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Original article

Secured wired BPL voice transmission system

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INFORMATION

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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

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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].

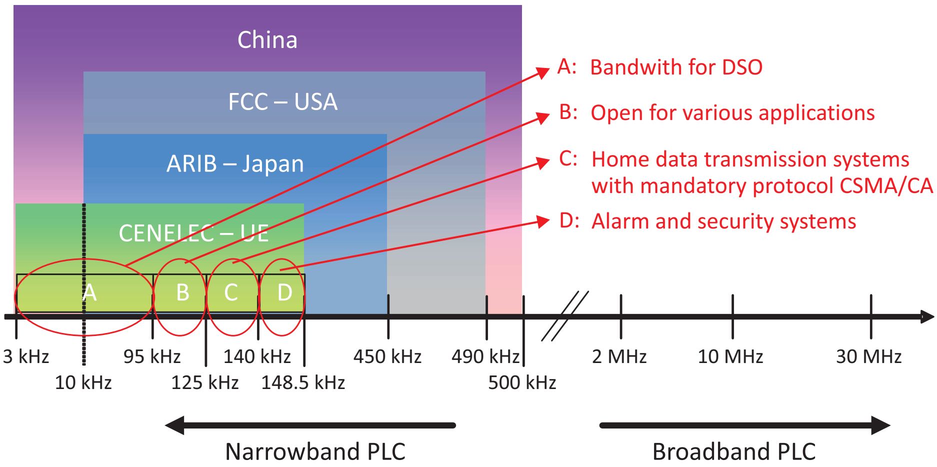

Fig. 1. Frequency bands used in PLC technology
Source: Own elaboration.

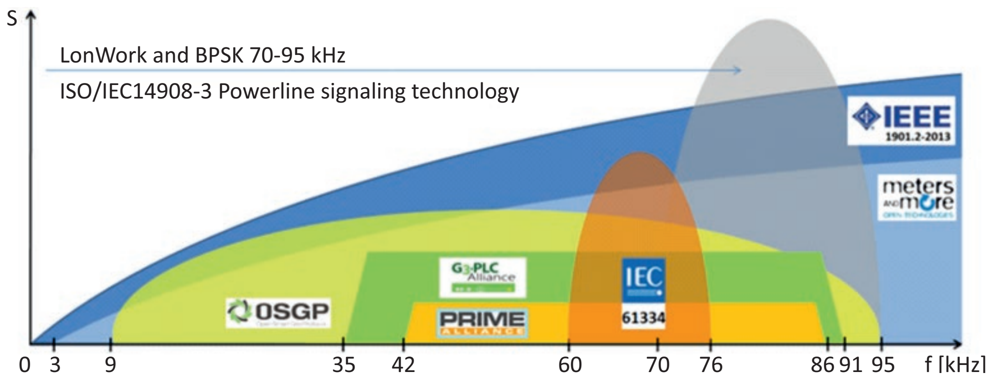

Fig. 2. Frequencies of the CENELEC A (European Committee for Electrical Standardization) band utilized by selected communication protocols
Source: Own elaboration.

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 pear-to-pear 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

