Heterogeneous networks model for lower error using concatenated encoding

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Abstract

Power line communication of the power distribution network requires higher reliability and better standards. In this paper, the ideas of cooperative communication motivate that we have presented a dual heterogeneous networks model with power line communication network and wireless sensor networks. Concatenated channel encoding with cyclic redundancy check code, convolution code, Reed Solomon code and the interleaver are respectively researched, which are used to analyse the performance of dual networks' communication scheme. The simulated results reveal that the dual networks have better communication quality than the one of single network. Compared to dual-network with RS code, the probability of frame error transmission and bit error rate for dual-network with convolution code are lower. On the basis of the characteristics of two different kinds of concatenated codes, we put forward an improved model, which is more close to reality. The results verify the feasibility of the design.

Keywords: power distribution network, power line communication, wireless sensor network, dual heterogeneous networks, concatenated channel encoding

Introduction

In 2009, National Institute of Standards and Technology (NIST) promulgated the smart grid interoperability framework, which proposed the application of wireless communication in the intelligent power grid. In January 2010, Pacific Northwest National Laboratory released a report about wireless communications for the electric power system, which focus on how, where and what type of wireless transmission satisfy requirements of power communication system. A new framework of the next generation power communication transmission network which based on packet transport network (PTN) and optical transport network (OTN) is suggested [1]. Much of studies have been carried on technology of Zigbee, WSN [2]. However, the wireless technologies existed and its standard protocol are difficult to meet the application requirements of network layer, since it has some disadvantages with real time requirement. The performance of bit error rate (BER) in wireless networks could hardly meet to the requirement of 10^{-9}, which is a requirement of industrial control. So the research of reliability and real-time characteristics during the power distribution network communication system is concerned urgently.

Today, electric power networks were built with an integrated and vertical structure. The power energy is mostly generated in centralized power plants and transported over a long distance transmission network to a distribution network before reaching the end users [3]. In this context, the distribution network is regarded as a passive system used to deliver reliable unidirectional power to end users.

With the development of power distribution network, a lot of wired and wireless technologies are relevant to these networks, such as power line communication (PLC) [4-8], wireless sensor networks (WSN) [9], WiMAX, ZigBee and so on, which can potentially be applied to and integrated into power distribution networks. The PLC systems generally operate by transmitting a modulated carrier signal on the wiring system [10]. It benefits from the ubiquity of already existing electrical power delivery networks and promises access to telecommunication service in every corner of a house without requiring installation of new infrastructure. The PLC in Smart Grid has been studied [10]. The PLC itself has low-speed shortcomings for data communication. In order to make the power distribution network communication reliable and robust, we need to improve the transmission media or use certain technologies. Bisceglie et al. argued that [10], as a result of the growing issues related to the quality of power line communication, the system of wide scope voltage checking is more demanding. In sensor networks (WSNs), every node could calculate local, global performances using local information and information exchanged with neighboring nodes.

Multiple Relay Selection Scheme [11] and Reed Solomon (RS) code [12] is concatenated as an inner code to improve the communication performance. Motivated by these ideas, combined with a variety of effective

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network routing algorithm [13], the communication system designs are analyzed through two representative medium voltage networks (33 and 11 kV) based on Figure 1 modeling approach and assessment framework.

In this paper, a scheme of dual heterogeneous networks of WSN and PLCN based on cyclic redundancy check (CRC) code, Reed-Solomon (RS) code, convolution code and the matrix interleaver respectively is proposed, inspired by the idea of cooperative communication [12]. The dual networks have higher reliability and better reliability than single network, which are suitable for the requirement of power distribution network environment. The operation model of dual networks communication with RS-CRC coding and the matrix interleaver is presented in section 3.1. Section 3.2 describes the simulations and testing results of applying CRC, convolutional code and the matrix interleaver. The performance of error frame transmission with CRC-RS-Inter and CRC-Con-Inter is presented in section 3.3. Finally, a few useful concluding remarks are given in section 4.

