# A Suitable Coding Scheme for Broadband Power-line Communication

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*Abstract*— **This paper introduces three coding strategies for using the Luby Transform (LT) code in a relay aided power-line communication scheme. In the first method, the relay decodes the received packets and re-encodes them for transmission towards the destination. In the second method, the relay only forwardes a random linear combination of its received packets towards the destination, while in the third method the relay tries to maintain the robust soliton distribution by favoring the first degree packets. Simulation results demonstrate that the use of LT codes in a network can significantly improve the system performance and reduce the overhead both in presence and in absence of impulsive noise. Also it is investigated that the first method outperforms the two ones but it has a higher complexity at the relay node.**

***Index Terms-*** LT codes, network coding, relay aided PLC, robust soliton distribution.

## I. INTRODUCTION

Broadband Power Line Communication (BPLC) can be a suitable infrastructure for modern multimedia applications such as broadband internet and Smart Grid applications. As a result, there has been a clear tendency to get power-lines communication (PLC) to operate in high frequency band (2-30 MHz) where data rates up to 200 Mbps can be achieved. But since power-lines are not designed for communication purposes it is difficult to guarantee communication reliability under adverse channel condition caused by frequency selectivity, time varying and noisy condition of power-lines. Thus, reliable communication over power-lines is only achievable if data is duly protected by using a suitable coding scheme [1]-[3].

Since BPLC is used for high data rate applications, there is no fixed-rate code that is robust against severe variations of channel statistics in time-varying power-line channel, unless it operates at a rate that is much below the channel capacity. Therefore using a new class of codes, named rateless or fountain codes, facilitates reliable communication over power-line. The performance of Luby Transform (LT) codes and Raptor codes, which are classes of fountain codes, has been considered in

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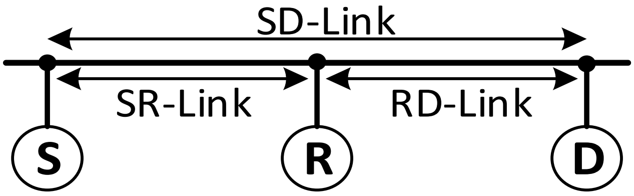

Fig. 1. GENERAL STRUCTURE OF RELAY AIDED POWER LINE COMMUNICATIONS (RA-PLC) SYSTEM

BPLC channels in [4] and [5] respectively. The results show that especially at lower values of signal-to-noise ratio (SNR), these rateless codes can greatly improve the performance in comparison to conventional fixed-rate codes. However the works in [4] and [5] only consider a direct-link BPLC.

Due to the exponential power loss over PLC channels and existence of several noise components consisting of colored background noise and impulsive noise, the use of direct communication over long PLC channels results in limited capacity and data rate. Relay-Aided PLC (RA-PLC) can overcome these limitations [7]. A relay-aided power-line communication has been investigated in [6] and [7] and results show that RA-PLC significantly improves the data rate and the network coverage. However these works have not considered any coding scheme in transmission.

In this paper, LT codes are investigated in RA-PLC systems. Because of the frequency selective property of power-line channels, the well-known multi carrier technique Orthogonal Frequency Division Multiplexing (OFDM) is considered as the modulation scheme. In OFDM, the total available bandwidth is effectively divided into *N* sub channels each of which is modulated with a separate symbol stream. Since each sub-channel has a bandwidth smaller than the coherent bandwidth of the channel, frequency response is almost flat in each sub-channel [2].

In this paper three cooperative protocols will be described, namely: (i) decode and forward at relay, (ii) linear combination at relay and (iii) selective combination at relay. Also, the performance of LT code against impulsive and background noise in power-line channels has been examined.

The rest of this paper is organized as follows: In section II, the system model is presented. Section III describes the coding scheme while section IV introduces the proposed algorithms and represents the simulation results. Concluding remarks are presented in section V.

## II. SYSTEM MODEL

Consider a relay aided power-line channel as shown in Fig. 1 with single antenna nodes. In this network, information is transmitted from source node S to destination node D with the assistance of the relay node R. It is assumed that channel state information (CSI) is available at the receiver side but not at the transmitter side. Also relay node uses the same transmission power as the source. The source-destination distance is equal to 90 m and the relay is located at the middle distance of source-destination. Due to the frequency selectivity of PLC channel, OFDM is used as the modulation scheme for data transmission and LT codes are used to combat the channel impairments.

