Embracing Wireless Interference: Analog Network Coding

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Winter Semester 2009/10

Abstract

Basically, in a wireless network there are 'n' nodes where they send and receive packets each other. Generally, for every network, throughput gain is more important. In order to improve the throughput multiple transmissions should occur simultaneously. But, if the network sends packets simultaneously, packet collision occurs. Packets may interfere at any node. Generally, this kind of interference is not supported by tradition approach because of collision. In contrast, this paper supports interference in which it allows the senders to transmit signal simultaneously which results an interfering signal. The interference is supported by using Analog Network Coding approach which is done at physical layer. Analog network coding is widely used in many applications such as video conference, mobile networks and voice conversation between two peers. This paper presents modulation/demodulation scheme which is used for designing analog network coding. Later the paper will discuss about how analog network coding approach increases throughput by comparing with others approaches and also the paper presents some future works on this approach in order to improve the efficiency. Finally, the paper concludes analog network coding approach by proving that this approach improved in throughput gain compared with other approaches.

1 Introduction

Generally, in a network there are number of nodes send and receive packets each other. In a traditional wireless networks it allows the sender to transmit packets one after the other so that the transmitted packet should not interfere and also the transmitted packet should not be resulted in collision. Since, collision occurs only when two senders transmit packets simultaneously. Therefore, colliding packets inferred at some nodes. This interference of packets occurs may be because of using single channel for transmission [2, 3, 4, and 5]. Consedering this scenario i.e., sending packets one after the other will not improve throughput gain. In order to improve the throughput this paper presents a new approach called *Analog Network Coding* which supports interference. The main idea of this paper is to demonstrate how this approach supports interference. For that, the approach needs a system setup since analog network coding is applicable at physical layer and which works at signal level. The analog network coding design is implemented using modulation/demodulation scheme.

There is no gain of throughput in traditional wireless network, consedering number of steps needed for transmission of packets. The throughput of wireless network increases only when the transmissions occur simultaneously. But, this kind of interference is not supported by most of the wireless networks so they try to avoid interference. Network coding technique used to avoid this kind of problems. The main goal of this paper is to send packets simultaneously without any collision. The best approach is to use *Network Coding*. Network Coding is a method of attaining maximum information flow in a network. Network coding technique allows senders to transmit the data simultaneously. There are two types of network coding namely digital network coding[7] and analog network coding. The difference between these two network coiding will be discussed in forecoming sections. Instead of avoiding interference 'Analog Network Coding' embrace wireless

*Master of Science Student; Representing the above topic in the seminar on 'Ad Hoc Netzwerke' interference in order to improve throughput. In the next section will discuss about two transmission networks namely uni-directional and bi-direction transmission networks to show throughput gain is more using this approach by comparing with traditional and digital network coding approach respectively.

Here, a brief explanation of throughput gain is presented by comparing analog network coding approach with other two approaches using bi-directional transmission network and uni-directional transmission network. Consider, bi-directional transmission network traditional network approach needs 4 steps for communication [7]. In the case of digital network coding approach the router performs XOR operation and transmit the resultant packet to their corresponding destinations. In this approach, the communication is reduced from 4 to 3 steps. But in our approach analog network coding, the router adds the two colliding signals and then the router decodes and forwards the interfered signal to their corresponding destinations. Therefore, communication steps is further reduced from 4 to 2. This is because the wireless channel naturally mixes these signals. Later on wards receiver can decode received packet by using some decoding method. The advantage in using analog network coding approach, it increases the network's capacity. Now consider uni-directional transmission network, the throughput gain of analog network coding approach is compared only with traditional network approach where digital network coding approach also takes 3 time slots like traditional network, so digital network coding is not consedered in this case. The throughput gain of analog network coding is reduced from 3 to 2 where transmission steps needed for traditional network is 3.

The main difference between digital network coding and analog network coding is, digital network coding is done at data link layer and while transmission, two senders transmits data one after the other then the router XORs the packets and sends the XORed packet to its corresponding destination. But the analog network coding is done at physical layer where two senders transmit signals simultaneously and the router decodes and forwards the mixed signal to their corresponding destination. And also, the number of time slot is less comparing to traditional and digital network coding approach. By saving number of time slots can be used to send new data which increases wireless network throughput.

At first, the paper presents about two different transmission networks namely, Bi-directional transmission and Uni-directional transmission network [6]. Further the paper discusses about these networks with example in order to compare the throughput gain of analog network coding with other two networks. Then, the paper demonstrate the working of analog network coding and show the throughput gain from 4 to 2 time slot using Bi-directional transmission network and throughput gain from 3 to 2 time slot using uni-directional transmission network respectively. Then, the paper describes designing of analog network coding using modulation and demodulation scheme. Later, paper discusses about problems in sending packets simulaneously and then comparing throughput gain of analog network coiding approach by comparing with other wireless network coding namely digital network coding and traditional approach [1]. Finally, paper discusses some future works on our approach to improve the technology.

