A Multi-Channel IEEE 1609.4 and 802.11p EDCA Model for the Veins Framework

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***Abstract*—Increasing the realism and thereby the explanatory power of Inter-Vehicle Communication (IVC) simulation is an ongoing research topic in the Car-2-X community. We contribute to this trend by extending the well-established Veins Framework for the OMNeT++ simulator by a multi-channel simulation model for IEEE 1609.4/802.11p enabling simulative studies to fully capture the distinctive properties of the envisioned radio technology. With this effort we help overcome the problem of using general or adjusted MAC/PHY models which could be shown to produce deviating results and thus decrease the validity of IVC simulations.**

***Index Terms*—Veins, OMNeT++, 1609.4, 802.11p, IVC, VANET**

I. Introduction

Inter-Vehicle Communication (IVC), the wireless exchange of information between vehicles, remains a hot topic in current research, as evidenced by the still growing number of dedicated publication venues. The idea of using simulations to better understand IVC systems and to study their performance has become well-established in the community and brings together multiple fields of research: the modeling of realistic vehicular mobility, improved coupled event-driven simulation, the modeling of protocol layers up to new applications, and all the way down to radio propagation and interference.

Attention is currently shifting from questions focusing on the design of isolated components and towards their interaction and performance in more complete systems. The free and open source framework Veins[1] carefully combines and integrates models from their respective domains, allowing for bidirectionally coupled traffic and network simulation [1] using validated physical-layer models for unobstructed [2] and obstructed [3] communication. It can thus provide researchers a solid platform to address these challenges.

The next step in this progress is the simulative representation of the wireless networking stack features of IEEE 1609.4 and IEEE 802.11p, which are unique to IVC. Using general IEEE 802.11 models or adjusting them to use the parameters of IEEE 802.11p has been to shown to produce substantially deviating results in many scenarios [4]. It is therefore highly desirable to use a model that covers features such as alternating access, i.e., periodically switching frequencies, different Enhanced Distributed Channel Access (EDCA) sub systems using both virtual and physical contention, and designated bit rates accompanied by their respective bit error probability.

[1] http://veins.car2x.org/

In this paper, with an additional focus on computational efficiency, we present such a model enabling a simulated Intelligent Transportation System (ITS) to use all of these features. An implementation is available as free and open source software, in the scope of our newly released Veins 2.0 simulation framework.

II. DSRC/WAVE: IEEE 1609 and IEEE 802.11p

Due to the specific characteristics of vehicular mobility (such as short connection times of oncoming vehicles, high relative velocities and possibly unstable connections) an extension to the IEEE 802.11 standard adjusted to IVC was created, published as IEEE 802.11p [5]. These MAC and physical layer specifications are part of a whole protocol stack designed to meet the requirements of vehicular communication, envisioned to establish the basis for an IVC system: the IEEE 1609 WAVE family of standards. Of these, IEEE 1609.4 [6] defines the multi-channel and Quality of Service (QoS) operation of radios; vehicles with a single radio will periodically switch between multiple channels.

III. Implemented Functionality

WAVE is envisioned to operate on different 10 MHz wide, non-overlapping channels. While there is only one Control Channel (CCH) to which every radio must tune for 50 ms in every 100 ms, there are several Service Channels (SCHs) on which a radio can transmit and receive in the remaining 50 ms time slots (synchronous channel switching among all participating vehicles can be supported by GPS data). Furthermore, to counter minor synchronization inexactness and to account for different frequency switching speeds of radios, a 4 ms guard interval at the beginning of every slot is added (cf. Table I).

Finally, each packet is assigned one of four possible Access Categories (ACs) which will affect both the internal *virtual* and the external packet contention as defined in [5], [6].