TABLE I. POWER-LINE CHANNEL FREQUENCY RESPONSE PARAMETERS

| | | |
|---|---|---|
| $N$ | Number of the path, where the path with the shortest delay has the index $i = 1$ | 1 |
| $a_0$ | Attenuation parameters | $-2.3 \times 10^{-3}$ |
| $a_1$ | | $3.75 \times 10^{-7}$ |
| $k$ | Exponent of the attenuation factor | 0.7 |
| $g_i$ | Weighting factor for path $i$ | 1 |
| $d_i$ | Length of path $i$ | 90 (m) |
| $v_p$ | Velocity of the light | $3 \times 10^8$ (m/s) |

### *A. Power-line Channel Model*

In this paper, the channel model is assumed to follow the statistical power-line channel model presented by Zimmermann in [9] that is a general channel model used by several researchers:

$$H(f) = \sum_{i=1}^{N} \underbrace{g_i}_{\substack{weighting\\ factor}} . \underbrace{e^{-(a_0 + a_1 f^k).d_i}}_{\substack{attenuation\\ portion}} . \underbrace{e^{-j2\pi f(d_i/v_P)}}_{\substack{delay\\ portion}} \tag{1}$$

Where parameters in (1) are described in Table I. According to [9], considering a number between 1 and 4 of multipath components ($N$) is a reasonable assumption. In this paper we consider a 90 m between the source and destination nodes.

### *B. Background and Impulsive Noise Model*

PLC noises can be classified in two general categories: background noise and impulsive noise. Background noise in the power-line is considered to be a colored noise with the power spectral density (PSD):

$$10\log_{10} N(f) = b + cf^d \tag{2}$$

Where values of the parameters $b$, $c$ and $d$ are considered to be −105, 90 and -0.5 respectively[7].

The impulses in power-line are causes by switching transients in the network and have durations of some microseconds up to a few milliseconds with random occurrences. These impulsive noises can reach the PSD values of more than 50 dB above the background noise and thus may cause numerous bits or burst errors in data transmission [10]. In this paper we use two simplified Markov models to represent burst errors caused by impulsive noise proposed by [4].

This model has two layers each described by a Markov chain. The first layer describes the event of occurrence of burst impulses and the second layer expresses the event of a single impulse within the burst event. For higher layer, the Markov model has two states: disturbed and undisturbed. Where in undisturbed state there is no impulse noise and within the disturbed state there are two other states with lower time resolution: noise and no noise. It means that when an impulse noise occurs (disturbed state), it may cause burst errors or some single errors due to a probability transition matrix $P_2$.

Fig. 2 illustrates these Markov models along with their transition probabilities.

According to [4], the stationary state distributions of first and second layer models are given as:

$$\pi_1 = [\pi_{1,1} \quad \pi_{1,2}] = [0.995 \quad 0.005], \quad \pi_2 = [\pi_{2,1} \quad \pi_{2,2}] = [0.5 \quad 0.5] \tag{3}$$

Where $\pi_{1,2}$ defines the probability of impulse noise occurrence and $\pi_{1,1}$ is the probability of absence of impulse noise . Also $\pi_{2,1}$ and $\pi_{2,2}$ are probability of occurrence of error in a disturbed state.

In addition, the transition probability matrices for first and second layers are respectively:

$$P_1 = \begin{bmatrix} 0.999 & 0.001 \\ 0.2 & 0.8 \end{bmatrix}$$
$$P_2 = \begin{bmatrix} 0.98 & 0.02 \\ 0.02 & 0.98 \end{bmatrix} \tag{4}$$

Where $P_1$ describes transition probability between presence of impulse noise and absence of impulse noise. And $P_2$ includes transition probability between burst and single errors occurrences.

### C. Coding and OFDM

The OFDM scheme uses 32 sub-channels in 2-20 MHz. Each sub-channel has a relative bandwidth of 562.5 KHz that according to [8] is smaller than coherent bandwidth of power-line channel. Also Quadrature Phase Shift Keying (QPSK) is used for each sub-carrier.

