APNOMS' 2017

Scalable TDMA Cluster-based MAC (STCM) for Multichannel Vehicular Networks

September 27, 2017

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Outline

- Introduction
- Background and Related Work
- The Scalable TDMA Cluster-Based MAC (STCM)
- Performance Evaluation
- Conclusions
- References

Introduction:
Motivation (1/4)

- **Intelligent Transportation Systems (ITS) provides :**
  - Time-critical safety applications
    - accident avoidance and mitigation of road intersection collision
  - Traffic efficiency
    - current road traffic data, ITS service advertisement
  - Infotainment applications
    - tourism and shopping information
- **Requirements of Vehicular Communication:**
  - Safety applications
    - High reliability/high packet delivery ratio
    - Strict delay constraints (100 ms)
    - High security
  - Non-safety applications
    - High throughput
- **Current Standards & Technologies for the MAC and PHY layer:**
  - IEEE 1609.4. (CSMA/CA)
  - IEEE 802.11p

Introduction:
Challenges (2/4)

- **Major Challenges of channel access mechanism:**
  - **Poor utilization of control channel interval (CCHI) and service channel interval (SCHI) (fixed value)**
    - In a congested vehicular traffic, the limited length of CCHI is unable to provide sufficient bandwidth for safety messages
    - In case of less safety message, CCHI is not fully used
    - Similarity for the service channel interval (SCHI) for Non-safety message exchanges
  - **Poor utilization of multichannel access method**
    - During the CCHI, all SCHs are not used
    - During the SCHI, CCH is not used
  - **Underutilization of Multichannel**
    - Unused default allocation time for data exchange, both in low/heavy traffic density

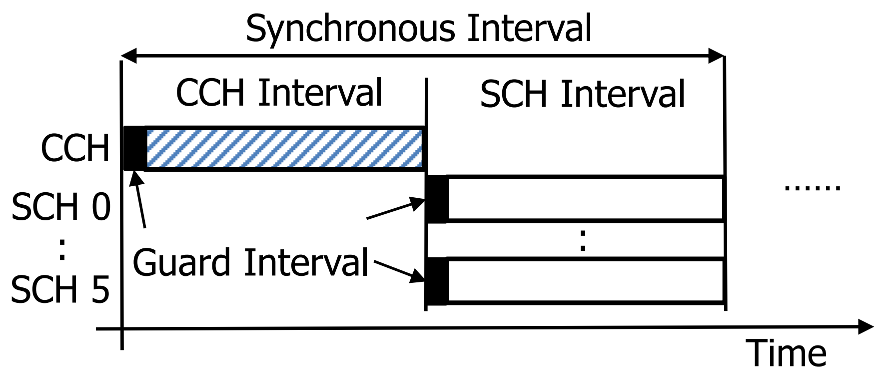

Fig. 1. Multichannel access mechanism in IEEE 1609.4.

Introduction:
Contributions (3/4)

- **The major contributions of this paper: *Scalable TDMA Cluster-based MAC (STCM)***
  - The U.S. Department of Transportation (DOT) and the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications 2 (VSC2) Consortium have proposed a new deployment option –
    - CH 178 is left for the exchange of management information only, including *WAVE Service Advertisements* (*WSAs*)
    - CH 172 is dedicated to V2V *Basic Safety Messages (BSMs)*

