Chapter 4: IP Address Auto-Configuration and Mobility Management in VANETs

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Goals of this chapter

- This Chapter discusses with the IP address passing mechanism and mobility management in VANETs

Outline

- 4-1: IP Address Passing for VANETs
- 4-2: Vehicular Address Configuration
- 4-3: Network Mobility Protocol for Vehicular Ad Hoc Networks

4-1: IP Address Passing for VANETs

Todd Arnold, Guohong Cao, and Jing Zhao
Pennsylvania State University, USA

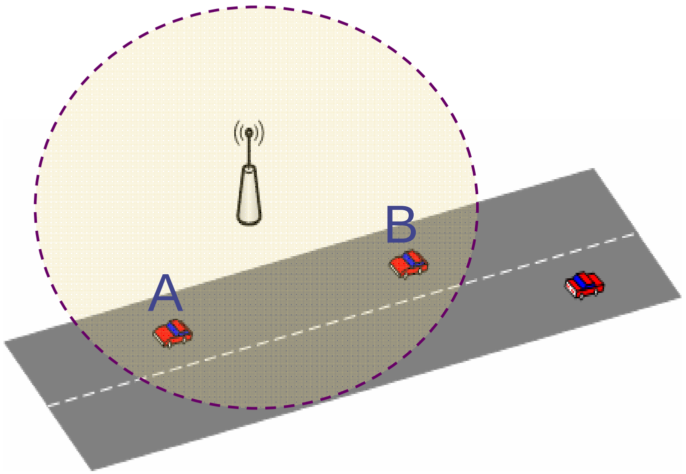
IEEE PerCom 2008

Section Outline

- Introduction
- Background
- Implementation
- Algorithms for Passing IPs
- Conclusion And Future Work

Introduction

- A vehicle associates with an AP and acquires an IP address the average connection time can be from **5** seconds to **24** seconds.
- Reduce the average IP acquisition latency to less than one-tenth of a second and significantly reduce the network overhead.
- 3 main steps:
  - Gathering the IP information
  - Passing the IP from car A to car B
  - Configuring car B's interface on the fly.



Background

- Assumptions：
  - Each vehicle only needs one wireless interface card and interface is capable of listening in promiscuous mode.
  - Each vehicle has a GPS receiver for identifying its own location and they know their neighbors' locations.
  - Four messages for acquiring a DHCP lease consists
    - DHCP **Discover** message
    - DHCP **Offer** message
    - DHCP **Request** message (as a response)
    - DHCP **Release** message

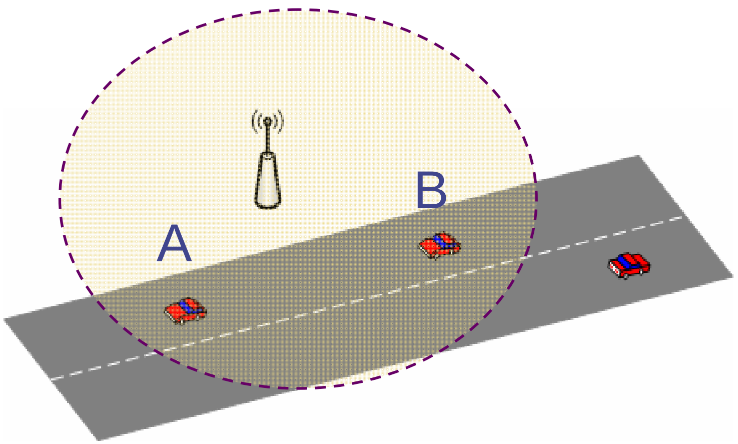
Implementation

- Overview
- Equipment
- Observations
- IP Passing
- Analyses

Overview

- Beside address, car A must provide the subnet mask and the network's default gateway.
- Nodes maintain an ARP (Address Resolution Protocol) cache to map IP addresses to MAC addresses.
- A Gratuitous ARP (GARP) message can be used to update ARP cache entries in other nodes.

(GARP - The GARP message is an ARP Request where the source and destination IP are identical.)



Overview

- IP passing packet format

0	Bits 31
Check Sequence	
Forwarded IP Address	
Forwarded Subnet Mask	
Default Gateway IP Address	
Default Gateway MAC Address	
Default GW MAC Addr. (cont.)	GPS Information
GPS Information (cont.)	
GPS Information (cont.)	
ESSID 0-32 bytes	

ESS: Extended Service Set

Equipment

- AP
  - Linksys WRT54GL
- Two node OS
  - Redhat Linux 2.4.25 kernal
- Network monitoring
  - Apple powerbook OS X 10.4.9
- Software
  - Ethereal 0.10.12-1011

A Traditional DHCP transaction

- After association has completed. (on a Linksys brand AP)
- Once the initial Discover message is sent, it takes almost 3 seconds for the DHCP server to respond with an Offer message.
- Packet **1**: The DHCP Discover message
- Packets **2-4**: ARP requests
- Packets **5-7**: remaining steps of the DHCP transaction

Packet #	Elapsed Time	Source	Destination	Protocol	Bytes	Information
1	0	0.0.0.0	255.255.255.255	DHCP	428	DHCP Discover - Transaction ID 0x4c08f26e
2	0.059079	00:18:39:ea:5f:02	Broadcast	ARP	128	Who has 192.168.1.100? Tell 192.168.1.1
3	1.078637	00:18:39:ea:5f:02	Broadcast	ARP	128	Who has 192.168.1.100? Tell 192.168.1.1
4	1.999697	00:18:39:ea:5f:02	Broadcast	ARP	128	Who has 192.168.1.100? Tell 192.168.1.1
5	2.495476	192.168.1.1	192.168.1.100	DHCP	428	DHCP Offer - Transaction ID 0x4c08f26e
6	2.497751	0.0.0.0	255.255.255.255	DHCP	428	DHCP Request - Transaction ID 0x4c08f26e
7	2.504289	192.168.1.1	192.168.1.100	DHCP	428	DHCP ACK - Transaction ID 0x4c08f26e

Capture of Apple's DHCP transaction

- After association has completed.
- On an Airport Express.
- This implementation of DHCP eliminates 2 ARP requests compared to the Traditional DHCP

