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Survey on Network Coding-aware Routing

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ABSTRACT

In recent times, network coding is considered as a powerful solution to increase throughput. This study presents the basic concepts of wireless network coding in the context of routing within wireless adhoc networks. This paper briefly describes the concept of network coding technology and provides survey of various network coding-aware routing protocols in wireless adhoc networks. We also identify the challenges and discuss new research directions related to network coding aware routing.

Keywords: network coding, wireless ad-hoc networks, routing protocols, throughput.

1. INTRODUCTION

In recent years, wireless ad-hoc networks have been receiving significant attention due to its potential applications. Ad hoc network consists of nodes that move arbitrarily and form dynamic topologies. The distributed nature of networks and their link stability poses critical challenges in the design of routing protocols for them. Network coding [1] was born around 2000, in a couple of papers that suggested that combining data at routers could improve network efficiency. Network coding offers a new paradigm for network communications and has generated abundant research interest in information and coding theory, networking, switching, wireless communications, cryptography, operations research and matrix theory etc. Intermediary nodes in the network are allowed to mix and combine the different received signals prior to their subsequent transmission. It has been shown that this approach may yield a reduction of the amount of data transmitted in the network, leading to a performance improvement together with many advantages and benefits in network robustness, security and efficiency. Over a wide range of potential applications, network coding has thus the potential to provide increased network capacity and efficiency and hence appears to present a new and promising way to advantageously impact the design and operation of modern communications networks..One of the simple applications of network coding in wireless communications is when two endpoints exchange packets via a common intermediate relay node; in that case, the relay can simply broadcast a XOR combination of the packet contents from both sides, allowing both endpoints to receive their data while reducing the total number of transmissions from 4 to 3 per transaction.

This approach may lead to significant improvements over classical routing algorithms, in which received packets are merely forwarded. Possible benefits of network coding are increased throughput, energy efficiency, robustness, adaptability, and security. Application areas are in wireless ad-hoc networks. To do so, we allow routers to "mix" or code packets' content before forwarding them. For example in fig.1, It allows A and B to exchange a pair of packets using 3 transmissions instead of 4.

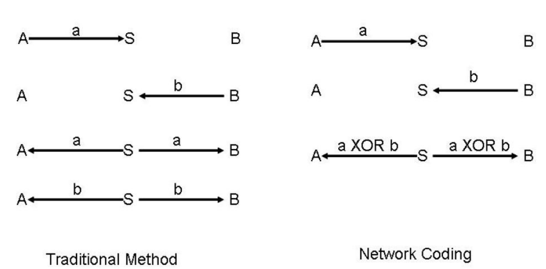

Figure.1 Network Coding versus Traditional Method of Communication.

One of the first practical network coding systems for wireless networks is COPE, introduced by Katti et al. [2], [3]. COPE is a new forwarding architecture for wireless network that inserts a coding shim between the IP and MAC layers, which identifies coding opportunities and benefits from them by forwarding multiple packets in a single transmission. In this paper we discuss the network coding scheme in wireless networks and review of network coding aware routing protocols. We also discuss the challenges and new research directions in network coding aware routing in wireless ad hoc networks.

The rest of the paper is organized as follows. Section 2 discusses background motivation related to network coding concept. Section 3 discusses the existing network coding aware routing techniques in wireless networks. Section 4 presents the open issues. In section 5 we discussed the new research directions and the proposed solutions in network coding aware routing over wireless networks. Section 6 presents the conclusion.

2. WIRELESS NETWORK CODING

Routing protocols play vital role in mobile ad hoc networks. Today there is a need for efficient routing protocols to improve performance of mobile nodes in mobile ad-hoc networks. In this current work, I will be focusing on the incorporation of wireless network coding into routing in wireless networks. The following are the main objectives of this research work.

2.1 XOR Coding

Network coding manipulates the data inside the packet itself through what's called a "bitwise exclusive or" (xor) operation to combine the information with that of another packet. A bitwise xor takes two bit patterns and performs the logical operation on each pair of corresponding bits, assigning a number "1" if the two bits are different and "0" if they are the same. These 1s and 0s are the codes, or evidence, by which an end station or any node with the intelligence to do so can deduce the message received from the sender. Fig.2.shows operations on packets of bits.

Packet 1	Packet 2	Coded packet
0	0	0
1	1	0
1	0	1
0	1	1

Figure.2 .XOR operation on packets

In this manner, network coding effectively allows destination nodes to receive multiple messages without an increase in the number of packets it receives or in overall network capacity.