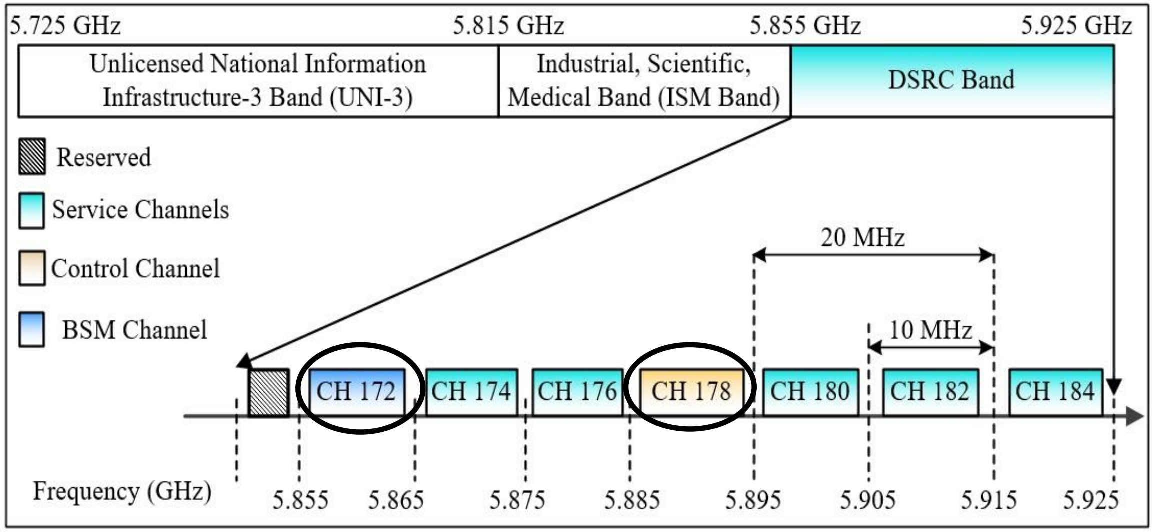

Fig. 2. Frequency spectrum allocation in the DSRC

Introduction:
Contributions (4/4)

- **The major contributions of this paper (cont.): *Scalable TDMA Cluster-based MAC (STCM)***
  1) Two mini-slots from two different channels for every vehicle in each synchronous interval (in 100ms)
     - Two dedicated CCHs to serve more vehicles
     - Increase collision-free channel access
  2) Dynamic reallocations of unused SCH slots
     - Enhance bandwidth utilization of the service channels (SCHs)
  2) Balanced slot allocations
     - Provide fairness by equal sharing of the wireless medium

- **K. Bilstrup et al. [8], [9]- a decentralized scheme called self-organizing TDMA (STDMA)**
  - vehicles can select the time slot in a logical frame based on the position information
    - However, the presence of hidden terminals seriously affects the performance
    - In the high vehicle density, there are more overlap in time slots

Background and Related Work

The TC-MAC [6][7]

- Integrates the centralized approach of cluster management and a new scheme for TDMA slot reservation
- Delivery of safety messages within reasonable time constraints
- Less collisions and packet drops in the SCHs

Limitation of The TC-MAC

- At light traffic load of vehicles, the ratio of missing safety/update messages is up to 50%
- Even in heavy traffic there is some missing at least 4% of safety packets
- TC-MAC only allocates default SCH slot, so the utilization of SCH slots is limited up to 50% depending on the traffic load of vehicles
- Both CCH and SCHs provide low throughput and poor utilization of channels.
- It does not expect all vehicles in the cluster to be communicating, or active, simultaneously.

Scalable TDMA Cluster-Based MAC (STCM) (1/8)

- **TDMA Cluster-Based MAC algorithm provides:**
  - Collision free channel access for both CCH and SCHs
  - Reducing of hidden terminal problem
  - Increasing safety message reliability
  - Fairness of accessing the channels
  - Efficient use of multichannel

- **Assumptions:**
  - Vehicles are equipped with GPS
  - Single transceiver in On Board Unit (OBU)
  - Two CCHs + Five SCHs
  - Fixed SCH slot size (t)
  - Fixed CCH mini-slot size ($t/nSCH$) [nSCH = Number of SCH]
  - Each vehicle in the cluster will receive a local ID (from 0 to N)
  - The cluster head (CH) always have ID 1
  - The ID 0 is reserved for “new entering vehicle”

Scalable TDMA Cluster-Based MAC (STCM) (2/8)

◆ Maximum Network Size of the VANETs:

- 4- Lane in each direction
- Inter-vehicle distance : 7.5 meters (including vehicle length) (if we consider high dense)
- RF- signal range: 300 meters
- Number of vehicles per lane = $^{300}/_{7.5} = 40$ vehicles
- Total 8 Lane 320 vehicles in 300 meter range
- Therefore, at least around 300 vehicles should be handled

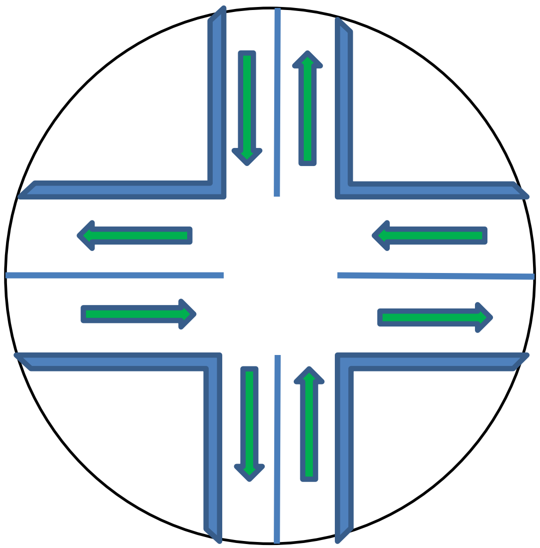

Fig. 3. A four-way intersection

Scalable TDMA Cluster-Based MAC (STCM) (3/8)