2 Illustrative Example

This section presents a simple example using two transmission networks namely uni-directional and bidirectional network respectively. Using this example the paper shows how the technique 'Analog network coding' improves throughput than usual traditional approach and digital network approach.

2.1 Bi-directional Transmission Network

In this network, consider three nodes namely node N1, node N2 and Router. This is also called three-node wireless network. Before dealing with this transmission techniques router's two methods of transmission should be known in advance. Router can transmit data in two different transmission methods. One is *Decode and forward* method and the other one is *Amplify and forward* [1]. Router can choose any one of these methods to transmit data to its destination. In decode-and-forward method, router first decodes the interfered signal and then forwards the decoded signal to its destination. In amplify and forward method, router amplifies and forwards the interfered signal. Here, the router have chosen decode and forward method for transmitting data is shown Bi-directional transmission network in figure 1. Now, consider Node N1 and node N2 want to exchange packets to each other. They cannot communicate to each other since both nodes N1 and N2 are not in a same zone. So, they need router to transmit data to their destination. In figure 1, the dashed circle shows the radio range of nodes N1 and N2. The comparison of throughput gain of analog network approach with other two approaches has shown in next section.

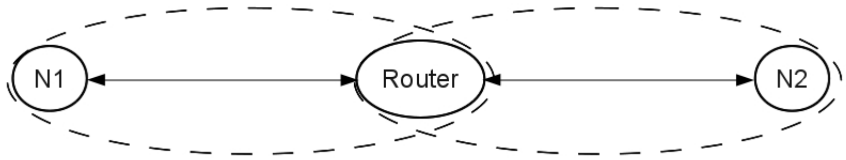

Figure 1: Bi-directional Transmission Network. Two Circles show the radio range of N1 and N2

2.1.1 Traditional Approach

According to the example given above throughput of the network is observed while sending message packet in traditional network approach. In traditional network approach shown in figure 2, node N1 sends message packet M1 to the router, router forwards the packet to node N2 and in similar way node N2 sends reply message M2 to the router, which forwards the packet to node N1 respectively. So, traditional approach needs 4 time slots.

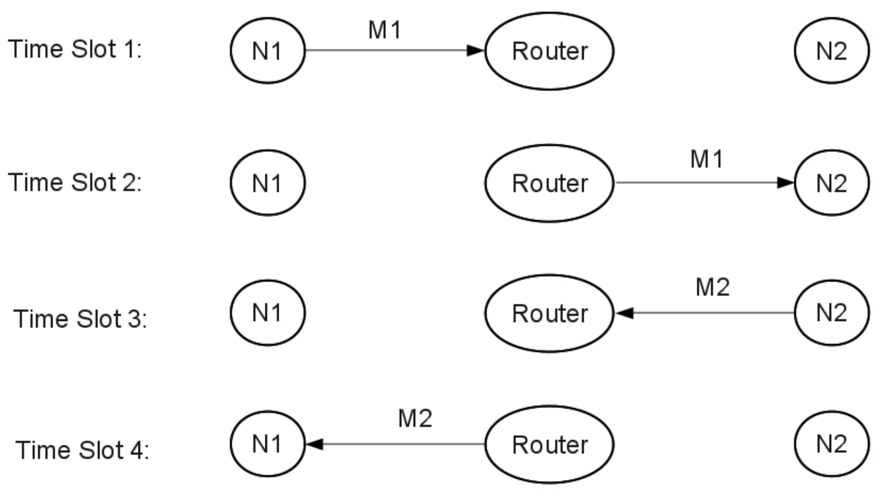

Figure 2: Four Time Slots for Traditional Approach

2.1.2 Digital Network Coding Approach

Using the same Bi-directional transmission network, Digital Network Coding reduces the number of time slots from 4 to 3 steps. Let us see how it works. Node N1 and N2 send message packet M1 and M2 to the router one after the other. Instead of forwarding the packet, router *XORs* the two packets and then forwards the XORed packet to their corresponding destination[7] shown in figure 3. After receiving the XORed packets from the router, node N1 XORs again with its own packet to get node N2's message packet M2. On the other hand, node N2 also follows the same way to get node N1's packet. Hence, digital network coding approach takes three transmissions instead of 4. In this way, the throughput is increased where saved transmission can be used to send new data. The concept of digital network coding is understandable while explaining with example. Assume, the bits of M1 are 1101 and M2 is 1010. The concept of Exclusive OR operation is when the two input bits are different it produces '1' as its output and if the two input bits are same it produce '0' as its output. Therefore M1$\oplus$M2 gives 0111 as result.

