Network Coding: An Optimized Solution for Cognitive Radio Networks

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Network Coding: An optimized solution for cognitive radio networks

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Abstract

The main goal of this chapter is to highlight current state-of-the-art protocols and algorithms along with design issues and challenges of network coding for Cognitive Radio Networks (CRNs). Network coding is a networking technique in which transmitted data is encoded and decoded to enhance network throughput, reduce delays and construct the network more robust. Network coding has been used in many networks like wireless sensor networks, traditional wireless networks, video multicast networks, P2P networks etc. However, in this chapter, we focus on network coding for CRNs. In CRN, a user can intelligently judge and scrutinize the environment then make decisions to adapt transmission schemes. Secondary users (SUs) in CRN employ network coding for data transmission. It condenses the transmission time. However, many technical issues still exist in this field. In order to provide a better understanding of the research challenges of Network Coding, in this article, we present a detailed investigation of current state-of-the-art protocols and algorithms for Network Coding in Cognitive Radio Networks. We also discuss open research issues in detail.

1. INTRODUCTION

Network coding (NC) is a technique of transmitting data in encoded and decoded form. Network coding is applied on the nodes of a network. It increases the throughput by sending more information in less packets transmission and stabilizes the network. In CRN, one of the advantage of Network coding is that Secondary User‘s (SUs) transmission time is reduced [1]. Network coding is an emerging technique used in many types of network. It makes the network robust to the packet loss by using Transmission Control Protocol (TCP). In order to amplify the throughput and robustness in Cognitive radio network, network coding is a pre-eminent selection.

Wireless networks are suffering from many problems like low throughput, dead spots etc. Variety of techniques was introduced in order to overcome these problems. Network Coding (NC) is one of the latest and emerging technique developed for the enhancement of throughput and to provide minimum transmission rate over wireless networks. It is also used to achieve a minimum energy-per-bit for multicasting in wireless networks. For improvement in energy efficiency, the network coding based scheme has only polynomial time complexity, flouting through the NP-hardness barrier of the conventional routing approaches. In [2], the author briefly discusses about the energy issues and efficiency of network coding regarding energy consumption.

Network coding when applied to Cognitive Radio Networks significantly enhances the performance of the network. The use of network coding increases the spectrum availability for the secondary users in CRNs by improving the estimation of primary user. Variety of algorithms based on network coding has been developed in order to decrease the need of bandwidth in cognitive radio networks. Network coding increases the spectrum utilization for secondary users by giving them opportunity to utilize the unused part of the spectrum owned by primary users. In contrast, using traditional techniques, the spectrum usage might be as low as 15%. In [3], the author identifies the one aspect of CRN as spectrum shaping and the view of network coding as a spectrum shaper. Using Network Coding, a number of secondary users may use the spectrum at the same time. Furthermore, network coding can achieve a potentially lower energy consumption compared to the conventional routing schemes.

Some up-to-date literature on network coding is [4, 5, 6, 7, 8]. The authors in [4] focus on network coding aware routing protocols in wireless networks. Physical layer network coding for wireless networks is discussed in

[5, 6]. Network coding for distributed storage is discussed in [7]. In [8], the authors present a survey on network coding in a theoretical form focusing on network coding theory including information theory and matroid theory. All the aforementioned works [4, 5, 6, 7, 8] focused on wireless networks in general. However, in this paper, we provide a survey on network coding schemes specifically designed for cognitive radio networks. To the best of our knowledge, this is the first work which provides such a comprehensive description of network coding in the context of cognitive radio networks. In this paper, our major focus will be on cognitive radio aspect of network coding and we recommend the readers to refer [5, 8] for more details on network coding in wireless networks.

Contribution of this chapter: In this chapter, we make the following contributions:

- We provide two simple illustrative examples which helps the reader to understand network coding basics
- We discuss how network coding is used in different networks
- We provide in-depth discussion of network coding in traditional wireless networks
- We discuss the usage of network coding in cognitive radio network by focusing on how it can be beneficial for these type of networks, its classification and advantages, and finally, we highlights issues and challenges

The remainder of this chapter is organized as follows: In Section 2, we discuss network coding basics. In Section 3, we discuss network coding applied to different networks. Network coding in traditional wireless networks in discussed in Section 4. Section 5 will be about cognitive radio network and network coding.. Challenges and open issues are presented in section 7. Finally, Section 7 concludes the paper.

2. Network Coding Basics

Network coding is a technique of sending data in encoded and decoded form. Network coding is applied to the nodes receiving or sending data packets. This causes less transmission time and thus increases the throughput of the network at high extent. It enhances the performance of the network by sending more data in limited amount of time. Network coding also use to handle incoming or outgoing data from a node.

Authors in [5] mentioned that Physical layer Network Coding (PNC) is industrialized in 2006 for applications in wireless networks. Its elementary idea is to feat the mingling of signals that arises naturally. A weighted sum of signals treated on receiver as an outcome of concurrent transmission at various transmitters. This sum is in a form of network coding process by itself. It could also be transmuted in other practice of network coding. In fact, in [5], the authors give an ephemeral conception of PNC, scrutinize a serious issue in PNC and anticipated that PNC in not only for wireless networks. Analog Network Coding (ANC) is a version of PNC that is also instigated in this paper. The authors also attempted to spread the application of PNC to optical networks.

