A Reliable MAC Protocol for Broadcast VANETs

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***Abstract*—The design of efficient and reliable broadcast MAC layers for wireless mobile ad hoc networks (MANETs) – especially when high user speeds are allowed – is a current challenge. Despite the absence of infrastructure which would permit channel allocation, awareness techniques allow a certain channel assignment. This paper presents MAC layer protocol designed for broadcast MANETs called COMB (Cell-based Orientation-aware MANET Broadcast). In principle, COMB allows the realization of a collision free transmission, high speed is supported and no handshake is required. COMB is based on localization aware cross layer dimensioned CDMA cells, and uses the SOTDMA protocol as intra cell scheme, while the inter cell scheme relies on direction and speed awareness.**

I. INTRODUCTION

If we are studying different medium access control(*MAC*) layer protocols, we see a straight development from static wired networks to a mobile computing scenario. We want to distinguish four major steps in detail:

- Wireless MAC:
  The core feature of an ad hoc network is to provide communication services without any infrastructure or centralized access point. Therefore, there is no base station to coordinate packet transmissions. Since channel resources are limited, transmissions will interfere with these neighbours that also have packets to transmit in the same channel. Consequently, the MAC (Medium Access Control) layer must be accomplished in a distributed way.
- *Mobile ad hoc network (MANET)* MAC:
  Moreover, ad-hoc networks allow stations to move which introduces more complexity, as it causes permanent network changes. This may significantly impact on the MAC layer's performance.
  The simplest protocol for MAC layers that can be used is the well known ALOHA protocol [3] where no control is used, however due to its low throughput it is only applicable in low density ad-hoc networks. Another of the earliest mechanism adopted was the CSMA (Carrier Sense Medium Access) protocol [4]. Nonetheless, it introduces the hidden terminal and exposed terminal problem. Thus, a variety of more complex MAC protocols have been proposed for mobile ad hoc networks (MANETs). Some of these general protocols include the Multiple Access with Collision Avoidance (MACA) [5], Media Access Protocol for Wireless LAN's (MACAW) [6], Floor Acquisition Multiple Access (FAMA) [7] and the MAC protocol of IEEE 802.11 [8].
- Broadcast MANET MAC:
  Unfortunately, these protocols are not suited for broadcast MANETs, as the required handshake cannot be performed, if we don't have a specified communication partner (CSMA, MACA, MACAW,...) or performance is too low (Aloha). Broadcast is a key service in many applications, e.g. road side units, link layer protocols and safety applications that send periodical beacons. In the last group we can find several applications such as disaster rescues, tactical communications for military usages and collision avoidance systems in transportation systems.
  Many MAC broadcast protocols for MANETs have been proposed in the literature. They can be classified in two groups:

  - Improved versions of the widely accepted IEEE 802.11 MAC protocols, which are all using the handshake technique. They include BSMA [10], BMW [11], BMMM [12], LAMM [12]
  - Innovative MAC protocols related to TDMA, FDMA or CDMA. Random access protocols such as CSMA/CA have proven not to be an efficient solution. Therefore, starting from the basic TDMA or CDMA is an important research topic. In this group we can find ADHOC-MAC [13], Five-Phase Reservation Protocol (FPRP) [9], Self Organized Time Division Multiple Access (SOTDMA) [14], CATA [15], ABROAD [16], RBRP [17] and SNDR [18].

One major concern and interest of investigations are complex dynamic and very extended MANETs, characterized by high sender density and high speed. Unfortunately, the above listed broadcast MANET MAC protocols are not suited for this kind of networks, because on the one hand, those based on IEEE 802.11 use handshake techniques in order to recognize possible packet collisions and retransmit again the messages. Furthermore, they assume quite static networks and prior knowledge of the number of receivers, which is not given. On the other side, the TDMA, FDMA or CDMA based solutions usually don't provide a solution for the hidden and exposed terminal problem. An example of extended and highly dynamical MANETs are collision avoidance systems for transportation, e.g. road (Car2Car), maritime (AIS) , air (ADS-B), railway (RCAS). These systems might be deployed in such a large area as the whole world. These systems broadcast periodically data inferred from the onboard GNSS system. Car2Car uses a protocol based on IEEE 802.11, whose problems have been already discussed. AIS MAC protocol is Self Organized Time Division Multiple Access (SOTDMA) a kind of split channel reservation multiple access (SRMA). ADS-B utilizes a protocol based on Aloha. However, as the speed and the senders' density increases, the number of packet collisions due to the hidden terminal problem and collisions in contention time are more critical.

