Chapter 7：TDMA-Base MAC Protocol on VANETs

A Cross-Layer Multihop Data Delivery Protocol With Fairness Guarantees for Vehicular Networks

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Outline

- Introduction
- Controlled Vehicular Internet Access (CVIA)
- Simulation
- Conclusion

Introduction

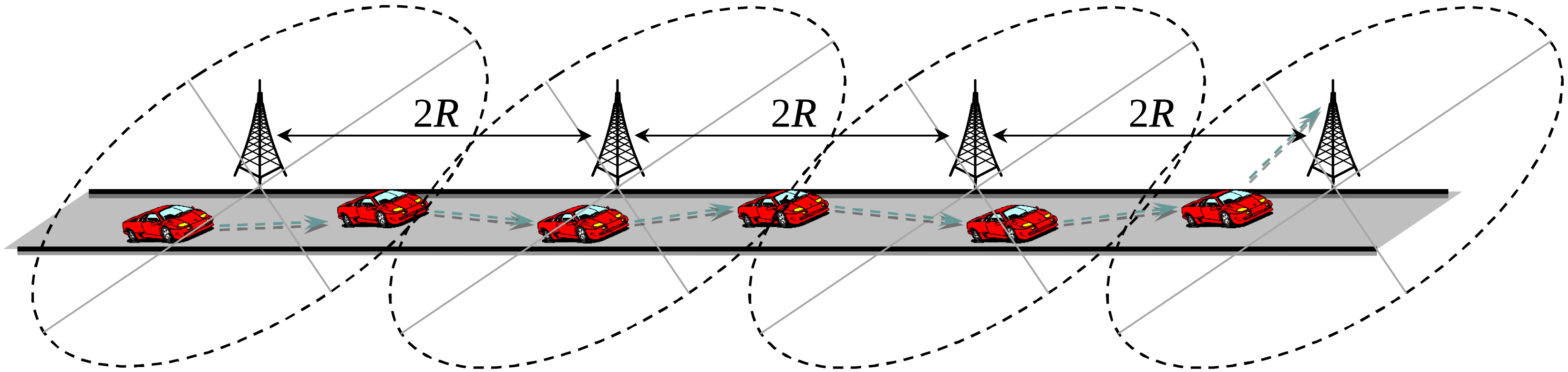
- Mobile wireless devices became the essential parts of our lives
- “anytime, anywhere” connectivity gains a growing importance.
- User spends hours in the traffic everyday
- Internet access from vehicles is in great demand.

Introduction

- DSRC(Dedicated Short Range Communication) is one of the ITS(Intelligent Transport System) standards
- DSRC systems use the IEEE 802.11 protocol as their MAC layer.

Introduction

- A full coverage deployment of APs is costly
- Multihopping with the IEEE 802.11 protocol suffers from several problems
  - low throughput
  - starvation of packets originating from vehicles far away from gateways.



Goal

- To increase the end-to-end throughput.
- Achieving fairness in bandwidth usage between vehicles.
- Mitigating the hidden node problem .
- Avoiding contention.

Network Assumption

- Vehicular network that accesses the Internet through fixed IGWs (Internet gateways) along the road.
- Gateways send periodic service announcements to indicate the availability of the service in their service area.
- The uplink and the downlink packets are transmitted over two frequency-separated channels.

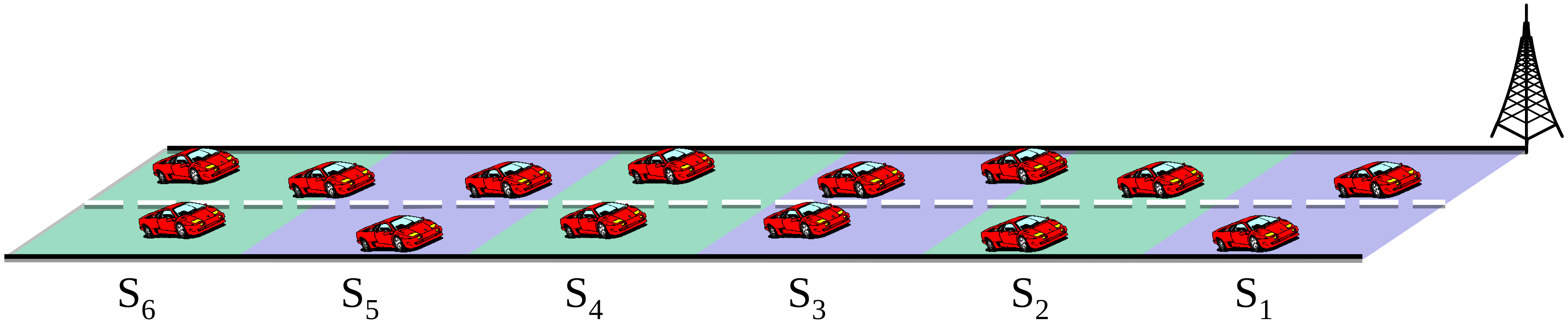
Network Assumption

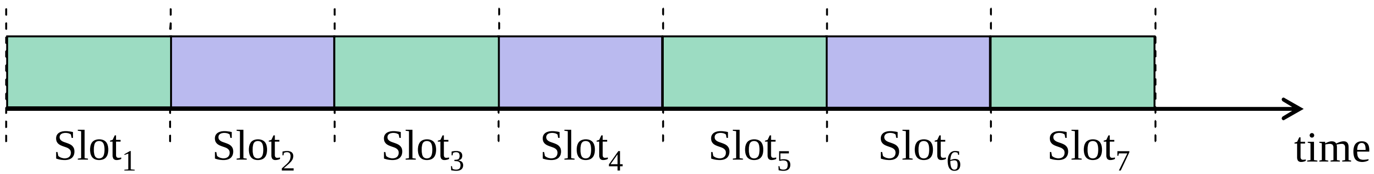
- Vehicles are equipped with GPS devices used for time synchronization and obtaining vehicle positions.

- Vehicle positions obtained via GPS are exchanged among one-hop neighbors.

Basic Idea

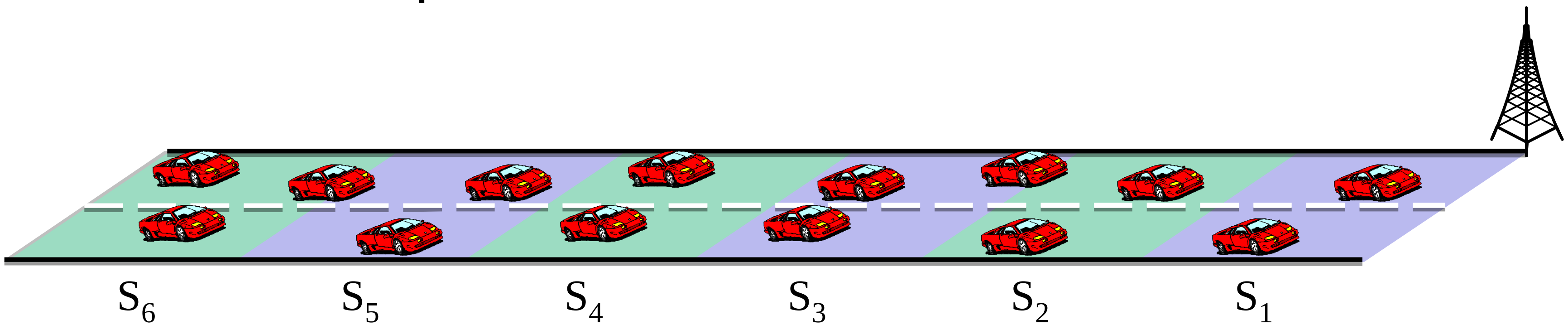
- Divides the time into slots and the service area of the gateway into segments.

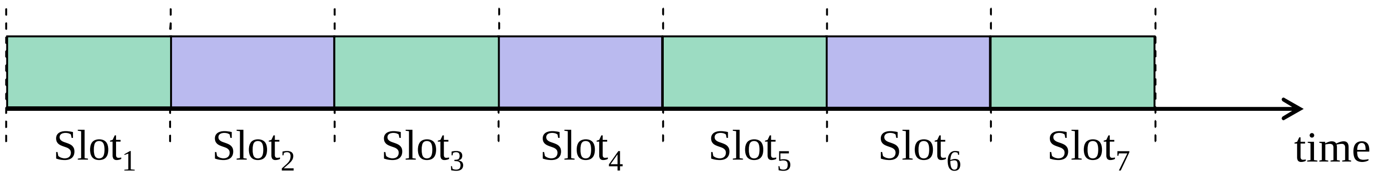




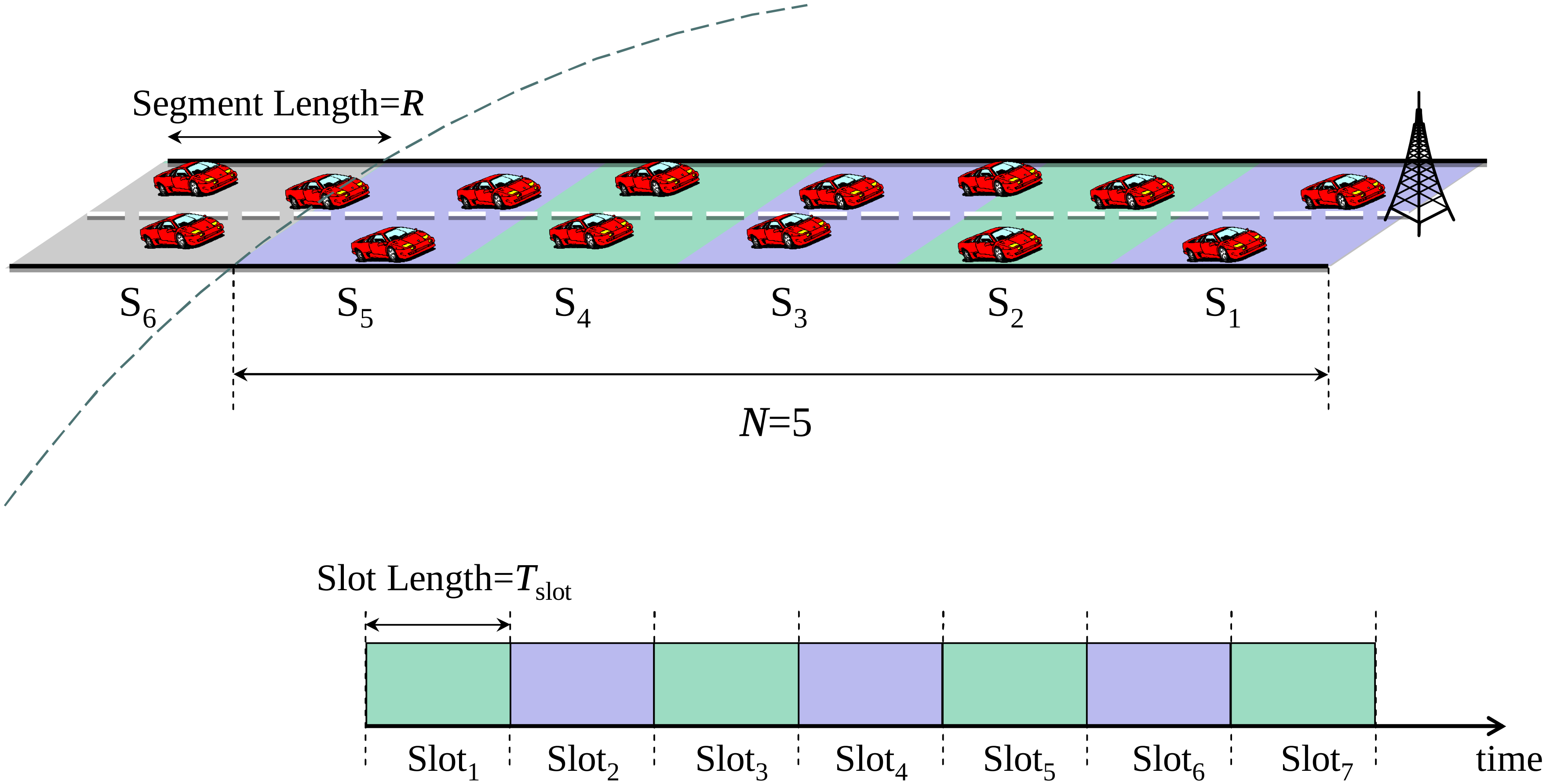
Basic Idea

- Controls time slots the vehicles are allowed to transmit in, how the vehicles access the channel, and to which vehicles the packets are sent.





CVIA-Definition



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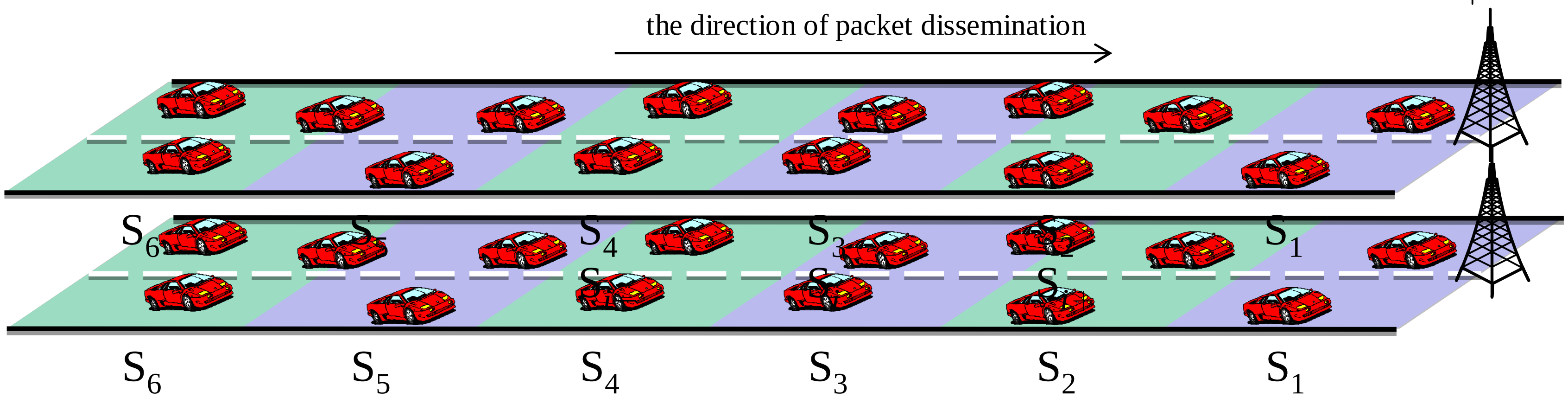
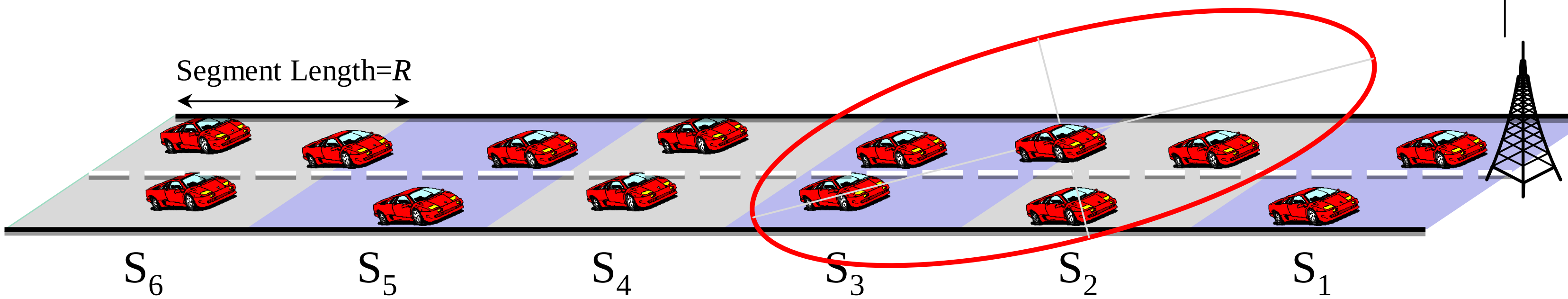


S_{i+} : The neighboring segment in the same direction of the packet dissemination.

S_{i-} : The neighboring segment in the opposite direction of the packet dissemination.

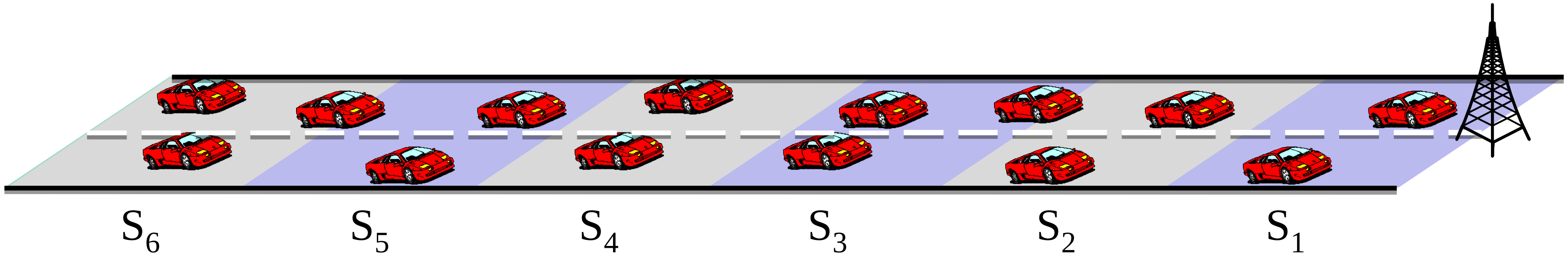
CVIA-Definition



Interference parameter (r) : $r = \left\lceil \frac{\text{Interference Range}}{R} \right\rceil + 1$

Interference Range=R $\Rightarrow \left\lceil \frac{\text{Interference Range}}{R} \right\rceil = 1 \Rightarrow r = 2$

CVIA-Definition



Interference parameter (*r*)：$r = \left\lceil \frac{\text{Interference Range}}{R} \right\rceil + 1$

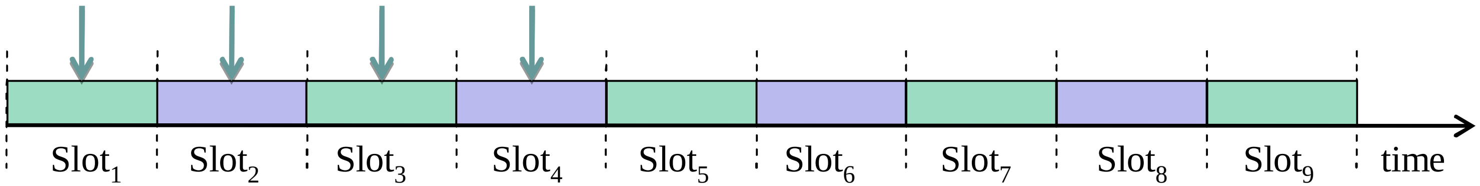
Active segment：S_i is active in TS_j if (i mod r)=(j mod r)

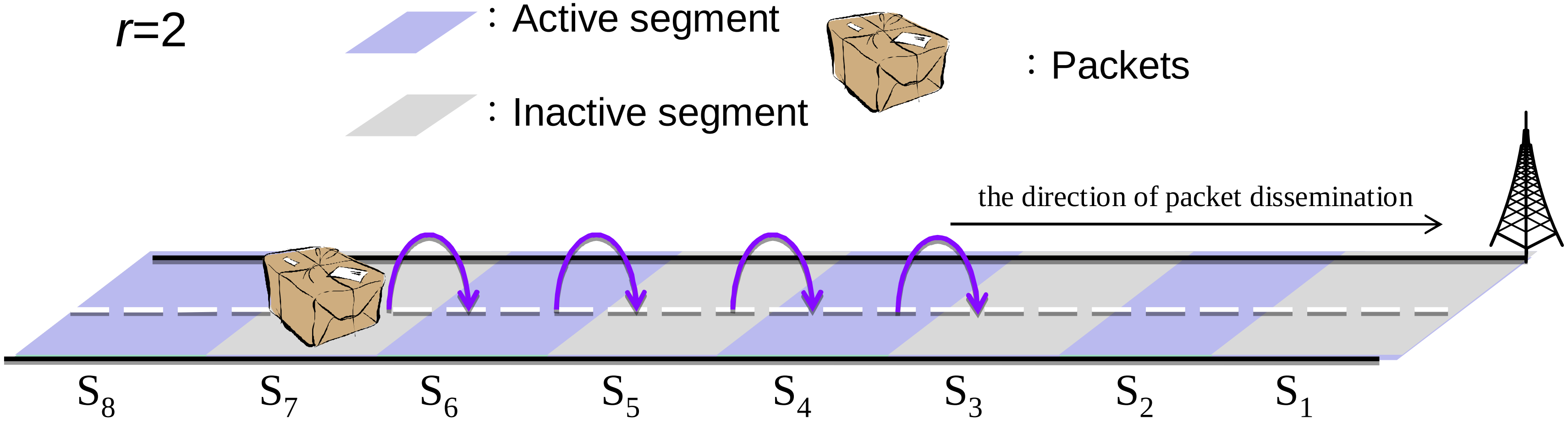
For example, r=2

when the current time slot is TS_5 ,

the segments S_1, S_3, and S_5 become active.

CVIA-Definition





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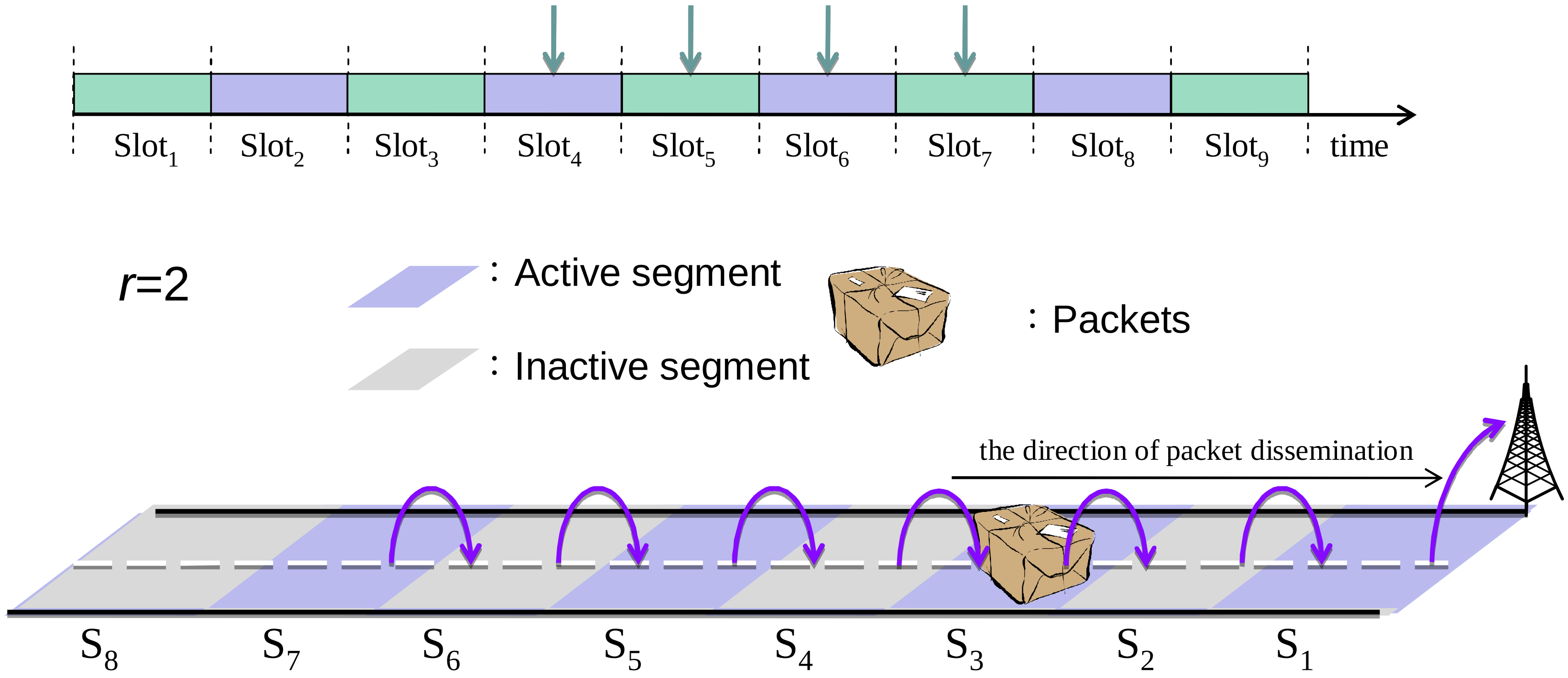

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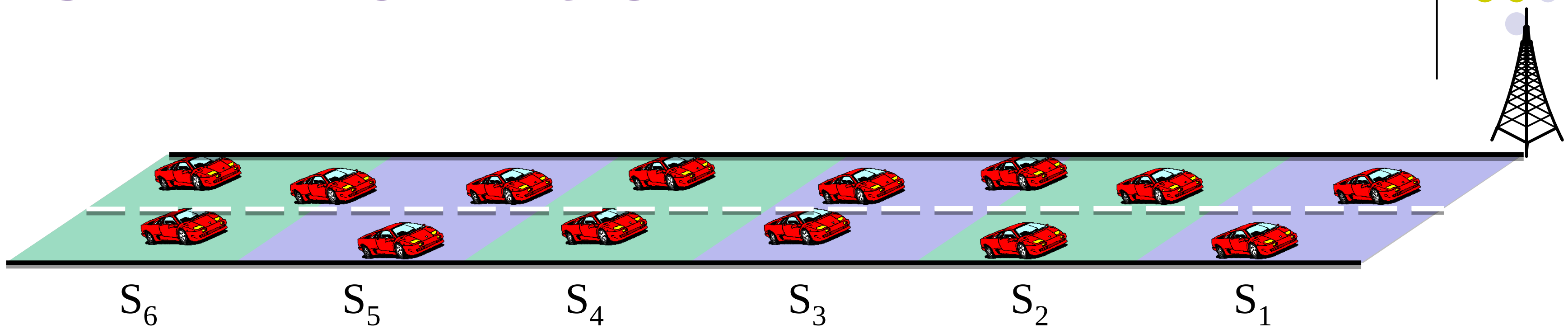


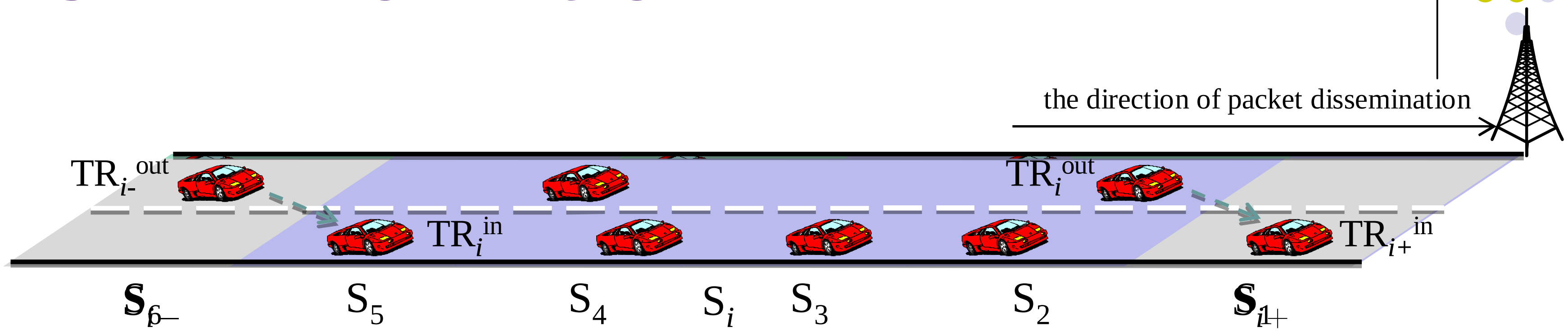
Inbound temporary router (TR_i^{in})：The vehicle closet to S_{i-} .

