Paper

Retransmission as a Replacement Forward Error Correction in Noiseless LV Networks used for Narrowband PLC

Piotr Kiedrowski

Faculty of Telecommunication, Information Technology and Electrical Engineering
UTP University of Science and Technology, Bydgoszcz, Poland

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Abstract—The article describes a project concerned with deploying PLC technology in railway light signals. The proposal increases reliability of communication between railway light signals and the railway automation center, relying on frame retransmissions instead of the FEC technique. The paper presents the results of long-term FER measurements performed in a narrowband PLC-based communication system. The said results are used as communication reliability metrics. Deployment of dual channels in order to increase communication reliability is discussed as well, as is efficiency of FEC-based convolutional coding. The results are verified in a real world environment.

Keywords—FEC, FER, narrowband PLC, PSK.

1. Introduction

Multichannel support is a receiver feature enabling the device to listen to a number of channels simultaneously, until the carrier signal is detected. Thereafter, only the channel on which the carrier signal was detected is considered for further data reception. After data has been collected or the time limit has expired, the receiver returns to the multichannel carrier detection mode. The multichannel option is a common feature of short-range communication devices, both of the wired and wireless variety [1]–[3].

This article presents a communication system that is based on the narrowband power line communication (PLC) technology implemented in the ST7580 chip [3]. The ST7580-based modem allows the receiver to operate in the single or dual channel mode. It forms a part of an LED-based signaling device used for rail traffic control. LED light signals used in railway traffic are more reliable due to the fact that they communicate with railway automation centers which control and monitor signal states. In the past, current flow was the only parameter monitored. Hence, reliability the signal status monitoring process was lower. It was simply assumed that if the current flows, the signal is working. Unfortunately, this was not always the case. The PLC modem allows to use the railway signal's power line both for power supply and data transmission purposes. Here, the use of wireless technology is irrational because of three reasons: security, long communication distances (excessively long for radio communications due to time delay restrictions characterizing the multi-hop technique [4]–[6], and strict reliability requirements. The use of other communication media, e.g. optical fibers, is linked with high investment costs.

The packet used for monitoring the state of railway traffic light signals comprises data about LED current and voltage, unit address and a control field. It is more than 100 bytes long and must be delivered to the railway automation center within 300 ms maximum. If not, the railway traffic on a given track is stopped due to security reasons. Hence, the new solution to be used in railway traffic signaling systems needs to offer a more reliable method of assessing the condition of light signals. Remote detection of signal damage is a welcome feature as well.

2. Communication System Requirements and the Problem Definition

The PLC modem is controlled by a microcontroller via UART operating at 57.6 kbps. To shorten the time of booting the system after power-up, the modem is not configured, meaning that it works with a default line frame format shown in Fig. 1.

4 Bytes	4 Bytes	1 Byte	1 Byte	From 0 up to 251 Bytes	4 Bytes
Preamble	Unique Word	PSK Mode	Length	Data	CRC
Overhead				Payload	

Fig. 1. Default format of the PLC line frame.

The length field defines the data volume plus the CRC code. The frame overhead is modulated using the most robust modulation possible, i.e. B-PSK coded modulation, where "coded" means that forward error correction (FEC) based on convolutional error correction coding is enabled. The potential modulation modes, together with their bitrates, are shown in Table 1, according to [7].

The duration of transmission of a 10 byte frame overhead is: 10×8 bits : 4800 bps = 16.7 ms. The time required for communication between the microcontroller and the mo-

Table 1
Modulation modes and bitrates available in the ST7580 chip

Modulation	B-PSK	Q-PSK	8-PSK	B-PSK coded	Q-PSK coded	B-PSK coded with PNA
Bit rate	9.6 kbit/s	19.2 kbit/s	28.8 kbit/s	4.8 kbit/s	9.6 kbit/s	2.4 kbit/s

Table 2
Time values for the state monitoring communication frame

Modulation	B-PSK	Q-PSK	8-PSK	B-PSK coded	Q-PSK coded	B-PSK coded with PNA
On line state frame duration	117 ms	67 ms	50 ms	217 ms	117 ms	417 ms
State frame communication time	177 ms	127 ms	110 ms	277 ms	177 ms	477 ms
State frame delivery time after powering the signal up	202 ms	152 ms	135 ms	302 ms	202 ms	502 ms

dem is another design parameter that needs to be taken into consideration. The railway light sign state monitoring packet is 116 bytes long. With additional of the remaining bytes of the local frame including two frame check sequence (FCS), it is 122 bytes. With UART working at 57.6 kbps bitrate and with one start and one stop bit, the local transmission time would be: $122 \times (1+8+1)$ bits : 57600 bps = 21.2 ms. This time should be doubled due to using duplex in communication and then increased by the time needed for the modem initialization. All together it gives: 2×21.2 ms $+ 18$ ms $= 60.4$ ms. Another important time is LED checking time (25 ms). The time of payload data transmission depends on the modulation used and length. The time values depend on the modulation used are summarized in Table 2.
Table 2 also shows the time elapsed from power-up the sign to the state frame delivery to the railway automation center. It increases the communication time by 25 ms. Figure 2 consists of oscillogram taken during the transmission of the state frame modulated with 5 types of available modulation of 5 state frames.

