

Comparison of Different Modulation Schemes for Signal Decoding in Analog Network Coding

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Abstract— This paper discusses different modulation schemes for the decoding of signals in Analog Network Coding (ANC). Analog Network Coding is a concept in which interference of the signals is considered as advantage rather than disadvantage. Router interferes the signal transmitted from two nodes that want communication between them. At the receiving end the node subtracts its own signal to decode the signal transmitted by the sender. Signal decoding at the receiving end is not a simple problem. Signal has to traverse through the channel to reach the receiver. Channel imparts many distortions in the signal in the form of magnitude and phase. Retrieval of the correct information of the signal in terms of its amplitude and phase is very important. The decoding of the signal at the receiving end depends upon number of factors and one of them is the modulation scheme used. In this paper we use different modulation schemes such as ASK (Amplitude Shift Keying), FSK (Frequency Shift Keying) and MSK (Minimum Shift Keying). We discuss how these modulation schemes affect the analog network coding process. Models are proposed for the retrieval of the signals. Simulations are performed to prove the results. Matlab/Simulink is used as a tool for simulations.

Keywords— Analog Network Coding, ASK, FSK, MSK, Digital Network Coding, Simulink

I. INTRODUCTION

There has always been a trend of increasing capacity of a communication system by using various means including OFDM, MIMO, and Cognitive Radios etc. In all these techniques, interference reduction is one of the premium tasks. Thus interference is considered as main hindrance in increasing the capacity of a communication system. Analog Network Coding (ANC) is a strategy in which interference is used as an advantage rather than disadvantage. In analog network coding, router adds (interferes) the two signals coming from two different points and broadcasts the combined signal [2]. Receiver subtracts its sent signal from the combined signal received from the router and gets the transmitted signal. Analog network coding gets its name from digital network coding in which the router XORs the bits coming from two different sources and transmits the XORed signal [1]. At receiving end, the receiver XORs the received signal with its own bit stream to get the transmitted signal. Analog network coding has better throughput than digital network coding as we will see shortly.

ANC can be best explained with a traditional example of Alice and Bob [3]. Consider the figure shown below [2]:

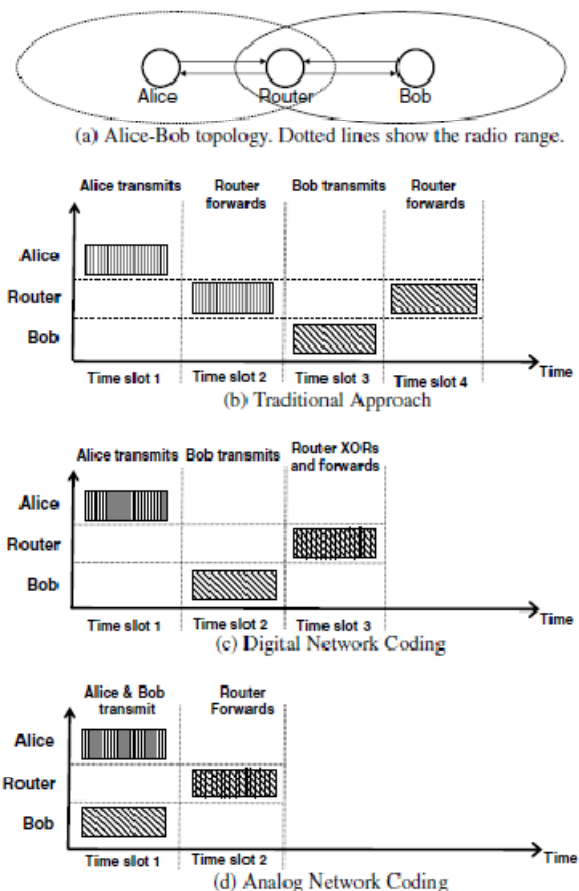


Figure 1: Alice-Bob Topology: Showing difference between traditional approach, digital network coding and analog network coding