All packets entering a segment go through TR_i^{in} .

Outbound temporary router (TR_i^{out})：The vehicle closet to S_{i+} .

All packets leaving the segment go through TR_i^{out} .

CVIA-Definition



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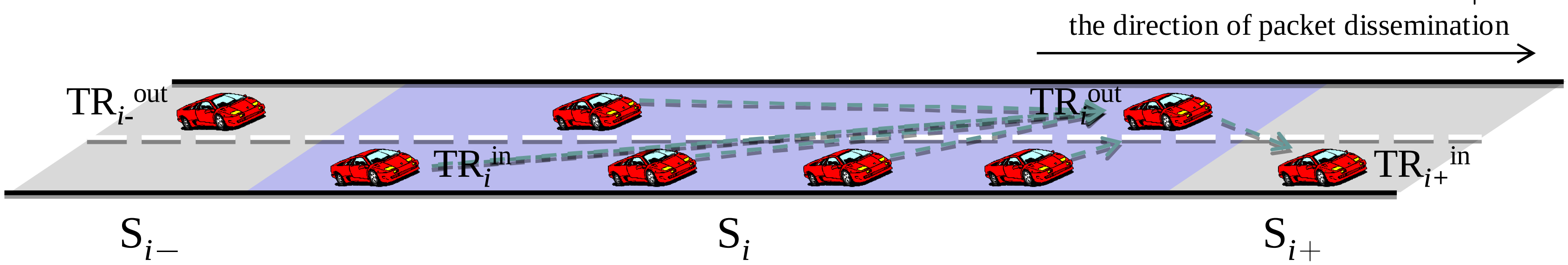
Outbound temporary router (TR_i^{out})：The vehicle closet to S_{i+} .

All packets leaving the segment go through TR_i^{out} .

CVIA-Overview

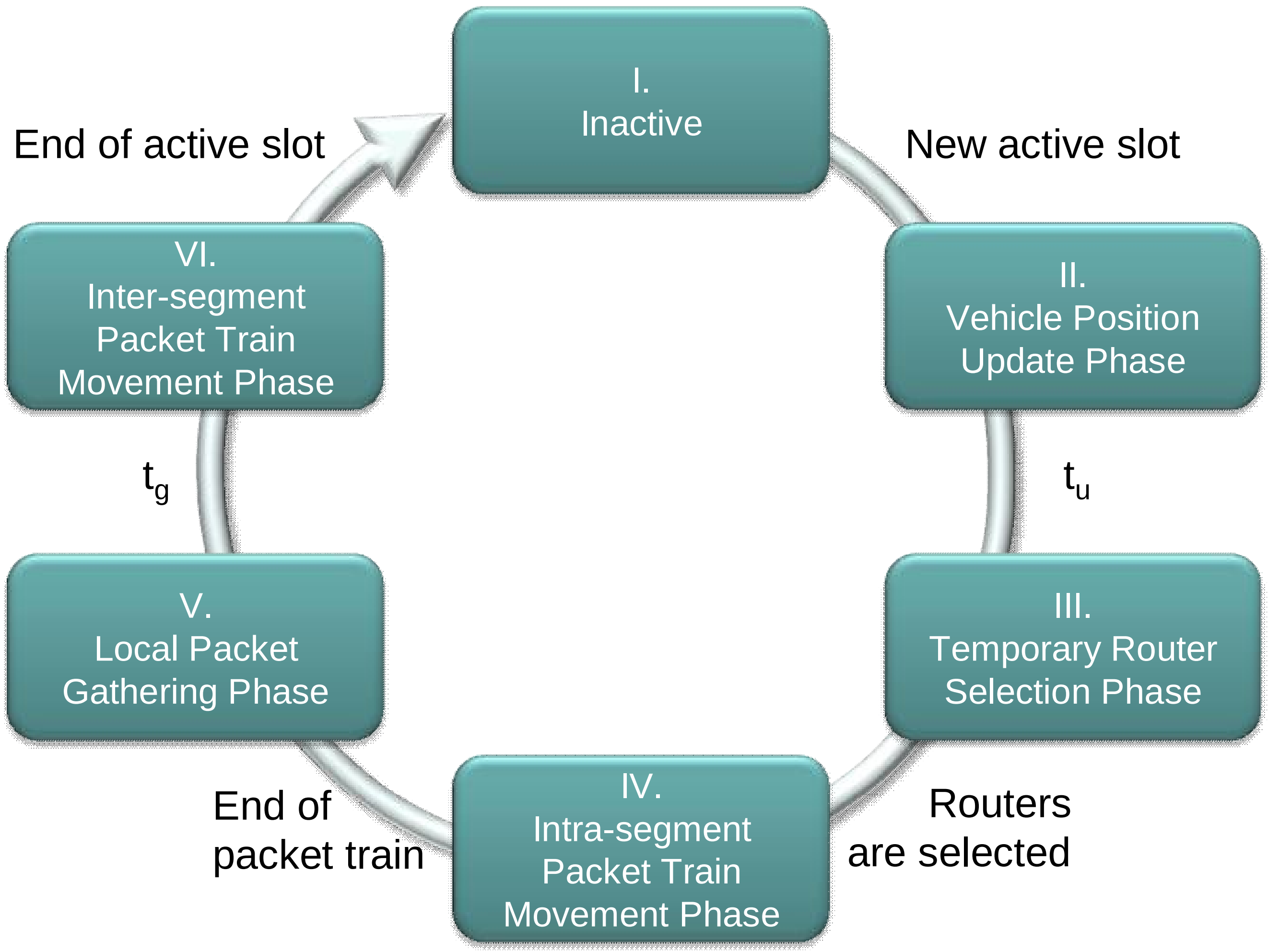


1. TR_i^{in} deliver packet train to TR_i^{out} .

2. TR_i^{out} gather local packets.

3. TR_i^{out} move out packet train to TR_{i+}^{out} .

CVIA-Overview



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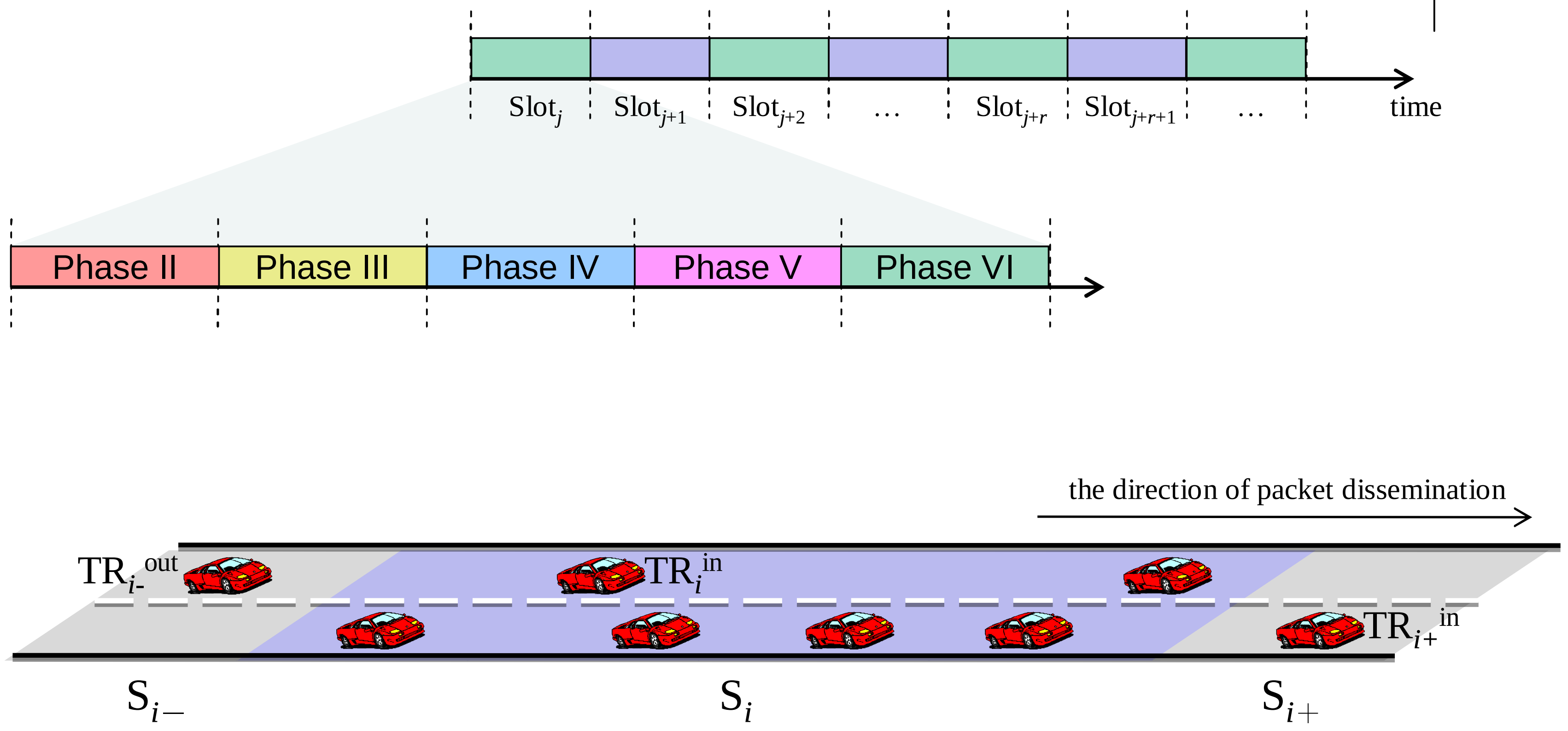

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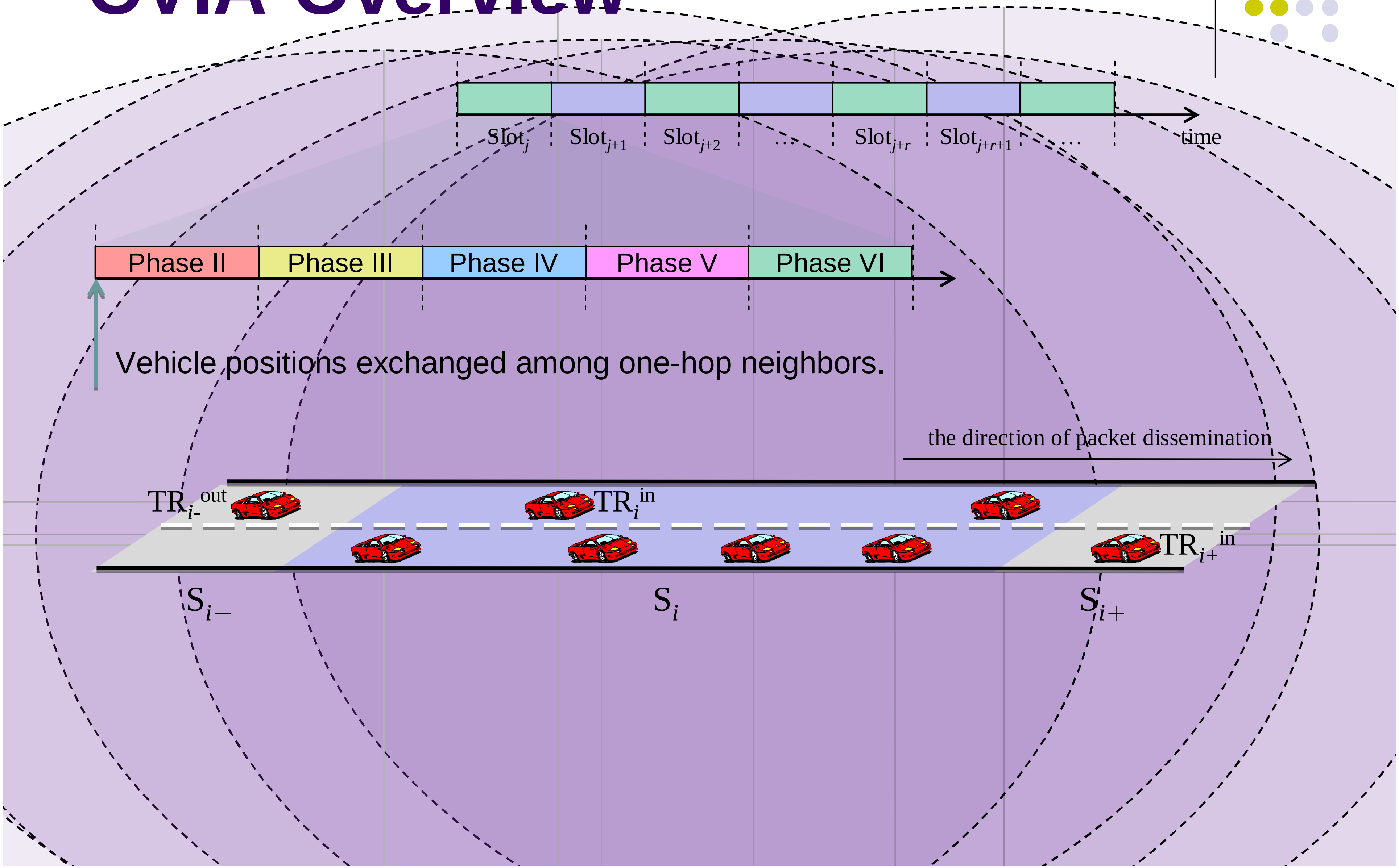

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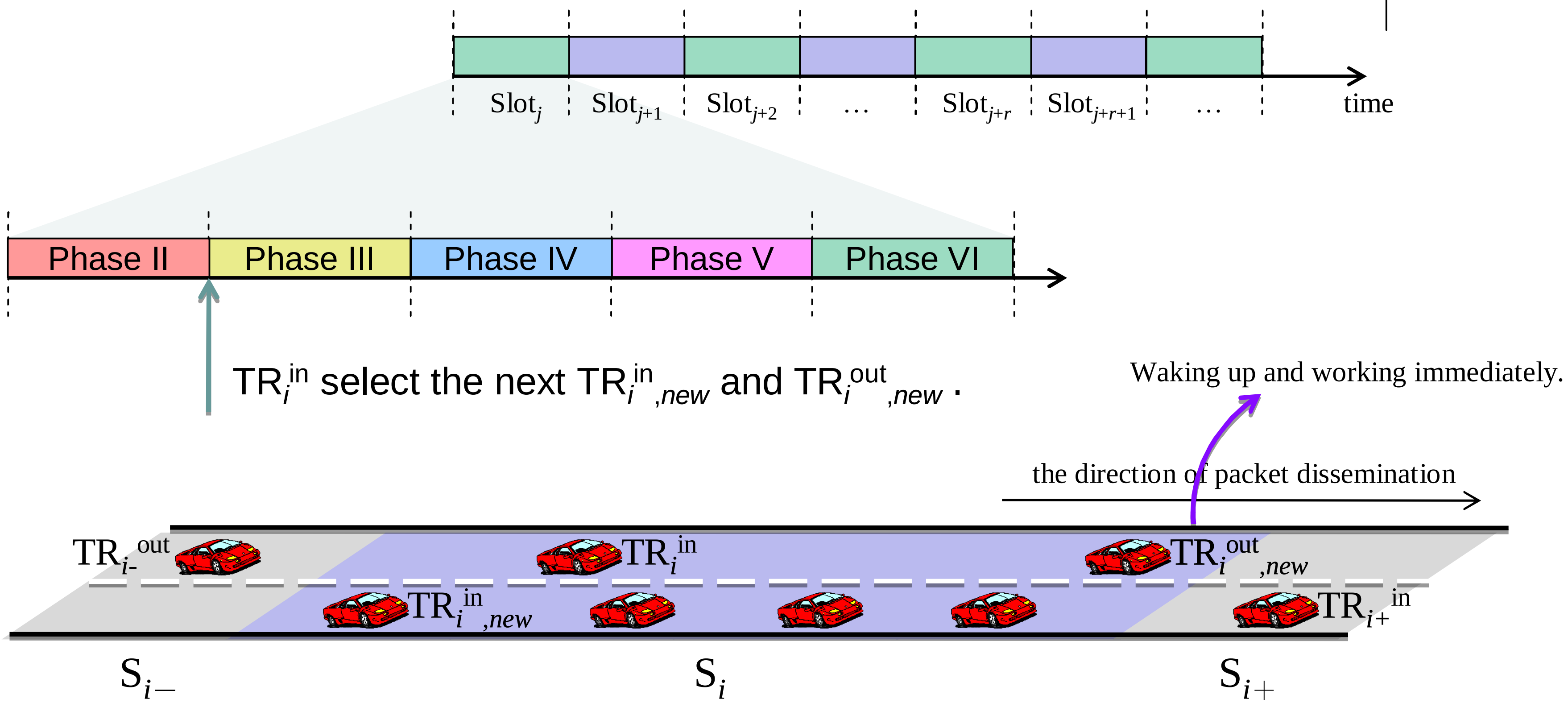

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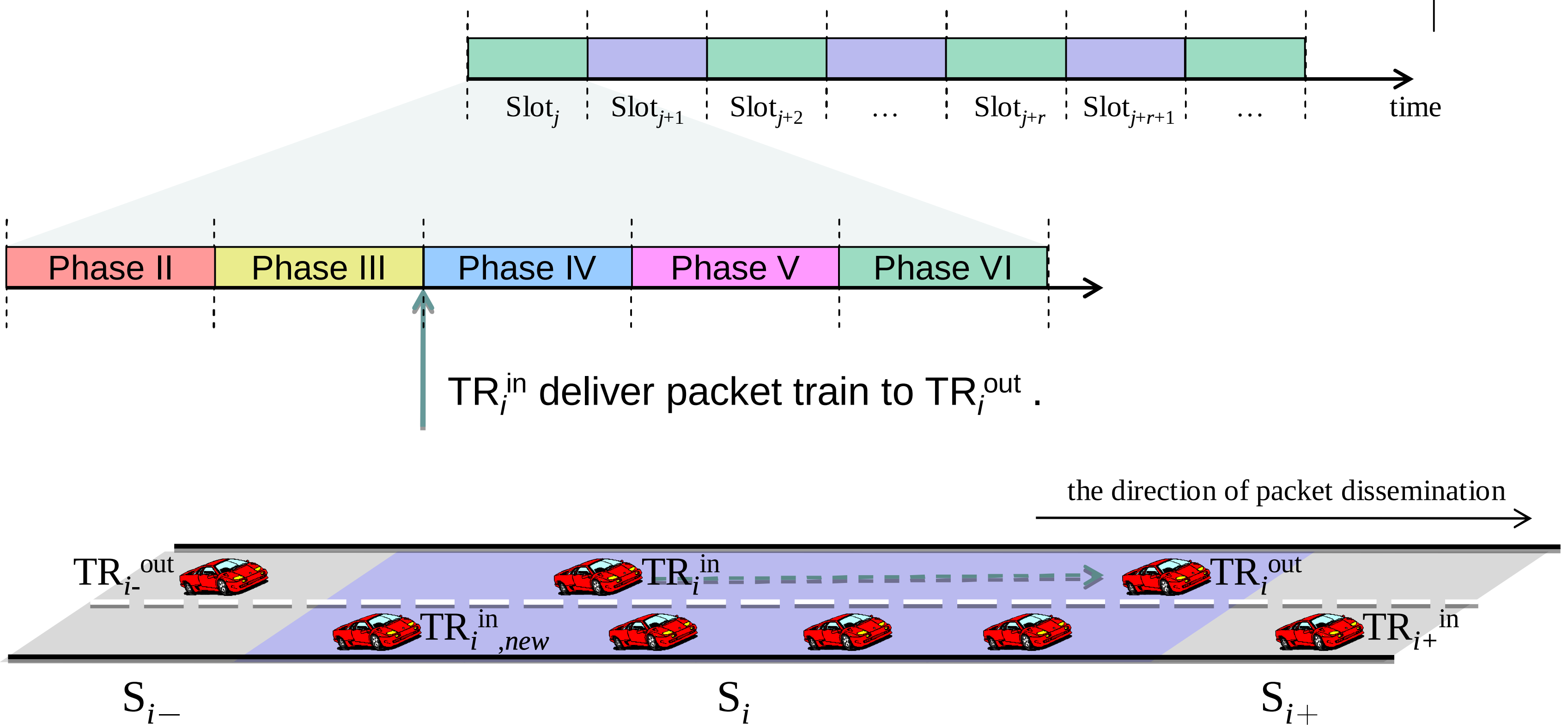

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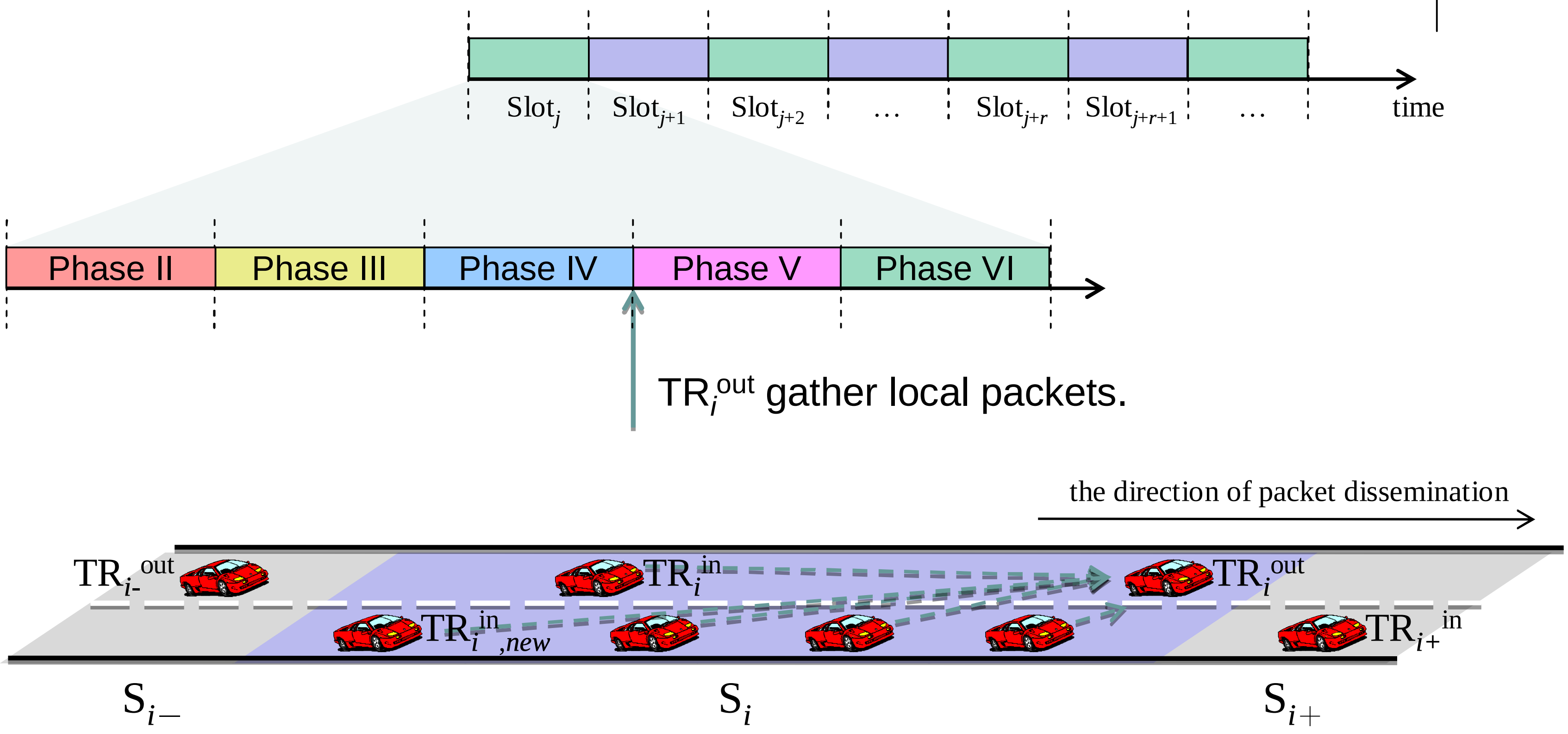

