Analysis and Design of Effective and Low-Overhead Transmission Power Control for VANETs

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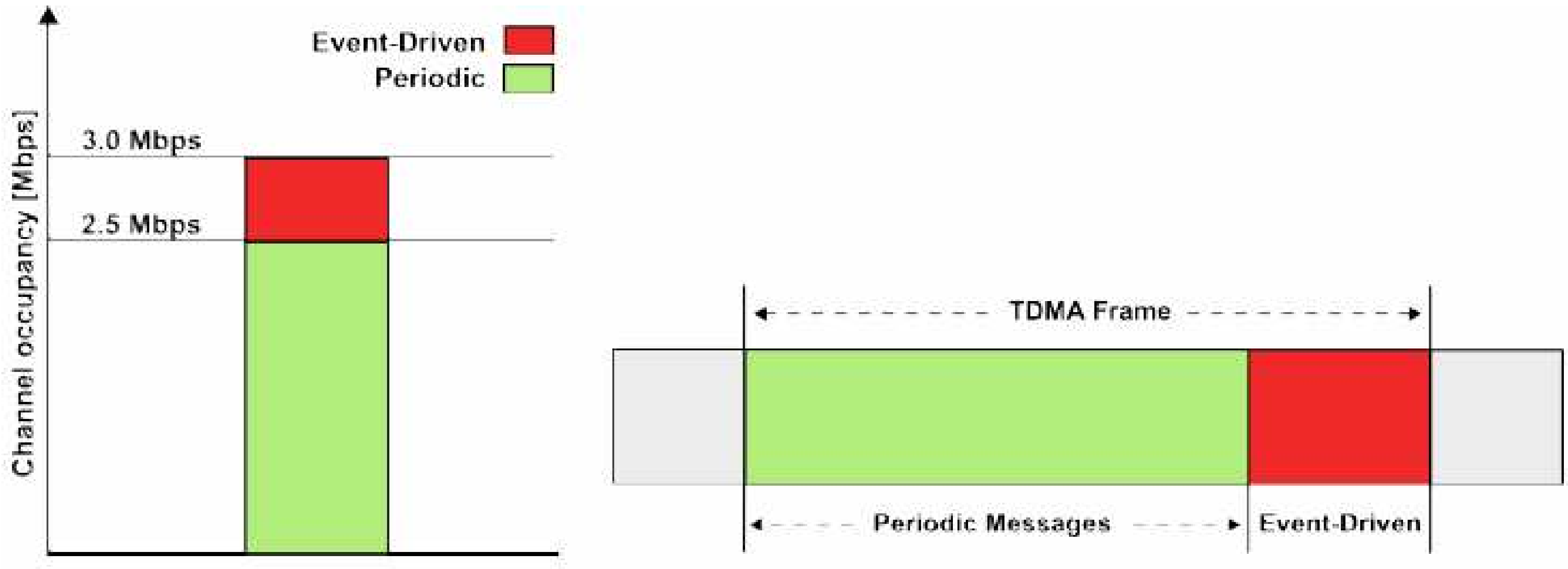
INTRODUCTION

- In VANETs, we use the control of vehicles' radio communication behavior to deal with the constrained available wireless bandwidth.

- For traffic safety, each vehicle will send out
  - One-hop beacons for mutual awareness.
  - Event-driven emergence messages (multi-hop) when hazardous situation is detected.

- TDMA-based approach would reserve specific slots for emergency messages.



Density (vehicles/km/lane)	Transmission Power			
	20 dBm	15 dBm	10 dBm	5 dBm
25	10.18 Mbps	7.64 Mbps	5.73 Mbps	3.46 Mbps
22	8.95 Mbps	6.72 Mbps	5.04 Mbps	3.04 Mbps
16	6.51 Mbps	4.89 Mbps	3.67 Mbps	2.21 Mbps
11	4.48 Mbps	3.36 Mbps	2.52 Mbps	1.52 Mbps
7	2.85 Mbps	2.14 Mbps	1.60 Mbps	0.97 Mbps

default power

- We need to adjust the transmission power dynamically in order to adapt to different traffic situations and efficiently exhaust the available bandwidth.

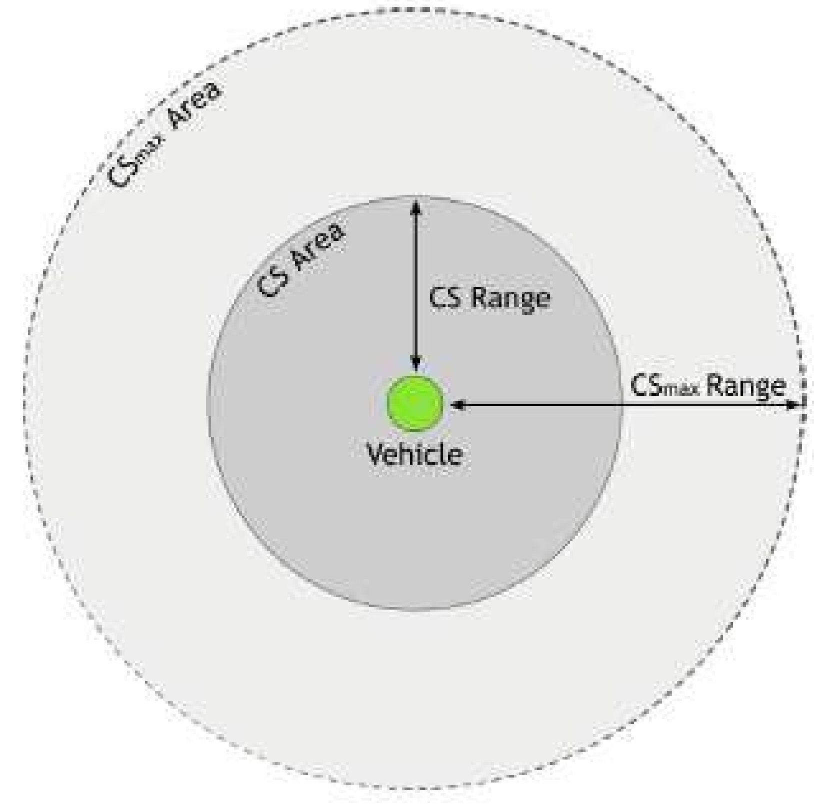
- Based on above concepts, a power adjustment approach should
  - Keep the beacon load at a preconfigured level.
  - Reserve some bandwidth for emergency messages.
  - Maximize the beacon transmission power without violating the MBL.
  - Requires a negligible amount of additional communication overhead.
  - Share the bandwidth used by beacons between nodes in a fair manner.

