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Fountain Code Based Encoding Scheme for Erasure Channels

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Abstract: This paper proposes a novel coding scheme based on Fountain codes which are error correcting codes for channels with erasure behaviour. Files sent over the internet are chopped into packets and each packet is either received without error or not received. Common methods for communicating over such channels employ a feed-back channel from receiver to sender that is used to control the retransmission of erased packets. These simple retransmission protocols have the advantage that they will work regardless of the erasure probability, but causes increase in traffic over the network. If the erasure probability is large, the number of feedback messages sent by the protocol will be large which leads to inefficient usage of channel bandwidth. Digital fountain codes address this problem very efficiently by creating erasure-correcting codes that require no feedback. In this work, a novel coding scheme based on fountain codes is proposed, which combines the separate coding and the joint coding over all the sub-carriers of OFDM. The simulation results show the robustness of proposed system model.

I. INTRODUCTION

It is a challenge to communicate both reliably and at a high throughput, because the wireless channel is a hostile environment which suffers from time-varying multi-path propagation and high levels of man-made interference. To overcome the multi-path effect, Orthogonal Frequency Division Multiplexing (OFDM) has become a popular scheme for recent wireless systems which operate at a high bit rate. For the effects of the noise and interference encountered in the transmission of the signal through the wireless channel, error correction coding is used as a means of utilizing wireless channels at full capacity. Over a finite block length, coding jointly over the sub-carriers yields a smaller error probability than can be achieved by coding separately over the sub-carriers at the same rate. This theory has been applied in practical OFDM-based wireless systems. In the current Forward Error Correction (FEC) layer for OFDM systems, the source bits are encoded jointly across the sub-carriers. However, coding can also be done in a crosswise way, which combines the separate coding and the joint coding over all the sub-carriers[1]. It is unknown whether the cross coding approach performs better or worse than the joint coding scheme in OFDM systems. Hence, it is of interest to investigate the performance of the cross coding scheme for OFDM systems.

The orthogonal frequency division multiplexing (OFDM) is a common technique in many practical applications. OFDM is a frequency division multiplexing scheme which uses multiple carriers with in the same single channel. The total data rate to be sent in the channel is divided between the various subcarriers. The data do not have to be divided evenly and it do not have to originate from the same information source.

Orthogonal frequency division multiplexing is a special case of FDM in which the carriers are orthogonal to each other. The orthogonality of the carrier avoids the necessity of the guard bands that were necessary to allow individual demodulation of subcarriers in an FDM system. The use of orthogonal subcarriers would allow the subcarriers spectra to overlap, thus increasing the spectral efficiency. The OFDM system is implemented in practice using the discrete fourier transform (DFT). Recall from signals and systems theory that the sinusoids of the DFT forms an orthogonal basis set and a signal in the vector space of the

DFT can be represented as a linear combination of the orthogonal sinusoids. One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions.

OFDM systems are implemented using a combination of Fast Fourier Transform (FFT) and inverse Fast Fourier Transform (IFFT) blocks as shown in below figure, that are mathematically equivalent versions of the DFT and IDFT, respectively, but more efficient to implement. An OFDM system treats the source symbols (e.g. QPSK or QAM symbols that would be present in a single carrier system) at the transmitter as though they are in the frequency-domain. These symbols are used as the inputs to an IFFT block that brings the signal into the time domain.

The IFFT takes in N symbols at a time where N is the number of subcarriers in the system. Each of these N input symbols has a symbol period of T seconds. The basis functions for an IFFT are N orthogonal sinusoids. These sinusoids each have a different frequency and the lowest frequency is DC. Each input symbol acts like a complex weight for the corresponding sinusoidal basis function. Since the input symbols are complex, the value of the symbol determines both the amplitude and phase of the sinusoid for that subcarrier. The IFFT output is the summation of all N sinusoids. Thus the IFFT block provides a simple way to modulate data onto N orthogonal subcarriers.

