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# A REVIEW ON NETWORK CODING AND ITS APPLICATIONS IN WIRED AND WIRELESS NETWORKS

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## ABSTRACT

Network Coding (NC) has been proved to be the breakthrough in the research field of networks and communication. It is an effective technique to increase network capacity and improve the throughput, robustness and reliability of networks. Network Coding refers to a scheme where a node is allowed to generate output data by mixing its received data. This paper presents the use of Network Coding in wired Networks and wireless networks. We also surveys the applications of Network Coding in the domains of peer-to-peer Networks, delay tolerant Networks. We also present a number of interesting research challenges in these domains, where the network coding can be used.

**KEYWORDS:** Broadcasting, Multicasting, Network Coding, Peer–to-Peer Networks, Wired and Wireless Networks

## INTRODUCTION

Network Coding is an area that has emerged in 2000[1] [2], and has since then attracted an increasing interest, as it promises to have a significant impact on both the theory and practice of networks we can broadly define network coding as allowing intermediate nodes in a network to not only forward but also combine their incoming independent information flows. Combining independent data streams allows to better tailor the information flow to the network environment and accommodate the demands of specific traffic patterns.

The first paradigm, that illustrated the usefulness of network coding established throughput benefits when multicasting error-free links. Since then, we have realized that we can get benefits not only in terms of throughput, but also in terms of Complexity, scalability and security. These benefits are possible not only in the case of multicasting, but also for other network traffic configurations such as multiple unicast sessions. Moreover, they are not restricted to error free communication networks, but can also be applied to sensor networks, peer to peer system and optical networks. It is infact advocated that first applications where network coding will have an impact will be peer to peer and adhoc wireless networks, these are environments that offer more freedom in terms of protocol design choices and where information inherently propogates in a distributed manner. For example, ongoing projects investigate the application of network coding ideas to content distribution [3].

## NETWORK CODING IN WIRED NETWORKS

NC was initially proposed as a distributed mechanism for achieving the multicast theoretic (max-flow min cut) Capacity in wired networks. In wired multicasting, information is sent from a set of source nodes to a set of destination nodes over a multihop network where the intermediate nodes merely forward their received packets via a pre-determined look-up table (routing). Ahlswede et.al., in [1] suggested the innovative notion of coding on layer-3 packets instead of look-up forwarding on specific outgoing links, and showed that network throughput can be increased. In a network employing NC, routers perform (random) linear combination of incoming layer-3 packets and broadcast the result to all its neighbors. Randomized linear network coding schemes were shown to be sufficient in achieving the information theoretic max-flow, min-cut bound on network capacity [2].Necessary & sufficient condition by Koetter et al.[4] while the concept of NC was developed for the network (IP) layer, it has often been implemented in practice at higher layers, such as the transport or application layers[5] [6] [7]. A fundamental reason as to why network coding is beneficial is based on the premise of simultaneous transmission from several (source) nodes to a single (receive) node. While this is feasible in a wired network whereby concurrent transmissions are deemed 'orthogonal', a multihop wireless network is quite different.

Wireless is a shared medium (at least for nodes within a common transmission range) and there is no natural spatial orthogonality. Thus wireless multihop networks have relied on other forms of orthogonality- in time (TDMA) or frequency(FDMA)- to achieve interference-free transmission Wireless Network Coding (WNC) uses non-orthogonal transmission that, nevertheless, allow recovery of multiple packets to enhance aggregate network throughput.

## NETWORK CODING IN WIRELESS NETWORKS

The broadcast nature of wireless (coupled with network topology) determines the nature of interference. Simultaneous transmissions in a wireless network typically result in all of the packets being lost (i.e. collision). A wireless network therefore requires a scheduler (as part of the MAC functionality) to minimize such interference. Hence any gains from network coding are strongly impacted by the underlying scheduler and will deviate from the gains seen in wired networks[8].Further, wireless links are typically half-duplex due to hardware constraints, i.e a node cannot simultaneously transmit and receive due to the lack of sufficient isolation between the two paths.

One of the potential application of WNC is in multicasting. A decentralized formulation to throughput optimization for the multicasting problem was introduced in [9][10]. However, if additional objectives such as maximizing throughput subject to delay constraints are considered, then network codes must be jointly designed with MAC as in [11] [12].Authors in [13] qualify the impact of random access MAC schemes (such as CSMA/CA) on performance of NC in all-to –all data dissemination system.

### Epidemic Algorithm for Rumour Spreading

This work focuses on networks represented as graphs & distributed algorithms, where similarly to our case, nodes do not have information about the nodes they are communicating with. At each round, each node randomly chooses a communication partner among the nodes that are connected to it through an edge, and either "pushes" or "pulls" information from it [14] [15].

