LT Codes for Video Streaming in Burst Erasure Channels: An Energy Analysis

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Abstract

The diffusion of mobile devices, that are capable to play videos, opened new challenges for video streaming applications. Since wireless communications are prone to erasures, an important goal is to research possible ways to reliably provide video content. Fountain codes are an efficient way to protect video streaming against erasures: in particular, burst erasures are the ones that can significantly reduce the quality of the transmitted video. In this work, Luby codes for burst erasure channels are investigated. Our main focus is on the design of Luby codes to make the receiver able to recover all the lost information without any retransmission. Furthermore, we analytically demonstrate that lower energy consumption is achievable by using LT codes instead of a general retransmission scheme.

Index Terms

Video streaming, LT codes, burst erasure channel, energy efficiency.

I. Introduction

In actual mobile networks, video streaming represents the biggest amount of data. For example, in north America, applications such as YouTube and Facebook, are about 40 percent of downstream traffic. During communications, mobile users can experience periods of disconnection because of mobility and conditions of the wireless link. These disconnections can be the cause of burst losses of packets.

The use of erasure codes is a method that can improve the experience of the users in terms of latency reduction and better video quality. Moreover, it can also reduce the energy consumption by avoiding retransmissions of lost information. The basic principle behind the use of erasure codes is that the original information is transmitted with additional redundant one, which can finally be used to recover

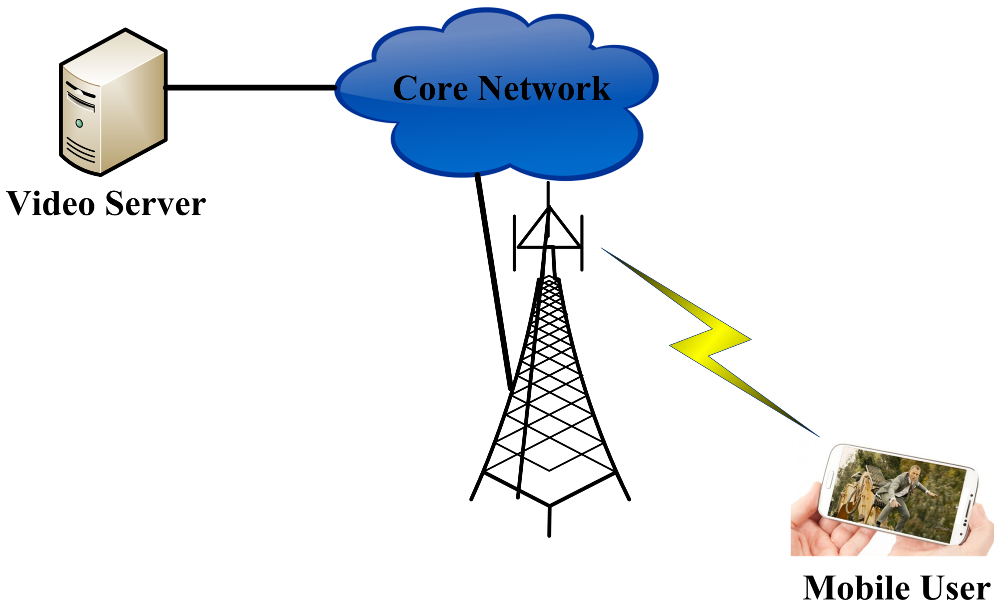


Fig. 1. The scenario analysed in this paper consists in a server which provides video streaming content to a mobile user.

lost data at the receivers. A receiver can reconstruct the source data once it receives a sufficient number of encoding symbols.

A digital fountain is an efficient way to implement erasure correction. The idea behind is that source information can be reconstructed from any subset of the received symbols, of same size of original data. Luby Transform (LT) codes [1] are a practical example of digital fountain codes.