Table I
Settings for WAVE according to [5]–[7]

Parameter	Value
CCH/SCH slot length − Guard Interval	50 ms − 4 ms
Contention Window aCW_{min} and aCW_{max}	15 and 1023
SlotTime	13 µs
SIFS	32 µs
Bandwidth	3 Mbit/s ... 27 Mbit/s

Table II
CONTENTION PARAMETERS FOR ACS ACCORDING TO [5]

Parameter	AC_BK	AC_BE	AC_VI	AC_VO
CW_{min}	aCW_{min}	aCW_{min}	$\frac{aCW_{min}+1}{2} - 1$	$\frac{aCW_{min}+1}{4} - 1$
CW_{max}	aCW_{max}	aCW_{max}	aCW_{min}	$\frac{aCW_{min}+1}{2} - 1$
AIFSN	9	6	3	2

When a vehicle tries to send multiple packets at once, the MAC layer uses an EDCA scheduling system similar to the one defined in IEEE 802.11e, but instead of having one queue per AC, it has one queue per combination of AC and channel type, which makes a total of eight internal queues, each controlled by one EDCA Function (EDCAF).

The EDCAF controls the back-off counter for each queue as well as the transmission initiation of a packet. A packet can be sent when the back-off counter for its queue is 0 and the physical channel was idle for at least the time of one Arbitration Interframe Space (AIFS); the length of the AIFS can be derived from the AC of a packet, as given in Table II, resulting in packets from higher ACs to have priority access to the channel.

A queue will be put into back-off mode when:

(a) the channel turned busy when the back-off counter was 0
(b) the packet was ready to be sent in the guard interval or a different channel was active
(c) a packet of this queue was transmitted successfully
(d) a higher AC packet was ready to be sent at the same time
(e) the transmission of a packet failed (i.e., no ACK was received)

The back-off time is determined by multiplication of a random number between $[0, CW]$, and the slot length of IEEE 802.11p. The value of CW is left unchanged in cases (a) to (c), and doubled or set to CW_{max}, depending on which value is smaller, in cases (d) and (e). The EDCAF reduces the back-off counter at each slot boundary, i.e., after one AIFS when the channel turned idle and at each passed slot afterwards. We illustrate the interaction of these mechanisms in Figure 1.

Finally, to fully provide a realistic model for vehicular network communication, the OFDM PHY layer needs to be carefully modeled as well. To accurately represent bit error probabilities, we adapt the implemented bit error models to fit real world measurements, namely the ones provided by Fuxjäger et al. [8] and Sjöberg et al. [9] who carried out extensive studies with IEEE 802.11p radios.

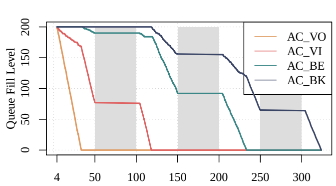

Figure 1. MAC layer queues contending for channel access in the simulation.

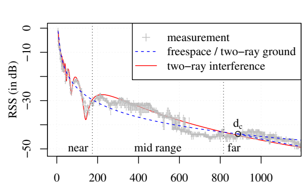

Figure 2. PHY layer threshold calibration against measurements. [2]

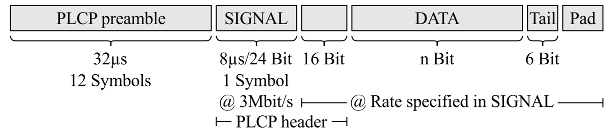

Figure 3. PDU packet format in IEEE 802.11p

We make use of the interference computation in MiXiM [10] to obtain Signal to Noise + Interference Ratio (SNIR) values for incoming packets to decide whether a packet can be decoded or not. To achieve this, we take the exact Protocol Data Unit (PDU) format as visualized in Figure 3 and compute bit error probabilities for header and payload separately. Different data rates for parts of the PLCP signaling and the encapsulated payload are considered and all timings are taken into account to provide a realistic representation of the physical layer. We conducted real life field tests (cf. Figure 2) for model validation and to parameterize sensing thresholds, as well as to check interference and transmission ranges.

IV. CONCLUSION AND FUTURE WORK

The MAC/PHY model presented in this paper includes all discussed features, enabling researchers to simulate their applications and algorithms on the MAC Layer of upcoming IVC hardware. An implementation is available as free and open source software for the OMNeT++ simulator, included in the comprehensive Veins framework for IVC simulation, which can thus be used to arrive at IVC simulations yielding higher explanatory power. Future work includes the support of unicast messages to accommodate comfort IVC applications.

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