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Wireless Network Coding and Concurrent MAC: Are these Approaches Complementary?

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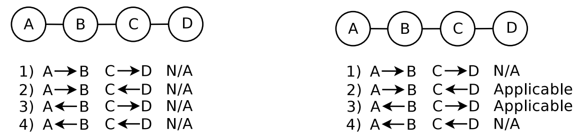
I. Introduction

The IEEE 802.11 MAC protocol precludes the possibility of concurrent transmissions by two neighboring nodes. There have been some MAC proposals such as CMAP [2] for enabling concurrent transmissions. Wireless network coding schemes like COPE [1] convey more information in one transmission by coding multiple packets together. Both CMAP and COPE have been shown to perform significantly better than 802.11 MAC without coding. The question we are intrigued by is, *are these schemes complementary?*, i.e., *when deployed together will the performance gain approach the sum of their individual gains?* We compare the relative performance of a COPE-like wireless network coding scheme (which we term WiNC) on top of CMAP-like concurrent MAC scheme (which we term CMAC) against that on 802.11, i.e., WiNC/CMAC against WiNC/802.11. Our preliminary results show that the scope for improvement using network coding is greatly reduced with concurrent MAC.

II. Motivation

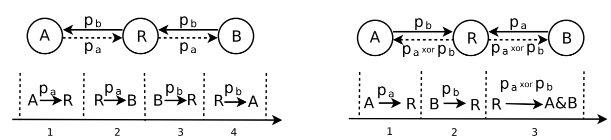
An illustration of CMAC is shown in Fig. 1. In the 4-node chain topology in Fig. 1(a), only one transmission can happen at a time with IEEE 802.11. However, in Fig 1(b), CMAC allows two concurrent transmissions since they do not interfere with each other. In Fig. 2(a), two nodes A and B exchange two packets via an intermediate node R. Without network coding, 4 transmissions are required. With network coding, node R broadcasts a coded packet $P_a \oplus P_b$ to its neighbors, and both node A and node B decode the packets. Thus, as shown in Fig. 2(b), only 3 transmissions are needed for the exchange.

With WiNC, the improvement is due to one transmission of R→A&B to both A and B, instead of two separate transmissions R→A and R→B. However, the reduction in the number of transmissions for a node pair does not guarantee network-wide savings. When a coded packet is broadcast, multiple receivers are involved and the entire neighborhood has to be silent. As a consequence, the potential for concurrent transmissions is reduced. Conversely, a CMAC scheme might hinder the opportunities for coding.



(a) 802.11 (b) CMAC

Figure 1: No concurrent transmissions permitted by 802.11. With a CMAC scheme A→B can be concurrent with D→C, similarly B→A with C→D as they do not mutually interfere with each other.

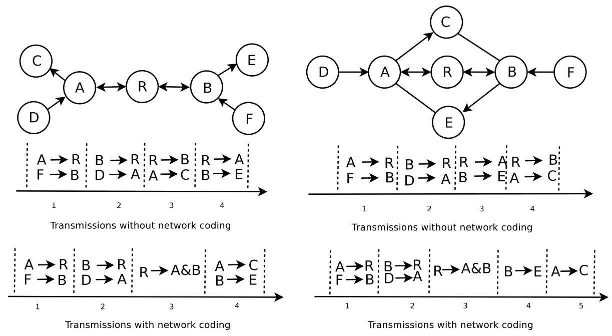


(a) Without network coding (b) With network coding

Figure 2: Without network coding an exchange of two packets between A and B requires 4 transmissions whereas 3 transmissions suffice with network coding.

Consider the scenario in Fig. 3(a). Nodes A and B need to exchange two packets mutually via the router R. Node D has one packet to node C via node A and also node F has one packet to node E via node B as well. Without network coding, totally four time slots are needed with CMAC. However, if network coding is applied at the router R, during the coded transmission, no other concurrent transmissions could happen. As a result, four time slots are required in total and no improvement can be obtained with network coding.

In some cases, network coding may even hurt the performance of CMAC. Let's take the modified topology in Fig. 3(b) which has additionally, node C and node E in the range of both node A and node B. In this case, without network coding, still four time slots are needed. However, when network coding is applied, five slots are required. This regression of performance occurs because the transmissions A→C and B→E can not happen at the same time. But there are clearly cases where network coding improves performance even on top of CMAC as shown in Fig. 4.



