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Enhancing Performance of Wirless Ad-hoc Networks with Network Coding

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***Abstract*—A wireless ad-hoc network can be made to perform better via a range of approaches. One such approach is network coding, which involves broadcasting of encoded packets and therefore can substantially enhance network capacity whilst preserving the quality of service. The use of routing algorithms that are aware of network coding can help to strengthen the benefits of this approach. In order to gain a more comprehensive understanding of the limitations associated with network coding and how it can be improved, the present study undertakes an investigation of the approach's benefits, assessment and comparison based on existing network coding algorithms, routing-supported algorithms for network coding, as well as a uniquely developed simulation model of network coding. According to the findings, compared to networks without network coding, those with network coding can manage traffic up to two times greater.**

Keywords—Network coding; coding aware routing; routing; ad hoc networks

I. INTRODUCTION

Wireless adhoc networks in which multi-hop wireless links support node connectivity are known as wireless ad-hoc networks (WMNs). These networks can be made to perform better via a wide range of mechanisms, including advanced physical layer methods, such as multi-radio and multi-channel technology, multi-path routing for load balancing and fault tolerance, protocols for reliable data transport as for real-time delivery, network management protocols, such as mobility and power management, and network monitoring, cross-layer design, and scheduling algorithms. Owing to its potential gauged from preliminary research and test-bed applications, the approach of network coding has roused a growing amount of interest in recent times for the possibilities it offers to both wired and wireless networks. Network coding can reduce bandwidth usage and enhance network capacity whilst preserving quality of service by broadcasting a single encoded packet consisting of multiple combined packets from the same or different traffic flows. Network coding fosters new coding possibilities in wireless networks because nodes can overhear packets not meant for them owing to the broadcast character of the wireless environment. The overhead packets subsequently facilitate the decoding of received encoded packets.

The purpose of network coding is to endow the nodes with "intelligence" and capacity for computation, allowing them to apply coding procedures on the content itself. Hence, network coding is conducive to the creation of progressive frameworks for communication systems and transmission models that could support the requirements of good network capacity and improved performance of the Future Media Internet. The creation of new packets through the merging of packets obtained on their incoming margins can be achieved by intermediate network nodes through the novel paradigm of network coding. In fact, given that network coding ensures a compromise between communication capacity and costs of computation, the technologies that could be developed based on this paradigm could enable the creation of better and more effective future networks. Furthermore, network efficiency can be significantly enhanced via network coding. In the case of standard routing, the data packets are not modified at intermediate nodes and the packet contains information intended to improve network performance, in addition to the actual message. On the other hand, in network coding, data packets undergo modifications at intermediate nodes through techniques such as xor or linear coding. The next sections comprehensively address network coding applications, benefits, related research and limitations, while a discussion on routing protocols aware of network coding is extended as well.

The mechanism underpinning network coding seeks to reduce the number of transmissions through the merging of multiple packets at intermediate nodes into just one packet that the receiving nodes can decode. This is made possible by coding techniques such as linear coding or xor coding. Moreover, packets overheard from adjacent nodes are employed in the decoding rather than being removed, which is another aspect in which network coding differs from standard routing. Furthermore, owing to their ability to overhear over network transmissions the nodes use the exchanged information to undertake decoding without additional overhead. Due to these characteristics, network coding is clearly compatible with the broadcasting nature of wireless network routing.

Both the intermediate and receiving nodes must have access to knowledge regarding packet information. The intermediate node sends the packet information to its neighbours, thus further complicating the process. Wireless networks have limited energy and bandwidth, which is why achievement of improved capacity and lifespan is so important. This achievement can be facilitated by network coding as it increases network capacity and reduces the number of transmissions.

The mechanism of network coding is illustrated in Fig. 1, based on the example of nodes X and Y, which use the intermediate node R to respectively transmit packets P1 and P2 to one another. For this purpose, standard routing would require four transmissions, as transmission of P1 and P2 by R occurs separately. However, in network coding, the two packets are transmitted together (P1+P2) by R since it can apply the xor coding technique. X and Y receive the combined packet and can then each undertake the decoding of P2 and P1, respectively. The opportunities for coding depend on the route paths that have been established. One study successfully managed to reduce the number of transmissions according to approaches for the selection of forwarding nodes by employing network coding to achieve broadcasting [26].