Since their release, LT codes have become more and more important in video streaming applications. In 2007, [2] designed a novel scheme in which LT codes were used for efficient and reliable streaming of multimedia contents. Side by side, [3] proposed a method to apply systematic LT codes for error protection of H.264/AVC multi-view video streams in order to improve performances in packet erasure channels. Next, [4] described the implementation of LT codes in layered video streaming systems. Since every video layer experienced equal packet-loss rate and lower layers are more important than the higher ones, the authors proposed an unequal protection mechanism, so that lower video layers could be received with more reliability than high layers under the same packet-loss rate. In 2010, [5] designed a joint scheme for video adaptation with erasure correction codes for wireless video broadcast, called JVEC. The framework was considering the presence of a feedback channel to make the source aware of the erasure state of transmitted packets at the receiver. In this way the source could set the erasure code on the fly to guarantee the successful decoding of important frames and recovery of erased frames. The analysis of joint unequal loss protection and LT codes was also investigated by [6]. The authors assigned different error-correcting codes to different layers to keep frame priority after LT encoding process: in fact, LT codes were mainly used to deal with varying conditions of the channel. In 2013, [7] modified robust Soliton distribution of LT codes in order to have symbols with low degrees so, faster decoding. In addition to that, it defined a novel non-repetitive encoding scheme to provide unequal error protection and to avoid repetition of encoding symbols with degree one. At the same time, [8] designed a scheme based on LT codes with unequal error protection and symbol interleaving to face burst packet errors that occur in a wireless channel during the transmission of 3D video streaming. The main achievement was higher quality in the user perception of the video. Next, [9] studied how to improve the reliability of mobile peer-to-peer video multicast systems via LT codes. The authors used both the exchange of buffer map information and a push-pull delivery mechanism among peers in order to send symbols on time while reducing redundancy.

This paper analyses the error-correcting capabilities of LT codes in presence of burst erasures. The scope of our work is to achieve better performances in video streaming in terms of reduction of losses: in particular, this aspect can either reduce or avoid retransmissions, can decrease the latency and can reduce the energy consumption of the communication. Moreover, since encoding is performed at network layer independently of upper layers, each packet has equal protection. Section II describes the theoretical model, defined to simulate LT codes characteristics and the behaviour of the burst erasure channel. Finally, Section III shows analytical and simulation results.

II. System Model

Figure 2 depicts how the real scenario is modelled: an LT encoder is encoding the information packets, which are the rows of matrix $\mathbf{U}$; next, it is sending the encoded packets (elements of matrix $\mathbf{X}$) via a burst erasure channel (BEC); the BEC channel is randomly erasing e symbols in a row and then, a belief propagation (BP) decoder is trying to recover the original source data from $n-e$ encoded symbols received. A brief description of LT codes and of the model of the channel, follows.

A. LT Codes

LT codes are rateless erasure codes which generate a variable quantity of encoding symbols according to the needs. The process LT codes use to generate encoded information, is a generalisation of the classical process of randomly throwing balls into bins. The encoder receives a stream of L source bits which are partitioned into $k = L/m$ input symbols over a finite field $\mathbb{F}_q$ (with $q = 2^m$). The k symbols are belonging to K source packets, which have same size. In particular, the encoder is efficiently creating