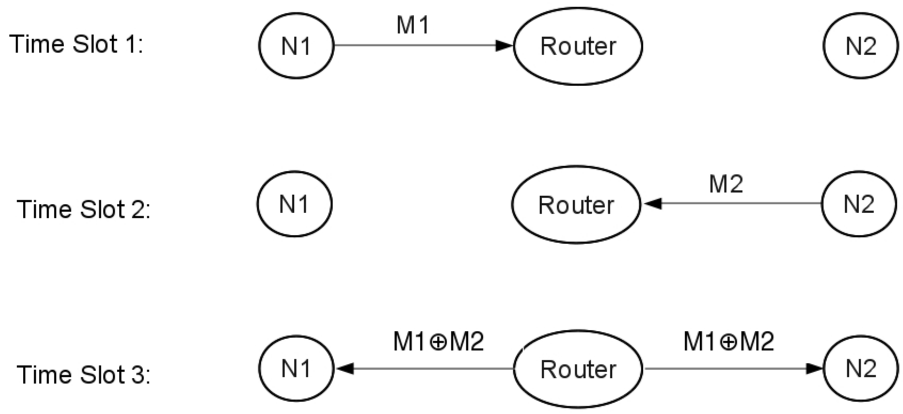

Figure 3: Three Time Slots for Digital Network Coding Approach

XOR operation:

$$\text{M1} = 1101$$
$$\text{M2} = 1010$$

$$Router = M1 \oplus M2 = 0111 \tag{1}$$

At Node N1:

$$\text{M1} \oplus (\text{M1} \oplus \text{M2}) = (\text{M1} \oplus \text{M1}) \oplus \text{M2} = 0 \oplus \text{M2} = \text{M2} = 1010$$

At Node N2:

$$\text{M2} \oplus (\text{M1} \oplus \text{M2}) = \text{M1} \oplus (\text{M2} \oplus \text{M2}) = \text{M1} \oplus 0 = \text{M1} = 1101$$

Above example describes the work of the router. According to our example, after receiving the message packets M1 and M2 one after the other, router XORs the bits which is nothing but 0111 in equation 1. Then, the router forwards 0111 (XORed version) to node N1 and node N2. Here node N1 XORs the received packet with its own bits and gets node N2's packet which is explained in 'At Node N1' part with calculation. Finally, node N1 recovers 1010 bits which is the message bit transmitted by node N2. Similarly, node N2 also applies the same method explained in 'At Node N2' and recovers 1101 which is the message bits transmitted by node N1 respectively.

2.1.3 Analog Network Coding Approach

Analog network coding approach further improves the throughput by reducing the time slot from 4 to 2. This is done only when node N1 and node N2 transmit their message packets S (M1) and S (M2) simultaneously to the router shown in figure 4. At router, these two packets S (M1) and S (M2) interfered because of simultaneous transmission and because of interference router receives *S (M1)*$\oplus$*S (M2)* of node N1's and node N2's signals respectively. The router decodes and forwards the received signals to nodes. After receiving, the combined signals S (M1)$\oplus$S (M2), router performs modulation and demodulation technique which is explained in next section, and cancels the interfering signals and deliver the packet successfully. So, totally analog network coding approach needed 2 time slots, one is for sending message packets to router simultaneously by nodes N1 and N2 and one more time slot consumed for the router to decode and forward right packets to their corresponding nodes. Therefore, analog network coding reduces the time slots from 4 to 2, which doubles the wireless throughput comparing to traditional network. The idea behind this analog network coding approach is similar to digital network coding but the difference is, in analog network coding the message packets can be transmitted simultaneously where as in digital network coding the messages has to be transmitted one after the other. One more difference is analog network coding done at physical layer i.e., network coding deals with signals where as bits are used for transmission in digital network coding since it is done at data link layer.

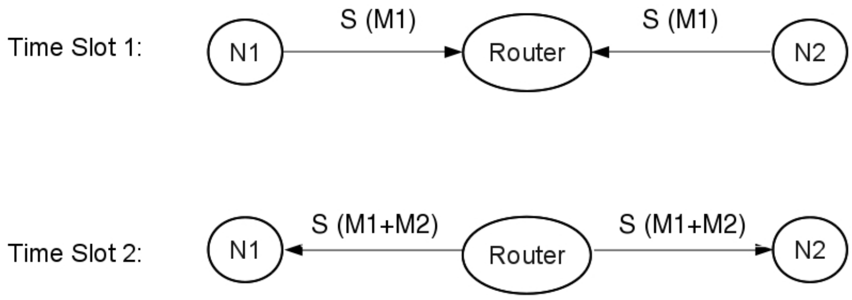

Figure 4: Two Time Slots for Analog Network Coding Approach

So far the paper discussed about Bi-directional transmission network. In which, the throughput of three approaches are discussed . In all three approaches, analog network coding approach gained throughput than other two approaches using bi-directional transmission network. Next section presents uni-direction transmission network for these approaches and discusses the throughput of these approaches as well.

2.2 Uni-Directional Transmission Network

Uni-directional transmission is nothing but, chain of nodes in a network [6] shown in figure 5. Generally, network has 'n' nodes but here it is considered that network having 4 nodes namely node N1, node N2, node N3 and node N4 respectively [1]. Node N1 is source node and node N4 is its destination node where the packets are transmitted from source to destination shown in figure 7. Considering throughput, traditional network approach needs 1/3 packet per time slot i.e., it needs 3 time slot to transmit message packet M1 from its source node N1 to its destination node N4. In this case of digital network coding does not provide throughput gain, and it's not needed o consider this approach for this scenario. it cannot transmit packet simultaneously because of collision at node N2. So, digital network coding approach does not work in this network. But, Analog network coding stands works well in this uni-directional transmission network and gains the throughput compared with traditional network approach.