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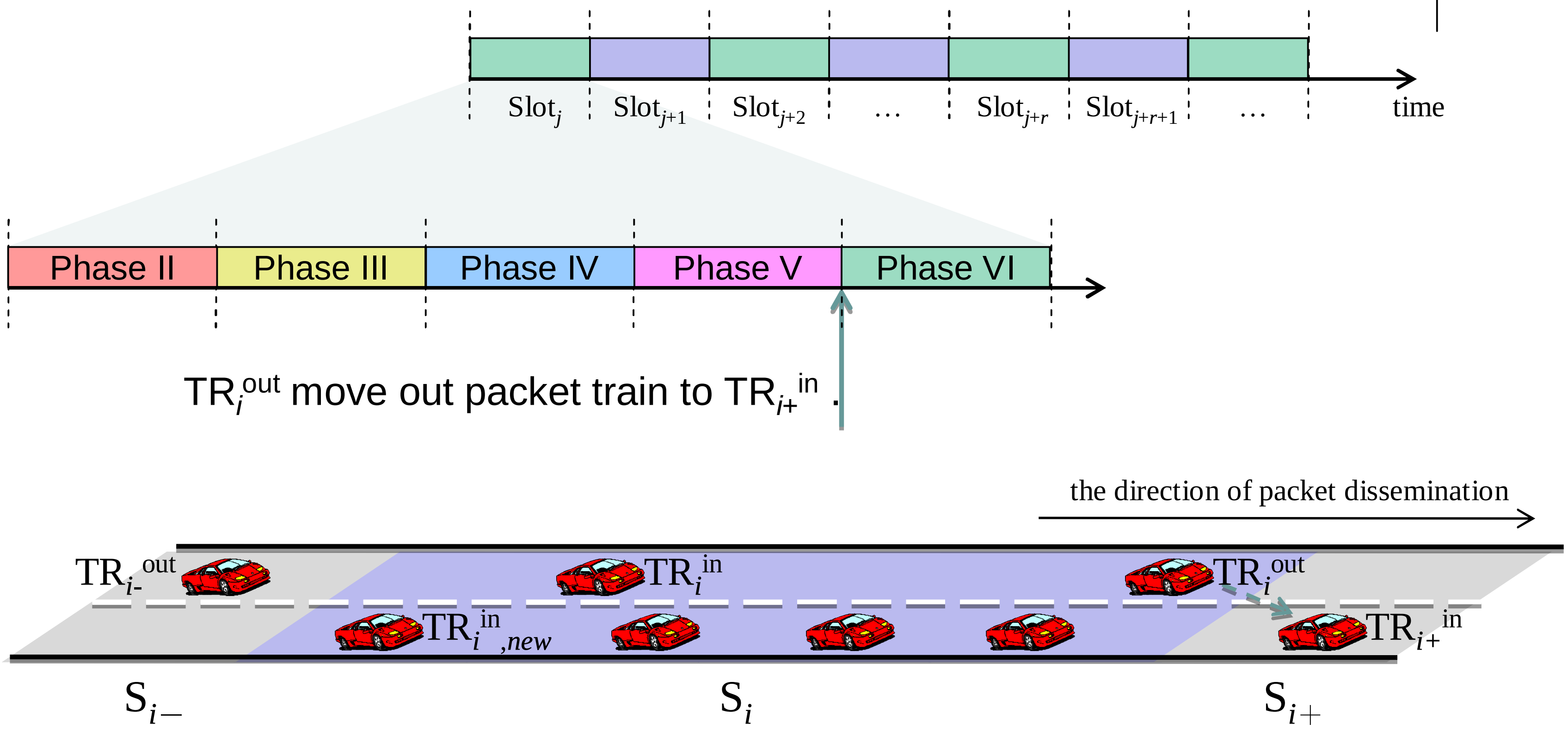

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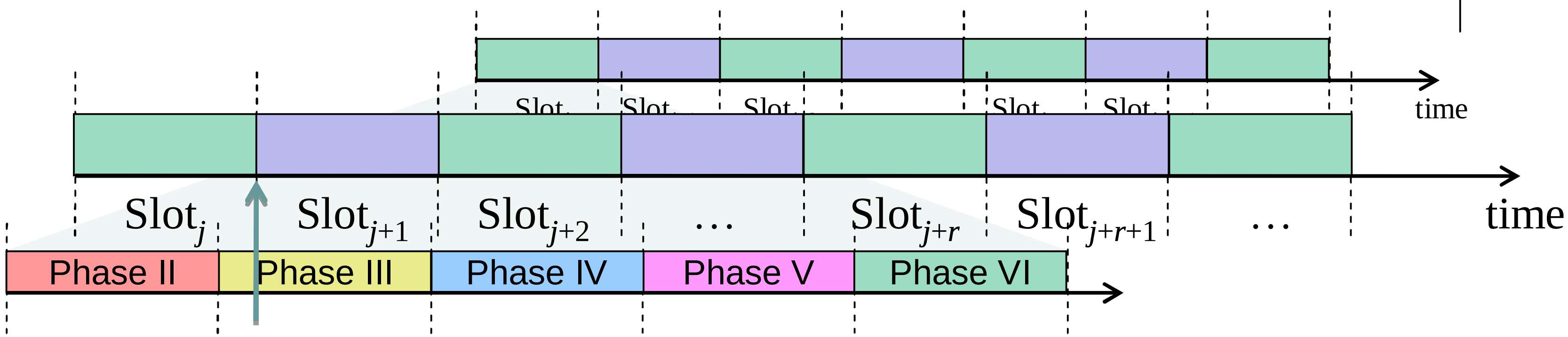
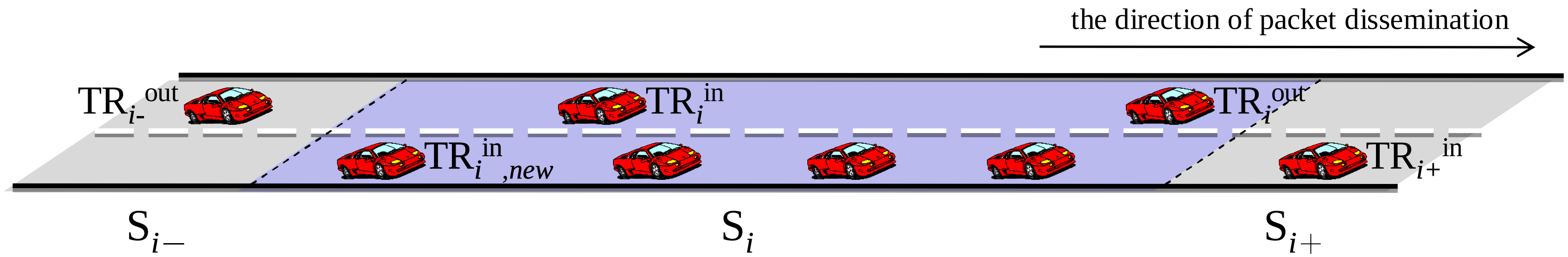
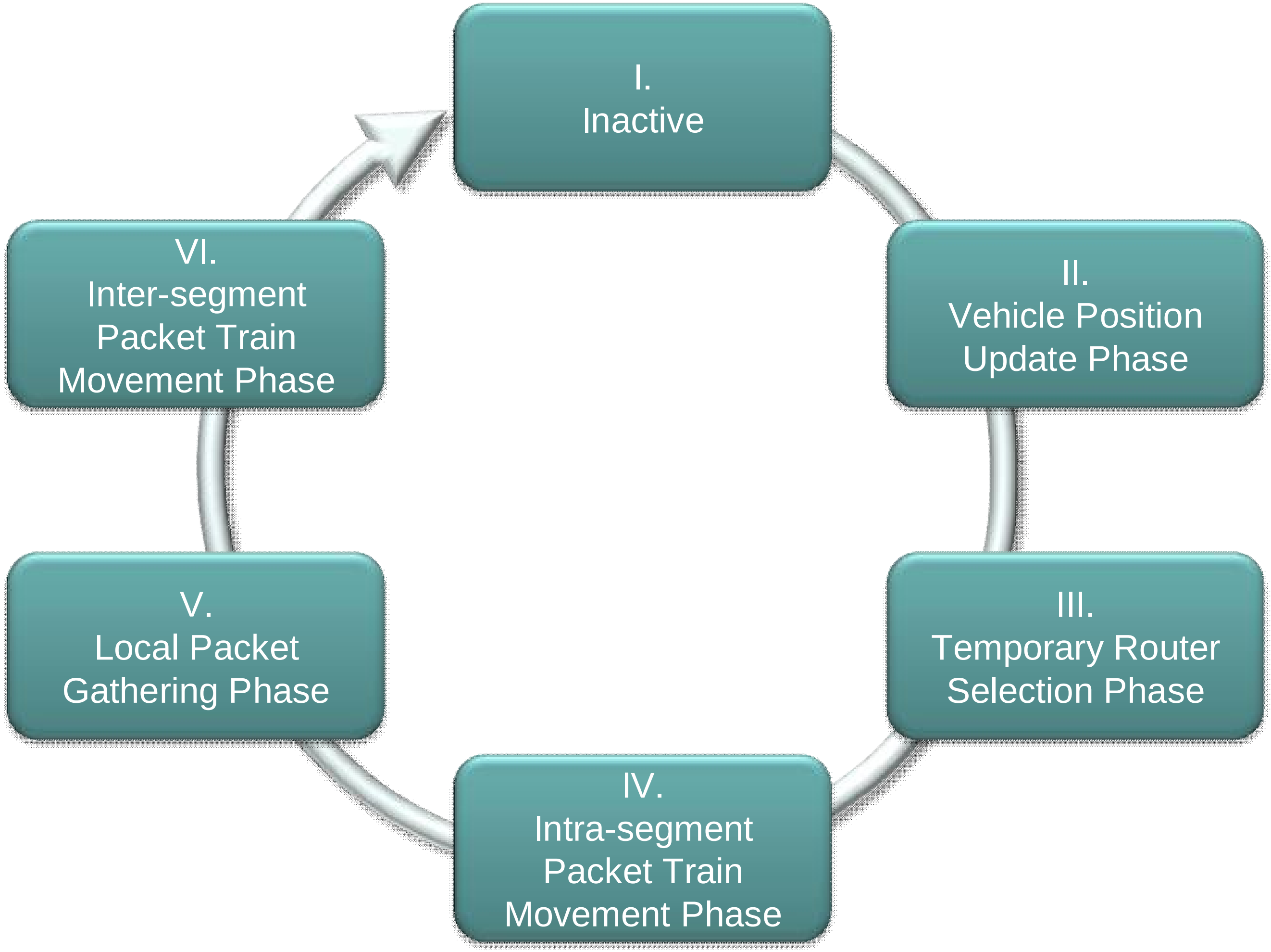




CVIA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CVIA - Inactive

Vehicles in inactive segments do not access the channel.

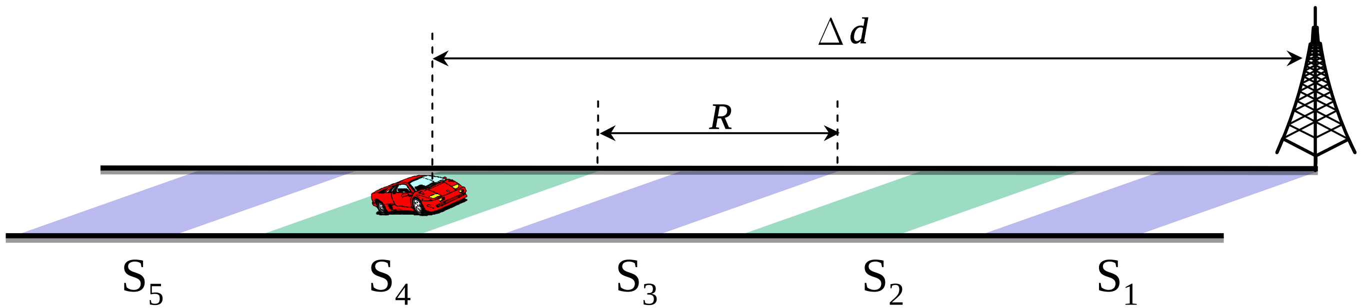
S_i is active in TS_j if (i mod r)=(j mod r)

$i = \left\lceil \frac{\Delta d}{R} \right\rceil$, Δd : The distance of the vehicle to the gateway.

$j = \left\lceil \frac{\Delta t}{T_{slot}} \right\rceil$, Δt : The time passed since an absolute reference point.

Vehicles obtain their positions and synchronize their clocks using GPS.

Vehicles learn the positions of gateways from a digital road map database or the service announcement packets broadcast periodically by gateways.



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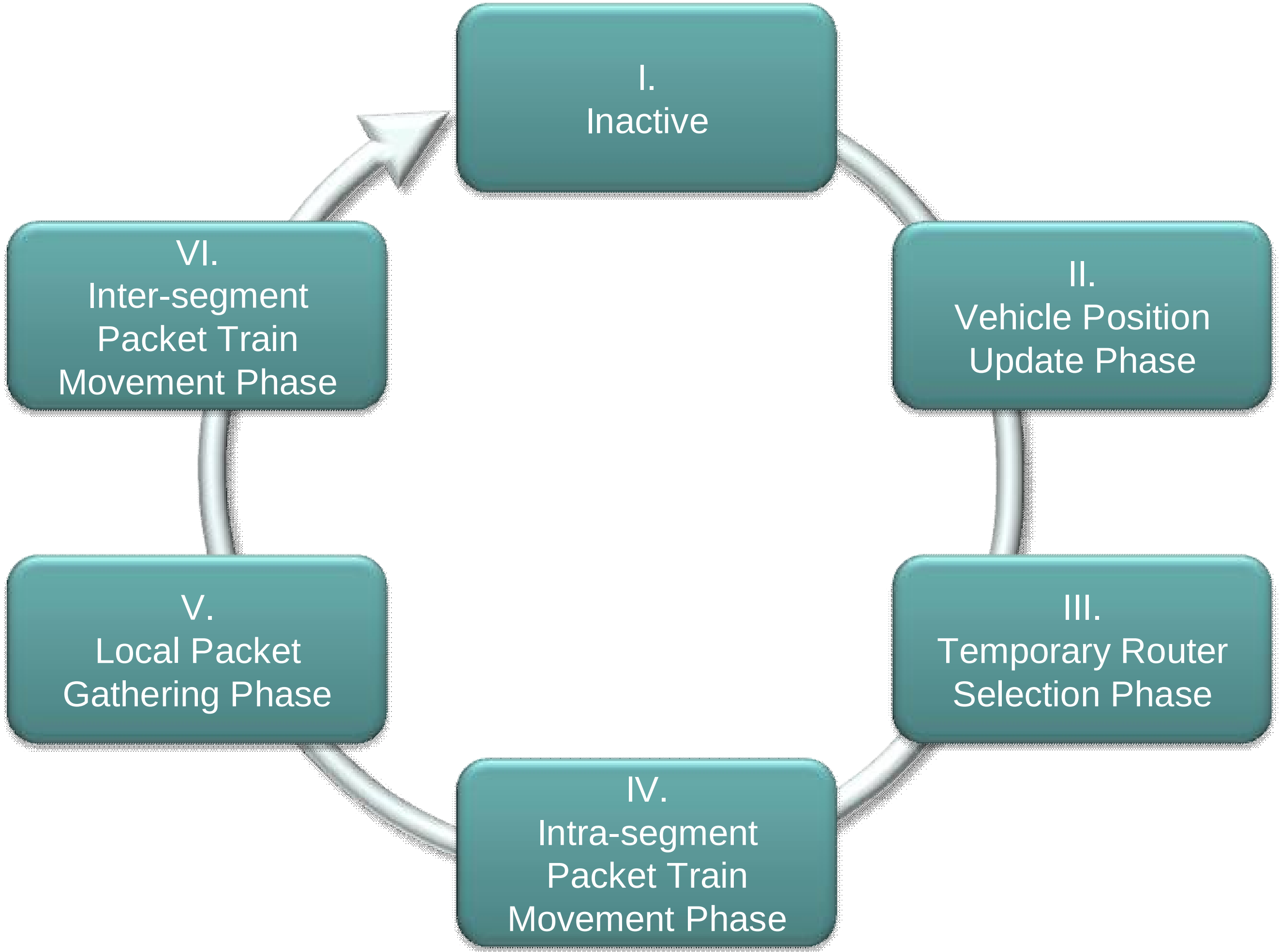
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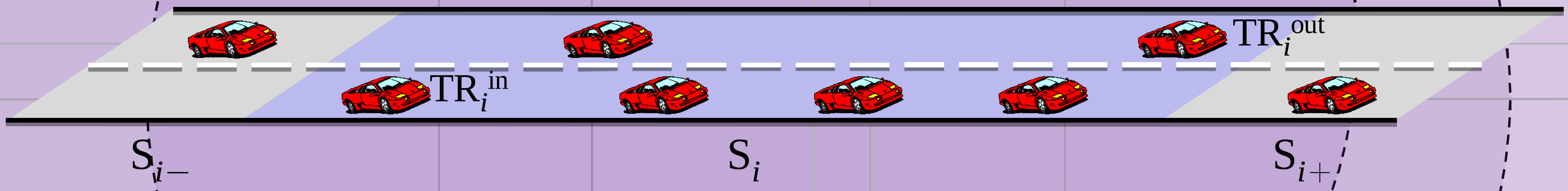
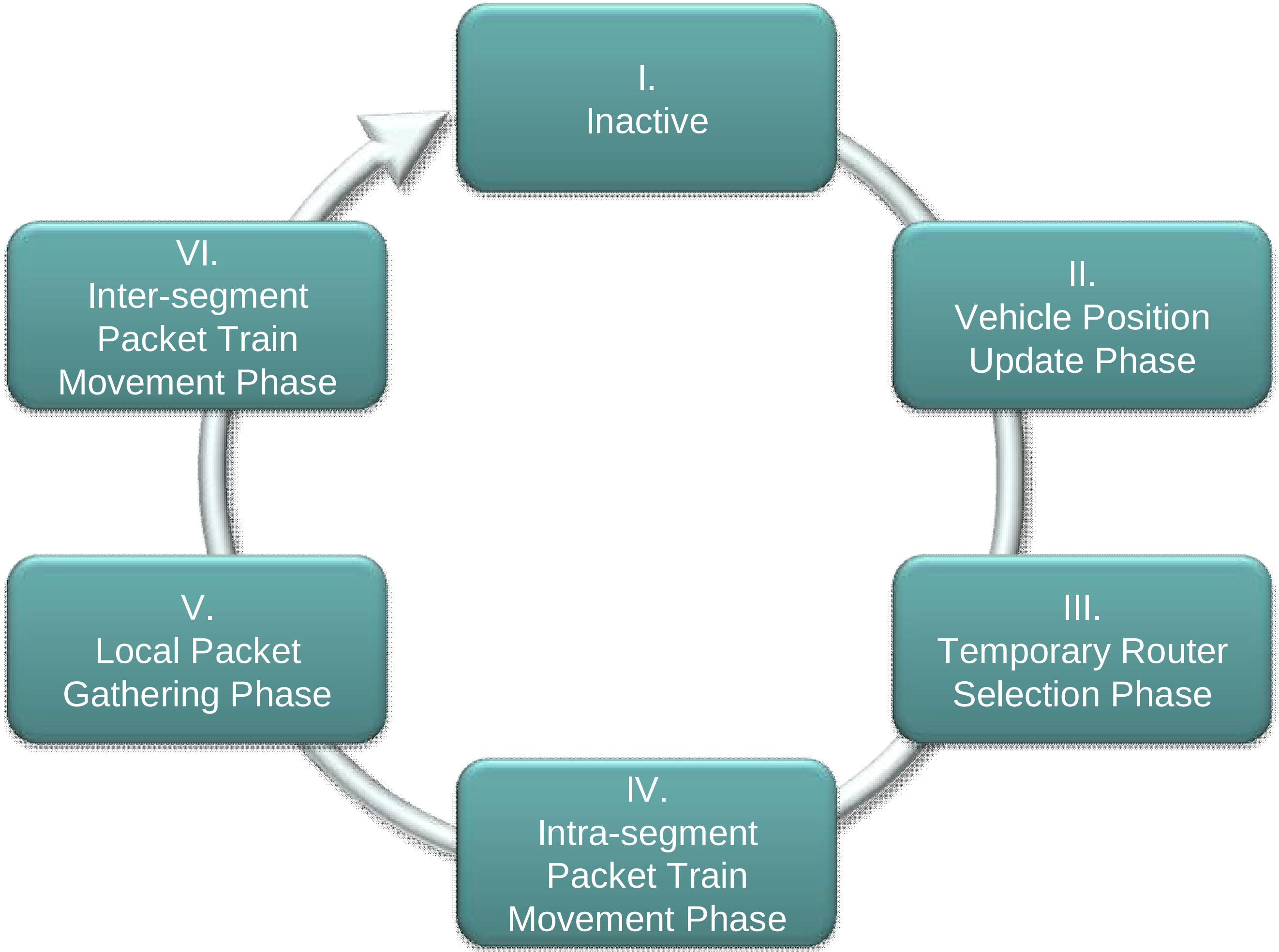
CVIA - Vehicle Position Update Phase



t_u ：A time interval reserved for position update packets (PUPs).
t_{PUP} ：The duration of a PUP.

Vehicles pick a random waiting time (RWT) from $[0,t_u-t_{PUP})$.
After an RWT, vehicles access the channel using DCF method of the IEEE 802.11 protocol.
The length of a PUP is short, RTS/CTS handshake is not used before sending PUP.

CVIA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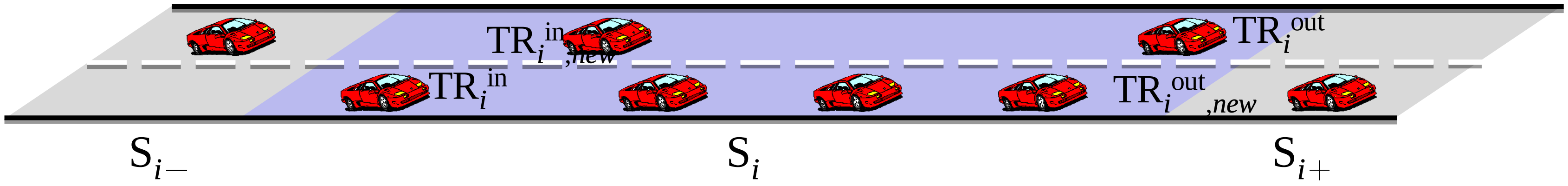
CVIA - Temporary Router Selection Phase



New TR_i^{in} and TR_i^{out} are selected by TR_i^{in}.

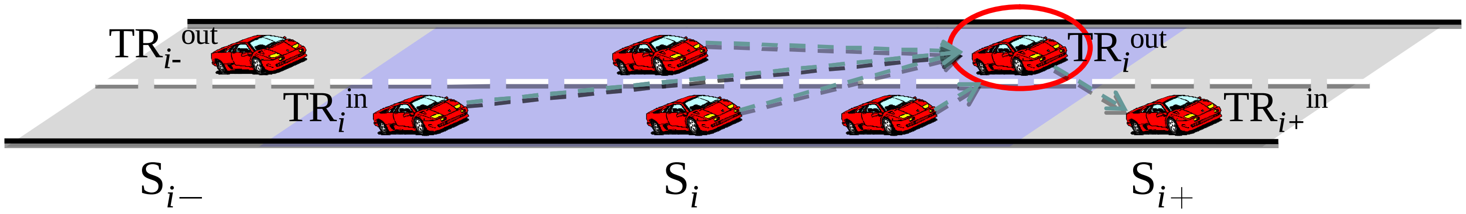
The selected routers are called $TR_i^{in}{}_{,new}$ and $TR_i^{out}{}_{,new}$ until they become active.

Use “router lifetime” and “safe area” concept.

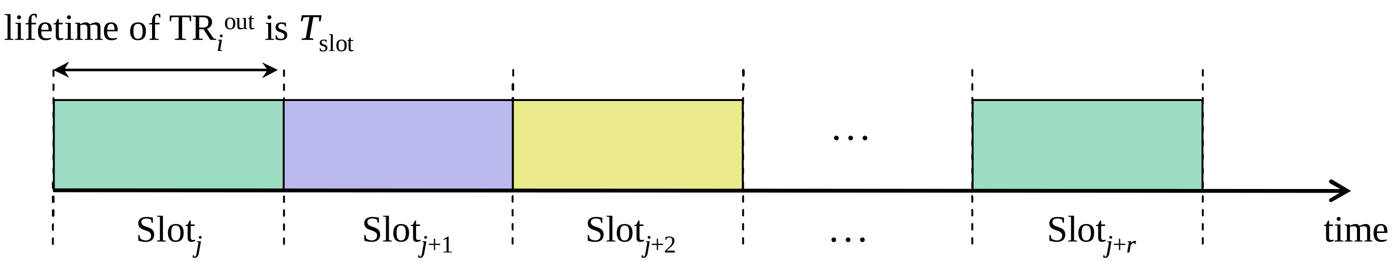
CVIA - Temporary Router Selection Phase

TR_i^{out} is responsible for

1. Receiving packet train relayed by TR_i^{in} .
2. Gathering local packets.
3. Creating a new packet train and sending this train out of S_i to TR_{i+}^{in} .



TR_i^{out} becomes active immediately and stays active until the end of TS_j .



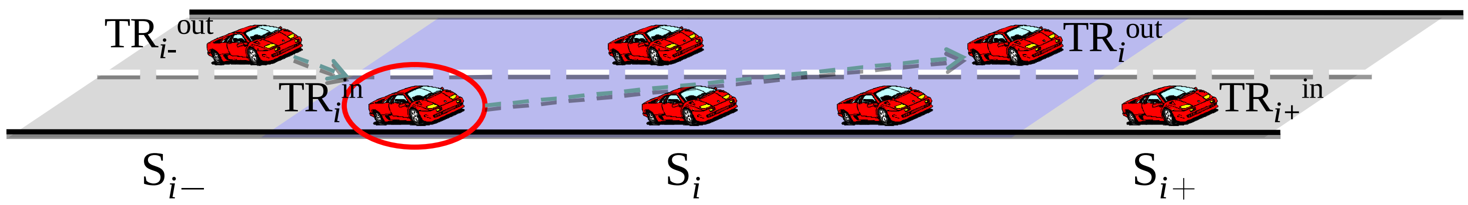
$x_{margin+,v} = (\Delta t_{pu,v} + 1 \cdot T_{slot}) \cdot V_{max}$

$\Delta t_{pu,v}$: The elapsed time since the last position update from vehicle v.

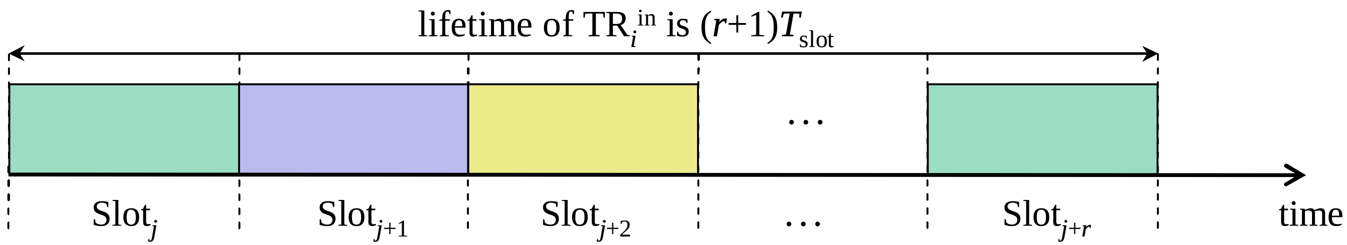
CVIA - Temporary Router Selection Phase

TR_i^{in} is responsible for

1. Receiving packet train coming from TR_{i-}^{out} in TS_{j+1}.
2. Selecting and announcing $TR_i^{in}{}_{,new}$ and $TR_i^{out}{}_{,new}$ at the beginning of TS_{j+r} .
3. Relaying the packet train to TR_i^{out} in TS_{j+r} (next active slot).



$TR_i^{in}{}_{,new}$ becomes active throughout TS_{j+1} and TS_{j+r} .



