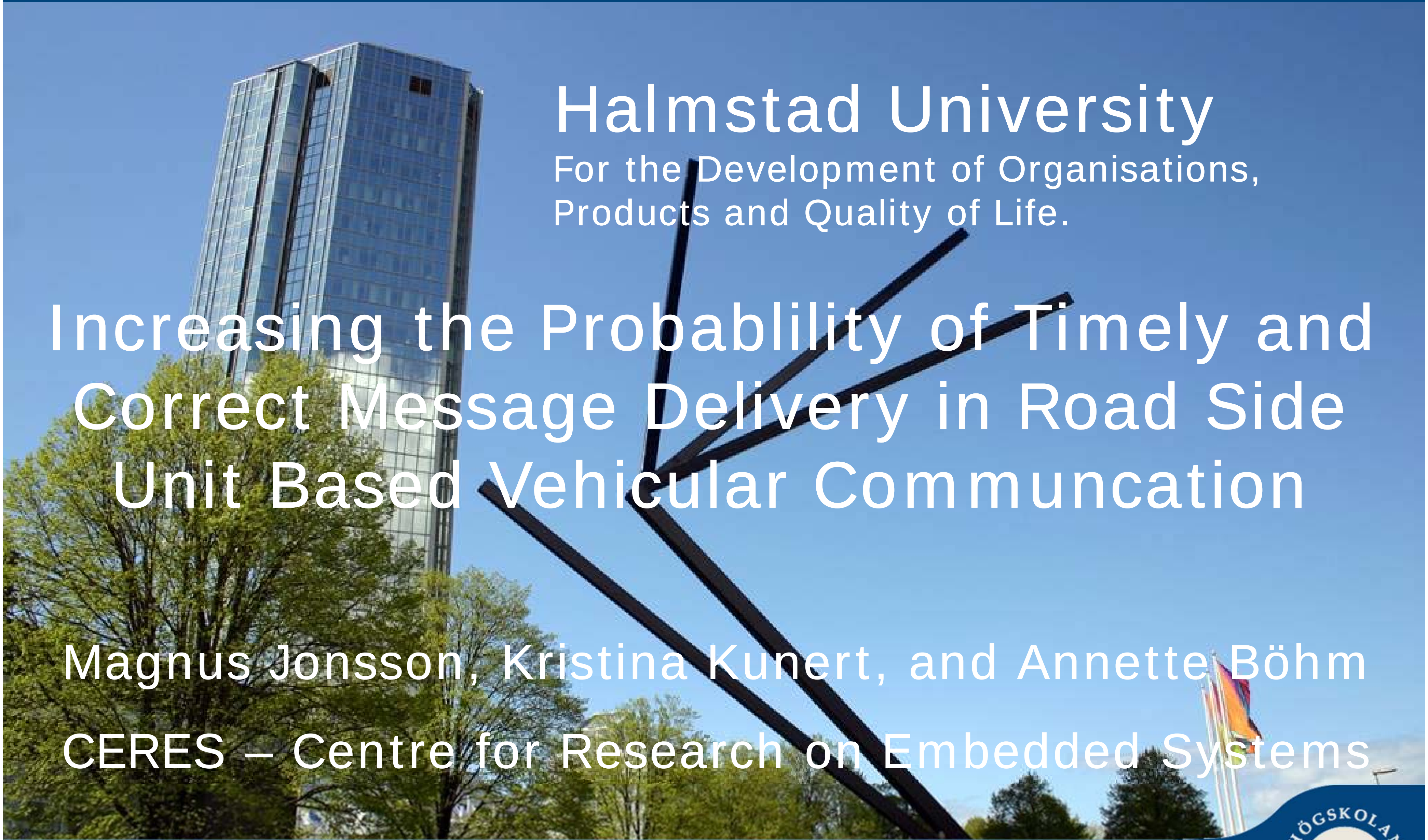


Halmstad University

For the Development of Organisations, Products and Quality of Life.

Increasing the Probablility of Timely and Correct Message Delivery in Road Side Unit Based Vehicular Communcation

