining cable network, utilizing a specially developed digital transmitter and receiver dedicated to BPL (Broadband over Power Line) modems [1]. The voice quality was evaluated for bidirectional transmission using a selected mode in BPL technology operating in the 2-7 MHz frequency range. The obtained test results confirmed the applicability of BPL technology in the 6 kV mining cable network for effective bidirectional voice transmission.

## 1. Broadband over power line wired medium

PLC is an alternative to other wired technologies for data communication, but the quality of transmission is relatively lower than, for example, fiber optic technology. The main disadvantage is the environment's negative impact on range and transmission quality [2, 3]. Therefore, prior to its implementation, respective power cable parameters, including attenuation, phase constant, characteristic impedance, etc., as well as mode frequency and type of coupling, must be carefully selected and considered [1]. However, the primary advantage of transmitting carrier-modulated signals over power lines is the possibility of reusing the existing infrastructure of power cables (wires), which does not incur any additional costs (neither operator fees). In addition, PLC transmission can be performed successfully under any operating conditions of the electricity grid, even under electricity outage, which is particularly essential during any emergency, e.g., mine disasters or military threats. The transmission channel is then constituted by the armor and/or the shield of the electric cable and the battery power supply of the modems. One must note that in the case of dense urban and underground environments, cable networks are laid directly underground or run in tunnels, which makes them most resistant to mechanical damage. However, it should be noted that the main task of any power grid is to transmit and deliver electricity at the frequency of 50/60 Hz. Therefore, PLC technology (of much higher frequency) should not interfere with this task and should be considered supplementary technology [4, 5].

In Europe, the two following frequency bands are assigned to PLC technologies [5-7]:

- 3-148 kHz for low bitrate PLC (CENELEC narrowband frequency band),
- 2-30 MHz for high bitrate PLC (BPL wideband frequency band),

as shown in Figure 1. Figure 2 displays the frequencies of the CENELEC A band with selected communication protocols.

High-bitrate PLC of 1-30 MHz consists of two sub-bands: 1-20 MHz (for domestic usage; internal PLC) and 2-30 MHz (for MV electrical network public usage; external PLC). The frequencies within the 1-30 MHz range are used e.g. for digital short-wave radio, called DRM (Digital Radio Mondiale) [5].



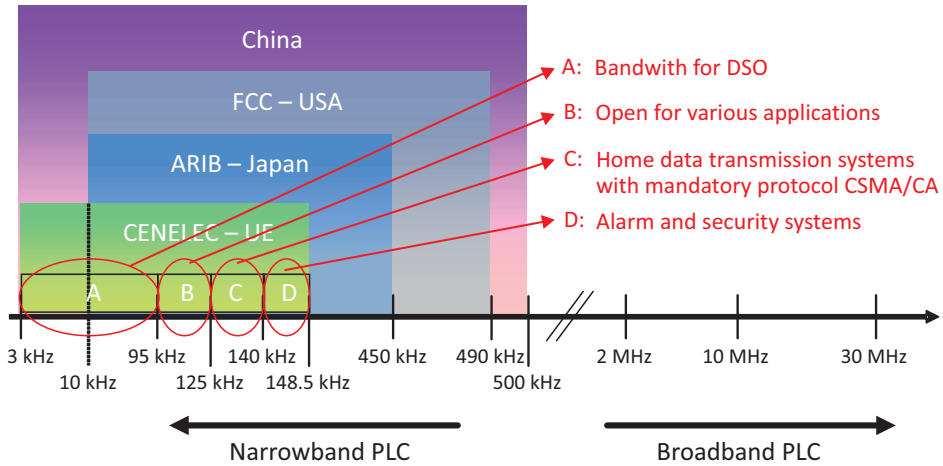


Fig. 1. Frequency bands used in PLC technology

Source: Own elaboration.