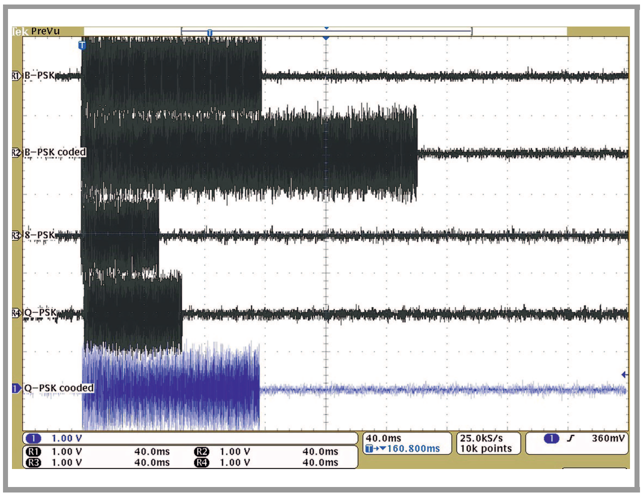

Fig. 2. Oscillogram of five frames: B-PSK, B-PSK coded, 8-PSK, Q-PSK and Q-PSK coded.

B-PSK coded [8], being twice slower. All frames presented in Fig. 2 carry the same information, even though their duration is different. The duration of Q-PSK coded frame is the same as B-PSK frame, while the Q-PSK coded modulation is more robust than B-PSK, so that, the Q-PSK coded modulation disqualifies B-PSK.

3. Modulation Selection

To meet the time and reliability requirements, that monitoring data must be delivered to the railway automation centre up to 300 ms. In real the time available for communication is decreased by 25 ms (LEDs checking time), i.e. is 275 ms. Analysing data from Table 2, it may be concluded that B-PSK coded and B-PSK coded with PNA modulations cannot be used because they are too slow in terms of throughput. From the four types of remaining modulations to be chosen the most reliable is Q-PSK coded (see Fig. 3) where two charts of FER vs. SNR for Q-PSK coded and B-PSK are shown.

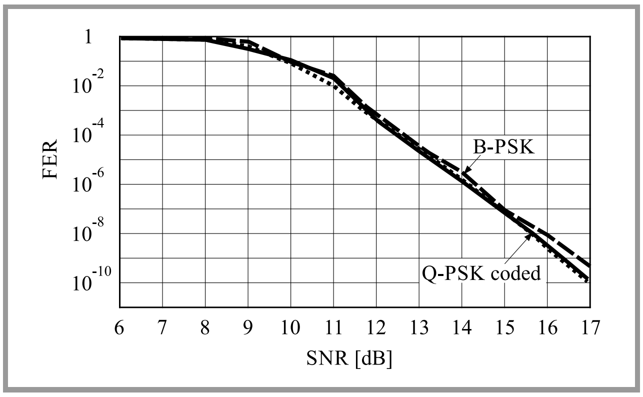

Fig. 3. FER vs. SNR for 37-bytes frames in B-PSK and Q-PSK coded modulations.

Finally, B-PSK was selected for the comparison, as B-PSK modulation has the same bitrate as the Q-PSK coded solution. Subsequently, three modulation types, namely 8-PSK, Q-PSK and Q-PSK coded were considered, with Q-PSK coded being the most robust of them all, and with Q-PSK and 8-PSK characterized by an extra feature: they are fast and offer state frame transmission lead-times of 127 ms and 110 ms, respectively, meaning that the state frame may be communicated twice when Q-PSK or 8-PSK modulation is used.

4. Frame Retransmission vs. FEC

Retransmission is a method of achieving good reliability by sending the same information more than once. It is used in communication systems whose physical or logical links are unreliable [9]. The frame is retransmitted if the sender does not receive any handshake information. The sender may also retransmit the frames by default [10], without any additional confirmation needed. The FEC method implemented in ST7580 increases the length of the frame more than two-fold. Thus, two frames may be transmitted within the same period of time, using the same type of modulation, if the frames are not coded. In Fig. 4, two FER vs. SNR lines are shown for Q-PSK and Q-PSK coded.