(a) No gain with coding (b) No coding is better

Figure 3: Two scenarios in which coding on top of CMAC is not better than CMAC without coding: (a) both need 4 time slots; (b) without coding only 4 slots whereas with coding we need 5 slots.

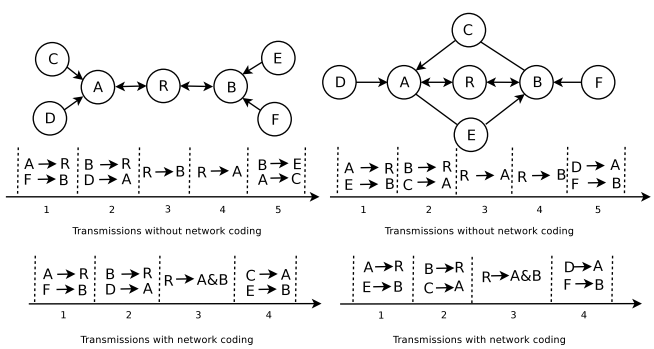


Figure 4: Two scenarios in which network coding improves upon CMAC. The total number of time slots needed are reduced from 5 to 4 in both cases.

III. Analysis

In this section, we analyze the reasons for the performance improvement/degradation of network coding when applied over CMAC. We take the simple exchange scenario in Fig 2 as an example. The difference between transmissions with network coding and general transmissions is that, the coded packet is broadcast at node R to two neighbors instead of transmitting the two native packets separately.

There are two ways a coded broadcast transmission could affect the other transmissions. First, the broadcast transmission itself can cause interference to the other transmissions. Second, without network coding the native packet transmission might be scheduled with other transmissions whereas the broadcast transmission might perturb the potential optimal scheduling. The illustration in Fig. 3(a) corresponds to the first case and that in Fig. 3(b) the second case.

During the entire duration of 4 transmissions without network coding or 3 transmission with network coding, node R is occupied while node A and B are free during some slots. We discuss this by looking at the roles of each of the nodes in the exchanges. The CMAC is modeled on a simple principle for concurrent transmissions: if any node is currently a transmitter, there can be only one receiver node in the transmitter's 1-hop neighborhood; conversely, if any node is a receiver, only one node in its 1-hop neighborhood is allowed to be a transmitter. Based on this, the potential roles of the three nodes, A, B, and R, during the 4 transmissions without network coding are summarized in Table. 1. Similarly, with network coding, the potential roles of the 3 nodes during the 3 transmissions are summarized in Table. 2.

By comparing the two tables, we could see that node A can act both as a transmitter and a receiver in Table. 1. However, it could only act as a receiver with network coding as per Table. 2. This difference in their roles indicates that, when network coding is applied on the CMAC, the potential for node A to transmit to someone else during the exchange is lost. The same is the case with node B.

This explains the interesting interplay of network coding and CMAC. Network coding does not work well with CMAC in Fig 3, in which the nodes A and B act as transmitters during the basic network coding transmissions. It also reasons why the network coding works fine when node A and node B act only as receivers in transmissions not involving the network coding exchanges as in Fig 4.

	A→R	R→B	B→R	R→A
A	N/A	Transmitter	Receiver	N/A
B	Receiver	N/A	N/A	Transmitter
R	N/A	N/A	N/A	N/A

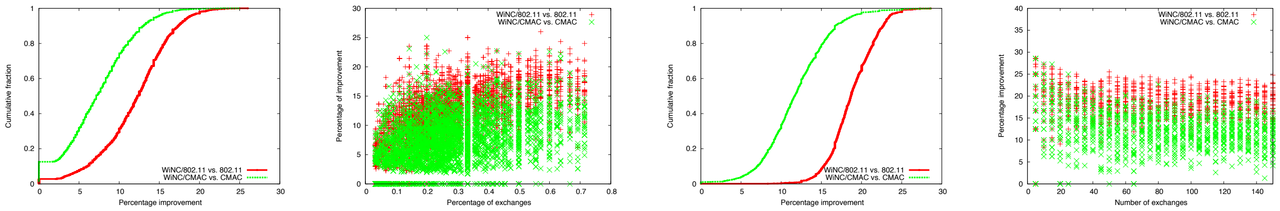
Table 1: Roles of nodes A, B, and R during the exchange of packets without network coding.