◆ Algorithm 1. Allocation of default CCH mini-slots and SCH slot

Algorithm 1. **Allocation of mini-slots and slot by the vehicles**

```
// id: vehicle ID from 0 to N_max
// nSCH: number of service channels
// N_max : maximum number of vehicles in a logical frame
// K: parameters for determining the position of mini-slots
// L: parameters for determining the position of mini-slots
// M[i]: parameters for determining the position of mini-slots
// miniSlot: number of mini-slots in a CCH slot
// CCHSlot: slot number where CCH mini-slot contains
// BSMSlot: slot number where BSMCH mini-slot contains
// CCH_1: BSMCH (CH 172) selection
//CCH_2: CCH (CH 178) selection
// SCHSlot: slot number of SCHs
// SCHch: channel number among the five SCHs

for id = 0 to N_max do
   K = id%(2 × nSCH)
   for i = 1 to 2 do
     miniSlot[i] = id%nSCH
     if i == 1 then
        M[i] = id/(2 × nSCH)
     else
        if K < nSCH then
          M[i] = (id − K + 2 × nSCH − 1)/(2 × nSCH)
        else
          M[i] = (id − K + 3 × nSCH − 1)/(2 × nSCH)
        end if
     end if
     L = ⌊M[i]⌋ + 0.5
     if (i == 1 AND M[i] < L) OR
        (i == 2 AND M[i] ≤ L )then
          CCHSlot[i] = (2 × ⌊M[i]⌋ − (nSCH/2 + 1)%⌊N_max/nSCH⌋
      if (i == 1) then
          Assign CCH_1 (CH 172)
      else
          Assign CCH_2 (CH 178)
      end if
     else
        CCHSlot[i] = (2 × ⌊M[i]⌋ − nSCH/2)%⌊N_max/nSCH⌋
        if (i == 1) then
           Assign CCH_1 (CH 172)
        else
           Assign CCH_2 (CH 178)
        end if
      end if
   end for
   SCHSlot = ⌊id/nSCH⌋
   SCHChannel = id% nSCH
end for
```

Scalable TDMA Cluster-Based MAC (STCM) (4/8)

◆ STCM default slot reservation:

- On the CCHs, Vehicle with ID 0 assigns –
  - Two CCH mini-slots –
    - $miniSlot_1 = id \,\%\, nSCH = 0$
    - $CCHSlot_1 = \left(2 \times \lfloor \mathrm{M[i]} \rfloor - \frac{\mathrm{nSCH}}{2} + 1\right) \% \lfloor N_{max}/\mathrm{nSCH} \rfloor$
      $= 57 = Slot\ 57$
  - pair1$(CCH_1, CCHSlot_1, miniSlot_1)$
    $= (CH\ 172, 57, 0)$
    - $miniSlot_2 = id \,\%\, nSCH = 0$
    - $CCHSlot_2 = (2 \times \lfloor \mathrm{M[i]} \rfloor + 1 - \mathrm{nSCH}/2) \% \lfloor N_{max}/\mathrm{nSCH} \rfloor$
      $= 58 = Slot\ 58$
  - pair2 $(CCH_2, CCHSlot_2, miniSlot_2)$
    $= (CH\ 178, 58, 0)$
- On the SCH, Vehicle with ID 0 assigns –
  - One SCH slot –
    - $SCHSlot = \lfloor id/nSCH \rfloor = 0 = Slot\ 0$
    - $\mathrm{SCHChannel} = \mathrm{id}\% \ \mathrm{nSCH} = 0 = \mathrm{SCH}\ 0$

