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A disjoint frame topology-independent TDMA MAC policy for safety applications in vehicular networks[☆]

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ABSTRACT

Medium access control (MAC) is a challenging problem in vehicular environments due to a constantly changing topology due to vehicle's mobility and stringent delay requirements, especially for safety-related applications (e.g., for vehicular-to-vehicular communication). Consequently, topology-independent TDMA MAC policies that guarantee a number of successful transmissions per frame independently of the underlying topology, can be regarded as a suitable choice for the particular vehicular environment. One such policy (TiMAC) is revisited and considered in this paper for a vehicular environment and is also extended to one that considers disjoint frames depending on the vehicle's direction of movement (d-TiMAC). Both TiMAC and d-TiMAC are evaluated against VeMAC – a well-established TDMA MAC protocol in the area of vehicular networks – based on simulations. It is observed that throughput under the considered TiMAC policy is close to that induced by VeMAC, whereas the number of retransmissions is reduced leading to a smaller time delay. Furthermore, the proposed d-TiMAC appears to achieve a higher throughput than VeMAC, and an even lower number of retransmissions (when compared to TiMAC), suggesting that d-TiMAC yields an even smaller time delay. Eventually, this observation is also supported when d-TiMAC is compared against TiMAC showing a further reduced number of retransmissions.

1. Introduction

Vehicular networks have seen a significant growth over the last decade, improving the quality – and most importantly – the safety of a journey. The timely access of the medium is a core factor when safety is considered [1,2], even at the expense of some throughput compromise [3].

Although contention-based MAC protocols are mainly proposed for vehicular networks [4,5], scalability issues arise, particularly when traffic load is increased. It has been shown [3] that the most prominent standard, IEEE 802.11p [6], suffers from time unbounded transmission delays and thus, it is not suitable for improving road safety. Currently, the research trend tends to consider TDMA-based approaches for medium access control to capitalize on the inherent time-coordinated transmissions [3]. The traditional problem of synchronization in TDMA-based approaches has been shown to be overcome by using GPS technologies that are present in vehicular networks [7–10].

Depending on the underlying communication configuration, vehicular networks can be categorized into three

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types: inter-vehicle communication or vehicle-to-vehicle, vehicle-to-roadside, and vehicle-to-infrastructure communication. Note that these types may co-exist in order to provide various services [11]. The focus of this paper is on vehicle-to-vehicle communication. Still, the results presented in this paper can be applied for the vehicle-to-infrastructure case, as well [12].

Several vehicle-to-vehicle protocols have been proposed in the past like VeSOMAC [13], ATSA [14], CFR [15], STDMA [16], VeMAC [17] etc. More can be found in Section 2. Under the well-established VeMAC [17], every node initially listens to the channel for one frame time and gathers information about neighboring nodes, subsequently reserving a time slot that neither its one-hop nor its two-hop neighbors use. VeMAC will be considered in the sequel for comparison purposes against the topology-independent MAC policies that is the focus of this paper.

Motivated by existing topology-independent MAC policies that guarantee data packet delivery on a per frame basis [18,19], these established frameworks are revisited here and further enhanced. This is achieved by allowing users (in this case vehicles) to transmit, within a frame, during a specific set of time slots carefully selected according to polynomials of Galois fields [20]. Since this approach is fully distributed and makes no assumptions regarding the topology – apart from an upper bound on the network size and the number of neighbor nodes – it can be effectively employed in vehicular networks. Its guaranteeing nature despite the topology unawareness, motivates its introduction in vehicular networks for safety applications.

The topology independent MAC policy presented in [18] (to be referred to hereafter as TiMAC), is revisited to show its effectiveness in vehicular environments and a novel policy (based on TiMAC) that considers disjoint subframes for each vehicles' direction called d-frames, is also proposed and evaluated. This MAC policy is referred to hereafter as d-TiMAC. The main contribution here is to show that by revisiting the existing topology-independent approaches, this can be beneficial for medium access control in vehicular networks. Furthermore, when the existing policies are enhanced by certain features (e.g., disjoint frames for different vehicle directions), the overall performance – in terms of throughput and time delay – can be further improved.

Both policies (the existing TiMAC [18] and proposed d-TiMAC) are evaluated here against the well-established VeMAC [17] policy. As it will be shown later, VeMAC has specific features suitable for vehicular environments, like time slots assignment depending on the direction of the vehicle and knowledge of two-hop neighbors. However, both TiMAC and d-TiMAC are also suitable for the particular environment, mostly due to their inherent topology-independent nature that guarantees a minimum throughput immune to mobility. In addition, d-TiMAC employs disjoint subframes for allocating time slots to vehicles depending on the direction of their movement.

Simulation results demonstrate the effectiveness of TiMAC for vehicular network environments, and reveal a further enhancement when d-TiMAC is employed. TiMAC's throughput is close to that of VeMAC and depending on the case, it may be slightly higher (which is a noteworthy result considering the lack of any information) as shown in a preliminary version of this work [21]. In addition, the number of retransmissions is smaller under TiMAC when compared against VeMAC. However, as it is shown here the proposed d-TiMAC achieves better results both in terms of throughput and time delay when compared to VeMAC. Finally, TiMAC is compared against d-TiMAC showing a further reduction of retransmissions, thus demonstrating the effectiveness of the proposed d-TiMAC for safety applications in vehicular networks.

Section 2 contains the discussion of previous related works, where similarities and differences with other approaches are presented. Section 3 briefly describes the most important characteristics of the considered vehicular network. VeMAC is discussed in Section 4, whereas Section 5 is devoted in TiMAC and d-TiMAC. The evaluation of their performance using simulation results is included in Section 6 and, finally, Section 7 concludes this study by summarizing its results and discussing future directions.

2. Past related work

Several works address the problem of multiple access in vehicular networks. In this section the emphasis is on approaches that are closely related to TiMAC and the proposed d-TiMAC policy.

TDMA-based approaches have recently gained a lot of attention [17,22]. In particular, a novel time division MAC protocol is proposed in [22], called VAT-MAC, where the number of vehicles within a range is predicted in order to properly allocate the time slots, avoiding collisions. Another TDMA variant of a MAC protocol that is proposed regarding VANETs applies game-theoretic techniques in order to settle the problem of slot allocation among the nodes.

ATSA [14] is an adaptive TDMA protocol focusing on vehicular networks where sets of timeslots are formed depending on vehicles' directions. In this protocol, the frame length is dynamically adapted (shortened or doubled) in order to facilitate the optimal number of vehicles, aiming to reduce the probability of collisions. CFR in [15] tackles the problem of collisions and that of the hidden terminal by taking advantage of the driving status and traffic flow of each vehicle in the network in order to appropriately allocate time slots. Another TDMA-based protocol is the self-organizing TDMA or STDMA [16]. Although limited to the highway case, it achieves some good results for various network densities by (re)allocating time slots depending on the traffic load of the network. VeSOMAC is one of the first medium access protocols for inter-vehicular networks [13,23]. It exploits the knowledge of vehicles' location and direction in order to minimize the delivery delay. VeSOMAC promises low-bounded time delay using an in-band control mechanism for exchanging TDMA frame information during the distributed MAC process.

One of the most eminent and widely used algorithms for vehicular networks is that of VeMAC [17,24]. VeMAC, which is considered in this paper for evaluation of both TiMAC and d-TiMAC, is shown to outperform other known protocols, such as ADHOC MAC [25]. A more detailed description of VeMAC is presented in Section 4. A similar concept with d-TiMAC is seen in [26] where frames are