

Feasibility of using Vehicle's Power Line as a Communication Bus

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ABSTRACT

The wiring in present day automobiles is the second heaviest and costliest part in the vehicle [7]. Also, with the increasing demand for drive-by-wire and many new features such as telematics, entertainment, multimedia, pre-crash warning, remote diagnostics and software update, the weight and cost factor will increase significantly along with complexity of the in-vehicle networks. One straightforward solution to reduce the complexity, cost and weight of present day and future in-vehicle networks would be to use the existing DC power line as a medium for data communication between various nodes within a vehicle. This paper presents a technique for making power line communication channel feasible for in-vehicle networking application.

Key Words: Forward Error Correction, Power Line Communication, In-Vehicle Networks, and Power Line Transceiver.

I. INTRODUCTION

Power lines were not designed to carry communication signals. The fact that the power line within a vehicle is a noisy environment presents an additional challenge of making the power line channel immune to noise so that reliable data communication is ensured. Previous work in the area of power line communication is limited to residential power line networks [3] and intrabuilding power line communication [4]. Studies by Vines et al. [3] describe in detail the impedance, signal attenuation and noise characteristics of power line networks.

We assume here that the major sources of data transmission errors within a vehicle are caused by the same sources of noise which cause transmission errors in intrabuilding power line channels. These include and are not limited to high frequency impulse noise and errors caused by impedance mismatches and EMI (Electromagnetic Interference). EMI noise can be eliminated by properly shielding the power line channel incurring negligible costs. These noise sources produce

both random and burst errors that interfere with the reception of data and lead to loss of information and in turn bandwidth.

Considering the present day in-vehicle network consisting of say CAN/LIN nodes, error in a few bits of the CAN/LIN message frame due to noise leads to the retransmission of the entire message frame. This results in considerable wastage of bandwidth and throughput. In this paper, we present a solution to this problem by dividing the message frame into packets of smaller lengths. Each packet is FEC (Forward Error Correction) coded using the rate one-half self-orthogonal convolution code [5]. The Appendix shows a brief description of this coding technique. In the event of a lost packet due to high noise on the power line channel, only the packet having the error is retransmitted. Previous studies have indicated the use of FEC coding and bit interleaving on very noisy power line channels reduces the packet error rate which in turn decreases the packet retransmission rate [5]. The performance of the technique presented in this paper is analyzed for varying packet lengths and error rates. Theoretical results show significant reduction in packet error rates and packet retransmission rates even at high percentage of error. Considerable increase in throughput is also obtained at high data rates and small packet lengths.

Section II gives a description of the conceptual power line transceiver system and also briefly discusses the FEC coding technique. Section III describes the tests to measure throughput and packet retransmission rates for varying packet lengths, data rates and error rates. Our results show considerable reductions in the error rates and packet retransmission rates for smaller blocks even at high error probabilities (10%) and data rates of up to 50 Kbps. The increase in throughput is more than 20% when a 1000-bit message is broken down to a series of 50-bit blocks. The code chosen is rate one-half (2, 1, 6) self-orthogonal code for reasons evident from [4]. Section IV presents the results and section V discusses the conclusions.

II. POWER LINE TRANSCEIVER SYSTEM

The block diagram of the power line transceiver (PLT) system is shown in Figure 1. The main blocks and their functionality are discussed briefly below.

We assume that a network node can generate either a CAN or LIN message. This assumption is just for convenience since nodes in present day in-vehicle networks consists of both CAN and LIN controllers. This assumption has no effect on the analysis of throughput and packet retransmission rate. The CAN/LIN message frame is passed into the power line transceiver system for further processing.

