ADAPTIVE CODING SCHEME FOR RAPIDLY CHANGING COMMUNICATION CHANNELS

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Abstract*: In this paper we investigate the problem of reliable and efficient data transmission over rapidly changing communication channels. A typical example of such channel would be high-speed free space optical communication channel under various adverse atmospheric conditions, such as turbulence. We propose a new concept of developing an error correcting coding scheme in order to achieve an extremely reliable communication through atmospheric turbulence. The method is based on applying adaptive error correcting codes to recover lost information symbols caused by fading due to turbulent channel.*

Keywords*: error correcting codes.*

ACM Classification Keywords*: E.4 CODING AND INFORMATION THEORY.*

Conference topic*: Information Retrieval.*

Introduction

We propose an entirely new concept of developing an error correcting coding scheme in order to achieve an extremely high reliable communication through atmospheric turbulence. The method is based on applying *adaptive* error correcting codes to recover lost information symbols caused by fading due to turbulent channel. *To the best of our knowledge, this solution based on our adaptive-controlled approach does not exist.*

The reason of proposing channel coding is to be able to detect or even to correct transmission errors if we append additional information (so called redundant information) to the information sequence. In order to find effective codes, we must first characterize the transmission channel. The atmosphere causes very slow fading (compared to the high communication rates) which significantly degrade transmission quality. Usually, the fading time-constant is much higher than the bit-duration. The fading process can be described by the "mean number of fades per second (NOF), "mean duration of fades"(DOF), and the "probability of fades"(POF). Using the binary intensity modulation the receiver performance, described by the receiver sensitivity and the noise processes of the detector is very important to calculate the error probability. The noise for a 1 and 0 level is different if we are using an avalanche photo-detector (APD). Additionally, the noise depends on the current mean received power. Due to these noise effects, *we can minimize the error probability by using an* ***adaptive*** *decision-threshold, optimized for the current mean received power.*

Note that since the transmitter laser power and receiver sensitivity are limited by the available technology, fading imposes a severe problem that can be solved by the use of forward error correction schemes (FEC) in order to improve system performance. Block coding can improve the bit error rate (BER) if the received power is rather high. Using block codes there is a threshold after which the coded transmission is better than the transmission without coding. This is because of the redundant bits which must additionally be transmitted using codes. The fade time caused by randomly varying communication channel is usually much shorter than the duration of a code block, so that the code should correct as much as possible errors which occur during a fade. With block codes we can improve the BER significantly.

Code Construction

The proposed work is based on the construction of special linear (N+m, N) block codes [1] which will correct any single burst of erasures up to the length m. This section explains briefly the code construction and states the two prepositions about a code. The generator matrix of the code has a very simple construction, that can be represented as follows. Let D_n denote an $n\times n$ binary matrix where all elements on or above a diagonal are 1's and all other elements are 0's. For an example D_3 will be a matrix

D_3 =

1	1	1
0	1	1
0	0	1

Then the generator matrix G of an (N+m, N) code will be

G= I_N |

D_r
D_r
..
D_r
D_r

Where I_N is an identity matrix of the dimension N and $r=\lfloor N/m \rfloor$.

The following prepositions can be proofed:

<u>Preposition 1.</u> A linear code (N+m, N) represented with the generator matrix G will be able to recover burst of erasures up to the length m in one block of the length N+m. (this is a guaranteed combination of erasures, in fact the given code can recover much more combinations).

The proof of preposition 1 is omitted and can be found in [1].

<u>Preposition 2.</u> Linear (N+m, N) codes described above are optimal in the sense that : a)they have a minimum number of redundant symbols if a linear code is used and, b) they meet Shannon bound when we consider the model of the channel where most probable errors are bust of erasures up to the some length.

Proof of preposition 2: a) If the number of check(redundant) symbols is less than m and the number of erasured symbols is at least m, then we will have less than N symbols which remain uncorrupted. Since the code is a linear in order to recover uniquely erasured symbols at least N symbols(where N is the number of information symbols of the code) are needed which we do not have in this case.

b) If the probability of erasure per symbol is P it is well known that the Capacity of the channel is C=1-P. According to the model of the channel the most probable erasure pattern would be of the length $N\times P$ per block of N symbols. The corresponding parameter of our code from the preposition 1 will be a linear (N,N-NP) code that corrects the burst of errors up to the length NP. The Rate of a given code will be N(1-P)/N=1-P which is just equal to C-the channel capacity.