- Awareness for MAC:
  Since GNSS is very oft present in high dynamic MANETS, the information given by the GNSS system (location, direction, speed, and precise timing) can be utilized by the MAC layer. Thus, our below presented MAC layer protocol COMB relies on location awareness, a subspace of situation awareness.
  A number of MAC protocols utilizing position information have been proposed, like GRID [19] and TPCPC [20]. However, these protocols are focused on unicast communication. Moreover, they rely on a handshake protocol and therefore there might be collisions during the contention.

This overview shows, that there still is a need for a MAC protocol allowing for mobility, broadcast and situation awareness and handling all related problems. COMB does not only rely on position, but on speed, direction, and time awareness in order to allow a robust protocol. It does not either use any handshake protocol in order to recognize and recover problems caused by packet collisions simply because collisions do not occur in the frequency domain.

The remainder of this paper is organized as follows: Next we describe SRMA protocols and their problems. Section 3 introduces the solution that COMB utilizes in order to solve the hidden terminal problem. Section 4 examines the collision produced during contention time, its solution and how it affects the hidden terminal problem. Finally, section 5 presents the COMB protocol before section 6 provides a summary.

II. SPLIT CHANNEL RESERVATION MULTIPLE ACCESS PROTOCOLS

SRMA protocols have two channels, a control channel and a data channel. In the control channel, the senders compete for the data channel. Each of the channels might be divided in successive channels, e.g. in FDMA each frequency can have a TDMA scheme. When a terminal wishes to send some message, it has first to reserve a data channel in the control channel. SRMA protocols can be implemented in many ways: the control and data channel might be differentiated in frequency, code or time. For example, the control and data channel might have different frequencies and each frequency partitioned in time slots. As a result, in the absence of the hidden terminal problem, collisions may only occur in the control channel during the contention time.

In order to additionally decrease the collision probability in the control channel, a sender should reserve not only a data channel but another control channel for the estimated next transmission. Since this scheme is developed in time, it is specially suited for TDMA schemes. Consequently, assuming no hidden terminal problem, once a terminal has entered the network and has obtained successfully a data channel and a next control channel, it does not need to contend again for a channel, and therefore no more collisions occur among the terminals within the network.

An example of such a MAC protocol is the Self Organized Time Division Multiple Access (SOTDMA) [14]. Its control channel and data channel are TDMA, and the channels within the control and data channel are as well TDMA. They are combined in the following way: the channel is divided into slots, in each slot there is a sub-slot for data and another one for control data. When a new sender comes into the network, it searches a free slot. In the free slot it sends the data and in the control sub-slot it reserves the next data and control slot as shown in Figure 1. Therefore, each node in a network knows in which slots the nodes in its range are planing to transmit, and thus, can infer which slots are free.

We can conclude that in SRMA protocols with periodical reservation, collision might only occur due to the hidden terminal problem and due to contention of terminals entering the network. In the following section a solution for the hidden terminal problem is introduced.

III. A CDMA LOCATION AWARE CROSS LAYER BASED SOLUTION FOR THE HIDDEN TERMINAL PROBLEM

The hidden terminal problem is produced when two nodes, A and C , are not in the range of each other, but are both in the range of another node B as can be seen in Figure 2.

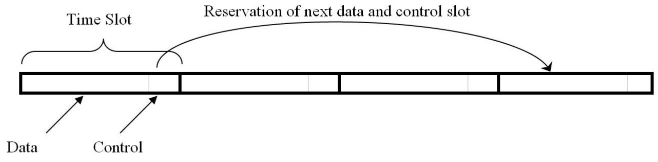


Fig. 1. SOTDMA MAC protocol.

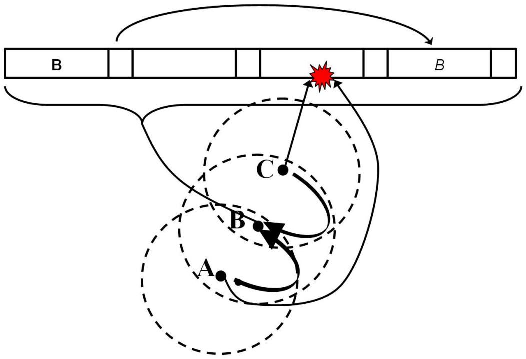


Fig. 2. Hidden terminal problem: A and C try to access the medium in the same channel because they can not ”see” each other. .