BACKGROUND

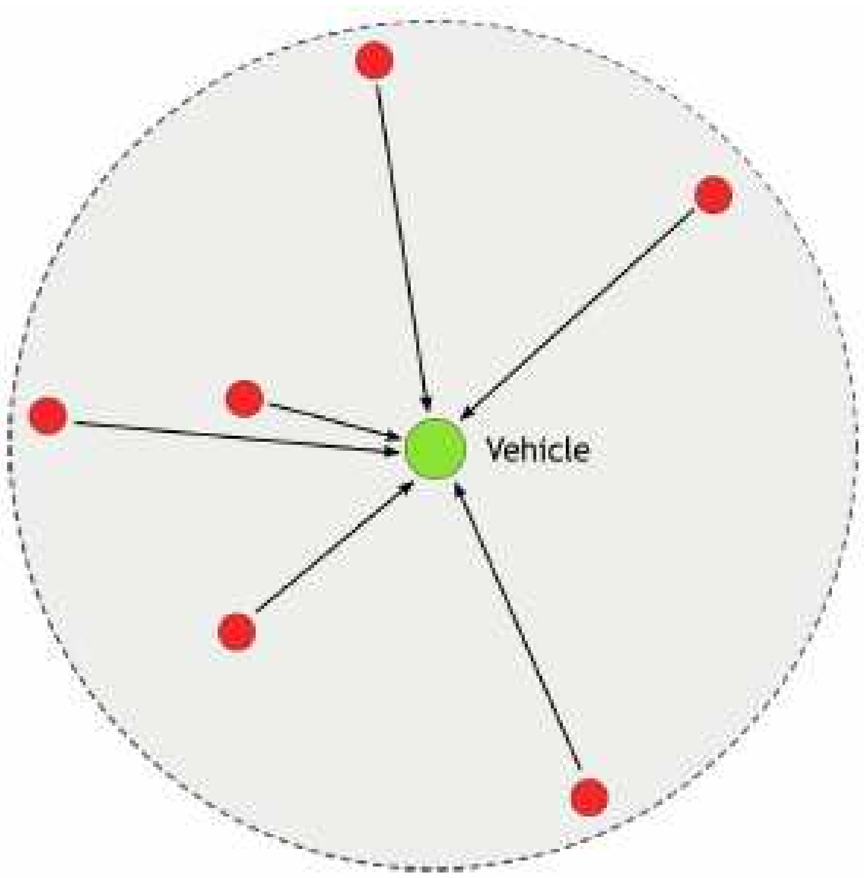
- For emergency messages
  - Limit the number of potential relay[6~12].

- For periodic beacon messages
  - Packet size：unsustainable in VANET.
  - Transmission rate：802.11p(WAVE).
  - Transmission power：FPAV[2]、D-FPAV[24]

- (CSR(v, pv))
  - The carrier sense range of node v using power pv.
- (CSA(v, pv))
  - The carrier sense area using (CSR(v, pv)) as radius.



- Beacon load
  - sum of all periodic status messages sensed by a reference vehicle during a time interval t



$$BL_v = \sum_{w \in W} s_w \cdot r_w \quad [bits/sec]$$

- Maximum beacon load (MBL)
  - Reserve some bandwidth for emergency messages.
- Extended messages
  - To obtain much more information.
  - Contain the list of the positions of all vehicles located inside CSAmax(v) as estimated by vehicle *v*.
  - Additional overhead because of bigger size and multi-hop.
  - A trade-off between additional overhead and estimation accuracy.

- D-FPAV
  - Distributed Fair Transmit Power Adjustment for Vehicular Ad Hoc Networks.
  - The transmission power start at lowest possible power level and is ‘virtually’ increased step-by-step while estimating the resulting beaconing load at each vehicle after each step.

Algorithm D-FPAV: (algorithm for node u_i)

INPUT: status of all the nodes in $CS_{MAX}(i)$

OUTPUT: a power setting $PA(i)$ for node u_i, such that the resulting power assignment is an optimal solution to BMMTxP

1. Based on the status of the nodes in $CS_{MAX}(i)$, compute the maximum common tx power level P_i s.t. the MBL threshold is not violated at any node in $CS_{MAX}(i)$

2a. Broadcast P_i to all nodes in $CS_{MAX}(i)$

2b. Receive the messages with the power level from nodes u_j such that $u_i \in CS_{MAX}(j)$; store the received values in P_j

3. Compute the final power level: $PA(i) = \min\{P_i, \min_{j:u_i \in CS_{MAX}(j)}\{P_j\}\}$

The D-FPAV algorithm.

