Poster Abstract: Network Coding with Limited Overhearing

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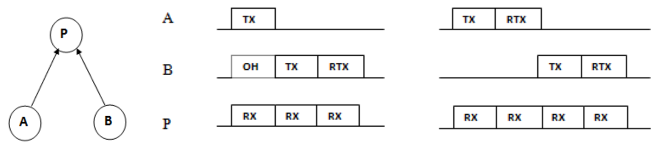
***Abstract*— The two key benefits of network coding are increased reliability and throughput. Most network coding approaches for wireless networks rely on overhearing neighboring transmissions. Overhearing in sensor networks, however, is not energy-efficient. In this paper, we extend GinMAC, a state-of-the-art MAC protocol, applying network coding with limited overhearing. Our approach reduces the delay allocating less retransmission slots. Our results show that network coding with limited overhearing reduces the power consumption of GinMAC while maintaining the desired level of reliability.**



(a) Sub Tree (b) TDMA Schedule

Fig. 1: Left: Binary Tree Topology; Right: TDMA Schedules with(left) and without(right) Network Coding

I. Introduction

Network Coding was introduced by Ahlswede et al. [1], proving that it can increase the multicast capacity of network. Since then, it has been investigated in several different networked scenarios which demand different traffic characteristics. Especially for wireless networks network coding has become a favorable tool for throughput enhancements and reliability improvements. Many subsequent studies on wireless network coding were trying to exploit the broadcasting nature of wireless medium. Most of them, however, assume free overhearing of neighboring transmissions.

The assumption of free overhearing is unreasonable in some environments. Wireless Sensor Networks (WSN) is one such environment where nodes having stringent energy requirements. More specifically, due to the fact that idle listening consumes the largest portion of radio communication energy consumption, network coding with overhearing becomes unrealistic in WSNs. Most previous research has focused on theoretical aspects of applying network coding to sensor networks while recently researchers have also studied more practical approaches, employing network coding in state-of-the-art WSN protocols [2] and [3]. The latter considers the data dissemination protocol deluge [4] and proposes a network coded variant, while the former improves the reliability of collection tree protocol [5]. These approaches have not explicitly limited and evaluated the cost of overhearing and idle listening.

In this paper we apply network coding in GinMAC, a Time Division Multiple Access (TDMA) based Medium Access Control protocol [6]. A limited amount of overhearing is incorporated in to the TDMA schedule. We investigate the impact of this strategy in a data gathering protocol with controlled delay and reliability guarantees based on GinMAC. Furthermore we analyze trade off between energy consumption and performance gains.

II. Design and Implementation

GinMAC is a single channel state-of-the-art TDMA-based MAC layer for performance-controlled sensor networks [6]. GinMAC uses an offline process to dimension a network before deployment. The heart of the dimensioned network is a TDMA schedule with an epoch length consisting of E slots. There are three types of slots, namely $basic$ slots for transmission (TX) and reception (RX), $additional$ slots for retransmissions (RTX) to increase reliability and $unused$ slots to decrease the duty cycle. Furthermore, leaving $unused$ slots enables BurstProbes, a novel mechanism for estimating the number of required retransmission slots and a tool to debug time-critical data delivery. The schedule determines latency, power consumption and reliability. The latter is increased by adding more retransmission slots.

In GinMAC, network coding can reduce the length of an epoch E which helps to reduce delay and improve the maximum throughput for a fixed number of transmitting sensors. To achieve this, the TDMA schedule is reorganized incorporating a limited amount of overhearing (OH) followed by rearranged retransmission slots. A given node overhears its neighboring transmission once in an epoch, since it knows when a transmission is scheduled for its neighbor. Since GinMAC assumes a deployment where nodes' locations are carefully selected, we can assume overhearing is possible. According to the TDMA schedule, the system maintains a data collection tree topology, so that each node knows its parent node. A comparative illustration of TDMA schedules with and without network coding is depicted in Figure 1. For the sake of simplicity we consider a simple tree of three nodes.