### Broadcasting in Radio Communication Networks

In this body of work the wireless environment is modeled as a graph, where, when a node transmits a message, it is received by all its neighbors is transmitting. Again transmissions are divided into rounds, where in each round a subset of the nodes transmits, in way scheduled to minimize conflicts & maximize information spreading. The goal is to disseminate the information in the smallest number of rounds. Both centralized & decentralized algorithms are presented.

Indicative results include that, the problem is NP-hard, there exist. Static networks where the number of required rounds in Θ ($\log^2 n$). While there exist mobile networks where the number of required rounds in Ω (n) [16] [17] [18]. Using a similar model, the problem of minimizing energy consumption over a static wireless network was recently studied in [19].

**Algorithm**

Within the scope of the network coding literature, a number of papers have proposed algorithms that employ network coding over a dynamically changing wireless environment & evaluated their performance through simulation results closest to our particular broadcasting problem is[20] which shows that from the viewpoint of packet delivery ratio & overhead, NC compares very favorably to flooding. Minimum cost multicasting using network coding was examined in [21] for mobile networks and in [10] for fixed networks. Our work differs in that, rather than solving the routing problem we focus on assessing the benefits network coding may offer.

## MULTICASTING USING NETWORK CODING

Multicasting using NC can be divided into two tasks

- **Routing:** Finding minimum-cost subgraphs to support multicast connections i.e., determining the rate at which to inject coded packets on each arc and
- **Coding:** Determining the contents of these packets.

**Multicasting in Wired Networks**

Lun et al. in [22] presented decentralized algorithms that compute minimum cost subgraphs for establishing single static multicast connections in wired & wireless networks that use coding. These algorithms, coupled with existing decentralized schemes for constructing network nodes constitute a fully decentralized approach for achieving minimum-cost multicast. They pointed out that multiple simultaneous multicast connections can be treated separately, which is referred to as superposition coding but it is sub-optimal.

Li & Li in [23] obtained, through linear programming a necessary & sufficient condition for multicast rate feasibility & an efficient & distributed sub gradient algorithm for computing the maximum multicast rate. They concluded that NC may not be instrumental in achieving better max multicast rates in most cases. Rather, it facilitates the design of significantly more efficient algorithms to achieve such optimality.

Chi.et al. in [24] proposed that NC base routing algorithm for multicast capacity. They showed that when the average node degree is high. The achievable throughput of network coding based Multicast is much higher than that of the shortest path distribution tree routing algorithm & slightly greater than that of the maximum rate distribution tree routing algorithm. Noguchi et al. in [25] proposed a technique for load balancing and pointed out that achieving max flow using network coding can create congestion.

Li & Li in [26] showed that throughput improvement due to network coding in directed network is 0(|V |) and therefore unbounded. For undirected networks with integral routing, there still exist configurations that are feasible with network coding but infeasible routing only for the multiple independent uncast transmissions. For undirected networks with integral routing, there still exist configurations that are feasible with NC but infeasible with routing only.

**Multicasting in Wireless Networks**

Xi & Yeh in [27] used NC to achieve minimum cost multicast in interference-limited wireless networks where link capacities are functions of the signal to interference-plus-noise ratio(SINR).They considered joint optimization of NC subgraphs with power control & congestion control without excessive control overhead & designed set of distributed, node-based scaled gradient projection algorithms and derived scaling matrices for fast, guaranteed global convergence.

Ho et al. in[28] compared multicast network coding for a time varying wireless network model with interference-determined link capacities instead of collision based wireless model with fixed link capacities and showed that the gap in multicast capacity between NC & routing decreases relative to a collision-based wireless model with fixed-link capacities and the main advantage of NC is reduction in complexity of optimization and operation as NC significantly reduces complexity of dynamic back pressure algorithms used for optimization.In order to reduce cost and complexity of coding, Zhang and Fan in [29] proposed to find nodes that need encoding instead of doing coding at all nodes. They used a modified Ford Fulkerson algorithm to obtain the maximum flow and encoding nodes in undirected graph instead of getting encoding nodes by subtree decomposition as presented by Fragouli et al. in [30].

Yuan et al. in [31] proposed a general modeling and solution framework for the throughput optimization problem in wireless networks instead of cost optimization. In the framework, data routing, wireless medium contention and network coding are jointly considered to achieve the optimal network performance. The cross-layer optimization approach decomposes the original problem into data routing sub-problems at the network layer, and power allocation sub-problems at the physical layer taking into account physical layer interference.

Fragouli et al. in [32] proposed & argued that main benefits of network coding in a wireless environment might manifest in situations where topology dynamically changes and operation is restricted to distributed algorithms that do not employ knowledge about the network environment. They proved that network coding can offer benefits of a factor of log n in terms of energy efficiency.