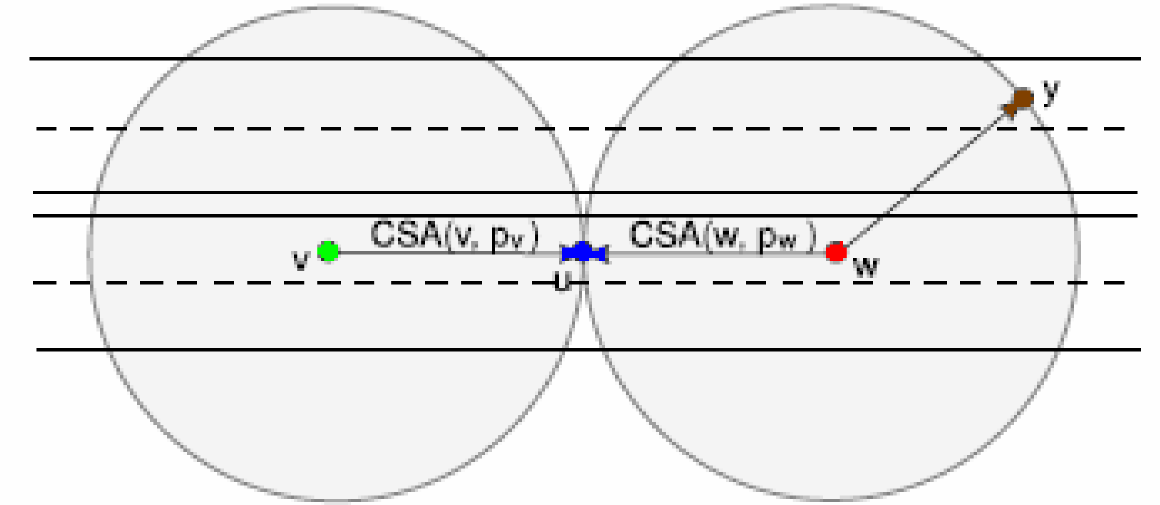
	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8
u_1	150	150	150	150	150			
u_2	50	50	50	50	50	50		
u_3	50	50	50	50	50	50	50	
u_4	50	50	50	50	50	50	50	
u_5	50	50	50	50	50	50	50	50
u_6		50	50	50	50	50	50	50
u_7			50	50	50	50	50	50
u_8					150	150	150	150

TABLE I

SUMMARIZATION OF D-FPAV EXECUTION. ENTRIES REPRESENT IN METERS THE MAXIMUM ALLOWED VALUE OF THE CS RANGE PER NODE.