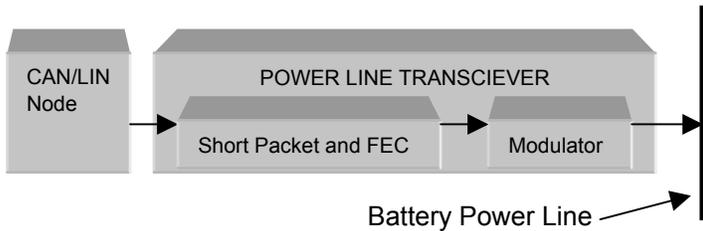


Figure 1: Power Line Transceiver System

POWER LINE TRANSCEIVER

The transceiver block is the major component of the entire system and performs the tasks of breaking the CAN/LIN message frame into packets of smaller lengths and coding the individual packets. The transceiver also modulates the packets in a way most suitable for transmission over the power line channel. The receiver part of the transceiver system (not shown in the figure) performs the above-mentioned tasks in the reverse order. I.e. the packets received are first demodulated, decoded and then combined in accordance to the standard message format of the network node. The message is finally passed on to the node for relevant processing. The CAN/LIN messages that are to be transmitted over the channel are stored in an input queue of the transceiver. Messages from this queue are processed in sequential order and therefore the queue can be considered as a first in first out (FIFO) queue. The packets are then encoded using error detection and error correction codes to enable detection and correction of errors during transmission. In the event of correct transmission, the receiver usually sends a positive acknowledgement to inform the transmitter of a successful packet transmission. For our analysis, the packets are coded using the rate one-half (2,1,6) self-orthogonal convolution code.

FEC CODING

In the simplest sense, FEC coding is the addition of redundant information bits to the original information sequence. This enables the receiver to decode the

message correctly even in the presence of errors in the data stream. A k -bit information sequence is transformed into an n -bit data stream by the addition of $n-k$ parity bits. These parity bits are calculated from the information sequence using a coding algorithm that enables correction of error patterns that occur with a high probability. The error patterns are corrected using a majority logic decoder [4]. The code rate is given by $R_c = k/n$. The addition of parity bits to the original information sequence reduces the rate at which information is sent over the channel by a factor of k/n . i.e. if the data rate is R , the use of FEC coding reduces the data rate to $R \cdot R_c$. However, the use of FEC coding reduces the packet retransmission probability and in turn increases the throughput.

Rate one-half FEC convolutional codes were selected due to their low implementation costs and their strong error correcting capabilities [5]. The $(n, k, m) = (2, 1, 6)$ self-orthogonal convolutional code [5] can correct error patterns of 1 or 2 bits in a constraint length of $L = (m+1)n = 14$ bits. Additionally, the use of FEC coding with bit interleaving enables the correction of both random and burst errors encountered in noisy power line channels [5].

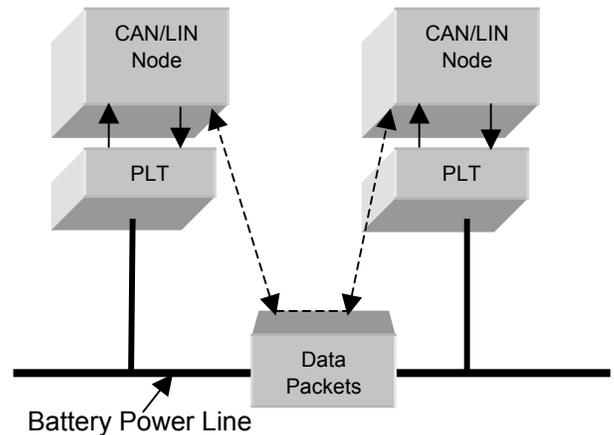


Figure 2. In-Vehicle Power Line Communication System

MODULATOR

The choice of the modulation scheme greatly influences the overall cost and complexity of the power line system. As the number of nodes within a vehicle will increase with the increase in number of features and services provided, it is necessary to keep the cost of each node to a minimum so as to make the power line system a viable candidate for future in-vehicle networking applications. Haidine et al.[6] discusses the use of OFDM (Orthogonal Frequency Division Multiplexing) modulation scheme over power line channel to provide services like online shopping, video-on-demand and interactive games to remote users. However, OFDM modulation scheme increases the system cost and complexity if incorporated in an in-vehicle network, as this would require a DSP processor at each node in the

network. Hence, keeping the cost and complexity factor in mind, modulation schemes such as QPSK (Quadrature Phase Shift Keying) and DQPSK (Differential QPSK) are prospective modulation schemes for in-vehicle power line networking application.

