Driver Assistance

Technical Report D2400.4.1

Analytical Performance Considerations of 802.11p

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Bernhard Kloiber, Thomas Strang, Fabian de Ponte Müller

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Introduction

Future driver assistance systems such as *Cooperative Adaptive Cruise Control (CACC)* are based on the periodic beaconing of *Cooperative Awareness Messages (CAMs)* from vehicles in the vicinity using the IEEE 802.11p communication technology. 802.11p provides several 10 MHz channels located in the 5,9 GHz frequency band, which have to be shared among all communication participants. The most important one is the control channel (CCH) which is used for the beaconing of CAMs.

In high dense traffic scenarios the number of communication participants might be high enough to cause congested channels, which leads to a dramatic decrease of the communication performance and the reliability of the whole system.

This technical report sums up some analytical performance considerations, based on simplified assumptions. We primarily address *Media Access Control (MAC)* layer issues as they are particularly challenged by a high number of fast mobile nodes. The main target of this preliminary analysis is to set the scope for a comprehensive simulative performance analysis.

The freeway, a challenging reference scenario

Figure 1 shows a possible classification of different scenarios using accident statistics provided by the Statistisches Bundesamt in Germany.

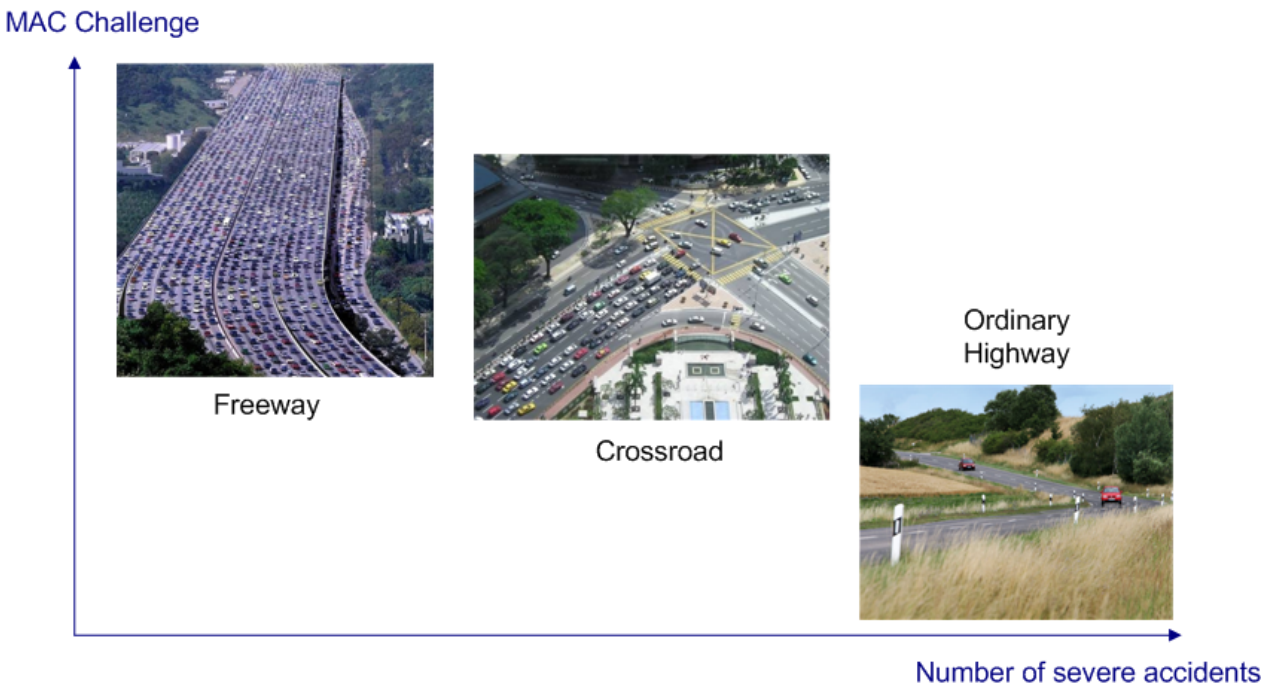

Figure 1: Classification of different scenarios

We will investigate a freeway scenario which seems to be the most challenging one for the communication in Vehicular Ad-hoc NETs (VANETs) in terms of media access. This freeway scenario is described by the following parameters and is the base for the rest of this technical report:

- Number of lanes l in each direction: 6
- Mean time ahead distance t_{AD} (see below) between consecutive cars: 1 s / 2 s
- Communication range r: 1000 m
- CAM size m: 100 Byte / 250 Byte / 500 Byte
- CAM transmission frequency f: 1 Hz / 2 Hz / 10 Hz
- Gross data rate R: 6 Mbps (Default on CCH)
- Slot time t_S: 13 µs
- Mean velocity v: 30 m/s