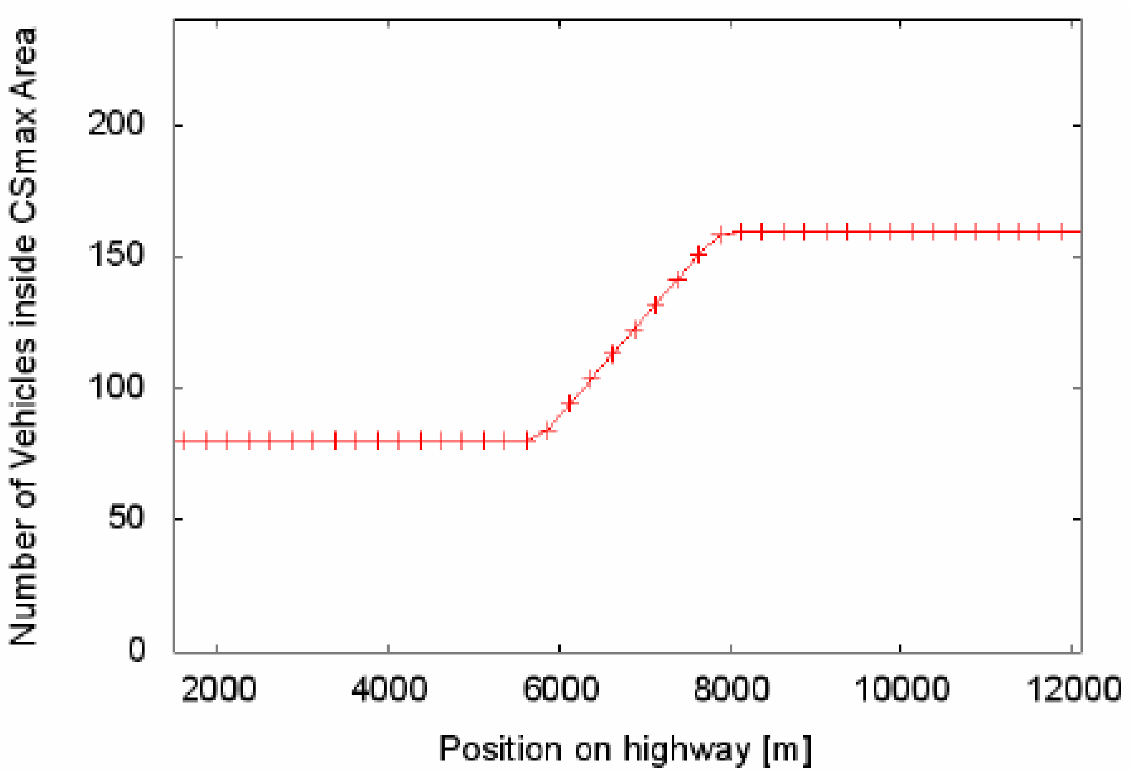
SENSITIVITY ANALYSIS

- Worst case

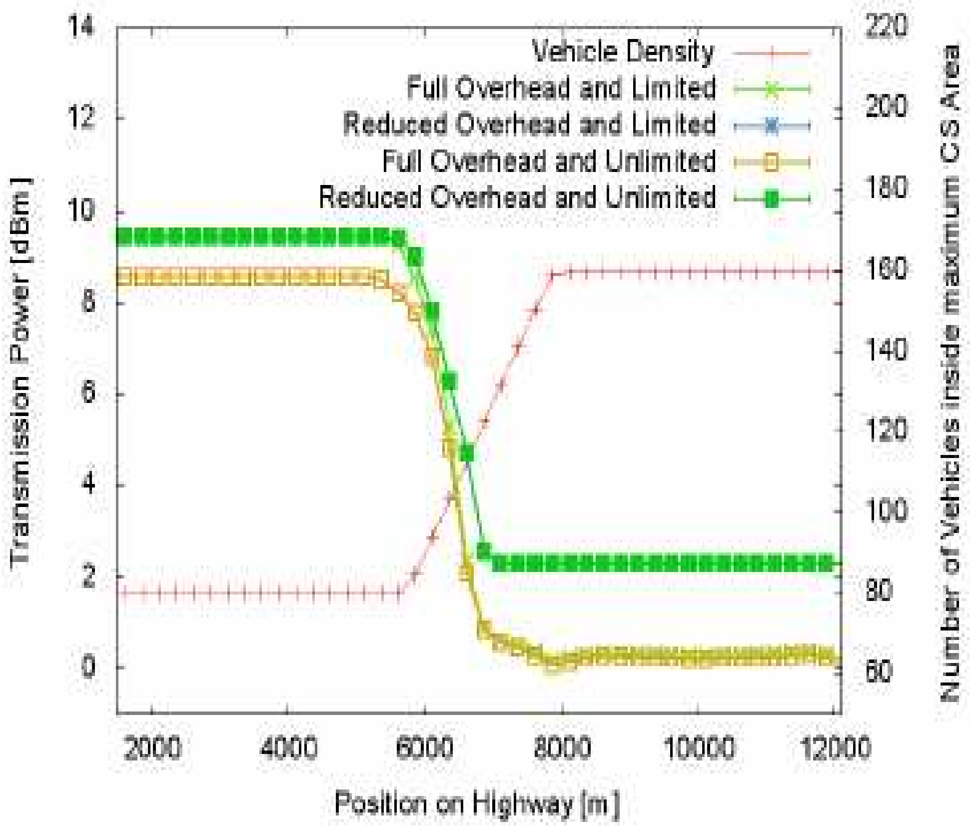


- Every vehicle has to periodically broadcast a list of known neighbors to provide this knowledge.
  - Extended beacon messages.

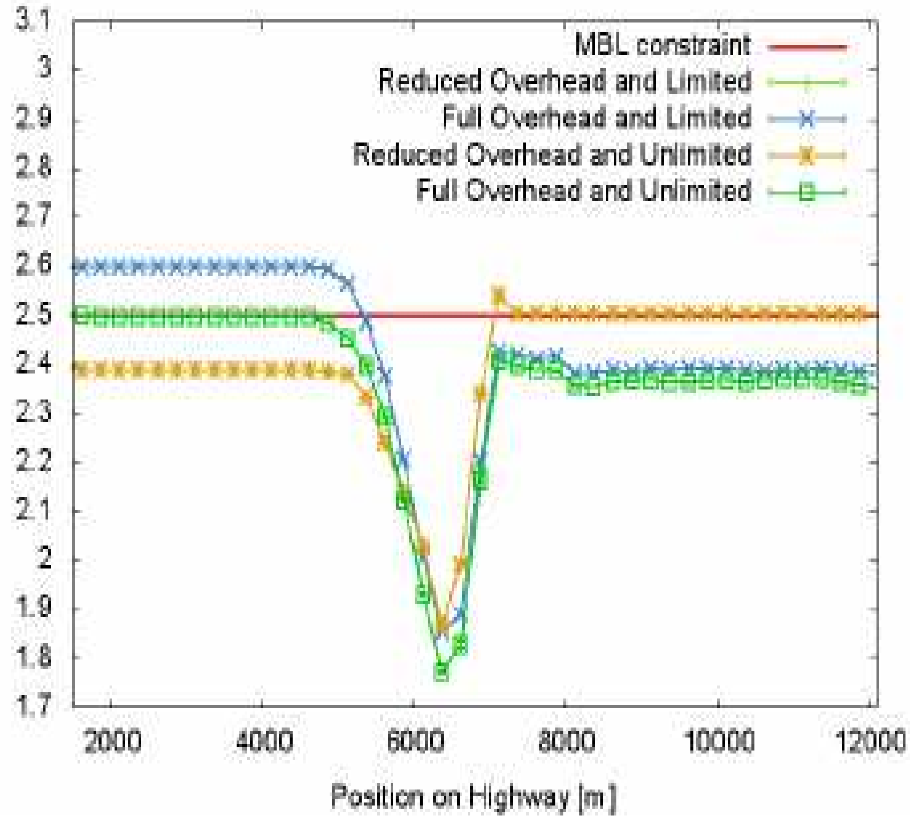
- Simulation setup
  - Full overhead.
    - Including information of all cars in its CSA(max) .
  - Reduced overhead.
    - Including information of all cars in its CSA(v,pv) .
  - Considered information range (CIR).
    - 1060m or 2120m
  - Power discrete level = 32.
    - Affects the power control protocol.