The block diagram of the conceptual in-vehicle power line communication system is shown in Figure 2. This system uses the vehicle's battery power line. The system, shown in Figure 2, consists of two nodes. Each node has a power line transceiver (PLT) and a CAN/LIN node. The dashed line indicates the flow of information from one node to the other

III. THROUGHPUT AND PACKET RETRANSMISSION RATE ANALYSIS

Two most important parameters to measure the performance of a given coding technique are information throughput and packet retransmission rate. This section outlines the parameters used to measure the throughput and the packet retransmission probability of the FEC coded power line channel.

MEASUREMENT OF BLOCK ERROR RATE AND THROUGHPUT

The block error rate, *BLKER*, is defined as [4]

$$BLKER = \frac{\text{Number_of_Incorrect_Blocks}}{\text{Number_of_Received_Blocks}} \quad (1)$$

The lost packet rate, *LSTPKT*, is defined as [4]

$$LSTPKT = \frac{\text{Num._of_Packets_not_Decoded}}{\text{Number_of_Packets_Sent}} \quad (2)$$

The packet overhead, *PKTOH*, is given by [4]

$$PKTOH = \frac{1 - \text{Num._of_Data_Bits}}{\text{Number_of_Packet_Bits}} \quad (3)$$

Information throughput, *C*, in Kbit/s can be calculated using these three parameters as [4]

$$C = (\text{DataRate})(1 - PKTOH)(1 - LSTPKT)(1 - BLKER)$$

To keep our analysis simple, we assume that the receiving node receives all the packets sent by the transmitting node. I.e. there are no packets lost due to decoding errors. This simplifies the equation of information throughput to

$$C = (\text{DataRate})(1 - PKTOH)(1 - BLKER) \quad (4)$$

The packet retransmission rate, *RET* is [5]

$$RET = \frac{BLKER}{1 - BLKER} \quad (5)$$

The (2, 1, 6) self-orthogonal convolution code is used for the calculation of theoretical information throughput and *BLKER* rate. For our analysis, we consider a *PKTOH* = 20%. The theoretical value of *BLKER* is given by [4]

$$BLKER = 100(1 - (1 - p)^L)\% \quad (6a)$$

$$= 100Lp\% \text{ (for } Lp \ll 1) \quad (6b)$$

Here, *L* denotes the packet length and *p* is the bit error probability after decoding. For the (2, 1, 6) self-orthogonal code, the relationship between *p* and channel bit error probability *p_c* is [5],

$$p = (0.63p_c)^3 \quad (7)$$

This implies that by incorporating the (2, 1, 6) self-orthogonal code in the information packets transmitted by the node, the decoded bit error probability of the power line channel is reduced by a factor given in Equation 7. The following section shows results of the analysis performed with data rates varying from 10Kbps to 50 Kbps and varying packet lengths from 1000 to 50 bits at varying error rates from 2% to 10%.

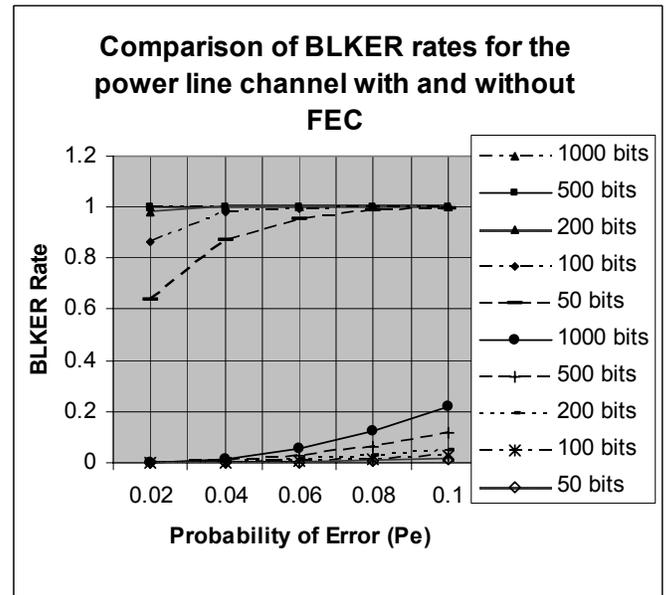


Figure 3: *BLKER* rate comparison of the power line channel

IV. RESULTS

The comparison of *BLKER* rates for the power line channel is shown in Figure 3. The upper set of curves corresponds to the case when no FEC coding was used and the lower set of curves corresponds to the case when (2, 1, 6) self-orthogonal FEC coding was used.