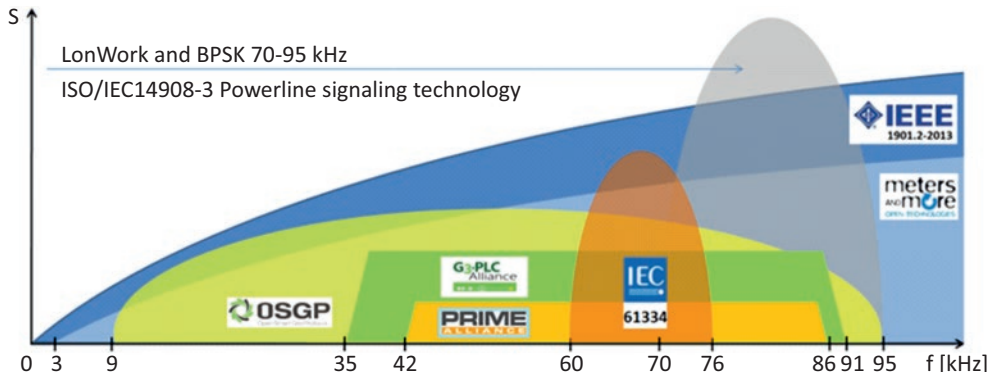


Fig. 2. Frequencies of the CENELEC A (European Committee for Electrical Standardization) band utilized by selected communication protocols

Source: Own elaboration.

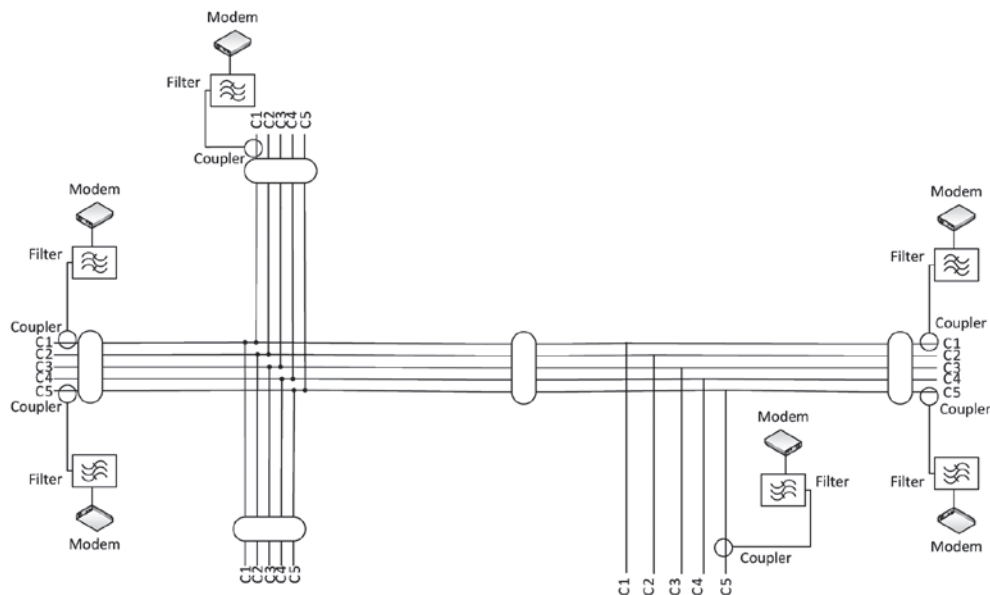
## 2. Secured voice transmission

The advantages of BPL-PLC technology over medium-voltage power lines also offer a chance to employ it for image and voice transmission. It is particularly important under various types of hazards, particularly power supply outage. The power cables located underground or in tunnels enable the connection of appropriate radio transmitters and receivers to modems, especially when using inductive coupling [1]. It enables setting a secure voice transmission, both peer-to-peer and/or master-slave, as shown in Figure 3.

## 3. Analyzed System

A 3-phase cable, located in the mine shaft headroom, about 300 m long with the CORINEX BPL apparatus installed, was selected in the test. This cable is a part of the tested medium voltage radial network of 6 kV, and its total length is equal to approx. 1300 m [1]. The tested





**Fig. 3.** Exemplary MV cable network system utilizing BPL technology located in tunnel

*Source: Own elaboration.*

cable was disconnected from the power supply and shorted, as well as earthed at both ends to simulate an emergency condition. The developed digital transmitter and receiver were connected respectively to BPL modems. The best quality of BPL transmission was obtained for the mode with a frequency band of 2-7 MHz. However, it should be emphasized that the BPL transmission is asymmetrical, showing different values of both capacity (bitrate) and SNR (Signal-to-Noise Ratio), as well as CFR (Channel Frequency Response) factors, for the reverse direction of transmission. For example, the capacity from point A to B (see Fig. 4) was around 34 Mbit/s, whereas from point B to A, it decreased to approx. 27 Mbit/s.