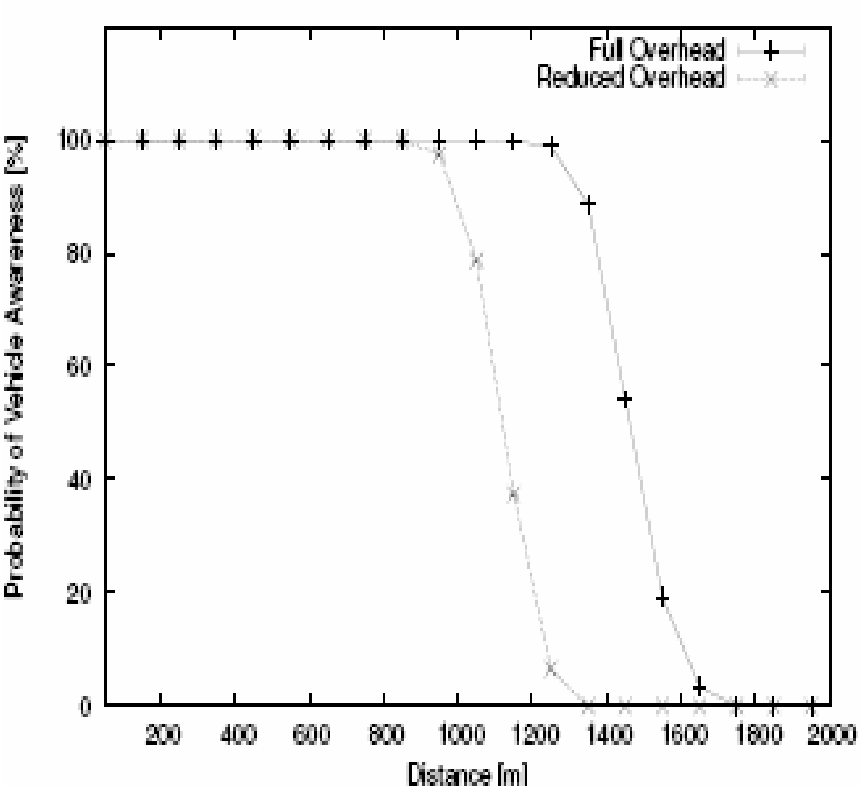
- Homogeneous area with 80 vehicles inside maximum CSA
- Homogeneous area with 160 vehicles inside maximum CSA
- Transitional area with increasing number of vehicles inside maximum CSA



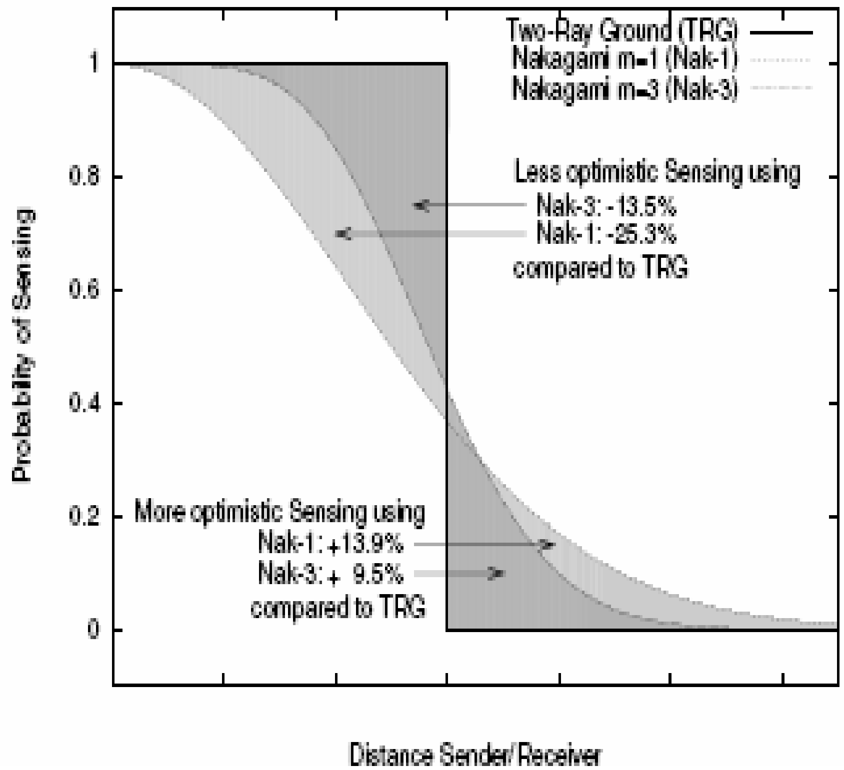
Vehicle Density
Full Overhead and Limited
Reduced Overhead and Limited
Full Overhead and Unlimited
Reduced Overhead and Unlimited
Transmission Power [dBm]
Number of Vehicles inside maximum CS Area
Position on Highway [m]
0
2
4
6
8
10
12
14
60
80
100
120
140
160
180
200
220
2000
4000
6000
8000
10000
12000



MBL constraint
Reduced Overhead and Limited
Full Overhead and Limited
Reduced Overhead and Unlimited
Full Overhead and Unlimited
Position on Highway [m]
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
2000
4000
6000
8000
10000
12000