We now discuss some illustrative examples to make the reader understand the basics of network coding.

Example 1: In Figure 1, there are two scenarios of network coding. First figure is of multicast with S1 and S2 as two sources, X and Y are two receivers and a and b are the packets. S1 and S2 want to transmit these packets holding binary information symbols. R is the intermediate node which combines a and b and create new packet a _ b where _ is the symbol for bitwise exclusive OR. As this is the coded network so R combines a and b. If this was not a coded network then R should produce two different packets a and b. So coding in the network augment the throughput because one transmission will produce less delay. In figure (b) of wireless point-to-point communication, S is the base station and the circle around it represents the range of base station, X and Y are in the range of base station but they cannot communicate directly to each other. If X wants to transmit a packet it will send to the S and Y will send packet b to S, they S generate new packet a _ b and transmit it to both X and Y. So this means that both these examples show the prospective of coding procedures in network nodes.

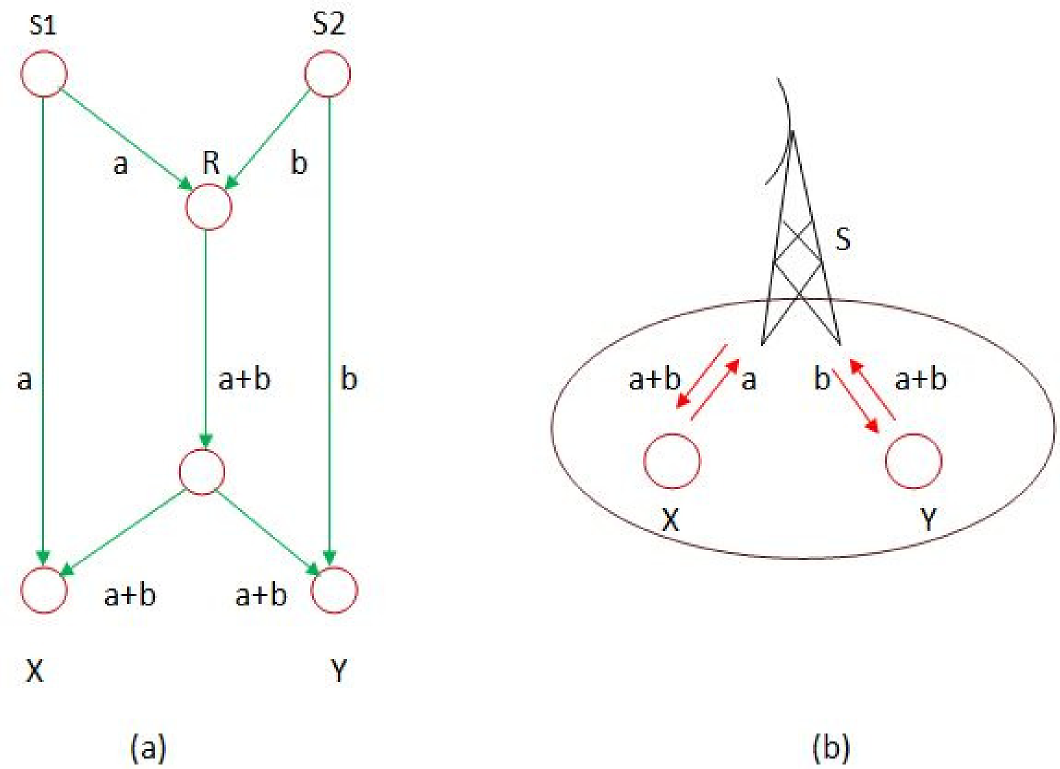

Figure 1: Network coding examples: (a)multicast with two sources and two recievers, (b)wireless point-to-point communication

Example 2: Figure 2 illustrates an example of ad-hoc cognitive radio networks in which network coding lessens the number of broadcasts. In this figure, 'v' is the relay node through which s1 and s2 relay their dta to d1 and d2 respectively. Suppose s1 and s2 send two packets p1 and p2 to d1 and d2, and node d1 comes to know about packet p2 and node d2 comes to know about packet p1. However d1 and d2 can receive their required packets if relay node 'v' XORs these two packets and broadcast the coded packet p1 transmits the two original packets to the destinations respectively.

