

Chapter 2

Background and Literature Review

This chapter provides the background information of VANETs that is related to our research. In reviewing recent literature, approaches proposed for the medium access control (MAC) in single-channel VANETs are presented. In addition, cooperative MAC protocols and cooperation based makeup transmission frameworks proposed in the literature in order to improve performance of wireless networks are discussed.

2.1 Medium Access Control in VANETs

Several approaches have been considered for designing a MAC protocol of VANETs. They are based on channel access schemes such as code division multiple access (CDMA), space division multiple access (SDMA), IEEE 802.11 random access, and time division multiple access (TDMA). MAC protocols based on CDMA channel access [1, 2] require each vehicle to have a database of allowable location-specific pseudo-random noise (PN) codes specified in its digital map. In addition, vehicles must be equipped with a large number of match filters, which depends on the length of PN codes. Similarly, MAC protocols based on SDMA channel access [3, 4] require each vehicle to have a location specific channel-allocation database in its digital map. These factors add complexity in the protocol development and make protocols difficult to implement. Hence, in the following, we focus only on MAC protocols based on IEEE 802.11 and TDMA channel access schemes, which are widely used in research studies related to VANETs.

2.1.1 IEEE 802.11

The IEEE 802.11 random access scheme is a well known MAC protocol in wireless networks [5]. Such a scheme allows a node to contend for the channel and access

it if it is found idle. Variations in the IEEE 802.11 standard are made to make it suitable for a high mobility scenario, which is highly likely in VANETs. The IEEE 802.11p standard [6] is developed for VANETs, which targets to support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. MAC protocols based on the IEEE 802.11p standard also support QoS provision and is governed by the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) standard [7], such that traffic packets are differentiated into four different access categories, AC0–AC3, where AC0 has the lowest priority and AC3 has the highest priority to access the channel. Service differentiation is achieved in terms of a back-off interval while accessing channel, such that a high priority traffic packet, in general, experiences a shorter back-off interval than that of a low priority packet. In [8], mathematical model to analyze the performance of IEEE 802.11p standard in terms of throughput is presented for a large scale vehicular networks providing in-vehicle Internet service. Although the IEEE 802.11 access scheme is considered in several studies to develop MAC protocols for VANETs, it suffers from the following problems.

- **Unbounded Latency:** IEEE 802.11 based MAC protocols suffer from an unbounded packet delivery latency in a high load condition [9]. In such a case, due to random access of the channel, a node may need to wait for a long duration or fail to access the channel [10] due to contentions and/or collisions.
- **Orphan Frame:** Feedback provisions such as acknowledgement (ACK) or clear-to-send (CTS) packets are used in IEEE 802.11 based MAC [11] to identify the transmission failure in point-to-point communication. In the IEEE 802.11 standard and its derivatives, a node attempts to retransmit a packet, for each failed transmission. It stops retransmission attempts either when it receives ACK from the target receiver or when the maximum retransmission limit is reached. This results in the orphan frame problem such that a source node, which failed to receive ACK, attempts to retransmit the packet which reached the target receiver. This phenomena can be common in VANETs with high relative mobility among nodes.
- **Broadcast Storm:** A broadcast storm occurs due to the random access of the channel [12, 13], when neighboring nodes attempt to flood a packet at the same time. Two or more neighboring nodes attempting to reserve the channel at the same time can result in transmission collisions and throughput reduction. A network layer (or routing) protocol can choose a relay node to rebroadcast a packet to alleviate such a phenomena in the IEEE 802.11 based networks [14].
- **Unreliable Broadcast Service:** In the IEEE 802.11p MAC protocol, even successful broadcast or multicast packets are left unacknowledged. This results in an unreliable broadcast/multicast service. Since broadcast service is critical to support safety related applications, MAC protocols based on the IEEE 802.11p standard may not be suitable for VANETs.

In addition, the performance of IEEE 802.11p MAC protocols gets adversely affected by the relative node mobility, which is a common phenomenon in VANETs [15]. On the other hand, the high priority safety messages in VANETs are short

range, uncoordinated, and broadcast in nature [16]. They have a strict delay requirement and demand a reliable broadcast service. However, due to the aforementioned limitations, MAC protocols based on the IEEE 802.11 are not suitable to provide the required QoS in VANETs.