Magnus Jonsson, Kristina Kunert, and Annette Böhm

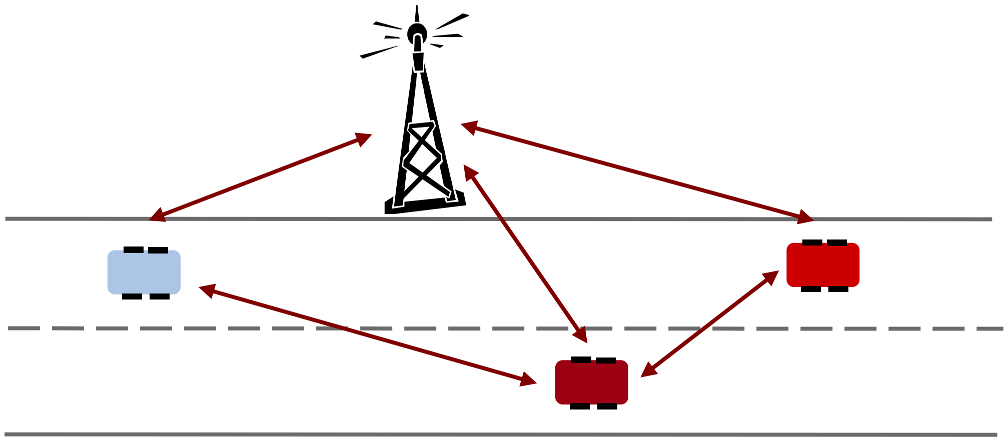
CERES – Centre for Research on Embedded Systems

The Presentation is Based on the Following Published Paper

Jonsson, M., K. Kunert, and A. Böhm, "Increasing the probability of timely and correct message delivery in road side unit based vehicular communication," *Proc. 15th IEEE Intelligent Transportation Systems Conference (ITSC 2012)*, Anchorage, AK, USA, Sept. 16-19, 2012.

Inter-vehicle communication

- Vehicle-to-vehicle (V2V)
- **Vehicle-to-Infrastructure (V2I)**
  - Road Side Unit (RSU)
  - Sparsely spaced

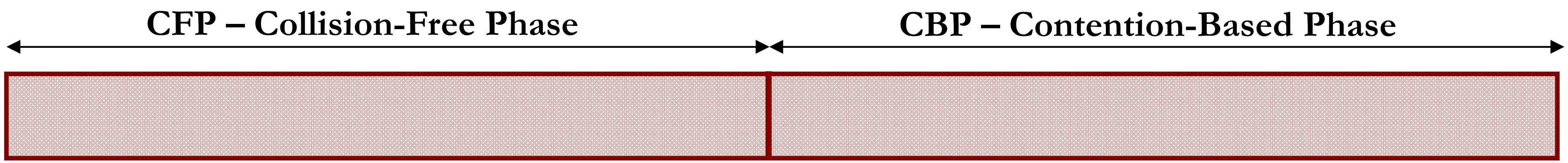


Contributions/Features

- Adding deterministic real-time communication
- Adding the possibility of (limited) retransmissions
- Still meeting deadlines
- Real-time analysis to calculate on the performance for different traffic scenarios

- The packet error rate can be considerably decreased, depending on the traffic scenario

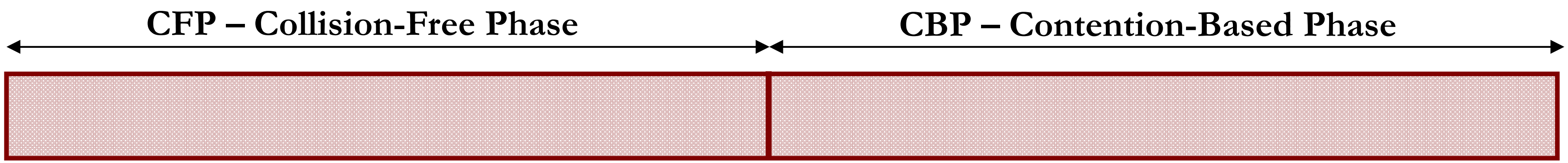
Reintroducing the collision-free phase to 802.11p



- Safety-critical real-time data
- Guaranteed delivery before deadline

- Non-safety-critical data
- Best-effort data delivery

Reintroducing the collision-free phase to 802.11p



- Master-slave scheme on top of IEEE 802.11p
- The RSU acts as master

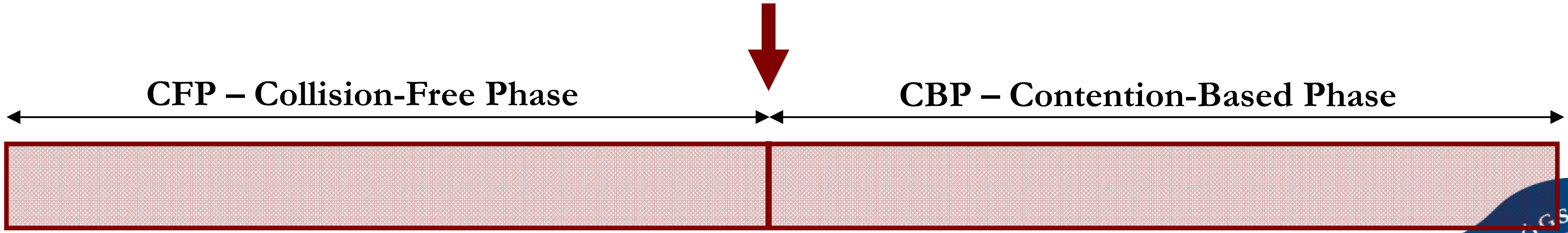
- Poll + data packet, or
- Data packet + ACK