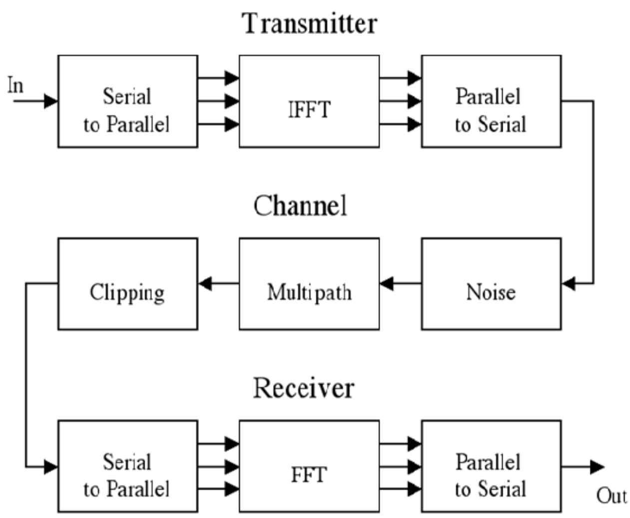

Fig.1 OFDM System

The block of N output samples from the IFFT make up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period. After some additional processing, the time-domain signal that results from the IFFT is transmitted across the channel. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain. Ideally, the FFT output will be the original symbols that were sent to the IFFT at the transmitter. When plotted in the complex plane, the FFT output samples will form a constellation, such as 16-QAM. However, there is no notion of a constellation for the time-domain signal. When plotted on the complex plane, the time-domain signal forms a scatter plot with no regular shape. Thus, any receiver processing that uses the concept of a constellation (such as symbol slicing) must occur in the frequency domain.

II. FOUNTAIN CODES

The basic principle behind the use of erasure codes is that the original source data, in the form of a sequence of k packets, along with additional redundant packets, are transmitted by the sender, and the redundant data can be used to recover lost source data at the receivers. A receiver can reconstruct the original source data once it receives a sufficient number of packets. The main benefit of this approach is that different receivers can recover from different lost packets using the same redundant data. In principle, this idea can greatly reduce the number of retransmissions, as a single retransmission of redundant data can potentially benefit many receivers simultaneously. Digital Fountain Codes concept was first proposed by M. Luby in 2002 and it was also called as universal erasure code because that it can be used independently of channel lossy rate[2]. Digital fountain codes use the concept of sparse graph codes as their core. Fountain codes are class of rateless codes designed for binary erasure channels (BEC), in which each code symbol is lost with fixed probability p intransit independent of all other symbols.

Properties

Regardless of the channel model, any coding scheme that potentially supports the reliable multicast transmission without feedback communication and at the sametime enables the receivers to benefit from the asynchronous data access, must satisfy two basic properties:

1. Ratelessness: encoder can create an arbitrarily large number of encoded symbols, This way, heterogeneous channel conditions can be supported.
2. Equal importance of encoded symbols: on a large scale, each encoded symbol should be an equally important description of the message as any other encoded symbol. This way, in the case of erasure channels, any pattern of loss of encoded symbols is supported and the receivers can benefit from virtually any encoded symbols they observe.

Based on the above properties, we can identify the fountain coding scheme for an arbitrary channel model with a probabilistic process that assigns to the message an infinite sequence of encoded symbols, all of which are the evaluations of an independently selected function of the message. LT (Luby Transform) codes are the first class of fountain codes fully realizing the digital fountain paradigm. LT codes are rateless because the encoding algorithm can in principle produce an infinite number of message packets (i.e, the percentage of packets that must be received to decode the message can be arbitrarily small)[3].

LT Encoder

Each codeword symbol C_n is generated from the message bits sequence as described by the following algorithm:

a) Source file is divided into k blocks denoted as m_1,m_2,m_3 upto $m_{k.}$
b) Randomly choose the degree'd' of the packet from a degree distribution (x).
c) Choose uniformly at random d distinct input packets.
d) Encoded bit is obtained as bitwise sum (modulo 2) of those d packets.

The encoding process defines a bipartite-check graph connected the codeword symbols with original message. The encoding operation can also be described by the generator matrix as given by

$$[C]^T = [G][S]^T \qquad (1)$$

where G is the generator-matrix corresponding to the bipartite check graph, S and C is the original message bits sequence and codeword symbols sequence respectively[4].

The following matrix illustrates the generator matrix corresponds to the bipartite graph

$$G = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \end{bmatrix}$$

Fig. 2 Generator Matrix

LT Decoder

The LT decoding algorithm is given follows:

a) Find a codeword c_n connected to only one original message symbol $s_{k.}$
b) Set the value of s_k equal to c_n: $s_{k=}c_{n..}$

c) Find all the code words that are connected to s_k, update these code words by $c_{ni} = c_n$ XOR s_k.

d) Remove the connection from generator-matrix G.

e) Repeat steps above until all the message symbols are recovered.

Fountain codes are used in data storage applications due to massive savings on the number of storage units for a given level of redundancy and reliability. The requirements of erasure code design for data storage, particularly for distributed storage applications, might be quite different relative to communication or data streaming scenarios. One of the requirements of coding for data storage systems is the systematic form where the original message symbols are part of the coded symbols. Systematic form enables reading off the message symbols without decoding from a storage unit. In addition, since the bandwidth and communication load between storage nodes can be a bottleneck, codes that allow minimum communication are very beneficial particularly when a node fails and a system reconstruction is needed to achieve the initial level of redundancy. In that respect, fountain codes are expected to allow efficient repair process in case of a failure. When a single encoded symbols is lost, it should not require too much communication and computation among other encoded symbols in order to resurrect the lost symbol. In fact, repair latency might sometimes be more important than storage space savings [4].