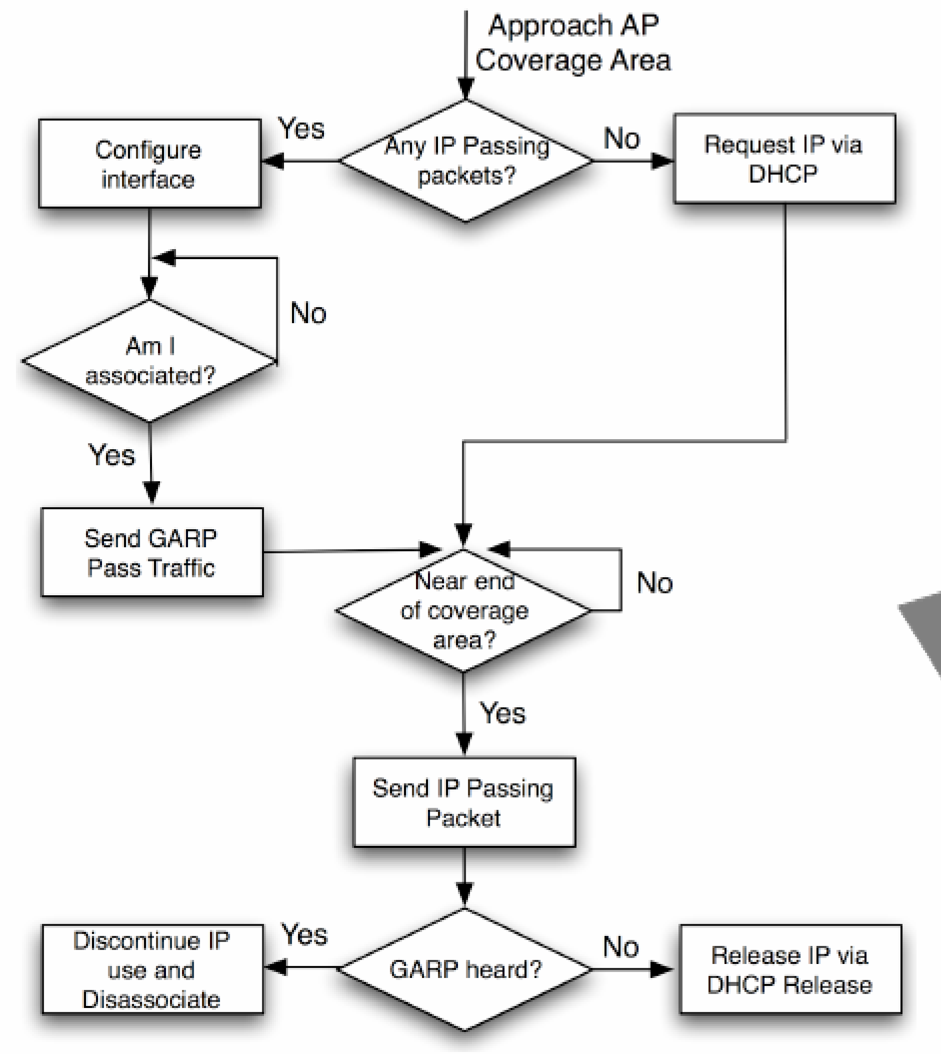
Packet #	Elapsed Time	Source	Destination	Protocol	Bytes	Information
1	0	0.0.0.0	255.255.255.255	DHCP	342	DHCP Discover - Transaction ID 0xd4e6c607
2	0.114077	00:14:51:6a:be:fb	ff:ff:ff:ff:ff:ff	ARP	42	Who has 10.0.1.3? Tell 10.0.1.1
3	0.500085	10.0.1.1	10.0.1.3	DHCP	590	DHCP Offer - Transaction ID 0xd4e6c607
4	0.500987	0.0.0.0	255.255.255.255	DHCP	342	DHCP Request - Transaction ID 0xd4e6c607
5	0.502556	10.0.1.1	10.0.1.3	DHCP	590	DHCP ACK - Transaction ID 0xd4e6c607

Capture of IP Passing DHCP transaction

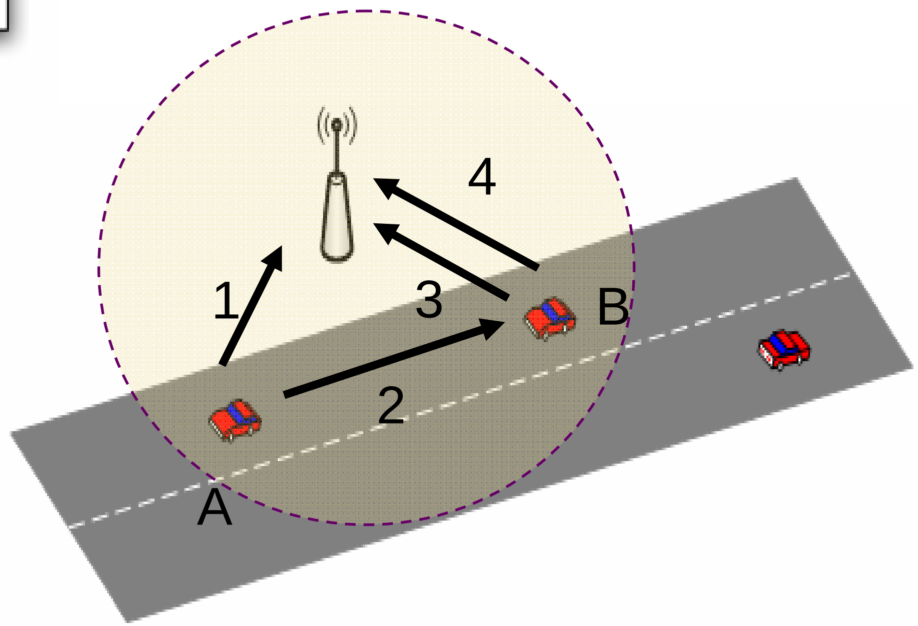
- Improve IP acquisition process.
- The number of non-association related packets is reduced from 7 to 2, with a significant reduction in overhead.

Packet #	Elapsed Time	Source	Destination	Protocol	Bytes	Information
1	0.000000	Agere_b6:34:9e	Broadcast	IEEE 802.3	128	Source port: picknfs Destination port: picknfs
2	0.078179	D-Link_d5:a9:dc	Broadcast	IEEE 802.11	104	Probe Request SSID: "598b[Malformed Packet]"
...						Association Process
3	1.997938	00:18:39:ea:5f:04	D-Link_d5:a9:dc	IEEE 802.11	122	Association Response[Malformed Packet]
4	2.013008	D-Link_d5:a9:dc	Broadcast	ARP	160	Who has 192.168.1.122? Gratuitous ARP

IP Passing



Approach AP
Coverage Area
Any IP Passing packets?
Yes
No
Configure interface
Request IP via DHCP
No
Am I associated?
Yes
Send GARP
Pass Traffic
Near end of coverage area?
No
Yes
Send IP Passing Packet
GARP heard?
Yes
No
Discontinue IP use and Disassociate
Release IP via DHCP Release



1
2
3
4
A
B

IP Passing

- **Step1**
  - For Node A to associates and perform a traditional DHCP request sequence.
- **Step2:**
  - Node A continues traveling until it no longer needs its IP.
  - Node A forwards it to Node B which is just about to enter the range of the AP and is not yet associated.
- **Step3:**
  - Node B parses the information and configures all relevant settings in preparation for when it is associated with the AP.
- **Step4:**
  - Node B is associated.
  - Node B sends the GARP as the final step to update the APs ARP cache.

Analyses

- A comparison of all three testbed implementations for acquiring an IP address. The bytes for IP passing represents the maximum amount required if the ESSID were 32 bytes.