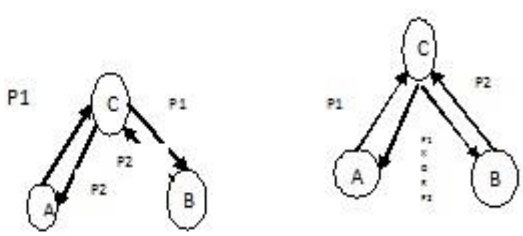


Fig.1 Network Coding

It is believed that the concepts of network coding cannot be effectively taken advantage of if they are not applied alongside routing. Modified paths allowing the combined coding of multiple packets can be obtained through implementation of network coding-aware routing [1] as this enables the identification of paths with a greater number of coding possibilities. In this way, the same volume of traffic can be transmitted from a source to a destination with less usage of bandwidth.

Network coding and its effect on other OSI layers must be clearly comprehended not only to be able to develop network coding-aware routing algorithms, but also possibly to permit cross-layer enhancement. To this end, causes and effects can be investigated with the help of simulation models, which can also enable a comparative assessment of how various approaches perform. In this study, the simulation instrument called NS-2 [3] has been employed to create a simulation model for network coding [2]. Furthermore, the study explores a number of routing methods (e.g. Dijkstra's, Bellman-Ford, and genetic ants-based routing algorithms) and routing metrics (e.g. number of hops, distance, expected transmission count (ETX), modified ETX, and coding-enhanced ETX) [4]. Moreover, the impact on routing of number of coding possibilities, packet queue length and others is used to explore solutions for improvement of metrics. Additionally, to effectively take advantage of the network coding concepts, novel network coding algorithms and network coding-aware routing mechanisms are created as well.

The network coding simulation model is consistent with the technique of Efficient opportunistic network coding[EON] independent of routing and the established COPE [6] technique. By comparison to methods without network coding, both EON and COPE have been demonstrated to help networks perform considerably better with regard to network capacity.

The simulation model and the applied network coding and routing algorithms are discussed. Additionally the findings of the comparative analysis of COPE and EON, on the one hand, and approaches without network coding, on the other, are presented.

II. SIMULATION MODEL

A. Network Coding Model

There are a number of elements making up the simulation model. The significance of the current study resides in the fact that aims to apply network coding in conjunction with dominant sets in order to reduce the number of transmissions and thus improve the efficiency of energy usage in MANETs. Additionally, to determine a heuristic solution for optimal network coding, the study also involves subjection of forward node sets to ant colony optimization.The study uses network coding for energy-efficient routing in multi-hop wireless networks, with the purpose of homogenizing the energy capacity of the network nodes and thus expanding network lifespan. Broadcasting represents the foremost process of routing protocols. To aid path selection, the broadcasting mode whereby information is transmitted by a source node to all nodes in the network is employed in this study. Additionally, a key goal of the study is to diminish the number of transmissions to make broadcasting more energy-efficient.

In the case of a point-to-point communication network, such as the Internet Backbone, with a directed graph G = (V, E), where V and E respectively represent sets of nodes and edges with noiseless information sharing between nodes, network coding is essential to optimize the network, since the assumption that multicast information is a "fluid" amenable to routing or replication at intermediate nodes is insufficient. Furthermore, it is necessary to decrease the amount of energy employed by each packet transmission between source and destination, according to the goal of network flow maximization. This requires finding out the overall amount of energy consumed by packet transmission between route nodes to the subsequent hop.

The condition and situation of neighbouring nodes are known to all nodes and they can also detect coding opportunities and even conduct coding, if the receiving nodes have decoding abilities. Network coding is directly dependent on the broadcast nature of the wireless environment when it comes to the sending of one encoded packet to multiple receivers. To this end, the wireless network has to be transformed into a graph with the edge between two nodes denoting the radio range that enables those nodes to communicate. The nodes retain the overheard packets only for a short while. Furthermore, the nodes let adjacent nodes know about the heard packets by annotating the packets they send. The nodes can apply the xor coding technique to multiple packets to send them as a single combined packet, as long as the targeted next hop has enough information to decode an encoded packet. However, the nodes must avoid excessive overhead when acquiring information about packets overheard by adjacent nodes, to make sure that coding is applied to the right set of combined packets. Moreover, a coded packet is meant for at least two next hops and therefore the nodes must ensure that their information can reach every next hop. Coding opportunities for forwarding multiple packets in a single transmission can be detected and taken advantage of through this process.