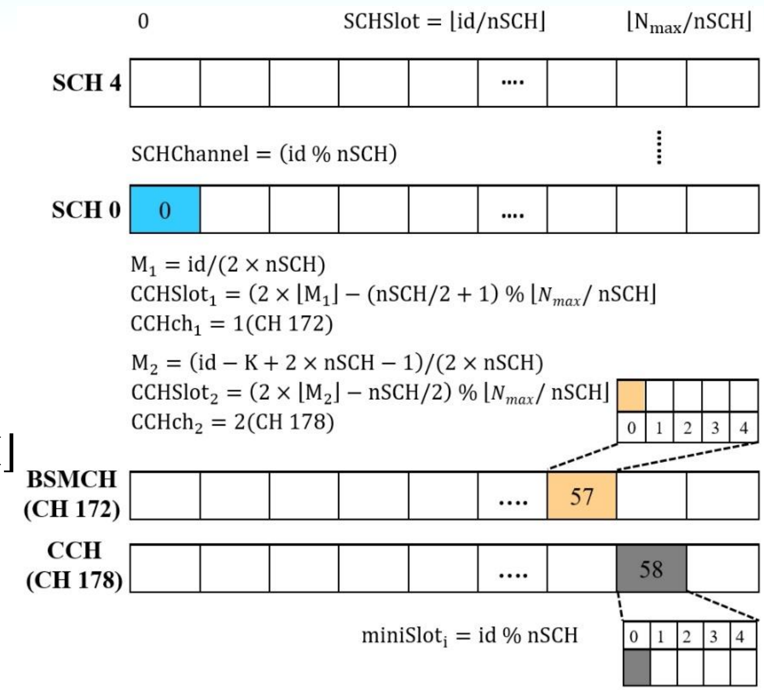

Fig. 4. TDMA frame structure of ETCM.
Example: Vehicle ID 0

Scalable TDMA Cluster-Based MAC (STCM) (5/8)

◆ STCM default slot reservation:

	TDMA MAC FRAME (100 ms)												
Channel/Slot	**Slot0**	**Slot1**	**Slot2**	**Slot3**	**Slot4**	**Slot5**	**Slot6**	**Slot7**	**Slot8**	**...**	**Slot57**	**Slot58**	**Slot59**
SCH4	4(1)	9(~~1~~)D	14(1)	19(0)B	24(0)	29(0)	34(0)	39(0)	44(0)	...	289	294	299
SCH3	3(1)	8(1)	13(~~1~~)F	18(0)[13(1)]F	23(0)	28(0)	33(0)	38(0)	43(0)	...	288	293	298
SCH2	2(1)	7(1)E	12(1)	17(0)[9(1)]D	22(0)	27(0)	32(0)	37(0)	42(0)	...	287	292	297
SCH1	1(1)	6(1)C	11(1)	16(0) [6(2)]	21(0)	26(0) [6(3)]	31(0)	36(0) [6(4)]	41(0)	...	286	291	296
SCH0	0(1)	5(1)A	10(1)	15(0) [5(2)]	20(0)	25(0) [5(3)]	30(0)	35(0) [5(4)]	40(0)	...	285	290	295
BSMCH (CH 172)	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**		**...**	**0-4**	**5-9**	**10-14**
CCH (CH 178)	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**		**...**	**295-299**	**0-4**	**5-9**