- Pure IEEE 802.11p

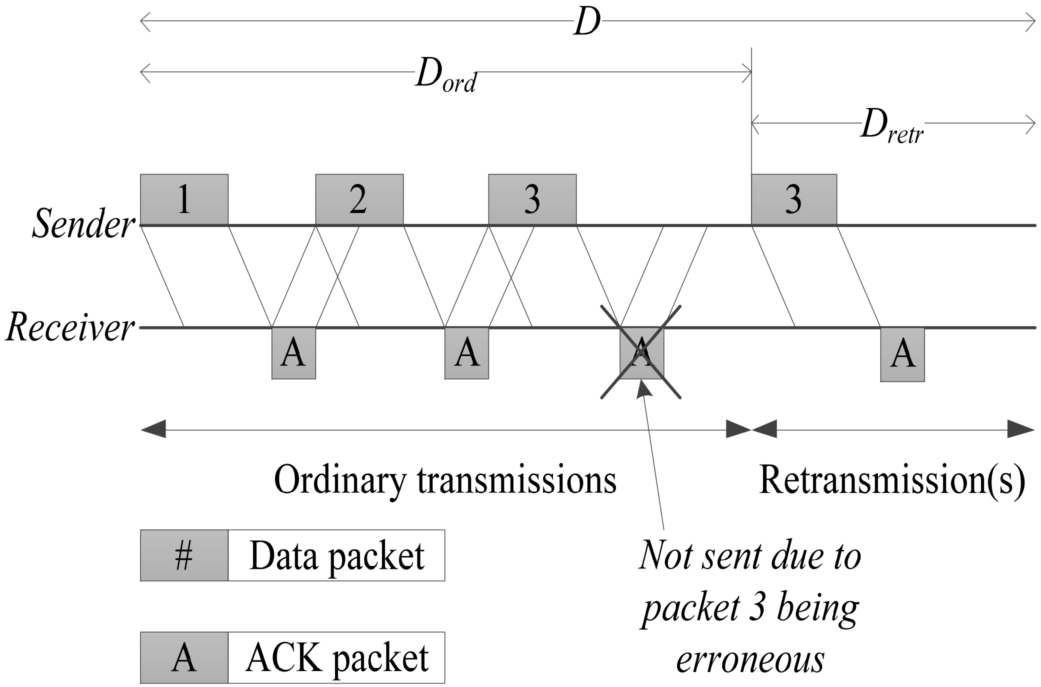
- Can be used for, e.g.:
  - connection-setup
  - Packets from non-connected vehicles

Real-time layer above 802.11p MAC layer

- Number of vehicles and their communication requirements known by the RSU
- Packets are scheduled in the RSU (master) according to EDF (Earliest Deadline First)
- **Real-time (RT) feasibility analysis**
  - RT channels defined by sending node, receiving node, period, maximum packet length and relative deadline: $\tau_i = \{S_i, R_i, P_i, L_i, D_i\}$
  - Determine if all RT channels are able to meet their deadlines



Retransmission scheme



- Divide the delay bound into two parts: one for ordinary transmissions, one for retransmission(s): $D_i = D_{ord,\, i} + D_{retr,\, i}$
- Introduce additional RT-channels for retransmissions:

$$\tau_{retr,i} = \{S_{retr,i}, R_{retr,i,}, P_{retr,i}, L_{retr,i}, D_{retr,i}\}$$

Real-Time Feasibility Analysis – Introduction

Two steps:

- Utilization check

$$U = \sum_{i=1}^{Q} \frac{E_i}{P_i}, \quad U \le 1$$

- Workload check

$$h(t) = \sum_{i=1}^{Q} \left(1 + \left\lfloor \frac{t - D'_i}{P_i} \right\rfloor \right) \cdot E_i ,$$

$$h(t) \le t$$

P_i period
D'_i adapted deadline
E_i experienced transm. time
Q number of channels