III. Proposed System Model

Fountain codes are designed for communication over Erasure Channels, which means that the encoded packet is either received error free or not received at all. However, the wireless channels are not erasure, but fading and noisy channels. In practical systems, fountain codes are used in combination with other error correction algorithms to convert the noisy channels into erasure channels, often Low-Density Parity-Check (LDPC) codes. LDPC codes together with Cyclic Redundancy Check (CRC) are employed to convert the channel[5].

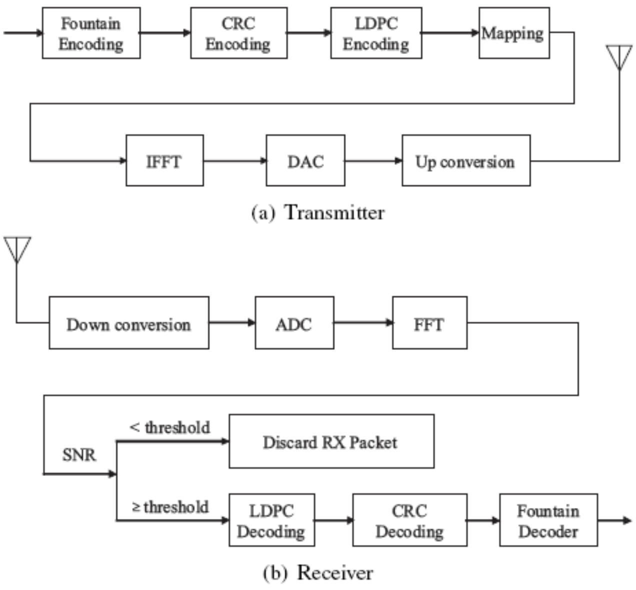

Fig. 3. Proposed System Model

Our FEC encoding scheme is performed in the following order: K source packets are encoded by fountain codes first. To each fountain-encoded packet, a CRC is first added and the packet is encoded by a LDPC code. So the source data is first encoded jointly over all the sub-carriers by fountain codes, then encoded separately over one sub-carrier by LDPC plus CRC codes. At the receiver, each fountain-encoded packet is first LDPC decoded when the SNR is equal to or higher than the threshold. The received packet is discarded if its energy is below the threshold. If the LDPC decoding fails, the received packet is discarded as well. If the LDPC decoding succeeds, the CRC is used to identify the undetected error from LDPC codes. If the CRC decoder fails, the receiver also assumes that the whole packet has been lost. Once the receiver has collected N surviving fountain-encoded packets, it starts to recover the source data.

IV. SIMULATION RESULTS

The bit error rate Vs SNR is plotted for SNR varying from -10 dB to 15 dB. It is found that as SNR increases the bit error rate performance improves. The performance is further improved with the introduction of fountain codes. The performance of the system has been depicted in the below figure.

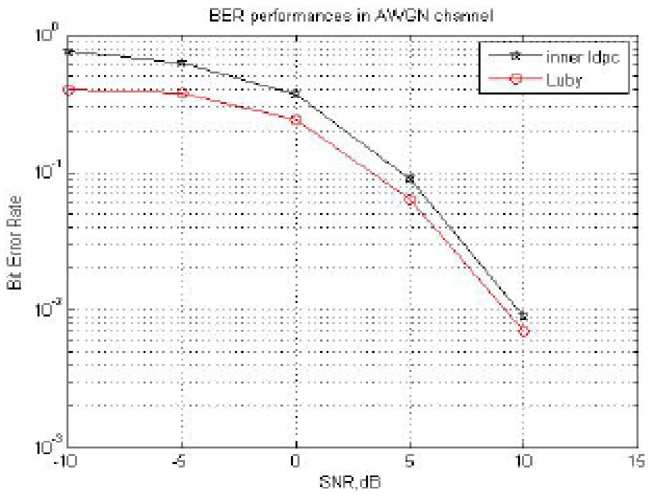

Fig. 4. Bit Error Rate Vs SNR

V. CONCLUSION

Fountain coded system is proposed for reliable transmission with low overhead in comparison with the traditional ARQ systems. It handles error management by sending additional packets so that at the event of loss of some packets, the lost information is extracted from the additional packets sent. The fountain codes as a rateless coding scheme find its application in broadcasting environment especially when the channel introduces erasures. The effectiveness of the fountain coding scheme improves as the number of transmitted packets increases as the overhead is reduced with increase in the number of transmitted packets.

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