Identifying the Parameters Affecting Network Coding in Wireless Networks

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***Abstract*—The wireless communication revolution has brought fundamental changes to the data networking, however wireless networks continue to suffer from numerous problems such as limited bandwidth, low throughput. It is possible to efficiently exploit the available bandwidth by the use of network coding, but at a certain cost of encoding/decoding overhead, which in certain cases turns out to be much lower than the coding gains. This is primarily facilitated by the broadcast nature of the medium, spatial diversity, and significant data redundancy. The basic idea of network coding lies in sending the information as a linear combination of packets arriving on the incoming edges, instead of simply relaying the packets of information as they are received. This can be used to attain the maximum possible information flow in a network. In this paper, we present various parameters affecting the network coding opportunity.**

***Index Terms*—Bandwidth, broadcast, encoding, decoding, linear combination, network coding, wireless communication**

I. Introduction

In existing computer networks, information is transmitted from the source node to each destination node through a chain of intermediate nodes by a method known as store-and-forward which demands data replication at each transmitting node. The main problem with this method is that when the overall network traffic volume is high, bottlenecks are common, resulting in long delays. Packets tend to bunch up at certain nodes, sometimes in excess of the nodes' ability to process them. Other routes and nodes may remain under-utilized.

As an alternative to this conventional method of routing, the concept of network coding was first introduced by R. W. Yeung and Z. Zhang in 1999. **'Network coding'** is a field of information theory and coding theory and is a method of attaining maximum information flow in a network. [1],[2],[3],[4]. Network coding is a simple extension of routing that allows for any node in the network to perform operations on its received data before it transmits any data. It is an elegant and novel technique introduced to improve network throughput and performance [5], [6], [7], [8].

The advantages of network coding over routing, the traditional way of operating a network, were exhibited by means of a very simple example known as the *butterfly* network. Fig. 1 (a) shows this network along with the edge capacities used and Fig. 1 (b) demonstrates the working of network coding as defined by Ahlswede et al. [9]. Here, the source S sends two bits, b1 and b2 into the multicast network with network coding applied before the link between nodes 3 and 4 is traversed. The single channel between these nodes is used to transmit b1 ⊕ b2. Because of this XOR-based coding, a throughput of 2 is achieved.

Manuscript received February 15, 2012; revised April 20, 2012. This work was supported in part by Indira Gandhi Institute of Technology, Guru Gobind Singh Indraprastha University, and Delhi, India.

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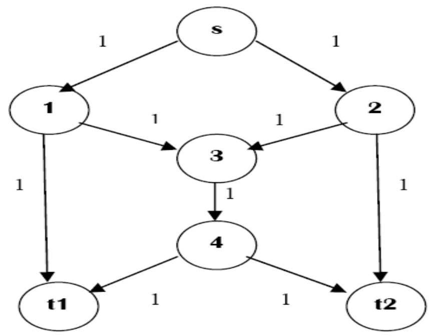

Fig. 1(a). Butterfly network showing the edge capacities

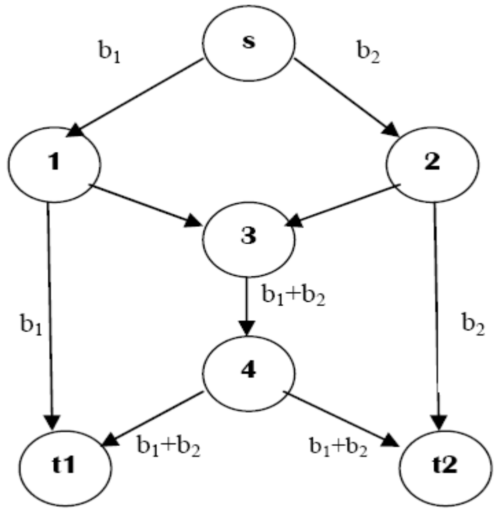

Fig. 1(b). Butterfly network showing the working of network coding

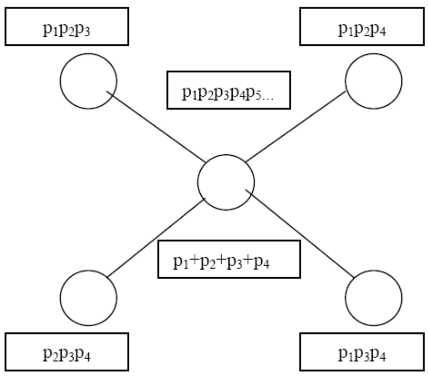

Fig. 2. Maximizing coding gains by making combinations of n packets if all receivers already have (n-1) packets of the same combination

