Abstract—When one considers the nature of wireless networks, it is difficult to accept the fact that packets are still routed the usual way. The purpose of this paper is to show how network coding can be used, in conjunction with rate adaptation, to provide increased throughput in a multi-rate multi-hop wireless network.

I. INTRODUCTION

Since the initial release of the IEEE 802.11-1997 specification [1], many modifications have been made to this original specification in order to provide increased throughput under varying and unknown conditions. Unfortunately, this protocol was limited and supported only two rates, 1Mbps and 2Mbps. Soon after that, the 802.11b specification was released, adding two additional rates, 5.5Mbps and 11Mbps, using same DSSS modulation as the original specification but which carried improvements. Although this specification gained wide acceptance and was being widely used, the IEEE 802.11 committee would later approve the specification used in this work, IEEE 802.11g. This new specification quickly gained acceptance because of its support of transmission rates as high as 54Mbps. More recently, the IEEE 802.11 committee approved a new specification, IEEE 802.11n, but it will take some time before devices carrying the 802.11n chips outnumber 802.11g and 802.11b devices. As a disclaimer, the author of this paper does not take credit for any algorithm that will be mentioned here.

II. NETWORK CODING

Network coding [2] can be used in a wireless network to take advantage of the fact that nodes in a wireless network are usually in close proximity, and can hear other nodes’ transmissions, and increase the overall throughput capacity of the network. In its most simple application form, network coding is done by combing packets, instead of simply routing them, before transmitting them to their destinations.

In this work, we used a modified version of COPE [5] in order to introduce network coding. COPE has a requirement of nodes in a neighborhood overhearing other nodes’ transmission in order to able to decode packets. Also, in this work nodes need to know which packets have been received by its neighbors via a perfect feedback system. Note that COPE is only concerned with the 1-hop neighborhood, in other words, it does not try to send coded packets to nodes more than one hop away. Like COPE, we are only concerned with packets one hop away and we also assume that coded packets can be decoded at destinations.

To help the reader understand how packets are coded, and later decoded, a simple example will be described; please refer to Fig. 1. Suppose node n1 wants to send a packet, pkt0, to node n3 while n4 wants to send a packet, pkt1, to node n2. Note, nodes n3 and n2 are considered direct targets (solid arrows) of nodes n1 and n4, respectively, while nodes n2 and n3 are considered overhearing targets (dashed arrows) of nodes n1 and n4, respectively. If nodes n3 and n2 can overhear the transmissions of nodes n4 and n1, respectively, then node n0 can apply network coding and combine pkt0 and pkt1 with XOR and send the coded packet (pkt0 XOR pkt1). Since nodes n3 and n2 overheard, and therefore have, packets pkt1 and pkt0, respectively, node n0 can send the coded packet and know that nodes n3 and n2 will be able to use the overheard packets along with the coded packets to once again apply XOR and get the needed packet. This last part is called decoding a packet.

III. RATE SELECTION AND RATE ADAPTATION

Although improvements have been made incrementally to IEEE 802.11 specifications, it is still up to each device maker to implement rate adaptation at the appropriate PHY/MAC layers. The idea of rate adaptation is to switch to a lower, or higher, rate based on link conditions in order to ensure...
data delivery, while at the same time achieving the maximum throughput possible. Situations arise when a node might have more than one node in its proximity and this node needs to send a packet to a direct target while enabling overhearing by the non-direct target. Deciding which rate to use that will ensure that both nodes receive the packet is called rate selection.

Over the past decade, many rate adaptation algorithms have been proposed [8]. The first such scheme was ARF (Auto Rate Fallback) [3], introduced in the WaveLan II card [4]. ARF works in a way such that when there is a new destination target, it will choose the maximum rate based on current link conditions. Its state machine then works based on the how well the first few transmissions went. If the first sent packet is not acknowledged, ARF immediately switches to the next lowest rate. If the first ten packets are transmitted successfully, ARF moves to the next highest rate. If neither of these conditions is met, ARF will simply maintain the current rate.

Other algorithms tried to improve on ARF, such as AARF [6], or took a completely different approach (ie. RBAR [7]). Despite the differences, most rate adaptation algorithms share the same goal which is to try to maintain the best possible rate given varying link conditions. The purpose of this paper is to show how the Network Coding aware Rate Selection (NCRS) algorithm, which is a combination of rate adaptation and network coding, outperforms other algorithms in static multi-hop multi-rate wireless networks.

IV. IEEE 802.11G

For the NCRS algorithm, 802.11g was used because it is not only widely used, but it also provides 8 additional transmission rates when compared to 802.11b. Since IEEE 802.11 does not provide a specification with rate adaptation algorithms, it was used a version of ARF since networks tested with the NCRS algorithm are always static, meaning that nodes have stable SNRs (Signal-to-Noise Ratios). Note that for a particular SNR, a node may choose to transmit at a lower rate in order to have fewer packets dropped. To confirm this, an experiment was executed.

For the experiment, we used a Linksys WRT54G router with the DD-WRT firmware as an access point serving as sender and a Netgear WG111v2 USB wireless adapter serving as receiver. For each square point in the packet delivery probability vs. SNR plot of Fig. 2, 10000 packets of 1500Bytes each were sent from the access point and the point represents how many of them were received. As a comparison, we also plotted in Fig. 2 results from a NS-2 simulation of the same scenario. The graphs clearly show that NS-2 simulations are in accordance with actual experiments and therefore can be used reliably. To show which rates are chosen based on SNRs, we also plot the results from a unicast link simulation in Fig. 3.

![Fig. 2. Packet delivery probability vs. SNR for both experiments and simulations. From left to right: 6, 9, 12, 18, 24, 36, 48, and 54Mbps](image)

![Fig. 3. Transmission rate vs. SNR for unicast link](image)

V. RESULTS

To measure how well NCRS performs, two other algorithms were used. The first, called MinRS, is an algorithm that selects the minimum transmission rate for an unicast link. MinRS bases its decision of which rate to choose on packet delivery probability. The second algorithm, called MaxRS, does the reverse. MaxRS selects the maximum transmission rate for an unicast link. The only difference between the two is that MinRS takes into account direct and overhearing targets whereas MaxRS, like NCRS, only takes into consideration direct targets. NCRS performs better than both algorithms because it tries to maximize goodput. MinRS, for example, only accounts for the probability that a packet will be delivered.

Although several simulations were done, emphasis will be given to the randomized grid simulation, which is a combination of smaller simulations shown in large scale, susceptible to applicability. For this simulation, 5x10 randomized grids of nodes were used. Nodes were initially separated along both axes by 25m. Their location in the grid was then randomized along both axes, horizontally and vertically.

We then deploy 4, 8, and 12 flows randomly in different grids to ensure that results are truly random. Each flow consists of 3 to 5 nodes. Flows of less than 3 nodes do not allow...
network coding and flows of more than 5 nodes do not fit in a column. Note, every flow going in one direction forms a pair with another flow going in the opposite direction in order to provide coding opportunities. All three algorithms were put to the test and their performances were measured by comparing the gain over routing (number of packets delivered to destination nodes by using rate adaptation algorithm / number of packets delivered to destination nodes by using the routing method) for each one. As Fig. 4 shows, for the three sets of flows, NCRS has an average of 18%, 11%, and 24% more gain than MinRS and 28%, 54%, and 55% more gain than MaxRS.

VI. CONCLUSIONS

Even though not every scenario is appropriate for NCRS, we have shown that in situations where the algorithm is applicable, large gains can be made. We have also shown that network coding can be used with rate adaptation algorithms to provide increased goodput in multi-rate multi-hop wireless networks.

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REFERENCES