Implementation	Time	Bytes	# of Messages
Traditional DHCP	2.5 s	2096	7
Apple DHCP	0.5 s	1906	5
IP Passing	0.09 s	296	2

Algorithms for Passing IPs

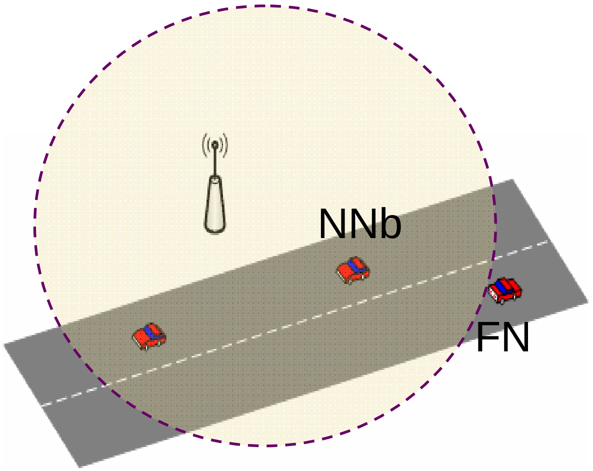
- When there are not enough IPs available to implement IP passing
  - Algorithms with Neighbor Topology Awareness
    - One-hop IP Passing
    - Releasing
    - Multi-Hop IP Passing
  - Distributed Algorithms without Neighbor Topology Awareness
    - One-hop IP Passing
    - Releasing
    - Multi-Hop IP Passing

Algorithms With Neighbor Topology

- One-hop IP Passing
  - Node knows all of its neighbors location and moving direction
  - Farthest Neighbor (FN)

$$D_{FN} = \max_{1 \le i \le n} \left\lfloor \frac{r}{d_i} \right\rfloor * d_i$$

  - Nearest Neighbor behind Association Point (NNb)



$$D_{NNb} = \min_{1 \le i \le n} \left\lceil \frac{|l_p - l_a|}{d_i} \right\rceil * d_i$$

D: The distance between the vehicle that is forwarding an IP and the receiving vehicle
r: The communication range of vehicles
d: The physical distance between any two cars
la: The location where a car starts to associate with the AP
lp: The location where a car starts to passing its IP

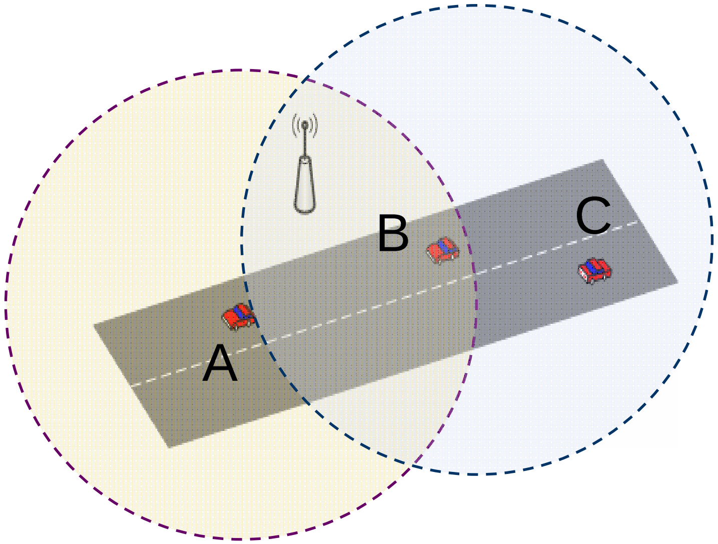
Algorithms With Neighbor Topology

- Releasing
  - When there are no nodes in need of an IP address a node releases the address
  - It requires the node to send a DHCP release message before it is out the AP's range
  - Let $t_{release}$ be the time it takes for the node to successfully send the DHCP release message (*v*: the velocity of the cars)

$$d_{release} = t_{release} * v$$

Algorithms With Neighbor Topology

- Multi-Hop IP Passing
  - The algorithms would have to select one or more intermediate nodes to send the IP through.
  - The leaving node cannot know who would eventually receive the IP.
  - **If any intermediate node cannot find a proper neighbor as the next hop, it will release the IP address to AP.**



A: leaving node
B: intermediate node (FN of A)
C: receiving node (FN or NNb of B)

Distributed Algorithms without Neighbor Topology

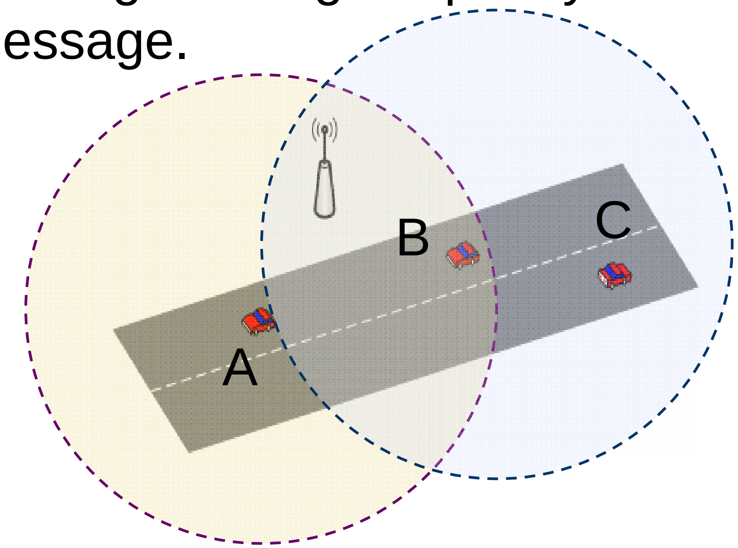
- One-hop IP Passing
  - The passing node sends the reference position of a node to pass to.
  - **Farthest Neighbor** (FN_u)
    - The passing node broadcasts the IP Passing message when it is about to leave the AP area.
    - All nodes that hear the message but do not yet have an IP address will broadcast an GARP message after a specific delay $\frac{\delta}{|l_r - l_i|}$.
    - *lr*: reference position
    - *li*: location of the i_{th} neighbor
    - δ is a constant to adjust the delay to a more reasonable value.
  - **Nearest Neighbor behind Association Point** (NNb_u)
    - Similar to the FNu, the distributed equivalent of the NNb algorithm (NNb_u) bases the waiting time on the distance from the association point.

Distributed Algorithms without Neighbor Topology

- Releasing
  - Happens when a passing node has no neighbors or no neighbors that need an IP address.
  - A passing node need to wait for receiving an ACK message or timeout.
  - $D_u = D - (t_{release} + t_{timeout}) * v$
  - D_u: To compute the **IP passing distance** (the distance between two nodes passing the IP address) for the distributed algorithms.
  - D: The distance between the vehicle that is forwarding an IP and the receiving vehicle.

Distributed Algorithms without Neighbor Topology

- Multi-Hop IP Passing
  - Can simply use FNu and NNbu wherever FN and NNb is used in the previous section.
  - The intermediate node does not broadcast GARP message as the final destination.
  - The intermediate node can still acknowledge the receipt of the IP passing message implicitly because it will rebroadcast the message.