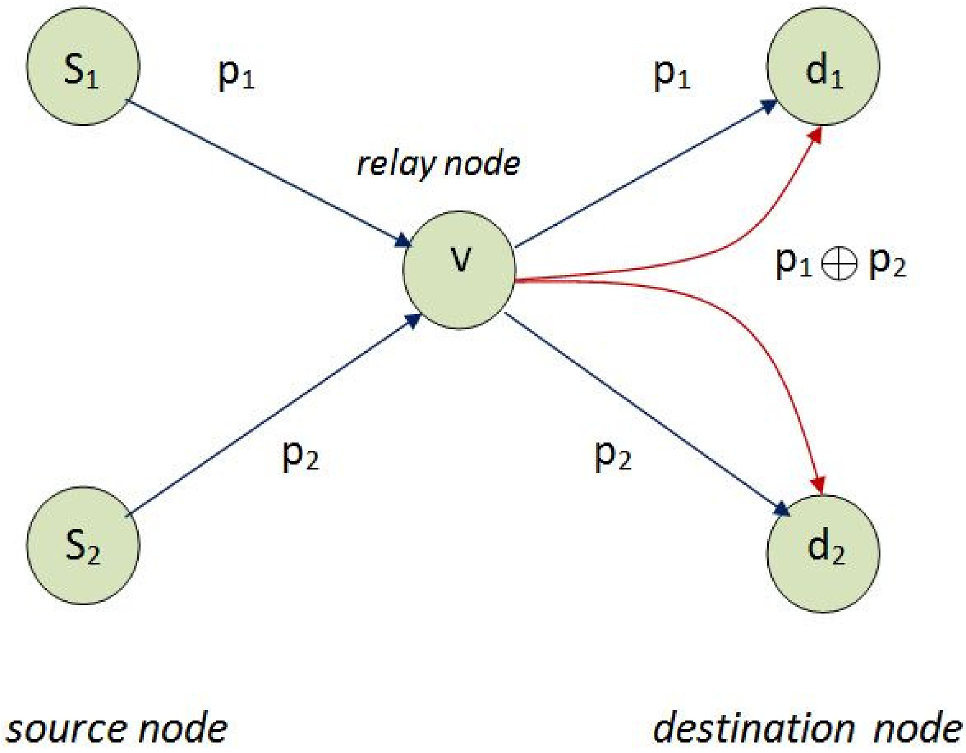

Figure 2: A sample example of multipath network coding

3. Network coding in different networks

We now describe each network and the use of NC coding in it in more detail.

3.1. OFDMA Networks

In [25], authors discuss the impacts of OFDMA systems parameters on network coding gain. They formulate the optimization frameworks and proposed channel aware coding aware resource allocation algorithms to exploit the network capacity in slow frequency. The also showed that node‘s power and traffic patterns are the dependencies of network coding gain.

3.2. Underwater Sensor Networks

Authors in [26] discussed that in past, we faced so many challenges like the presence of high error probability, long propagation delays and low acoustic bandwidth. They proposed that network coding is the gifted solution for these types of problems in underwater sensor networks.*3.3. Vehicular Ad Hoc Networks (VANETs)*

Network coding in the context of Vehicular Ad Hoc Networks is discussed in [27]. By using network coding, the authors describe the reliable dissemination of video streaming in case of emergency.

3.4. Optical Networks

In [21], authors used Network coding for optical networks.

3.5. Delay Tolerant Networks (DTNs)

In [28], the authors proposed the features for the advancement of reliable transport's performance in Delay Tolerant Networks's unicast and multicast flows. Their proposed scheme comprises of random linear network coding of packets.

3.6. Wireless Sensor Networks (WSNs)

Table 1 shows Parameters used to Evaluate Network Coding in WSNs. As in [29], the parameters used are number of encoded packets needed for successful decoding N. [2] evaluate network coding using the parameter of remaining energy per bit and remaining energy of cluster head. and in [30] the parameters used for evaluation are reliability, number of packets, traffic, energy consumption etc.

Table 1: Parameters used to Evaluate Network Coding in WSNs

Reference	Parameter Name
[29]	number of encoded packets needed for successful decoding N
[2]	Remaining energy per node , remaining energy of cluster head
[30]	Reliability , Number of packs , Traffic , Energy consumption , Delay

3.7. Wireless Relay Networks

In [31], many kinds of protocols have been exposed with the detection of wireless relay network (RN). Network Coding changes the wireless relay coding from 'store and forward' to 'store, process and forward'.

4. Network Coding in Traditional Wireless Networks

Wireless networks are suffering from many problems like low throughput, and dead spots. Variety of techniques was introduced in order to overcome these problems. Network Coding (NC) is one of the latest and emerging technique developed for the betterment of throughput and to provide minimum transmission rate over wireless networks. It also used to achieve a minimum energy-per-bit for multicasting in wireless networks. For improvement in energy efficiency, the network coding based scheme has only polynomial time complexity, flouting through the NP-hardness barrier of the conventional routing approach. Table 4 Parameters used to Evaluate Network Coding in Traditional Wireless Networks. In traditional wireless networks, physical layer network coding has been studied extensively [32, 33, 34, 35, 36, 37, 38, 39, 40, 41].

In [42], the author concluded that now-a-days the use of multimedia application over wireless networks is at its peak but there is huge amount of packets loss and delay in transmission, as the available bandwidth for wireless networks fail to meet the requirements. The author suggested that network coding may apply in different layers which increases the throughput.

In [43], the authors proposed COPE, which is used to maximize the throughput. COPE is based on network coding based packet forwarding architecture. COPE simply categorized packets in small size or large size simulated queues and then scrutinize only head packets to bound packet reordering. COPE familiarize limited packet reordering when the order of arrival packets is different from the departure. COPE improved transmission efficiency by around 30 percent. And this improvement can further increase by 45 percent by using flow-oriented architecture.

In [4], authors discussed basic concepts of application of the state-of-theart Network Coding (NC) within wireless ad hoc networks in the perspective of routing and recognize demarcation among NC-aware and NC-based routing methods in wireless ad hoc networks. Authors emphasizes on existing NC-aware routing protocols by providing different assessments and its advantages over traditional routing. In [44], relay-aided network coding (RANC) is discussed by developing the physical layer multi-rate ability in multi-hop wireless networks.