2 Communication system model

On the basis of discussion and analysis of the power line communication and wireless sensor networks (WSN), this paper design of dual networks communication module adopting WSN and power line communication network (PLCN). Both networks are introduced with noises of different distribution, so that one of the networks is independent fading network. We consider two binary symmetric channels as WSN and PLC network, the initial seed of which are different. We assume that two networks transmit same information m(t) at the same time. CRC, RS, and interleaving are cascaded, which compose CRC-RS-Inter link. CRC-Inter-Con link is get with CRC, interleaving and convolution cascading. By combining CRC-RS-Inter and CRC-Inter-Con coding mechanisms, we expect that our proposed model can serve power communication with better reliability requirements. In PLC system, the electric facilities are generally stationary installed, they are rarely be moved, so the performance demand of mobility is low. Good mobility of WSN system made up for shortcomings of PLC system very well. Once a sensor node can't detect an event, PLC system can ensure the normal communication. The logic structure of dual-network module is shown in Figure 1.

Random binary numbers m(t) are transmitted in WSN and PLCN network, which are generated by Bernoulli Binary Generator. Firstly, information data are checked with CRC Generator (CRC-32). Then each data frame (or packet) is appended with 32 check bits is encoded into one RS codeword. Cyclic redundancy check (CRC) code is concatenated as an inner code. RS(n, k) codeword used Equation (1) to calculate the length code n, m is m hexadecimal number, $q(q \geq 2)$ is integer number.

$$n = m - 1 = 2^q - 1 . \quad (1)$$

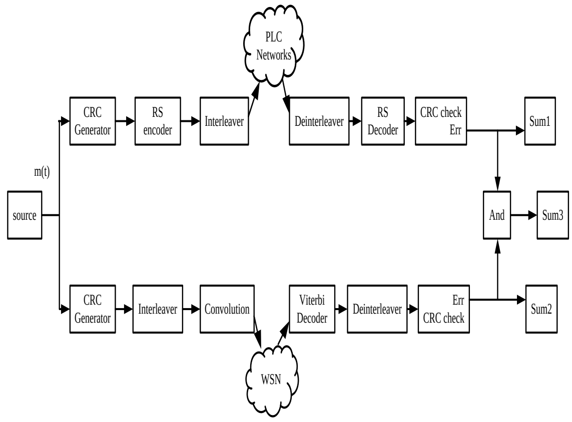

FIGURE 1 Logic structure of dual-network module

RS(31,15) is selected, which has been used in military communication. Since Binary Symmetric Channel (BSC) can reflect the characteristics of two different networks when set up different error probability, so BSC is selected approximately equal to the characteristics of PLCN and WSN. By using the method of corresponding decoding arithmetic, CRC-32 Syndrome Detectors check each error frame and output check result in receiving terminal. If the error of frame happens in data frame, the port of terminal outputs mark information 1.When date frame has no error in course of transmission, it will output mark information 0. Finally, we get transmission results of dual networks by doing logic operation between output values of WSN and PLCN. *Sum1* and *Sum2* terminals applied to calculate the error frames transmitted by WSN and PLCN, respectively. Error frames transmitted in the dual networks' result are got by *Sum3*. The bit error rate (BER) of dual-network is calculated with logic terminal, Error Rate Calculation and Cumulative Sum logic module on the matlab software platform of computer.

3 Communication system design

System study is divided into the following three parts: part 1, both networks use CRC, RS and interleaving code (CRC-RS-Inter). In order to get two single-networks about PLCN and WSN, two BSC are set with different parameters. Part 2, in this section, both networks transmit message with CRC, convolution and interleaving code (CRC-Con-Inter). Part 3, we use CRC-Con-Inter to approximate PLC networks, and CRC-RS-Inter to model WSN. Here we focus on the major parameters of probability of frame error transmission (PET) and bit error rate (BER) for the dual networks and two single-networks in power communication.