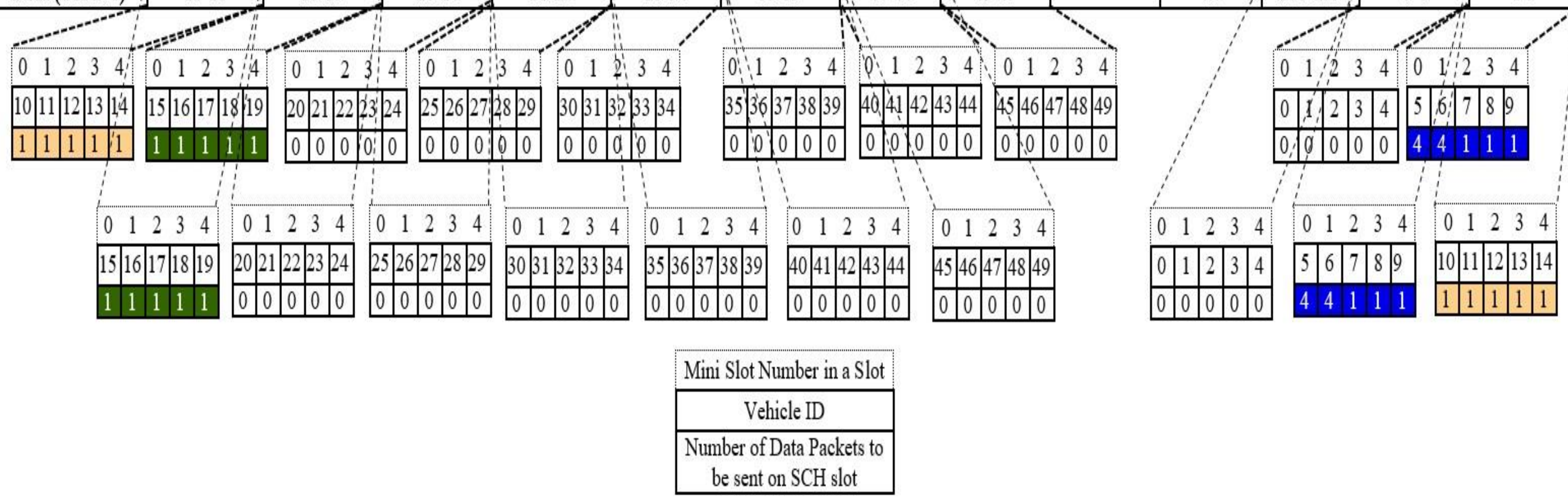

Fig. 5. TDMA map of STCM protocol ($N = 45$, $nSCH = 5$, $nCCH = 2$.)

Scalable TDMA Cluster-Based MAC (STCM) (6/8)

◆ Non-safety Message Exchanges in STCM –

- Before sending the non-safety messages, handshake messages are exchanged through the CCH mini-slots of the sender

- Different scenarios should be considered –
  - Vehicles, V_A [ID 5, SCH slot $(SCHch, SCHSlot) = (0, 1)$] and V_B [ID 19, SCH slot $(SCHch, SCHSlot) = (4, 3)$]
    - SCH slots of vehicle V_A and V_B are on different position and not consecutive
    - Vehicle V_A can use both V_A and V_B default slots without any problem

  - Vehicles, V_C [ID 6, SCH slot $(SCHch, SCHSlot) = (1, 1)$] and V_D [ID 9, SCH slot $(SCHch, SCHSlot) = (4, 1)$]
    - SCH slots of V_C and V_D are on same slot but on different SCHs channels
    - vehicle V_c can only use only its default SCH slot

  - Vehicles, V_E [ID 7, SCH slot $(SCHch, SCHSlot) = (2, 1)$] and V_F [ID 13, SCH slot $(SCHch, SCHSlot) = (3, 2)$]
    - vehicle V_E could not use two consecutive SCH slots
    - Using two consecutive SCH slots creates missing of safety/update messages

Scalable TDMA Cluster-Based MAC (STCM) (7/8)

Reallocation of unused STCM Slot –

- Assume, three vehicles V_X, V_Y, and V_Z belong to the even number position time slot and require $2, 3$ and 0 SCH slots, respectively.
- In STCM, the Shortest Job First (SJF) algorithm is used to give the prioritization to reallocate the empty SCH slots by a station.
- According to SJF, the vehicle V_X gets the permission from V_Z to use the upcoming SCH slot of vehicle V_Z at the second cycle
- If two or more vehicles have requested for the same number of SCH slots, then the priority will be given to a vehicle with the smaller ID