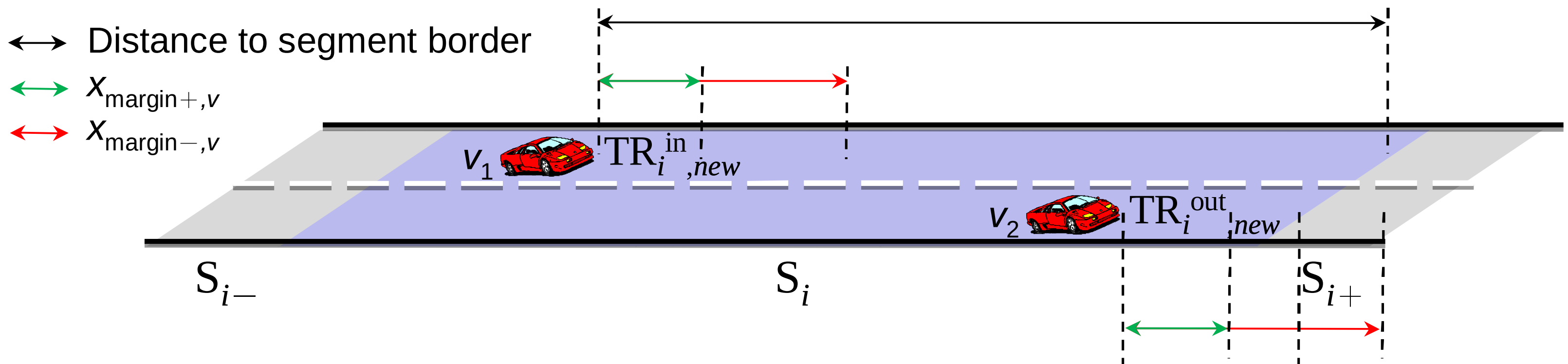
$x_{margin-,v} = (\Delta t_{pu,v} + (r+1) \cdot T_{slot}) \cdot V_{max}$

$\Delta t_{pu,v}$: The elapsed time since the last position update from vehicle v.

CVIA - Temporary Router Selection Phase

If vehicle v's distance to segment borders is more than $x_{margin+,v}$, the vehicle can safely be selected as $TR_{i}^{out}{}_{,new}$.

If vehicle v's distance to segment borders is more than $x_{margin-,v}$, the vehicle can safely be selected as $TR_{i}^{in}{}_{,new}$.



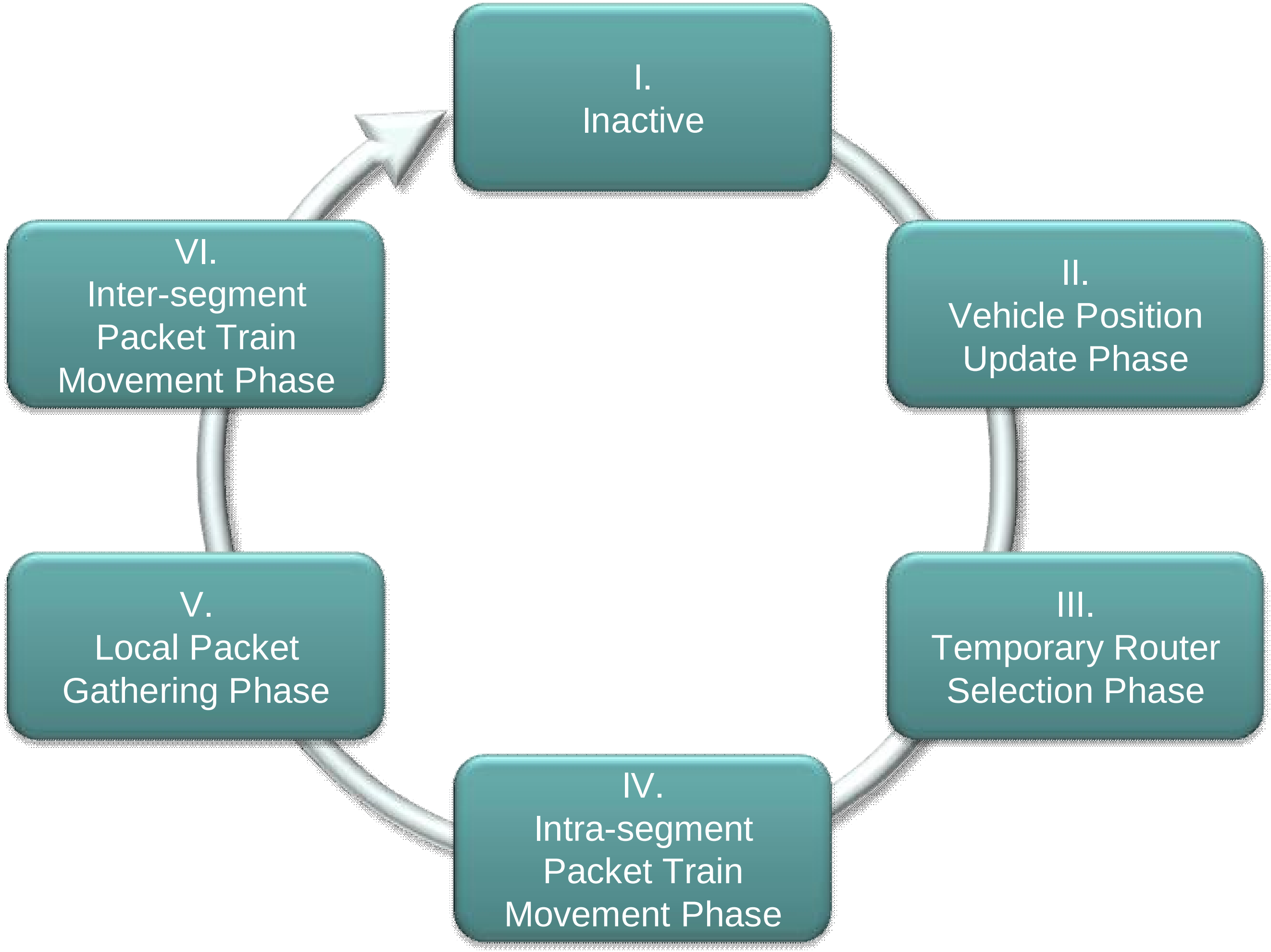
Among the vehicles inside the safe area, TR_i^{in} selects

the vehicle closest to S_{i+} as $TR_i^{out}{}_{,new}$ and

the vehicle closest to S_{i-} as $TR_i^{in}{}_{,new}$

$TR_i^{in}{}_{,new}$	v_1
$TR_i^{out}{}_{,new}$	v_1, v_2

CVIA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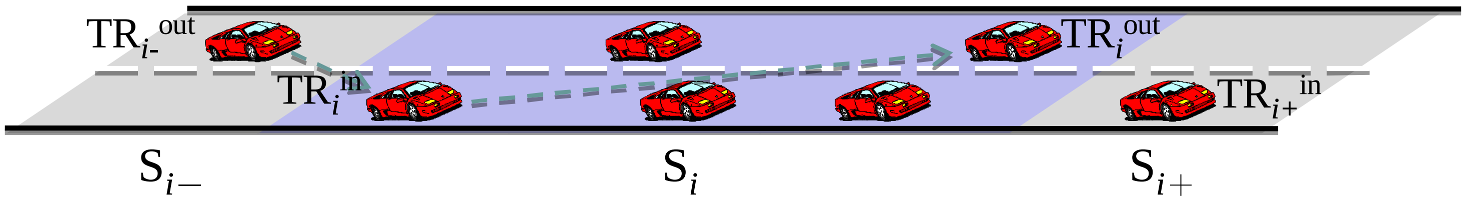
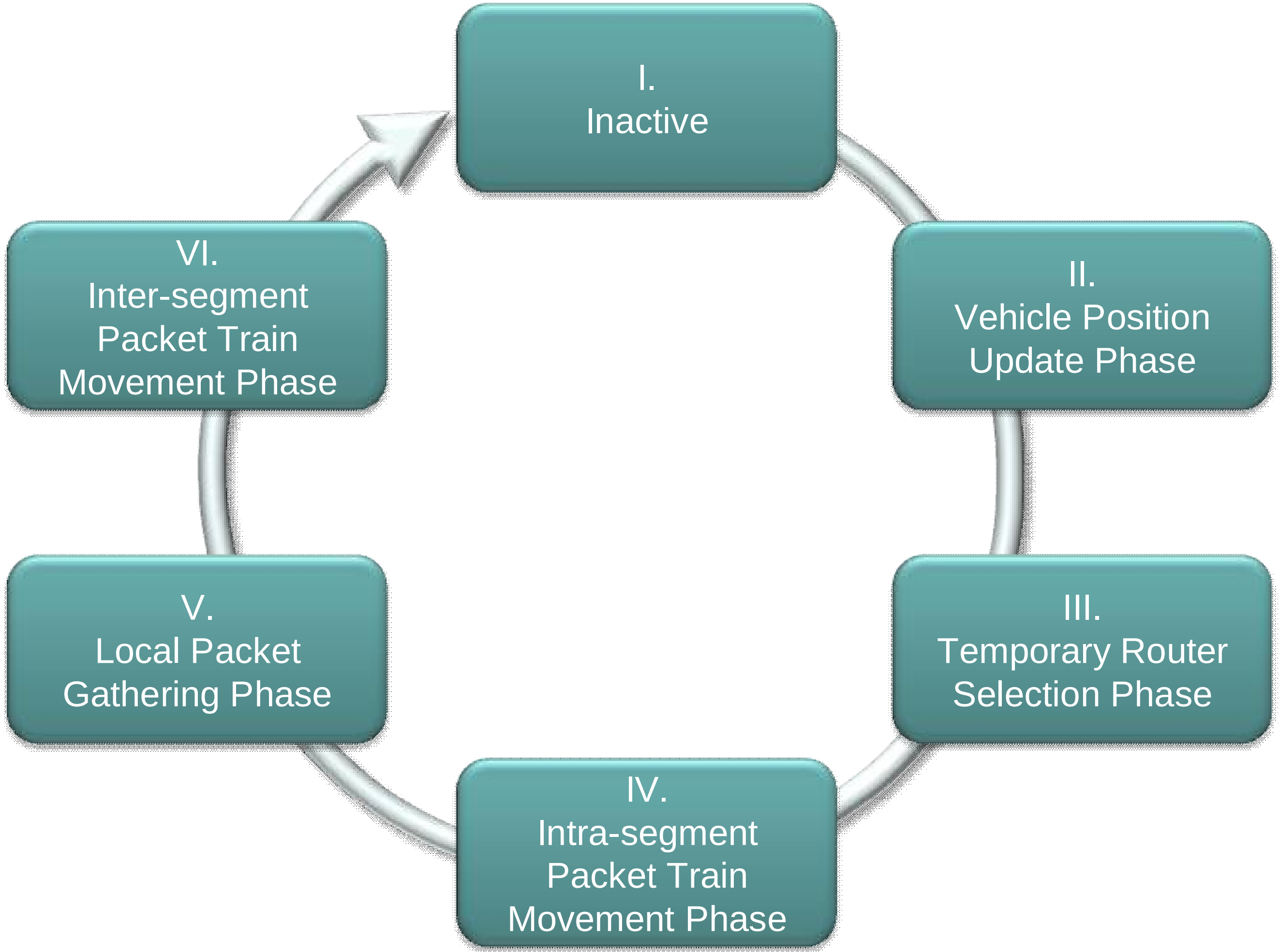
CVIA - Intra-segment Packet Train Movement Phase



TR_i^{in} delivering the packet train coming from S_{i-} to TR_i^{out} .

To avoid contention, TR_i^{in} has the highest access priority and waits only SIFS duration before accessing the channel.

CVIA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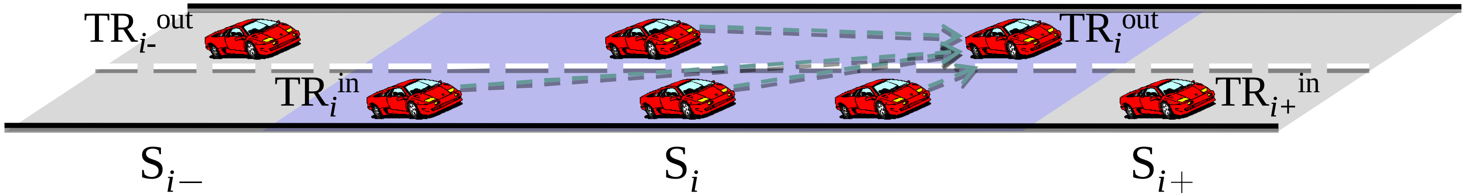
CVIA - Local Packet Gathering Phase

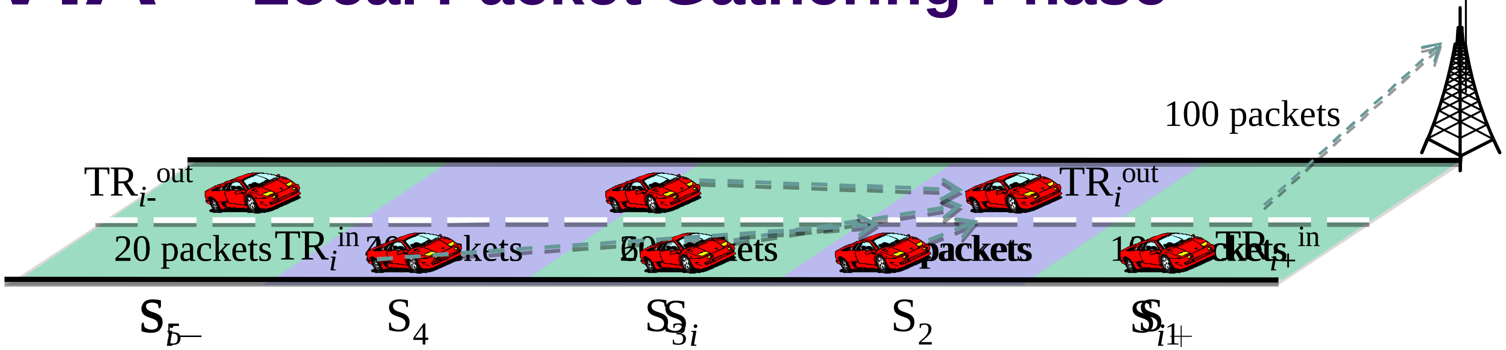


Vehicles directly send their packets to TR_i^{out} .

Each vehicle starts this phase with a random backoff counter.

TR_i^{out} has the highest channel access priority in this phase.

CVIA - Local Packet Gathering Phase

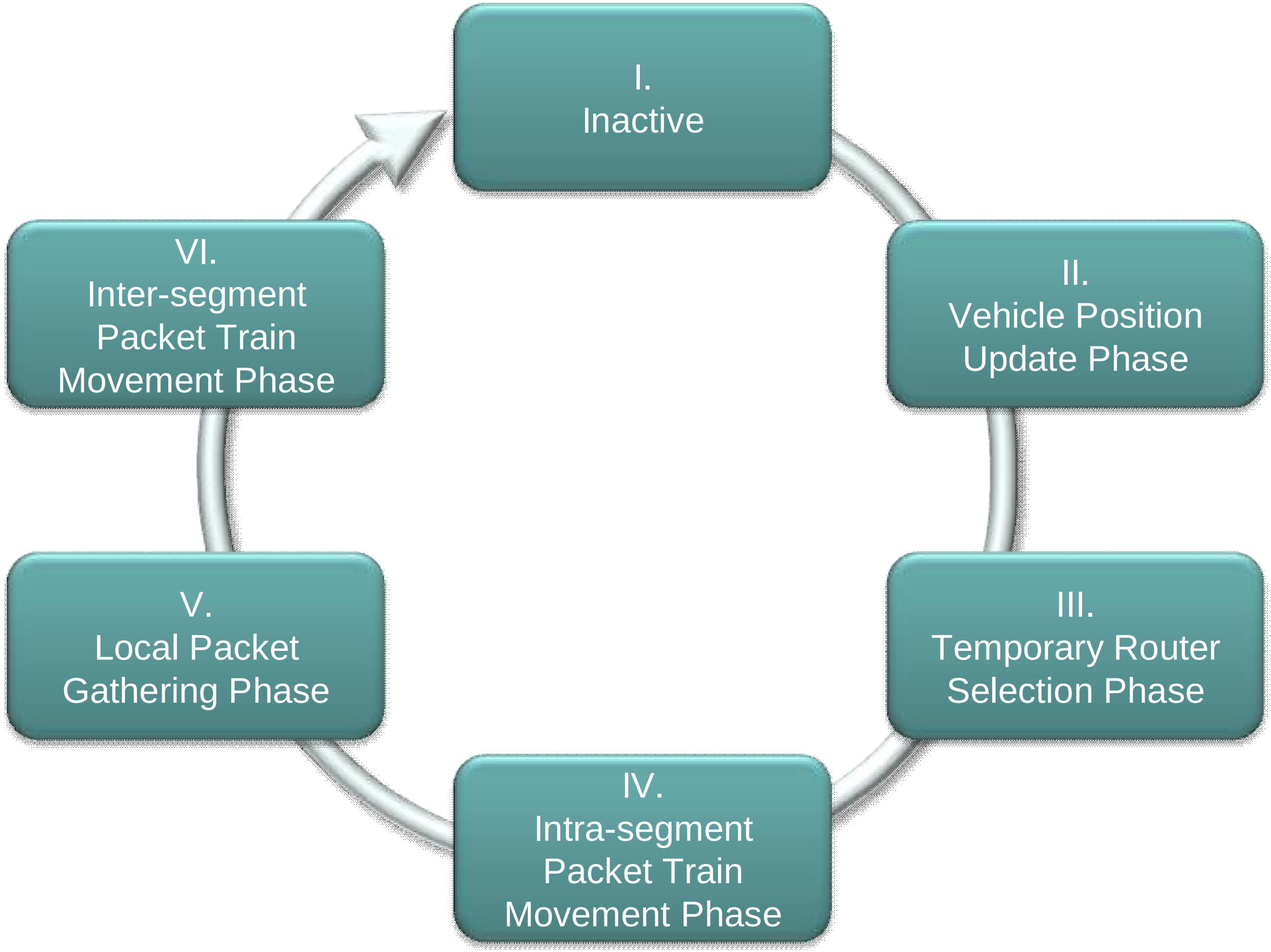


TR_i^{out} accesses the channel and ends the LPG phase in 2 cases：

1.When the total number of packets queued up in TR_i^{out} reaches $\left(\frac{C}{N}\right)(N-i+1)$.

2.When the time left in the active slot is just enough to move out all packets in the queues.

CVIA



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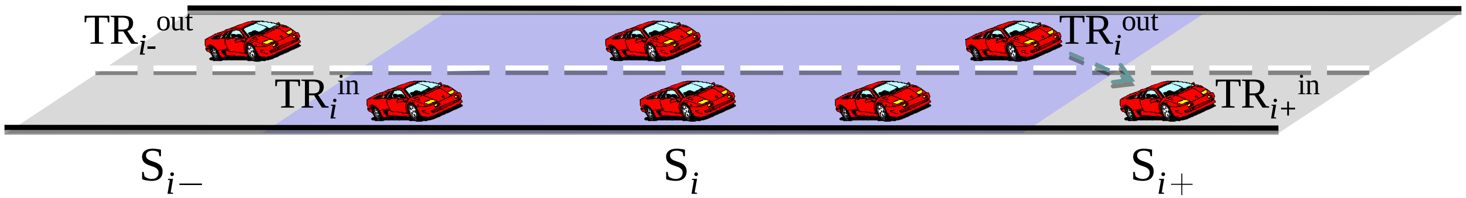
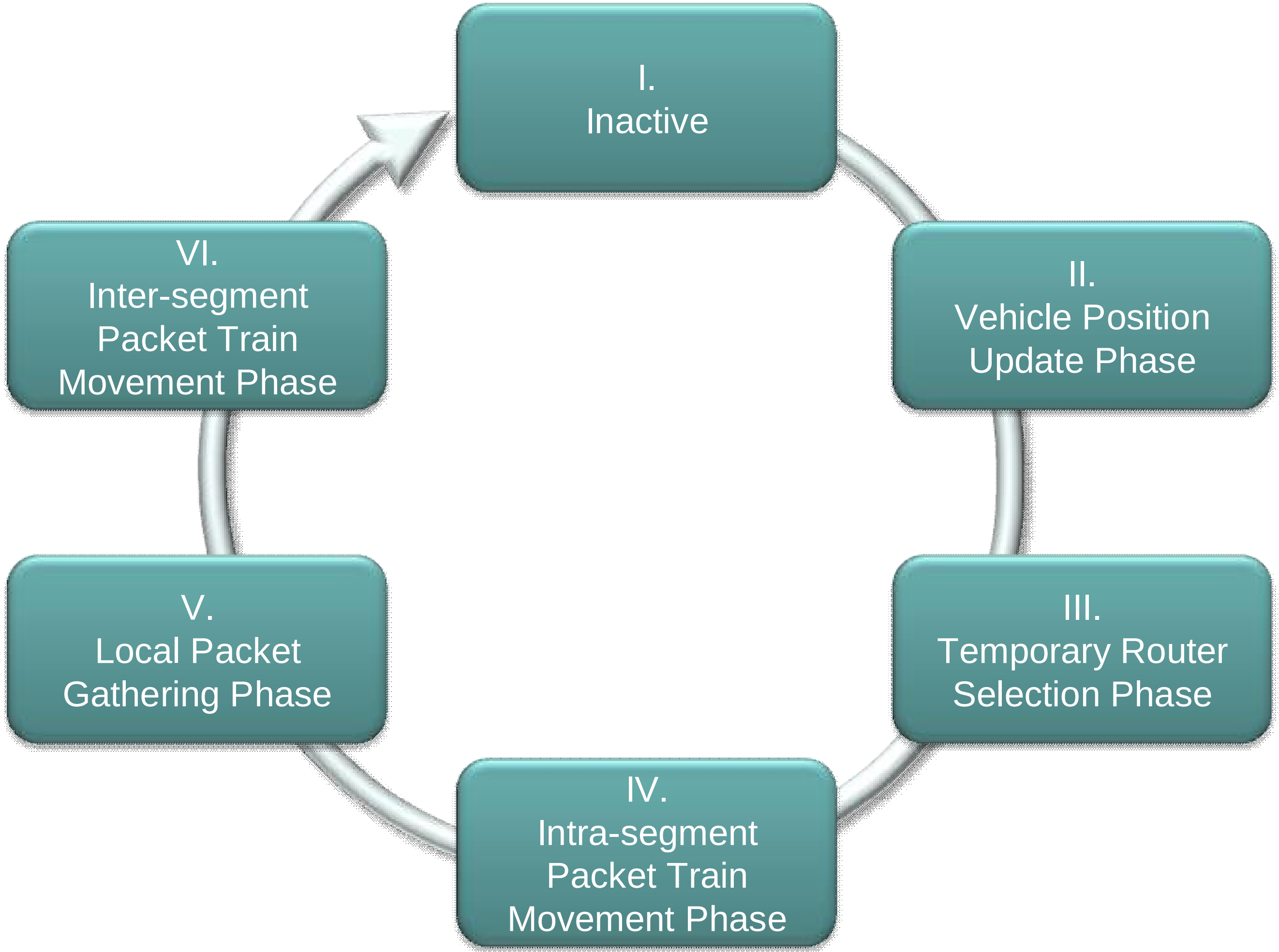
CVIA - Inter-segment Packet Train Movement Phase



TR_i^{out} forms a packet train and moved to TR_{i+}^{in} before the end of TS_j .

There is only one TR_{i+}^{in} in S_{i+}, TR_i^{out} does not need to specify the vehicle ID of the destination in the data train.