2.1.2 Time Division Multiple Access

In [12], the ADHOC MAC, a *distributed time division multiple access* (TDMA) based MAC protocol, abbreviated as *D-TDMA* MAC, is proposed for VANETs. The ADHOC MAC is based on RR-ALOHA [17] and supports reliable multi-hops, point-to-point, and broadcast services. The channel time is partitioned into time frames and each frame is further divided into a fixed number of time slots. Nodes contend for time slots. A single time slot is used by only one node within a two-hop transmission distance. Since each node, within its two-hop transmission distance, uses an unique time slot, the hidden node terminal problem is solved. In addition, the broadcast storm problem is solved as a node rebroadcasts a packet only when needed, i.e., if it does not sense retransmission of the packet from any of its neighboring nodes in the previous time slots. In [18], it is shown that the network throughput reduces due to the mobility among nodes in ADHOC MAC. Under such a mobile scenario, transmission collisions increase among vehicles moving in opposite directions or between vehicles and the stationary road side units (RSUs), reducing the throughput. VeMAC, an improved D-TDMA MAC, is proposed in [19] to minimize the throughput reduction due to the relative mobility as well as to provide a reliable broadcast service. Moreover, VeMAC has been implemented as a stand-alone protocol and tested with various experiments, demonstrating its potential to support road safety applications [20]. Thus, D-TDMA MAC protocols possess high transmission reliability as the probability of transmission collisions is low and they have explicit ACKs for each transmitted messages, as compared with the IEEE 802.11p [21]. However, dynamic networking conditions in VANETs result in the wastage of time slots in the D-TDMA MAC protocols. The wastage occurs when the number of nodes sharing a time frame is not enough to use all the available time slots of the time frame. Furthermore, upon a transmission failure, a source node has to wait until the next frame for retransmission despite the presence of unreserved time slots, during which the channel remains idle.

2.2 Link-Layer Cooperation

This section describes the cooperation objectives and issues at the MAC layer. In addition, cooperative MAC protocols proposed in the literature to mitigate the various wireless channel impairments are discussed.

2.2.1 *Objective and Issues*

In cooperative communications, a pair of source and destination nodes (an $s - d$ pair), with a poor channel condition, use the antenna of their common neighboring node(s), a helper node(s), to achieve transmission diversity. The helper node should have a better channel condition to both source and destination nodes. Cooperative relay transmission at the MAC layer can provide following advantages [22–26]:

- increasing the communication reliability even in a poor channel condition between $s - d$ nodes,
- increasing the throughput of an individual link as well as of the overall network,
- reducing the transmission power, thus reducing interference and improving spatial frequency reuse,
- reducing the energy consumption in an energy-constrained wireless network, and
- increasing the transmission range of a node and consequently the coverage area of the network.

Implementation of cooperation can be beneficial and can improve the performance of the MAC protocol. However, to exploit the benefits of the cooperation, the following fundamental decisions must be appropriately made [23, 27]:

- *When to Cooperate:* When a helper should offer to cooperate is the first key decision. For example, the helper may offer cooperation after it receives signalling messages such as request-to-send (RTS) and clear-to-send (CTS) , if it can increase the data rate between the $s - d$ pair or a source/destination may ask for help from its neighboring node(s) before establishing connection (transmitting RTS and/or CTS packets) to improve the transmission data rate. Based on the cooperation decision, cooperative MAC (cooperation enabled MAC layer protocol) is classified as either a proactive or a reactive cooperative MAC protocol. In a proactive protocol, the $s - d$ pair requests for cooperation proactively from a helper before a packet transmission. In contrast, in a reactive protocol, cooperation is triggered only after a communication failure between the $s - d$ pair.
- *Who are the potential helpers:* How does a node decide if it can be a helper and provide cooperation to an ongoing transmission between an $s - d$ pair? One of the primary metrics for this decision is the effective transmission rate between the $s - d$ pair with cooperation enabled transmission. Cooperation is performed if the transmission rate with cooperative relay transmission through the helper is higher than that of direct transmission between the $s - d$ pair.
- *How to support concurrent transmissions:* The introduction of the helper-destination transmission increases the interference range, such that nodes in the neighborhood of a helper are affected in addition to the neighboring nodes of the $s - d$ pair. Hence, cooperative relay transmission between the helper and destination must not interfere any ongoing transmission in the helper's neighborhood.

Moreover, signalling overhead due to the introduction of cooperation must not be significantly high as compared with payload data, otherwise cooperation may reduce throughput and may not be beneficial [28].

2.2.2 *Link-Layer Cooperation*

To exploit the benefits of node cooperation, several cooperative MAC protocols have been proposed for the legacy IEEE 802.11 networks with distributed control [23, 24, 29–33]. In [29] and [30], the cooperative MAC schemes (namely rDCF and CoopMAC respectively) exploit the multi-rate capabilities of the IEEE 802.11 networks. Helper nodes are chosen to shorten the transmission time of a packet. In [31], a similar cooperation scheme called CC-MAC is proposed for uplink transmission. The CC-MAC reduces occurrences of a transmission bottleneck due to congestion in the vicinity of access points and allows the nodes to perform concurrent transmissions which further increase throughput. In all aforementioned studies, cooperation is performed based on previous transmission attempts. In [23], it is shown that cooperation based on historical transmissions does not work for a network where nodes are moving with high relative mobility. Changes in traffic load, channel condition, network topology are frequent and common in MANETs, hence historical transmissions may not correctly reflect the present channel condition. In such a case, it is very likely that the source does not find helpers, or helpers fail to perform cooperation. This results in a delay in packet delivery and/or a throughput reduction.