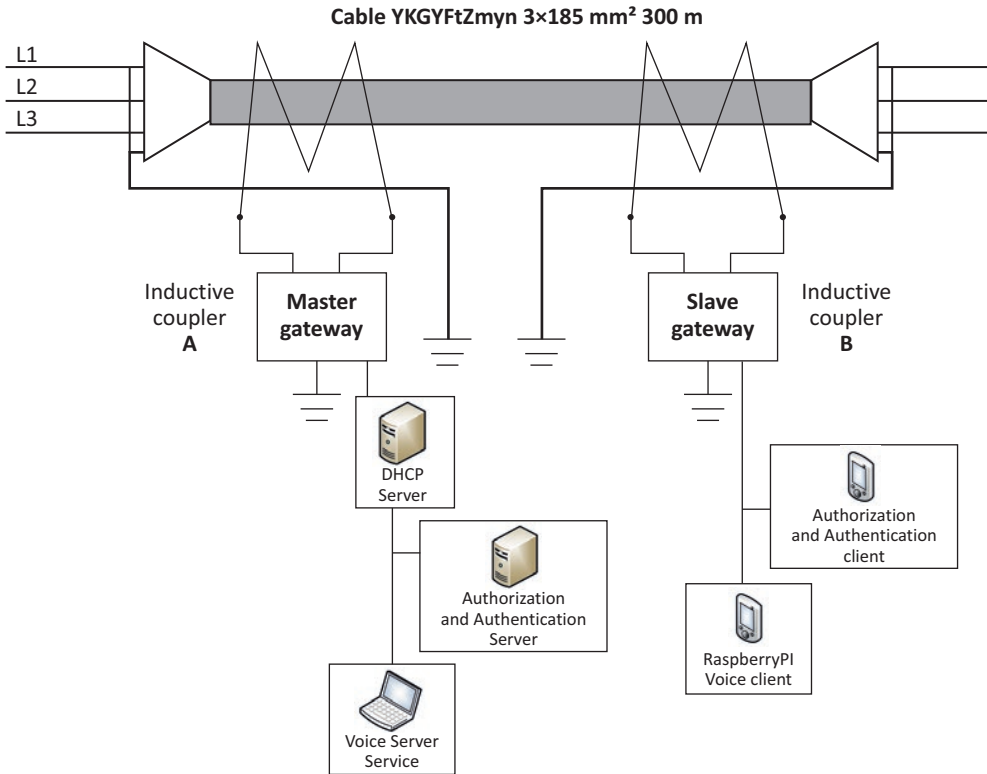
#### 4. About the Test

Cooperation among members of the V4 (Visegrad) group and the macro-region of Central and Eastern European countries, referred to as the Three Seas Initiative, forces to set an operational language. It seems that the primary spoken language would be English, as well as Polish. In this scenario, the transmission involved two-way communication from point A to point B and vice versa. The nature and structure of the evaluated system are described in Figure 4.

The set of selected test signals was sourced from ITU (International Telecommunication Union) [8]. It comprised of 16-bit PCM (Pulse Code Modulation) WAV files, lasting approx. 7-8 s each, including sentences spoken by both male and female lectors. In this set, each lecturer, including two male and two female individuals, in a different age, provided voice samples comprising of two spoken sentences. From the broad range of available languages, American English and Polish samples had been selected.

Each file was transmitted through the BPL wired medium and recorded on the receiving side. The speech samples were processed in 3 bitrates: 8, 16, and 24 kbit/s. Later, the set of received signal samples was evaluated in a subjective quality assessment study.