Suppose that Alice and Bob want to exchange the packets of information to each other. In traditional approach, Alice transmits its packet to the router and router forwards it to Bob. Similarly Bob transmits its packet to the router and the router forwards it to Alice. It requires four transmissions to complete the task of exchanging the packets of information as shown in Figure 1. In digital network coding, Alice transmits its bits to the router, and then Bob transmits its bits to the router. Router

then XORs the bits received from Alice and Bob and then transmit the combined signal. At receiving end Alice and Bob again XOR their bit streams with the one received from the router and get the desired packets from each other. This scenario needs three time slots to accomplish the task as shown in Figure 1. In analog network coding, Alice and Bob transmit signal to router which adds them and broadcasts. At receiving end, Alice and Bob subtract their own signals with the received one to get their desired signals. It requires two time slots to accomplish the task. Thus analog network coding gives two fold increase in throughput as compared to traditional approach. It also gives a gain of 1.5 as compared to digital network coding. It looks quite simple to add two signals and transmit the resultant signal and at the receiving end, receive the signal by subtracting original value. But in fact it is not that simple. Signal has to traverse the channel before reaching the receiver. Channel imparts many distortions to the signal. Thus a modulation scheme is needed such that it can bear all these distortions from the channel. In the following sections we will analyse different modulation schemes for signal encoding and decoding and compare their performances.

II. AMPLITUDE SHIFT KEYING

In this discussion we will consider two possibilities of amplitudes that are 0 and 1. This type of amplitude shift keying (ASK) is also called On-Off keying (OOK). ASK signal can be represented by the following equation.

$$S_{ASK} = pA \cos(\omega_c t + \theta) \quad (1)$$

where,

p = Probability of the signal being 0 or 1.

ω_c = Frequency of the carrier

θ = Phase of the carrier.

The two nodes of Alice and Bob will transmit the same signal to the router with the same carrier frequency and phase. The only difference between the two signals is the message that both nodes want to transmit. Let S_1 be the signal transmitted from one node and S_2 be the signal of the second node. The router will broadcast the sum of these two signals which can be written as:

$$S_{router} = S_1 + S_2 \quad (2)$$

$$S_{router} = pA_1 \cos(\omega_c t + \theta) + pA_2 \cos(\omega_c t + \theta) \quad (3)$$

Since frequency and phase of the carrier is the same we can come up with a new equation given by:

$$S_{router} = (A_1 + A_2)p \cos(\omega_c t + \theta) \quad (4)$$

At the receiving end, receiver will get somewhat distorted signal. Since information is only in the amplitude, only parameter of concern is the amplitude. At the receiver, the signal can be represented by the following equation:

$$S_{receiver} = hA p \cos(\omega_c t + \theta) \quad (5)$$

Where,

h = distortion factor from the channel

$$A = A_1 + A_2$$

This distortion factor fortunately can be catered in thresholding. At the receiving end, receiver can subtract its value to get the desired transmitted value. Only thing that remains of concern is that which signal was transmitted. We can set a threshold γ such that if the received value is greater than this threshold we can infer that signal transmitted was A and 0 if the received value is less than the threshold. Now it becomes simple problem of detecting the transmitted signal.

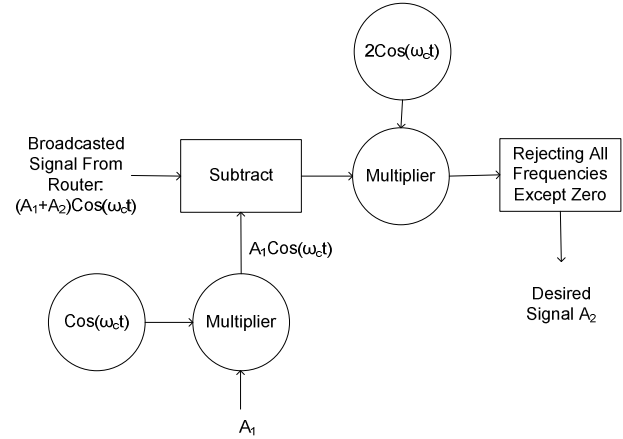


Figure 2: Proposed model for retrieving signal in ASK

At the receiving end, the receiver integrates the received signal, multiplied with the carrier. Then decision is made on the basis of threshold. The probability of error can be represented by the equation:

$$p_{err} = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{A^2 T_b}{8 N_0}} \right) \quad (6)$$

Where,

T_b = Bit duration

N_0 = Noise power.