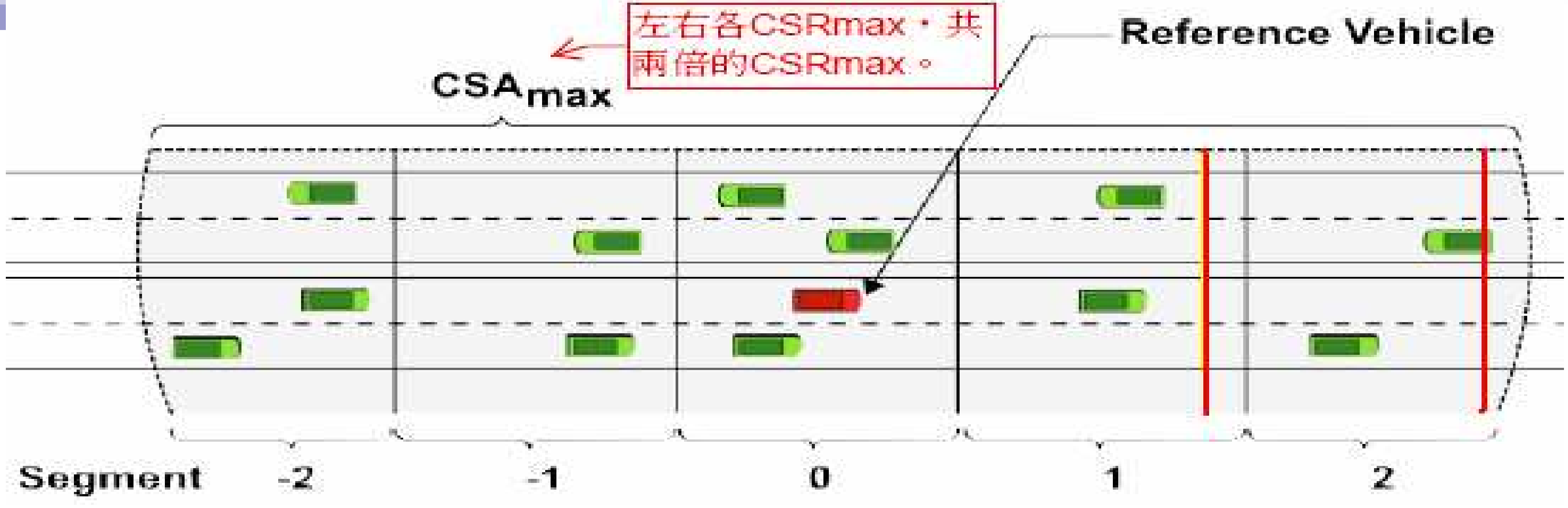
Full Overhead
Reduced Overhead
Probability of Vehicle Awareness [%]
Distance [m]
0
20
40
60
80
100
200
400
600
800
1000
1200
1400
1600
1800
2000



Two-Ray Ground (TRG)
Nakagami m=1 (Nak-1)
Nakagami m=3 (Nak-3)
Less optimistic Sensing using
Nak-3: -13.5%
Nak-1: -25.3%
compared to TRG
More optimistic Sensing using
Nak-1: +13.9%
Nak-3: + 9.5%
compared to TRG
Probability of Sensing
Distance Sender/Receiver
0
0.2
0.4
0.6
0.8
1

LOWOVERHEAD TRANSMISSION POWER CONTROL

- Because the reduced overhead is still not negligible, we propose a DVDE/SPAV protocol.
- Distributed vehicle density estimation (DVDE)
  - Analysis and provide surrounding traffic information.
- Segment-based Power Adjustment for Vehicular environments (SPAV)



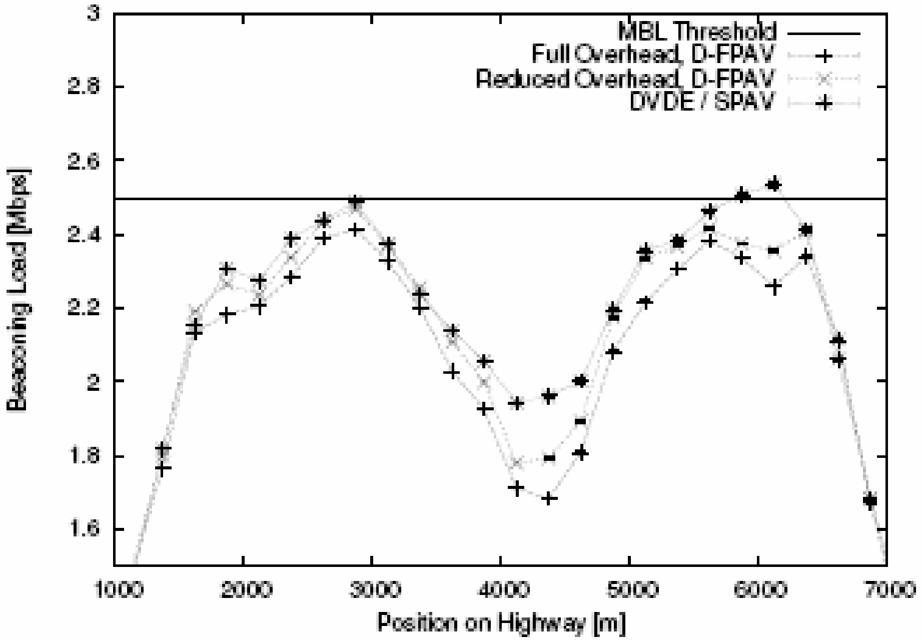
- VDH(E(v,5))={3 , 2 , 4 , 2 , 2}.