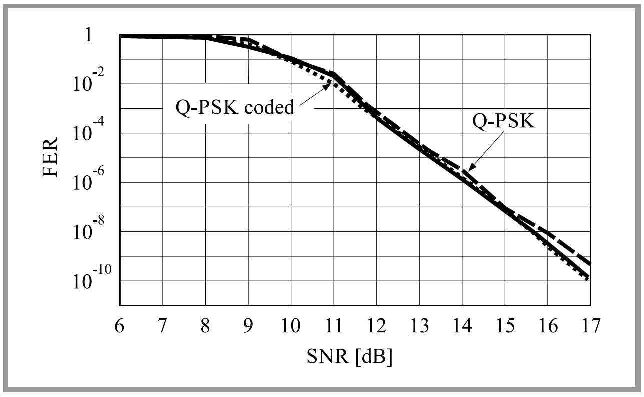

Fig. 4. FER vs. SNR for 37-byte frames: performance of Q-PSK and Q-PSK coded modulations.

From Fig. 4, one may see that FER is the error probability, and with the same noise level affecting the communication of both frame types, reliability is still worse while relying on retransmission rather than on FEC. With frame retransmission, FER is lower because the probability is the product of two components for each frame. Assuming that noise is a short-term phenomenon, FER may be lower. Assuming also that noise of the narrowband variety, deployment of the dual channel mode may be useful.

5. Single Channel and Dual Channel FERs vs. SNR in Improving Q-PSK Modulation Performance

To demonstrate the advantages that dual channel operation of the receiver offers in terms of the quality of communications, three FER vs. SNR charts are presented (Fig. 5). They depict the following: FER on a 72 kHz low band channel, FER on a 86 kHz high band channel and FER on a dual channel (72 and 86 kHz).

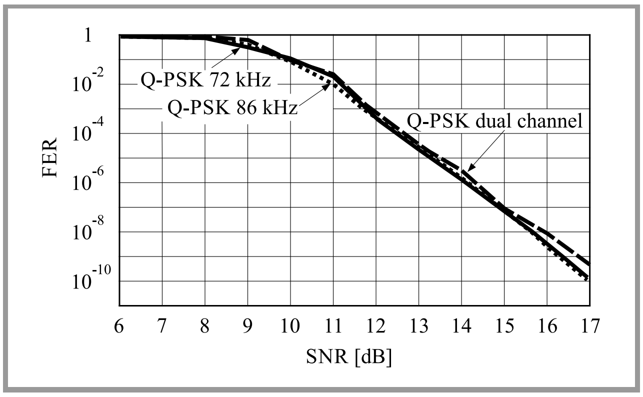

Fig. 5. FER vs. SNR for 37-bytes Q-PSK modulated frames, received in the following receiver modes: single low channel, single high channel and dual channel.

From Fig. 5, one may conclude that by turning on the dual channel mode in the receiver, transmission quality is lowered, but only slightly. Therefore, the dual channel option may remain turned on at all times, which allows the receiver to receive frames transmitted both on low and high channels.

6. Experimental Results

To check the efficiency of the proposed method, a mixed network was used, where old and new railway signal monitoring systems, i.e. those relying on the flow of current and PLC-based, were operated simultaneously. After power is supplied to the railway signal, it sends a Q-PSK coded state frame and current flow should be detected as well. During the period of several minutes over which the experiment lasted, three state frames were transmitted every second: Q-PSK coded (alternately over high/low channel), Q-PSK over high channel and Q PSK over low channel. On the receiving side, one error free Q-PSK coded frame and at least one error free Q-PSK frame are expected every second. If they are not received, a counter is incremented. There are two counters: one for missed or erroneous coded frames (MECFC), and the other one for missed or erroneous non-coded two frames (MEN2FC). The measurement results obtained from ten LED signal-controller pairs during the experiment that lasted half a year show that the summarized MECFC is 141, and MEN2FC is 36. The total observation time was 6.5 million seconds. The average SNR level, calculated based on the number of error free and erroneous frames received, was 23.8 dB. For 8 signal-controller pairs, the reading of MECFC counters was always greater than the reading of MEN2FC counters, and for 2 pairs, the readings were the same and equaled 0.

7. Conclusions

This paper has demonstrated that the FEC technique based on convolutional coding is more effective than sending the same information twice within the same time period, but without relying on FEC. Activation of the dual channel receiver mode in the PLC modem does not improve transmission quality but allows the modem to transmit data over two communication channels. Therefore, it allows transmit two consecutive frames carrying the same data in two different ways. Based on experimental results, it may be concluded that using frame retransmission over different frequency channels renders the communication more reliable than when relying on FEC. This statement applies only to low voltage networks with low noise levels, such as signaling cables used in railway automation systems. Errors caused by external interference are rare. Due to its the short duration and narrowband character, the frame retransmission mechanism helps achieve good reliability levels. Future work will focus on the compression of data transmitted within state monitoring frames. By shortening frame length and applying 8-PSK modulation, retransmission could be used more than once, which would probably improve communication reliability even further.