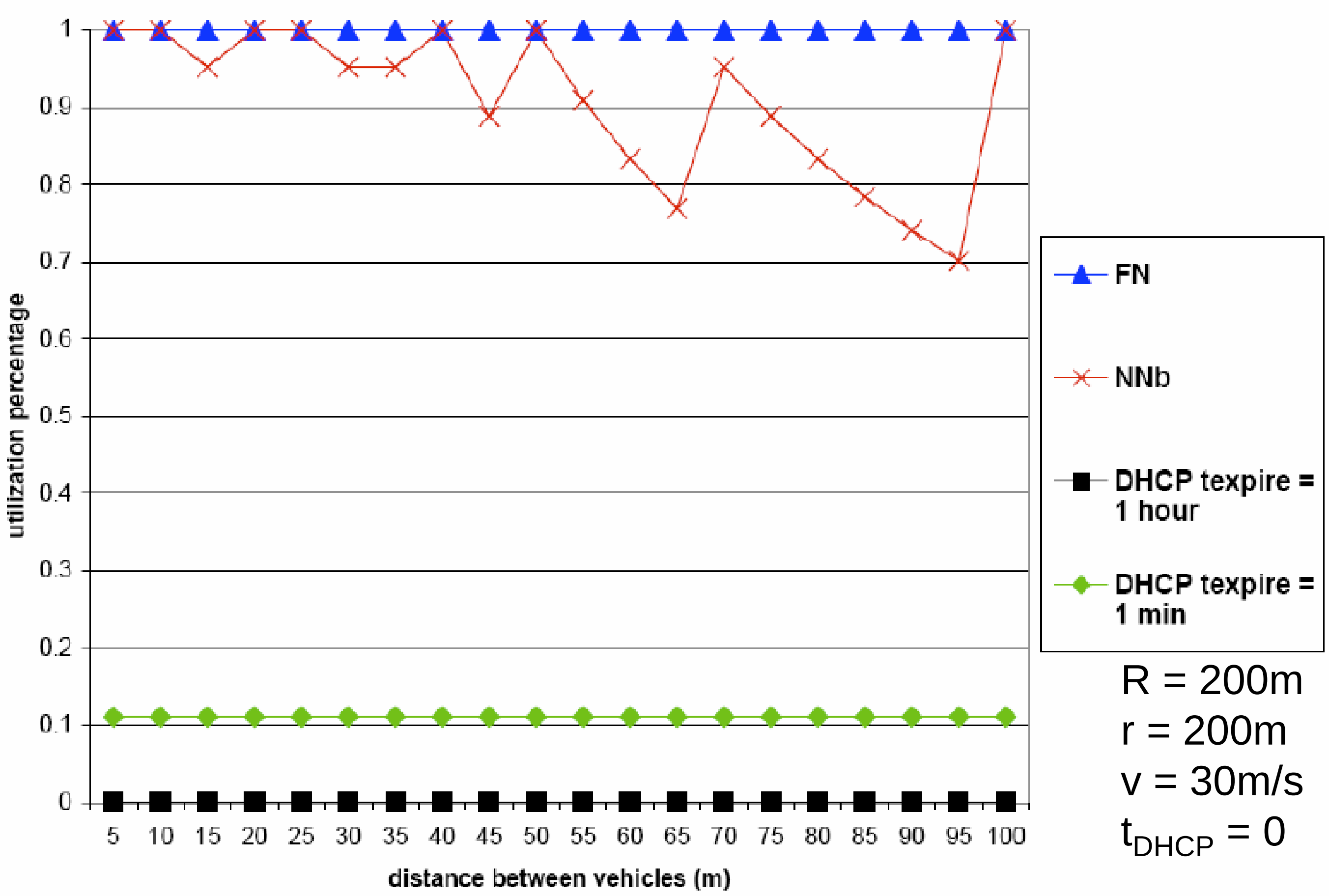


A: leaving node
B: intermediate node (FN of A)
C: receiving node (FN or NNb of B)

Use Fraction

$$u_{DHCP} = \frac{\frac{R}{v} - t_{DHCP}}{t_{expire}}$$

$$u = \begin{cases} \frac{R}{D} & D > R \\ 1 & D \leq R \end{cases}$$



R = 200m
r = 200m
v = 30m/s
t_{DHCP} = 0

t_{DHCP}: The time required to obtain an IP address via DHCP

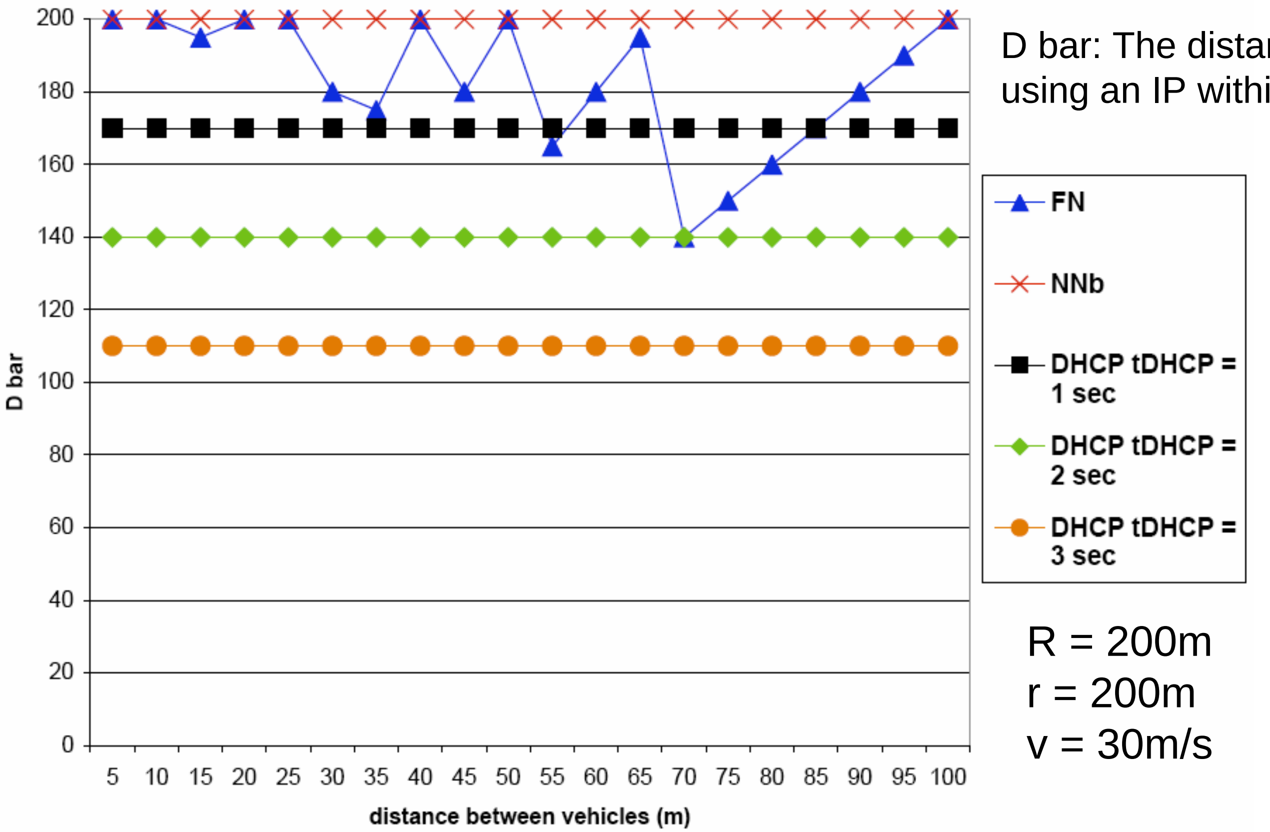
U: Use Fraction

t_{expir} :theuse fraction is the time that a DHCP lease is used divided by the time until it expires