CVIA



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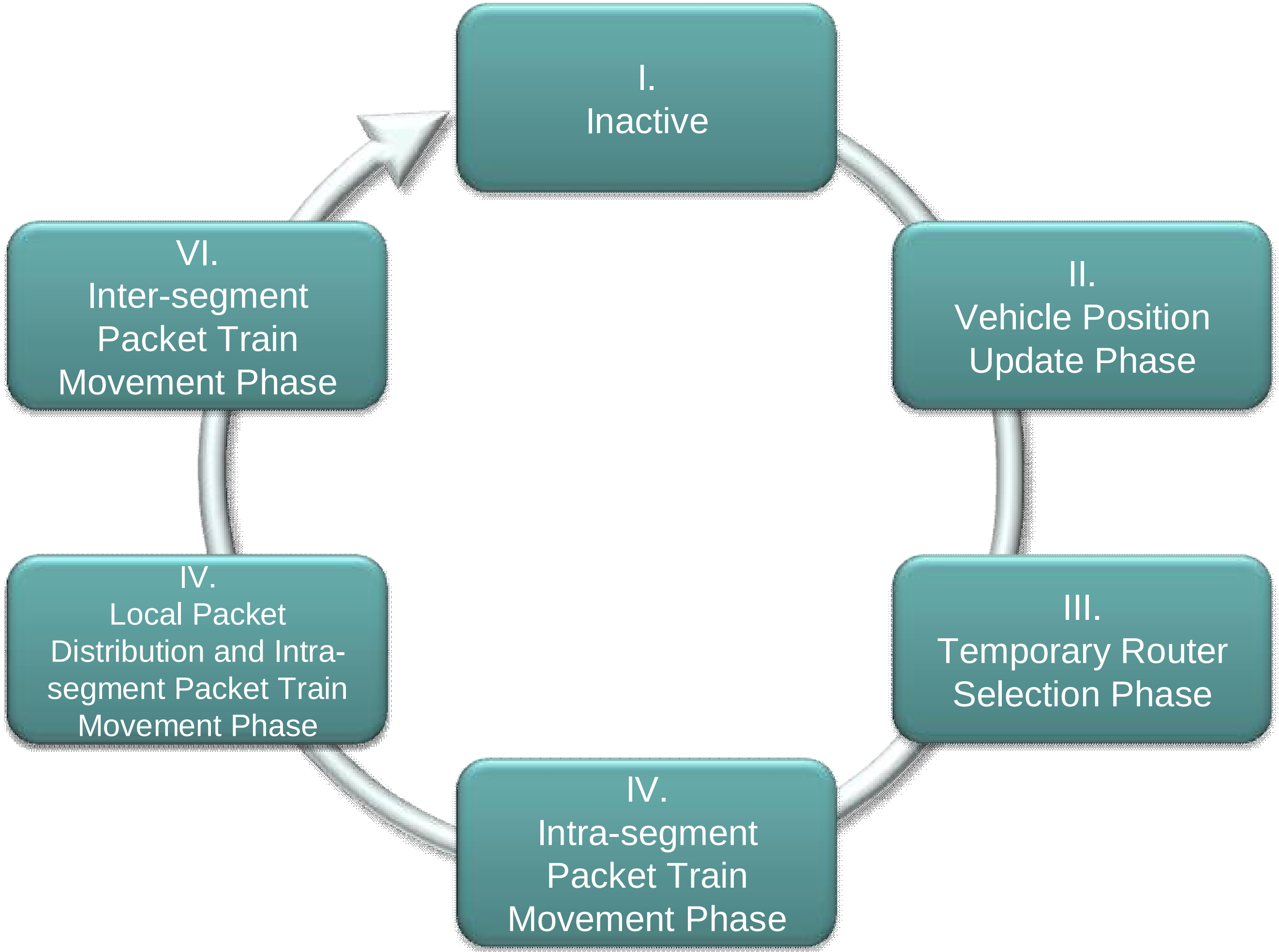
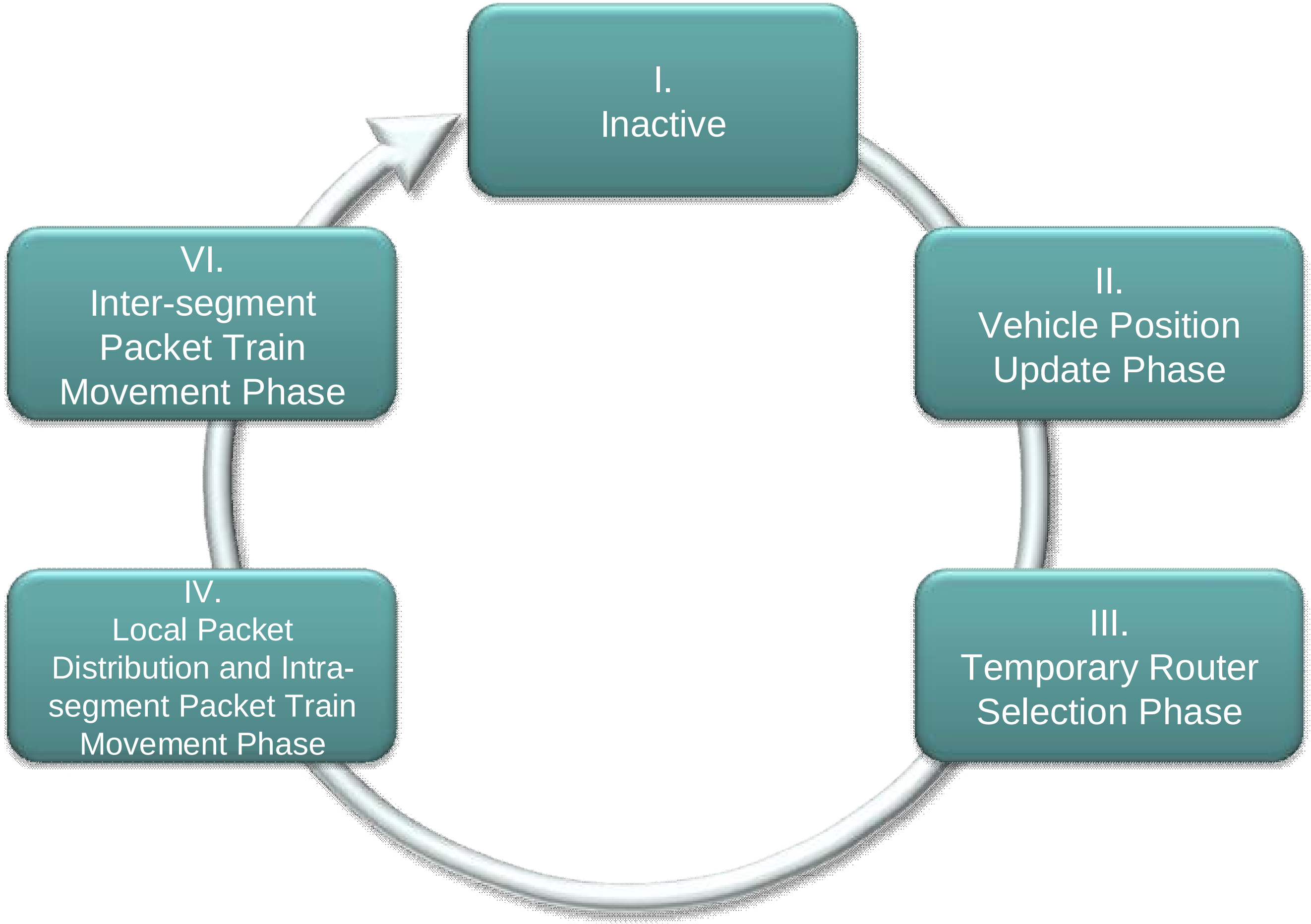
CVIA-State diagram-Download

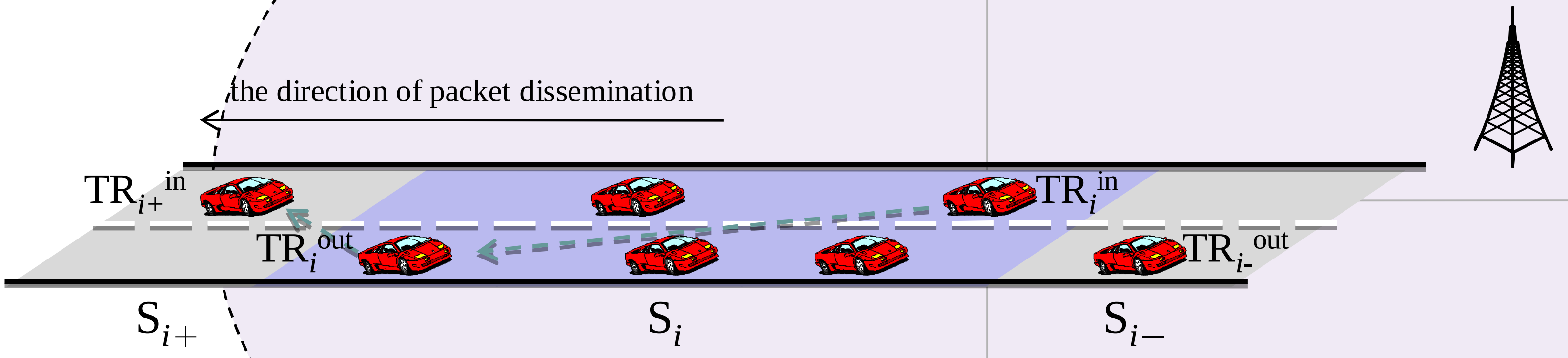


CVIA-State diagram-Download



CVIA - Download

Local Packet Distriburion and Intra-segment Packet Train Movement Phase



TR_i^{in} delivering the packet train coming from S_{i-} to TR_i^{out} .

Some packets leave the train, and a shorter train keeps moving away from the gateway.

Performance Evaluation

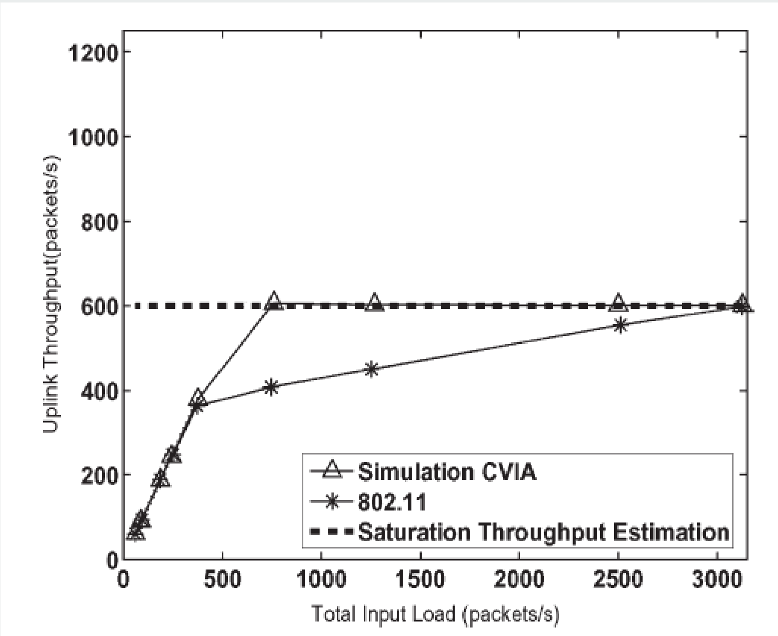
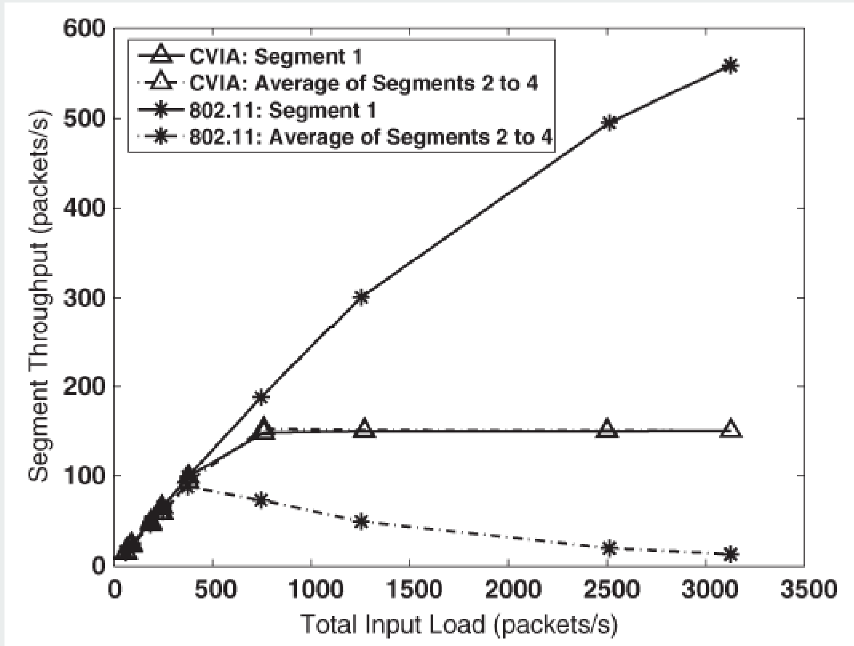
Simulation scenarios	
Density	34 vehicles/km
Speed	90 ±5 km/h (do not change during simulation)
Transmission range	350 m
Data rate	27 Mbps
Payload	2312 or 500 bytes
Base protocol	802.11a
Interference range to transmission range ratio	1
Maximum number of packet retrials	10
Simulation time	10 s
Simulation repetitions	20

Performance Evaluation

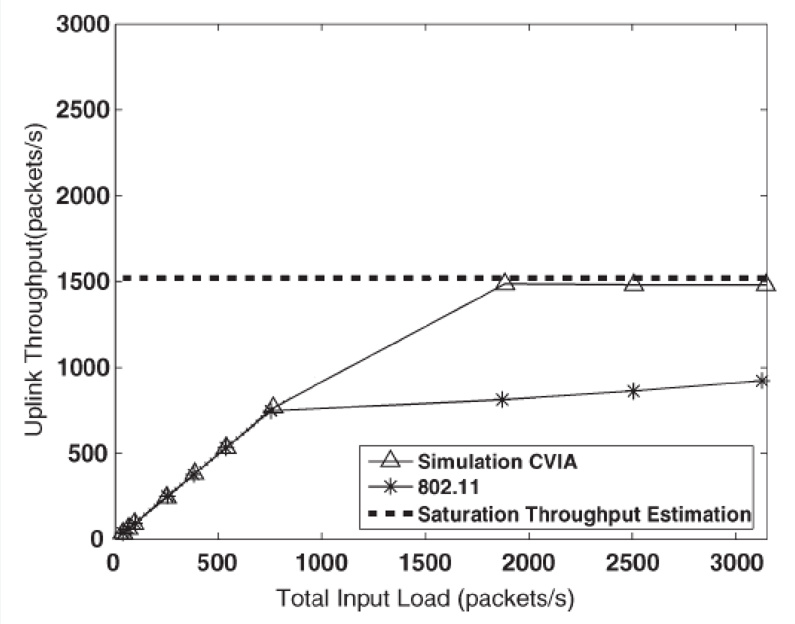
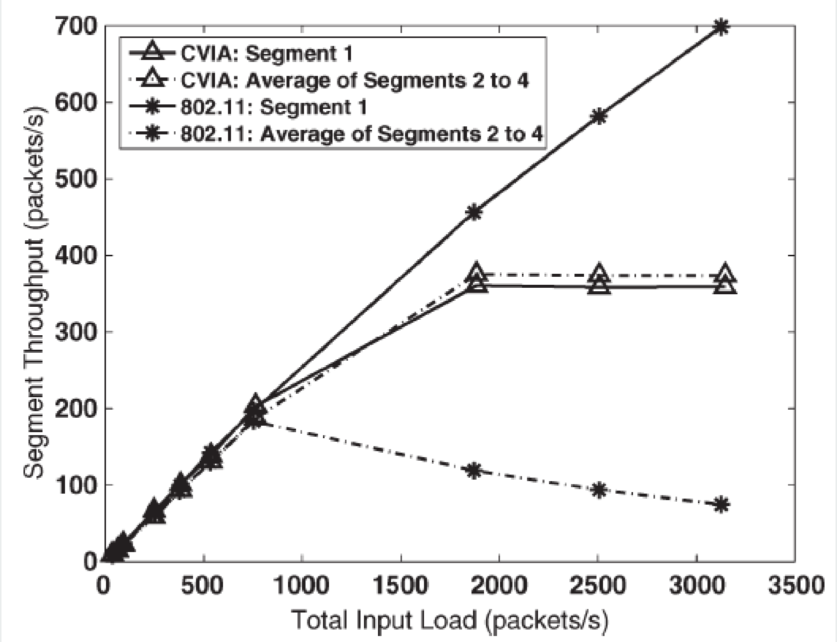
CVIA parameters	
T_{slot}	100 ms
N	4 or 8
r	2

Scenario	payload	VTR
I	2304 bytes	4R (N=4)
II	500 bytes	4R (N=4)
III	2304 bytes	8R (N=8)

Performance Evaluation

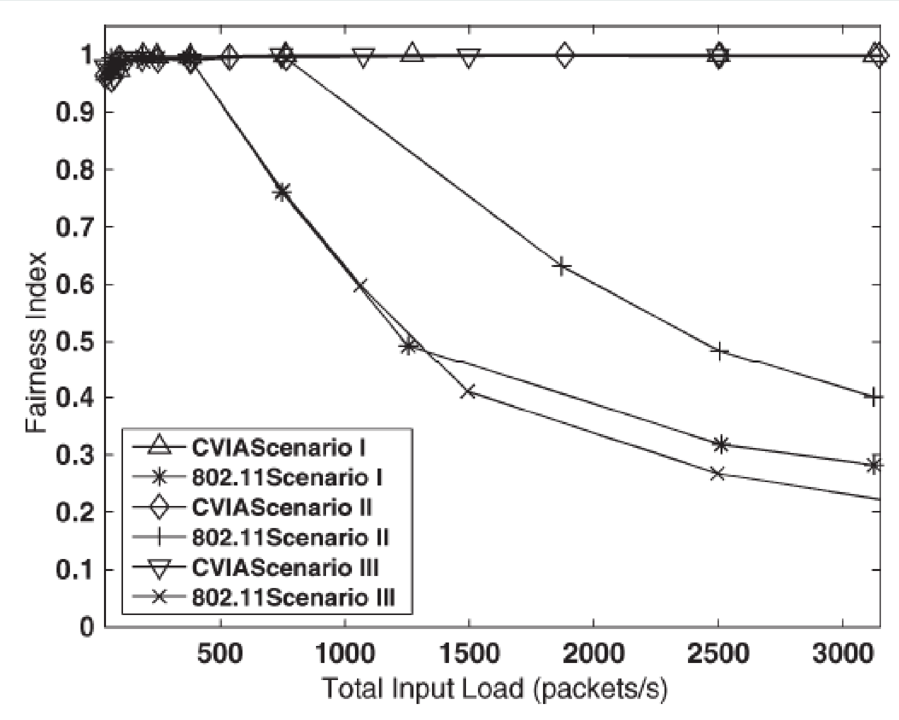
Scenario I	
Throughput	Detailed segment throughputs
	

Performance Evaluation

Scenario II	
Throughput	Detailed segment throughputs
	

Performance Evaluation

Fairness

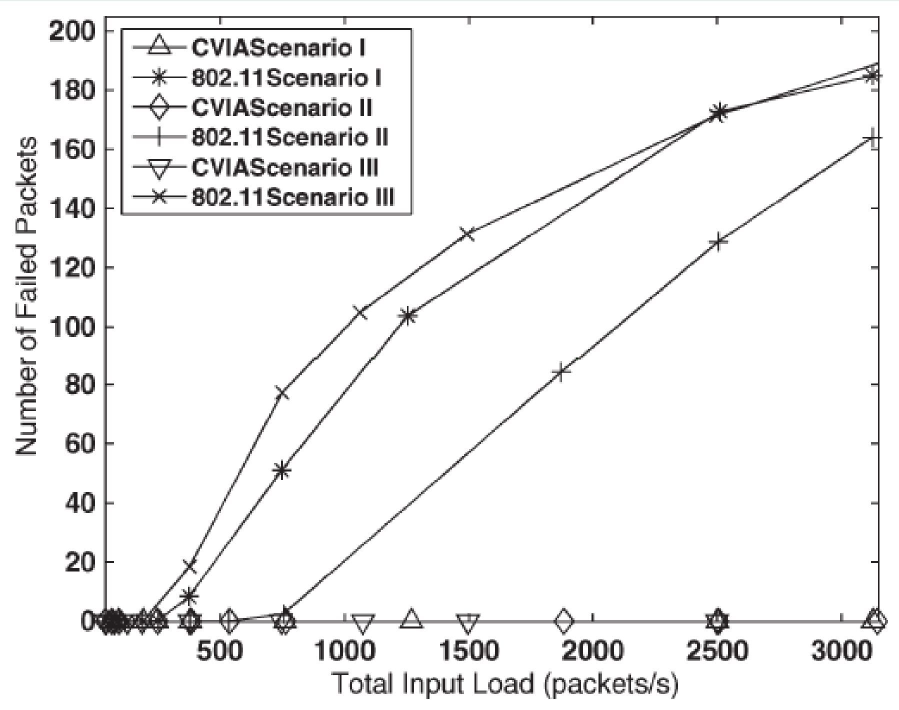


$$\text{Fairness Index (FI)} = \frac{\left(\sum_{i=1}^{N} \mathrm{Thr}_i\right)^2}{N \cdot \sum_{i=1}^{N} \mathrm{Thr}_i^2}$$

Thr_i : the throughput of segment i

Performance Evaluation

Failed packets



In LPG phase, the contention-based channel access is used.

Probability of packet collision ≈ 0.3

Probability of packet dropping ≈ 0.3^{10}
≈ 5×10^{-6}

Conclusion

- Mitigates the hidden node problem.
- Avoids contention while moving packets among road segments.
- Provides fairness among segments by controlling the contents of the packet trains.
- Unnecessary RTS/CTS overhead while moving packets among road segments.
- The throughput gain obtained using the proposed CVIA protocol is higher for short payload scenario.

Self-Configuring TDMA Protocols for Enhancing Vehicle Safety With DSRC Based Vehicle-to-Vehicle Communications

Fan Yu and Subir Biswas

Department of electrical and computer engineering, Michigan State University

IEEE Journal on Selected Areas in Communications, JSAC 2007

Outline

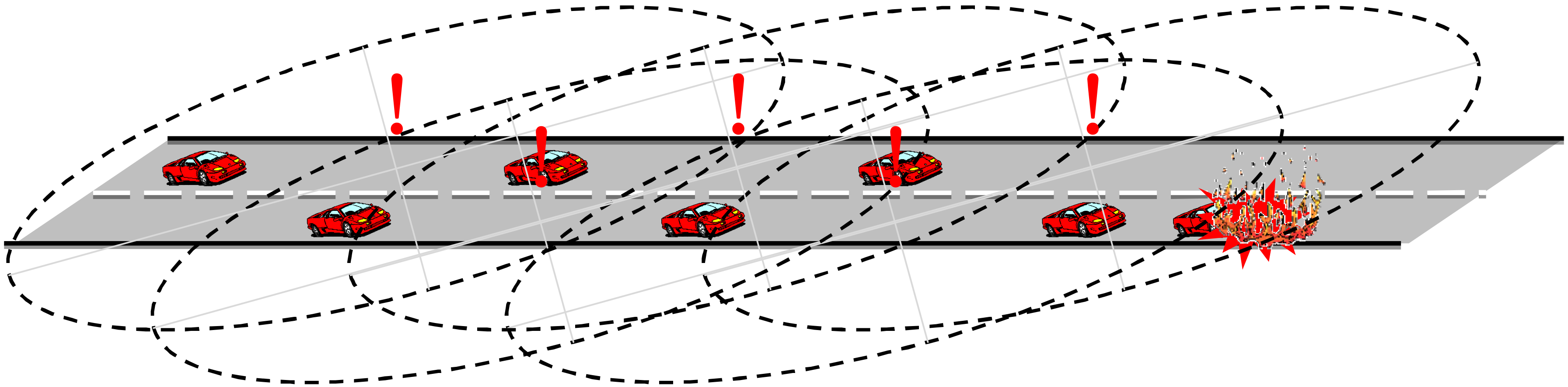
- Introduction
- *VeSOMAC* MAC protocol
- Simulation
- Conclusion

Introduction

- The ITS architecture is currently being developed for enhancing vehicle safety using V2V and V2R communications.
- DSRC is a communication standard for ITS.
- IEEE 802.11a is recommended as the MAC for DSRC.
- It suffers from unbounded delivery latency at higher loads because of the underlying random access.
- This implies that 802.11a may not be able to provide the required message delivery latency for a delay-sensitive ITS safety application

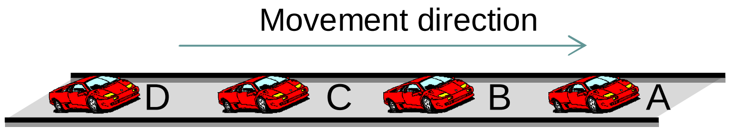
Goal

- Propose a MAC protocol for distributed TDMA allocation in V2V wireless networks.
  - Minimizing the multi-hop delivery delay.
  - Fast reconfiguration during frequent topology changes.
  - Can work without network time synchronization.

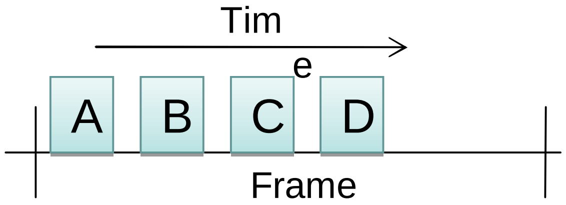


Network Assumption

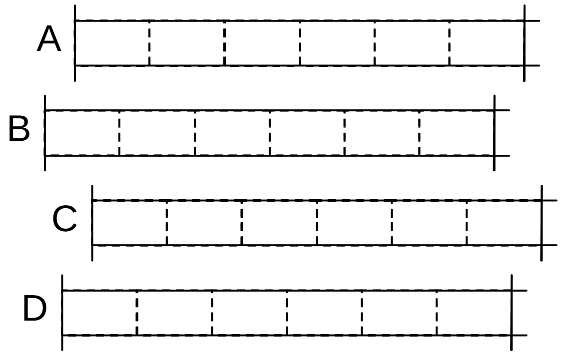
- Each vehicle is equipped with GPS devices used for obtaining vehicle positions and speed.
- Uni-direction



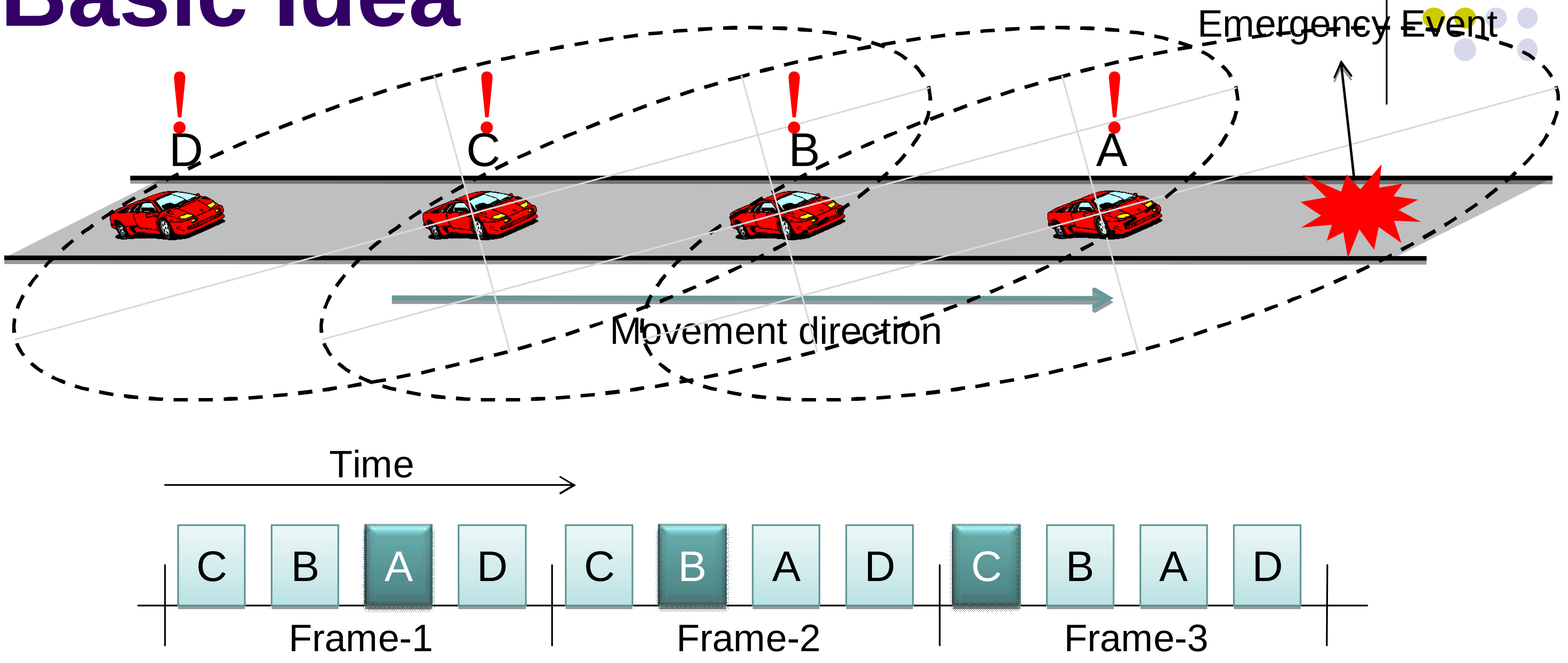
- Each vehicle allocated one slot in one frame.