In the case of the SOTDMA protocol, B would ”see” the slots reserved by A and C. However, since A and C cannot see each other, they might try to access the same slot and collide.

Nonetheless, if the nodes A and C send their messages with different CDMA codes, node B can receive both messages at the same time. Therefore, since nodes which are close to each other, i.e. that are in the range of each other, do not have the hidden terminal problem, they may send with the same code as collisions are avoided by other means. Thus, it is only necessary to assign distinct codes to ”far-away” nodes.

In order to accomplish this idea, the world map is divided into virtual hexagonal code cells according to geographical positions, where a different code correspond to each cell. The dimension, i.e. the diameter, of the cell should be in the order of the range of the nodes, as seen in Figure 4. This way, every node in any position inside a cell is able to receive signals from the other nodes of the same cell. Thus, the SOTDMA structure is seen by all the nodes avoiding this way possible collisions. Furthermore, since messages from other cells are

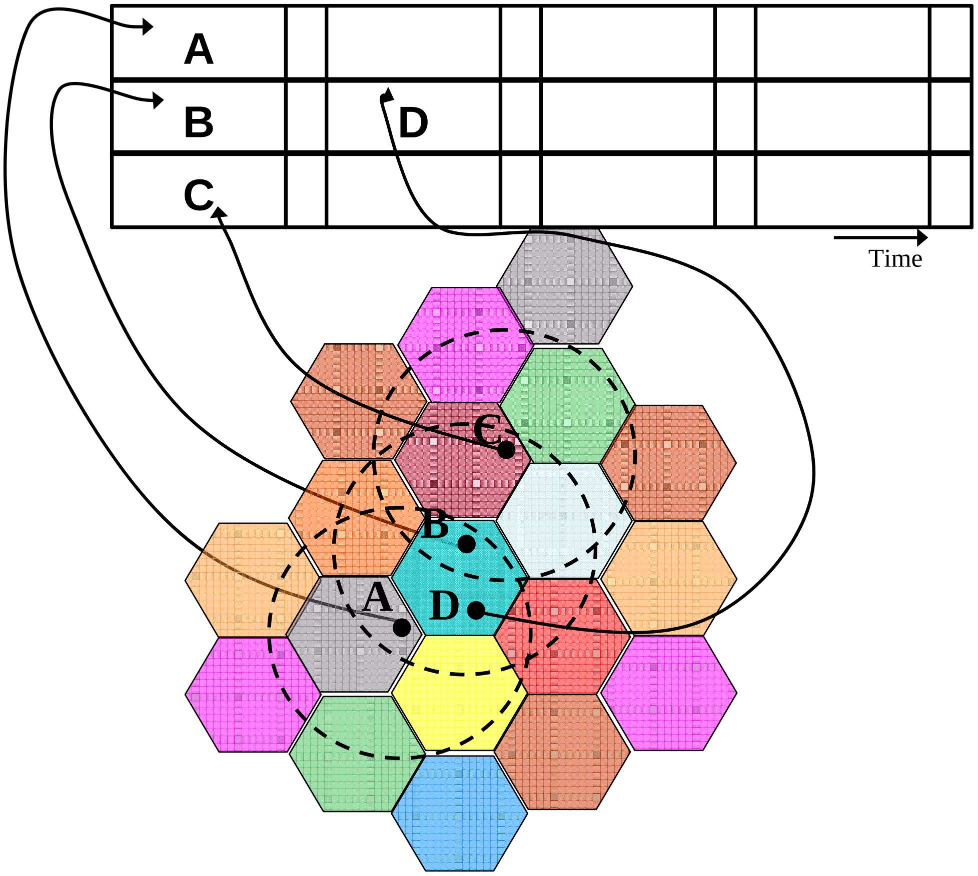


Fig. 3. Different colors mean different codes.
A, B and C try to access the same time slot, but with different codes. Therefore, there is no collision. D and B are in range of each other and send with the same code. Consequently, they choose different time slots and there is no collision, either.

received with another code, there are no collisions due to the hidden terminal problem as observed in Figure 3. The CDMA code with which a node should transmit, is inferred according to its location calculated from its GNSS system.

Since we want to reuse codes (for practicability reasons) and at the same time avoid the hidden terminal problem, we need sufficient guard spaces between cells that share the same code. We decided to have at least three cells with different codes between them, to be definitely on the safe side, see Figure 5. Consequently, only twelve codes constitute a network free of interference and hidden terminal problem as seen in Figure 6 .