Table 2: Parameters used to Evaluate Network Coding in Traditional Wireless Networks.

Reference	Parameter Name
[45]	Protocol handshake duration , Retransmission rate, Average decoding delay
[25]	Throughput gain, End to end throughput , Normalized throughput
[46]	Full decoding percentage , Total Cost , Node decoding percentage
[11]	Bit error rate , Capacity
[47]	Detection probability
[15]	Average number of transmissions
[48]	Transmission time, throughput
[7]	Storage per node
[17]	Transmission time, Transmission Delay
[26]	Normalized energy consumption , Successful delivery ratio
[49]	Packet delivery ratio , End-to-end delay , Resource redundancy degree , Useful throughput ratio
[31]	Channel Capacity , Bit Error Rate
[43]	Average NTEI
[44]	Throughput , Coding+MAC gain
[1]	Throughput , Confliction probability
[50]	Throughput per Direction
[51]	Cumulative fraction of flows , Throughput
[20]	Throughput , Cumulative Distribution , Packet Delivery Ratio
[22]	Localization error
[52]	Cumulative fraction of flows , MORE Throughput
[23]	Throughput
[53]	Allocated Redundancy , Throughput
[54]	Cumulative Fraction of Flows , Bandwidth Overhead , Signatures per second, Latency
[55]	Average Number of Transmissions , Average Number of Linearly Dependent Packets , Average Broadcast Time , Average Number of Collisions
[56]	Number of GOPs , Percentage of optimal redundancy , Average PSNR ,Quality degradation
[8]	Complexity

In this study [49], relay-aided network coding (RANC) is discussed which tells us how to progress performance gain of network coding by developing the physical layer multi-rate ability in multi-hop wireless networks and here nodes are acceptable to broadcast at diverse rates according to the channel state. While relayed packets may frequently pass on at a high rate, the liberation of the total packets essential for decoding to each end node can be much earlier than direct transmission. Authors examine transaction in expanding performance of RANC and they systematically offer the solution by isolating the original design problem into sub-problems; flow partition and scheduling problem. To better up the bandwidth utilization in wireless network by easy operation like bitwise XOR, network coding develops the transmit nature of wireless medium. The desired operation of network coding (NC) does not need any advancement of hardware. NC was anticipated by Ahlswede et al, for multi-cast in wired networks. In scheme called COPE, proposed by Katti et al, the performance growth in terms of throughput and bandwidth effectiveness appears from coding and listening, and is an escalating role of number of flows assisted from network coding. In COPE, except for end, the packet sent by a starting node should be effectively overheard by all other nodes, and this node maybe the blockage of COPE performance. Developing the physical layer multi-rate capability allow to fight the crash of poor channel state on the recital of network coding. In contrast to COPE, RANC itself broadcast its native packet above a short range and enhances the performance of network coding in which the node that has bad channel condition among far neighbors. In this paper, the author also develops the coding structure for RANC. Substitution in performance gain of RANC in also discussed. RANC protocol has been established by decaying the original dilemma into two, the flow partition and scheduling problem. This supports to diminish the global cost. Replication is used to assess this strategy that RANC can expressively outclass COPE in terms of the throughput of network coding.

[57] In wireless sensor networks (WSNs), neighboring sensor nodes have connections of data. The scheme of compacting the sensor data with other‘s involvement to progress energy effectiveness in WSNs is called Distributed Source Coding (DSC). Using DSC, network architecture extensively manipulates the compression effectiveness. Dynamic clustering scheme is discussed in the paper in assessment to previous schemes which signify that this scheme has more efficiency than static clustering schemes.

WSNs are occasional systems based on the combined effort of various sensor nodes to monitor a physical phenomenon and involve spatially dense sensor operation to attain acceptable exposure. In Slepian-Wolf theorem two connected sources can be encoded though just encoders have individual admittance to the two supplies, providing both encoded streams are accessible at the decoder. Channel coding derived practical code constructions and Turbo codes or low-density parity-check codes (LDPC) reported Capacityapproaching code constructions. The partition method in WSNs with DSC is not useful in applications due to manufacturing and financial causes.. While winding up, analytical framework to sculpt the dilemma of partition and dynamic clustering scheme is offered to resolve the problem. It can panel the network vigorously adaptive to the topology and connections of the network with better density performance.

5. Cognitive Radio Networks and Network Coding

In this section, we first give an overview of cognitive radio networks and after that we will discuss network coding schemes in cognitive radio networks .

5.1. Cognitive Radio Networks

Cognitive radio networks is an emerging field and recently it gained a lot a attention from the networking research community [57, 58, 18, 59, 60]. This is primarily because (1) availability of limited spectrum, (2) fixed spectrum assignment policy, and (3) inefficiency in spectrum usage.

Cognitive radio networks are composed of two types of users. The first one is called Secondary Users (SUs) and the second one is called Primary Users (PUs). The PUs have higher priority over the licensed channels, while SUs have lower priority. SUs use the licensed channel opportunistically and are required to vacate the licensed channels as soon as PUs arrive over it. We now discuss network coding schemes proposed for CRNs.

5.2. Network Coding in Cognitive Radio Networks

In [19], authors explored network coding aware channel allocation and routing in cognitive radio networks and exploit the throughput by distributing the channel and link rate, including different stages and tell about the availability of maximum number of channels in any wireless network.