	A→R	B→R	R→A&B
A	N/A	Receiver	N/A
B	Receiver	N/A	N/A
R	N/A	N/A	N/A

Table 2: Roles of nodes A, B, and R during the exchange of packets with network coding.

IV. Evaluation

In this section, we compare the performance of network coding over 802.11 MAC and over CMAC with time slots as the metric.The transmission scheduling problem can be solved as a conflict-graph coloring



(a) coding gain with other ongoing one-hop transmissions
(b) improvement vs. percentage of network coding transmissions
(c) coding gain without other ongoing one-hop transmissions
(d) improvement vs. number of network coding transmissions

Figure 5: WiNC/802.11 versus WiNC/CMAC: Coding gain over CMAC is much less than that over 802.11.

problem. Considering each transmission as a vertex in the graph, if two transmissions are in conflict with each other, an edge can be placed between the two vertices. The total time slots required is the minimum number of colors that could color the graph.

We generate the topologies randomly in a 500×500 area with the transmission range of 100 units. The packet exchanges with network coding are randomly selected to happen between two non-adjacent nodes via an intermediate relay node in between them. Some other one-hop transmissions are also randomly selected for adjacent nodes. We conduct two sets of experiments: first, packet exchanges in the presence of other ongoing one-hop transmissions; Second, packet exchanges without ongoing one-hop transmissions.

In the first case, we vary the number of total nodes from 100 to 340; the number of packet exchanges is varied from 5 to 50; the number of ongoing one-hop transmissions is varied from 20 to 150. We ran each combination 5 times. The improvement of network coding with 802.11 and CMAC are calculated. From the cumulative distribution fraction figure in Fig. 5(a), we could see that the improvement of network coding over 802.11 MAC is more significant. Nearly 75% of the results have 10% improvement, however, only 25% have 10% improvement over CMAC.

The improvement with the percentage of packet exchanges is stated in Fig 5(b). From the figure we could see that, with the increase in the percentage of the number of exchanges, both of the improvements increased. However, the gap between the two also increases. The improvement with CMAC is not as much as that with 802.11 MAC. This clearly indicates that the network coding opportunities restrain the possibilities of concurrent transmissions.

We did another set of experiments, in which there are no ongoing one-hop transmissions and only several packet exchanges with network coding. We vary the number of exchanges from 5 to 150. The number of nodes varies from 100 to 340. We ran all the combinations for 5 times each.

The results are summarized in Fig. 5(c). The difference between the performance improvement of network coding over 802.11 MAC and network coding over CMAC is even more significant in this case. Almost 80% have 15% improvement over 802.11 MAC, but only 10% have 15% improvement over CMAC.

In Fig. 5(d) we can see that if there are more network coding opportunities in the network, the 802.11 MAC with network coding has more improvement over CMAC with network coding. We also see the trend of coding gain over CMAC decreasing when compared that over 802.11 with the increasing number of packet exchanges. This indicates that the coding gain over CMAC does not scale with the number of coding opportunities as it does over 802.11.

V. Conclusion

We investigated how network coding interplays with a concurrent MAC scheme in wireless networks. We analyzed several scenarios for identifying the causes for improvement and degradation in performance when they are deployed together. Through simulation based evaluation, we demonstrated that the improvement of network coding over concurrent MAC is less significant than that over the existing 802.11 MAC. In our ongoing work, we are working towards designing scheduling strategies to maximize the benefit of network coding over concurrent MAC schemes.

References

[1] Katti, S., Rahul, H., Hu, W., Medard, M., and Crowcroft, J. XORs in the air: Practical wireless network coding. In *Proceedings of SIGCOMM* (2006).

[2] Vutukuru, M., Jamieson, K., and Balakrishnan, H. Harnessing Exposed Terminals in Wireless Networks. In *Proceedings of 5th USENIX Symposium on Networked Systems Design and Implementation* (2008).