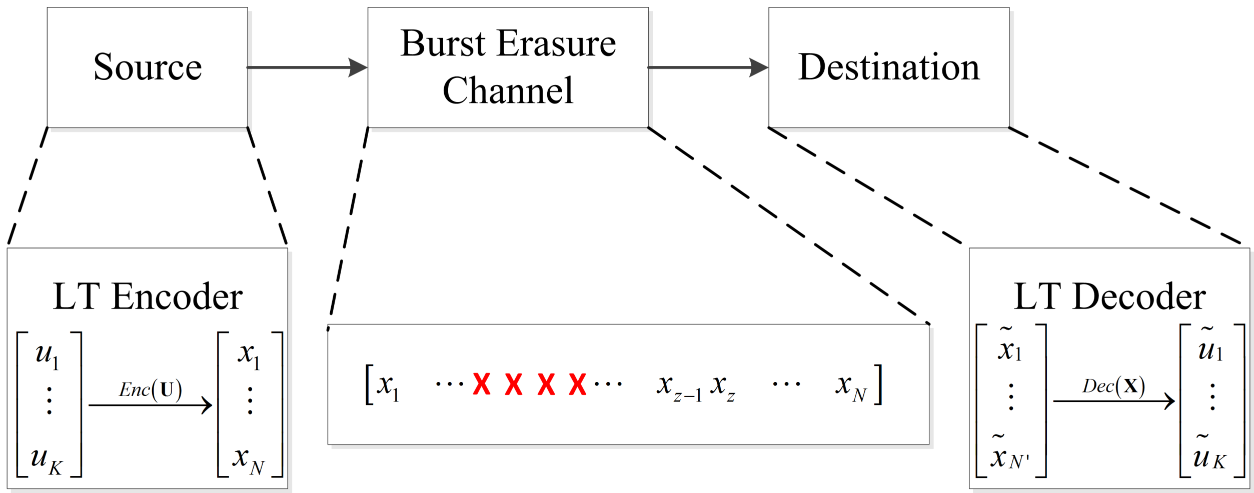


Fig. 2. The scenario depicted in Figure 1, has been modelled by a point-to-point network, in which a source is sending packets to a destination via a burst erasure channel. In order to protect the information packets against erasures, LT codes are implemented. In particular, the encoder is collecting a stream of k symbols belonging to K packets (rows of matrix $\mathbf{U}$). Then, they are encoded into a stream of n symbols which belongs to N encoded packets (elements of matrix $\mathbf{X}$). The burst erasure channel is erasing e symbols so, the decoder has to recover the source information from the $n - e$ encoding symbols received.

encoding symbols according to the so called Robust Soliton distribution. In particular, this probability distribution is the sum between the distribution

$$\tau(i) = \begin{cases} {}^{S}/_{ik} \quad \text{for } i = 1, \ldots, {}^{k}/_{S} - 1 \\ S \log \left({}^{S}/_{\delta} \right) \Big/ k \quad \text{for } i = {}^{k}/_{S} \\ 0 \quad \text{for } i = {}^{k}/_{S} + 1, \ldots, k \end{cases} \tag{1}$$

and the ideal Soliton distribution

$$\begin{gathered} \rho(1) = {}^{1}/_{k} \\ \rho(i) = 1/i(i-1) \quad \text{for } i = 2, \ldots, k \end{gathered} . \tag{2}$$

Hence, after normalising, it results to be

$$\begin{gathered} \beta = \sum_{i=1}^{k} \rho(i) + \tau(i) \\ \mu(i) = {}^{(\rho(i) + \tau(i))}/_{\beta} \quad \text{for } i = 1, \ldots, k \end{gathered} . \tag{3}$$

The parameter δ represents the upper bound on failure probability at the decoder, given a set of n encoded symbols. Next, the variable S is defined as $c\sqrt{k} \log \left({}^{k}/_{\delta} \right)$, where $c > 0$ is a constant.

The decoder implemented in this work is a BP decoder, which works as follows. First, it looks for an encoded symbol of degree one and if there are not, it returns a decoding failure. On the other

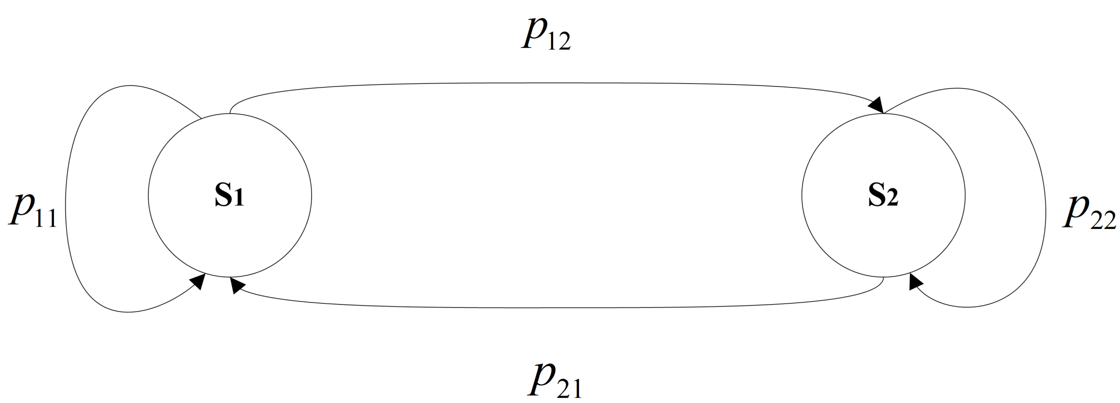


Fig. 3. Markov binary process, which models the burst packet erasure channel. The system can be either in the states S_1 or S_2, which are respectively the error-free state and the one in which packets are erased. Next, conditional probabilities p_{12} and p_{21} are the transition probabilities and p_{11}, p_{22} are the probabilities of keeping the system in the current state.

hand, a symbol of degree one directly recover the value of its neighbouring source symbol. Once this symbol is recovered, its value is added to the ones of all its neighbouring encoding symbols. Finally, the connections of this symbol with other encoding symbols, are removed. These steps are repeated till the decoding process is completed.