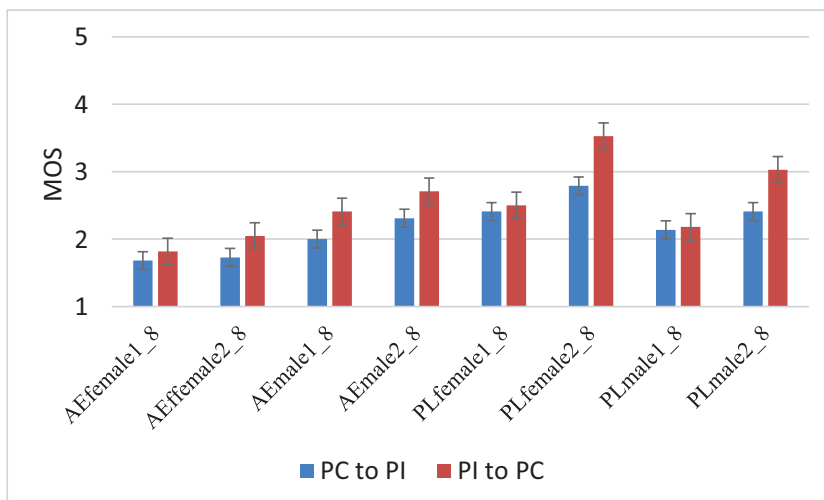


**Fig. 4.** Tested wired BPL system

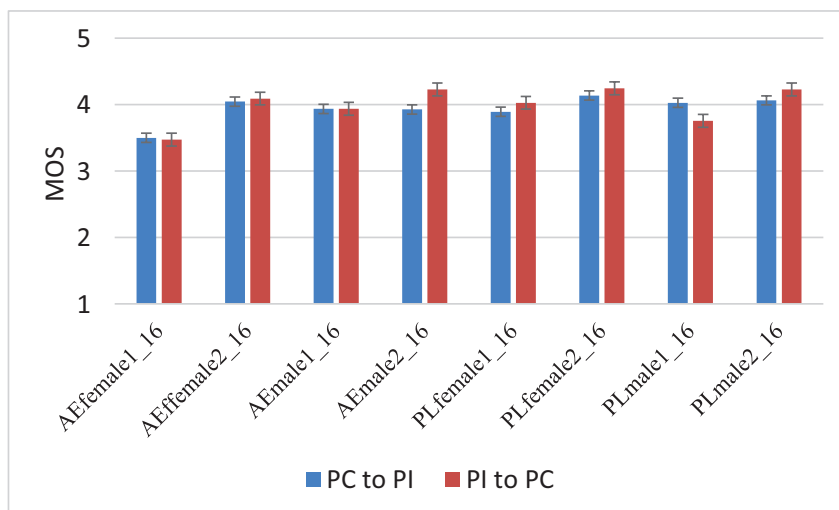
*Source: Own elaboration.*

The listening study was performed according to [9], in turns, one participant after another. A single session, preceded by a training phase, took approx. 10 minutes. It is worth mentioning that none of the 15 participants had any hearing disorders. The group, including male and female individuals aged 25-35, assessed the quality using Beyerdynamic Custom One Pro headphones in a 5-step MOS (Mean Opinion Score) scale. Each signal sample was given a mark from 1 (bad quality) to 5 (excellent quality). Figures 5-7 display the results of this study.

When examining these results, one should take account of the fact that any system is considered high-quality whenever it receives a MOS score of above 4.0. As shown, the lowest bitrate equal to 8 kbit/s proved to be insufficient when it comes to delivering clear and understandable voice messages. On the other hand, the medium bitrate of 16 kbit/s was ranked patently better. Nevertheless, not all samples were perceived as of high quality. Whereas, when it comes to the highest bitrate of 24 kbit/s, all voice messages, whether spoken by a male or female lector, were clear and easily understandable. It is worth mentioning that Polish was indicated as the mother tongue, whereas English was the second language of choice. Moreover, the participants pointed out that sentences spoken by a male lector seemed more appealing. Additional information considering the subjective and objective quality evaluation of speech and music signals and low-bitrate audio coding may be found in [10-15].



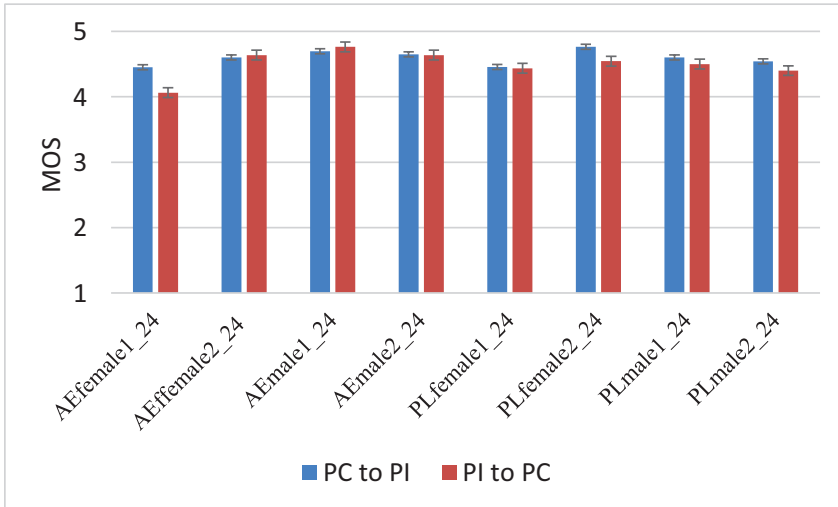
**Fig. 5.** Subjective test results – American English and Polish speech samples transmitted at 8 kbit/s (PC:A – PI:B)  
 Source: Own elaboration.