How the adaptive coding works in presence of fading channel

The performance of free-space optical communication systems can be degraded by many factors, such as fog, obstruction of line-of-sight path, atmosphere turbulence etc. These factors in turn will cause a channel fading an intensity of which will depend on the real conditions of the channel. In many situations it would be possible to estimate the intensity of fading in the channel and apply appropriate error correcting codes to recover loosed information symbols caused by fading. In order to facilitate this adaptive coding concept we will make some assumptions. At first we assume that on-off keying (OOK) modulation is used, i.e. we have a binary channel. Secondly the information is divided into blocks (packets) of the length N, and as a result of fading some symbols may be erasure or loosen, however the locations of such symbols in the whole packet will be known at the receiver end. We assume also that before transmission a transmitter (sender) knows the intensity of fading of the channel, which will allow him to estimate the maximum number of consecutive symbols m corrupted (erasured) as a result of that fading. These m symbols will form a burst of erasure of the length m . Finally we will assume that there will be not more than one burst of length m per each block of the length N .In the case if there is more than one burst of error such packets should be simply retransmitted.

We have developed linear (N+m, N) codes which will correct any single burst of erasures up to the length m. The parameter m actually determines the number of redundant symbols that should be attached to N information symbols in each packet. m in fact determines the intensity of fading in the channel, so it can be adjusted before transmission. Thus the number of redundant symbols that will determine the information transmission rate will depend on the conditions of the channel. Note that proposed (N+m, N) codes have very simple structure and as a result can be effectively implemented on DSP-based hardware devices.

Let's consider some numerical example. Suppose N=500 and m=50. Let's denote by

P(N,r) the probability that in the block of N symbols exactly r consecutive symbols will be corrupted. P(N,0) will denote the probability that none of the N symbols will be corrupted. Lets consider the case when P(N,0) = 0.05 , $\sum_{i=1}^{50} P(500,i) = 0.9$, $\sum_{i>50} P(500,i) = 0.05$. This means that with the probability 0.95 the length of the burst of corrupted symbols will not exceed 50. In order to keep the same rate 0.95 for the probability, that the number of erasures will not exceed the level which will be recovered by our code construction, we will need to put m=55, which means that actual block length would be N=555. We can then approximate that P(555,0) will be (500/555)* 0,05= 0,045 and $\sum_{i>50} P(555,i)$ will be equal to 0.055 .

Now let's compare the number for retransmissions per 1000 blocks needed before and after our encoding scheme. Since before encoding our system cannot tolerate any erasures the number of retransmissions per 1000 blocks would be 950, since the probability that there is no error in block with 500 symbols is 0.05. After encoding when we have 555 symbols we will need only in average 55 retransmission per 1000 blocks, since the probability that errors will not tolerated by our system is equal to 0.055. As a result of our coding scheme, for this example we achieve more that 17 times reduction in retransmission rate which greatly enhances the efficiency of our communication system.

Also note that we can adjust the variable rate coding scheme (adaptive coding), depending on the probability of fade at certain time (which we can measure or probe) and adjust the redundant scheme accordingly. This is because of the redundant bits that must additionally be transmitted using codes. The threshold depends on the used code. *The "fade time" is usually much shorter than the duration of a code block, so that the code should correct as much as possible errors that occur during a fade.* We wanted to illustrate the coding gain in dB, with or without coding, at least qualitatively.

We now explain how the coding gain curves should be drafted. For the future curves we will have BER(P) (in our case actually P will denote the probability for the burst of erasure which will be transferred into the length of the burst equal to $N\times P$): this BER(P) is a function of SNR and σR (the turbulence strength variance parameter). Thus we will have 3 parameters : SNR, σR and P(P determines the Capacity and C = 1-P). For a given σR , we will have pairs (SNR, P) and a coding gain will be determined as (SNR1- SNR2) if we go from (SNR1 , P1) to (SNR2 , P2) where SNR1 >SNR2 and P1<P2 . As a result of coding we can achieve the same BER for less SNR.

How the code parameters are related to the most probable fading time and the most probable idle time between fades are explained below. Code parameters we have developed will depend on the most probable duration of fade(FD) and the most probable duration of idle time (IT) between fades. For example, if information speed is 10 Gbit/sec(= 107 bits/sec), FD is 5x10-4 sec (= 0.5 msec), and (IT) is 2 msec an average 5000 consecutive bits will be corrupted followed by in average 15000 uncorrupted bits. According to our construction a liner code (20000,15000) will take care for 5000 corrupted bits. Actually the rate of the linear code will be equal to

1-FD/IT .

Conclusion

In this paper we have introduced an idea of adaptive coding scheme for rapidly changing communication channels. We have suggested an optimal fade – tolerant

linear code construction and showed how they can be used to achieve high reliability and efficiency of information transmission when the channel model can be represented as fading channel with variable fading rate.

Bibliography

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