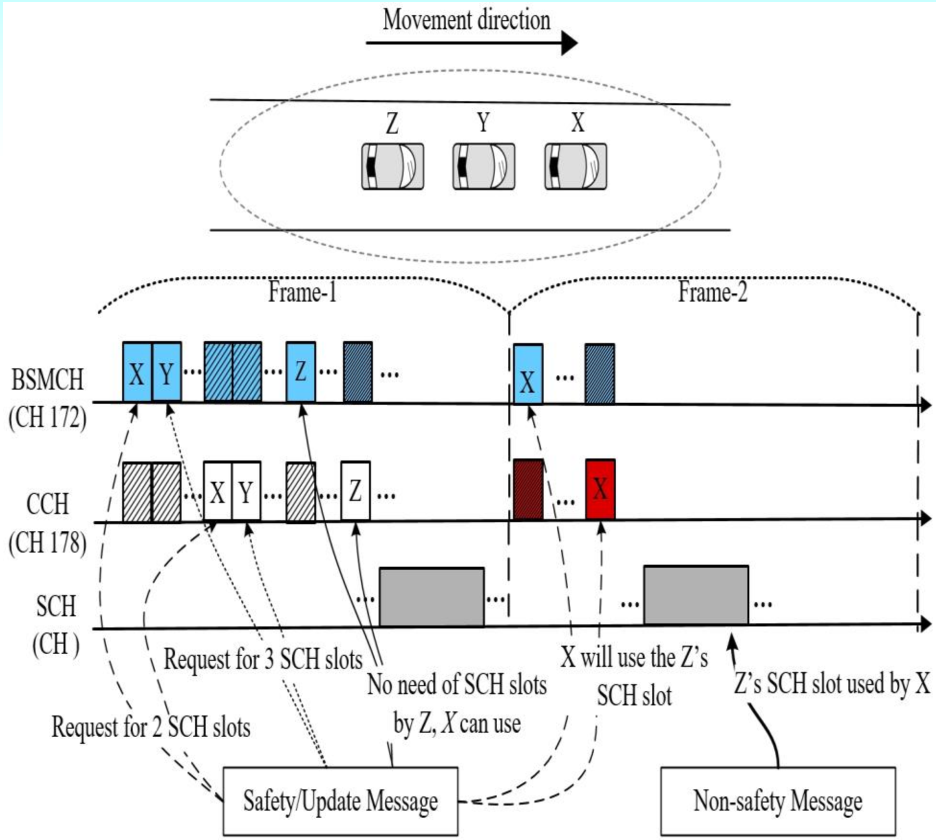

Fig. 6. Sequence Diagram for reallocating of SCH slot

Scalable TDMA Cluster-Based MAC (STCM) (8/8)

◆ Reallocation of unused STCM Slot (cont.) –

- Vehicles those use even number position time slots can use only empty SCH slots at the even position.
- Similarly, vehicles using odd slots can only access the odd number position SCHs slots
- As shown in Fig.3, when vehicle V_5 has many non-safety packets while vehicles V_{15}, V_{25}, V_{35} do not have any packet.
  - Vehicle 6 that listens the status information of vehicles V_{15}, V_{25}, V_{35} from the CCH mini-slots
  - Broadcasts required SCH slot information through update message to all vehicles.
  - The three vehicles then apply SJF algorithm to make the priority among requested vehicles
  - At the next cycle, they give confirmation through their mini-slots regarding default SCHs slots
  - Vehicle 6 broadcasts along with reallocating information to the receiver
  - It makes the receiver to tune to SCH slots of vehicles $V_{15}, V_{25}, V_{35} \ldots$ and to prevent access of those slots from others

Performance Evaluation (1/3)

Simulation Configuration

- ns-3.22 simulator [12]
- Intelligent Driver Model (IDM) and the MOBIL lane change model [13][14]
- single RF transceiver
- frame size is 100 ms for all protocols
- safety/update messages have the bounded delay of 100 ms

TABLE I. DENSITY LEVELS IN THE HIGHWAY (COMMUNICATION RANGE 300 METERS)

Density Level	Number of Vehicles per Lane	Vehicles Gap (m)	Number of Vehicles (2 lanes)	Number of Vehicles (3 lanes)
Low	10	30	40	60
Medium	20	15	80	120
High	30	10	120	180
Very High	40	7.5	160	240

TABLE II. Simulation Parameters

Parameter	Value
Physical rate of each channel	6 Mbps
Number of CCH ($nSCH$)	1
Number of SCHs ($nCCH$)	6
Safety/update Size (MAC payload)	200 bytes
Non-safety Size (MAC payload)	1024 bytes
Transmission Range	300 m
Frame Size	100 ms
Simulation time	500 s
IEEE 1609.4 WAVE [1]	
CCH interval	50 ms
SCH interval	50 ms
Minimum contention window (CW_{min})	3
Maximum contention window (CW_{max})	15
Slot duration	9 μs
SIFS	16 μs
TC-MAC [6] [7]	
Mini Slot Size	0.263 ms
SCH Slot Size	1.5 ms
Total Number of SCH Slot in a Frame	378 slots
STDMA [8][9]	
Minimum number of candidate slots	5 slots
Slot reservation duration	600 ms
Guard Interval (GI)	30 μs
STCM	
Mini Slot Size	0.301 ms
SCH Slot Size	1.625 ms
Total Number of SCH Slot in a Frame	300 slots
Guard Interval (GI)	30 μs
Inter Frame Gap (IG)	700 μs

Performance Evaluation (2/3)

