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

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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 now 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 dis-
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: $122 \times (1 + 8 + 1) \text{ bits} = 57600 \text{ bps} = 21.2 \text{ ms}$. 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: $2 \times 21.2 \text{ ms} + 18 \text{ ms} = 60.4 \text{ ms}$. 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.

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 coded and B-PSK coded, B-PSK coded with PNA, are shown.

### Table 1

| 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

| 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 |

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.
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.](image)

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.](image)

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 QPSK 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 transmitting 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 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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