III. FREQUENCY SHIFT KEYING

In frequency shift keying, the frequency of the carrier is determined by the message signal. That is, the information we want to transmit, is in the frequency of the transmitted signal. We can write FSK mathematically as under:

$$S_{FSK} = \begin{cases} S_1 = A \cos(\omega_1 t + \theta_1) \\ S_2 = A \cos(\omega_2 t + \theta_2) \end{cases} \quad (7)$$

Where,

S_1 and S_2 are the two signals sent

ω_1 = Frequency of the first transmitted signal S_1

ω_2 = Frequency of the second transmitted signal S_2

Consider the same scenario as discussed in previously, where two nodes Alice and Bob want to exchange the message to each other. Now, the router will mix the two signals received

from those two nodes and broadcast. When these two signals are added, it will take the form as shown below:

$$S_{router} = S_1 + S_2 \quad (8)$$

After adding these two signals, the above equation takes the form:

$$S_{router} = A[\cos(\omega_1 t + \theta_1) + \cos(\omega_2 t + \theta_2)] \quad (9)$$

The router broadcasts the signal described in (8). At the receiving end, all it needs is to multiply the signal with the carrier of same frequency of that node. Let us see how this happens mathematically.

Let us assume that the broadcasted signal is at the node which transmits its signal with a carrier frequency ω_1 . Now the signal in (8) is multiplied with a carrier of frequency ω_1 and the signal takes the form:

$$S_{receiver} = A[\cos(\omega_1 t + \theta_1) \cos(\omega_1 t + \theta_1) + \cos(\omega_2 t + \theta_2) \cos(\omega_1 t + \theta_1)] \quad (10)$$

Using the trigonometric identity and using the fact that information is in the frequency, not in the phase we omit the phase part in the equation to emphasize on the frequency, we get:

$$S_{receiver} = \frac{A}{2} [\cos(2\omega_1 t) + 1 + \cos\{(\omega_1 + \omega_2)t\} + \cos\{(\omega_1 - \omega_2)t\}] \quad (11)$$

Now passing the signal described in (10) through high pass filter, eliminating dc value and normalizing we get:

$$S_{receiver} = A[\cos(2\omega_1 t) + \cos\{(\omega_1 + \omega_2)t\}] \quad (12)$$

Again multiplying with the carrier of same frequency we get:

$$S_{receiver} = A[\cos(2\omega_1 t) \cos(\omega_1 t) + \cos\{(\omega_1 + \omega_2)t\} \cos(\omega_1 t)] \quad (13)$$

Again using the same trigonometric identity and expanding the terms we get:

$$S_{receiver} = \frac{A}{2} [\cos(3\omega_1 t) + 2\cos(\omega_1 t) + \cos\{(2\omega_1 + \omega_2)t\} + \cos(\omega_2 t)] \quad (14)$$

Now passing the signal described in (13) through low pass filter and then through band stop filter tuned to ω_1 we get the term $\cos(\omega_2 t)$. This is the signal required at the receiving end. This whole process can be diagrammatically represented as under:

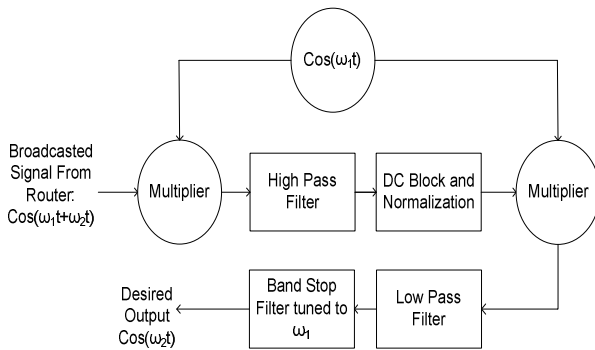


Figure 3: Proposed model for retrieving signal in FSK

Bit error probability for frequency shift keying is given by the following equation:

$$p_{err} = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{A^2 T_b}{4 N_0}} \right) \quad (15)$$