By using the mean time ahead distance and the mean velocity, the mean distance d between consecutive cars can be calculated:

$$d = v \cdot t_{AD}$$

$$d\big|_{t_{AD}=2s} = 30\frac{m}{s} \cdot 2s = 60m$$

$$d\big|_{t_{AD}=1s} = 30\frac{m}{s} \cdot 1s = 30m$$

As we now know the mean distance, we can calculate the mean number n of cars on the freeway with l lanes per direction within the communication range r:

$$n = \left(2 \cdot \frac{r}{d} + 1\right) \cdot l \cdot 2$$

$$n\big|_{t_{AD}=2s} = 408$$

$$n\big|_{t_{AD}=1s} = 804$$

Simple throughput considerations

For some first throughput considerations, we will neglect the overhead caused by MAC and PHY headers. Further investigations including the MAC/PHY overhead will be shown in the next sections.

Using the possible number of cars within communication range, the different CAM transmission frequencies and CAM packet sizes, the net throughput S can be calculated by the following equation:

$$S = n \cdot m \cdot f$$

For a CAM packet size of 100 Byte, this results in:

$$S\big|_{n=408,\, f=1Hz} = 408 \cdot 100 Byte \cdot 1Hz = 40,8 \frac{KB}{s} = 0,3264 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=2Hz} = 408 \cdot 100 Byte \cdot 2Hz = 81,6 \frac{KB}{s} = 0,6528 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=10Hz} = 408 \cdot 100 Byte \cdot 10Hz = 408 \frac{KB}{s} = 3,264 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=1Hz} = 804 \cdot 100 Byte \cdot 1Hz = 80,4 \frac{KB}{s} = 0,6432 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=2Hz} = 804 \cdot 100 Byte \cdot 2Hz = 160,8 \frac{KB}{s} = 1,2864 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=10Hz} = 804 \cdot 100 Byte \cdot 10Hz = 804 \frac{KB}{s} = 6,432 \frac{Mbit}{s}$$

Considering a CAM packet size of 250 Byte, the results are the following:

$$S\big|_{n=408,\, f=1Hz} = 408 \cdot 250 Byte \cdot 1Hz = 102 \frac{KB}{s} = 0,816 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=2Hz} = 408 \cdot 250 Byte \cdot 2Hz = 204 \frac{KB}{s} = 1,632 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=10Hz} = 408 \cdot 250 Byte \cdot 10Hz = 1020 \frac{KB}{s} = 8,160 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=1Hz} = 804 \cdot 250 Byte \cdot 1Hz = 201 \frac{KB}{s} = 1,608 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=2Hz} = 804 \cdot 250 Byte \cdot 2Hz = 402 \frac{KB}{s} = 3,216 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=10Hz} = 804 \cdot 250 Byte \cdot 10Hz = 2010 \frac{KB}{s} = 16,080 \frac{Mbit}{s}$$

Finally, with a CAM size of 500 Byte we get:

$$S\big|_{n=408,\, f=1Hz} = 408 \cdot 500 Byte \cdot 1Hz = 204 \frac{KB}{s} = 1,632 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=2Hz} = 408 \cdot 500 Byte \cdot 2Hz = 408 \frac{KB}{s} = 3,264 \frac{Mbit}{s}$$

$$S\big|_{n=408,\, f=10Hz} = 408 \cdot 500 Byte \cdot 10Hz = 2040 \frac{KB}{s} = 16,320 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=1Hz} = 804 \cdot 500 Byte \cdot 1Hz = 402 \frac{KB}{s} = 3,216 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=2Hz} = 804 \cdot 500 Byte \cdot 2Hz = 804 \frac{KB}{s} = 6,432 \frac{Mbit}{s}$$

$$S\big|_{n=804,\, f=10Hz} = 408 \cdot 500 Byte \cdot 10Hz = 4020 \frac{KB}{s} = 32,160 \frac{Mbit}{s}$$

Communication overhead

As already mentioned the throughput considerations so far do not include any communication overhead caused by additional MAC and PHY headers or trailers, arbitration and contention procedures.

In Figure 2 the complete MAC frame format is shown. The different header fields sum up to a length of 32 Byte, the trailer contains the 4 Byte frame check sequence. This makes a total of 36 Byte MAC overhead.