In [61], the authors anticipated that in cognitive networks, the need of bandwidth can be amplified by using distributed cooperative spectrum established on network code. They investigate and designate the algorithm of the distributed scheme based on network code and deprived of the network code the throughput increases outwardly. An approach named as gossiping updates for efficient spectrum sensing (GUESS) is anticipated to shrink the protocol overhead. In this paper, transmitting data is diminished by network coding.

In [1], Secondary Users (SUs) utilize network coding for data transmissions in view of Cognitive Radio (CR) networks. In [47], authors describe the use of spectrum sensing that it is used to identify the spectrum hole and detect the presence of primary user. Network coding is applied to different cognitive user in order to enhance the spectrum efficiency of cognitive frequency band.

In Figure 3, example of butterfly network, traditional routing and NC based routing are explained. S is the source and Eand F are information sinks. Let the source multicast b1 and b2 two unit data, to E and F. and the links are like SA, AC, CD, DE and so on. In figure (a), E obtain only b1 in one unit time since only one unit data can be broadcast per unit time in excess of link CD, so utmost broadcast of multicast cannot be obtained. However if we want to transmit b1 _ b2 to both E and F at the same time we establish NC in traditional routing, in this technique C can XORs the incoming data and broadcast the coded data b1 _ b2 on link CD and finally it will decode this data correspondingly. So E and F can receive b1 and b2 in one unit time, through which maximum multicast transmission capacity can be achieved.

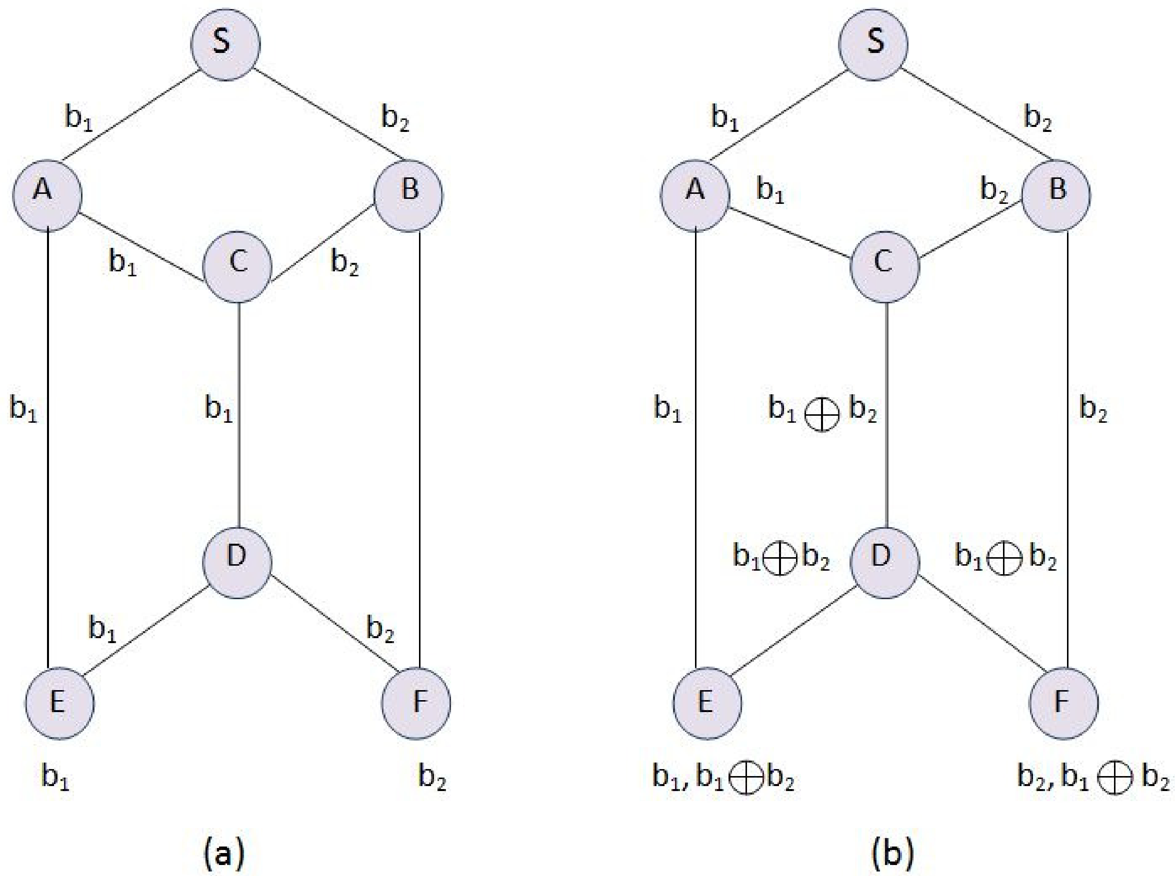

Figure 3: Butterfly Network: (a)Traditional routing, (b)NC based routing

5.3. Classification of NC schemes

In this section, we provide the classification of Network coding as showed in figure.

In Figure 4, we provide classification of network coding [62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74]. There are three types of network coding schemes available. The one is Random network coding, other is Vector network coding, and the third is linear network coding. Now we further classify linear network coding on the basis of coding over field size, the one is equal to one and the other is greater than one. The one with field size equals to one is again classify in two categories and then subcategories. Same case with the one having field size greater than one. And we further describe the linear network coding in multiple paths below in Figure 5.