Adaptations to the RT analysis

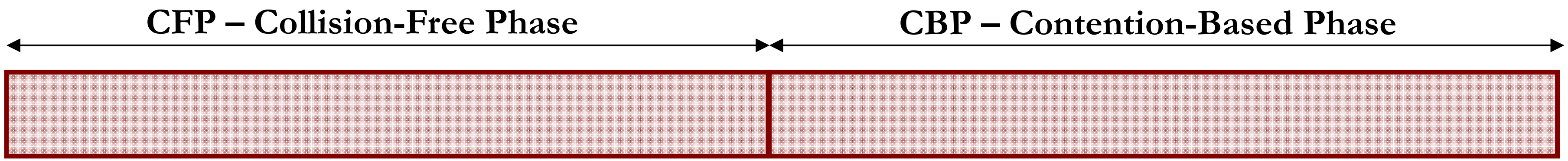
- RSU schedules both ordinary and retransmission RT channels, both I2V and V2I (initiated by a polling packet from the RSU)

$T_{wait\_poll,i}$: *V2I transmission*
$T_{wait\_data,i}$: *I2V transmission*
$T_{wait\_retr\_poll,i}$: *V2I retransm.*
$T_{wait\_retr\_data,i}$: *I2V retransm.*

$$T_{wait\_poll,i} = T_{procRSU} + T_{AIFS} + T_{poll} + T_{prop} + T_{procV} + T_{AIFS} + T_{data,i} + T_{prop} + T_{procRSU\_CRC} + T_{margin}$$

$$T_{wait\_data,i} = T_{procRSU} + T_{AIFS} + T_{data,i} + T_{prop} + T_{procV\_CRC} + T_{AIFS} + T_{ACK} + T_{prop} + T_{procRSU} + T_{margin}$$

RT analysis (cont.)



$$T_{CFP*} = T_{CFP} - T_{blocking}.$$

$$T_{blocking} = \max\left\{\max_i\left\{T_{wait\_poll,i}\right\}, \max_i\left\{T_{wait\_data,i}\right\}\right\}.$$

$$r^e = r \cdot \frac{T_{CFP*}}{T_{SF}}.$$

$$T^e_{wait_{poll},i} = T_{wait_{poll},i} \cdot \frac{T_{SF}}{T_{CFP*}}$$

RT analysis (cont.)

- Utilization check including both ordinary and retransmission RT channels

$$U = \sum_{i=1}^{\alpha}\left(\frac{T^{e}_{wait\_poll,i}}{P_i}\right) + \sum_{i=1}^{\beta}\left(\frac{T^{e}_{wait\_data,i}}{P_i}\right) + \sum_{i=1}^{\gamma}\left(\frac{T^{e}_{wait\_retr\_poll,i}}{P_{re,i}}\right) + \sum_{i=1}^{\delta}\left(\frac{T^{e}_{wait\_retr\_data,i}}{P_{re,i}}\right)$$

Adaptations to the RT analysis

- Worst case queuing delay for ordinary transmissions

$$d_{ordI2V} = D_{ord,i} - T_{CBP} - T_{wait\_data,i} - \max\left\{T_{wait\_data,i}, T_{wait\_poll,i}\right\}$$

$$d_{ordV2I} = D_{ord,i} - T_{CBP} - T_{wait\_poll,i} - \max\left\{T_{wait\_data,i}, T_{wait\_poll,i}\right\}$$

Adaptations to the RT analysis

- Worst case queuing delay for retransmissions
- Retransmission deadline is divided into deadline for the actual retransmission RT channel depending on number of allowed retransmission attempts

$$D_{re} = \frac{D_{retr}}{N_{attempt}}.$$

$$d_{retrI2V} = D_{re} - T_{CBP} - T_{wait\_data,i} - \max\left\{T_{wait\_data,i}, T_{wait\_poll,i}\right\}$$

$$d_{retrV2I} = D_{re} - T_{CBP} - T_{wait\_poll,i} - \max\left\{T_{wait\_data,i}, T_{wait\_poll,i}\right\}$$

Adaptations to the RT analysis

- Workload function including both ordinary and retransmission RT channels

$$h(t) = \sum_{\substack{i \in [1,\alpha], \\ d_{ordV2I,i} \le t}} \left(1 + \left\lfloor \frac{t - d_{ordV2I,i}}{P_i} \right\rfloor \right) \cdot T^e_{wait\_poll,i} +$$