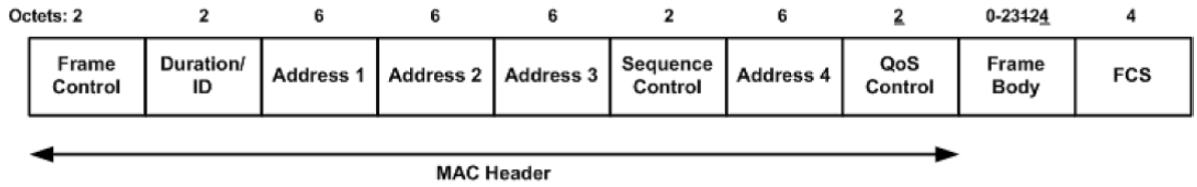

Figure 2: MAC frame format [1]

The PHY frame format is depicted in Figure 3. It starts with 10 short and 2 long preamble symbols, which have in total a duration of 32 µs. The preamble is then followed by one 8 µs OFDM symbol. Additional 2 Byte for service are part of the PHY header as well. For the PHY trailer we have 6 tail bits and some pad bits (which we assumed to be 2 bit), so that this results in 1 Byte for the trailer. Altogether the PHY overhead consists of fixed 40 µs plus 3 Byte transmitted with the chosen data rate (6 Mbps in our case).

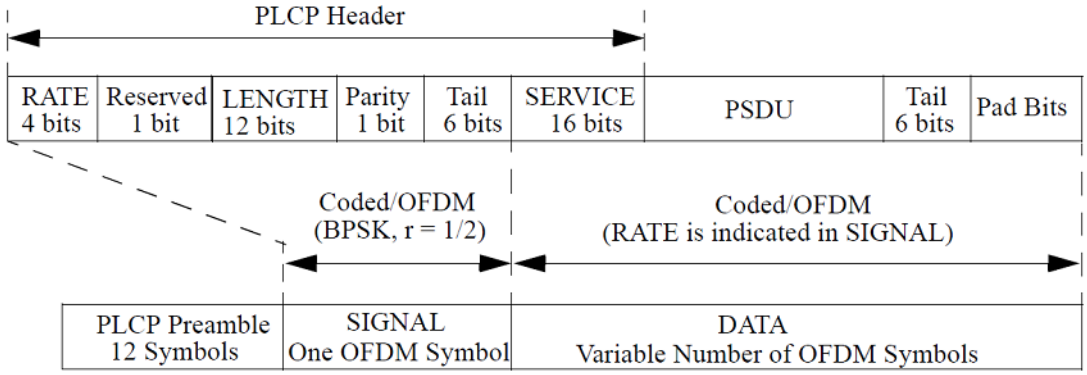

Figure 3: PHY frame format [1]

For arbitration we assume that CAMs are transmitted using the highest AC (Access Category), i.e. they are queued into the AC[VO] (AC VOice) queue. The duration of the AIFS (Arbitration InterFrame Space) for voice traffic (AIFS[VO]) is calculated according to [1] by the following formula:

$$t_{AIFS[VO]} = t_{SIFS} + AIFSN[VO] \cdot t_S = 32\mu s + 2 \cdot 13\mu s = 58\mu s$$

The minimum contention window size CW_{min} for AC[VO] is 4. Because CAMs are broadcast messages, the binary exponential backoff mechanism doesn't work, i.e. the contention window size

stays 4. The backoff counter is randomly chosen out of the interval [0; CW_{min} - 1], consequently the mean backoff counter size is 1,5. This results in a mean contention duration t_C of

$$t_C = 1.5 \cdot t_S = 1.5 \cdot 13\mu s = 19.5\mu s$$

Assuming that there is always contention in high dense scenarios, each node is spending

$$t_{AIFS[VO]} + t_C = 58\mu s + 19,5\mu s = 77,5\mu s$$

per packet for arbitration and contention in average.

Mean channel occupancy

With the additional knowledge about the communication overhead it is then possible to calculate the mean channel occupancy t_{occ} for each message by the following equation:

$$t_{occ} = t_{AIFS[VO]} + t_C + t_{PHY\_preamble} + t_{PHY\_3Mbps} + t_{PHY\_6Mbps} + t_{MAC} + t_{CAM}$$

Using all the assumptions above, we get for the different CAM packet sizes:

$$t_{occ}\Big|_{m=100Byte} = 58\mu s + 19,5\mu s + 32\mu s + 8\mu s + \left(\frac{3Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{36Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{100Byte}{6\frac{Mbit}{s}}\right) = 302,8\mu s$$

$$t_{occ}\Big|_{m=250Byte} = 58\mu s + 19,5\mu s + 32\mu s + 8\mu s + \left(\frac{3Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{36Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{250Byte}{6\frac{Mbit}{s}}\right) = 502,8\mu s$$

$$t_{occ}\Big|_{m=500Byte} = 58\mu s + 19,5\mu s + 32\mu s + 8\mu s + \left(\frac{3Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{36Byte}{6\frac{Mbit}{s}}\right) + \left(\frac{500Byte}{6\frac{Mbit}{s}}\right) = 836,2\mu s$$