The LT code is used to transmit data. More details about the coding properties is presented in the following section.

## III. CODING TECHNIQUES

Luby Transform Code or LT code is a class of fountain codes that are useful for sending data over erasure channels. Using appropriate coding schemes such as cyclic redundancy codes (CRC), the channel can be considered to be an erasure channel. Fountain codes are rateless in the sense that the number of encoded packets generated from the source message is potentially limitless and is determined on the fly. The encoder of a fountain code generates an endless supply of encoded packets from limited original file and the original source data can be decoded from any set of encoded packets that is slightly larger than the original file. In fact, LT code is a sparse random linear fountain code with a super-cheap approximate decoding algorithm [11].

Let us assume that $s_1, \dots, s_K$ are generated packets in source. Each encoded packet $t_n$ is produced by the source from (5):

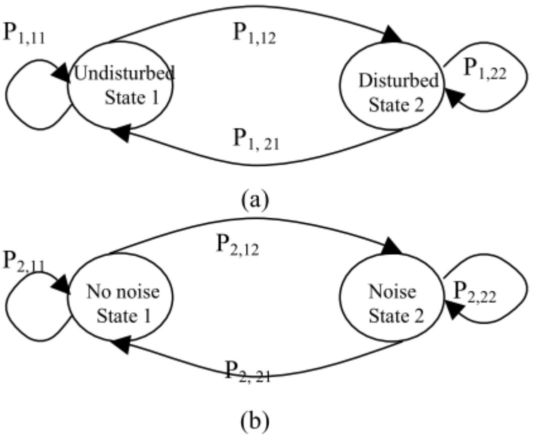

Fig. 2. MARKOV MODEL FOR BURST NOISE: (A) MODELING BURST GROUPS (B) MODELING SINGLE IMPULSES WITHIN A BURST GROUP

$$t_n = \sum_{k=1}^{K} s_k G_{kn} \tag{5}$$

Where in (5) the $G_{kn}$ is a random sequence of bits produced by the encoder and is used to select the bits of the original packets to be sent to the receiver. The transmitted packet $t_n$ is then the bitwise sum, modulo 2, of the source packets for which $G_{kn}$ is 1. Then the original package can be decoded from:

$$s_k = \sum_{n=1}^{N} t_n G_{nk}^{-1} \tag{6}$$

Encoding procedure is described as follow:

1. Randomly choose the $d_n$ of the packet from a degree distribution $\rho(d)$; the appropriate choice of $\rho$ depends on the source file size $K$, as we will discuss later.
2. Choose, uniformly at random, $d_n$ distinct input packets, and set $t_n$ equal to the bitwise sum, modulo 2, of those $d_n$ packets.

This encoding operation defines a graph connecting encoded packets to source packets. If the mean degree $d$ is significantly smaller than $K$ then the graph is sparse. LT decoding procedure is described as follow. We will call the encoded packets $t_n$ check nodes.

1. Find a check node $t_n$ that is connected to only one source packet $s_k$ (if there is no such check node, this decoding algorithm halts at this point, and fails to recover all the source packets).
    a. Set $s_k = t_n$ .
    b. Add $s_k$ to all check nodes $t_{n'}$ that are connected to $s_k$: $t_{n'} = t_{n'} + s_k$ for all $n'$ such that $G_{n'k} = 1$.
    c. Remove all the edges connected to the source packet $s_k$.
2. Repeat (1) until all $s_k$ are determined.

The probability distribution $\rho(d)$ of the degree is a critical part of the design. According to [11],We use robust soliton distribution $\mu(d)$ for degree distribution, in order to ensure that there are not some source packets that are not connected to any node and also that in each iteration there is at least one check node who has degree one in the graph:

$$\mu(d) = \frac{\rho(d) + \tau(d)}{Z} \tag{7}$$

$$Z = \Sigma_d \, \rho(d) + \tau(d) \tag{8}$$

Where $\rho(d)$ is soliton distribution defined:

$$\begin{aligned} \rho(1) &= \frac{1}{K} \\ \rho(d) &= \frac{1}{d(d-1)} \quad \text{for } d = 2,3,\cdots,K \end{aligned} \tag{9}$$

And:

$$\tau(d) = \begin{cases} \frac{s}{K}\frac{1}{d} & d = 1,2,\cdots,(\frac{K}{S})-1 \\ \frac{s}{K}\log(\frac{S}{\delta}) & d = \frac{K}{S} \\ 0 & d > \frac{K}{S} \end{cases} \tag{10}$$

Where $S$ is the expected number of degree-one check nodes and is equal to:

$$S \equiv c \log_e(\frac{K}{\delta})\sqrt{K} \tag{11}$$

Parameters $c$ and $\delta$ are used for designing the sparse-graph code.