Network coding improves throughput as depicted in Fig. 1. However, in more complex situations, such as that shown in Fig. 2, a router can have numerous possibilities of combining the packets, and, it must choose the one that maximizes the number of packets delivered in one transmission. Router will maximize coding gain by making n packets combinations if all recipients already have $n - 1$ packets of the same combination.

The goal of this paper is to explain the various parameters affecting the network coding. The next section describes the affects of various parameters such as, number of blocks, packet buffer size, latency, etc.

II. Parameters Affecting Network Coding

A. Latency (Data Rate)

Technically, latency refers to a delay. In order to increase the benefits from the use of network coding, the mean packet latency introduced by coding and decoding must be minimized. Results have shown that latency varies primarily based on the parameters like, data rate and the packet combination size, and is not heavily dependent on the underlying topology. In general, the latency added by XOR coding decreases with increasing the data rate of transmission [10].

B. Number of Packet Combinations

The number of packets combined and the underlying topology affects the linear network coding performance in terms of decoding gains. The packet combination size, in turn affects the latency. For relatively small packet combinations, Gaussian elimination does not introduce additional computational delays due to a large number of packet combinations [10]. Increasing the number of packets put into combination might lead to performance degradation due to higher complexity and longer time needed for sufficient number of coded packets to be received.

C. Packet Buffer Size

The packet buffer size affects the network coding gains at the time of making encoding/ decoding decisions. The number of decoded packets on each node is not a linear function of buffer size [10] but increases with an increase in buffer size. Larger packet buffers give more combining opportunities to nodes and ensure higher network coding gains. However, if applied to the same packet combination size, having a larger packet buffer size does not bring significant decoding gains.

D. Number of Blocks

A node can start the decoding process only after it receives a sufficient number of linearly independent blocks [11], [12]. This is possible only if there are an optimal number of blocks in the network [13]. If the number of blocks is too less then the linear dependence among the blocks increases due to which a node will not be able to decode successfully. However it has been shown that on increasing the number of blocks beyond an optimal value the network coding gain decreases because of higher encoding and decoding overhead.

E. Block size

The coding bandwidth is maximized for a particular range of block sizes depending on the network conditions and the number of blocks [12].The optimal block size shifts upwardsas the number of blocks increases. Very large block size results in a decrease in coding bandwidth, while a very small block size increases the header overhead incurred to carry the coding coefficients, consequently leading to a reduction in network coding gains [13].

F. Density

Density is denoted as m/n where m is the number of blocks a node randomly selects to encode a new coded block for its downstream nodes, and n is the number of original blocks in the session[12],[13]. The average downloading time steadily decreases when density decreases, since each node has fewer blocks to encode, thus leading to a higher coding bandwidth, and smaller computational overhead of encoding. However if the density is too low then the linear dependence among the blocks increases (as the corresponding coding matrix would be too sparse to be full rank if the density is too low), due to which a substantial number of peers will not be able to decode successfully.

G. Aggressiveness

Aggressiveness is the number of blocks which a node needs to buffer before it can start producing new coded blocks. In order to reduce the delay in waiting for new coded blocks, the node produces a new coded block upon receiving a.n coded blocks($0<a\leq 1$), where the tunable parameter a is called aggressiveness. [14]The average downloading time steadily decreases as the aggressiveness becomes lower and results in an increase in network coding gains. However as the aggressiveness reaches a certain critical point, the number of blocks required to decode sharply increases resulting in longer, rather than shorter downloading times [13].