Let us now demonstrate how this analog network coding works with uni-directional approach and improves throughput. As the network have only four nodes, in which node N1 and node N3 are in same radio region and both transmit packet simultaneously. And nodes such as node N2 and node N4 are said to be receiving nodes because it always receives packets from other two nodes so they are also called receiving nodes. Node N1 transmits message packet Mi to node N2. Then, node N2 transmits Mi to node N3 shown in figure 6. After transmitting the message packet Mi, node N2 stores a copy of the packet Mi which was sent by node N1. Next, node N1 again transmits another message packet Mi+1 to node N2. At the same time node N3 transmits packet Mi to node N4 as well as to node N2; node N3 also stores a copy of Mi in its buffer. Transmission of packet Mi+1 from node N1 to node N2 and transmission of packet Mi from node N3 to node N2 and node N4 happens simultaneously. Because node N1 and node N3 are in same radio region they can transmit packet simultaneously. These two transmissions Mi+1 and Mi collide at node N2 such that node N2 receives interfering signals ((Mi+1)⊕Mi) of node N1 and node N3 respectively. Then node N2 inserts inverse of Mi as Mi^{-1} to its buffer. And then cancels the interfering signal by performing $((\text{Mi}+1)\oplus\text{Mi})\oplus \text{Mi}^{-1} = (\text{Mi}+1)$. Finally, node N2 will be having the packet Mi+1 transmitted by node N1 and node N4 receives Mi transmitted by N1. Here, analog network coding allows node N1 and node N3 to transmits simultaneously. So, the time slot is reduced from 3 to 2. In the case of traditional approach time slot is 3 where it has to transmit the packet in each hop from source to its destination. Hence, Analog network coding requires only 2 time slots for transmitting message packets from source to its destination.

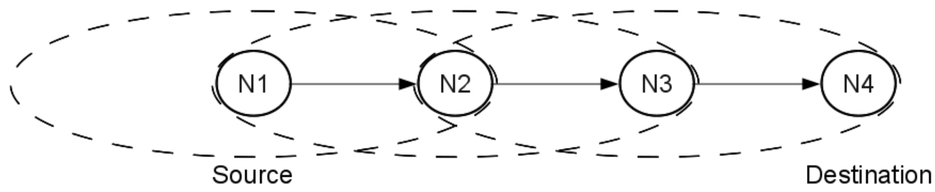

Figure 5: Uni-Directional Transmission Network. Two Circles show the radio range of N1 and N2

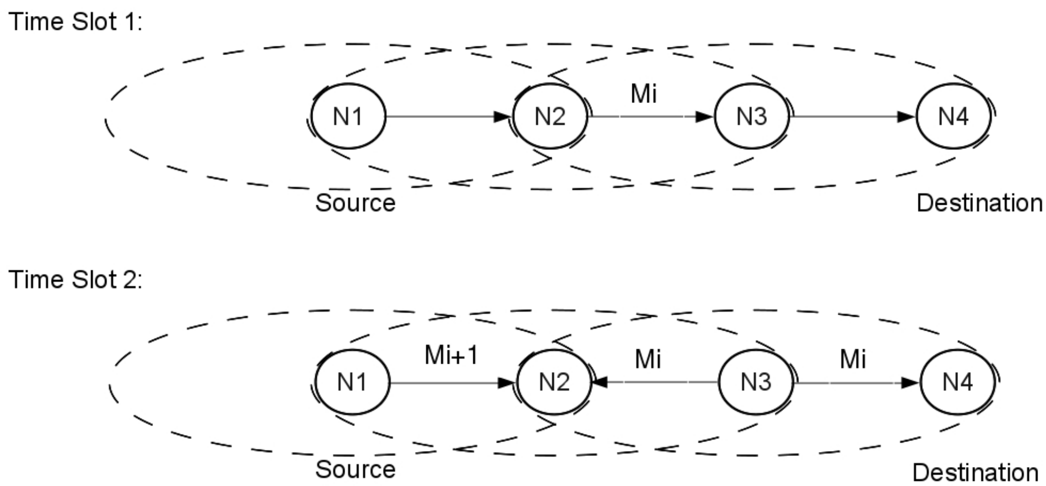

Figure 6: Analog Network Coding Approach

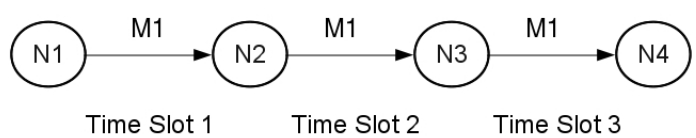

Figure 7: Traditional Network Approach

3 Implementation of Analog Network Coding

So far, we discussed about the throughput gain of analog network coding using bi-directional and uni-directional transmission networks comparing with traditional wireless network and digital network coding. The following section presents the implementation of analog network coding which needs modulation/demodulation technique at the router node to implement analog network coding.