As is evident from the curves, The *BLKER* rate is 1 when the packet length is 1000 bits even at an error probability of .02. This means that when the packet length is 1000 bits, none of the packets sent by the transmitter reach the destination correctly when no FEC coding is incorporated. In contrast, for the case when FEC coding is implemented, almost all the packets of length 1000 bits are received correctly when the probability of error is .02. But, the real gain obtained from the use of FEC coding is visible at higher error rates of .1 where 20% of packets of length 1000 bits are in error. However, when the length of the packet is reduced, the *BLKER* rate decreases drastically. For a packet length of 50 bits, the *BLKER* rate is 0.12426. So approximately, one packet will be in error even at error probability of 0.1.

Figure 4 compares the throughput of the power line channel for the case when FEC coding is incorporated and for the case where FEC coding is not incorporated. The data rate is fixed at 50Kbps.

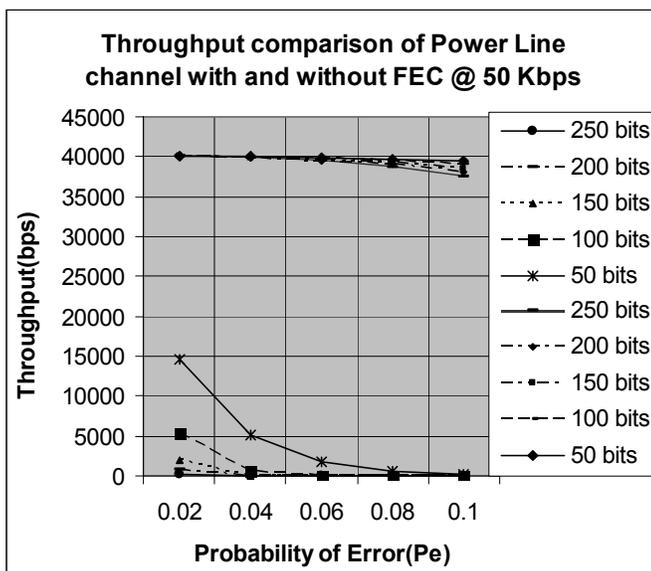


Figure 4: Throughput comparison of power line channel at 50 Kbps

The use of FEC coding reduces the overall throughput as explained in Section II and hence the peak throughput of the power line channel does not exceed 40 Kbps even at a data rate of 50 Kbps. The lower set of curves show the throughput of the power line channel without FEC coding. The peak throughput obtained is 14566.79 bps when the length of the packet is 50 bits at error probability of .02, but as the probability of error increases, the throughput reduces to approximately zero. On the other hand, the use of FEC coding increases the throughput to 40 Kbps at error probability of 0.02. As the error probability increase to 0.1, the throughput reduces to only 39502.26 bps when the length of the packet is 50 bits and throughput reduces to 31149.59 bps when the length of the packet is 1000 bits (not shown in the graph) giving a gain in throughput of

approximately 20% when a series of 50 bit packets are used.

The packet retransmission rate as a function of error rate for various packet lengths is shown in Figure 5. As is evident from the graph, the retransmission rate is lower by approximately 26% for a packet of length 50 bits when compared to a packet length of 1000 bits.