In Figure 5, S is the source and T is the destination, and there are three link-disjoint paths between these source and destination. The source S sends packets to relay nodes R1, R2 and R3 simultaneously. In figure a, S sends packets p1, p2 and p3 to R1, R2 and R3 one by one. As sometime packet loss occur, so R1 receives all three packets but R2 and R3 fail to receive p2 and p3 respectively. So devoid of network coding, R1 forward p1, p2 and p3, R2 forward p1 and p2 and R3 forward p1 and p3 to destination T. We see that from R1, packets p1 and p3 change their path and went wrong while going to T, whereas p2 and p3 lost on their path from R2 and R3 to T respectively. And as a result only p1 and p2 are received. In figure b we applied linear network coding for transmitting packets. In this strategy relay produce the output packet zij by linearly merging the received packets. Here R1 receives p1, p2 and p3 and produce encoded packets z11, z12 and z13, correspondingly encoded packets z21 and z22 are produced by R2, and z31 and z32 are produced by R3. Here z11, z13, z22 and z32 are lost on their way to T. So at the end destination T receive z12, z21 and z31. By solving following equations T can decode the real packets because these packets are the permutations of linear independent packets:

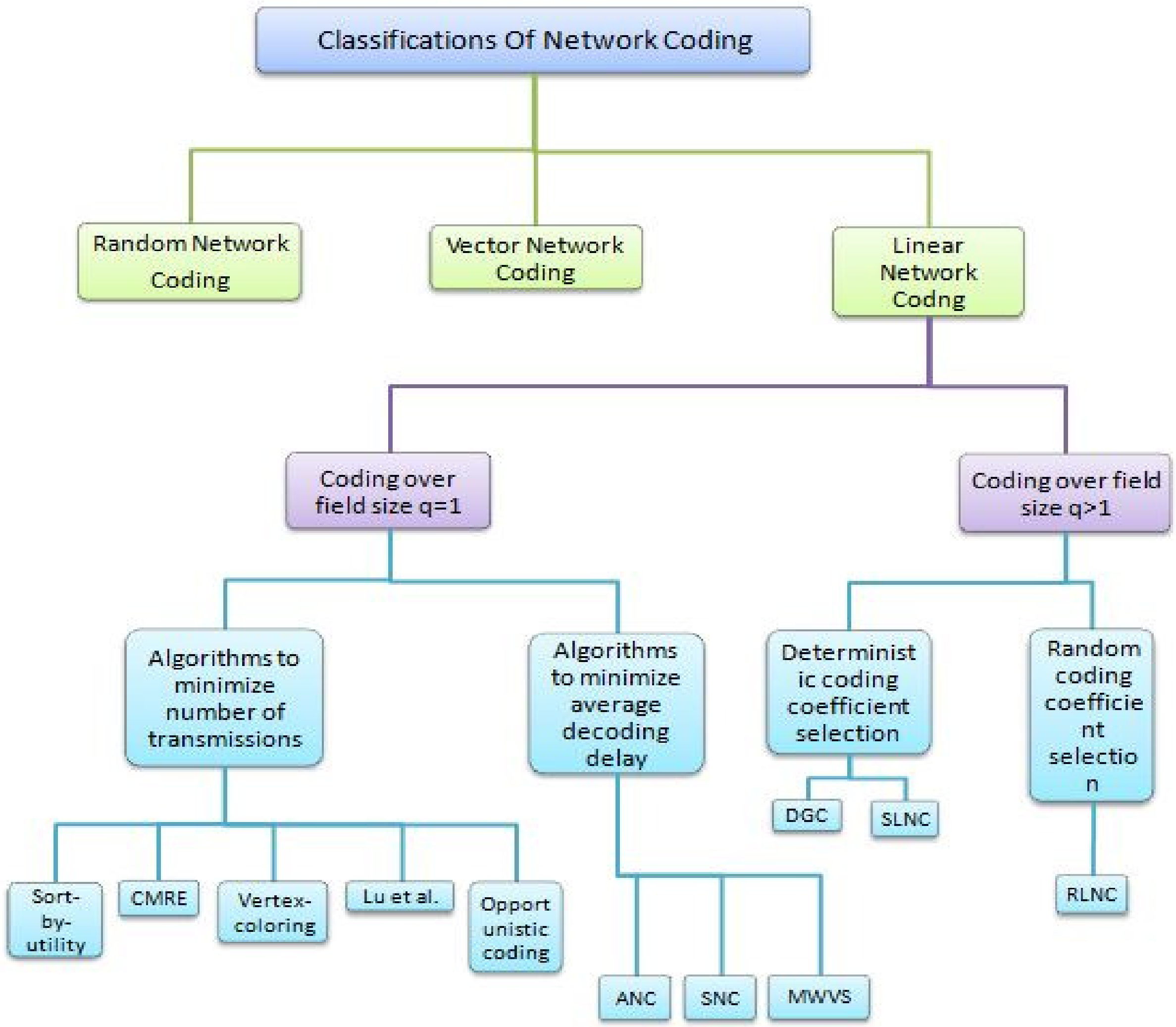

Figure 4: Classification of Network Coding

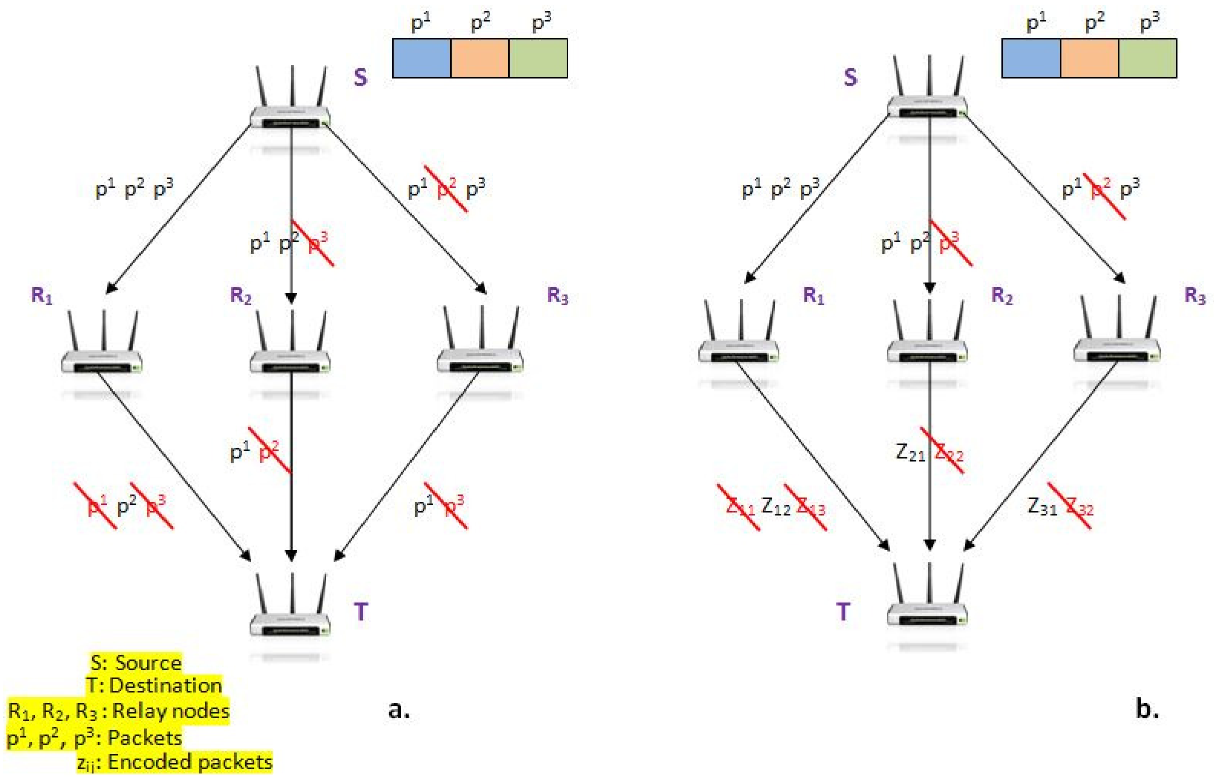

Figure 5: Random linear network coding in multiple paths

$$Z12 = \alpha\ 1p1 + \alpha\ 2p2 + \alpha 3p3 \tag{2}$$

$$Z21 = \beta 1p1 + \beta 2p2 \tag{3}$$

$$Z31 = \gamma 1p1 + \gamma 3p3 \tag{4}$$

Here (α1, α 2, α 3), (β1, β2) and (γ1,γ3) are the encoding vectors generated by R1, R2 and R3 respectively. We now describe in Table 3 parameters used to evaluate network coding in CRNs.

Table 3: Parameters used to Evaluate Network Coding in CRNs.