3.1 Modulation/Demodulation Technique

Here, Modulation/Demodulation technique is applied for bi-directional wireless network approach. First, let us discuss the working of modulation and demodulation technique by sending one message bit using PSK[1] with a simple example. Transmission of information signal and carrier signal over communication medium is called modulation. Information signal is nothing but the information to be transmitted Actually, there are various modulation techniques used for implementation namely, Digital Frequency modulation, Phase-Shift Keying modulation (PSK) and Quadrature Phase Shift Keying (QPSK) modulation etc., In this paper QPSK scheme [9] used for implementing analog network coding. Generally, all the schemes mentioned here are used to deliver message data to its corresponding destination by changing the signal phase. The QPSK scheme referred as 4-QPSK because there are four possible phases used in which the carrier signal is sent in four possible phases 0°, 90°, 180°, 270°. The QPSK scheme with its associated bits are shown in table 1. The phases are separated by 90° each and phases changes for each time slot. The QPSK scheme is represented on a constellation diagram[10] as shown in figure 9.

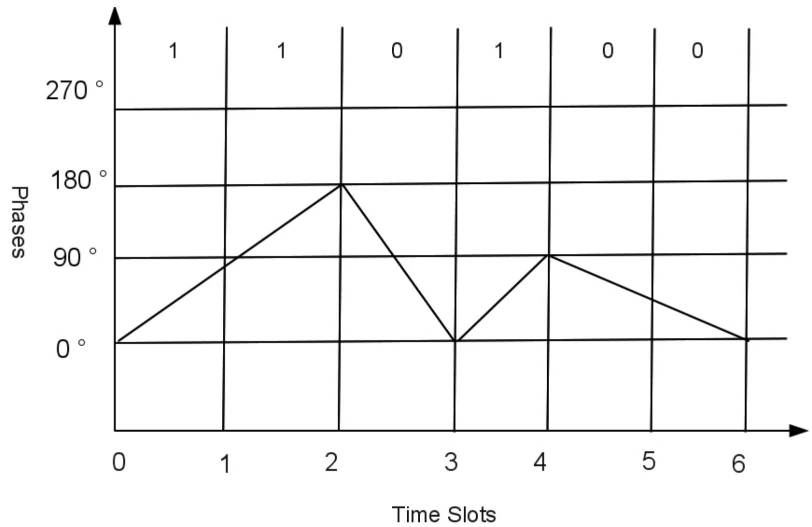

Figure 8: Example for Single Message Transmission using Modulation Technique

Now, let us consider that the sender wants to send 110100 bit information to receiver. Here, information signal is nothing but the information to be transmitted i.e., 110100 and the carrier signal is the phase or wave where digital bits of 0's and 1's are mapped to the signal accordingly. Simply to say modulation is mapping up of digital bit streams into signals. For each time slot 0, 1, 2, 3 etc., as in figure 8 shows the phase changes according to the information being transmitted. When the digital bit '0' represents phase difference of 0°and less. The digital bit '1' represents 90°and more. The sender sends the information through phases with high frequency. While receiving, the receiver has to demodulate the signal to get the information. To demodulate receiver follows the same method in reverse direction. Mapping bit '0' to 0°and bit '1' to over 90°. So far, the paper discussed modulation and demodulation technique by sending one message using PSK [1].

Phases	Bits
0°	00
90°	01
180°	10
270°	11

Table 1: Quadrature Phase-Shift Keying

Now, let us discuss the modulation and demodulation technique for bi-directional network approach. At first, the algorithm which uses this technique assumes that the two signals synchronized correctly at

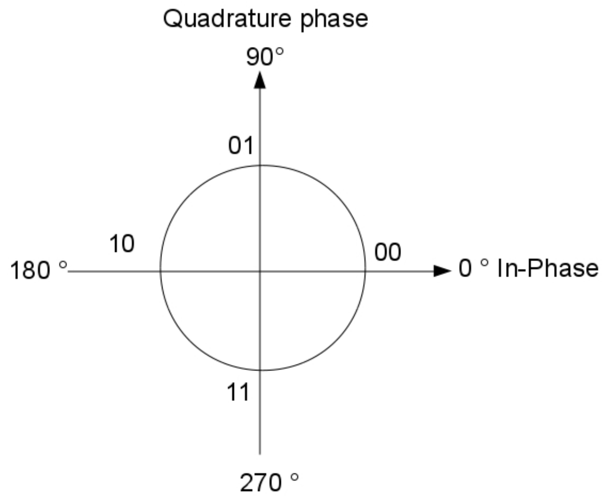

Figure 9: Constellation Diagram

the router. Then, the channel and its frequency for transmitting signal from source to its destination also assumed which is nothing but carrier-phase synchronization and carrier-frequency synchronization. As discussed earlier in section 2.1.3, when node N1 and node N2 sends packet simultaneously, router receives the sum of two packets assuming that these two packets synchronized at the same time at router. So, router receives :

$$\begin{gathered} \text{R (M)} = \text{S (M1)} + \text{S (M2)} \\ = [x1cos(t) + y1sin(t)] + [x2cos(t) + y2sin(t)] \\ = \text{(x1+x2) cos (t)} + \text{(y1+y2) sin (t)} \end{gathered} \tag{2}$$

