Cooperative Media Access Control in Wireless Networks

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Abstract — *We present CMAC/DRS, a cooperative relaying enhanced MAC protocol which solves mandatory tasks in cooperative networks in a throughput efficient way. Our main focus is the relay selection process; we only select relays if requested by the destination and try to minimize the collision probability of messages in this process. We compare CMAC/DRS with CMAC/ARS and standard non-cooperative IEEE 802.11. Our simulation results indicate considerable throughput benefits of CMAC/DRS compared to the reference protocols.*

I. Introduction

In cooperative relaying, e.g. in Figure 1 a node denoted as relay R overhears the direct transmission between S and D and, on demand, forwards this data to D. D combines both messages to mitigate small scale fading effects. R is chosen from the common neighbors of S and D based on current Channel State Information (CSI) from the candidates to S and D. `RTS` and `CTS` messages of IEEE 802.11 protocols can be exploited at relaying candidates to estimate their CSI to S and D trying to keep the overhead introduced by the relay selection small. Furthermore, a selected relay needs also to reserve the channel in its neighborhood. Thus, it is appealing to combine cooperative relaying protocols with an IEEE 802.11 like MAC protocol [1, 2, 3].

The performance of cooperative relaying schemes mainly depends on the relay selection. Distributed relay selection requires the exchange of messages which are prone to collide. Due to collision it can happen that no relay can be selected and cooperation is not available.

In the remaining part of this paper we introduce Cooperative Medium Access Control with Dynamic Relay Selection (CMAC/DRS) which addresses the problem of relay selection and tries to avoid collisions between potential relaying nodes. Furthermore it only uses cooperation if required and skips relay selection otherwise.

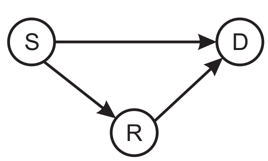

Figure 1: Basic cooperative relaying scheme

II. Protocol Description: CMAC/DRS

CMAC/DRS which is based on CMAC/ARS [1] works as depicted in Figure 2: at the beginning the source broadcasts a `RTS` frame to initiate the transmission with a certain destination and reserves the channel in its neighborhood for the time of the relay selection. The destination replies with a Conditional Clear to Send (`CCTS`) frame if it is ready to send and occupies the channel for the whole needed transmission time. If the direct link between source and destination is bad a relay is selected distributively. The current relay is confirmed within the data transmission of the source. The data packet also extends the source's channel reservation until planned `ACK` reception time. After data transmission the relay waits for an `ACK` from the destination. If the relay does not receive the `ACK` within a certain period of time, it assumes a failure and forwards the overheard message. At the end an `ACK` frame completes the cooperative transmission.

A. Cooperation on demand

Cooperative Relaying consumes time and energy for relay selection and overhearing packet transmissions. However, cooperation is only used when the direct transmission from source to destination does not succeed. Thus, in CMAC/DRS the destination uses the `RTS` message to estimate the current Packet Error Rate (PER) of the source-destination link. If the current PER drops below an application depended threshold the relay selection is skipped which is reported via the `CCTS` message. Thus cooperation is only used on demand [4].

B. Distributed Relay Selection

Relay selection is a significant topic in cooperative relaying. Main challenge is to choose a node that can effectively improve data transmission out of a set of potential relays. CMAC/DRS uses three busy tone slots and a static number of `RRTS` slots to solve this problem. Busy tones are used to signalize that there exist neighboring nodes that may help to send packets in a cooperative manner. Moreover the busy tones assist to separate relays into sets with different capabilities, e.g. relays that provide an outage rate of 0.01, 0.1 and 0.5. Busy tones are consulted to estimate the number of competing relays [5]. The estimated number of relaying candidates is reported by the source using `NRC` (Number of Relay Candidates) message. The potential relays use this information to derive their slot transmission probability in the contention window. This reduces the probability of colliding `RRTS` (Relay Ready To Send) messages. For instance, if 13 relays are available each of them broadcast a `RRTS` message at N available slots with a probability of $1/13$. This equation maximizes the probability that only one single frame is sending at the same time [6].

III. Simulation

We implemented CMAC/DRS and CMAC/ARS [1] in a modified version of a 802.11 simulator[1] for ad hoc networks. CMAC/ARS has not been implemented one-to-one in our simulator because this approach presumes a few assumptions that can not be applied practically [7]. The main difference between both implemented cooperative protocols is that CMAC/ARS uses constant slot transmission probabilities for RRTS frames. Therefore the number of available slots significantly affects the success of relay selection. In order to provide a fair comparison, both CMAC/DRS and CMAC/ARS use seven `RRTS` slots.