◆ Packet Delivery Ratio (PDR) and Average End-to-End Delay

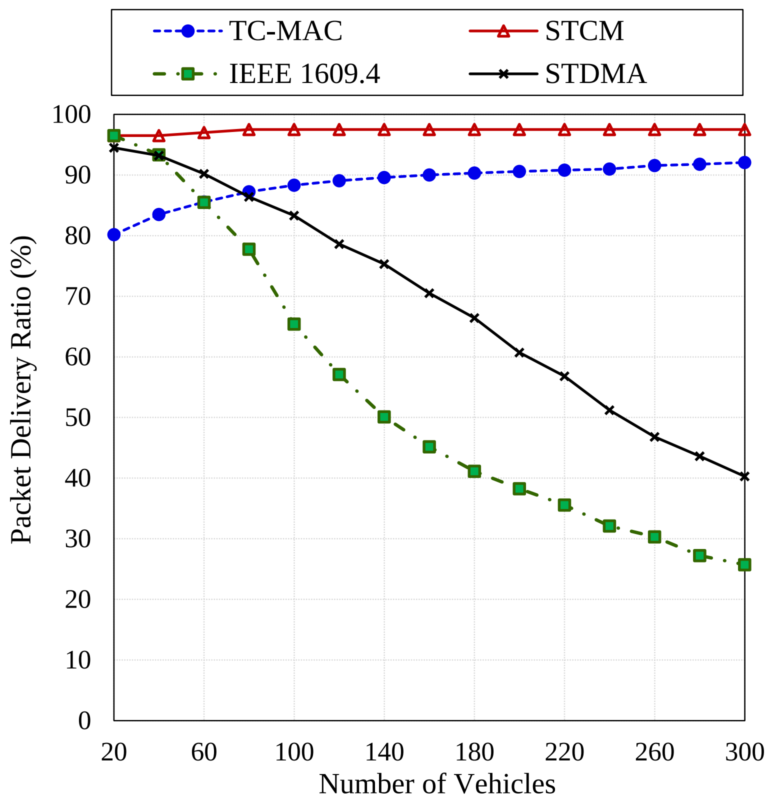

Fig. 7. Packet Delivery Ratio (PDR) of the safety messages

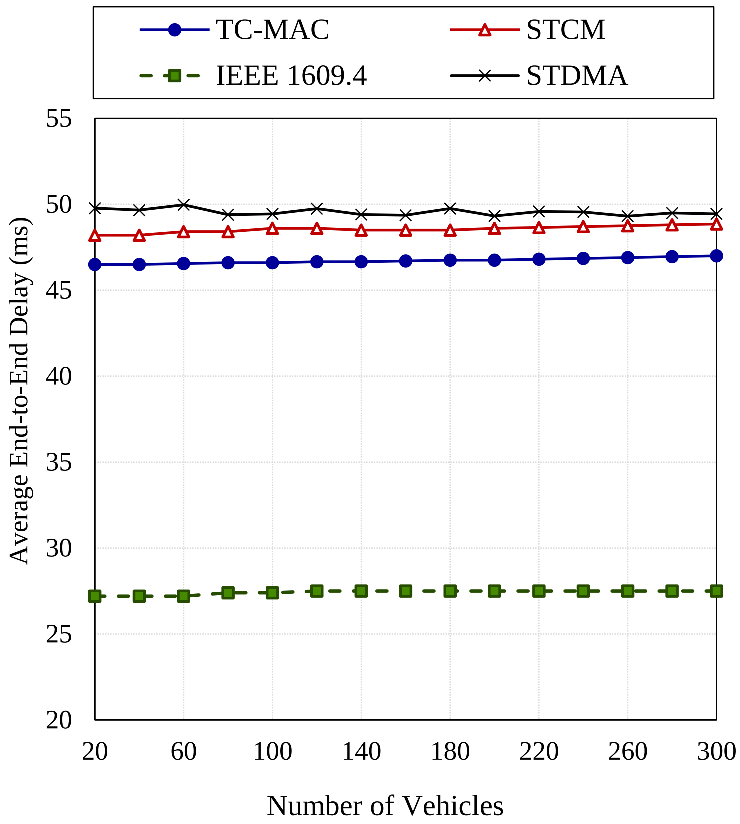

Fig. 8. Average End-to-End Delay of the safety messages

Performance Evaluation (3/3)

- **Average Throughput of the Non-safety messages and Channel Utilization of the SCHs**