An important parameter of LT codes is the *average degree* D of an encoding symbol. Each encoding symbol is obtained by summing a random number of source symbols, called degree. Then, the number of source symbols used in average to create an encoded symbol is expressed as

$$D = O\left(\log\left(\frac{k}{\delta}\right)\right). \tag{4}$$

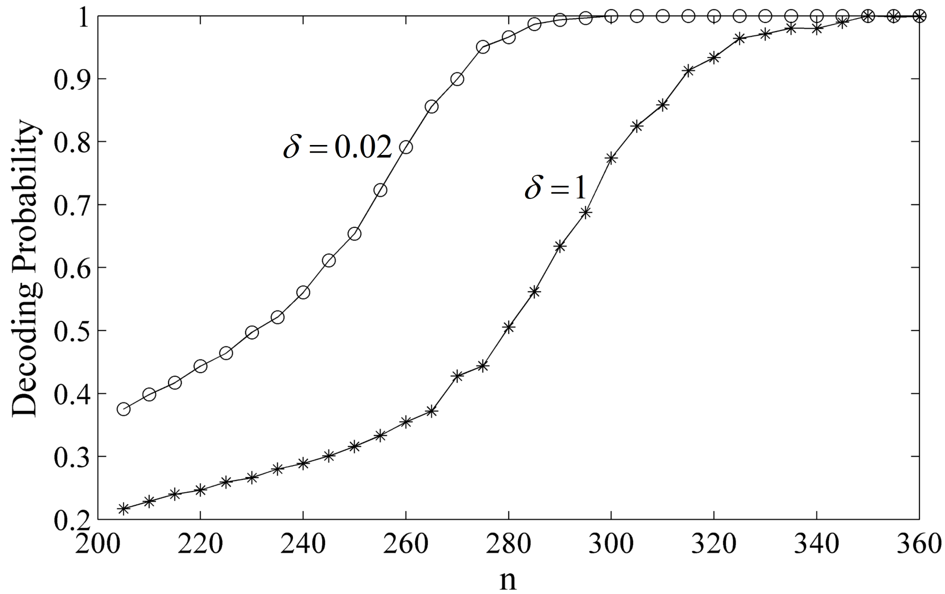
Normally, the aim is to keep D as low as possible since it represents the average number of operations, needed to generate an encoding symbol.

B. Burst Erasure Channel Model

Figure 3 shows the Markov binary process, which models the BEC. The characterisation of the channel used in this paper is an adaptation of the Gilbert-Elliot channels described in [10], [11].

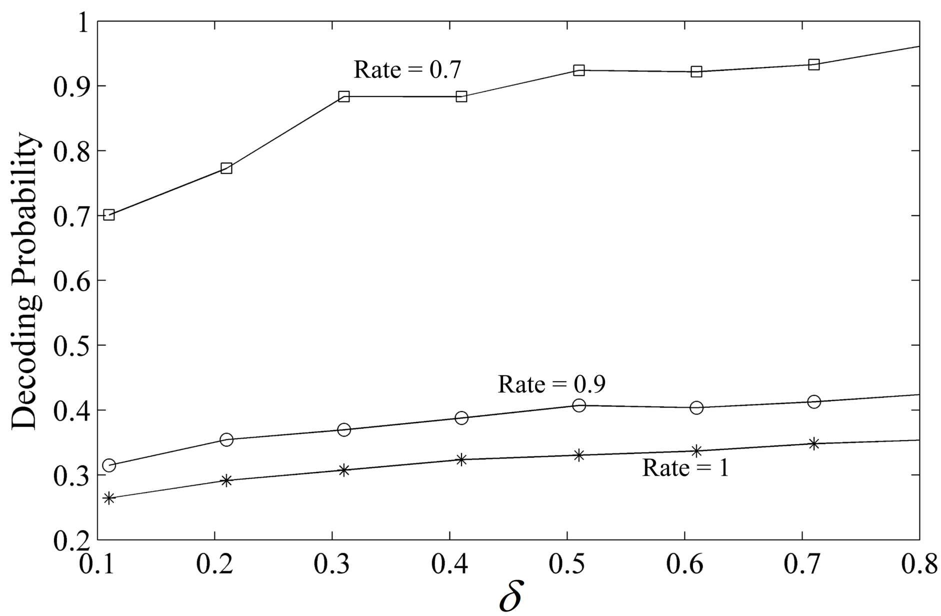
The BEC channel is a channel with memory. There are two different possible states, S_1 and S_2, which respectively are error-free transmission and erasure of symbols. The transition matrix of the channel is