IV. MINIMUM SHIFT KEYING

A Frequency shift keying described in earlier section was a type of discontinuous phase frequency shift keying. Before we discuss minimum shift keying it will be helpful to see what is continuous phase frequency shift keying (CPFSK). CPFSK is mathematically represented by the following equation:

$$S_{CPFSK} = \begin{cases} S_1 = A \cos(\omega_0 t + \Delta\omega + \theta_1) \\ S_2 = A \cos(\omega_0 t - \Delta\omega + \theta_2) \end{cases} \quad (16)$$

Where,

$\Delta\omega$ = Frequency deviation

Frequency deviation can be represented in terms of bit duration and bit frequency as under:

$$\Delta\omega = \frac{n\pi}{2T_b} = \frac{n\omega_b}{4} \quad (17)$$

Where,

ω_b = Bit frequency

This is obvious from the relation of CPFSK that the bandwidth of FSK signal will be minimum if $\Delta\omega$ is minimum. This leads to obvious choice of $n = 1$ in (17), that is, frequency deviation will become $\omega_b/4$. Thus the frequencies will have minimum separation in this case and thus it is called Minimum Shift Keying (MSK). So minimum shift keying is actually continuous phase frequency shift keying when separation between the frequencies is minimum. Thus CPFSK and MSK are primarily the same. One of the advantages of MSK is that this modulation scheme is very robust. It can easily negate the distortions introduced by the channel. All it needs is to detect the amplitude and phase of the combined signal sent by the router. All this procedure is discussed in [2] in great detail. The same procedure for receiving the signal can be used for MSK as that was described in previous section. Major advantage of MSK is that it is a spectrally efficient modulation scheme as compared to the others [4, 5]. Using the same procedure discussed in previous section, MSK signal can be recovered at the receiver.

V. SIMULATIONS AND RESULTS

Simulations are carried out using Matlab/Simulink [6, 7]. The models proposed in previous sections are validated on Simulink. The model for Amplitude Shift Keying (ASK) is given as under:

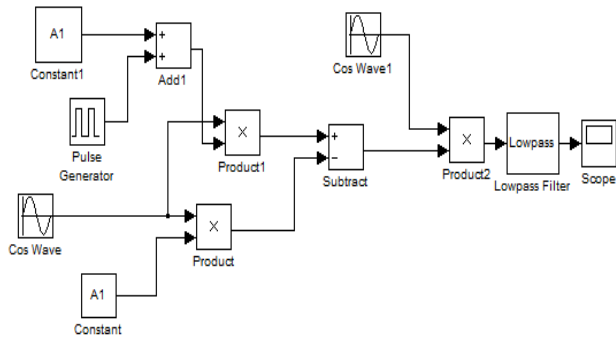


Figure 4: Simulink model for retrieving signal in ASK

Just before the filter, the resulting signal will be the desired signal imposed on the sinusoid. Following result is obtained by following this procedure:

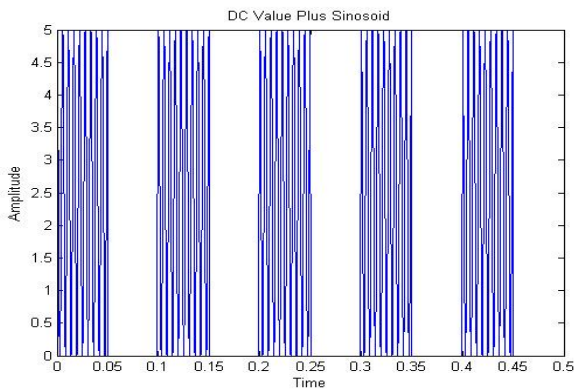


Figure 5: A_2 plus sinusoid

As can be seen in the figure, the desired signal A_2 is super imposed on the sinusoid (cos signal). After low pass filter, the sinusoid is removed and we get the signal A_2 that was desired.