Sending coded data through the erasure channel is commonly based on channel estimation at transmitter to adapt transmission rate to the quality of the channel. This fixed-rate coding at transmitter must be designed to carry a rate below the capacity of the channel. Using fixed-rate codes may be an efficient solution for transmission over channels with static characteristics but it's not robust to the severe variation of channel statistics in power-lines unless it operates at a very low rate.

LT codes generate an infinite number of code packets without any knowledge about channel statistics and send them to the destination. During this endless transmission, some packets will be erased cause of channel distortion but it doesn't have any effect on transmission manner. The destination ignores these erased packets and gathers other packets until the message has been successfully decoded. In practice, this may correspond to the case where CRC bits are embedded within the original message. It is assumed that the entailed rate loss is negligible.

## IV. SCENARIO DESCRIPTION AND SIMULATION RESULTS

Three different cooperative protocols are described in this section depending on how the source, the destination and the relay operate during the transmission process.

### *A. Scenario 1: decode and forward at relay*

In this scenario, the transmission of data stream over the RA power-line channel is divided into two phases:

1. In phase one, the source node transmits coded data to the destination and the relay node, which is located between source and destination. Both relay and destination decode as described in section III. Since the relay node is located half way between the source and the destination and the fact that channel attenuation increases exponentially with the distance, it is expected that coded data is received with fewer errors in the relay. As a result the relay node could decodes the received message earlier than the destination. After the relay decodes the message successfully, it sends the source an acknowledgment signal and the source will stop transmitting.
2. In phase two, the relay node encodes the data and transmits it to the destination on its own. So the destination decodes based on both data received from the source in phase one and data from the relay in phase two.

Shows the probability of decoding failure at the destination versus the total received overhead from source and relay in destination in scenario 1, in comparison to No-relay scenario in which there is no relay in the network and the source transmits coded data to the destination.

As shown in Fig. 3, the amount of received overhead at the destination will decrease significantly by using a relay in the described coded network in comparison to no-relay scenario. The amount of transmitted overhead from source node is also illustrated in Fig. 3 so it's deduced that the source transmission power and running time will decline by approximately a factor of seven compared to no-relay scenario.

Occurrence of impulsive noise in channel will erase lots of packets due to burst errors and will increase amount of transmitted overhead dramatically. Those almost flat lines on Fig. 3 graphs show case of the occurrence of impulsive noise during transmission. It can be seen that the described scenario is more robust against occurrence of impulsive noise in power-line channel.

In scenario 1, as relay decodes the received packets and encodes them before retransmitting them to the destination, the relay node must have complete knowledge of code generator matrix used in source and it must have the capability of decoding and encoding data. This might not be desirable in situations where idle receiver nodes are used as relays.

### *B. Scenario 2: linear combination at relay*

In scenario 2, the transmission of data stream is done in one phase: The source node transmits coded data to the destination and the relay. The relay does not attempt to decode the message, it merely combines received coded packets and sends them to the destination. It means that the relay