Average Distance Used

$$\bar{D}_{DHCP} = R - t_{DHCP} * v$$

$$\bar{D} = \begin{cases} R & D > R \\ D & D \leq R \end{cases}$$

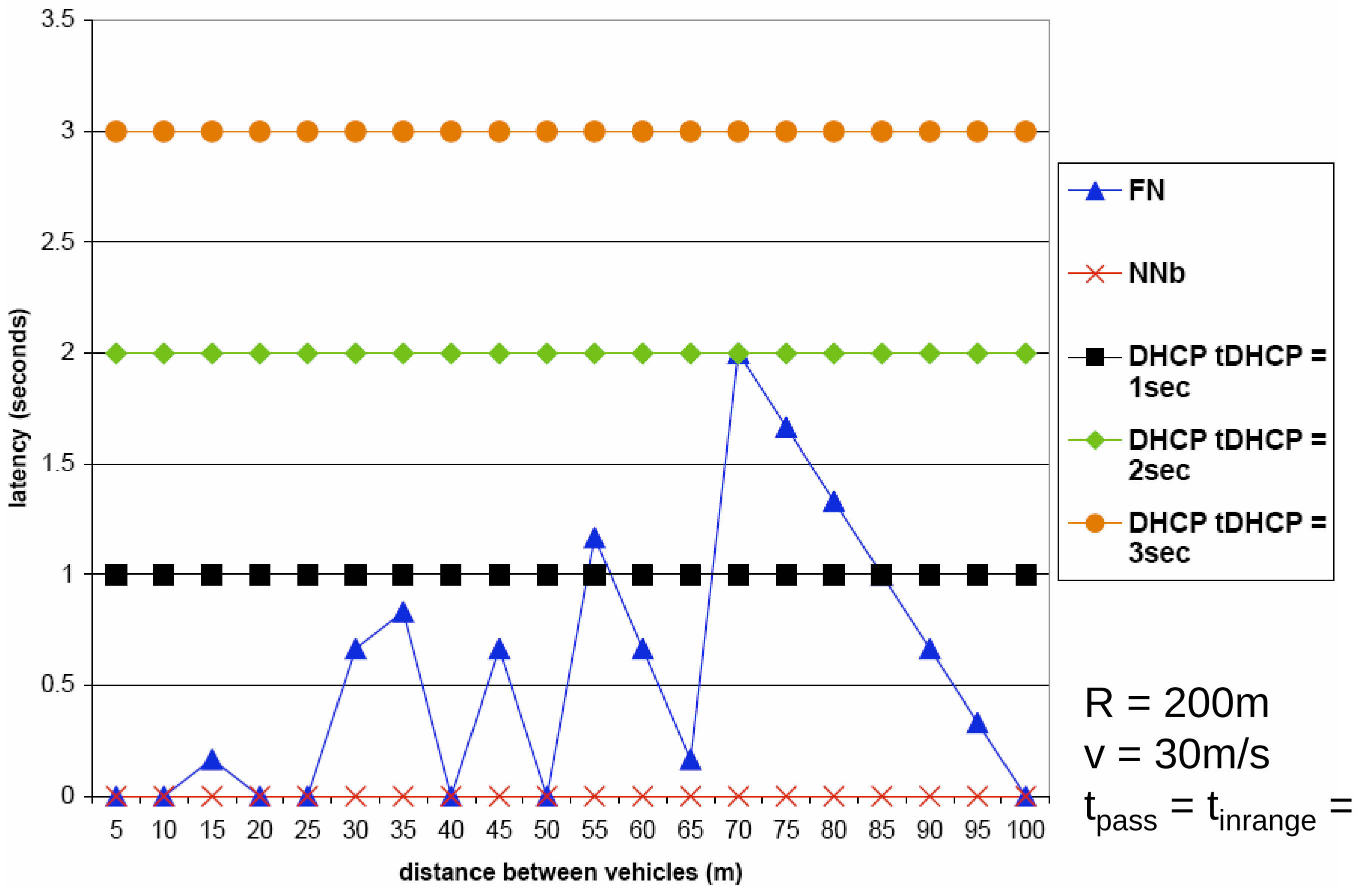


D bar: The distance a node covers while using an IP within range of an AP.

R = 200m
r = 200m
v = 30m/s

Average Latency to Connectivity

$$lat = t_{pass} + t_{GARP} + t_{inrange} \qquad t_{inrange} = max(-t_{pass}, \frac{R-D}{v})$$



t_{pass}: The lat for the IP passing algorithms is equal to the time it takes to pass the IP address.

t_{GARP}: Send the GARP

$t_{inrange}$: the time the node is in range before it receives the passed IP address (can be negative, but can only offset tpass because the GARP must be sent while in the AP's range)