PET used Equation (2) to calculate, *e* is error frame transmission number, *t* is total frame transmission number. Both *e* and *t* are integer number. BER has a similar definition with Equation (2).

$$PET = \frac{e}{t} . \quad (2)$$

3.1 PERFORMANCE OF DUAL NETWORKS WITH RS AND INTERLEAVING

The relationship between probability of frame error transmission and the network error probability in PLC network, wireless sensor networks and dual networks with convolution codes are shown in Figure 2. Here, the frame length is 1468 bits, and 2090 data frames are transmitted continuously. When the network error probability is less than 10-2, all the frames can be received successfully. As the network error probability increasing, the probability of frame error transmission becomes appear. When the network error probability of WSN and PLCN is 0.03, the error probability of single network system is about 0.3828, 0.3962 respectively, and the dual-network system is 0.1459.When *NEP*>0.03, the curves of error transmission rates are gradually increasing rapidly, but frame error rate of dual networks (i.e. Dual networks-RS in Figure 1) is less than that in single networks (i.e. PLCN-RS, WSN-RS in Figure 1). When *NEP*=0.04, frame error rate of single network is bigger than 0.5, date packets can't be effectively transmitted. When the network error rate increased to 0.06, the frame error rate of single network and dual networks are all almost to 1, at this time, system will not be able to transmit data frames rightly.

The figure below shows the bit error rate under different network error rate condition. The bit error rates of two single-networks are almost consistent (i.e. PLCN-RS, WSN-RS in Figure 2), and the curve of dual networks mechanism (i.e. Dual networks-RS in Figure 2) is lower obviously. For example, when network error probability is 0.01, the bit error rate of PLC network and WSN are 5.53×10^{-6}, 9.98×10^{-6}, while dual network is less than 10^{-9}; when network error probability is 0.05, the bit error rate of PLC network, WSN and dual network are 0.0181,0.0189 and 3.4288×10^{-4}. When bit error rate is 0.1, they become 0.0964, 0.0971 and 0.0093 respectively.

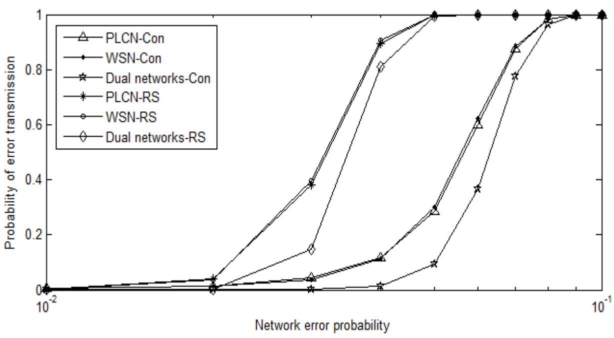

FIGURE 2 The relationship between probability of error frame transmission and the network error probability about WSN, PLCN and dual networks

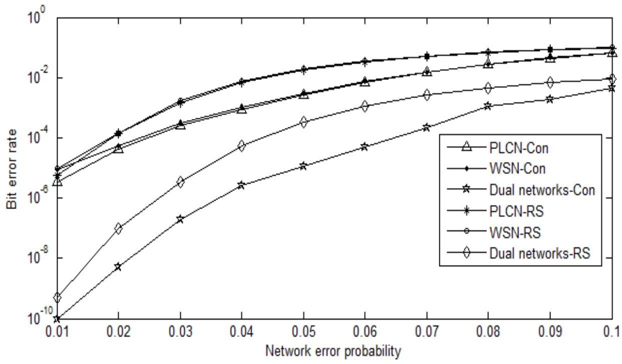

FIGURE 3 The relationship between bit error rate and network error probability about WSN, PLCN and dual networks