Where, R (M) is the router which receives the sum of signals from node N1 and node N2 in one transmission and is carrier frequency. The above mentioned equations are represented using Euler's relation [8]. In this scheme, the phase of QPSK changes once for each time period. Here, the number of phases are not considered since the information is delivered in binary scheme (BPSK). So, for each time slot two bits of information is delivered because of four phases such as 00, 01, 10 and 11 shown in table 1. The four phases are divided into two phases each namely in-phase (I) and quadrature phase (Q) given in equations (3) and (4)[6]. Here, two cosine waves are referred as in-phase signal and two sine waves are referred as quadrature phase signal in equation (2). The in-phase and quadrature phase are also known as real and imaginary signals. These two signals interfered at the router R (M) and the nodes N1 and N2 have to decode the signals and get its desired packets accordingly. By using the in-phase and quadrature phase of received signals router helps the nodes to decode interfering signals. The in-phase and quadrature phase can be written as:

$$I = x1 + x2 \tag{3}$$

$$Q = y1 + y2 \tag{4}$$

Router R (M) receives the above two phase signals where x1 and x2 are two cosine waves and y1 and y2 are two sine waves of S (M1) and S (M2) respectively. The message packet S (M1) sent by node N1 has to reach its corresponding destination and similarly, S (M2) should reach node N1. Since, router R (M) has combined signals of nodes N1 and N2; it cannot separate the desired message which is sent by N1 and N2. Hence, modulation and demodulation technique is needed at router R (M) to convey the message packet to its destination. As discussed that whatever phases used does not matter but the final message is conveyed in digital bits. Considering this main point the modulation technique treats the phases of QPSK such as in-phase and quadrature phase as digital bit stream. After applying modulation technique as said already that for each time slot two bits of information is delivered so, router R (M) receives the XORed version of message bits for in-phase and quadrature phase simultaneously as shown in the following equations (5) and (6)[6]:

$$In - Phase : Si(M1 + M2) = Si(M1) \oplus Si(M2) \tag{5}$$

$$QuadraturePhase : Sq(M1 + M2) = Sq(M1) \oplus Sq(M2) \tag{6}$$

And then the router R (M) transmits the following signal to node N1 and node N2:

$$S(M1 + M2) = x3cos(t) + y3sin(t) \tag{7}$$

After receiving the above signal from the router R (M), nodes N1 and N2 demodulate it by mapping digital bits into in-phase Si and quadrature phase Sq respectively. The working of modulation and demodulation scheme is shown in table 2(a) and table 2(b) respectively.

In-Phase Binary Bits		Xk = 2N-1	
Si (M1)	Si (M2)	X1	X2
0	0	-1	-1
0	1	-1	1
1	0	1	-1
1	1	1	1

Table 2(a) Modulation at node N1 and N2

Demodulation at R (M)	XOR Operation at R (M)	Nodes N1 Receives
X1+X2	Si (M1+M2)	S (M1)
-2	0	-1
0	1	1
0	1	1
2	0	-1

Table 2(b) Demodulation at router R (M)

Table 2: Modulation and Demodulation Technique

The paper have explained the modulation and demodulation technique only for in-phase where in equation (7)[6], the x3 cos part is explained and the same method is applied for quadrature phase also. Table 2 (a) depicts that the quadrature phase considered as binary bits. Here, Si (M1) and Si (M2) are the message bits received by router R (M) from the nodes N1 and N2. They are represented as in-phase data bits. The in-phases X1 and X2 are calculated using the formula Xk = 2N-1 where 'k' is either X1 or X2 and N = Si (M1), Si (M2) for X1, X2 respectively. In Table 2 (b) shows, how the router demodulates binary bits and sends it to node N1. Router R (M) demodulates by adding X1 and X2 of in-phase and performs XOR operation and receives Si (M1+M2). Then, router applies modulation and sends S (M1) to node N1. Similarly, node N2 also receives message bit using modulation and demodulation technique. Finally, the message has been delivered to their destination. In this section the paper proposed the working of modulation and demodulation technique on bi-directional network approach. In the next section is discussing problems at nodes while sending message packet if they not synchronized at router and also discusses some possible solution.

4 Problems in Sending Message Packets

In this section, the paper discusses problems when two message packets not synchronized correctly at router. Basically, the concept of analog network coding is to send the message packet simultaneously. So, both signals of nodes N1 and N2 should sync at the router. Therefore, synchronization of signals and the channel status are important. So, the two main cases need to consider are [1]:

- Node N1's transmitted signal and node N2's transmitted signal synchronized correctly at router.
- Status of the channel.