R = 200m

v = 30m/s

$t_{pass} = t_{inrange}$ = 100us

Denied Request Fraction

- Only using DHCP

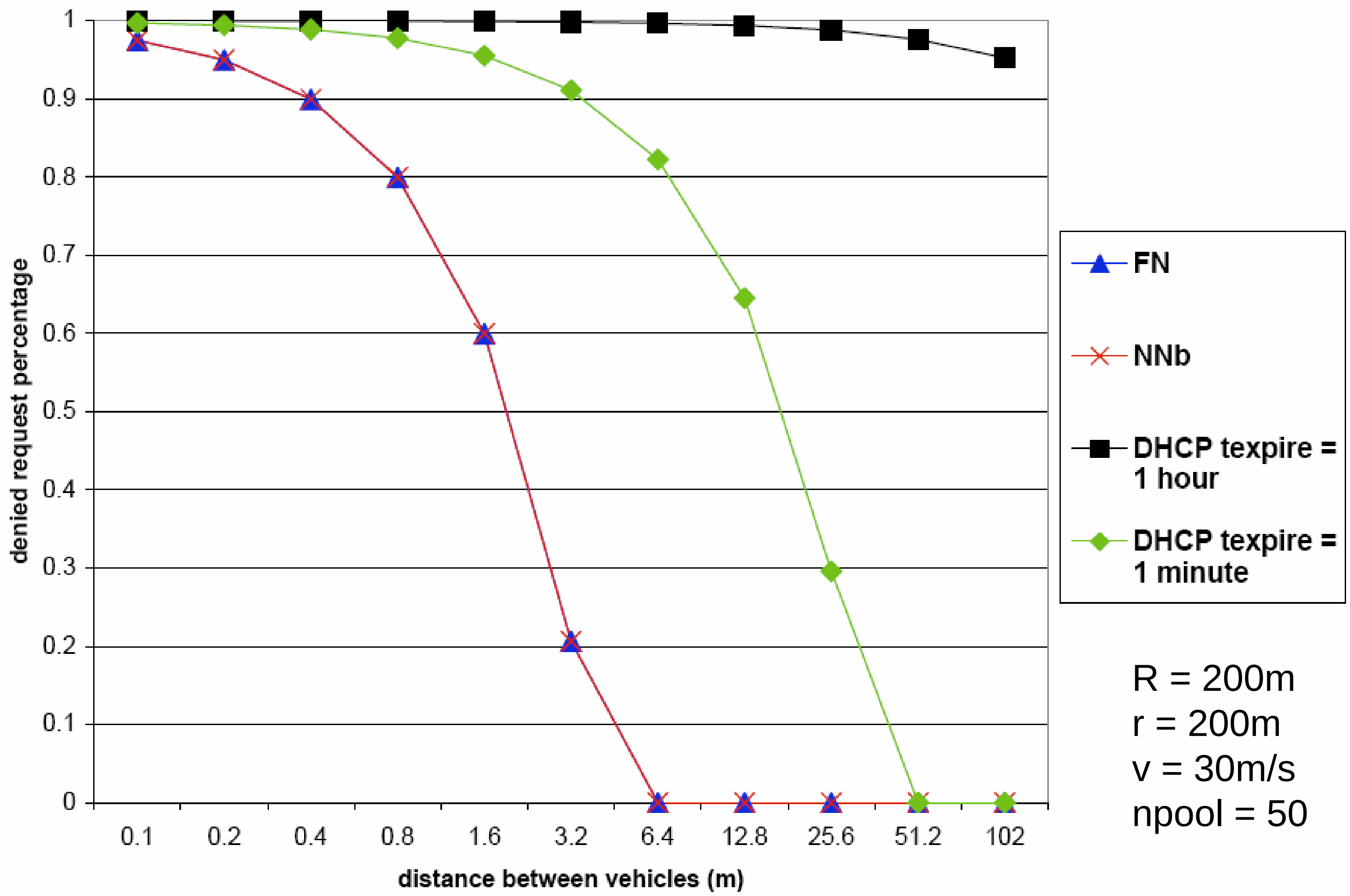
$$dr = max\left(0, \frac{\left\lceil \frac{v * t_{expire}}{d} \right\rceil - n_{pool}}{\left\lceil \frac{v * t_{expire}}{d} \right\rceil}\right)$$

- IP passing algorithm

$$dr = max\left(0, \frac{\left\lceil \frac{max(R,D)}{d} \right\rceil - n_{pool}}{\left\lceil \frac{max(R,D)}{d} \right\rceil}\right)$$

t_{expire}: The number of cars that enter the range of the AP.
n_{pool}: The total number of leases an AP has to Distribute.

Denied Request Fraction



R = 200m
r = 200m
v = 30m/s
npool = 50

Conclusion And Future Work

- Conclusion
  - IP passing lowers the network overhead.
  - Avoid collisions and contention for passed IPs.
- Future Work
  - Bidirectional passing.

4-2: Vehicular Address Configuration

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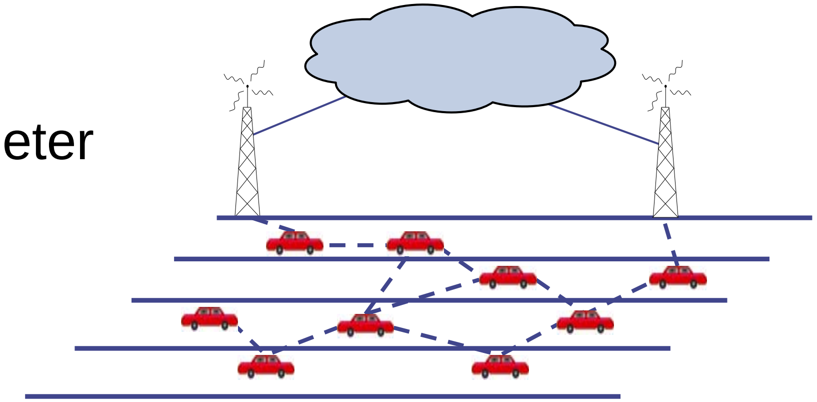
IEEE GLOBECOM 2006

Section Outline

- Introduction
- Related Work
- Vehicular Address Configuration Protocol
- Two Main Tasks Of VAC Functionalities
- Conclusion

Introduction

- Solution developed for traditional ad-hoc networks cannot be directly applied to VANETs
- VANETs differ from usual ad-hoc network
  - vehicular environment
  - node distribution
  - movement
- VANETs have peculiar properties
  - high density of nodes
  - high absolute speed
  - practically “infinite” network diameter

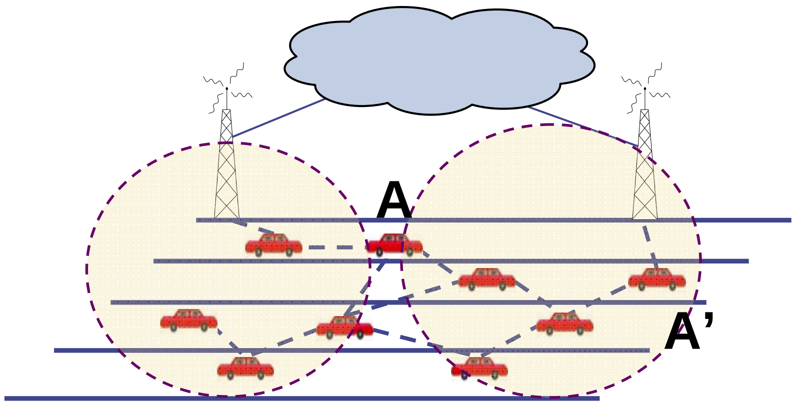


Related Work

- Address configuration approaches in ad-hoc networks categorizing them into three groups:
- Decentralized
  - A node that needs an address makes a request to the network and receives the configuration parameters through its interaction with other nodes.
- Best-effort
  - Do not ensure that every address is unique in the network: their main goal is just that of guaranteeing the correct routing of packets.
- Leader-based
  - Makes use of a hierarchical structure to perform the address configuration procedure.

