University of Ottawa
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Research seminar

Performance analysis of the EDCA MAC protocol over the CCH of an IEEE 802.11p WAVE network

presented by:

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Outline

• Introduction to IEEE 802.11p WAVE Networks
• Brief description of the Enhanced Distributed Channel Access (EDCA) MAC protocol
• Our proposed model
• Analytical and numerical results
• Summary
IEEE 802.11p WAVE Networks

- **WAVE**: Wireless Access in Vehicular Environments
- Not a standard yet
- Used by IEEE 802.11 devices in the Dedicated Short-Range Communications (DSRC) band, @ 5.9 GHz, allocated for Intelligent Transportation Systems (ITS) communications
- Its purpose is to provide wireless communications between stations on the roadside (RSU) and mobile radio units (OBU), and between OBUs → improve safety and efficiency
IEEE 802.11p WAVE Networks
IEEE 802.11p WAVE Networks

• These communications will happen...
  – over line-of-sight distances of less than 1Km
  – generally involving high-speed vehicles (~120 Kph), and occasionally stopped and slow-moving vehicles

• Transactions must be completed in time frames shorter than the minimum possible with IEEE 802.11 networks

• The reason is standard authentication and association procedures
IEEE 802.11p WAVE Networks

- WAVE networks do not require nodes to follow authentication or association procedures
- Nodes “join” a BSS by being aware of its existence and deciding to participate in it
- Moreover, a WAVE node does not need to join a BSS to communicate
- A node may send/receive data frames in the context of a BSS, or it may send/receive data frames outside the context of a BSS using the wildcard BSSID
IEEE 802.11p WAVE Networks

- WAVE networks operate with a single Control Channel (CCH) and several Service Channels (SCH)

Channels available for IEEE 802.11p
IEEE 802.11p WAVE Networks

• Service Channels (SCH) are used to conduct two-way communications between RSU and OBUs, and between OBUs

• Control Channel (CCH) is used for broadcast transmissions and to establish new communications over SCHs
IEEE 802.11p WAVE Networks

- Time is subdivided into synchronization intervals of 100 ms each
- During the first half of each interval (50 ms) it is mandatory for all stations (OBUs and RSUs) to listen to the CCH, unless they are transmitting
- Therefore, really urgent messages have to be sent over the CCH during the mandatory periods
IEEE 802.11p WAVE Networks

- IEEE 802.11p frames can carry two types of application information: **IP** and **WSMP** (WAVE Short Message Protocol)
- WSMP frames include:
  - WAVE Announcement Frames
  - Beacons, and
  - WSMs carrying safety-related messages
- WAVE Announcement Frames and Beacons are used to broadcast information about services available over SCHs
IEEE 802.11p WAVE Networks

- SCHs can be used for both WSMP and IP frames
- The CCH can only be used for WSMP frames
IEEE 802.11p WAVE Networks

- The most time-critical messages, carrying urgent safety-related information, are transmitted over the control channel (CCH)
  ⇒ If we are interested in the performance of WAVE networks as a way to improve safety, we have to analyze the CCH
IEEE 802.11p WAVE Networks

• Information transmitted over the CCH can have one of several priorities

• The highest priority is given to safety-related urgent messages
  – Information present at RSUs (accidents, obstacles, slippery or damaged roads, broken or missing traffic signs, etc.)
  – Information generated by cars (emergency vehicle approaching, vehicle braking suddenly, with malfunctioning brakes, speeding over a certain limit, or posing any type of risk to other vehicles)
IEEE 802.11p WAVE Networks

- The second highest priority may be given for vehicles to advertise their presence to other vehicles in case visual detection is not possible (e.g. obstacles, uneven terrain, haze, heavy rain, sunshine right in front of eyes, etc.)
- A lower priority may be given to non-urgent messages (e.g. informing that a vehicle needs help because it broke down, ran out of gas, or collided with an obstacle, but poses no risk for other vehicles)
IEEE 802.11p WAVE Networks

- WAVE devices use the Enhanced Distributed Channel Access (EDCA) MAC protocol to orderly gain access to the transmission medium.
- EDCA is a contention-based protocol, evolved from the Distributed Coordination Function (DCF) also known as CSMA/CA.
Distributed Coordination Function (DCF)

- Carrier-sense multiple access, collision avoidance (CSMA/CA):
  - Sense the medium
  - If it is not free, select a random backoff count
  - Count down whenever medium is idle
  - Transmit when count is zero
  - If collision, start again, select backoff from a larger interval
Enhanced Distributed Channel Access (EDCA)

- Time to sense the medium shorter for higher “priority”
- Random backoff interval smaller for higher “priority”
Enhanced Distributed Channel Access (EDCA)

- In IEEE 802.11p, the following parameters are used

<table>
<thead>
<tr>
<th>AC (Priority)</th>
<th>CWmin</th>
<th>AIFS N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ↓</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3 ↑</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ \text{AIFS } [\text{AC}] = \text{SIFS} + \text{AIFS N}[\text{AC}] \cdot \text{SlotTime} \]
DCF Markov model
Our proposed model