2.2 COPE

Network coding-aware routing mechanisms improve the performance in wireless networks. It includes Developing solutions for efficient communication in mobile networks maximizing throughput and minimizing delay and provide several simple improvements to reduce the number of operations needed to perform decoding design and implement coding aware routing protocol in wireless networks balancing traditional routing metrics like delay, throughput, and packet loss and coding gains

Fig.3 shows the coding opportunity at node 6, which reduces transmissions. The example shows two flows, one from node 1 to node 4 and the other from node 4 to node 5. The link transmission rates are set to 1 unit and the value of each flow is also set to 1 unit. If we assume a simple scenario where there are no losses on these wireless links, then Figure 3(a) shows the best paths for the two flows in absence of network coding. These are the shortest and minimum interference paths for the flows, which results in an end-to-end throughput of 0.25. However, if the nodes are allowed to perform network coding, then the throughput of these flows can be improved by choosing paths for the two flows as shown in Figure 3(b). Note that such a choice increases the path overlap of the two flows to increase coding opportunities. Using the techniques developed in this paper, it can be shown that routing the flows as in Figure.3 (b) results in a throughput of 0.3325, an improvement of 33% compared to the previous case COPE.

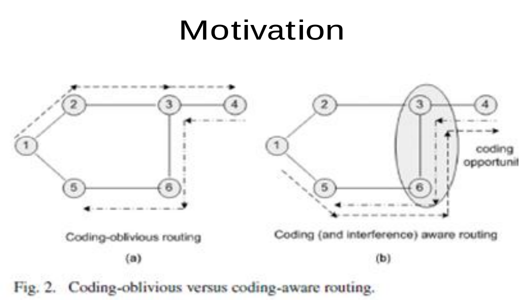

Figure.3.Network Coding aware Routing

COPE [3] uses network coding to utilize the broadcast nature of the wireless channel. Fig. 4 shows that the best coding scenario can be selected so that the maximum number of neighbors benefitted. Therefore, we can reduce the number of transmissions.. To maximize the number of packets delivered in a single transmission B can mix p1, p3, p4 and broadcast then nodes A, C and D can decode and get p1,p3,p4 respectively, that is at node A we get $p1=p4 \oplus p3 \oplus p1 \oplus p3 \oplus p4$.

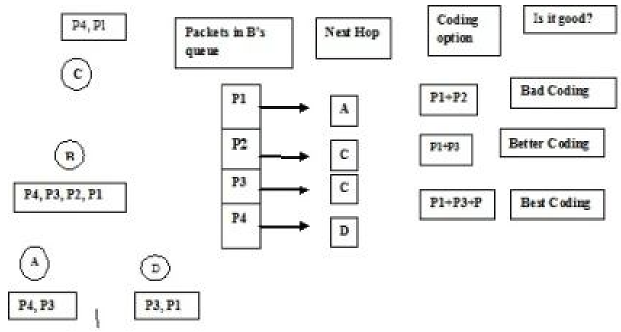

Figure.4. COPE Architecture

Advanced COPE

Advanced COPE[9] keeps separate virtual queues for each input-output pair and serve them in a round robin manner, what would happen in the cross network case is illustrated in Fig. 8. Here, the uncoded packets take up a much smaller fraction of the bandwidth, and the total throughput of the system improves.