Figure 4 shows the relationship curve of probability of error frame transmission and the frame length about WSN, PLCN and dual networks, and the network error probability of PLCN and WSN are set to be 3×10^{-2} in the simulation. It can be seen that, with the frame size increasing, the frame error rate has a tendency to increase. What's more, the probability of error packet transmission of dual networks (i.e. Dual networks-RS in Figure 4) is less than the probability of error packet transmission of single WSN (i.e. WSN-RS in Figure 4), PLCN (i.e. PLCN-RS in Figure 4) network. For instance, *PET* for PLCN and WSN scheme are 0.2913 and 0.3288, while *PET* for dual networks system is 0.0928, when the frame length is 1093bits. When frame length is 2893bits, the *PET* for two single network become to be 0.6249, 0.6239, where the reliability of the single network significantly get worse, but The *PET* for dual network is only 0.3893, which still has high reliability. The *PET* of dual network is 0.6086, when frame length increased to 4693. At this packet size, almost no data is transmitted successfully to the destination in single network.

3.2 PERFORMANCE OF DUAL NETWORKS WITH CONVOLUTION CODE AND INTERLEAVING

We can see in Figure 2, probability of frame error transmission increases with network error probability increasing. Compared to single communication links of PLCN and WSN, the dual-network has higher successfully transmission rate. The error probability of single network system is about 0.114 and 0.117, when the NEP of WSN and PLCN is 0.04, while the dual-network system is 0.013.When *NEP*>0.04, the communication quality gets bad rapidly. When *NEP*=0.06, the error rate of dual-network is about 0.37, where can communicate with high quality. Under the same condition, dual networks with CRC-RS-Inter coding has no packets receive rightly. The *NEP* of dual networks with CRC-RS-Inter (i.e. Dual networks-RS in Figure 2) is higher than the *NEP* of dual networks with CRC-Con-Inter (i.e. Dual networks-Con in Figure 2), what indicates the CRC-RS-Inter system has better probability of successful transmission.

Figure 3 also describes the PLCN, WSN and dual-network with CRC-Con-Inter coding. Compared with dual CRC-RS-Inter communication (i.e. Dual networks-RS in Figure 3), dual network with convolution code as inner code (i.e. Dual networks-Con in Figure 3) gets smaller bit error rate, which ensure good reliability and robustness. For example, when network error probability is 0.04, the bit error rate of two single networks in CRC-RS-Inter are 0.007 and 0.0075,which in CRC-Con-Inter are 8.9×10^{-4} and 9.9×10^{-4}, and the bit error rate of dual networks in CRC-RS-Inter is 5×10^{-5} ,which in CRC-Con-Inter is 2.6×10^{-6}. The bit error rates in CRC-RS-Inter are 0.0681, 0.0688 and 0.0046, and what in CRC-Con-Inter are 0.0269, 0.0277 and 0.0011, when network error probability is set to be 0.08.

The relationship about the probability of frame error transmission and the frame size about WSN, PLCN and dual networks in CRC-Con-Inter are shown in Figure 4. Along with the frame size increasing, the frame error rate has a same tendency of increase. Dual networks (i.e. Dual networks-Con in Figure 4) show better performance than PLCN (i.e. PLCN-Con in Figure 4) and WSN (i.e. WSN-Con in Figure 4) single network. For instance, *PET* for PLCN and WSN scheme are 0.0916 and 0.0969, while *PET* for dual networks system is 0.0096, when the frame length is 1093bits. When frame length is 1693bits, the *PET* for two single network and dual-works become 0.1214, 0.1258 and 0.016. When frame size grows to 4993bits, they become to be 0.2325, 0.2195 and 0.0553. Especially the *PET* of dual networks in CRC-Con-Inter is always smaller than the *PET* for dual networks in CRC-RS-Inter structure under the same frame size. When frame lengths are changed, curve of dual networks-RS change obviously, however, the variety is little.

3.3 PERFORMANCE OF ERROR FRAME TRANSMISSION WITH CRC-CON-INTER AND CRC-RS-INTER

In this section, a dual networks system has been developed for the distribution network. As we known, RS code has a strong ability of correcting burst error, so RS code is commonly used in wireless communication systems. We consider CRC-RS-Inter coding link as WSN, and CRC-Con-Inter link to be PLC network. The simulation analysis is done as following.