$$\mathbf{T} = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \tag{5}$$



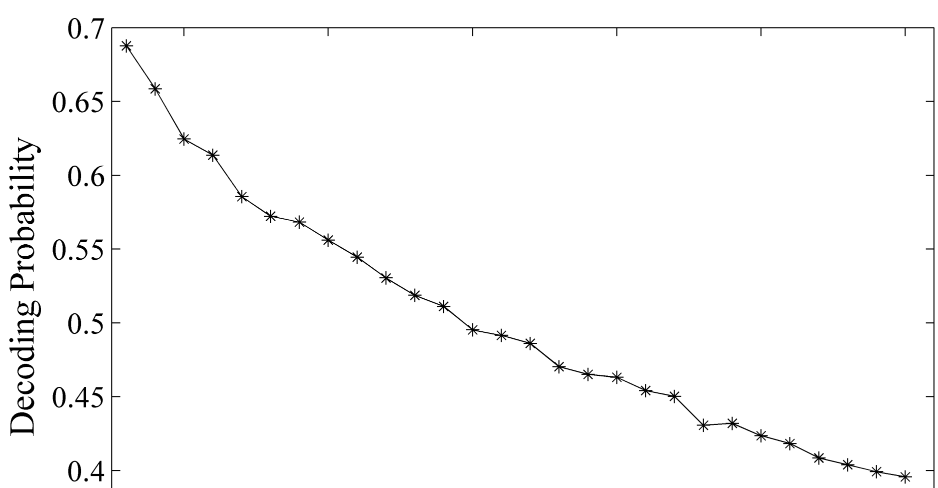
Decoding Probability
n
$\delta = 0.02$
$\delta = 1$

(a)



Decoding Probability
δ
Rate = 0.7
Rate = 0.9
Rate = 1

(b)



Decoding Probability

in which p_{12}, p_{21} and p_{11}, p_{22} are respectively the conditional probabilities of changing state and keeping the actual state. In the context of this work, the conditional probability of symbols to be erased follows a uniform distribution and the conditional probability of a correct transmission is its complement. Hence,

$$\begin{aligned} p_{22} &= \tfrac{1}{a} \\ p_{11} &= 1 - p_{22} \end{aligned} \tag{6}$$

where $a > 0$ is a constant. Side by side, the conditional probabilities of moving from one state to another one, are following exponential distributions. In order to have burst erasures of symbols, the probabilities of changing state p_{12}, p_{21} are very small compared to p_{11}, p_{22}.

III. Analysis and Simulation Results

The theoretical model in Figure 2 has been implemented in MATLAB. The source is generating source information composed by *K* packets of same size (1600 bits). Since the symbols are over a finite field of size $q = 2^8$, each packet is constituted by 200 symbols. Next, the *K* packets are concatenated in a matrix and encoded into *N* packets. In order to obtain reliable results, the simulations were performed with iteration equal to 100.

Figure 4(a) and 4(b) are obtained in presence of error-free transmission. The former simulation is important to evaluate the minimum redundancy LT codes requires to successfully decode all the information. Moreover, the parameter δ has been changed to show its influence on the decoding probability. The latter represents how decoding probability of LT codes depends on both δ and the rate of the code (defined as $r = k/n$).

Figure 4(c) and 4(d) consider the communication via the BEC defined in Subsection II-B. The first represents the successful decoding probability by increasing the burst erasure probability; the value of *n* has been fixed at the optimum value previously found in Figure 4(a) for $\delta = 0.02$. The second shows how the rate of the code changes when the burst erasure probability is increasing: in particular, *n* has been augmented to maintain a constant decoding probability of 0.9.