3. OTHER NETWORK CODING AWARE ROUTING PROTOCOLS

The design objective of NCAC-MAC [10] is to increase the throughput and reduce the delay. Before attempting to transmit, the source node checks the surrounding medium. NCAM [11] formulate congestion control for unicast flows over coded wireless networks as a network utility maximization problem and present a distributed solution. Second, by mimicking the structure of the optimal solution, they proposed a “network-coding aware” queue management scheme (NCAQM) at intermediate nodes. ANCHOR [12], is an active network coding based high-throughput optimizing routing protocol, where every node not only exploits the existing opportunities to network coding, but also actively optimizes the routing for exploiting potential but not straight forward opportunities to network coding. ANOC [13] applies the idea of cooperative networking]. ANOC is built upon the classic Onion Routing protocol, and resolves its conflict with network coding by introducing efficient cooperation among relay nodes. CAR[16] aims to maximize the number of native packets coded in each single transmission. Opportunistic transmission may increase coding opportunities and the introduced small forwarding delay .CAR also adds extra network coding chances. CAR gives the coded packet that consists of a larger number of native packets with a smaller forwarding delay. In CEO [17], proposed a principle called consistency of encoding and overhearing (CEO).CORE [18] explores the combination of opportunistic routing and network coding for improving the performance of a WMN. In CORMEN[19],every node independently can take the decision whether to code packets or not and forwarding of packets is based on the coding opportunity available. OPNC[20] proposed to use relay node selection, which finds a proper node for network coding since the OPNC alone in the topology of multiple relays and sink nodes cannot guarantee network coding gain. In BEND[21] a MAC layer solution to practical network coding in multi-hop wireless networks is provided. It is the first exploration of the broadcasting nature of wireless channels to proactively capture more coding opportunities. In BEND, any node can code and forward a packet even when the node is not the intended MAC receiver of the packet; if the node believes that in doing so it can lead the packet to its ultimate destination. COPR [22] considered energy efficient network coding design in wireless networks with multiple unicast sessions. This approach decomposes multiple unicast sessions into a superposition of multicast and unicast sessions, with coding occurring only within each session. DCAR [23] the Distributed Coding-Aware Routing mechanism has the capability to discover high throughput paths with coding opportunities while conventional wireless network routing protocols fail to do so. This also proposes a novel routing metric called Coding aware Routing Metric (CRM) which facilitates the performance comparison between “coding-possible” and “coding-impossible” paths. EAR [24] addressed the problem of reliable unicast transmission across wireless networks with packet-erasure channel. However, existing NC schemes do not always fully exploit the potential of NC due to the lack of understanding of the u se of the encoded packets receivers cannot decode. To overcome this limitation, we propose a NC framework called encoded packet-assisted retransmission (EAR).

NCAPQ[25] scheme improves throughput compared to COPE this significant increase in throughput comes without significant loss in fairness. The modifications it proposed are minimal on top of COPE, thus making the scheme suitable for practical deployment. R-CODE [26] is a network coding-based reliable broadcast protocol. This introduced a guardian–ward relationship between neighboring nodes that effectively distributes the responsibility of reliable information delivery – from the global responsibility of the source to the localized responsibilities of guardians to their corresponding wards. CAMP [27] proposed a novel coding-aware multi-path routing protocol (CAMP), which forwards packets over multiple paths dynamically based on path reliability and coding opportunity. CAMP employs a route discovery mechanism which returns to the source multiple paths along with ETX (Expected Transmission Count)of all links on each path. Using a novel forwarding mechanism, CAMP splits the traffic among multiple paths and actively creates instead of passively waiting for coding opportunity by switching its path to maximize the switching gain. CAOR[28] integrates intra-flow network coding based opportunistic routing with inter-flow network coding for lossy wireless networks. The simulation results show that CAOR achieves an average throughput 20% to 30% higher than existing work. Moreover, CAOR also reduces on the average 20% of the number of transmissions for sending a batch of packets. Decoding buffer management [14] maximizes coding opportunities. The decoding buffer is limited in overhears or transmits practical wireless network and often tend to overflow. While decoding buffer is limited, some cached packets have to be moved out. How many packets a node actually used to decode or be dropped before entering decoding buffers. A node filters the (overheard or transmitted) packets which are invaluable for future decoding, instead of storing them in the decoding buffer..At the relay node,1. Combine packets if both buffers are non-empty.2. If only one buffer is non-empty, transmit the HOL packetuncoded.3. If both buffers are empty, do nothing. but this method proposes buffer equalization to improve coding opportunities.

4. OPEN ISSUES

The Coding-aware routing maximizes the coding opportunity by finding the coding possible path for every packet in the network. Network coding is a promising technology that can effectively improve the efficiency and capacity of multihop wireless networks by exploiting the broadcast nature of the wireless medium. However, current packet routing schemes do not take advantage of the network coding, and the benefits of network coding have not been fully utilized

Although the potential of the Network Coding paradigm is great, there are still many open problems that prevent a successful immediate deployment of derived technology in real-world applications. The NC-aware routing paradigm considers NC opportunities at intermediate nodes to assist route selection for packet delivery in wireless networks. Considering the issues of data delivery, coding-aware routing protocols either deal with route selection issues or focus on packet forwarding issues within wireless networks.

The fundamental problems with NC-aware routing in wireless networks are related to finding routes with the highest coding opportunities and determining the exact coding capability at each node in the wireless network. The purpose of these two findings is to reduce the number of transmissions required to deliver data from various sources to respective destinations within a certain network topology. However, packet combinations in the network may increase delay, complexity and even generate overly redundant information when they are not designed properly. Typically, the best performance is not achieved when all the nodes perform network coding. The problem of efficiently placing network coding nodes in overlay networks to increase the innovative packets. The proper selection of the network coding nodes is crucial for minimizing the transmission delay in streaming overlays.