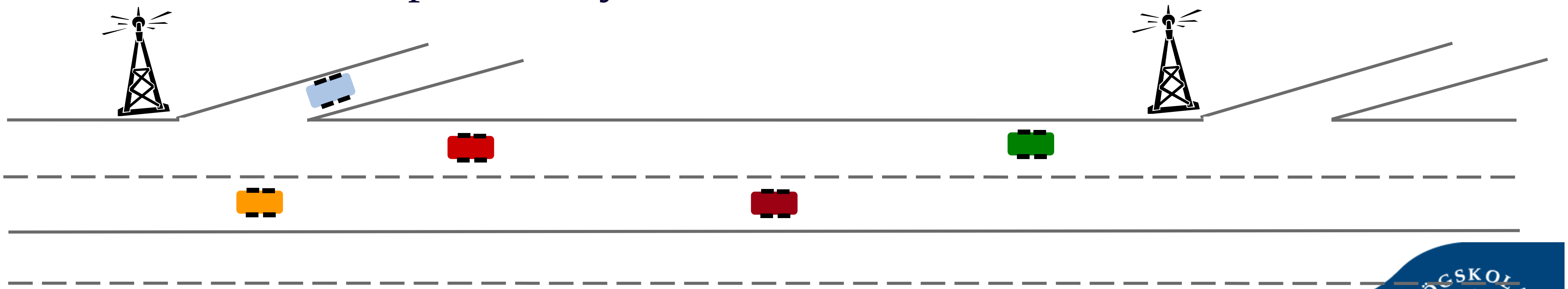
$$\sum_{\substack{i \in [1,\beta], \\ d_{ordI2V,i} \le t}} \left(1 + \left\lfloor \frac{t - d_{ordI2V,i}}{P_i} \right\rfloor \right) \cdot T^e_{wait\_data,i} +$$

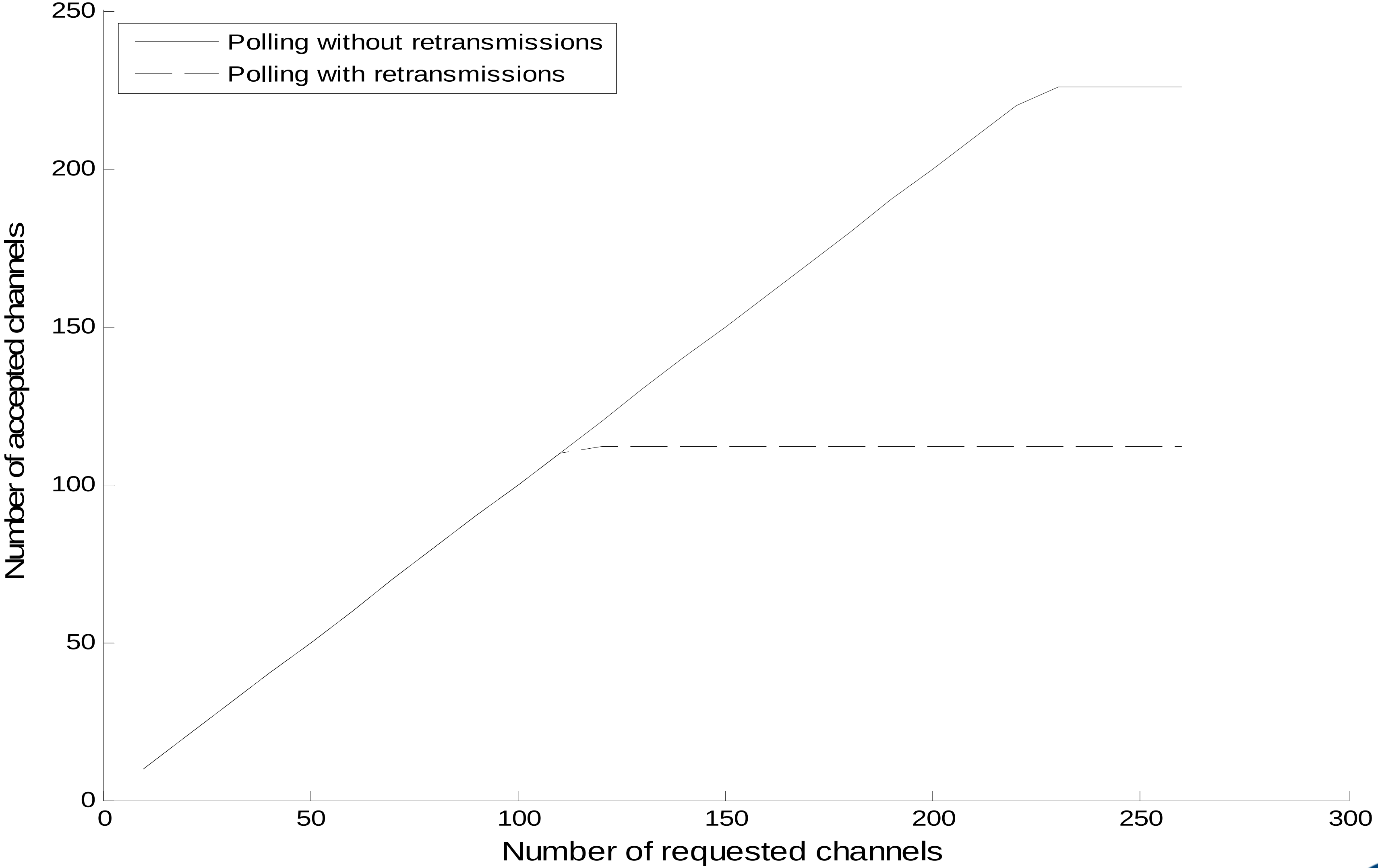
$$\sum_{\substack{i \in [1,\gamma], \\ d_{retrV2I,i} \le t}} \left(1 + \left\lfloor \frac{t - d_{retrV2I,i}}{P_{re,i}} \right\rfloor \right) \cdot T^e_{wait\_retr\_poll,i} +$$