Figure 1b illustrates the TDMA schedule for both approaches. In GINSENG it allocates one retransmission slot for each child node whereas in Network Coding it only allocates one retransmission slot for both nodes. Network coding is applied in the retransmission slot, where it sends a coded packet after performing binary XOR operation on its own packet and the overheard packet of the neighbor. This allows the receiver to recover one packet loss with a simple XOR operation. This saves one transmission slot from overall schedule compared to GinMAC with basic retransmissions, while paying an additional listening slot. Furthermore, our network coding approach does not rely on acknowledgements from the receiver when retransmitting as GinMAC.

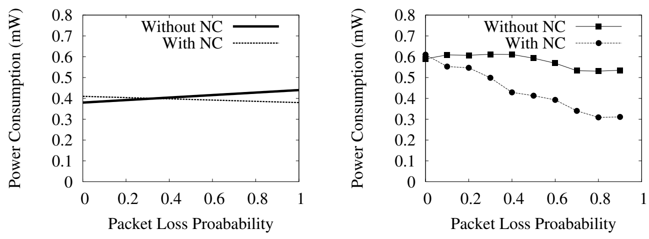
In addition to including overhearing in GinMAC schedule, we implement coding and decoding of packets in the MAC layer. We include an additional header field in the GinMAC frame to communicate the details of the coded packets to the receiver to recover the lost packet, which however adds a negligible overhead.

III. Evaluation

We analyze performance gains and trade-offs considering the binary tree with three nodes illustrated in Figure 1a, since both GinMAC and network coding approach recover errors in a hop by hop fashion. As the key contribution of our approach suggests limited amount of overhearing, power consumption becomes a primary performance metric. Furthermore, we measure the impact on reliability as the packet reception rate at the parent. We consider a simple analytical model with a constant packet loss probability of p in each link, with independent packet losses. The average power consumption for basic GinMAC with the TDMA schedule illustrated in Figure 1a is $2(1+p)E_{tx}+4E_{rx}$, whereas with network coding it becomes $(3-p)E_{tx}+4E_{rx}$ assuming constant power for transmission and listening. Accordingly the packet reception probability at the parent becomes $1-p^2$ for GinMAC while for network coding being $(1-p)(1+p(1-p)^2)$.

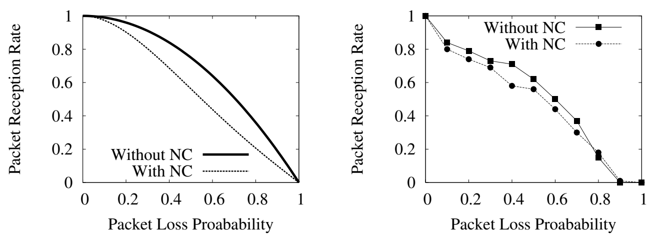
We use the COOJA simulator to simulate an environment monitoring application for a three node binary tree to experimentally verify the analytical results. We simulate GinMAC with and without network coding. We measure the power consumption using Contiki's software-based power profiler. Our results are shown in Figure 2. The experimental results show a decline in power consumption for both the approaches deviating from the analytical results. This is due to the difference of packet reception power consumptions between normal and erroneous packets which is assumed to be equal in the analytical model. Since network coding requires one less retransmission slot, it in turn reduces the average power consumption compared to the GinMAC, as our results show. Further, it shows a decline in power consumption when the packet loss probability is high, which is again due to having common retransmission slot for both child nodes. Even though an additional overhead incurs for overhearing, it balances out with the reduced cost of retransmission.

In Figure 3, the packet reception rate is plotted against the packet loss probability. This shows approximately similar error recovery capabilities in both GinMAC and network coded version of it. These results imply the introduction of overhearing followed by a simple network coding scheme can compress the TDMA schedule reducing the power consumption while trading off with reliability.



(a) Analytical Results (b) Experimental Results

Fig. 2: Power Consumption Vs Packet Loss Probability



(a) Analytical Results (b) Experimental Results

Fig. 3: Packet Reception Rate Vs Packet Loss Probability

IV. Conclusions

We apply Network Coding with the limited amount of overhearing introduced in GinMAC, a state-of-the-art TDMA based MAC protocol. We apply Network Coding in GINMAC, a state of the art TDMA based MAC protocol introducing a limited amount of overhearing. Analytical and Simulation results verify that this approach reduces the delay and power consumption while maintaining a desired level of reliability.

Acknowledgments

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