5. NEW RESEARCH DIRECTIONS

Simulation and/or analytical models will be developed and the benefits of the proposed techniques evaluated through comparison with current state of the art protocols. We focus on the design of efficient multicast network codes for dynamic networks. We consider the problem of maintaining the feasibility of a given network code upon a change in the network topology or the addition of a new user. Our goal is to minimize the number of encoding coefficients that needs to be modified to keep the network code feasible. We present a new network coding algorithm that uses path-based coding assignments to efficiently handle frequent changes in the network topology and the multicast group. In addition, we believe that smarter network coding algorithm is desirable to further improve packet delivery reliability, as well as constrain energy consumption. We can analyze the coding performance with constrained decoding buffers. In practical wireless network coding, each node caches relayed packets and overheard packets in a buffer for decoding. This buffer is defined as decoding buffer. Relay nodes determine whether network coding can be performed according to cached packets in decoding buffers at their neighbors. We analyze the coding performance with constrained decoding buffers. We analyze the effect of scheduling policies and bandwidth allocation on coding performance .Coding performance and the optimal bandwidth allocation can be evaluated.

5.1 Best Coding

If we mix some packets then only some neighbors will be benefitted so that it reduces only some transmissions. Therefore we need to perform proper (which, how many) mixing of packets so that maximum neighbors benefitted. we need to find an algorithm to find the neighbor nodes packets information of common packets-decoding capability here the objective is to reduces the number of transmissions

5.2 Dynamic Buffer Allocation at the intermediate node in network coding system

In this approach we can combine packets if both buffers are non-empty.If only one buffer is non-empty, transmit the packet uncoded. If both buffers are empty, do nothing. One of buffers at the relay can be empty. Then Fall back to normal transmission. The solution may be to do Buffer Equalization. We can provide Packet scheduling for both the sources. Here the Objective is do not let the buffer become empty.

5.3 Decoding Delay

NC induces “decoding delay,” i.e., receivers may not decode network-coded packets until a sufficient number of innovative packets are received. The solution is to consider the number of coding opportunities and consider the delay. Implementation Objective is Balance delay vs throughput.

5.4 Decoding Buffer Management in Network coding system

The problem is to maximize coding opportunities, a node tend to store both kinds of packets in its decoding buffer as more as possible. The decoding buffer is limited in practical wireless network and often tends to overflow. While decoding buffer is limited, some cached packets have to be moved out, or be dropped before entering decoding buffers. That means coding opportunities for these packets are lost. The decoding buffer could be a bottleneck in practical wireless network coding. The solution is, some of the packets cached in decoding buffer are actually invaluable to opportunistic coding. Hence, filtering these invaluable packets in decoding buffer will not reduce any coding opportunities. A node filters the (overheard or transmitted) packets which are invaluable for future decoding, instead of storing them in the decoding buffer. Here the objective is Efficient use of decoding buffer to increase coding opportunities.

5.5 End to end Delay

Packet1 may need to wait for packet 2 on a device to do network coding, which increases end-to-end delay for packet 1. The Solution may thus there is a tradeoff between energy-efficiency and end-to-end delay while assigning the waiting time in the network coding process. We need to Consider the initial energy of the nodes .Maximize coding opportunities with respect to end to end delay. The objective is to balance the energy efficiency and end –to-end delay

5.6 Energy Efficiency

To increase network coding opportunities we forward packets through the same paths. If some nodes are frequently used the energy of the nodes will be consumed more. So the life time of the network will be reduced. The Solution is we can consider the initial battery levels of the nodes. Therefore we need to Balance the traffic. Coding opportunities vs energy consumption of the path. The objective is Reduce total energy consumption of the path. Here the objective is balance the energy efficiency and end –to-end delay.

5.7 Scheduling

In traditional network coding if there is no coding opportunity the system fall back to normal transmission. The solution is Schedule the packets to increase coding opportunities. Give priority to the packets needed by the next hop which cause a coding opportunity at the neighbor node. Here the objective is increasing coding opportunity.

6. CONCLUSION

In this paper we described the concept of wireless network coding in the context of wireless networks. We also presented the milestones of network coding aware routing protocols. Then we identified the challenging issues related to this field. We finally provided some new research directions to improve the performance of network coding aware routing in wireless ad hoc networks. We hope this helps for the future work in the area of network coding aware routing.

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