- Asynchronous

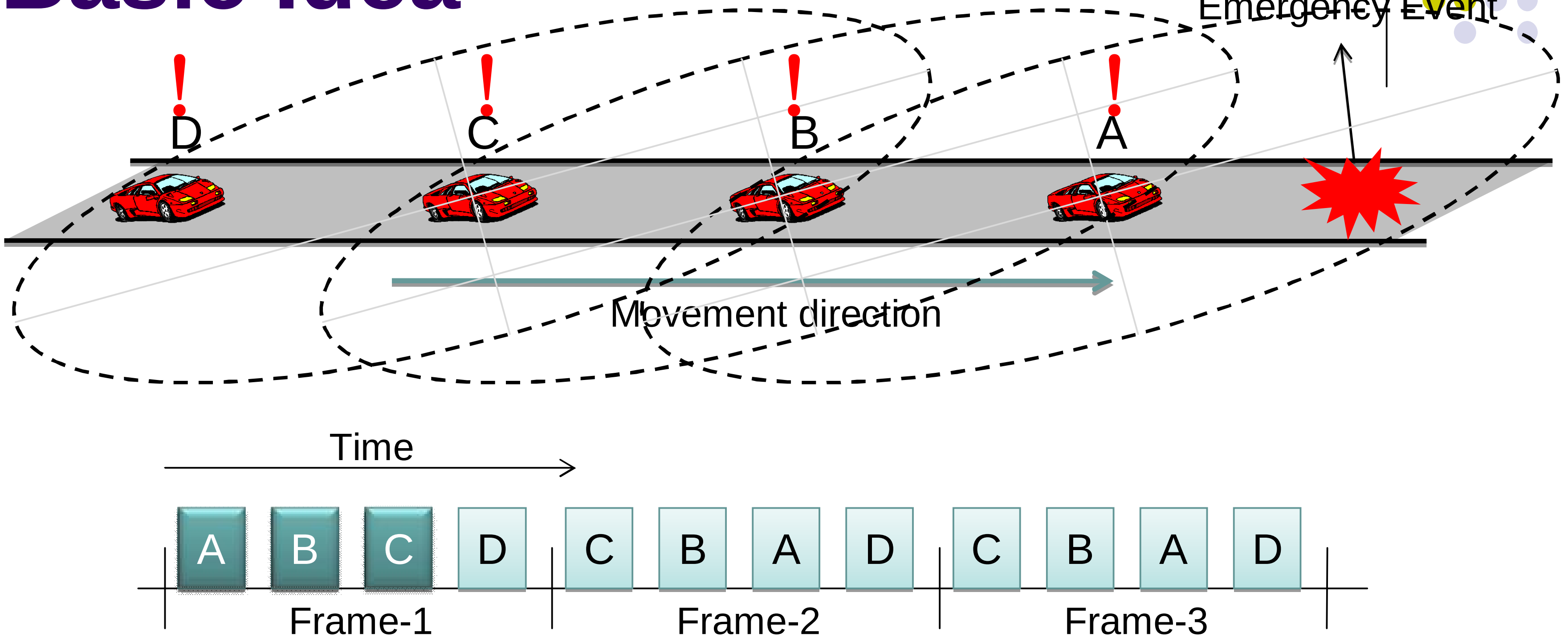


Basic Idea



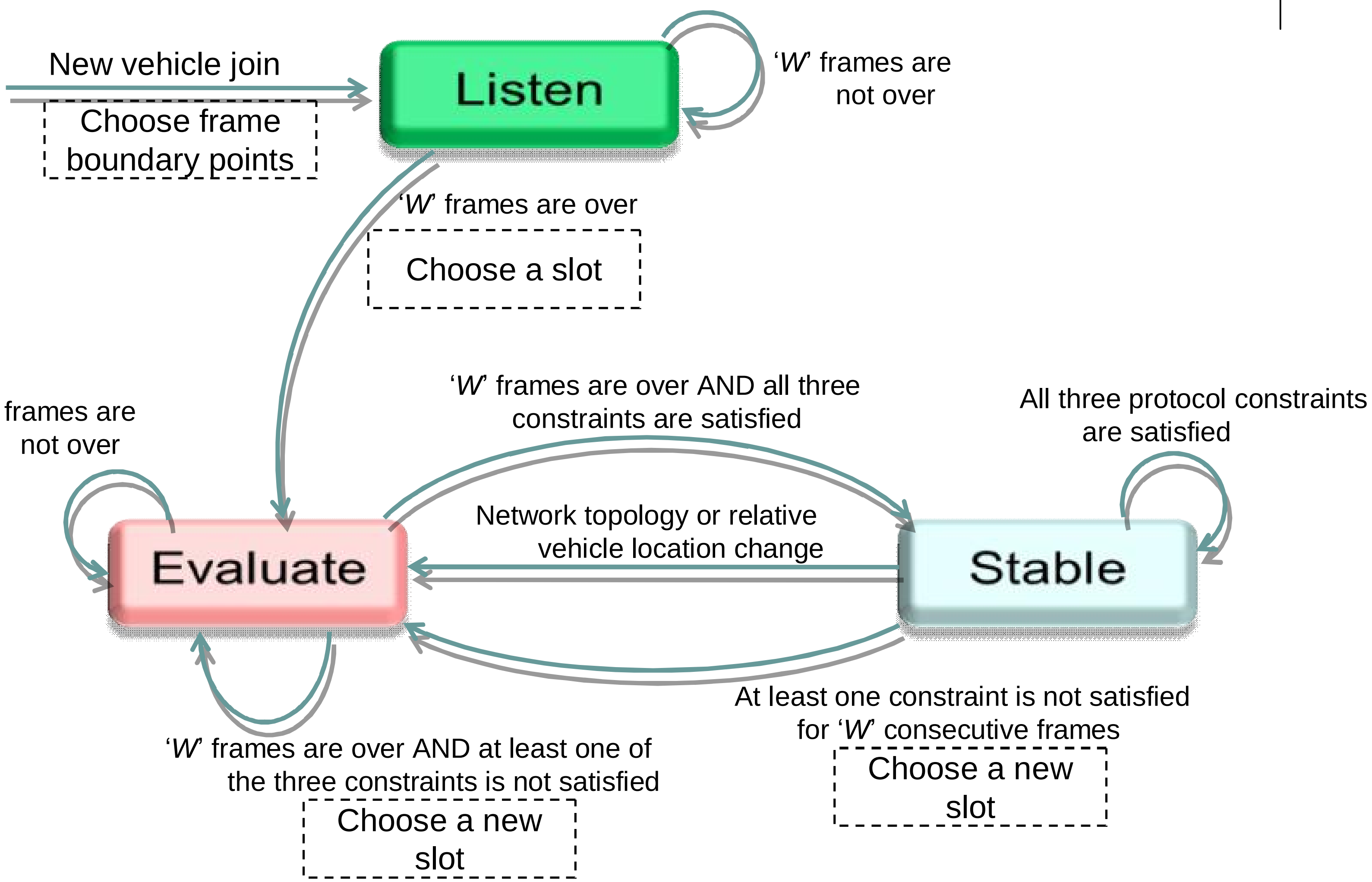
Need 3 Frames

Basic Idea



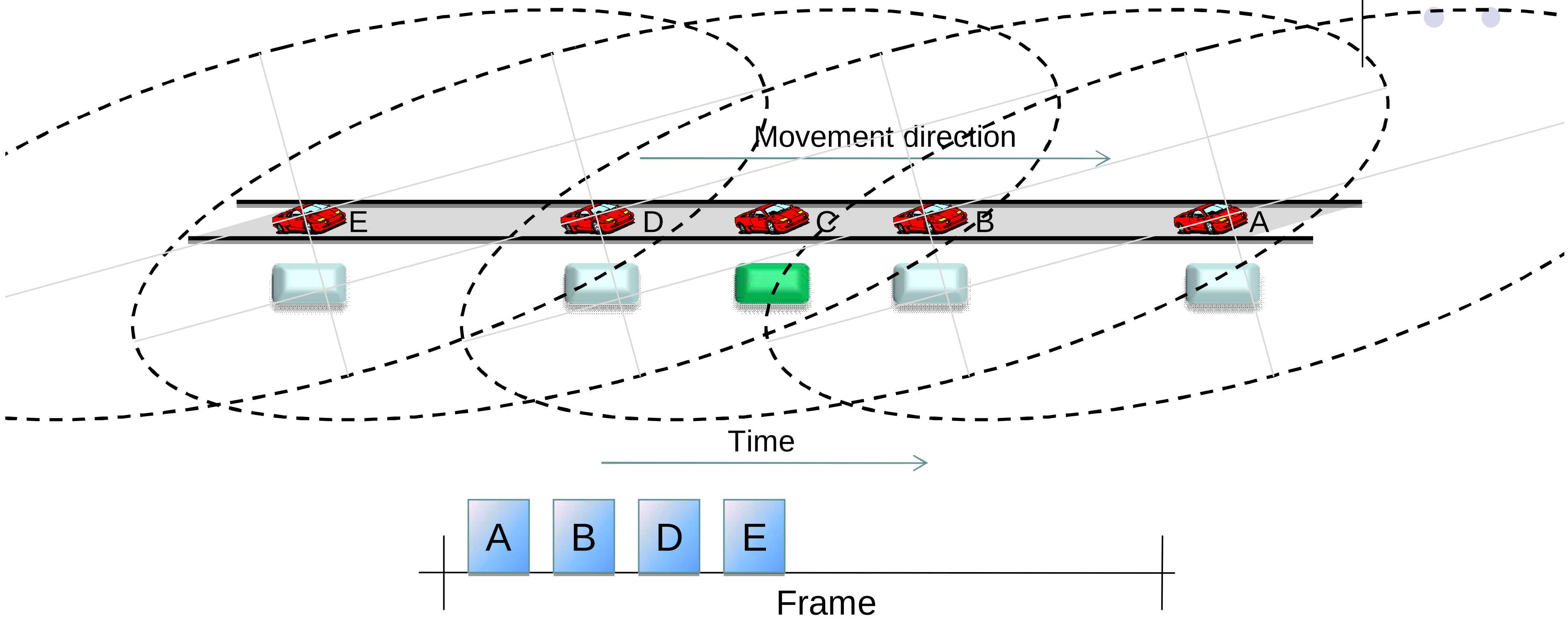
Need 1 Frame

Protocol State Machine



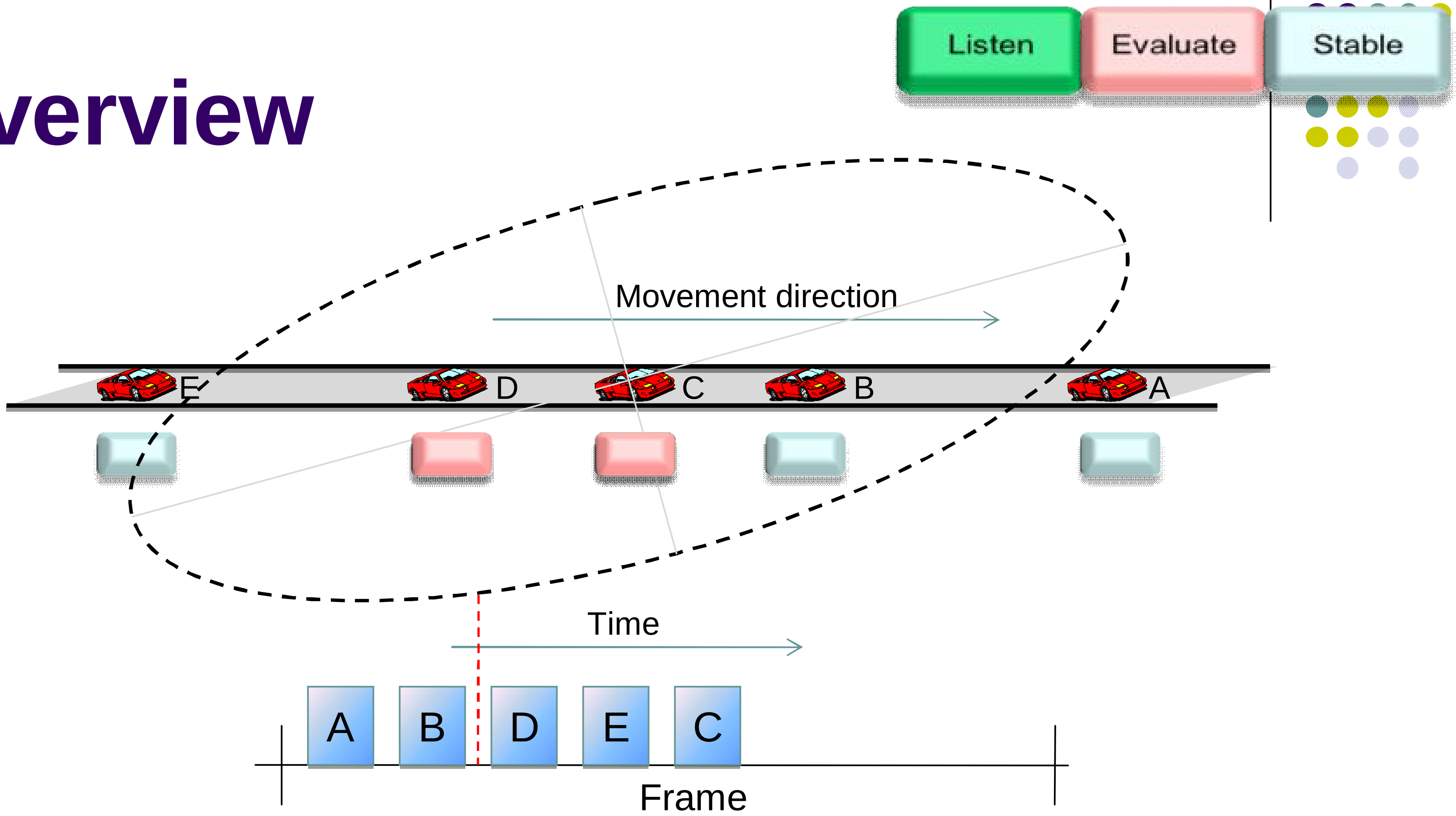
Overview

Listen
Evaluate
Stable



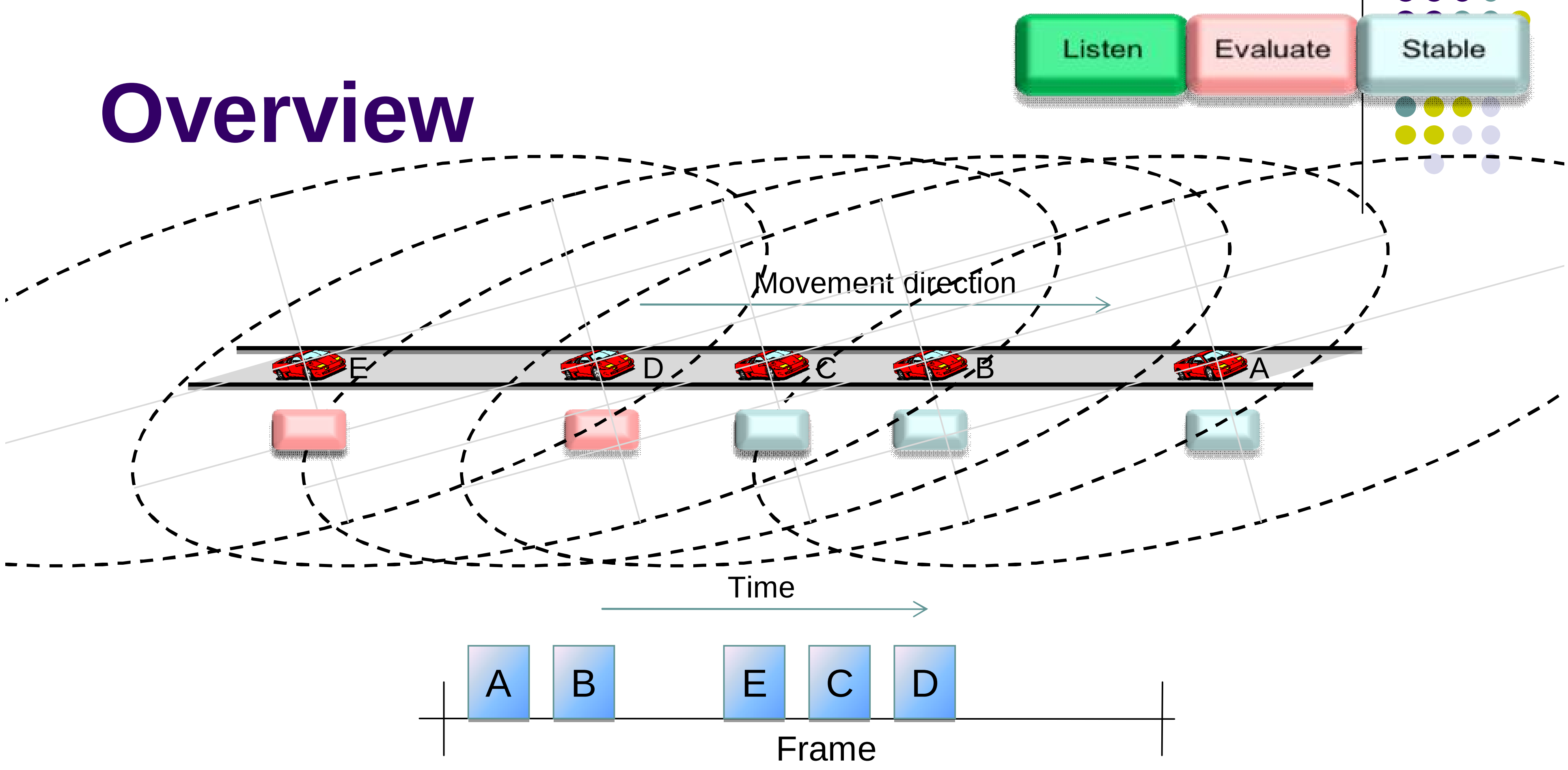
Movement direction
E
D
C
B
A
Time
A
B
D
E
Frame

Overview



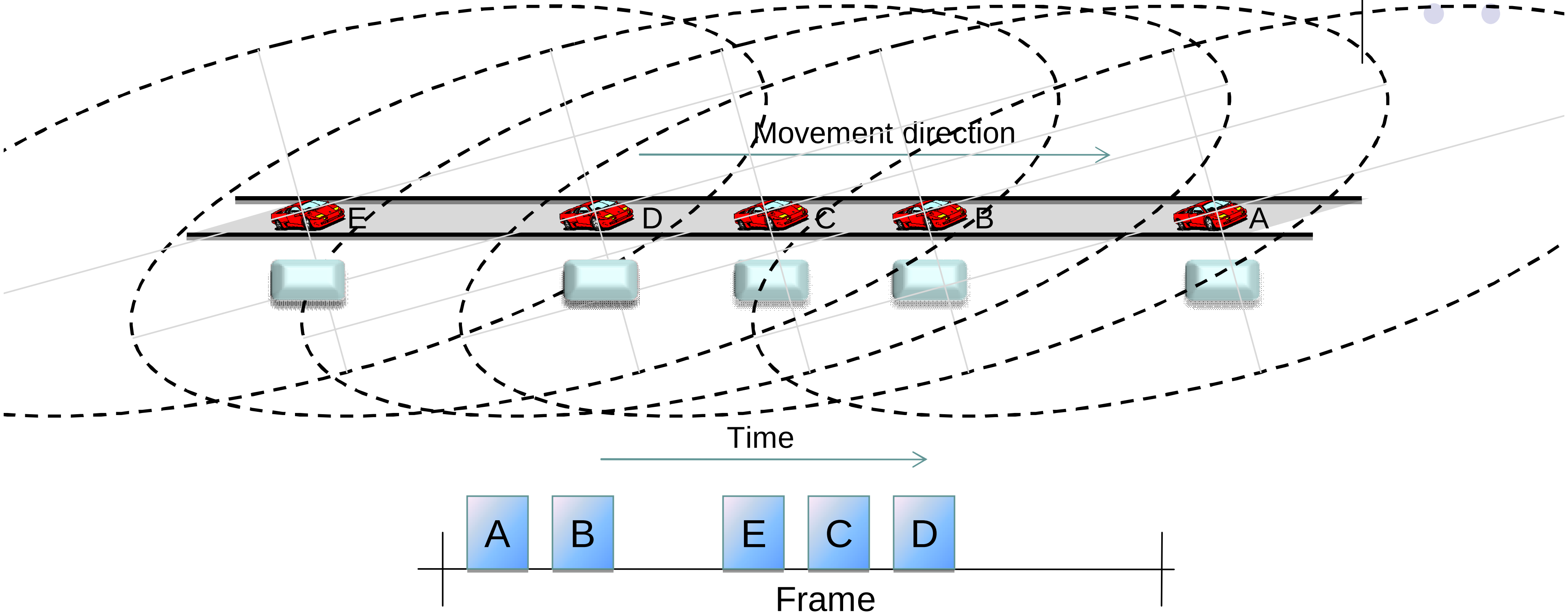
Listen
Evaluate
Stable
Movement direction
E
D
C
B
A
Time
A
B
D
E
C
Frame