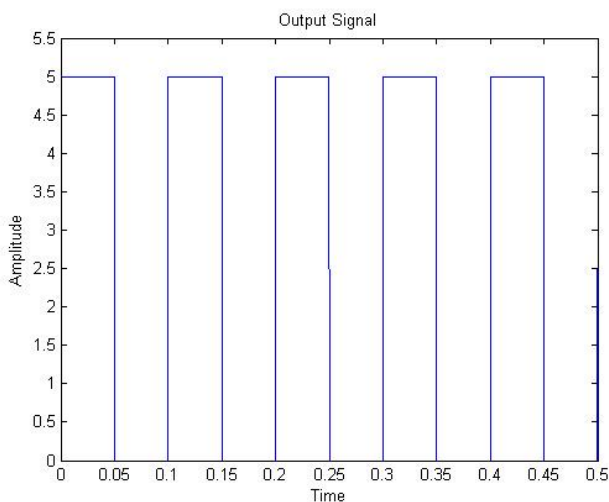


Figure 6: Output signal for FSK

The Simulink model for Frequency Shift Keying (FSK) is given below:

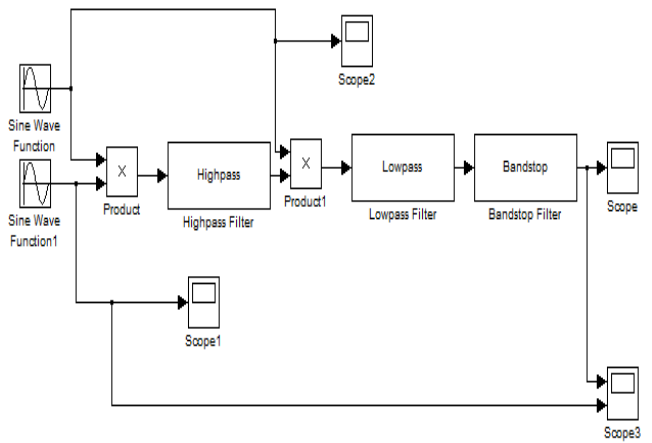


Figure 7: Simulink model for retrieving signal in FSK

The original signal of the receiving node is given as under:

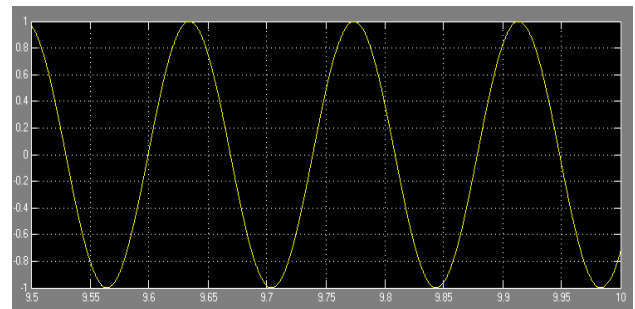


Figure 8: Signal of receiving node A_1

The signal from the router is given by:

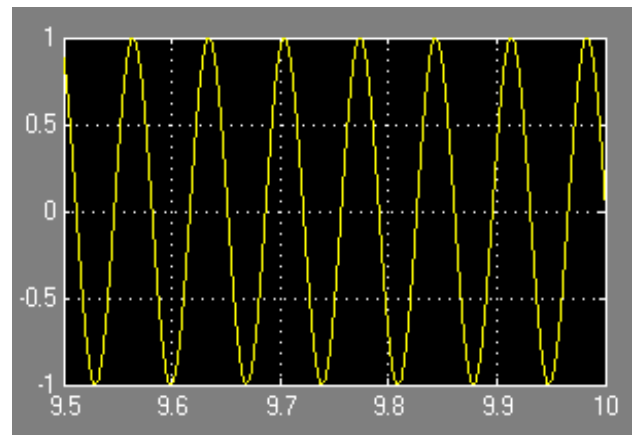


Figure 9: Desired signal A_2

After passing through all the blocks described in Simulink model, the output signal is given by:

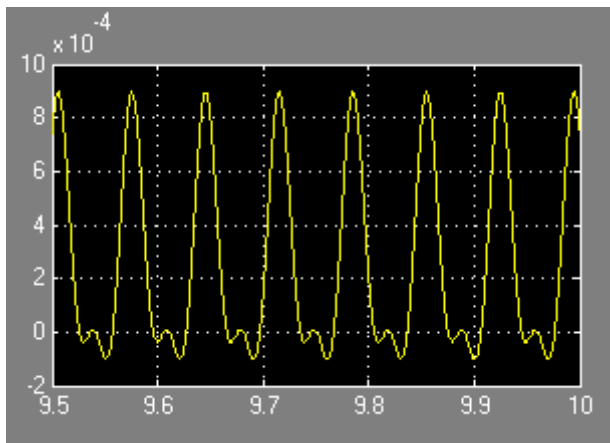


Figure 10: Desired Output Signal

We can see that the desired signal has the same frequency as that was sent by the transmitting node to the router. For comparison, both the signals are plotted in the same figure as follows:

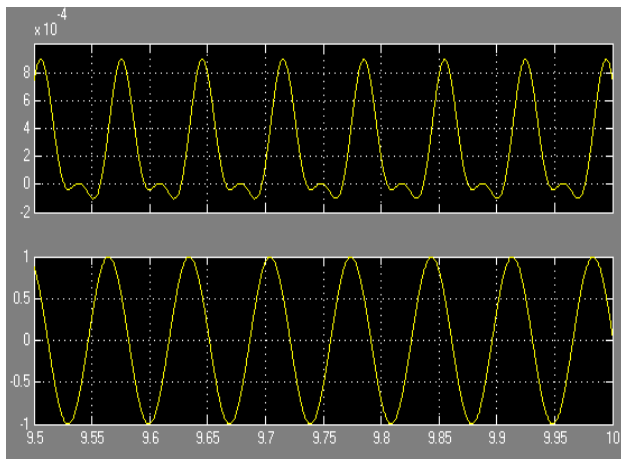


Figure 11: Comparison of desired signal and output signal

We see from the figure that output (desired signal)'s frequency is almost the same of that signal which was transmitted from the transmitter and reached the receiver via router.

VI. CONCLUSIONS

In this paper we discussed different modulation schemes in Analog Network Coding. Analog Network Coding is a very useful technique as it makes the performance better by reducing the number of transmissions. ASK, FSK and MSK are discussed as modulation schemes. Receiver models are proposed to retrieve the signal from the one that is transmitted by the router. The proposed models are checked by simulation software Matlab/Simulink and the results are according to the expectations. The results are also shown.

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REFERENCES

- [1] S. Katti, H. Rahul, D. Katabi, W. H. M. Medard, and J. Crowcroft. XORs in the Air: Practical Wireless Network Coding. In *Proc. of ACM SIGCOMM 2006, Pisa, Italy*.
- [2] S. Katti, S. Gallakota, D. Katabi. Embracing Wireless Interference: Analog Network Coding. In *ACM SIGCOMM, 2007*
- [3] J. F. Kurose, K. W. Ross, Computer Networking: A Top-Down Approach, Addison-Wesley, 2010
- [4] Bernard Sklar, Digital Communications: Fundamentals and Applications, Prentice Hall PTR, 2001
- [5] Peyton Z. Peebles, Digital Communication Systems, Prentice Hall, Inc, 1987
- [6] Steven T. Karris, Introduction to Simulink with Engineering Applications, Orchard Publications, 2008
- [7] Ashsish Tewari, Modern Control Design with Matlab and Simulink, John Wiley and Sons, 2002