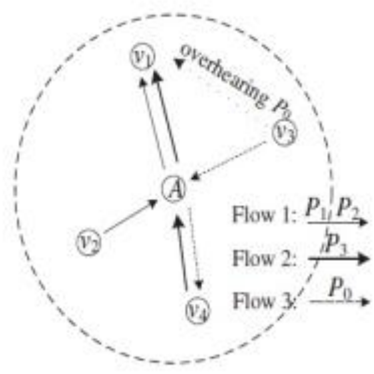
Listening, coding and learning are the main components of network coding, on the basis that the forwarding node is aware of the next hop of each packet waiting to be transmitted. In network coding, the nodes must undertake listening to and storage of the packets that could be subsequently used for the decoding of coded packets. There are two major sources from which these packets can be obtained:

1. Packets that the nodes themselves transmit: nodes store copies of the packets sent to the router so that the coded packet returned by the router can be decoded.
2. Packets that the nodes overhear: Due to the fact that wireless environments possess a broadcast character, packets can be easily overheard by the nodes, provided that they have omnidirectional antennae.

Packets are usually propagated to a single next hop and the nodes ignore the overhead packets that are not meant for them. On the other hand, all messages transmitted over the wireless network are scanned by nodes in network coding and the overhead packets are kept for a duration T with a value higher than the maximum one-network latency (T generally has a value of 0.5 s).The packets that the neighbours of a node retain in their listening module are monitored by the learning module because they are important for coding decisions. Since deterministic information can underpin this process of supervision, reception reports sent by the neighbouring nodes or acknowledgement of the nodes as prior hops on the packet transmission route is necessary to validate that packets are available. Nodes cannot perform network coding if they are unaware of the packets present in the packet pools of neighbouring nodes. They can obtain this knowledge from reception reports, which are disseminated via annotation of broadcasted information packets and are the means through which nodes can let their neighbours know about the packets they possess. For nodes lacking information packets for standard broadcast, transmission of reception reports is done in special control packets.

By enabling combined coding of packets by nodes, network coding contributes to improve throughput. All nodes retain the packets to be broadcasted to the next hop in their FIFO forwarding queue. Awareness of packet transmission opportunities prompts the nodes to determine whether other packets in the queue can be used for the coding of the first packet in the queue. To attain the highest throughput, the number of native packets coded in a single transmission has to be elevated by the nodes and at the same time all targeted next hops must be ascertained to have enough information to decode the received packets. Neighbouring nodes that overhear these packets retain them in their packet pools. The following figures present the basic procedures of the xor process on packet data bits.

If all next hops r_i have every n-1 packet p_j for $j \neq i$, then a node can apply the xor coding technique on n packets (p_1, p_2,..,p_n) combined in order to transmit these packets to n next hops (r_1, r_2,….,r_n).



(a) Flows passing through node *A*.

Fig.2. Network flows

In Figure 2, a large-sized packet is possessed by each of Flows 1, 2, and 3, which are directed towards neighbours v1 (Flows 1 and 2) and v4 (Flow 3) through node A. It is assumed that there is just one case of packet overhearing, namely, packet P0 transmitted by v4 to node A is overheard by v1.

Flow is the core element of the network coding model proposed in this study, with a queuing structure based on flow and a novel coding algorithm that is aimed to facilitate automatic decoding. If it does not have enough packets, a targeted receiver will be unable to derive a new native packet from the received coding packet, and therefore it will discard it. Furthermore, the suggested flow-based configuration can be used even in cases where automatic decoding is impossible, but extended decoding deferral is the cost of obtained improvement.

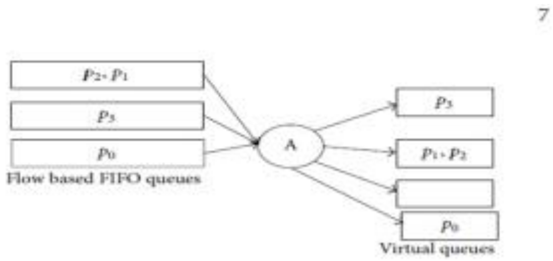


Fig. 3. Flow-based queuing structure

Arbitrary wireless topologies are produced by the underlying network topology generator designed in NS-2. These topologies circumscribe a random number of nodes that rely on wireless links (denoted by dashed lines in Figure 1), which are chosen based on node locations, transmission "range" or other node parameters, in order to support communication with a random number of adjacent nodes. The information regarding targeted topology, nodes, links and parameters required for communication, such as throughputs, number of packet retransmissions, and loads, are prepared for incorporation in the NS-2 simulation model [3], where the primary simulation occurs, by the network description program that is designed in NS-2 as well. The functional layers of the primary simulation are traffic generator for production of network load, routing module for direction of packets within the network, wireless module for link condition-based transmission of packets to the correct destination via the wireless channel, network topology module for establishing network structure and link conditions, as well as network coding module for coding.