$$\sum_{\substack{i \in [1,\delta], \\ d_{retrI2V,i} \le t}} \left(1 + \left\lfloor \frac{t - d_{retrI2V,i}}{P_{re,i}} \right\rfloor \right) \cdot T^e_{wait\_retr\_data,i}$$

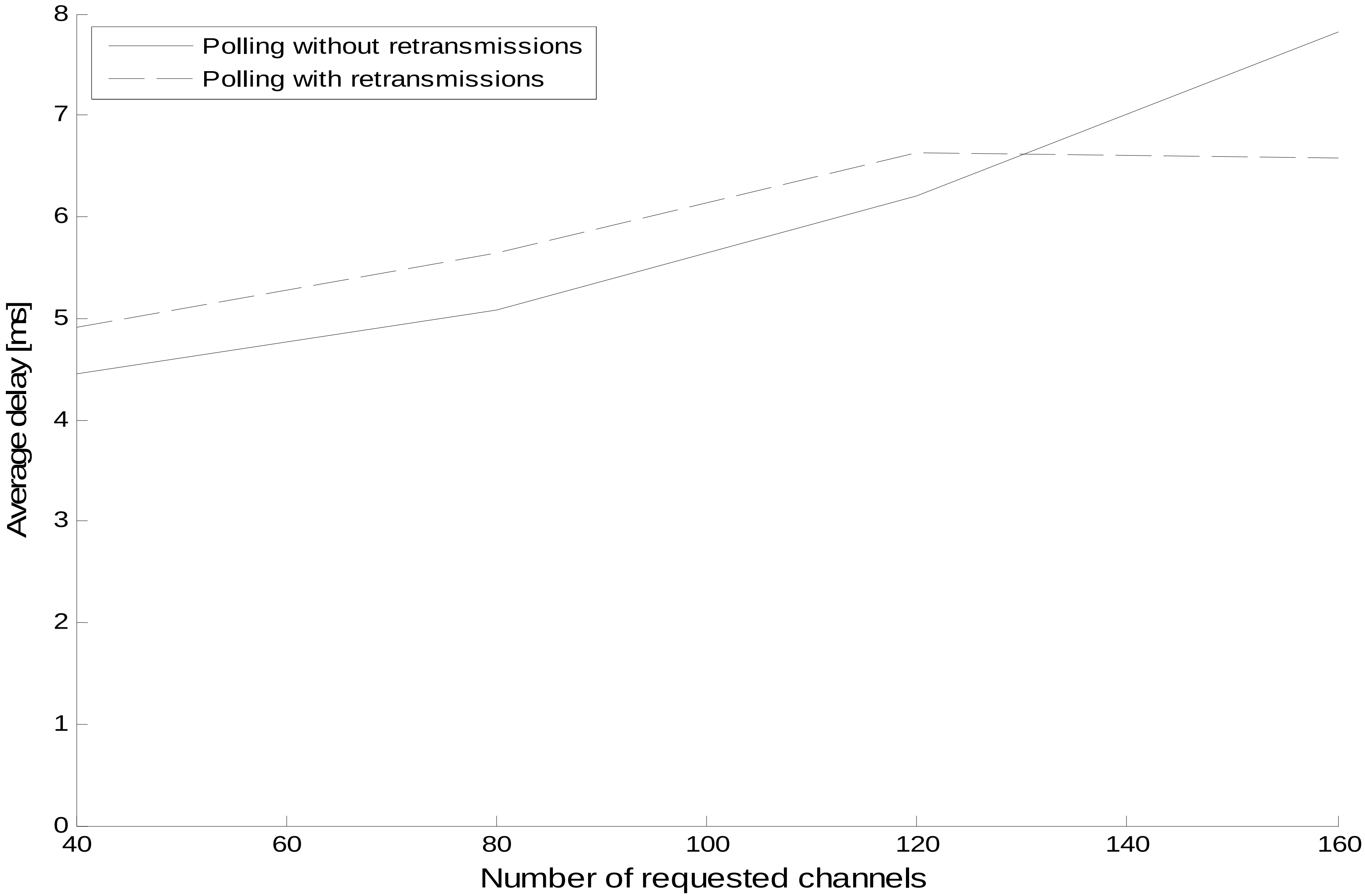
Simulation results

- **Merge Assistance Scenario**
  - RSU as central node controlling medium access for passing vehicles
- **Simulation details**
  - Period: 2Hz
  - Max number of allowed retransmission attempts: 3
  - Number of available retransmission RT channels: 20
  - Packet error probability: 0.1

