Network Coding Report 1

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***Abstract*— As a brand-new way to further utilize the bandwidth in our network, Network coding, immediate after proposed, has provoke new thinking in how to achieve full capacity of our current network. A great many of works have been done to explore the concept of network coding in different aspects. First brought up as a method to achieve optimal throughput of information transmission in multicast directed acyclic network, the concept of network coding now extended to a much broader field such as in the wireless packet network, undirected network, and multiple unicast session. In this paper, first we summarize the fundamental knowledge and give you a general idea about what network coding is. Then, we showed the conclusion of many papers related to network coding. After reading this paper, you are supposed to get a general view about the advantages and disadvantages of network coding as well as the basic conditions where network coding can be applied.**

***Index Terms*— Network coding, Network Capacity, Full throughput, Multicast**

I. Introduction

THE basic task of routing, in traditional networks, is to provide a shortest (or most efficient) path from source to corresponding terminal and a strong immunity against certain kind of network failure such as linkage break down. In a sense, this type of routing scheme helps avoid collisions of data stream as much as possible and select preferable path to transmit information as fast as possible. Although the traditional way of routing seems more than optimal, it has been proved that this strategy may not make full use of the network capacity in certain cases [1]. Thanks to the pioneer work done in [1], we come to know the power of network coding. Network coding theory has point out that it is necessary to consider encoding/decoding data on nodes in network in order to achieve optimal throughput. Just consider a simple classical network communication scenario below:

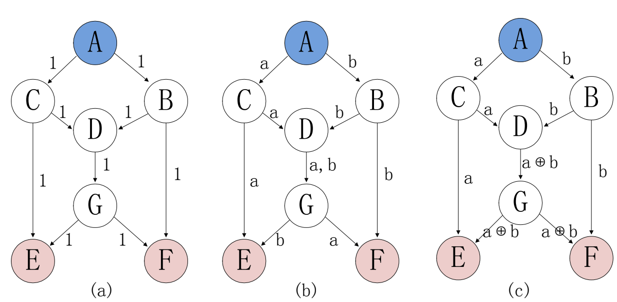

Fig. 1. Networks with multicast from A to E and F

In Figure 1(a) we denote a network as a directed acyclic graph with all link capacity 1 bit. Node A is assigned as the source node where information is distributed and node E F as the terminal nodes where the information sink. If we want to transmit 2 bits, say, bit a and bit b, to both E and F, we will have two strategies in Fig1 (b) and (c). Fig1 (b) simulate the current network layer routing method: each node can only replicate the bit it received to their outgoing link. Fig1 (c) enable each node to do modulo 2 operation to the bits it received before transmission. It is easy to check that bit a and bit b in Fig1 (b) will be transmitted one after the other from node D to node G while in Fig1 (c) one transmission is enough since the algebraic operation done by node D to generate just one bit "a+b" before transmission. The network which allows coding operation on node D has showed certain advantage over that not in the same scenario.

We will explain the advantage in two ways. As observed in Fig1 (c) , a total of 9 bits is sent. If network coding is not allowed, at least 1 more bit are required to make sure sink E and F can derive the 2 bits transmitted. So first we can see that networking coding, even at a signal node in the network, can save the bandwidth in 10 percent. Consider another condition where the link capacity of network in Fig1 (a) is revised to 2 and we want to send a series of bits to both E and F. With the help of network coding, we can easily see that a total of 4 bits can be send to E and F at a time. However when network coding is not allow, it can be showed that only 3 bits can be sent at a time. So one third of throughput enhancement is showed.

In other realistic scenario, the maximum capacity can be achieved by introducing network coding is investigated and analyzed by the aid of graph theory. In graph theory, the max-flow between a certain pair of source node and sink node in a weighted directed graph is calculated according to the well-known Max Flow-Min Cut theorem.