Lun et al. in [33] showed how network coding, combined with distributed flow optimization,gives a practical approach for unicasting that promises to significantly outperform the present approach of end-to-end or link-by-link re-transmission combined with route optimization for any performance measure which increases with the number of transmissions made by each node.

Katti et al. in [34] proposed COPE, an architecture for wireless mesh networks. They addressed the common case of unicast traffic, dynamic and potentially bursty flows, and practical issues facing the integration of network coding in the current network stack. The testbed deployment results showed that COPE largely increases network throughput. The gains vary from a few percent to several folds depending on the traffic pattern, congestion level, and transport protocol. Due to coding, COPE has to send less number of packets and as a result load on bottleneck link reduces, giving it double advantage.

Sengupta et al. in [35] obtained a theoretical formulation for computing the throughput of network coding on any wireless network topology and any pattern of concurrent unicast traffic sessions. They advocated that routing be made aware of network coding opportunities rather than, as in COPE, being oblivious to it. They studied the trade-off between routing flows “close to each other” for utilizing coding opportunities and “away from each other” for avoiding wireless interference and presented a method for computing source-destination routes and utilizing the best coding opportunities from available ones so as to maximize the throughput.

## BROADCASTING IN WIRELESS NETWORKS USING NETWORK CODING

To realize energy savings in a wireless ad-hoc network, where each node of the network is the source transmitting information to all other nodes, Fragouli et al. in [36] proposed fully distributed algorithm to perform network coding while addressing practical issues such as forwarding factor, managing generations and impact of transmission range.

Li et al. in [37] applied network coding to deterministic broadcast approaches, resulting in significant reductions in the number of transmissions in the network. They proposed two algorithms, that rely only on local two-hop topology information and makes use of opportunistic listening to reduce the number of transmissions: 1) a simple XOR-based coding algorithm that provides gains up to 45% compared to a non-coding approach and2) a Reed-Solomon based coding algorithm that determines the optimal coding gain achievable for a coding algorithm that relies only on local information with gains up to 61%.

## APPLICATIONS OF NETWORK CODING IN PEER-TO- PEER NETWORKS

Gkantsidis and Rodriguez in [38] used network coding for content distribution of large files. The randomization introduced by the coding process eases the scheduling of block propagation. They showed that expected file download time and robustness of the system is significantly improved with network coding.

Hamra et al. in [39] showed that network coding can improve the performance of the file sharing application in wireless mesh networks but not as in wired networks [38] inspite of wireless broadcast advantage and cited reasons for the behaviour. They also identified the main parameters that influence the performance of network coding in wireless environment and showed how these parameters interact with each other and influence the behavior of network coding. They also identified the main parameters that influence the performance of network coding in wireless environment and showed how these parameters interact with each other and influence the behavior of network coding.

## APPLICATIONS OF NETWORK CODING IN DELAY TOLERANT NETWORKS

Delay Tolerant Networks are the networks that experience frequent, long-duration partitioning and may never have an end-to-end contemporaneous path. Forwarding mechanisms in such networks usually resort to some form of intelligent flooding, as for example in probabilistic routing. Widmer and Boudec in [40] proposed a network coding based algorithm that significantly reduces the overhead of probabilistic routing algorithms.

They showed that the algorithm achieves the reliability and robustness of flooding at a small fraction of the overhead.

## RESEARCHIC CHALLENGES

Much work has been done in designing algorithms but this has to be translated into practical network coding based protocols so that performance gains can be realized in real networks. Impact of network coding specific parameters such as generation size, type of code etc. on performance measures such as delay, net-throughput etc. needs to be investigated.Existing works in ad hoc networks frequently assume that all nodes cooperate without being self-centered.

When we allow some of the nodes to be self-centered, enforcing cooperation becomes a difficult problem. Network coding can potentially be used to devise more robust co-operation mechanisms as network coding spreads the information of a packet into number of packets.

In Network coding based demand driven resource distribution in Peer-to-Peer Networks, efficient mixing of content chunks based on demand pattern is likely to improve performance significantly. In intelligent flooding based forwarding mechanisms, draining packets out of the system once they are delivered is a challenging issue. It is even more challenging for network coding based flooding because a delivered packet may be part of many coded packets in the system.

Multicasting in Delay Tolerant Networks has its own challenges. Benefits of network coding based multicast in traditional networks are well understood. So, network coding based multicast for Delay Tolerant Networks is a promising approach that should be explored. Interaction of network coding based approaches with such networks needs to be analyzed.

## CONCLUSIONS

In this paper, we have studied about the network coding and its benefits in wired and wireless networks. We have also present the applications of network coding in peer-to-peer networks, Delay-Tolerant networks. We have also studied about the researches challenges in Network Coding.

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