$$S_j(0)\times 0.9 + S_j(1)\times 0.1$$

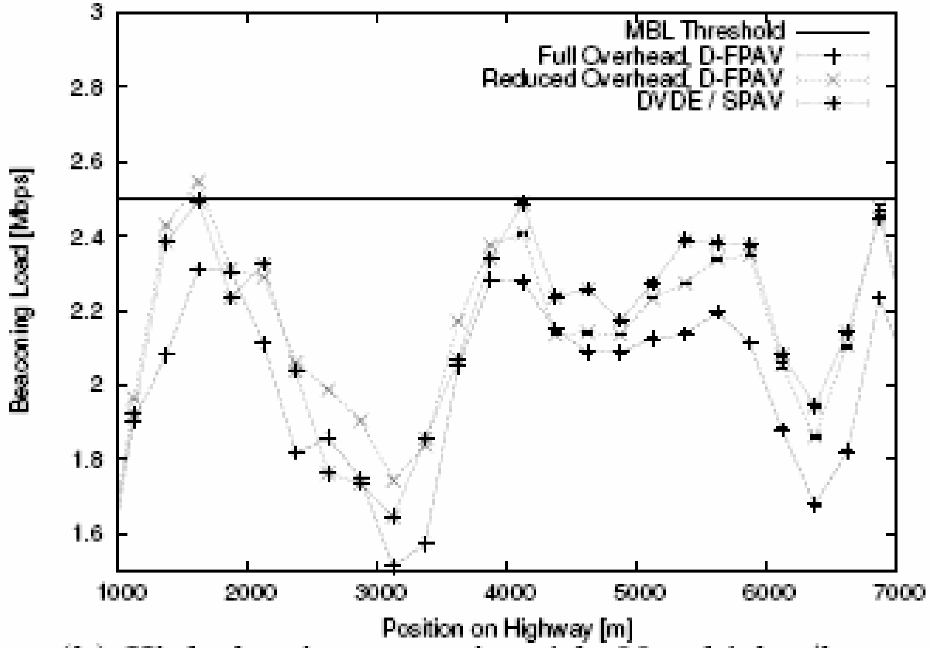
- VDH
  - Based on information received by others (beacon).
  - Other cars’ periodic broadcast (extended message).
  - Merge.

- SPAV
  1. Compute a maximum common power for all cars in its environment.
  2. Each segment derives a catchment area.
  3. For a vehicle v, its beacon transmission power is correspond to the minimum catchment area.

COMPARISON OF DVDE/SPAV AND D-FPAV



(a) Low-density scenario with 36 vehicles/km



(b) High-density scenario with 66 vehicles/km

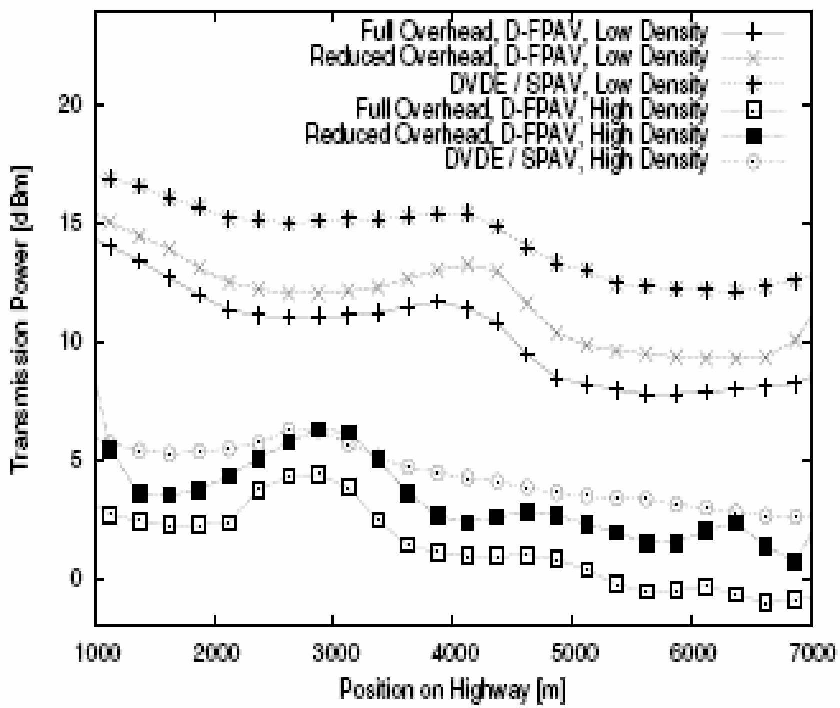
Bidirectional highway with 3 lanes per direction.