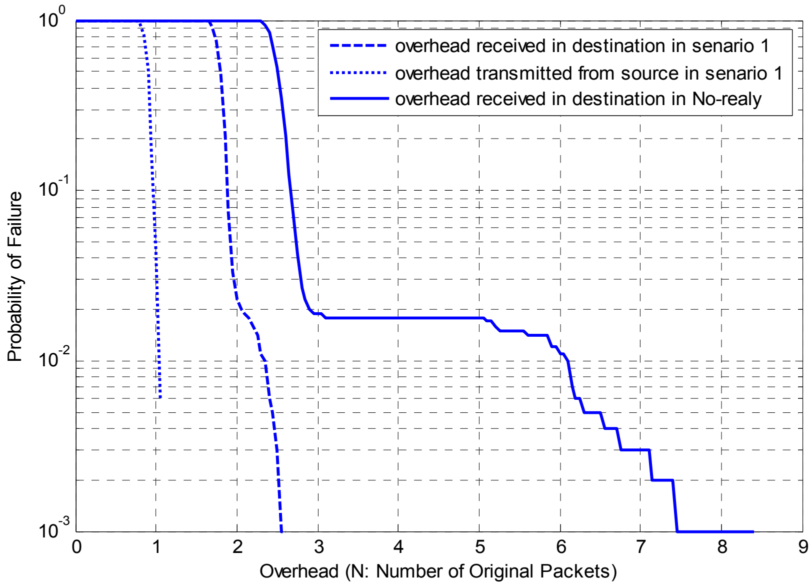

Fig. 3. PROBABILITY OF DECODING FAILURE AT THE DESTINATION VERSUS THE RECEIVED OVERHEAD IN SCENARIO 1

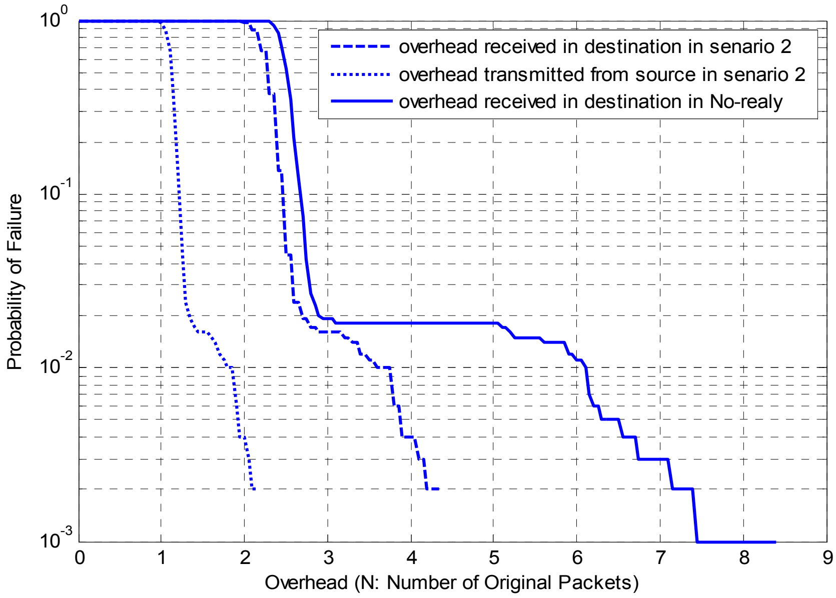

Fig. 4. PROBABILITY OF DECODING FAILURE AT THE DESTINATION VERSUS THE RECEIVED OVERHEAD IN SCENARIO 2

operates network coding on received coded packets. The destination decodes based on data received simultaneously from both source and relay.

As mentioned before, one of the main features of LT code is its sparse code graph; the combination at relay must maintain this property. The proposed method is to combine *n* received coded packets in each transmission slot, where *n* is chosen from robust soliton distribution. In each transmission time slot, a random number *n* is generated using robust soliton distribution. Then the relay chooses *n*