Overview

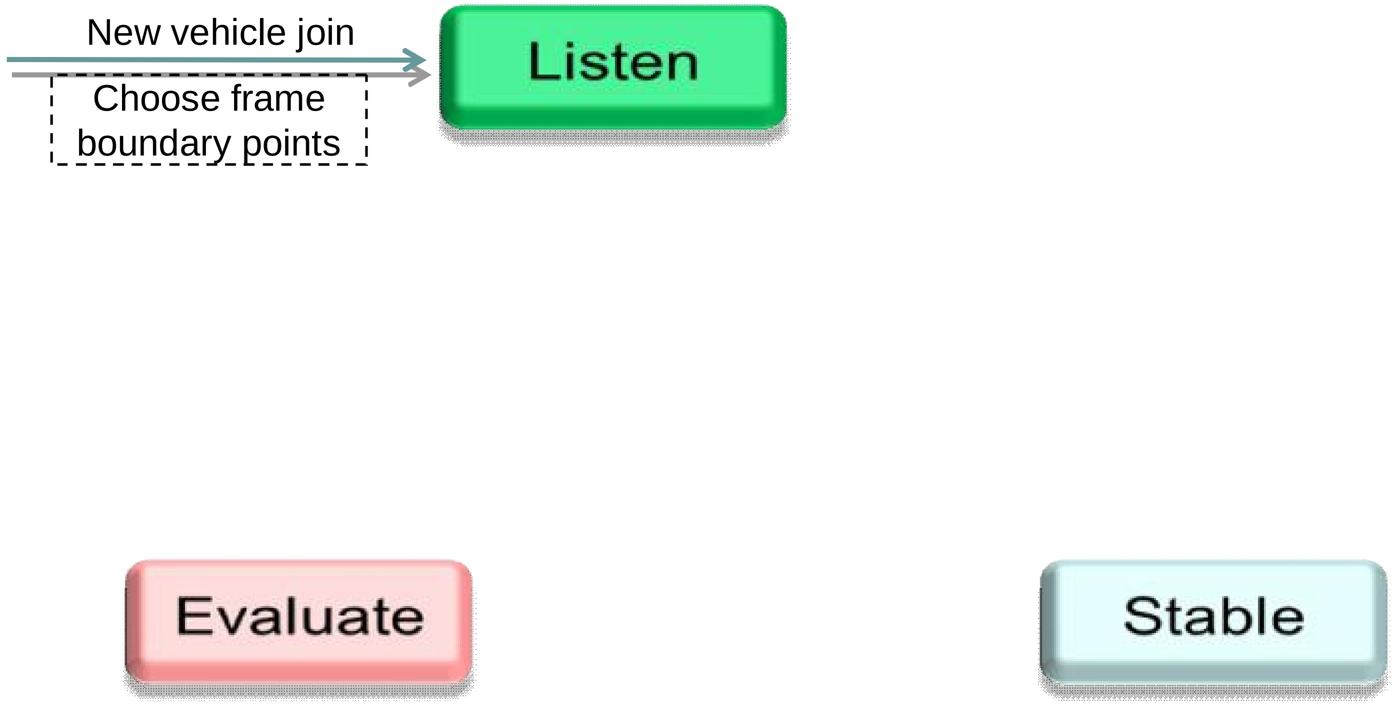

Listen
Evaluate
Stable
Movement direction
E
D
C
B
A
Time
A
B
E
C
D
Frame

Listen Evaluate Stable

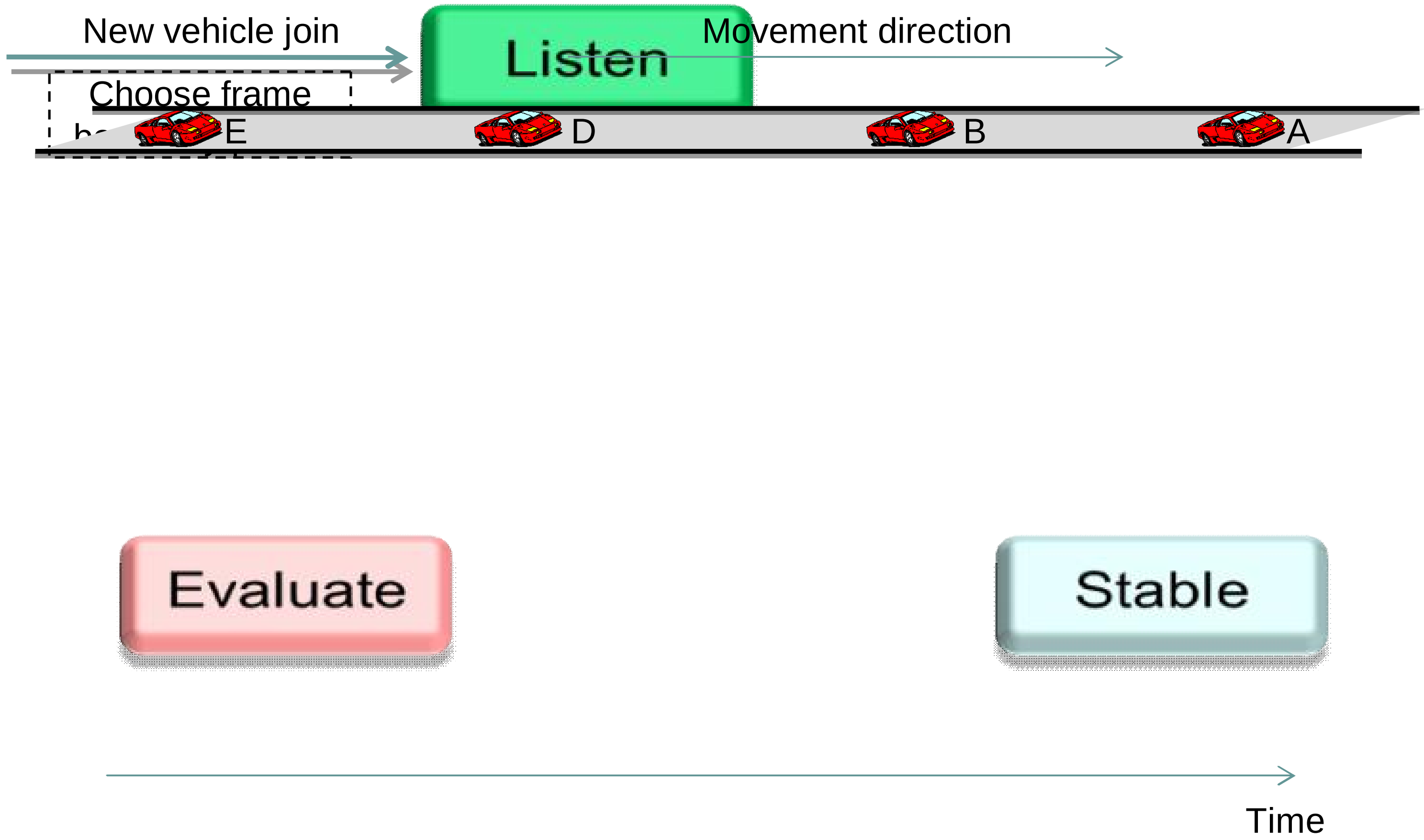
Overview



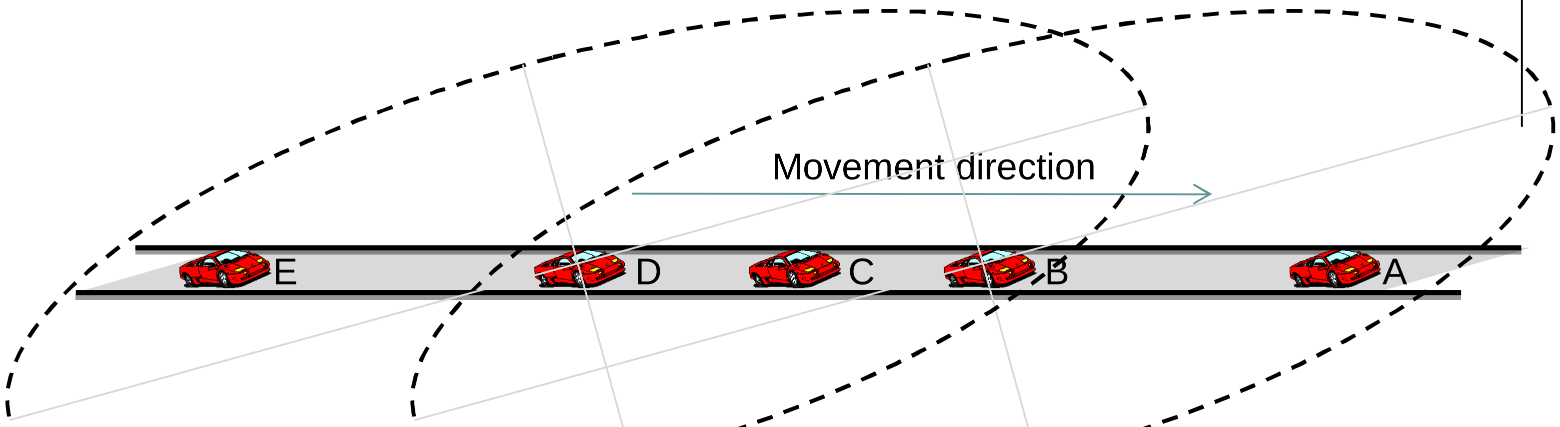
Protocol State Machine



Protocol State Machine

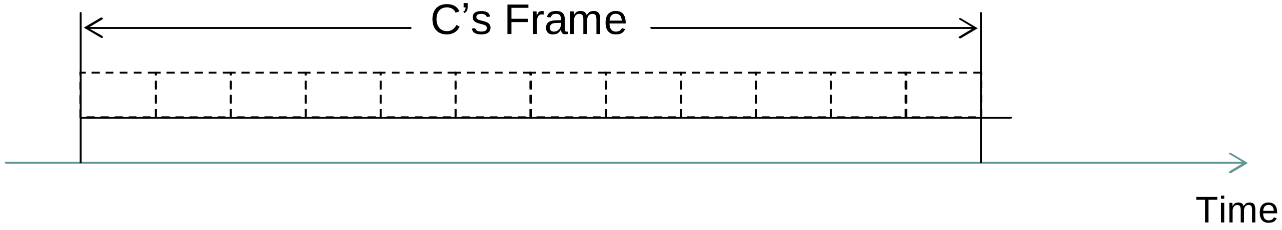


Listen



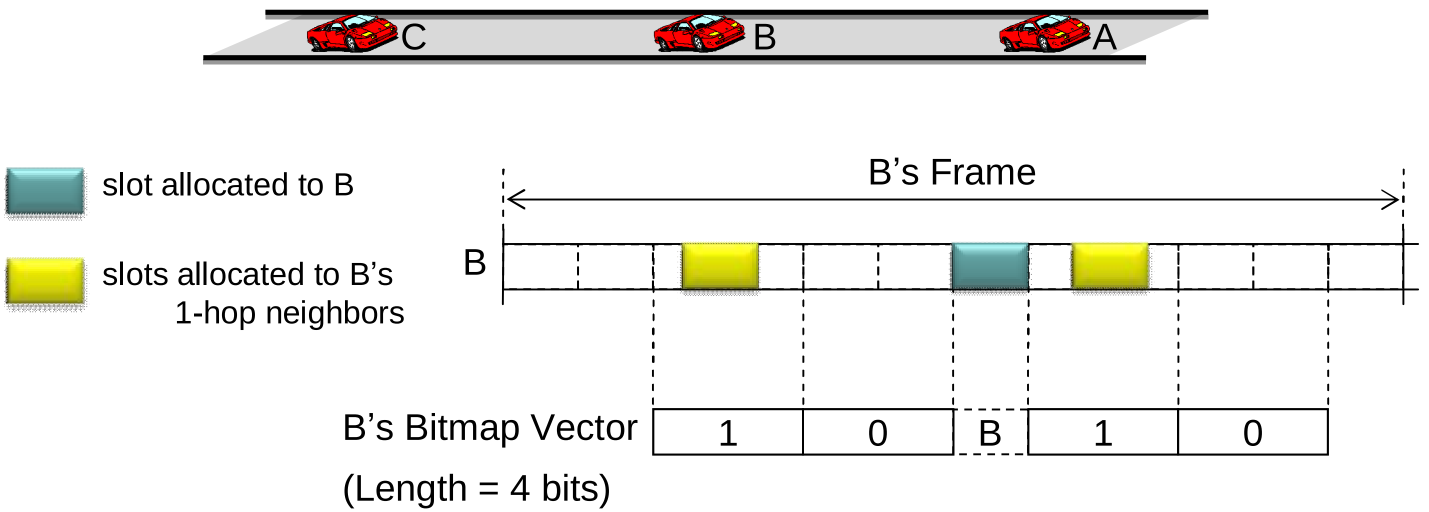
Receive the packets from 1-hop neighbors:

1. Location
2. Allocated slot
3. Bitmap

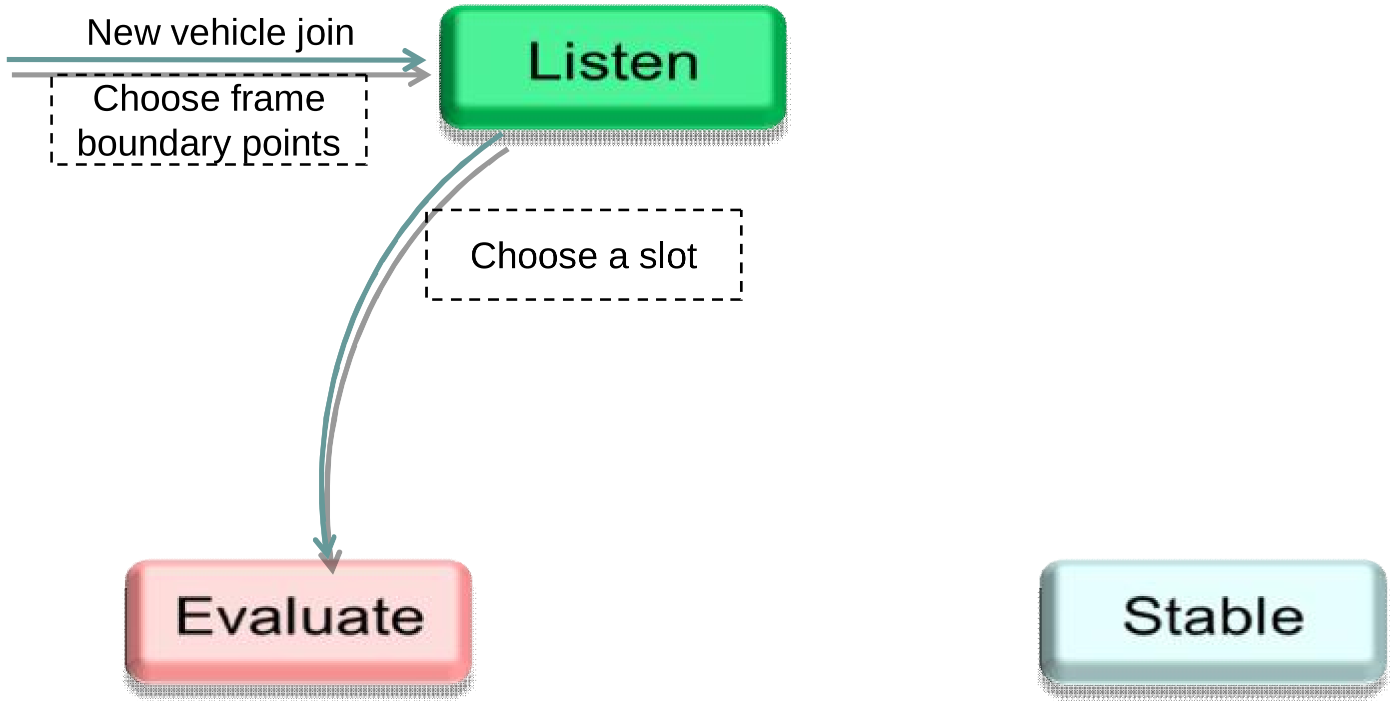


Bitmap

- Informs vehicle's 1-hop neighbors about the slots occupied by its 1-hop neighbors.
- By listening to the bitmaps in all received packets, a vehicle can detect the slot locations of its 1-hop and 2-hop neighbors.



Protocol State Machine



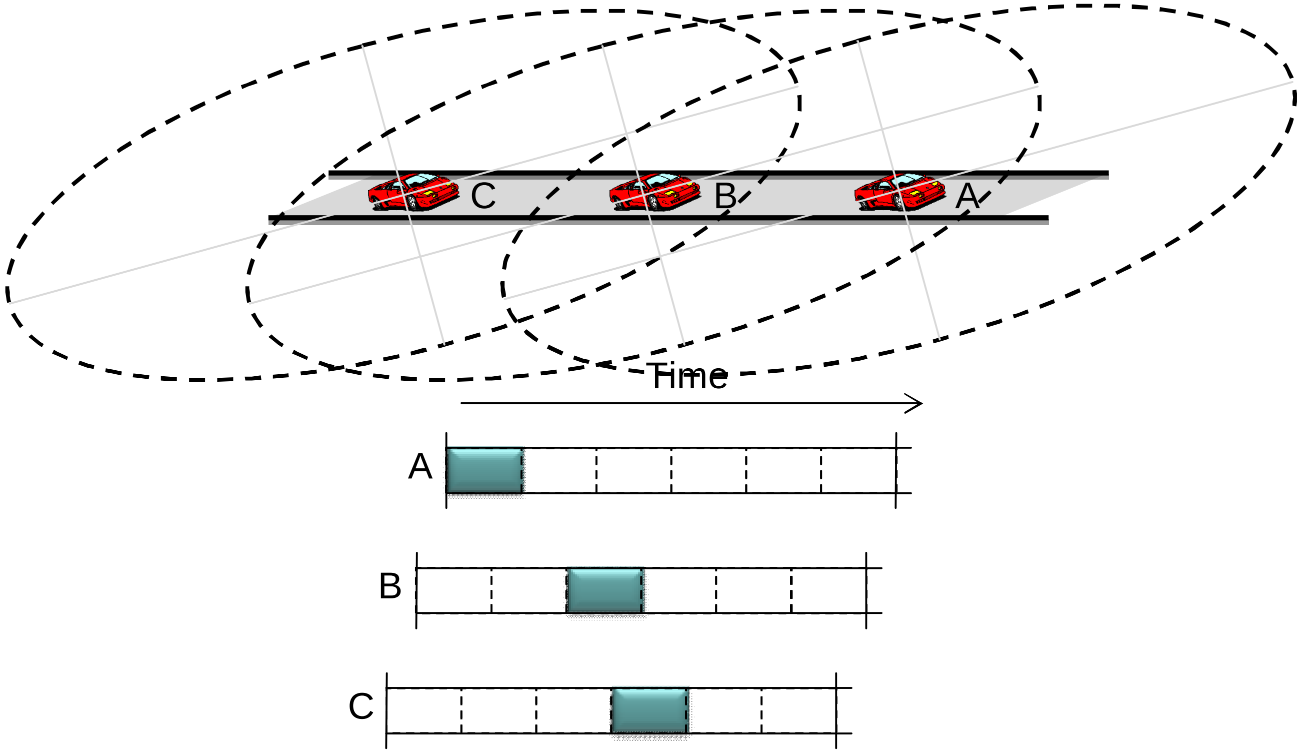
Constraint

- Slot allocation in VeSOMAC needs to satisfy the three constraint
  - Timing Constraint
  - Bitmap Constraint
  - Ordering Constraint

Constraint

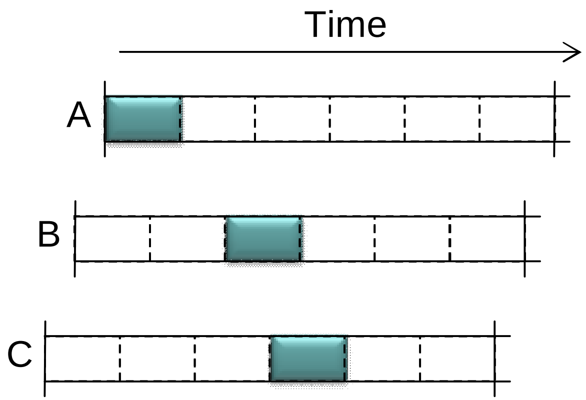
- Slot allocation in VeSOMAC needs to satisfy the three constraint
  - Timing Constraint
    - No two one-hop or two-hop neighbors' slots can overlap.
  - Bitmap Constraint
  - Ordering Constraint

Constraint - Timing Constraint

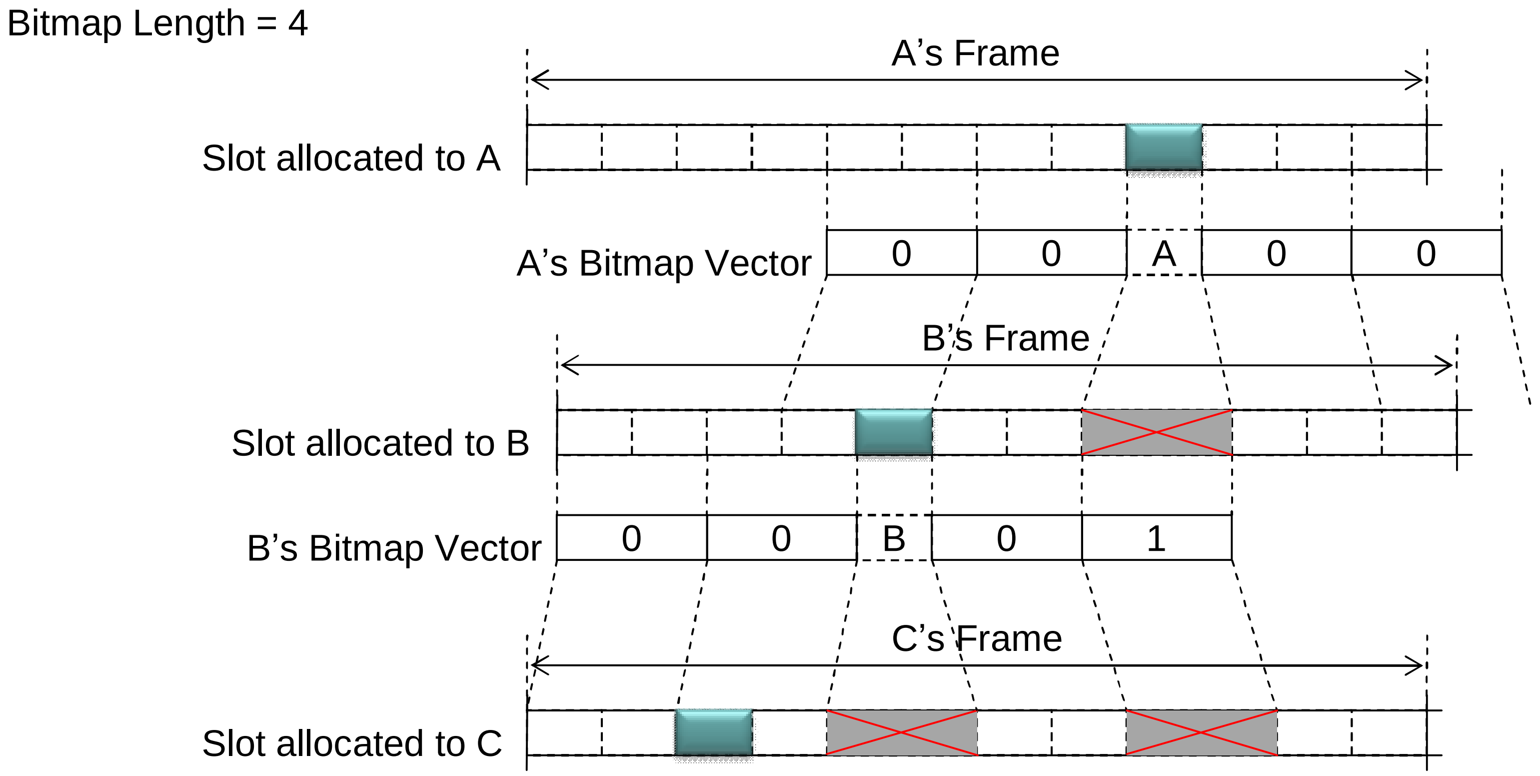


Constraint - Timing Constraint

Bitmap Length = 4



Constraint - Timing Constraint



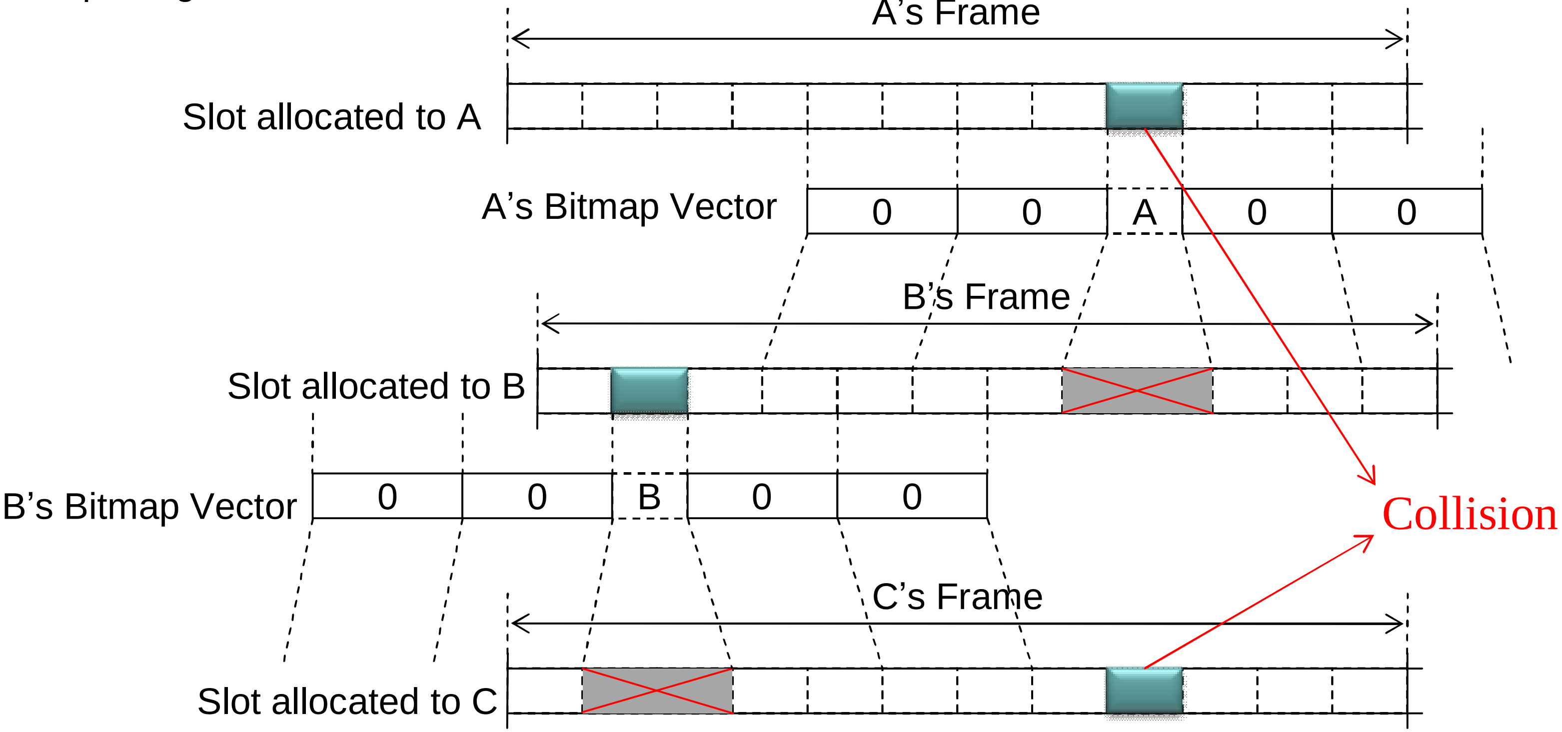
Constraint

- Slot allocation in VeSOMAC needs to satisfy the three constraint
  - Timing Constraint
  - Bitmap Constraint
    - For 1-hop neighbors *i* and *j*, *i*'s chosen slot should be able to be represented within the bitmap vector of *j*. The same is applicable for vehicle *j*'s slot.
  - Ordering Constraint

Constraint - Bitmap Constraint

Why Bitmap Constraint?