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References

[1] P. Nicopolitidis, G. I. Papadimitriou, and A. S. Pomportsis, "Adaptive wireless push system for multichannel environments with single-receiver clients", *Electron. Lett.*, vol. 47, no. 2, pp. 147–148, 2011 (DOI: 10.1049/el.2010.3166).

[2] S. Kim and G. B. Giannakis, "Sequential and cooperative sensing for multi-channel cognitive radios", *IEEE Trans. on Sig. Process.*, vol. 58, no. 8, pp. 4239–4253, 2010 (DOI: 10.1109/TSP.2010.2049106).

[3] R. Fiorelli and M. Colombo, "AN4068 Application note. ST7580 power line communication system-on-chip design guide", ST Microelectronics, July 2012, p. 33 [Online]. Available: https://www.st.com/content/ccc/resource/technical/document/application_note/71/8d/7f/e6/13/68/46/46/DM00050178.pdf/files/DM00050178.pdf/jcr:content/translations/en.DM00050178.pdf

[4] R. V. P. Yerra, M. P. R. S. Kiran, and R. Pachamuthu, "Reliability and delay analysis of slotted anycast multi-hop wireless networks targeting dense traffic IoT applications", *IEEE Commun. Lett.*, vol. 19, no. 5, pp. 727–730, 2015 (DOI: 10.1109/LCOMM.2015.2401582).

[5] J-S. Liu, Ch-H. R. Lin, and J. Tsai, "Delay and energy trade off in energy harvesting multi-hop wireless networks with inter-session network coding and successive interference cancellation", *IEEE Access*, vol. 5, pp. 544–564, 2016 (DOI: 10.1109/ACCESS.2016.2645704).

[6] M. Piechowiak, P. Zwierzykowski, P. Kotlarz, and P. Żmudziński, "The impact of selected parameters on the performance of routing protocols in wireless sensor networks", *Image Process. & Commun.*, vol. 22, no. 1, pp. 57–62, 2017 (DOI: 10.1515/ipc-2017-0006).

[7] ST Microelectronics, "UM0932 User Manual. ST7580 – FSK, PSK Multi-Mode Power Line Networking System-On-Chip", ST Microelectronics, Oct. 2013, p. 43 [Online]. Available: https://www.st.com/content/ccc/resource/technical/document/user_manual/8d/ce/5e/34/e0/03/41/ef/CD00270292.pdf/files/CD00270292.pdf/jcr:content/translations/en.CD00270292.pdf

[8] P. Kiedrowski, T. Marciniak, Z. Lutowski, and Ł. Zabłudowski, "Effectiveness of BPSK modulation with peak noise avoidance algorithm in smart street lighting communications based on PLC", *Image Process. & Commun.*, vol. 23, no. 1, pp. 5–10, 2019 (DOI: 10.1515/ipc-2018-0001).

[9] Y. Hayashida, N. Sugimachi, M. Komatsu, and Y. Yoshida, "Go-back-N system with limited retransmissions", in *Proc. of the 8th Ann. Int. Phoenix Conf. on Comp. and Commun.*, Scottsdale, AZ, USA, 1989, pp. 183–187 (DOI: 10.1109/PCCC.1989.37383).

[10] ETSI EN 300 324-1 V2.1.1 (2000-04-08), "V interfaces at the digital Local Exchange (LE); V5.1 interface for the support of Access Network (AN); Part 1: V5.1 interface specification", ETSI, 2001, p. 201 [Online]. Available: https://www.etsi.org/deliver/etsi_EN/300300_300399/30032401/02.01.01_60/en_30032401v020101p.pdf

Piotr Kiedrowski received his M.Sc. in Electronics and Telecommunications from the UTP University of Science and Technology, Bydgoszcz, Poland and the Ph.D. degree in Telecommunications from the same University in 1994 and 2002, respectively. He has been working as a researcher and an academic teacher at UTP since 1994. His professional work focuses on: communication systems for smart grids, narrowband and broadband PLC and design of measuring equipment. His research interests focus on communication protocols, as well as on network testers and analyzers.

https://orcid.org/0000-0002-3180-3098
E-mail: piotr.kiedrowski@utp.edu.pl
Institute of Telecommunications and Computer Science
Faculty of Telecommunication, Information Technology and Electrical Engineering
UTP University of Science and Technology
Al. Prof. Kaliskiego 7
85-796 Bydgoszcz, Poland