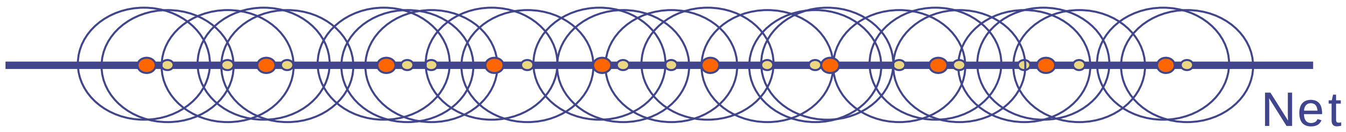
Problem Statement

- The same address IP_A could be assigned again as soon as car A goes out of the range of the Internet gateway.
- Since the spread of a VANET is theoretically infinite, nodes located very far from each other can utilize the same identifier.
- Configuration protocol has to perform in ad-hoc networks
  - the initial address configuration
  - the Duplicate Address Detection (DAD) procedure.

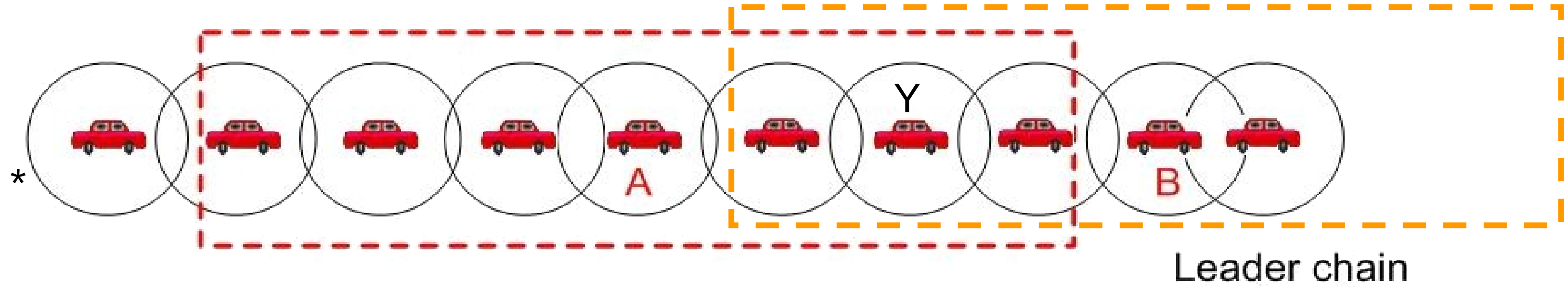


Vehicular Address Configuration Protocol

- Leader-based solution
  - bigger nodes are Leaders whereas smaller ones are normal nodes that rely on Leaders for configuring their IP addresses

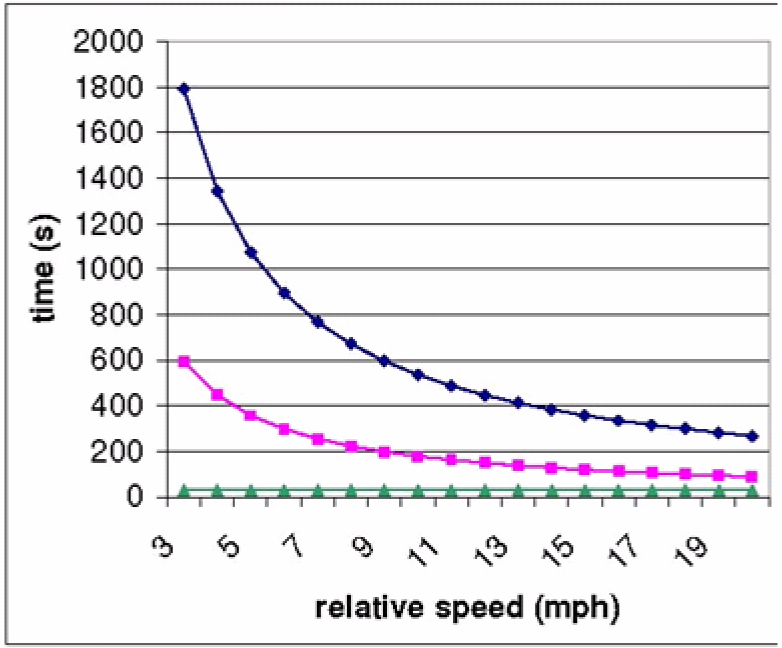


- Reliable communication within a given SCOPE
  - The SCOPE of Leader A is the area covered by the set of Leaders whose distance from A is less or equal to scope hops.
  - $SCOPE_A = 3$



Address Validity Time

- This Figure shows the duration of an IP address from when it is assigned to a node to when the node needs to be reconfigured.

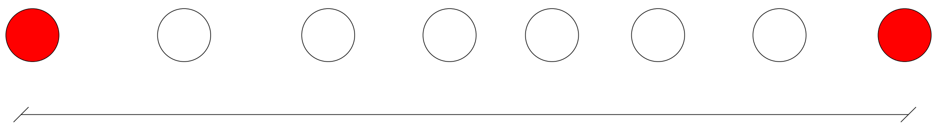


Two Main Tasks Of VAC Functionalities

- Building and maintenance of the Leader chain
  - how to elect Leaders in the network and how to change them when node mobility makes it necessary
- Address configuration and maintenance
  - management of addresses that can be assigned to nodes in the network

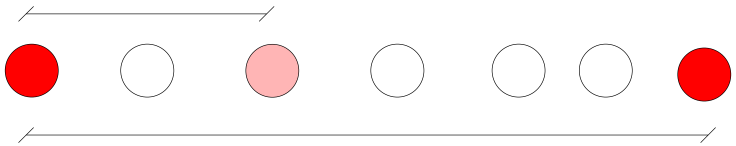
Leader Chain's Configuration And Maintenance

- TH_max and TH_min are thresholds for maximum and minimum distance between two Leaders.
  - Distance(L1, L2) > TH_max



A new Leader (L3) is elected

  - Distance(L1, L3) < TH_min



A Leader (L3) becomes normal

L1 1 2 3 4 5

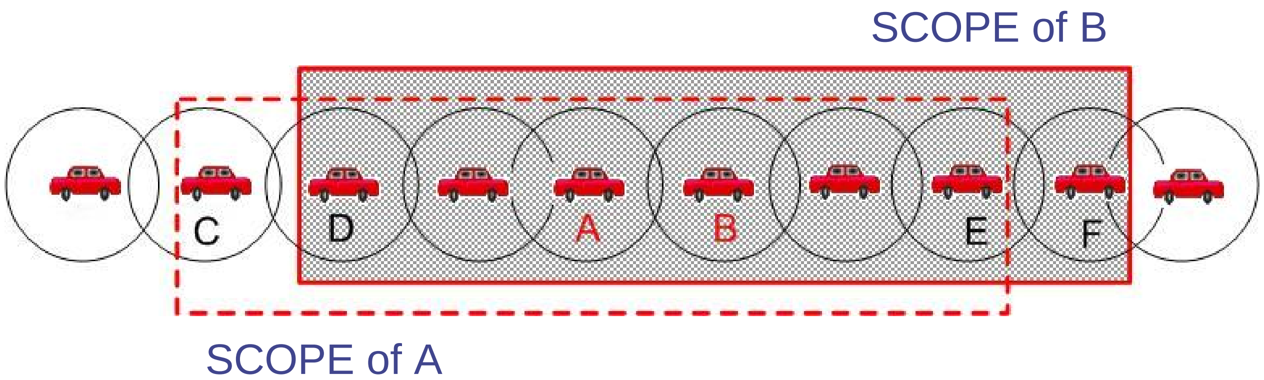
> TH_max

Address Configuration And Maintenance

- Synchronization of address information
- Modified DHCP protocol
- Duplicate Address Detection (DAD) procedure
- Evaluation Assessment