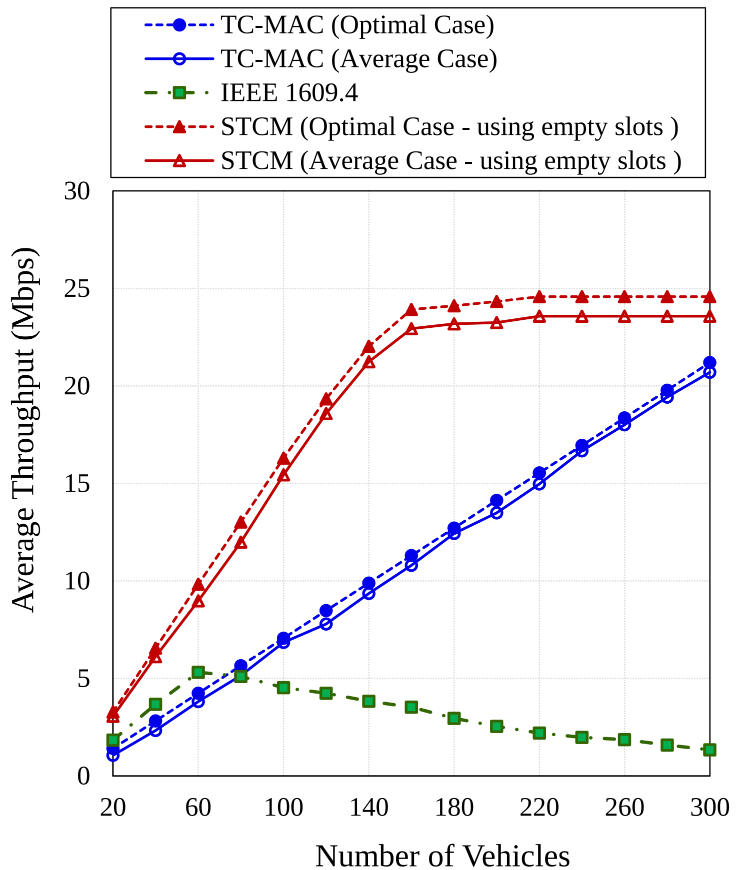

Fig. 9. Average Throughput of the non-safety message

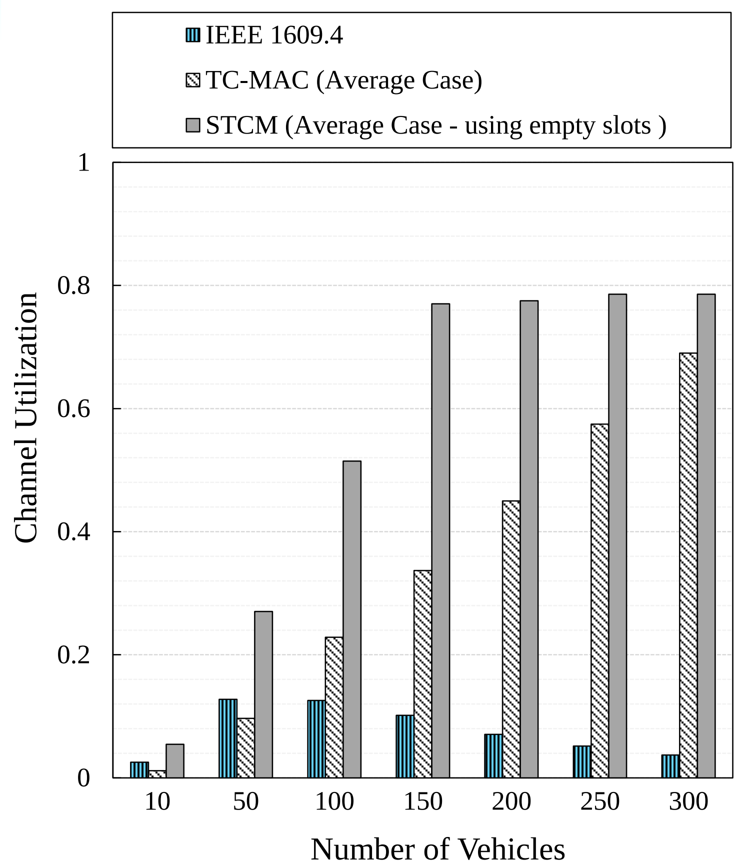

Fig. 10. Channel Utilization of the SCHs

Conclusions and Future works

- **We proposed Scalable TDMA cluster-based MAC (STCM) :**
  1) **Enhanced performance with collision-free channel access and reliable time-critical safety message**
     - two mini-slots for each vehicle in each 100ms sync interval
  2) **Enhanced service channel utilization**
     - dynamic reallocation of unused slots
  3) **Increased fairness among vehicles**
     - balanced slot allocations

- **Simulation results show that:**
  - the packet delivery ratio of safety messages was greatly enhanced with 97% delivery
  - throughput (channel utilization) was improved on average 90% more than TC-MAC

- **Future Works:**
  - Dual-radio vehicular transceivers
  - Multi-rate and Multihop

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Thanks

Questions?