**Fig. 6.** Subjective test results – American English and Polish speech samples transmitted at 16 kbit/s (PC:A – PI:B)  
 Source: Own elaboration.

## Conclusions

As shown, the BPL wired medium, thanks to its high resistance to mechanical damage and other physical properties, can provide a reliable voice transmission system. Even in a narrow-band scenario caused, e.g., by bandwidth limitations, severe damage, etc., the technology ensures a stable and reliable connection. It is evident that today’s multimedia content consumers favor wireless connectivity [16]. However, only a wired medium can provide a secured auxiliary transmission link. One can imagine situations in which utilizing a full-size PC or



**Fig. 7.** Subjective test results – American English and Polish speech samples transmitted at 24 kbit/s (PC:A – PI:B)

*Source: Own elaboration.*

notebook can be impossible. This study shows that a voice transmission system comprising of a Raspberry PI device does not lag behind a regular computer. Thanks to its integrated ADC converters, some listeners tended to favor this device. Future studies may involve different audio codecs as well as objective quality metrics.

### Acknowledgement

No acknowledgement and potential funding was reported by the authors.

### Conflict of interests

All authors declared no conflict of interests.

### Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.


### Ethical statement

The research complies with all national and international ethical requirements.

### ORCID

Grzegorz Debita  <https://orcid.org/0000-0003-1984-4740>

Przemysław Falkowski-Gilski  <https://orcid.org/0000-0001-8920-6969>

Marcin Habrych  <https://orcid.org/0000-0003-2067-0135>

Bogdan Miedziński  <https://orcid.org/0000-0001-5354-7024>

Jan Wandzio  <https://orcid.org/0000-0002-3177-8419>

Przemysław Jedlikowski  <https://orcid.org/0000-0002-1862-0457>

## References

1. Debita G, Habrych M, Tomczyk A, Miedziński B et al. *Implementing BPL Transmission in MV Cable Network Effectively*. *Elektronika i Elektrotechnika*. 2019;25(1):59-65.
2. Mlynek P, Misurec J, Koutny M. *Modeling and Evaluation of Power Line for Smart Grid Communication*. *Przegląd Elektrotechniczny*. 2011;87(8):228-32.
3. Meng H, Chen S, Guan YL, Law CL et al. *Modeling of Transfer Characteristics for the Broadband Power Line Communication Channel*. *IEEE Transactions on Power Delivery*. 2004;19:1057-64.
4. Lampe L, Tonell AM, Swart TG. *Power Line Communications*. 2<sup>nd</sup> Ed. Hoboken, NJ: Wiley; 2016.
5. Carcell X. *Power Line Communications in Practice*. London/Boston: Artec House; 2006.
6. Habrych M, Wąsowski M. *Analysis of the Transmission Capacity of Various PLC Systems Working in the Same Network*. *Przegląd Elektrotechniczny*. 2018;94(11):130-4.
7. *EN 50065-1:2011. Signalling on Low-Voltage Installations in the Frequency Range 3 kHz to 148,5 kHz – Part 1: General Requirements, Frequency Bands and Electromagnetic Disturbances*. Brussels: European Committee for Standards – Electrical; 2011.
8. *ITU-T P.501. Test Signals for Telecommunication Systems*. Geneva: International Telecommunication Union; 2017.
9. ITU-R BS.1284. *General Methods for the Subjective Assessment of Sound Quality*. Geneva: International Telecommunication Union; 2003.
10. Počta P, Beerends JG. *Subjective and Objective Assessment of Perceived Audio Quality of Current Digital Audio Broadcasting Systems and Web-Casting Applications*. *IEEE Transactions on Broadcasting*. 2015;61(3):407-15.
11. Gilski P. *DAB vs DAB+ Radio Broadcasting: a Subjective Comparative Study*. *Archives of Acoustics*. 2017;42(4):157-65.
12. Uhl T, Paulsen S, Nowicki K. *New Approach for Determining the QoS of MP3-coded Voice Signals in IP Networks*. *EURASIP Journal on Audio, Speech, and Music Processing*. 2017;1:1-9.
13. Falkowski-Gilski P. *Transmitting Alarm Information in DAB+ Broadcasting System*. *Proceedings of SPA Conference*. 2018;1:217-22.
14. Uhl T. *QoS by VoIP Under Use Different Audio Codecs*. *Proceedings of Joint Conference – Acoustics*. 2018;1:311-4.
15. Backstrom T, Fischer J. *Fast Randomization for Distributed Low-Bitrate Coding of Speech and Audio*. *IEEE/ACM Transactions on Audio, Speech, and Language Processing*. 2018;26(1):19-30.
16. Falkowski-Gilski P. *On the Consumption of Multimedia Content Using Mobile Devices: a Year to Year User Case Study*. *Archives of Acoustics*. 2020;45(2):321-8.