Although the hidden terminal problem has been solved, a new problem arises when the nodes move. A node that crosses from cell to cell has to contend for a new slot. When more than one node crosses to the same cell, they may try to access the same slot, and a collision occurs as observed in Figure 7.

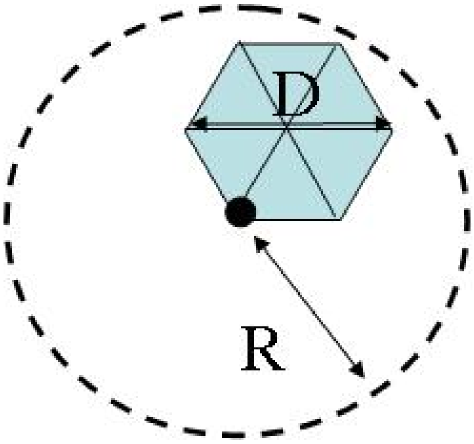


Fig. 4. The cell dimension is related to the range (see 1.

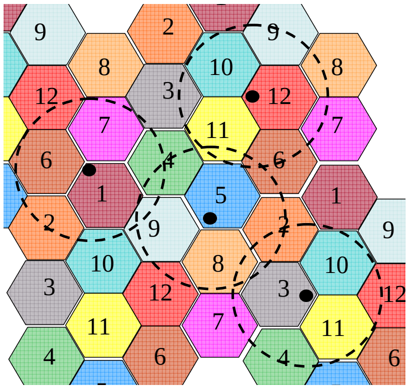


Fig. 5. When there are three cells between two cells that share the same code, the hidden terminal problems does not occur.

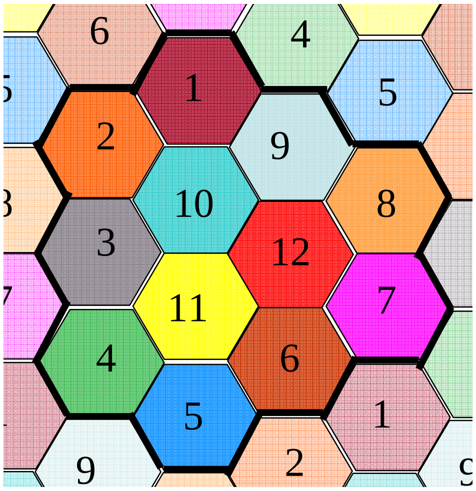


Fig. 6. The basic cell pattern with 12 different orthogonal CDMA codes. Ordering of the codes is arbitrary, but has to be equivalent in neighboring cell groups.

In the next section this problem is discussed.

IV. A CDMA SITUATION AWARE CROSS LAYER SOLUTION FOR CONTENDING NODES

Due to the fact that the range of the nodes is slightly bigger than the cell dimensions, the nodes close to the border of other cells are able to receive all the transmitted signals from that cell, and therefore know its SOTDMA structure. Since a GNSS system provides speed and direction of the moving terminals, the nodes know with antelation to which cell they are about to cross. Nodes inside a cell reserve a slot for their next message in the SOTDMA slot structure of the cell they are in. However, when they know that in the moment they will send the next message they will be geographically located in another cell, they should reserve the next slot in the SOTDMA structure of the target cell, i.e. they make the reservation indicating the next code they will use is the one of the target cell.