Reference	Parameter Name
[75]	symbol error rate
[57]	Average throughput
[10]	Dissemination delay
[76]	Outage probability
[77]	broadcast cost
[3]	PU idle probability, SU throughput , Additional gain on SU‘s throughput from backoff

	based adaptive sensing over random channel sensing
[12]	Probability of success , step time overhead
[78]	Normalized packet delay of a message
[79]	PER performance
[80]	Spectral Efficiency versus
[81]	Error probability. Diversity gain
[82]	Cooperative ENSR
[83]	Bit error rate
[14]	Mesh number , Total bits
[84]	Average capacity , Uniform capacity
[85]	Batch delay
[60]	Decision time , Energy dissipation
[86]	Batch delay
[87]	Average ICI received by the central cell
[61]	Throughput
[18]	Secondary user goodput
[19]	Throughput
[88]	Spectrum efficiency , Probability of successful control information
[89]	LT decoding error probability , Spectral efficiency

5.4. Benefits of Network Coding in CRNs

In [2], the authors discuss about the efficiency of network coding regarding energy issues, which is a great advantage. Network coding (NC) was a new coding idea first proposed by R. Ahlswede et al. in 2000. Network coding allows the node to code the incoming data also the transmitting one. NC also improves the broadcast efficiency by merging data in data based wireless sensor networks (WSN). This paper presents the benefits of NC applied in WSN. By comparing result of analysis and simulation, it shows that network coding can significantly lessen the time of information exchange. NC is more appropriate in wireless networks like such as wireless Ad Hoc networks, wireless mesh networks and cognitive radio networks etc. As the authors talk about the benefits of NC. One of the major assistance in WSN is energy saving. Another benefit authors explained in throughput enhancement. NC also maintains the network load balance. It also increases the network security.