Motivated by issues with cooperation based on historical transmissions, authors in [24, 32, 33] propose cooperative MAC protocols in which decision of cooperation and helper selection are made during the ongoing transmission. Cooperation decisions are made based on the strength of control signal and/or information exchange among nodes. In [32], the CD-MAC is proposed to improve transmission reliability in which the source node searches for a helper to retransmit its packets, if the destination sends the negative acknowledgement or does not acknowledge the reception. Similarly in [33], cooperation is enabled when vehicles missed broadcast packets from an RSU, such that helper nodes are selected to rebroadcast the packets, improving the overall throughput of a network and avoiding collision due to rebroadcasting. In [24], Zhou et al. propose a cooperative MAC protocol, ADC-MAC, which is backward compatible with the IEEE 802.11.

All of the aforementioned cooperative MAC protocols are based on the IEEE 802.11 and force neighboring nodes to stop their transmissions during the cooperative transmission for an $s - d$ pair. Nodes in the vicinity of the helper along with the $s - d$ pair should back-off their transmissions until the ongoing transmission finishes. In addition, the interference area increases with the introduction of helpers, which further increases the probability of hidden and exposed node problems. Node cooperation mechanisms for TDMA MAC are presented for infrastructure based wireless networks in [34–36]. As communication links are established between a

central controller (or access point) and mobile nodes in such networks, cooperative relay transmission is performed by dedicated helper nodes and coordinated by the controller. Furthermore, there are dedicated time slots to perform cooperation which are allocated to helper nodes even if cooperation is not required. Thus, such schemes cannot be applied directly in VANETs. When VANETs use D-TDMA, operations must be performed in distributed manners, which involve cluster formation, slot allocation and cooperation decisions. Focusing on distributed operations, in [37–39], node cooperation schemes with distributed cooperation decisions are presented. In [37], a node cooperation scheme is presented in which helper nodes perform dynamic cooperative retransmission to the target receiver during the source node's time slot. However, application of such cooperative retransmission to VANETs is not straightforward as each node with a time slot must broadcast its neighborhood information to its nearby nodes in every frame, in order to continue using its time slot in the next frame. In [38, 39], node cooperation schemes are presented for multi-hop communication by using idle time slots. Such schemes require acknowledgement (ACK) from the target relay node, during the source node's time slot. Neighboring nodes participate to perform cooperative relay transmission only if they have the packet and do not receive ACK from the target relay node. However, such a scheme leads to a large (and may be variable) time slot duration in order to accommodate ACKs during the source node's time slot, which is not desirable. Hence the aforementioned node cooperation schemes cannot be directly applied in VANETs.

2.2.3 Cooperation for Makeup Transmission

A makeup strategy is a proactive process in which transmission failures, that might have happened when a source node broadcasts a packet, are corrected before the detection of such transmission failures by the source node [40]. Several makeup strategies have been proposed to improve the reliability, latency and efficiency of broadcast service in wireless networks. When an opportunistic makeup strategy is deployed [40], neighboring nodes of a source node (that received the packets from the source node) rebroadcast the packets with probability 1, until the predefined QoS is achieved. In a probabilistic scheme, packets are rebroadcast with a predetermined probability [41]. Such a decision to rebroadcast the packet does not address the effects of dynamic networking conditions, which may lead to wastage of makeup opportunities when relay nodes are not in a good channel condition to the nodes that failed to receive the packet from the source node. Different from these schemes, in [40, 42–44], the probability of rebroadcast is calculated based on the distance or position of the source node with respect to the node that performs rebroadcast. Such position based makeup strategies are suitable for relaying a packet in a multi-hop scenario, so that packets can be delivered to the nodes beyond one-hop transmission distance from the source node. Similarly, in [14], a received signal strength (RSS) based makeup strategy uses instantaneous channel condition information to perform

makeup transmissions. Such a scheme requires additional transmission overhead in terms of signalling and time to choose the best relay node. This results in a longer, and may be variable, time slot duration to accommodate the signalling and relay selection, which is not desirable in D-TDMA MAC. Thus, the existing makeup strategies either do not address the dynamic networking scenario in VANETs or are not suitable for D-TDMA MAC based broadcast services. Moreover, the node cardinality of a relay node must be considered to ensure that a maximum number of nodes, which fail to receive the packet from a source node, will receive the packet before it expires.

2.3 Summary

In this chapter, existing MAC protocols proposed for VANETs and their limitations are discussed. The IEEE 802.11p and distributed TDMA based MAC approaches are not free from packet dropping and throughput reduction due to a poor channel condition. Further, these approaches can be inefficient in utilizing the available radio resources. On the other hand, CDMA and SDMA based MAC protocols are not realistic to implement in VANETs. Such limitations can be resolved by introducing cooperation among nodes in the MAC layer. Existing studies in link-layer cooperation focus on cooperation in the IEEE 802.11 based networks and/or infrastructure based TDMA network, which cannot be directly implemented in VANETs. Moreover, VANETs require more from the cooperation at the MAC layer to enhance the reliability of the broadcast service. In this book, we focus on the operations in a control channel MAC protocols in VANETs. Thus, this chapter focuses on the VANETs that operate in a single frequency channel. Multi-channel operations in VANETs, including multi-channel MAC protocols and node cooperation in multi-channel environments, are discussed in Appendix A.

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