4.1 Synchronization and Channel Status

The synchronization problem occurs when signals of nodes N1 and N2 does not arrive router at the same time. This may happen when one node sends packet first and the other node starts to send a bit late therefore, they do not interfere simultaneously. Let us say for example, node N1 started sending packet S (M1) early and node N2 started sending S (M2) after node N1. They do not arrive exactly at the router. There are few bits at the end of node N1 and few bits at the beginning of node N2 were not used. So,those few bits considered as free bits. These free bits can be used for synchronization. Similarly, the status of the channel differs, where node N1 sent S (M1) to router is not the same channel where node N1 receives S (M1+M2) from router as shown in figure 4. While receiving S (M1+M2), node N1's channel differs from previously it sent packet S (M1) to router. To solve this task, the paper proposes an approache to estimate the synchronization of channel and channel status. There are two approaches, one is estimating the *channel blindly* and other one is using *pilot symbols* which are nothing but inserting 64-bit length sequence at the beginning of each packet before transmission. Here, the pilot symbol approach is used for estimating the channel.

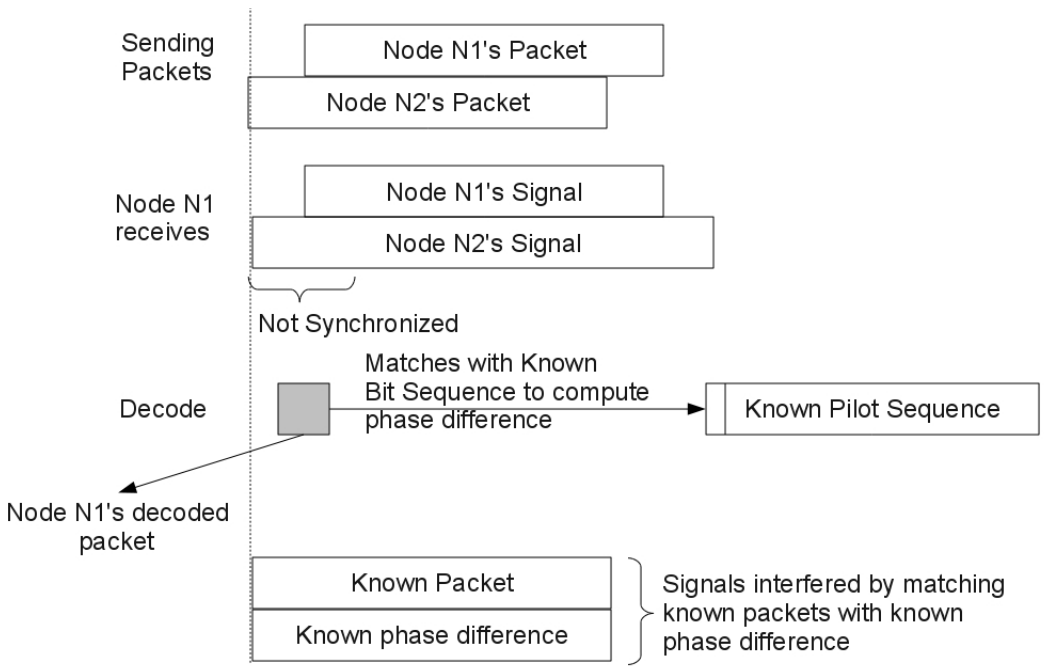

Figure 10: Synchronization of Two Signals

As discribed earlier, let us consider node N1 started sending its packet M1 early and node N2 sends after N1 and also consider the sizes of these packets are same. In this case, these two packets do not interfere at the same time. Therefore, the 64-bit length sequence is attached at the beginning of nodes N1 and N2 as shown in figure 10. Once these two signals of nodes N1 and N2 reaches the router, router then forwards the non-synchronized signals to both the nodes. After receiving, node N1 searches the header of its packet using energy detector [1]. Then, it searches for free bits and decodes it. Then it checks for known pilot bit sequence of each frame in order to arrange with received signal. Once the match found, node N1 starts to apply demodulation technique in section 3.1. The technique looks for synchronization of two signals but it could not find any. Since, node N2 was started a bit late. So, it waits for node N2 to synchronize. Once, node N2 sync with N1 then N1 applies usual demodulation technique and gets S (M2). Similarly, node N2 also applies the same technique and get N1's message S (M1). Finally, synchronization and channel status has been detected using pilot bit sequence. This section discussed problems in synchronization of two node's signals at the router and channel status and also discussed solution for this problem with an example. The next section, discusses about some benefits gained in using analog network coding approach by comparing with other approaches.

5 Analog Network Coding Vs Other Approaches

Analog Network Coding is done at physical network layer over signals. This approach is applied on bi-directional transmission network and uni-directional transmission network to see the throughput gain. Similarly, traditional network and digital network coding also applied on those transmission networks. Comparing throughput gain, Analog Network Coding stands first. In bi-directional approach, analog network coding doubles the throughput i.e., gains $4/2 = 2$ time slots compared with traditional network approach and gain $4/3 = 1.3$ time slots compared with digital network coding approach. In uni-directional approach, it's been able to compare the throughput only with traditional network approach as it has been discussed early in section 2.2, in digital network approach it cannot transmit packet simultaneously because of collision at node N2. So, analog network approach gains $3/2 = 1.5$ time slots compared with traditional network approach.