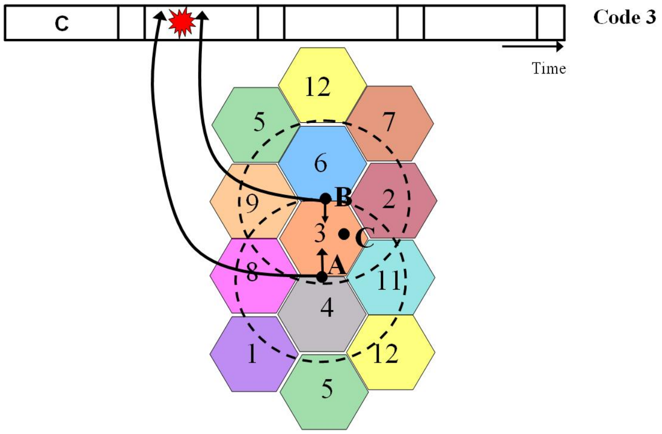


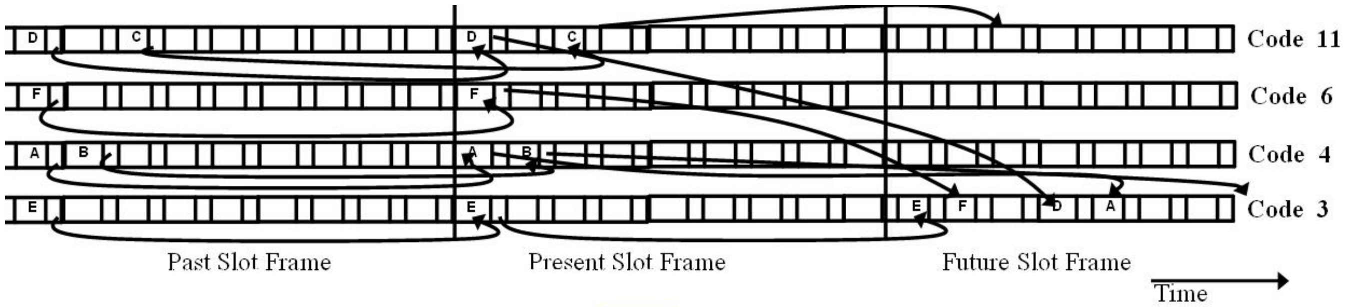
Fig. 7. Collision of contending nodes: A and B move into a new cell and must change their CDMA codes. However, they try to access the channel in the same time slot and collide.

In order to delimit the slot structure of the SOTDMA protocol, we will define as ”slot frame”, the minimum number of slots between two consecutive messages of a node.

Consequently, several nodes coming from a same cell ”1”, will never produce a packet collision due to contention when they cross to cell ”2”. However, nodes crossing from different cells to a same one, may collide. Since one cell is surrounded by six cells, there might be a maximum of six nodes contending for a same slot.

In order to solve this problem, we will define a ”cell crossing priority”, starting with the cell situated in the north of the target cell and then the successive cells going clockwise direction.

Considering its cell crossing priority and the start of the slot frame, the node will reserve the first free slot corresponding to its priority of the next slot frame, i.e, the node in cell priority ”1” will reserve the first free slot, and the node within the cell priority ”2” will reserve the second free slot. Therefore, the nodes crossing to a target cell should listen to the slot frame of the target cell and the surrounding cells. This is illustrated in Figure 8.



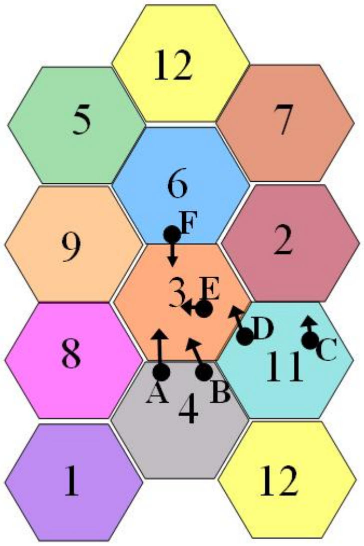


Fig. 8. Nodes moving to a target cell.

V. CROSS LAYER CHARACTERISTIC OF COMB

An important issue of COMB is the cross layer dependency. The dimension of the cell should be smaller than the range, which is controlled by the physical layer. Since range can not be assumed to be invariable, this relation might seem very restrictive. In order to minimize possible problems produced by the variability of the range, we should assure the existence of three cells with different codes between two cell sharing the same code. In this case twelve orthogonal codes would be necessary as seen in figure 6.

The ideal cell dimension D (see Figure 4) is

$$D = R - 2 \cdot F \tag{1}$$

where, R is the minimum range and F is the distance of a slot frame (one is necessary to observe the slot frame of the target cell, and a second one to make the reservation). F can be calculated as:

$$F = v \cdot t \tag{2}$$

where v is the maximum speed of the node and t is the minimum time between two consecutive messages of a node. For example, if the nodes have a range of 7 km, the messages are sent each second, and it is moving at 300 km/h, then in order to receive two slot frames before crossing to the new cell $2 \cdot F = (300 \cdot 1000) \cdot \frac{2}{60 \cdot 60} = 0,167m$

Considering the cell size given by the minimum range, then the maximum range would be delimited by the maximum range where no hidden terminal problem is present. This is given for a node located in the middle of the shortest distance between two cells sharing the same code, as seen in Figure 9. This node would have the borders of its range in the borders of the cells with same code.