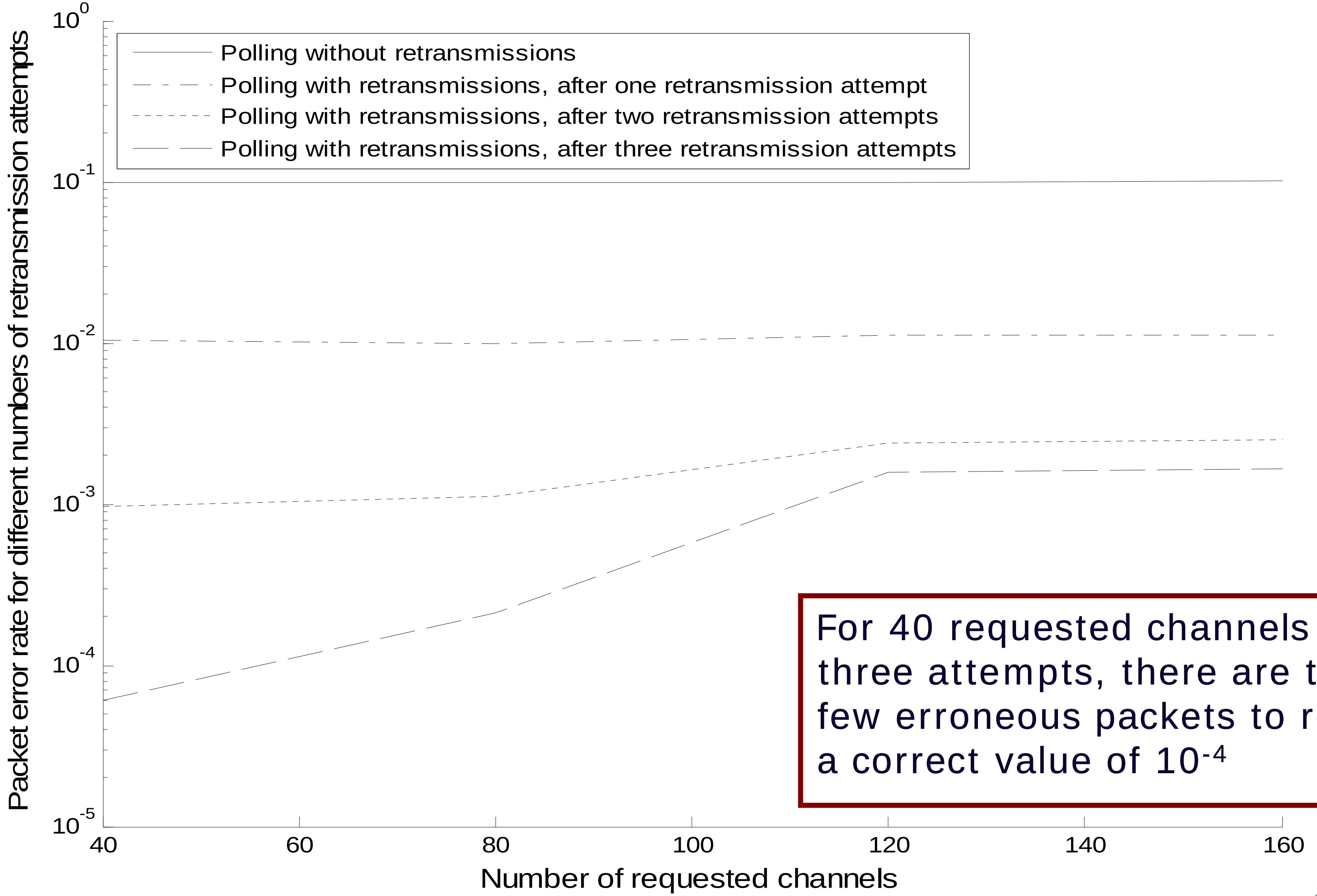




Polling without retransmissions
Polling with retransmissions
Number of accepted channels
Number of requested channels
0
50
100
150
200
250
300