H. Number of Nodes

Network coding requires a moderate to large number of nodes to be profitable to the system. This is because network coding is more efficient when the number of neighbors that can benefit from the same transmission increases [15], [16]. As the number of nodes in the system increases, nodes would probably have more neighbours from which to get the chunks and the information in the network would be diversified. Consequently, the coding gain from each transmission will increase.

I. Channel Capacity

Channel capacity factor is the ratio of channel capacity to the total demand traffic in the network. Results show that as the channel capacity is increased for a given traffic load, more traffic can be sent via the same path [17]. In other words, with the increasing channel capacity factor, the Opportunity for network coding increases.

J. Traffic Factor

Traffic load factor is the ratio of total demand traffic to the channel capacity. As the traffic load increases, while the channel capacity remains constant, the network coding opportunity initially increases [17]. However, as the traffic is further increased, the energy consumption from the increased load outweighs the energy reduction due to network coding, thereby decreasing the opportunity for network coding.

K. Node Degree

Initially as the node degree is increased upto a certain optimal value, the network coding gain increases [17]. However, further increase in node degree, increases energy dissipation thereby decreasing the nodes' residual energy, and consequently, the network coding gain. If nodes have too few neighbors, then the resultant topology minimizes the introduction of new information, leading to redundant blocks being sent between the nodes. Too many neighbors, however, result in the reception of same information by the common downstream nodes.

L. Nodes' Geographic Proximity to other Nodes

Farther the destination nodes are from the source node, the more is the number of hops that a packet needs to traverse, and hence, the more is the encoding overhead. The geographic proximity of nodes' has a significant impact on the nodes' energy consumption. At the system level, it results in increased energy consumption. It has been observed that in such cases, the coding overhead surpasses the network coding gains.

M. Idle lIstening Capability

The idle listening capacity of nodes creates an environment conducive to network coding since each node stores the packets it overhears for a limited period. It also tells its neighbors which packets it has heard by annotating the packets it sends. Thus nodes in each area have a large and partially overlapping reservoir of packets they can use for decoding. When a node transmits a packet, it uses its knowledge of what its neighbors have heard to deliver multiple packets in a single transmission.

N. Number of Edges Between its Neighbors

In network coding, an intermediate node modifies/generates a new coded packet. If network coding is used in case of a network with multiple paths between the nodes, the destination can receive different packets from different paths [18]. This is in contrast to multipath version without network coding, where replicated packets arrive at the destination via different paths.

O. Node Arrival Rate in Dynamic Networks

Node arrival rate can be defined as the rate at which the new nodes get added into the network. Frequent addition of new nodes results in an increased encoding/decoding overhead. The closer the added nodes are to the region where network coding gains are high, the more is the energy dissipation[19]. In addition, with the increase in the number of new nodes, the number of packets in the network increase, which may exceed the buffer limits of many routers. One of the major problems with network coding is that the loss of one packet can affect many other packets and render some information useless at the receiver. Hence, in such situations network coding gain subsides.

P. Type of Topology-Dense/Sparse

It has been shown that dense topology leads to more redundancy since in densely connected topology, nodes are more likely to have direct downstream neighbours in common. Further, in dense topology rapid dissemination of innovative blocks occur since the distance that a packet needs to travel(in terms of link delays) is much shorter. Whereas, if the topology is too sparse, then the coded blocks will not be able to travel effectively through the topology, which results in reduction in network coding gains. [14]

III. Conclusion and Future Work

Network coding is a particular in-network data processing technique that exploits the characteristics of the wireless medium (in particular, the broadcast communication channel) in order to increase the capacity or the throughput of the network. This can be used to attain the maximum possible information flow in a network. This paper summarizes the parameters affecting the network coding opportunities in wireless networks. The knowledge of how various network parameters affect network coding is crucial in order to achieve coding gains that exceed the encoding/decoding overheads. The network coding technique can be simulated and the proposed results can be analyzed graphically using NS2 simulator.

Acknowledgment

We would like to thank Mr. Vivekanand Jha, for his valuable guidance and cooperation.

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