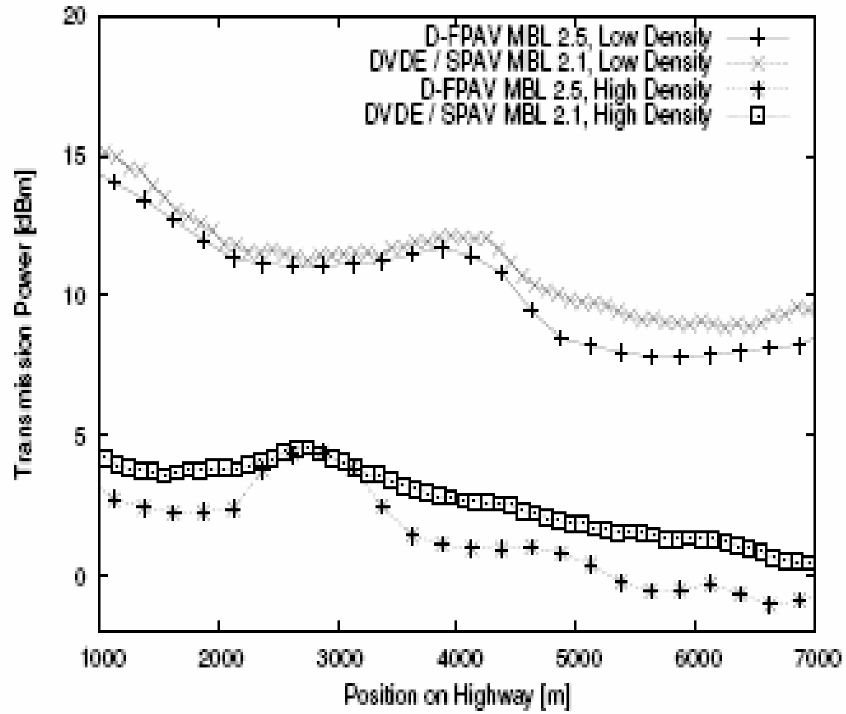
Number of segments：21.

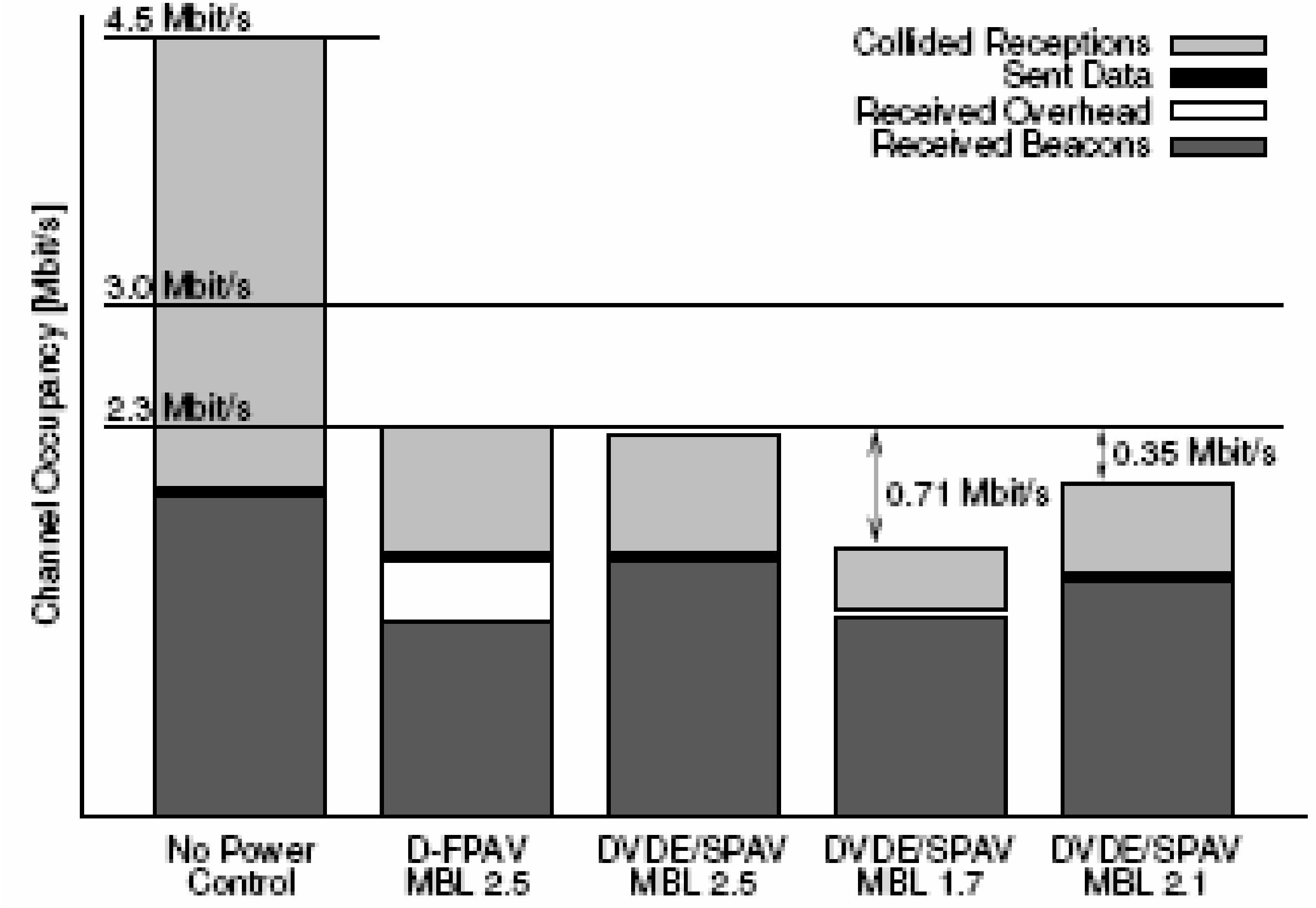
- Additional overhead from extended messages

	Low density	High density
D-FPAV full overhead	22.8%	41.4%
D-FPAV reduced overhead	16.2%	18.6%
DVDE/SPAV	0.42 %	0.42 %

- Comparison of transmission power.







- Use higher transmission powers to increase mutual awareness between vehicles.
- Reserve more bandwidth for event-driven messages.

CONCLUSIONS

- We make an analysis of Accuracy vs. Overhead.
- We propose a transmission power adjustment protocol with negligible overhead which is independent of number of nodes, and it allows to use higher transmission powers or reserve more bandwidth for event-driven messages.