• Key features to consider:
  – Transmissions on CCH are *broadcast*
  – There is no way to know if a frame transmission is successful or not
  – Several priorities, each with different time to sense the medium and selecting backoff count from different intervals
  – We want to model the system at different traffic-load levels, not just at saturation
EDCA-CCH for highest priority

τ₃ = Probability that station of priority 3 transmits on current cycle

τ₃ = b₀
$\tau_2 = \text{Probability that station of priority 2 transmits on current cycle}$

$\tau_2 = b_0$

$\pi_i = \text{Probability that no stations of priority } i \text{ or higher transmit on current cycle}$
EDCA-CCH for lowest priority

\[ \pi_i = \text{Probability that no stations of priority } i \text{ or higher transmit on current cycle} \]
Throughput calculation

- We solve the Markov equations for $b_0$
- The probabilities $\tau_1$, $\tau_2$, $\tau_3$, are found iteratively using successive approximations
- With these values, we calculate:

$$P_{tx,i} = 1 - (1 - \tau_i)^{N_i}$$

$$P_{s,i} = \frac{1}{P_{tx,i}} N_i \cdot \tau_i \cdot (1 - \tau_i)^{N_i - 1} \prod_{j=1}^{3} (1 - \tau_j)^{N_j}$$

$$S_i = \frac{P_{tx,i} \cdot P_{s,i} \cdot E[P]}{E[\text{cycle}]}$$
Frame-error-rate calculation

• We also obtain:

\[ P_{coll,i} = 1 - (1 - \tau_i)^{N_i-1} \prod_{\substack{j=1 \,\text{to} \,3 \,\text{if} \,i \neq j}} \left(1 - \tau_j\right)^{N_j} \]
Frame-service-time calculation

• To calculate the service time of the frame at the HOQ for priorities 2 and 3, we have:

\[ E[X_i] = E[n_{x,i}] \cdot E[\text{cycle}] + T_s \]

\[ E[n_{x,3}] = \frac{1}{CW_3+1} \left[ \frac{(CW_3+1) \cdot CW_3}{2} \right] = \frac{CW_3}{2} \]

\[ E[n_{x,2}] = \frac{1}{CW_2+1} \left[ 2 + E[n] \right] + \]

\[ \frac{1}{CW_2+1} \left[ (3 + E[m]) \pi_2 + (4 + E[m] + E[n])(1 - \pi_2) \right] + \]

\[ \frac{1}{CW_2+1} \left[ (4 + E[\ell]) \pi_2^2 + (5 + E[\ell] + E[n]) \pi_2 (1 - \pi_2) + (5 + E[\ell] + E[m])(1 - \pi_2) \pi_2 + (6 + E[\ell] + E[m] + E[n])(1 - \pi_2)^2 \right] \]
Buffer occupancy calculation

• For the highest priority, we also obtain (G/G/1 queuing model):

\[
E[N_{\text{buff}}] = \frac{E[Y^2] + E[Y] - 2 \cdot E^2[Y]}{2 \cdot (1 - E[Y])}
\]

where:

\( Y = \) Number of frames that arrive during the service time of the frame currently being serviced
Frame delay calculation

- To calculate the total frame delay, we use Little’s theorem:

\[
E[D] = \frac{E[N_{\text{buff}}]}{\lambda_{\text{eff}}}
\]
Numerical analysis

• Different scenarios were analyzed:
  – One high-priority station generating different traffic loads
  – A varying number of high-priority stations, each generating a constant amount of traffic (10%)
  – A fixed number of high-priority stations (5) and a varying number of lower-priority stations, each generating a constant amount of traffic (10%)
Numerical results: throughput

- One high-priority station, different traffic loads
Numerical results: throughput

- A varying number of high-priority stations
Numerical results: throughput

- A varying number of lower-priority stations
Numerical results: frame-error rate

• One high-priority station, different traffic loads

No losses!!!
Numerical results: frame-error rate

• A varying number of high-priority stations

![Graph showing frame-error rate (FER3) with varying number of high-priority stations (n3).]
Numerical results: frame-error rate

- A varying number of lower-priority stations
Numerical results: delay

- One high-priority station, different traffic loads
Numerical results: delay

- A varying number of high-priority stations
Numerical results: delay

- A varying number of lower-priority stations
Summary

• We have proposed a model for EDCA on the CCH of a WAVE environment, based on discrete-time Markov chains
• Our model captures the fact that EDCA can establish priorities among stations
• The model can vary the traffic generated per station
• We present results related to throughput, losses, buffer occupancy and delays, all of which are very important QoS metrics
Summary

• The main differences between this work and what is already available in the literature are:
  – That in our case there are no unreasonable simplifying assumptions
  – That the protocol priorities are very explicitly modeled
  – That traffic load can be varied
  – That the total frame delay is calculated, and not only the service time when the frame is already at the head of the queue
Thank you..?