## Biographical note

**Grzegorz Debita** – Eng., Ph.D., received both M.Sc. and Ph.D. degrees from the Wrocław University of Science and Technology. He is currently employed at the General Tadeusz Kościuszko Military University of Land Forces. His research focuses on designing both wired and wireless telecommunication systems.

**Przemysław Falkowski-Gilski** – Eng., Ph.D., received both M.Sc. and Ph.D. degrees from the Faculty of ETI at the Gdańsk University of Technology. Currently, he works as an Assistant Professor. His field of interest is related to electronic media, particularly digital broadcasting systems, as well as quality evaluation of networks and services.

**Marcin Habrych** – Eng., Ph.D., D.Sc., received M.Sc. degree in 2002 and Ph.D. degree in 2007 from the Institute of Electrical Power Engineering at Wrocław University of Science and





Technology. Since 2008 he holds the position of Assistant Professor at WUST. Currently, as a D.Sc., he is focused on power system protection, power line communications, current and voltage converters, as well as reactive power compensation.

**Bogdan Miedziński** – Eng., Ph.D., D.Sc., Prof., received both M.Sc. and Ph.D. degree in electrical power engineering from the Wrocław University of Science and Technology in 1967 and 1971, respectively, and the title of Professor in 1992. From 1967 to 2012, he was employed at WUST as Full Professor. In 2012 he joined the Institute of Innovative Technologies, EMAG in Katowice, where he holds Full Professor's position. His area of research includes power system protection, power line communications, sensors, and data transfer.

**Jan Wandzio** – Eng., Ph.D., received Ph.D. degree in 2015 from the Institute of Geoenvironmental Mining and Geology at the Wrocław University of Science and Technology. Since 2008 he has been employed in KGHM Polska Miedź S.A.

**Przemysław Jedlikowski** – B.Sc., currently an M.Sc. student at the Wrocław University of Science and Technology and an employee at the Department of Computer Engineering. His area of interest includes database management, system administration, and digital signal processing.

### Bezpieczny przewodowy system BPL do transmisji mowy

#### STRESZCZENIE

Opracowanie bezpiecznego systemu transmisji mowy nie jest trywialnym zadaniem. Media przewodowe, z uwagi na niezawodność i odporność na uszkodzenia mechaniczne, zdają się być idealnym rozwiązaniem. Kabel BPL (Broadband over Power Line) jest odporny na przerwy w dostawie prądu i częściowe uszkodzenie przewodników fazowych, zapewniając ciągłość transmisji w przypadku awarii. Wydaje się odpowiednim narzędziem do dostarczania istotnych danych, w szczególności wyraźnych i zrozumiałych komunikatów głosowych. Artykuł ten opisuje taki system, który został opracowany oraz zbadany w rzeczywistych warunkach pracy. Obejmował on dwukierunkową transmisję próbek mowy w języku angielskim (amerykańskim) oraz polskim. Skuteczność zaprojektowanego rozwiązania została oceniona w badaniu subiektywnym na grupie 15 osób.

#### SŁOWA KLUCZOWE

BPL (Broadband over Power Line), bezpieczeństwo, przetwarzanie sygnałów, transmisja głosu, medium przewodowe

#### How to cite this paper

Debita G, Falkowski-Gilski P, Habrych M, Miedziński B, Wandzio J, Jedlikowski P. *Secured wired BPL voice transmission system*. Scientific Journal of the Military University of Land Forces. 2020;52;4(198):947-55.

DOI: <http://dx.doi.org/10.5604/01.3001.0014.6065>



This work is licensed under the Creative Commons Attribution International License (CC BY).

<http://creativecommons.org/licenses/by/4.0/>