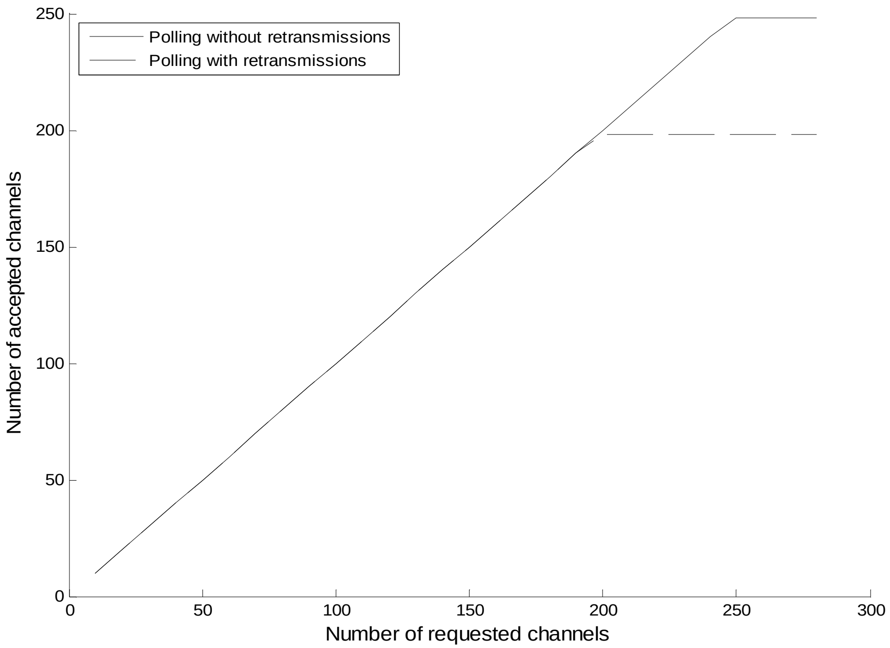


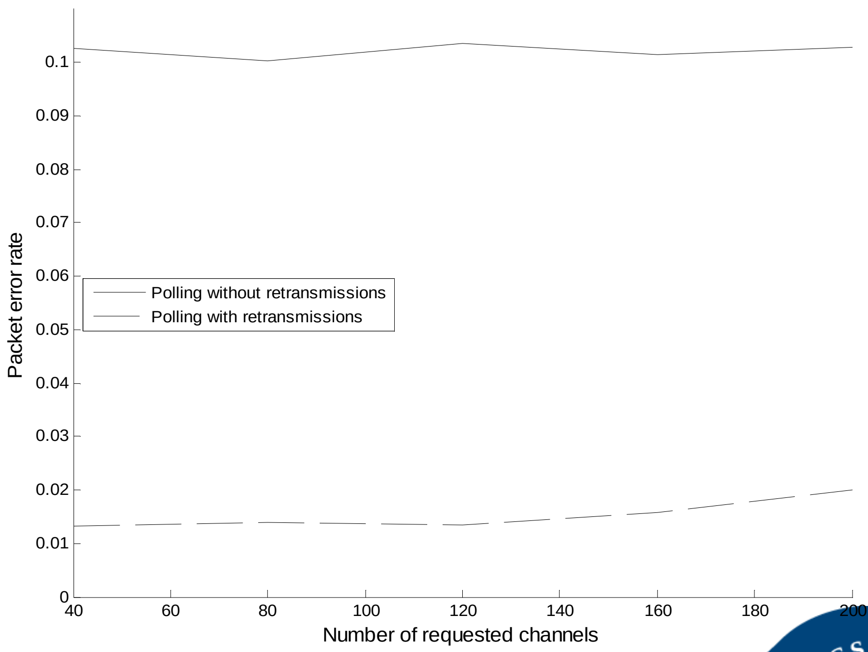
Polling without retransmissions
Polling with retransmissions
Average delay [ms]
Number of requested channels
0
1
2
3
4
5
6
7
8
40
60
80
100
120
140
160



For 40 requested channels and three attempts, there are too few erroneous packets to reach a correct value of 10^{-4}

- Merge Assistance Scenario with priority zones
  - the send frequency of vehicles in the three different zones are set to 1, 2, and 5 Hz
  - Max number of allowed retransmission attempts: 1
  - Number of available retransmission RT channels: 20





Conclusion

Supporting reliable real-time traffic for safety-critical proactive ITS safety applications through:

- Introduction of RT layer on top of IEEE 802.11p MAC
- Introducing a retransmission scheme

- Real-time guarantees for both ordinary transmissions and retransmissions are offered, decreasing the PER by several orders of magnitude.