Therefore, the range has a certain margin where it can move and still no collision is produced. However in case the necessary margin would be bigger, more codes can be added to the system.

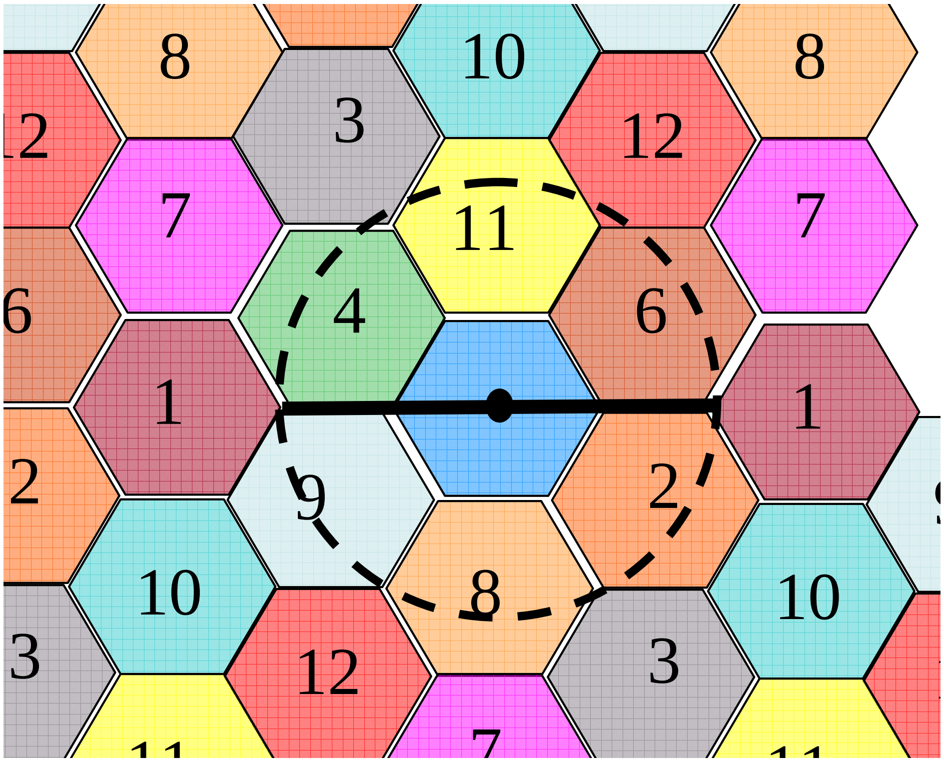


Fig. 9. The maximum range is given for a node located in the middle of the shortest distance between two co-channel cells.

VI. THE COMB PROTOCOL

In this section we will finally present the specification details of the protocol we often mentioned in the sections above:

1) Divide the map in hexagonal cells where its dimension is given by equation (1).
2) Give each cell a code of a group of twelve orthogonal CDMA codes in such a way that there are three cells between two cells with same code.
3) Inside a cell the messages are codified with the corresponding cell code.
4) Inside a cell the messages are sent according the SOTDMA protocol. The time is divided in ”slot frames” where the frame duration is the minimum time between two consecutive messages coming from a same node.
5) The nodes observe the ”slot frames” codified with its cell code. The nodes send their messages in their already reserved slots and reserve a free slot in a next ”slot frame”.
6) When a node is about to cross a cell border, it must observe the ”slot frame” of the target cell and reserve one of the first six free slots according to its current’s cell priority.
7) The cell priority is given by the position of the current cell with respect to the target cell. The highest priority corresponds to the cell in the north.

VII. CONCLUSION

In this paper we have presented COMB, a new MAC layer for broadcast MANETs. COMB divides the network in cells characterized by one CDMA code while within each cell an SRMA protocol is used. Our protocol cooperates with the physical layer in order to control the range. The protocol is orientation aware and using GNSS data. Positioning is necessary in order to recognize in which cell the vehicle is and which CDMA code should utilize. Speed and direction information are used when crossing to another cell.

With this approach, we can avoid the hidden terminal problem and collisions due to contention neither in control nor in data channels. The necessary overhead is minimum and since only 12 CDMA orthogonal codes are necessary, it is practically realizable. Furthermore, the network may have any structure, it is easily scalable and the terminals may move as fast as required.

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