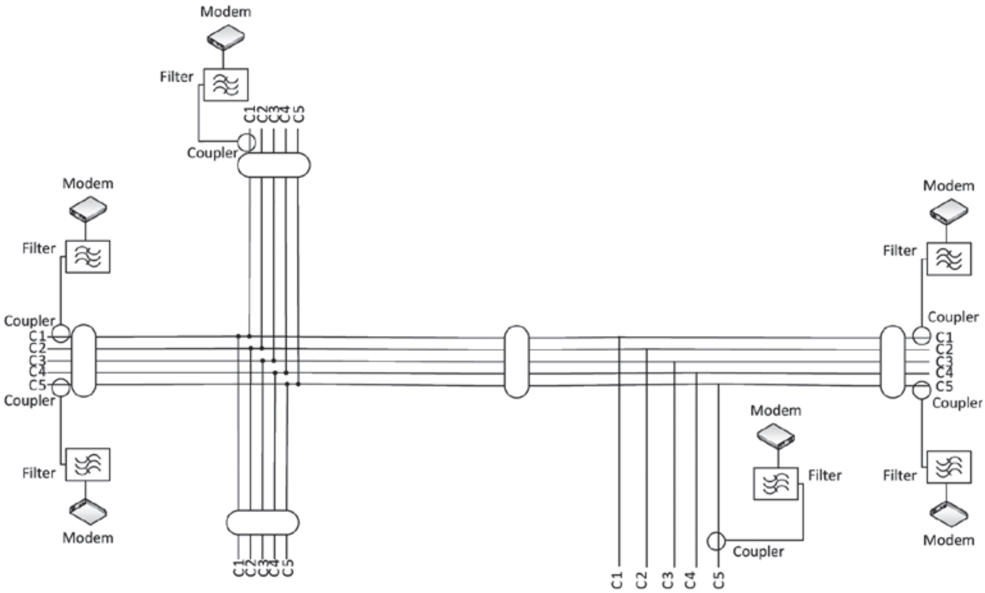

Fig. 3. Exemplary MV cable network system utilizing BPL technology located in tunnel
Source: Own elaboration.

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 lector, 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.

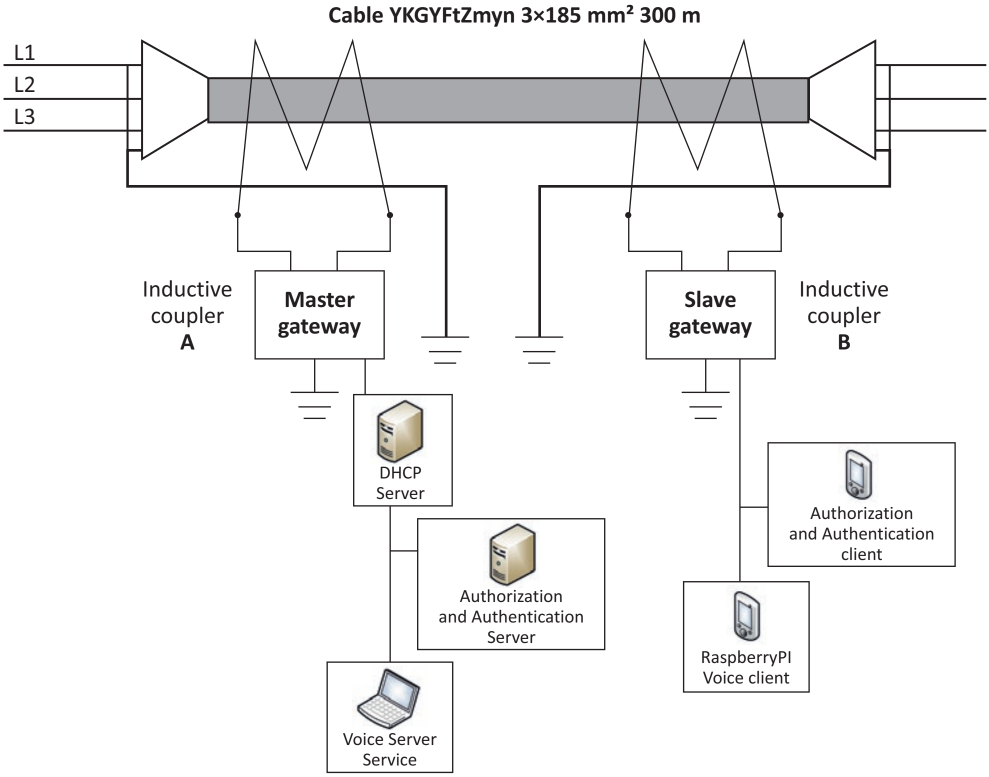

Fig. 4. Tested wired BPL system
Source: Own elaboration.

The listening study was performed according to [9], in turns, one participant after an-other. 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].