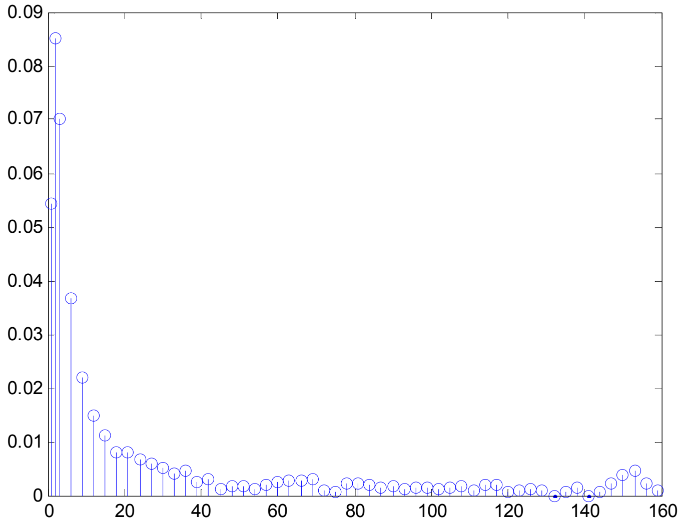

Fig. 5. THE DEGREE DISTRIBUTION OF RECEIVED PACKETS AT THE DESTINATION IN SCENARIO 2

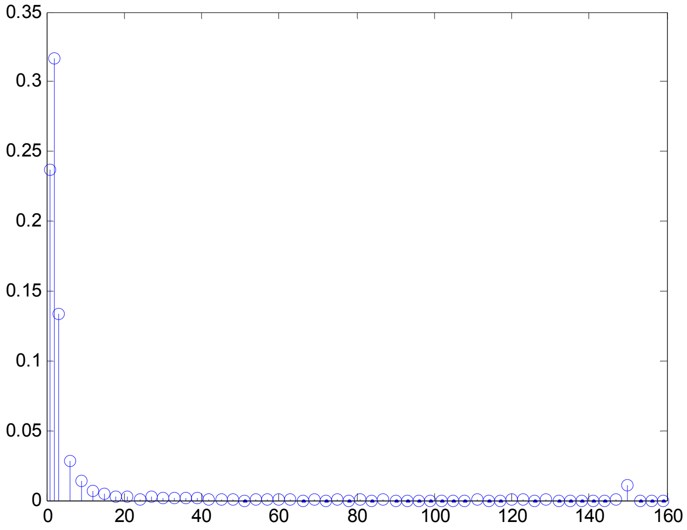

Fig. 6. THE ORIGINAL ROBUST SOLITON DISTRIBUTION

packets uniformly at random and the final coded packet is the bitwise sum, of those *n* packets.

Fig. 5 shows the probability of decoding failure at the destination versus the total received overhead from source and relay at the destination compared to No-relay scenario. As illustrated in this figure, the amount of received overhead at the destination and transmitted overhead from source will decrease noticeably by using transmission scheme described in scenario 2. It can be seen that scenario 1 is more effective in overhead reduction compared to this scenario at the cost of more complexity. As before the almost flat lines in graphs of Fig. 4 show the effect of impulsive noise.

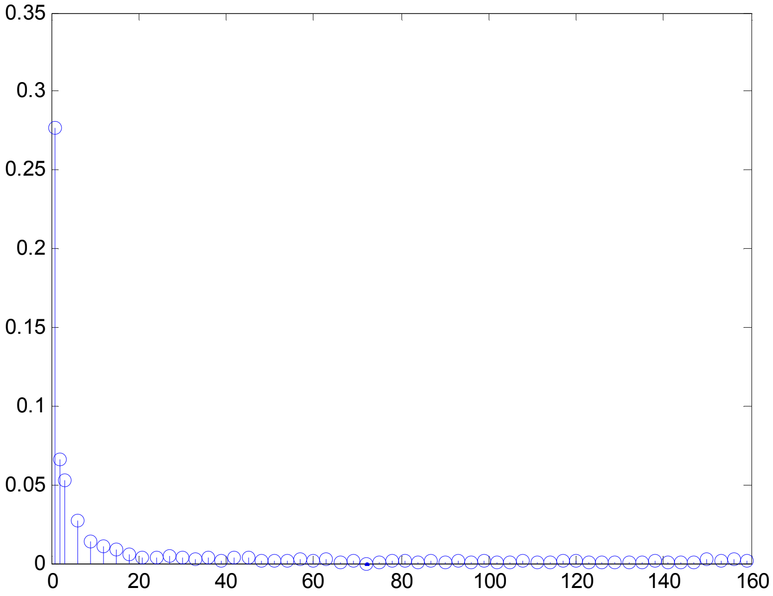

Fig. 7. THE DEGREE DISTRIBUTION OF RECEIVED PACKETS AT THE DESTINATION IN SCENARIO 3

By using the method of scenario 2, the code graph will have a degree distribution “almost” similar to robust soliton. Fig. 5 shows the degree distribution of received packets at the destination in scenario 2. As shown in Fig. 5, the main difference between the degree distribution in scenario 2 and the original robust soliton distribution (Fig. 6), is the probability of receiving a first degree packet a destination.