The frame size is fitted as 1468 bits. Figure 5 represents the relationship between bit error rate and network error probability about WSN, PLCN and dual networks. The bit error rate of dual networks is less than the bit error rate of single WSN, PLCN network, when the network error probability belongs to [0.01, 0.1], which denotes that dual-network enable high performance. Such as when *NEP*=0.03, bit error rate in WSN is 0.0016, and it in PLCN is 2.2×10^{-5}, but bit error rate for dual networks is only 3.3×10^{-7}. Then we study the mixing dual networks (i.e. Dual networks-Mixing), dual network which both use RS code as inner code (i.e. Dual networks-RS) and dual network which both consider involution code as inner code (i.e. Dual networks-Con). The curve of dual networks with mixing code method is higher than curve of dual networks-Con, however lower than dual networks-RS. Although the reliability of dual networks with mixing links isn't the best, but this model is closer to reality. The simulation results show that this system has well quality of communication. For example, when *NEP* is 0.01, the bit error rate of dual networks with mixing links is less than 10^{-9}; when *NEP*=0.05, the bit error rate is about 5.1×10^{-5}. When *NEP*=0.07, the bit error rate become to be 7.5×10^{-4}.

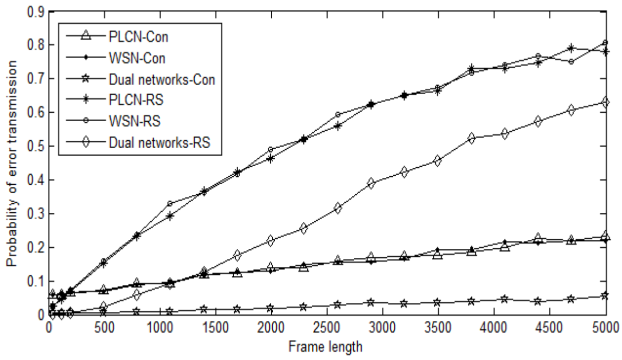

FIGURE 4 The relationship curve of probability of error packet transmission and the frame length about WSN, PLCN network and dual networks

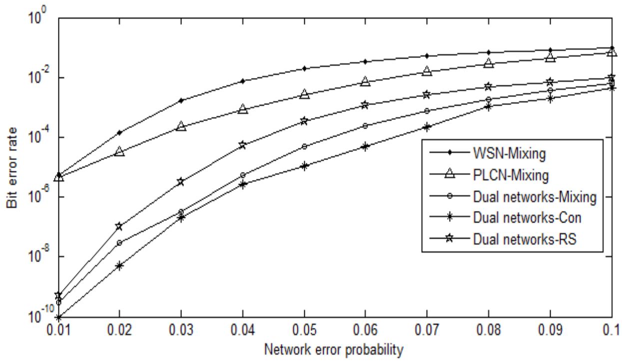

FIGURE 5 The relationship curve between bit error rate and network error probability about WSN, PLCN and dual networks

4 Conclusions

In industrial area, communicate often accompanied by various kinds of interferences. So it usually requires communication system has higher reliability (*BER* less than 10^{-9}). Many communication schemes cannot meet the strict requirements in power distribution network control environment. In this paper, we proposed novel dual heterogeneous networks communication model with WSN and PLCN, which transmit original information at the same time, on which is an improved method based physical layer. The simulation results indicate that the reliability of dual-network is better than that in single-network. Along with network error probability increasing sharply, the probability of frame error transmission of dual-network increases slowly. What's more, the reliability and robustness of dual-network with the interleaving, CRC code and convolution code concatenated are higher than that in dual-network with CRC code as inner code of RS code. In the end, in order to close to real communication environment, we put forward mixing the interleaving, CRC code and convolution code concatenated respectively to simulate the communication quality of WSN and PLCN. The bit error rate is analysed, and results show that the dual-network obviously improves the service quality of the power distribution network communication. Dual networks with PLCN and WSN is an ideal solution when realized good reliability and seamless coverage.

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