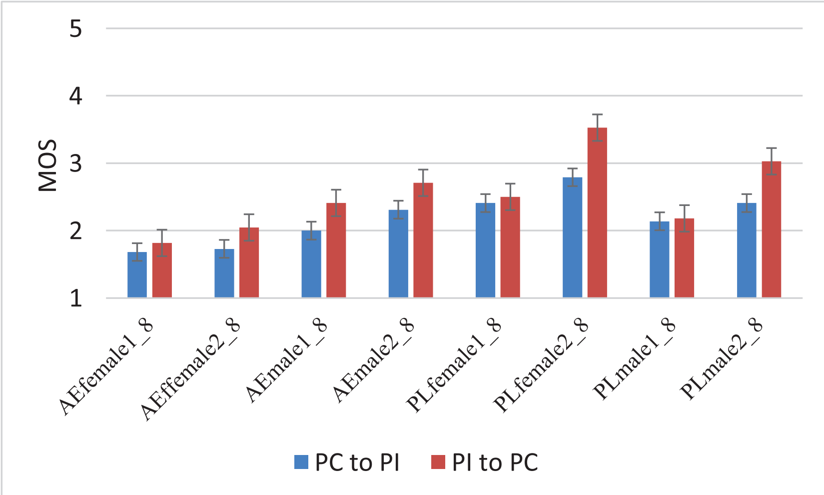

Fig. 5. Subjective test results – American English and Polish speech samples transmitted at 8 kbit/s (PC:A – PI:B)
Source: Own elaboration.

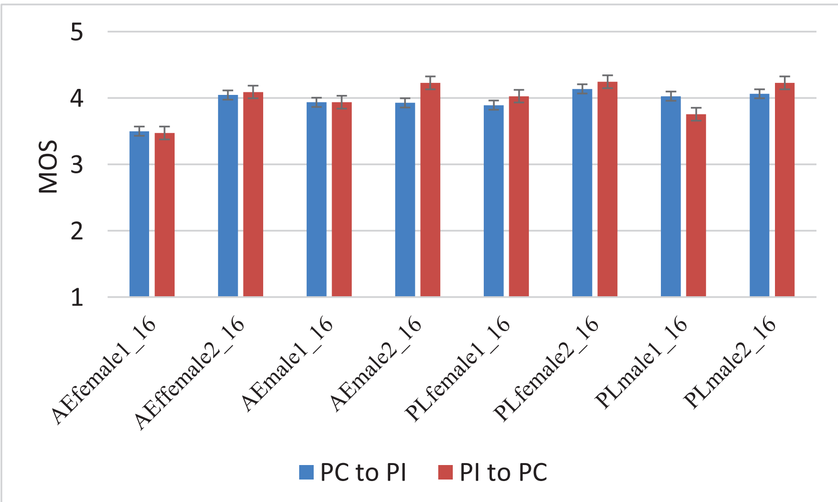

Fig. 6. Subjective test results – American English and Polish speech samples transmitted at 16 kbit/s (PC:A – PI:B)
Source: Own elaboration.

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 narrowband 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

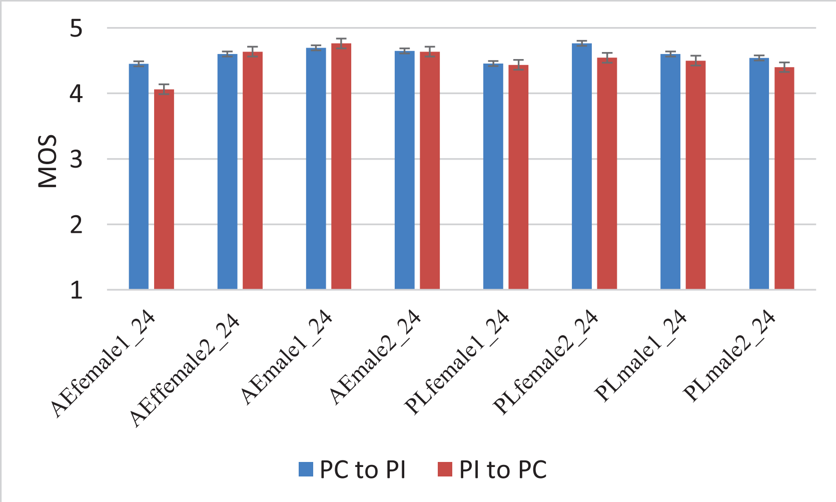

Fig. 7. Subjective test results – American English and Polish speech samples transmitted at 24 kbit/s (PC:A – PI:B)
Source: Own elaboration.

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.

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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.

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Biographical note

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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

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