A. Energy Analysis

In order to keep the analysis general, the cost of a particular acknowledgment service is not included in the following definition of E_{block}. Furthermore, if all the source packets are not correctly received, all the source block is retransmitted. If no coding scheme is used, the energy spent to correctly transmit/receive each block of packets can be defined as

$$E_{block} = 2kE_{R/T} \sum_{i=1}^{b} 2e_i \tag{7}$$

where $E_{R/T}$ is the energy consumption for transmission/reception of a symbol (measured in mJ/symbol), e is the number of erasures and the b sums ($b > 1$) represent the times needed to retransmit all the packets in order to guarantee a full reception of the source block. In fact, each retransmission of erased information is also prone to burst erasures. Since each symbol is m bits, the energy consumption per bit becomes

$$E_{cons} = mE_{block}. \tag{8}$$

If LT codes are used (no retransmissions needed), E_{block} and E_{cons} respectively become

$$E_{block_{LT}} = nE_{R/T} \tag{9}$$

and

$$E_{cons_{LT}} = mE_{block_{LT}}. \tag{10}$$

Hence, when the condition

$$n \leq 2k \sum_{i=1}^{b} 2e_i \tag{11}$$

is verified, LT codes consume less energy per bit then the basic retransmission scheme considered.

By applying the results of Figure 4(d) in the equations above, the implementation of LT codes results in a lower energy consumption. This is clearly drawn in Figure 5: by varying the burst erasure probability, the energy consumption needed to send a block without LT codes grows more than the one required by LT codes. Moreover, while LT codes are successful at the first transmission, the 'no code policy' requires several retransmissions: that also results in an augmented latency.

IV. Conclusion

This paper studied LT codes for video streaming. In particular, the aim was to fully investigate if LT codes could, at the same time, make the communication reliable and reduce the total energy consumption of the transmission. First, the nature of LT codes was analysed: especially, some simulation results were fundamental to understand how to set main parameters to optimise LT codes. Next, the error-correcting capabilities of LT codes were studied: the interest of this work was focused on how to correct erasures due to burst erasure channels. Finally, the energy consumption of LT codes was analytically calculated from simulation results. The bound on the number of encoding symbols, which makes LT codes more energy efficient than using a general retransmission policy, was calculated.

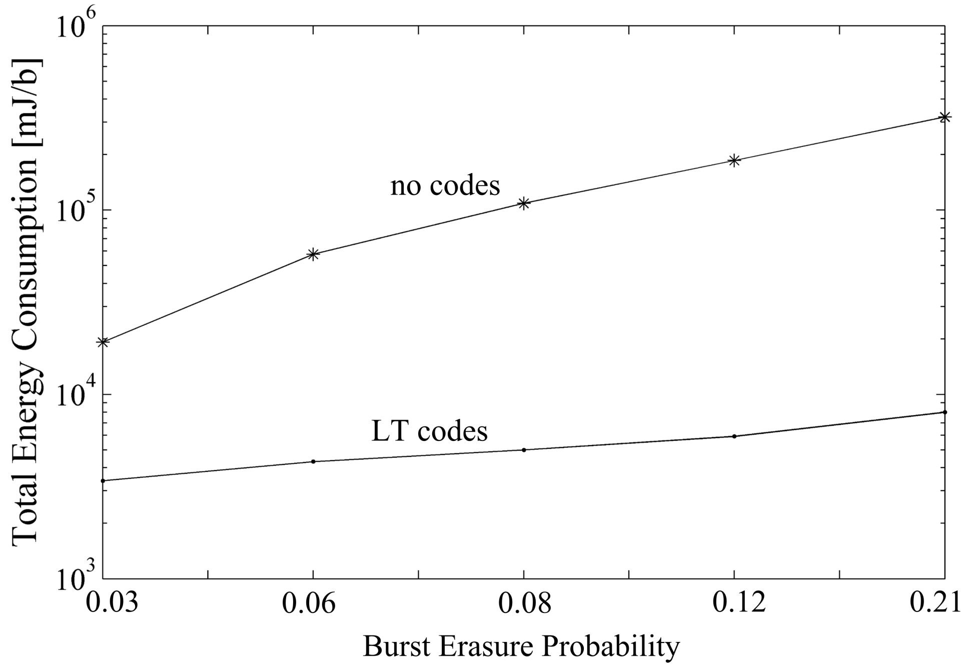


Fig. 5. Energy consumption of LT codes compared to energy consumption of transmission without coding schemes. The basic retransmission policy considered, retransmits all the source block if packets are lost.

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