Bitmap Length = 4

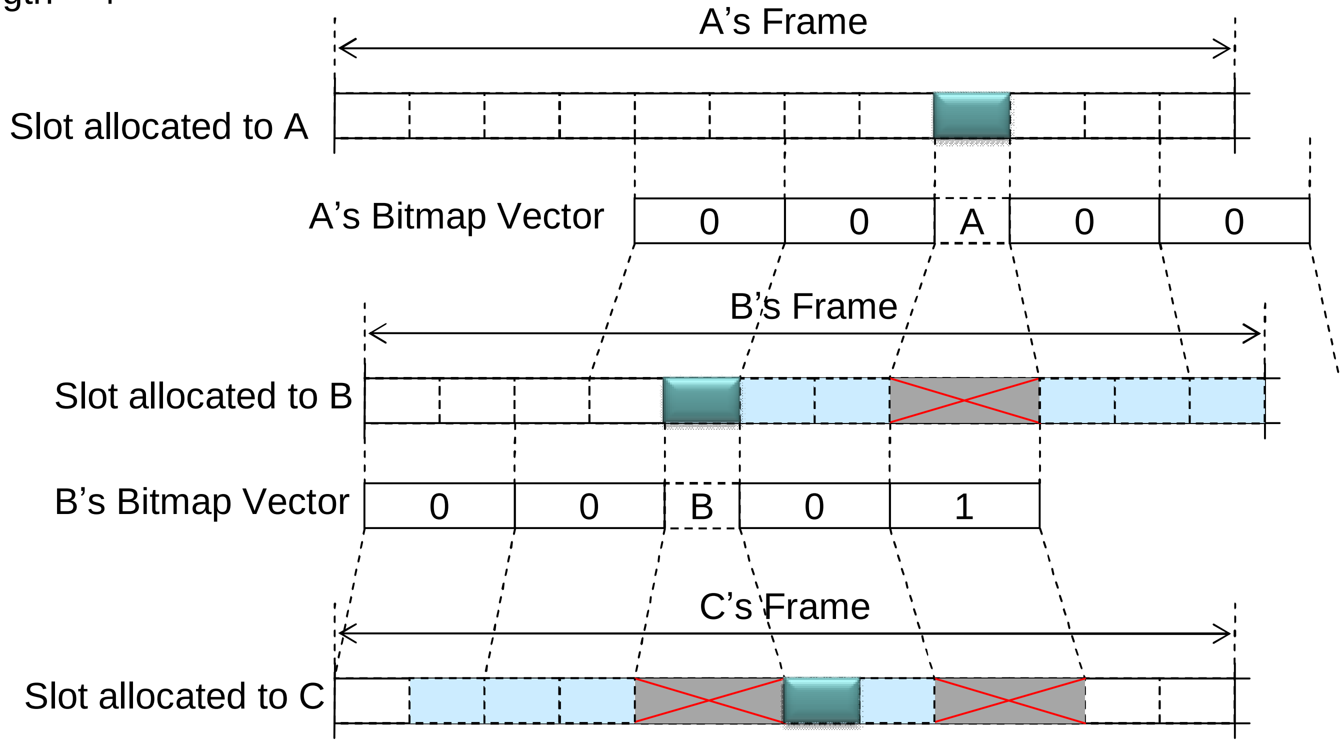


Constraint - Bitmap Constraint

A and B are 1-hop neighbors

A and C are 2-hop neighbors

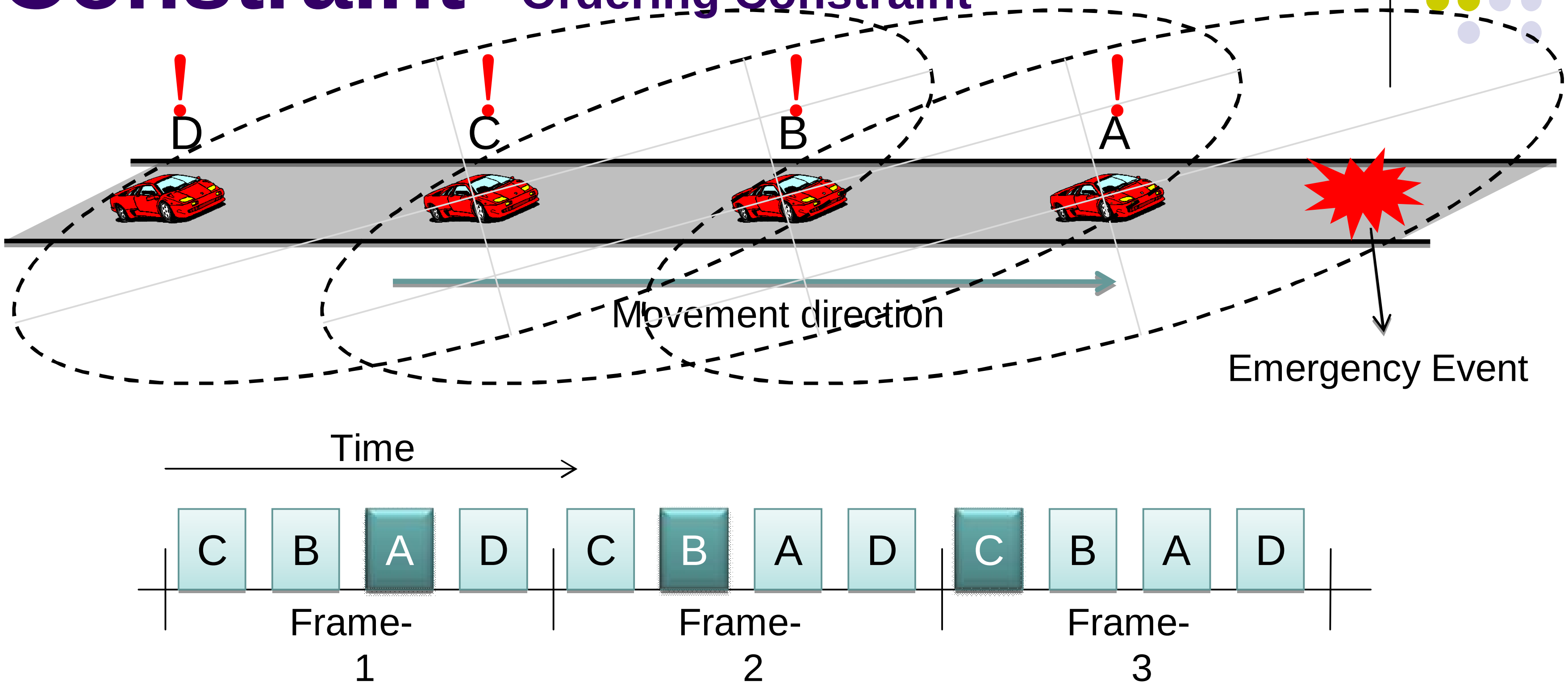
Bitmap Length = 4



Constraint

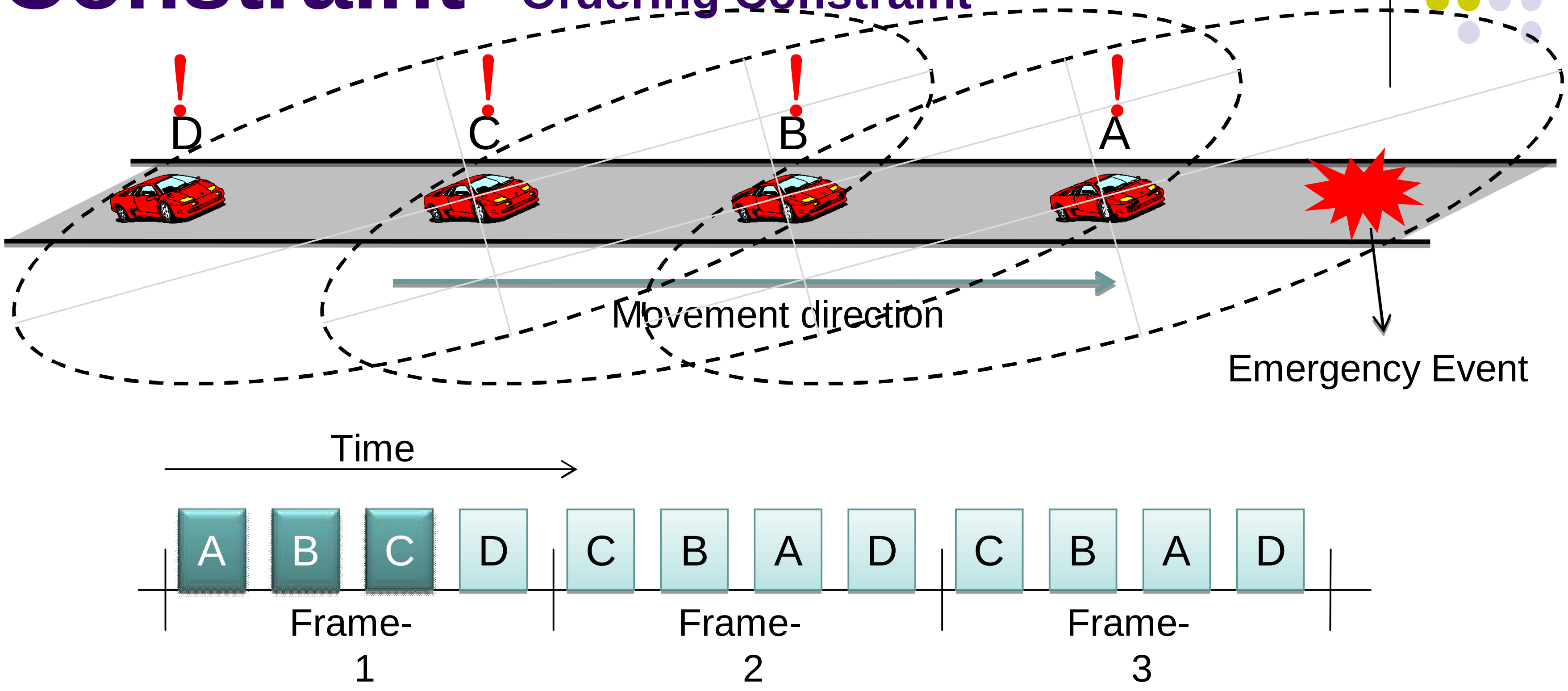
- Slot allocation in VeSOMAC needs to satisfy the three constraint
  - Timing Constraint
  - Bitmap Constraint
  - Ordering Constraint
    - If two vehicles *i* and *j* are geographical neighbors and *i*'s location is ahead of *j* in the platoon, then *i*'s chosen slot should be earlier than *j*'s slot in the time domain.

Constraint - Ordering Constraint



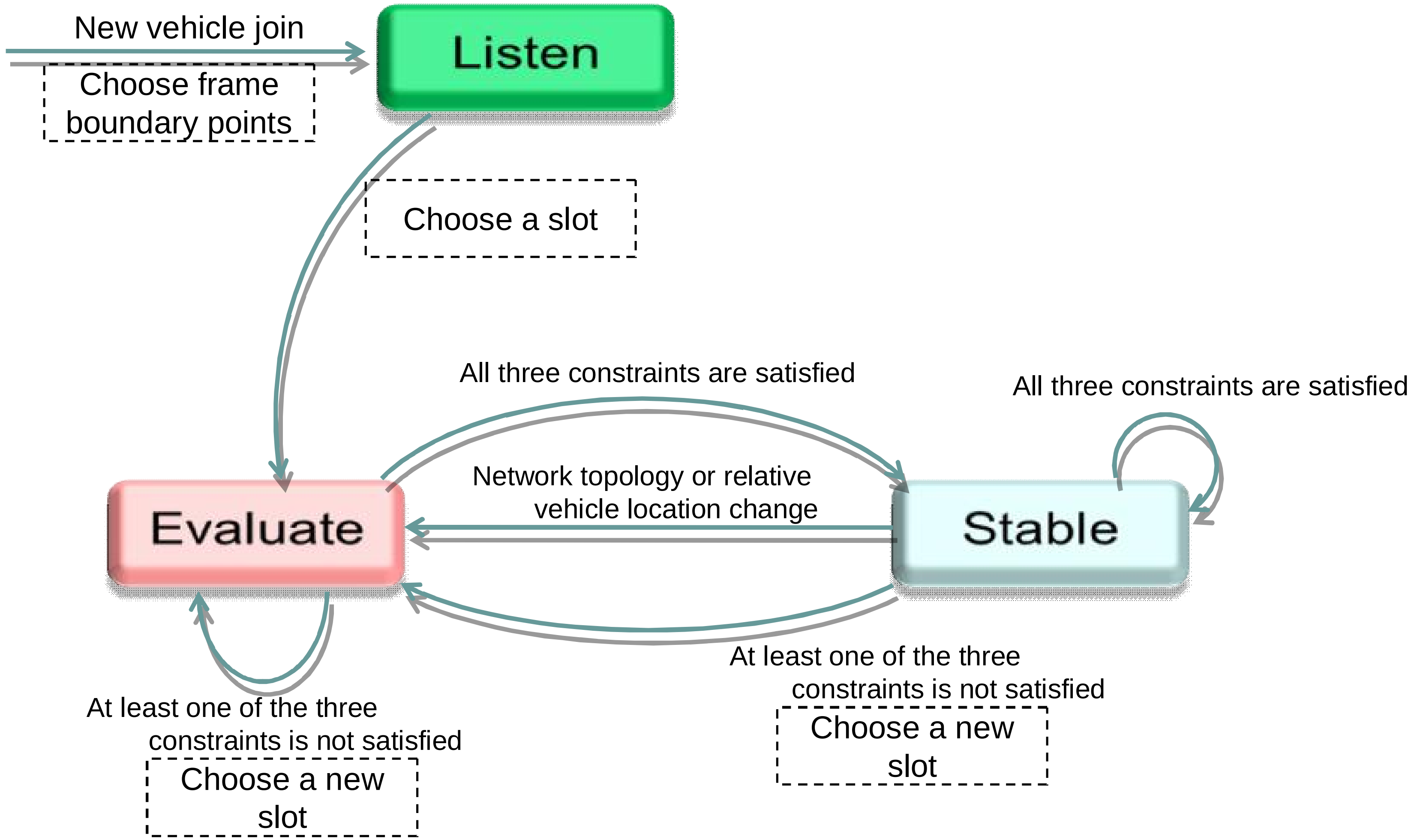
Need 3 Frames

Constraint - Ordering Constraint

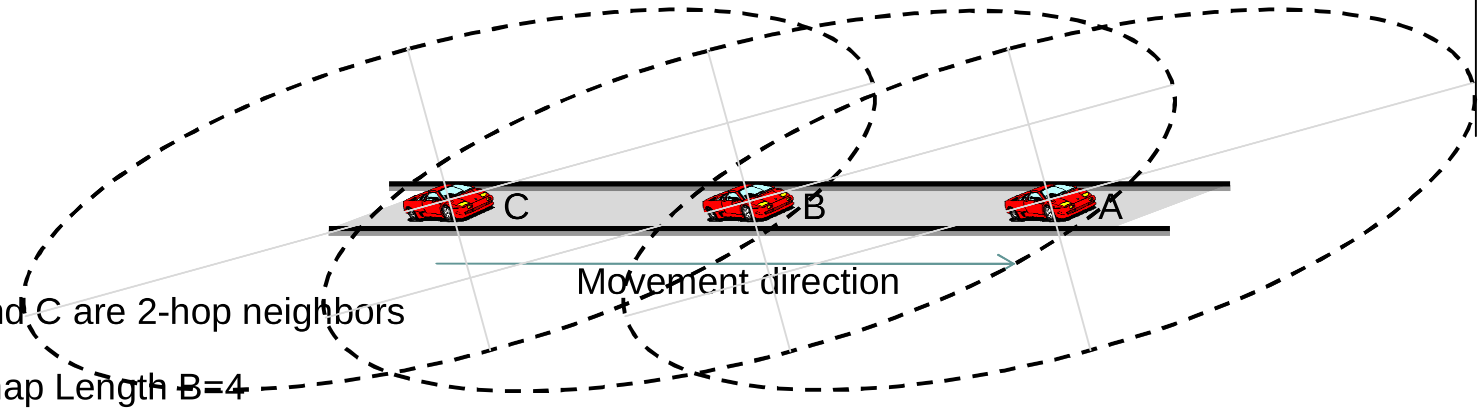


Need 1 Frame

Protocol State Machine

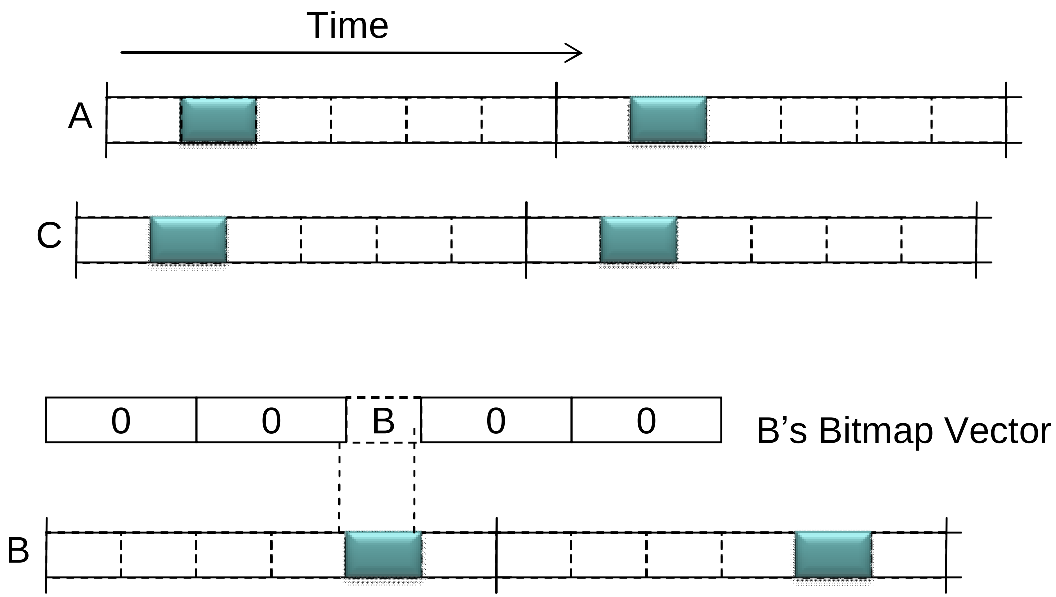


Collision Detection and Resolution

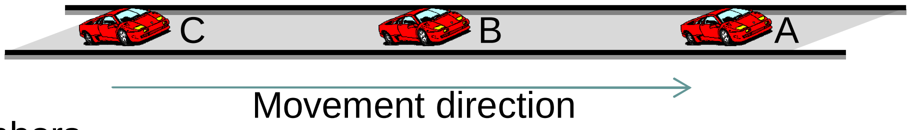


A and C are 2-hop neighbors

Bitmap Length B=4

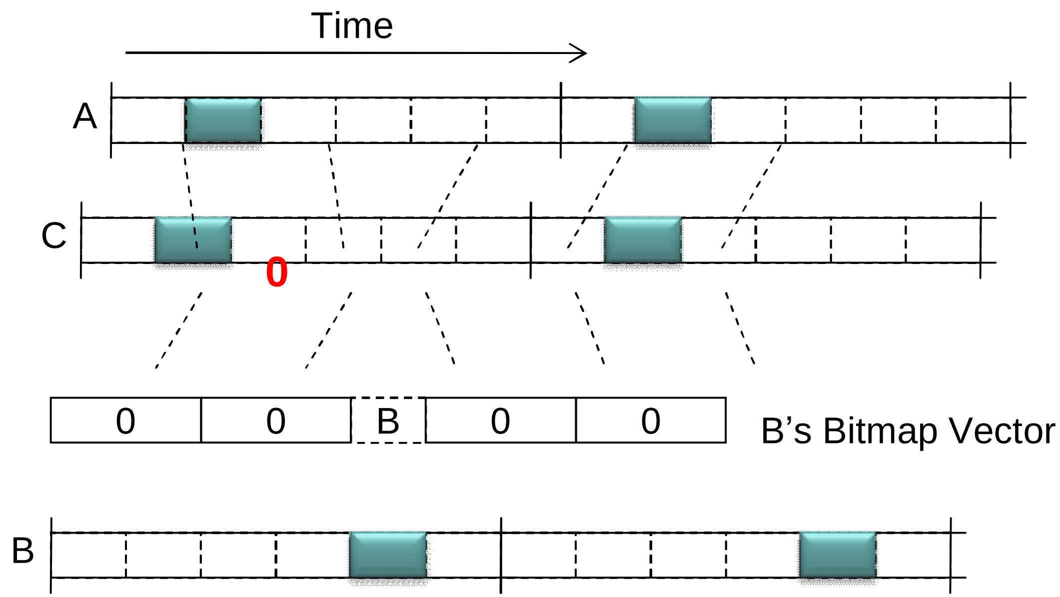


Collision Detection and Resolution



A and C are 2-hop neighbors

Bitmap Length B=4



Performance Evaluation

Simulation	
Simulator	ns-2
ITS application	CCA (Cooperative Collision Avoidance)

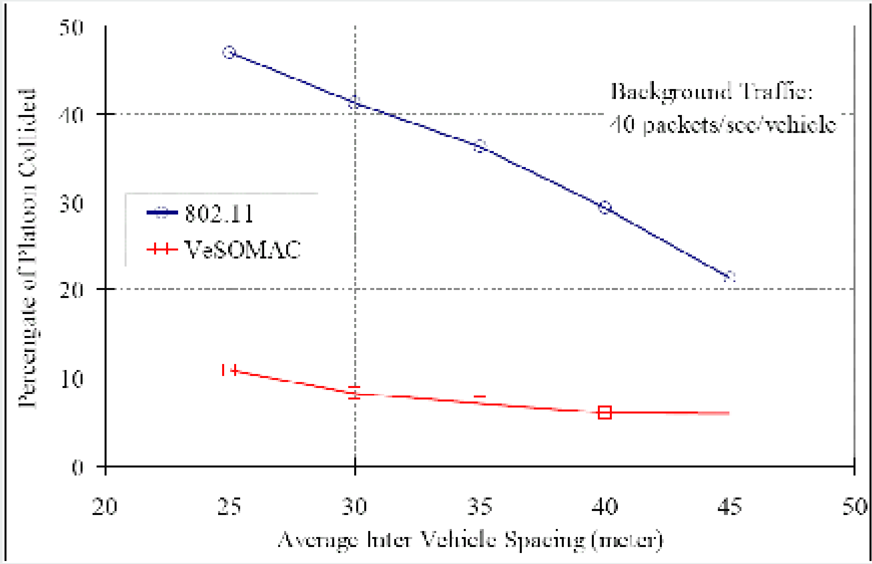
Simulation parameters (Vehicle Related)	
Platoon Size	50 vehicles
Vehicle Speed	68mph (= 108Km/hr = 30m/sec)
Inter-vehicle Spacing	25m to 45m (= 0.8sec to 1.5sec)
Vehicle Length	4m
Emergency Deceleration	$8m/s^2$ (56.25m)
Regular Deceleration	$4m/s^2$ (115.25m)
Drivers' Reaction Time	0.75sec to 1.5sec

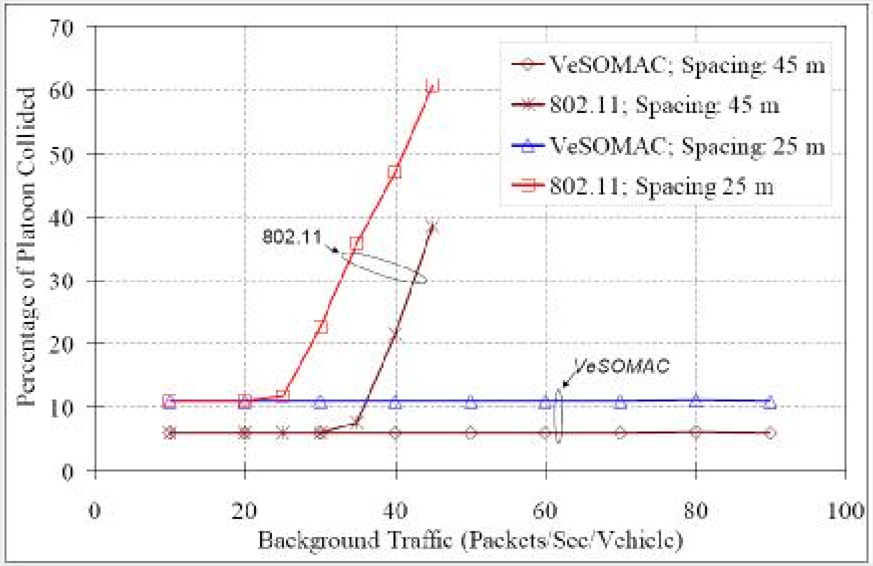
Performance Evaluation

Simulation parameters (Network Related)	
Channel	DSRC 5.9GHz band, 24Mbps
Radio Range	300m
MAC Protocols	IEEE 802.11 and Worst case *VeSOMAC*
WCW Packet Size	300bytes (0.1ms)
WCW Message Period	100ms
VeSOMAC Frame Size	100 packets (10ms)
VeSOMAC Bitmap Size	96 Bits (very weak bitmap constraint)
VeSOMAC Evaluation Time	*W* = 3 frames

Performance Evaluation

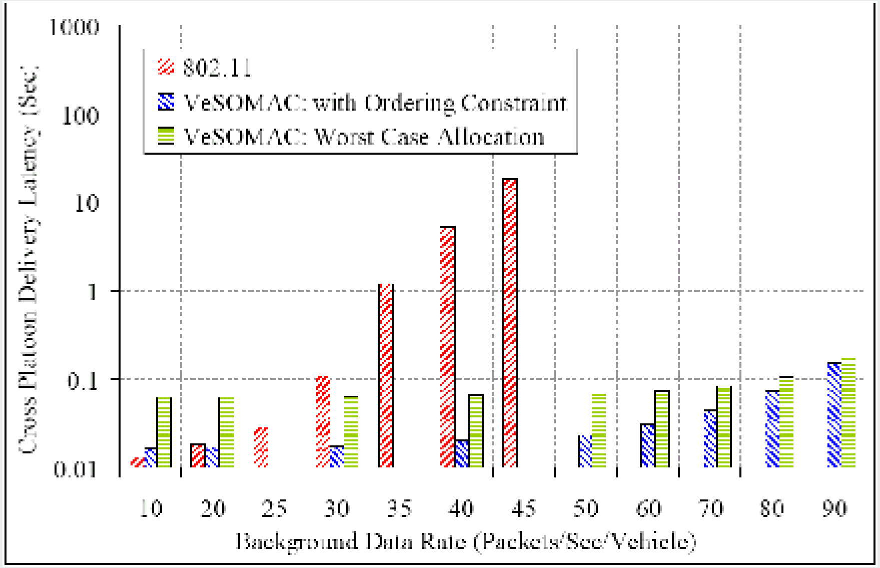
Vehicle Crash Performance	
Effects of Vehicle Spacing	Effects of Background Traffic

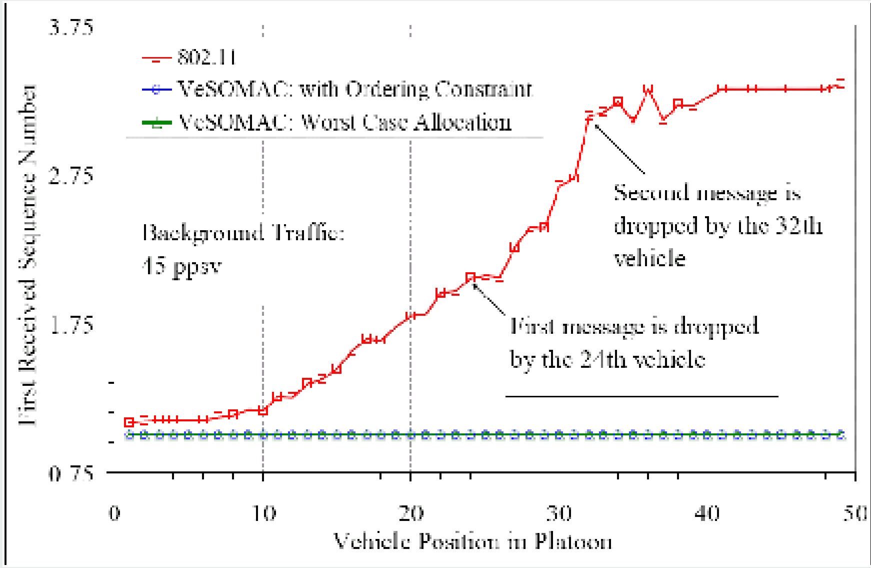




Performance Evaluation

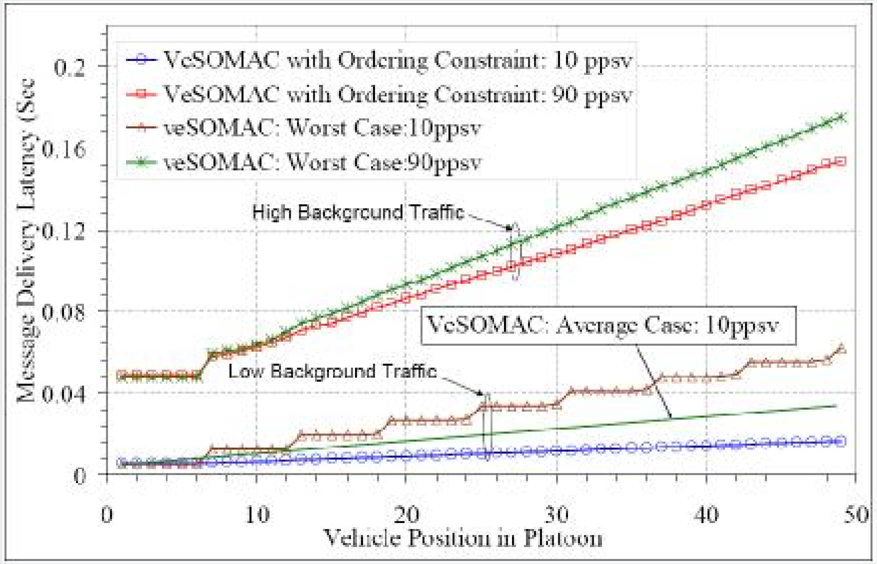
Data Plane Network Performance	
Cross-Platoon Message Delivery	Packet Drops





Performance Evaluation

Data Plane Network Performance
Cross-Platoon Message Delivery



Conclusion

- Distributed TDMA allocation.
- A bitmap vector is used for exchanging relative slot timing information across the 1-hop and 2-hop neighbor vehicles.
- Can work without network time synchronization.
- Minimizing the multi-hop delivery delay of ITS safety messages.
- The protocol convergence during topology changes is fast.

Thanks~~~