5.5. Network Coding based routing in Cognitive radio

In [15], the authors confer about the routing scheme with network coding for cognitive radio network. We have to propose a routing protocol if we are given with the cognitive radio nodes with the geographical locations. This routing protocol should play down the average number of transmission per packet. The packets in this protocol use temporary nodes hop by hop, until they reach their destinations. Performance can also be enhanced by using the algorithm they proposed. Simulation shows that, as compare to DSR protocol, this algorithm gains much better performance in term of lower number of transmission.

5.6. Secure Transmission of Network Coding

In [90], the authors examined the research done on secure transmission on network coding in wireless networks. Security issue is the key problem in wireless networks and to overcome this, network coding is used. As there is so much pollution in networks, therefore, a scheme was proposed named as secure XOR network coding which filters the polluted message. Secure network coding scheme uses different coding strategies and different coding methods based on current network safety situation. Adaptive network coding scheme is more appropriate for the multifaceted and unstable practical wireless network environment. In [21], the authors present the use of network coding to provide resource effective and preemptive protection. The construction of rectilinear amalgamations of packets received at diverse inputs links at in-between nodes was presented by network coding which boosts the capacity. The authors convey the addressing network coding-based protection of bidirectional unicast connection and the use of p-cycles has been enlightened. Diversity coding is also discussed in which mishmashes are molded at special nodes.

5.7. Network Coding for Commercial Devices

In this paper [91], the authors describe the ability of network coding that it has the potential to simplify the design with higher throughput and lower energy expenditures. They argue that network coding complexity is not an issue for current mobile devices even without hardware acceleration. They provide two design styles of network coding inter- and intra-session network coding using commercial platforms, supplying real-life measurement results on commercial devices.

5.8. Network Coding in Multi Channel CRN

It is critical to have efficient data transmission secondary users to communicate with each other [86]. Channel fading is the main issue during transmission even if they have full access to that channel. Now under practical fading channels conditions, the authors proposed the random linear coded scheme for the efficient data transmission in multi channel cognitive radio networks. The authors analyze two the performances of two multichannel automatic repeat request (ARQ) based schemes. Simulations shows that this coded scheme outperforms the ARQ based scheme in term of batch delay transmission.

6. Issues and Challenges of Network Coding in CRNs

There are plenty of issues and challenges of network coding in CRN. Some have been resolved but with some limitations and some are still under observation. The main issues are:

6.1. PU Activity

PU activity is the foremost and intrinsic challenge of CRN. Since SUs operate on licensed channels of PUs, therefore whenever PU arrives on its channel, then SU has to vacate this channel if it is currently utilizing it because PUs have the highest priority to access the channel. The dynamicity of PU activity imposes a big challenge to network coding in cognitive radio networks.

6.2. Multiple Channels Availability

Traditionally wireless networks operate on single channel and so the network coding. But in cognitive radio networks, there are multiple channels available and SUs exploit them opportunistically whenever they are available. Since traditional algorithms for network coding are developed for single channel, therefore there is a need to investigate network coding algorithms to provide support for multiple channels.

6.3. Heterogeneous Channels

Since there are multiple channels available in cognitive radio networks, each channel has different characteristic like bandwidth, data rate, bit error rate etc. Therefore network coding has to deal with heterogeneous channels in cognitive radio networks which is also an important challenge which needs investigation.

6.4. Contention among SUs

Another challenge may occur when secondary user is using some part of spectrum and another secondary user is accessing the same part of spectrum at the same time. So there might be interference among them. So, it is necessary to develop protocols for channel access among SUs in network coding for cognitive radio networks.

6.5. Spectrum Sensing

Another challenge is to sense the spectrum for secondary user when primary user is not using it. Incorrect spectrum sensing results in either false alarm or miss detection. In false alarm, there is no PU activity, but the spectrum sensing detects that there is PU activity. In this case, there is an opportunity to exploit a spectrum band but due to false detection, this opportunity is lost. In miss detection, there is PU activity but spectrum sensing detects that there is no PU activity, so SU keeps on using the spectrum band which results in interference among PUs and SUs. This is very serious issue because in cognitive radio networks, we can compromise on losing an opportunity of spectrum access but we cannot compromise on interference with PUs. So, it also needs further investigation.* Sometimes due to incorrect spectrum sensing, there was a spectrum conflict between PUs and SUs and communication become will be distress.

7. Conclusion

In this chapter, we presented a comprehensive survey of network coding evolving from traditional wireless networks to emerging cognitive radio networks. To the best of our knowledge, this is the first novel work which provides comprehensive survey on taxonomy of network coding for cognitive radio networks which provides various examples, benefits and different mechanisms. In this paper, first introduction and basics of network coding are presented by different examples by explaining in detail what work is done in network coding and how does it work. Subsequently, applications of network coding are discussed. After this, network coding is described for different types of networks OFDMA networks, underwater sensor networks, vehicular ad-hoc networks, optical networks, wireless sensor networks etc. followed by traditional wireless networks. Then network coding for cognitive radio networks is described followed by its classification, benefits and different mechanisms. Finally issues and challenges of cognitive radio networks in network coding are highlighted.

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