Assuming each message occupies the channel for the duration calculated above and the messages arrive in a manner that no collisions occur, then the mean number of possible message transmissions c per second can be calculated by the equation:

$$c = \frac{1}{t_{occ}}$$

For the different CAM message sizes we get as mean number of possible message transmissions:

$$c\Big|_{m=100Byte} = \frac{1}{302,8\mu s} = 3302$$

$$c\Big|_{m=250Byte} = \frac{1}{502,8\mu s} = 1988$$

$$c\Big|_{m=500Byte} = \frac{1}{836,2\mu s} = 1195$$

Mean arrival rate and inter arrival time

Knowing the mean number of cars within the communication range and the CAM transmission frequency, the mean arrival rate can be calculated by the following equation:

$$\lambda = n \cdot f$$

Using the possible number of cars within communication range and the different CAM transmission frequencies we get:

$$\lambda\big|_{n=408,\, f=1Hz} = 408 \cdot 1Hz = 408 \frac{CAMs}{s}$$

$$\lambda\big|_{n=408,\, f=2Hz} = 408 \cdot 2Hz = 816 \frac{CAMs}{s}$$

$$\lambda\big|_{n=408,\, f=10Hz} = 408 \cdot 10Hz = 4080 \frac{CAMs}{s}$$

$$\lambda\big|_{n=804,\, f=1Hz} = 804 \cdot 1Hz = 804 \frac{CAMs}{s}$$

$$\lambda\big|_{n=804,\, f=2Hz} = 804 \cdot 2Hz = 1608 \frac{CAMs}{s}$$

$$\lambda\big|_{n=804,\, f=10Hz} = 804 \cdot 10Hz = 8040 \frac{CAMs}{s}$$

The arrival rate calculations above lead us to the mean inter arrival times $t_{arrival}$ within the communication range between consecutive messages:

$$t_{arrival} = \frac{1}{\lambda}$$

$$t_{arrival}\big|_{n=408,\, f=1Hz} = \frac{1}{408 \frac{CAMs}{s}} = 2,451ms$$

$$t_{arrival}\big|_{n=408,\, f=2Hz} = \frac{1}{816 \frac{CAMs}{s}} = 1,225ms$$

$$t_{arrival}\big|_{n=408,\, f=10Hz} = \frac{1}{4080 \frac{CAMs}{s}} = 0,245ms$$

$$t_{arrival}\big|_{n=804,\, f=1Hz} = \frac{1}{804 \frac{CAMs}{s}} = 1,244ms$$

$$t_{arrival}\big|_{n=804,\, f=2Hz} = \frac{1}{1608 \frac{CAMs}{s}} = 0,622ms$$

$$t_{arrival}\big|_{n=804,\, f=10Hz} = \frac{1}{8040 \frac{CAMs}{s}} = 0,124ms$$

Conclusion

This technical report represents simple performance considerations for IEEE 802.11p by analytical calculations under simplifying assumptions. The main purpose of the analysis was to get a set of indicators to set the scope for a simulative comprehensive analysis the performance of the MAC layer in IEEE 802.11p based VANETs. Considering our freeway reference scenario we calculated the necessary net throughput of the communication channel. We estimated net and gross throughput limits, i.e. with and without the overhead caused by MAC/PHY headers, arbitration and contention procedures. The net results show pure necessary throughputs for perfectly sequentially arriving CAMs. Compared with the gross data rates provided by each 802.11p channel it became obvious, that high dense traffic scenarios can produce such high amount of data traffic that the channel capacity is exceeded. The mean channel occupancy per message shows the amount of time each message occupies the communication channel in average, including also the communication overhead, i.e. MAC/PHY headers and arbitration and contention procedures. Using this information the total amount of CAM transmissions per second can be estimated. The mean arrival rate and inter arrival time of CAMs, dependent on the respective communication scenario, have been calculated as well. In comparison with the mean channel occupancy for high data traffic scenarios, the mean inter arrival time is shorter than the mean channel occupancy of the messages themselves. Our analysis has shown that a simulation environment for high dense traffic scenarios shall be able to support around 400 vehicles in reception range of about 1000m for a typical speed dependent spacing between the vehicles. Each node in the network shall be able to process about 1200 CAM messages of a typical size of 500 byte (signed CAMs). Depending on other factors such as increased beaconing frequency, the simulation parameters might be even more challenging.

List of Acronyms

AC	Access Category
AIFS	Arbitration InterFrame Space
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
FCS	Frame Check Sequence
MAC	Media Access Control
NET	NETwork
OFDM	Orthogonal Frequency Division Multiplexing
PHY	PHYsical
PLCP	Physical Layer Convergence Procedure
QoS	Quality of Service
SIFS	Short InterFrame Space
VO	Voice

References

[1] IEEE Computer Society, "*IEEE Std 802.11-2007 - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*", June 2007