### C. *Scenario 3: selective linear combination at relay*

In scenario 3, the relay checks the degree of received packets and changes its strategy when the packet degree is one. In this case the relay forwards this degree one packet to the destination without any combination. The rest of transmission process will continue as in scenario 2.

As shown in Fig. 7, this selective combination in scenario 3 will result in a degree distribution of received packets that is more similar to original robust soliton distribution compared to the degree distribution obtained in scenario 2. In scenario 3, the relay needs to know the degree of each packet. This information is to be included in a packet. Fig. 8 shows the probability of decoding failure in destination versus the total received overhead from source and relay in destination, in comparison to No-relay scenario. As expected, the amount of received overhead in destination and transmitted from source will decrease noticeably in scenario 3 compared to no-relay scenario. Also these values are decreased noticeably compared to those in scenario 2. Again those almost flat lines in Fig.8 graphs show the occurrence of impulsive noise. It can be seen from smaller flat lines in Fig. 8 compared to Fig. 3 that scenario 3 is more robust against impulsive noise compared to scenario 2.

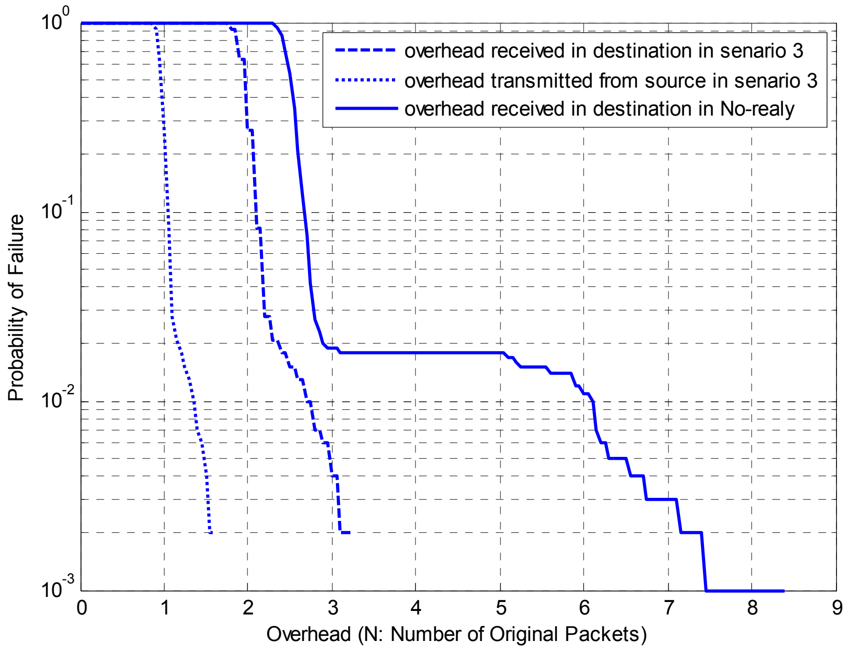

Fig. 8. PROBABILITY OF DECODING FAILURE AT THE DESTINATION VERSUS THE RECEIVED OVERHEAD IN SCENARIO 3

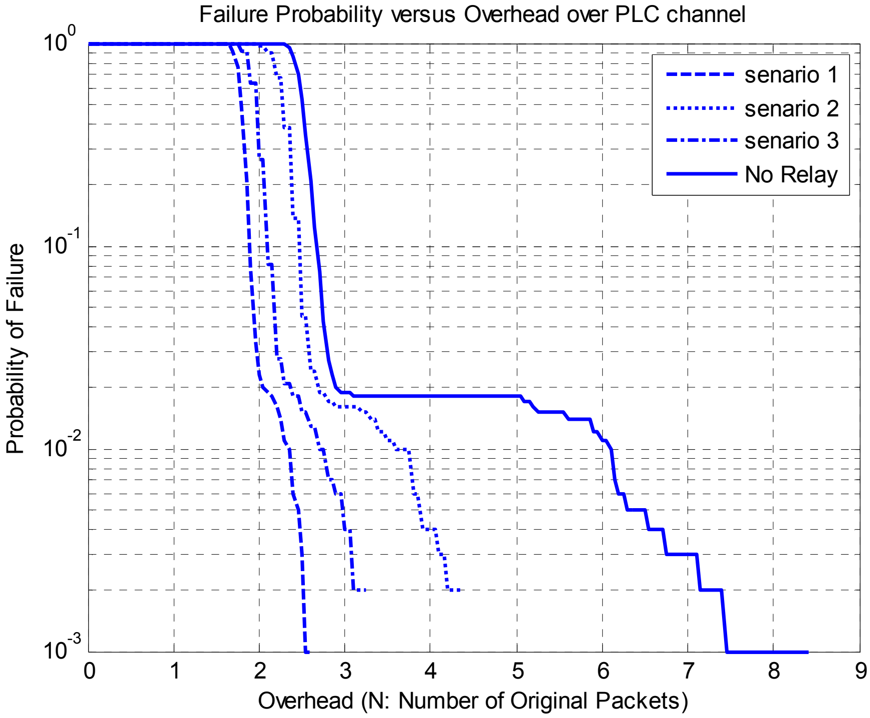

Fig. 9. PROBABILITY OF DECODING FAILURE AT THE DESTINATION VERSUS THE RECEIVED OVERHEAD