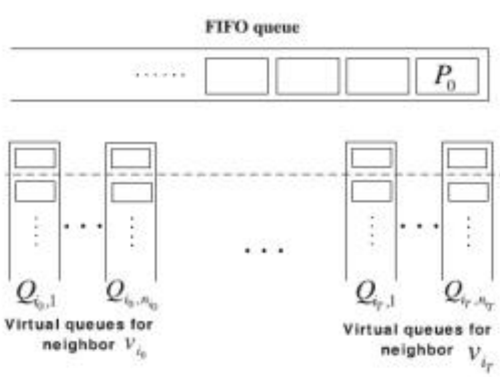


Fig.4. Network node queues

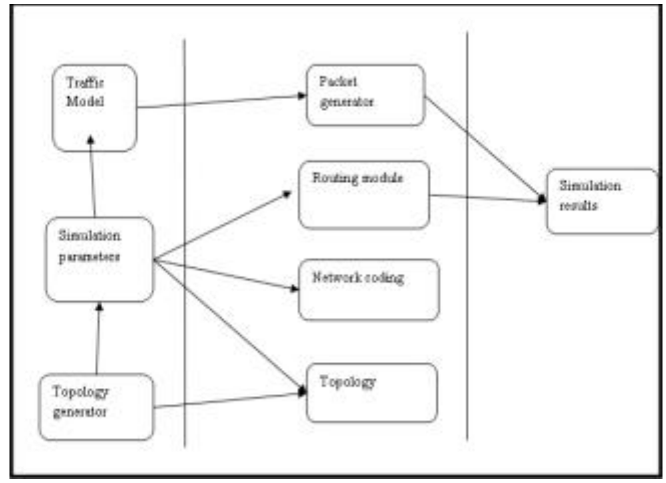


Fig.5. simulation model

B. *Proposed Network Coding aware routing*

The model comprises two network coding algorithms. The new technique of efficient and routing-independent EON [5] is the first of these two algorithms, which diminishes extra overhead due to its capability to choose packets for combined coding not on the basis of traffic information but on the basis of node location. This algorithm was developed in such a way as to be compatible with the WMN. The COPE technique is the second algorithm [6]. Displaying greater complexity but also generating a significant amount of overhead by comparison to EON, this algorithm can be applied solely with routing algorithms based on ETX.

To determine the routing table, three algorithms are used, namely, the Dijsktra and Bellman-Ford algorithms with the shortest paths, and an ants-based routing algorithm that employs the probabilistic routing tables revised by ants whose route movement is determined by network conditions. Hop count, distance, and metrics based on delivery probability are among the main metrics that facilitate the computation of link cost(s) as part of routing determination. This paper presents a novel, practical, routing-independent network coding algorithm: Simplicity is its main benefit as it introduces little overhead to the network since nodes do not need to keep track of received traffic for their neighbouring nodes. Algorithm makes coding decisions based solely on the information about the packet previous and next hop node position. Algorithm functions between the MAC and link layers, with small modifications made only to the MAC layer. Using different topologies and different traffic loads and distributions in the simulation model we evaluated algorithm performance and compared it to a well-known COPE algorithm. Essentially the Coding Process is about making decisions on which packets the coding node can encode together in order that the receiving nodes will be able to decode the coded packet. The more packets we code together or more loosely the conditions in coding process are the higher the possibility of receiving nodes not being able to decode packets. Though, if coding conditions are hard to meet, than there are few coding opportunities and low bandwidth saving benefits.

We define packet bearing on a coding node as the unit vector showing direction between previous hop and next hop of the packet. We may assume that nodes on one side of the coding node have the knowledge of the content of packets of the first flow, while nodes on the other side of the coding node recognize the content of packets from the second flow, thus matching them up for encoding. Nodes that are placed in approximately the same bearing from the coding node, can also hear each other transmissions, thus being able to decode the packet.

Each node maintains two packet queues. The highest priority queue is used for signalization packets and the lower priority queue is for packets carrying information through the network. If signalization queue is empty the coding algorithm takes the packet that is at the head of the queue and then searches the rest of the queue looking for possible coding matches. If a coding opportunity is found, the packets are encoded using XOR operation into a coded packet accompanied with the headers for the decoding process at the receiving nodes. If no coding opportunities are found the packet is transferred to the MAC layer as is and the native packet is transmitted.