In multicast communication, there can be multiple receivers with different max-flows because a max-flow is defined for a point-to-point communication. We define the max-flow of a point-to-multipoint communication as the minimum of the max-flows of all the terminals in the network. A detailed proof is given in [1] that the multicast capacity of a network represented by a directed graph (i.e. the maximum number of bits that can be transmitted from the source to all the receivers simultaneously) is equal to the minimum value of the max-flows of all terminals. Notice that this is consistence with the example of Fig1 (c) since the max-flows of example in Fig1 is 2 which is equal to the throughput achieved when network coding is applied.

II. Relative Work

Although network coding shows certain potential to achieve the capacity of network in Fig 1, realistic network environment is much more complicate. There are many network communication patterns such as unicast, multicast, broadcast, multiple unicast, multiple multicast and multiple broadcast. Also, the mathematical modeling of network may have different forms such as directed network, undirected network, acyclic network and cyclic network. This can also affect the analysis of performance of network coding. Moreover, we have integral routing as well as fractional routing. All these factors lead to various network environments.

Among these various conditions,[9] analyzed the benefit of network coding in improving throughput for single transmission sessions, include single unicast, single broadcast, and single multicast. [9] proved that the improvement is always bounded by a constant factor 2. As a further study, [10] investigate the benefit of network coding over routing for multiple independent unicast transmissions through the comparison between the maximum achievable throughput with network coding and that with routing only. The result depends crucially on the network model [10].

Many paper concerning the marriage of network coding and wireless packet networks claimed that wireless packet networks are a most natural setting for network coding because the very characteristics for wireless links that complicate routing, namely, their unreliability and broadcast nature, are the very characteristics for which coding is a natural solution. [11] introduced a concept of COPE (stands for an opportunistic approach to network coding) in which case each node snoops on the medium, learns the status of its neighbors, detects coding opportunities and codes as long as the recipients can decode. This makes network coding in dynamic wireless networks possible. [12] show that mutual exchange of independent information between two nodes in a wireless network can be efficiently performed by exploiting network coding and the physical layer broadcast property offered by the wireless medium.

A. Advantages of Network Coding

The main advantage for network coding, as an original purpose of this topic, is its high transmission capacity with the max-flow, which means by employing network coding, the theoretical upper bound of transmission rate can be achieved by the sender. Due to the fact that all sessions do not need to have the same distribution trees according to some coding algorithm in transmission, the multisession IP can provide effective network resource utilization[1]. Besides, network coding has an effect on load balance and bandwidth saving , which also provide an alternative method as traffic engineering[4]. Using linear programming formulations, the maximum throughput that a multicast application can achieve with network coding in unreliable ad hoc networks is 65% higher than conventional multicast[5].

Another advantage for network coding is its superior performance in reducing the number of retransmissions in lossy networks compared to end-to-end automatic repeat request(ARQ) in both low-loss and high-loss regimes. We hypothesize that network coding achieves a logarithmic reliability gain with respect to multicast group size compared to a simple ARQ scheme[6].

In heterogeneous networks with dynamic node arrival and departure patterns, expected file download time improves by more than 20% with network coding compared to coding at the server only and, by more than 2-3 times compared to sending unencoded information. In addition, network coding improves the robustness of the system and is able to smoothly handle extreme situations where the server and nodes leave the system[7].

Last but not least, coding can be used to maintain connections after permanent failures such as the removal of an edge from the network. Using network coding, it was shown that a set of connections can be robust to a set of permanent failures. Also, if a multicast connection is achievable under different failure scenarios, a single static code can ensure robustness of the connection under all of those failure scenarios[8].

B. Disadvantages and Vista of Network Coding

From the network coding theory, it is easy to see that data integrity is critical for networks using network coding. One packet lost in the network may have a domino effect because other packets may have a dependency on it[4].Moreover, as some mathematic process have been used, the sequence of arrival is important as well[2]. These features make the networks with network coding quite vulnerable. Since the research is usually based on one-source multi-sink network with no package loss, many potential problems are omitted by network coding. This may result in poorer performance of network flow control by network coding.

There is still a lot of works to do with network coding such as algorithms in managing data flow and network coding for multi-source environment. It is a very attractive interdisciplinary study area that poses interesting questions across diverse areas such as information theory, algorithms, algebra and coding theory, and graph theory.

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