For our simulations we randomly place nodes on an $100 \times 100\ m^2$ area, where each 5 msec a packet with size 1024 bytes is injected. Source and destination of this transmission are random. Relays perform decode and forward. Further assumptions are given in [7]. Figure 3 depicts a

[1] http://wiki.uni.lu/secan-lab/802.11+Network+Simulator.html

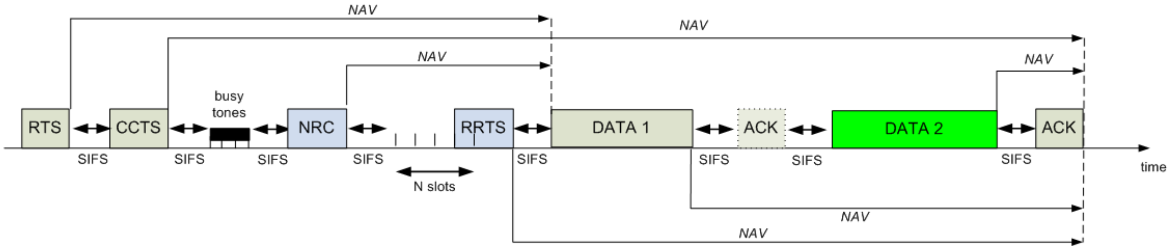

Figure 2: CMAC/DRS frame exchange sequence

throughput comparison of CMAC/DRS, CMAC/ARS and 802.11. IEEE 802.11 achieves a fairly low throughput due to many required retransmissions. Throughput of CMAC/ARS raises continuously from sparse networks with only 10 available nodes to networks with 40 radios, afterwards it drops instantly. The value decreases mainly because of collisions of RRTS frames. Consequently relay selection fails and data frames cannot be sent in a cooperative manner. CMAC/DRS reaches at a point of 25 network nodes a throughput value that stays nearly constant around 620 kB/s. With increasing node density benefits of dynamic slot transmission probabilities arise, as the probability of RRTS frame collisions is minimized even in dense networks.

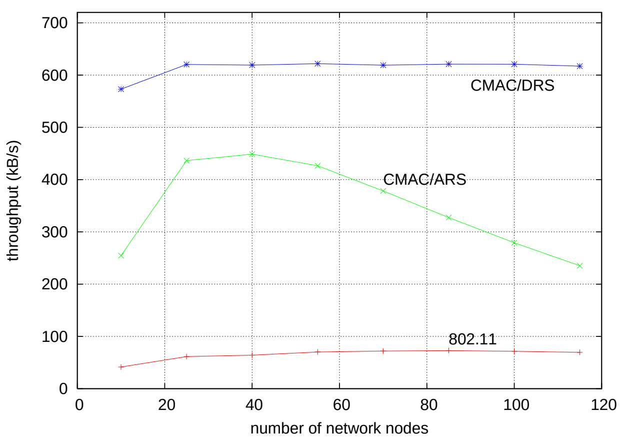

Figure 3: Throughput comparison

Figure 4 illustrates the dropped packet rates of CMAC/DRS, CMAC/ARS and IEEE 802.11 in the given scenario. In other words we measured how many packets are dropped because the retransmission retry threshold of 7 was reached. While rates of CMAC/ARS and CMAC/DRS are fairly low, 802.11s rate is permanently around 4 %. Regarding CMAC/ARS we can recognize that the ratio of dropped packets raises at networks with 70 or more radios. Again the reason are RRTS collisions as nodes have to transmit directly if relay selection fails. It appears that more packets are dropped at sparse networks as there are less potential relays available. Overall simulations have shown that CMAC/DRS outperforms CMAC/ARS in many comparison criteria by far and therefore it is a promising state of the art cooperative MAC layer protocol.

IV. Conclusion

This paper shows significant benefits of cooperative communications demonstrated by simulation results. CMAC/DRS represents an efficient MAC layer protocol to provide relaying in wireless networks. Fundamentals of this proposed scheme are distributed relay selection with dynamic slot transmission probabilites and cooperation on

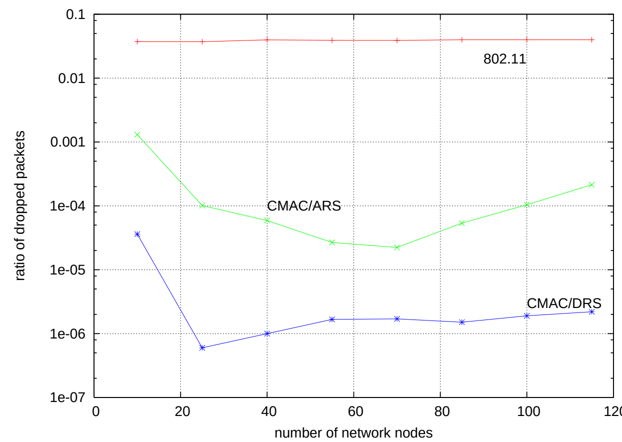

Figure 4: Dropped packets

demand. Evaluations demonstrate gains of CMAC/DRS by terms of throughput and outage.

Acknowledgements

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