Upon the packet reception in the NC module further actions depend on whether the packet is coded or native (not coded). In the case of the coded packet the process checks the packet pool where all received and overheard packets are stored for decoding purposes to determine whether it has already received N-1 of the packets coded in the coded packet. If not the coded packet cannot be decoded and it is simply dropped. If the node has at least the required N-1 packets, i.e., enough information, it decodes the coded packet using these packets with the XOR operations, thus gaining a set of native packets. Each native packet is treated individually. From here on the process is the same as upon receiving a native packet. The process checks whether the node has already received the packet. If so it drops it. If the packet is new its copy is inserted into the packet pool for decoding purposes. It does so for every received native packet, as all received packets are potentially needed for further decoding purposes. The process checks whether the node is the next hop for the native packet. If so, and if the packet has been a part of the coded packet, ACK message is scheduled and the packet is sent to the upper layers for further processing.

III. SIMULATION RESULTS

We evaluated using a simulation model built in NS-2 [3] for analysis of network layer NC algorithms. Representative networks consist of twenty wireless nodes that have optimal symmetric wireless links (1Mbit/1Mbit). The configuration of the nodes is identical to that in a uniform network. Exponential distribution of inter-arrival times and fixed packet lengths of 10kbit ensures that the intensity of the traffic load is the same on every node. The simulation-based increase in traffic load continues until none of the two scenarios can manage it any longer. The traffic produced by the network nodes as source nodes has identical probabilities and relies on homogeneous probability distribution between all the nodes in the network to choose the destination nodes. The delay between the source and destination nodes for the increasing network load is shown in Fig.6. We present the traffic throughputs in Fig.7.Denoting the ratio of the number of source packets (non-coding) to the number of packets necessary for transmission of source packets (with coding) ,the coding gain associated with every node . The results indicate that the maximum load is associated with COPE, followed by EON, whereas the minimal load is associated with the scenario without network coding. This suggests that network capacity can be enhanced considerably by EON and COPE.

In addition to being compatible solely with networks employing routing grounded in delivery probability metrics, COPE requires information about the packets possessed by adjacent nodes, and therefore necessitates a higher level of processing power and storage. Moreover, owing to the reports issued by nodes upon reception of packets, there is high overhead in COPE and consequently, the network load is great even under conditions of normal operation. By contrast, EON works independent from routing protocols and displays greater efficiency, whilst also being more effective in terms of required processing power and storage as well as generated overhead.

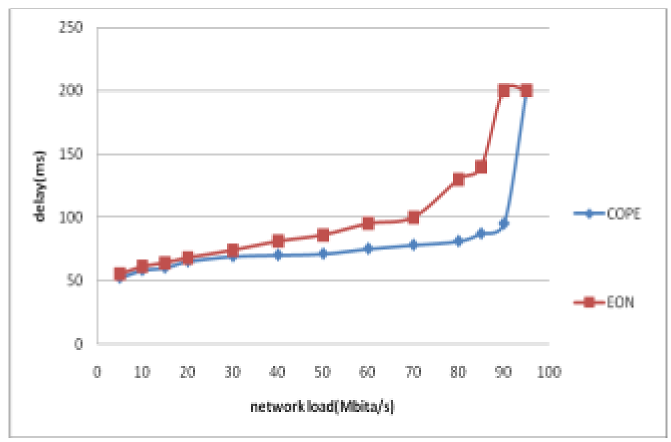


Fig.6. EON, COPE scenario involving delay and network load

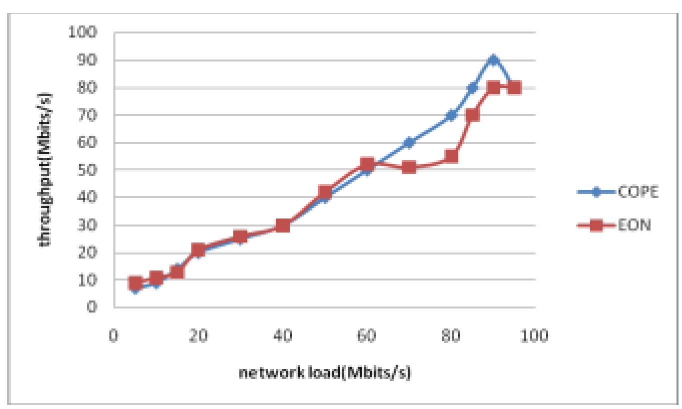


Fig.7.EON, COPE involving throughput with network load.

IV. CONCLUSION AND FUTURE WORK

This study has summarized the representative findings of network coding research obtained via a specifically developed network coding simulation model. These findings indicate that network capacity improvement can be achieved in WMN networks with network coding application. Novel network coding algorithms and network coding-aware routing will form the focus of a future study.

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