Fig. 9 depicts the comparison of different scenarios. It can be seen that scenario 1 outperforms other scenarios at the cost of more complex relay structure and that scenario 3, outperforms scenario

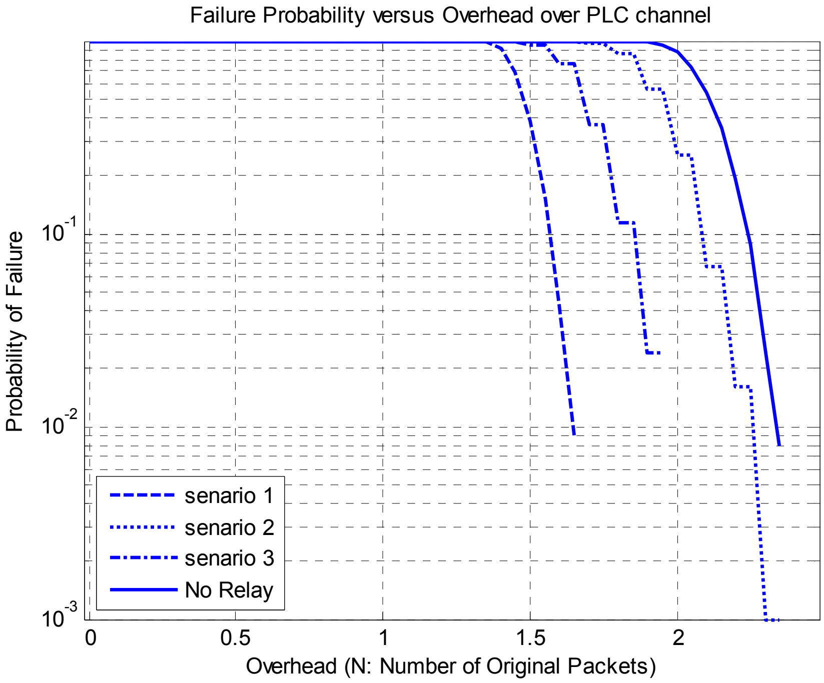

Fig. 10. PROBABILITY OF DECODING FAILURE AT THE DESTINATION VERSUS THE RECEIVED OVERHEAD WITH NO IMPULSIVE NOISE

2 due to the partial knowledge of the encoding matrix. In order to analyze the effect of background noise on performance of LT Code in RA-PLC with the three described scenarios, all simulations have been repeated by ignoring the occurrence of impulsive noise. The results are shown in Fig. 10. As expected,there is no flat line in graphs of Fig. 10. It can be concluded that these three scenarios are robust again both background noise and impulsive noise.

## V. CONCLUSION

The use of a relay node in a BPLC network using LT codes was investigated in this paper. Three different strategies where proposed. i) In the first method, the relay decoded the received packets and re-encoded them for transmission towards the destination. ii) In the second method, the relay only forwarded a random linear combination of its received packets towards the destination, while iii) in the third method the relay tries to maintain the robust soliton distribution by favoring the first degree packets. The simulation results showed that all of the proposed methods significantly improve the system performance, with scenario 1 outperforms the two other scenarios and scenario 3 outperforms the second scenario.

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