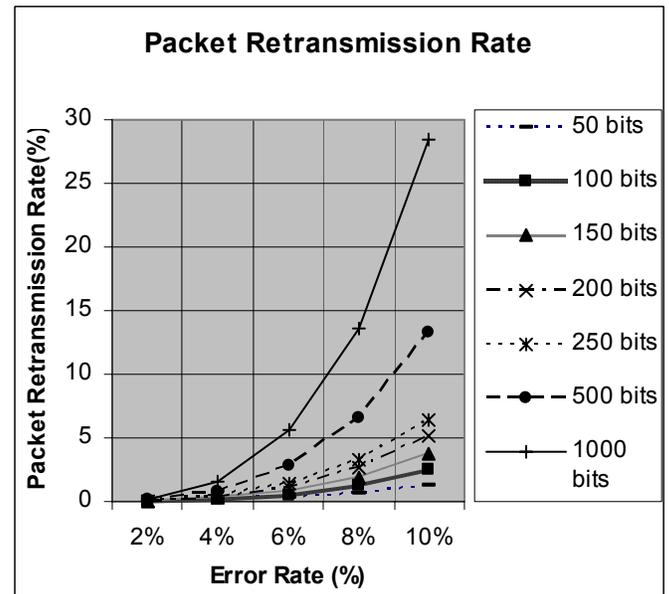


Figure 5: Packet Retransmission Rate of power line channel

V. CONCLUSION

The effectiveness of FEC coding and short packet transmission over noisy power line communication channel for in-vehicle networking application has been demonstrated. Considering the fact that the power line channel is the most error prone channel, the use of FEC coding and short packet transmission considerably enhances the throughput performance of the power line channel when compared to a channel without FEC and short packet transmission technique. Our main goal in this paper was to demonstrate the effect of FEC coding and short packet transmission on the throughput and packet retransmission rate of a noisy in-vehicle power line channel. We have kept our analysis simple and concise without going into the details of the packet format and modulation method. These topics are the subject of future study where we develop a protocol for the power line communication for in-vehicle networking applications. Since the bandwidth of the power bus is low compared to the dedicated communication bus, the power bus can be used for those applications (such as body modules) that do not require high bandwidth. Additionally, since the power line channel is a

discontinuous medium (having many connectors and terminators throughout the length of the line), the use of power line channel as a communication bus would allow for system expansion (adding new nodes to the network with enhanced functions and capabilities). These new nodes can be connected to the power line by means of simple plug and play units and hence will not require additional components for communication. The power line transceiver required to interface the network nodes to the power line channel can be implemented at a low cost in CMOS VLSI technology. The transceiver acts as an additional physical layer interface to higher layer protocols such as CAN and LIN and the power line. Therefore, the system requires no changes in the existing protocols. Also, the cost of FEC coding will be negligible when built into the power line transceiver when compared to the cost incurred while using stand-alone devices for the purpose of error correction. The power line channel can be used in both fault-tolerant architecture where it acts like a secondary back up bus when a fault occurs on the primary bus, as well as non fault-tolerant architecture where it acts as the primary medium for data communication. In the former case, if the primary low-bandwidth communication bus breaks down or becomes faulty, then the vehicle's power line can be used as a back up bus with limited features rather than adding an additional back up communication bus. This ensures that the system does not break down completely in the event of a fault on the primary bus. Using the power line channel in a fault-tolerant architecture would therefore reduce the overall weight of the vehicle without incurring additional costs. In the latter case in which the power line is used as the primary communication medium, additional fault-tolerant features will have to be incorporated to ensure proper functioning of the system in the event of an error.

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APPENDIX

RATE ONE-HALF SELF-ORTHOGONAL CONVOLUTION CODING

The purpose of (Forward Error Correction) FEC coding is to improve the capacity of a communication channel by adding redundant information bits in the original data stream. These redundant information bits are chosen in accordance to a coding algorithm and are added to the original data stream using a technique called convolutional coding. Convolutional codes are commonly specified by three parameters; (n, k, m).

- n = number of output bits
- k = number of input bits
- m= Number of memory registers

The measure of coding efficiency is code rate and is given by k/n . For the analysis, we have chosen the rate one-half (n, k, m) = (2, 1, 6) self-orthogonal convolution code which produces a two bit output for every one bit input. The constraint length $L = (m+1)n$ represents the number of output bits from the convolutional encoder that are influenced by a single input bit to the encoder. Convolutional encoding is usually performed in hardware using a series of memory registers whose outputs are connected to modulo-2 adders in accordance with a

generator polynomial. The interested reader is referred to [5] for a detailed explanation of the convolutional coding technique.