6 Future Works

In this section, this paper proposes some future works that are to be done on analog network coding in order to improve efficient performance.

1. Theoretically the approach have shown that the throughput gain has been improved while using analog network coding approach much better than with other two approaches on uni and bi directional transmission networks. But, practical work also needed to run analog network coding on these approaches in order to examine the results. Since, in uni-directional approach it has been assumed that the signals of nodes N1 and N2 synchronized at router and performed calculation on that assumption in section 3.1. Practically, this will not happen because, pilot bit sequences is inserted at the beginning on each packets for synchronization and channel status discussed in section 4.1. So, practical attention is needed more for analog network coding approach on various networks.

2. As discussed in section 4.1 while dealing with synchronization the size of packets of nodes N1 and N2 are assumed as same. So, it should be tested by checking with different packet sizes. One possible solution for this is, if packets are not in same size then shorter packets are padded which is usually done in digital network coding approach[7].

3. This paper described modulation and demodulation technique, discussed problems like synchronization and channel status for bi-directional approach only. That is, considered only three-node linear network having N1, N2 and Router respectively. In this scenario, analog network coding works fine and improves Bit Error Rate (BER) performance. Whereas, in a network having 'n' nodes it is difficult to improve rather reduces BER. Analog network coding should be tested in a huge network and needed to be checked BER on huge network as well.

7 Conclusions

Basically, transmission networks tries to avoid simultaneous transmission in order to prevent collision. But this paper embraces wireless interference using Analog Network Coding approach. The paper shown that the approach gained throughput by comparing with uni-directional and bi-directional transmission networks with demonstration. Analog network coding approach gained $4/2 = 2$ time slots compared with traditional approach without network coding and $4/3 = 1.3$ time slots compared with digital network coding. The paper also proposed the implementation of analog network coding using modulation and demodulation scheme for bi-directional approach. Then, discussed about Bit Error Rate that this approach improved BER only in small networks having few nodes. Analog network coding approach is more similar to digital network coding approach. But the difference is, in analog network coding message packets transmitted simultaneously and also it is done at physical layer. Finally the paper discussed some future enhancements in order to improve the performance of analog network coding. However, Analog Network Coding needs further research to improve the technology.

References

[1] S. Katti, S. Gollakota, D. Katabi, *Embracing Wireless Interference: Analog Network Coding,* Proceedings of the 2007 conference on Applications, technologies, architectures and protocols for computer communications; Session:Wireless, Pages: 397-408, 2007, DOI= http://doi.acm.org/10.1145/1282425

[2] D.N.C. Tse and G.W Wornell. *Cooperative diversity in wireless networks: efficient protocols and outage behavior,* IEEE Trans. Inform. Theory; Volume 50, Pages: 3062-3080, 2004, DOI = http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.122.4103

[3] Ram Ramanathan, *Challenges: a radically new architecture for next generation mobile ad hoc networks,* International Conference on Mobile Computing and Networking Proceedings of the 11th annual international conference on Mobile computing and networking; Session:Challenge Papers, Pages: 132-139, 2005, DOI = http://doi.acm.org/10.1145/1080843

[4] Claude E. Shannon, *Two-way Communication Channels*, Proc. Fourth Berkeley Symp. on Math. Statist. and Prob., Vol. 1 (Univ. of Calif. Press, 1961), Pages:611-644, DOI = http://projecteuclid.org/euclid.bsmsp/1200512185

[5] David Tse, Pramod Viswanath, *Fundamentals of Wireless Communication,* Cambridge University Press, 2005, DOI = http://www.cambridge.org/9780521845274

[6] Shengli Zhang, Soung Chang Liew, Patrick P.Lam, *Hot topic: physical-layer network coding,* International Conference on Mobile Computing and Networking Proceedings of the 12th annual international conference on Mobile computing and networking; Session:New Topics, Pages: 358-365, 2006, DOI = http://doi.acm.org/10.1145/1161129

[7] Sachin Katti, Hariharan Rahul, Wenjun Hu, Dina Katabi, Muriel Medard and Jon Crowcroft, *XORs in the air: practical wireless network coding,* ACM SIGCOMM Computer Communication Review, Proceedings of the 2006 conference on Applications, technologies, architectures, and protocols for computer communications; Session:Coding, Pages: 243-254, 2006, DOI = http://doi.acm.org/10.1145/1159942

[8] *Euler's Formula,* http://en.wikipedia.org/wiki/Euler's_formula

[9] Supplement to IEEE Standard for Information Technology- Telecommunications and Information Exchange Between Systems- Local and Metropolitan Area Networks- Specific Requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band, DOI = http://doi.ieeecomputersociety.org/10.1109/IEEESTD.2000.90914

[10] *Constellation Diagrams,* http://en.wikipedia.org/wiki/Constellation_diagram