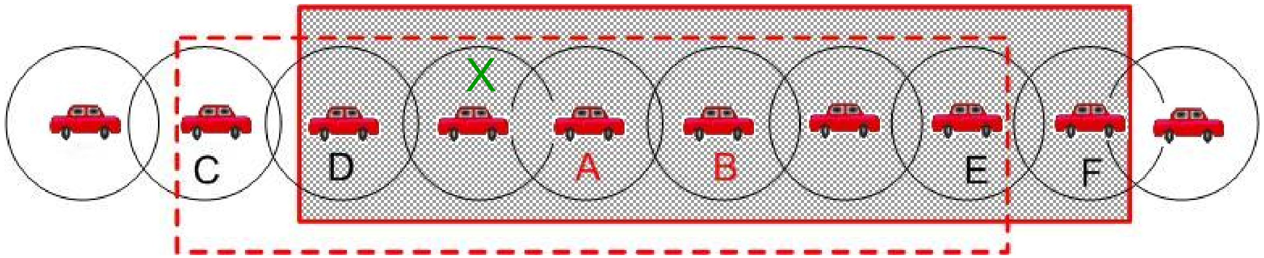
Synchronization Of Address Information

- A node configured from Leader A has a valid address even outside A's range if it remains in A's SCOPE.
- Requires only single-hop communications between nodes and Leader.
- Each Leader sends in broadcast a Hello packet to all the Leaders in its SCOPE periodically.



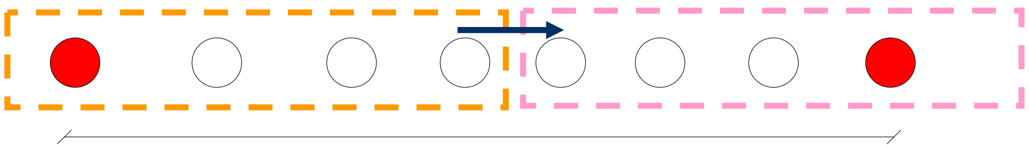
Modified DHCP Protocol

- X is not configured yet.
- X will gather Hello packet from the close Leader.
- After estimating, X will send the nearest Leader a request for the address.



Duplicate Address Detection (DAD) Procedure

- X is configured with the IPx within the SCOPE of A
- B is "N" hop far from A
- N > scope, B is not in the SCOPE of A
- X doesn't hear anymore packets from A
- X receives packets from B
- So X needs a new address



- DAD procedure does not introduce additional signaling traffic, but it is effective to determine when the node has to configure a new address.

Evaluation Assessment

- Qualnet simulator v3.7
  - 50 nodes
  - 15000mx20m terrain (single direction of travel?)

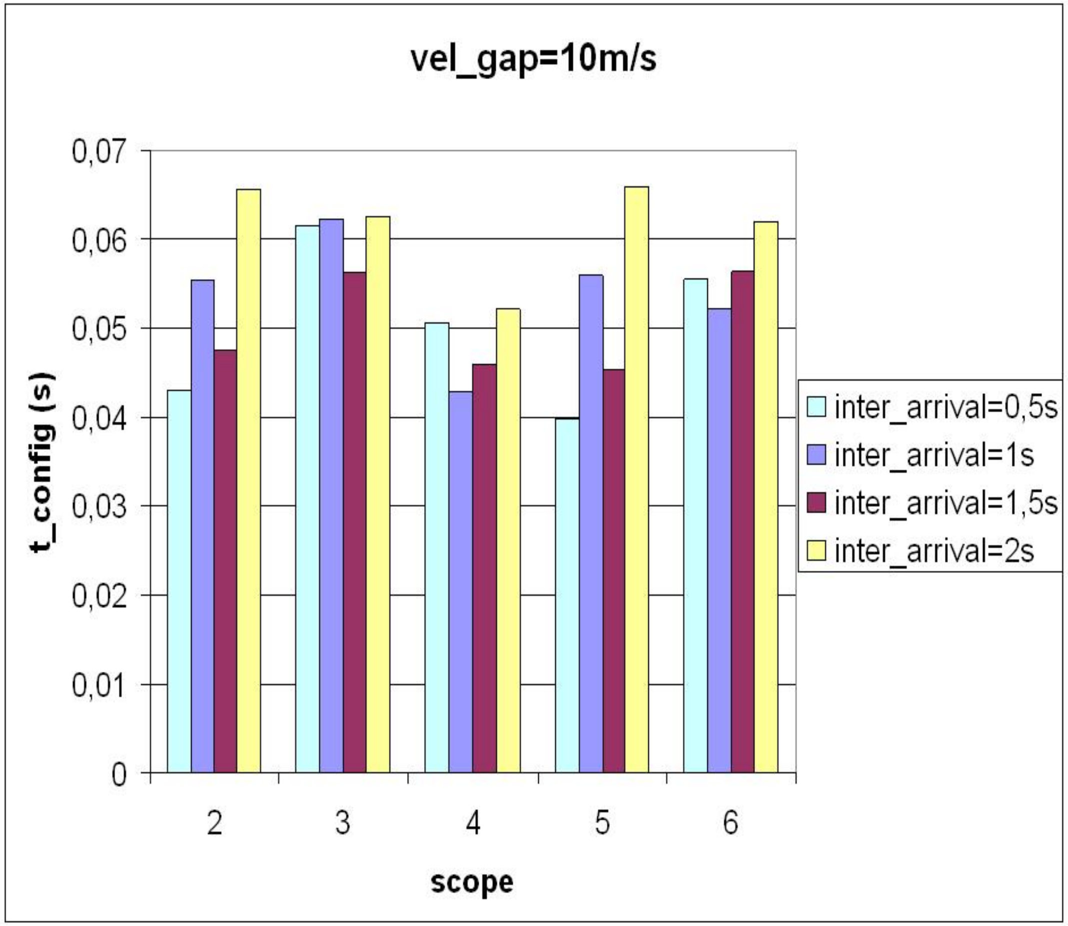
- Parameters
  - scope: size of the SCOPE set
    - 2, 3, 4, 5, 6
  - Vel_gap: maximum difference between cars' speed
    - 5, 10, 15, 20m/s.
  - Inter_arrival: a new car enters the highway every…
    - 0.5, 1, 1.5, 2s

Evaluation: Configuration Time

- Low configuration time for all scope size and cars' interarrival times
  - Always less than 70ms
  - Allows also real-time application

Configuration Time In Seconds

- Configuration time per scope for several values of inter_arrival time and with constant vel_gap.

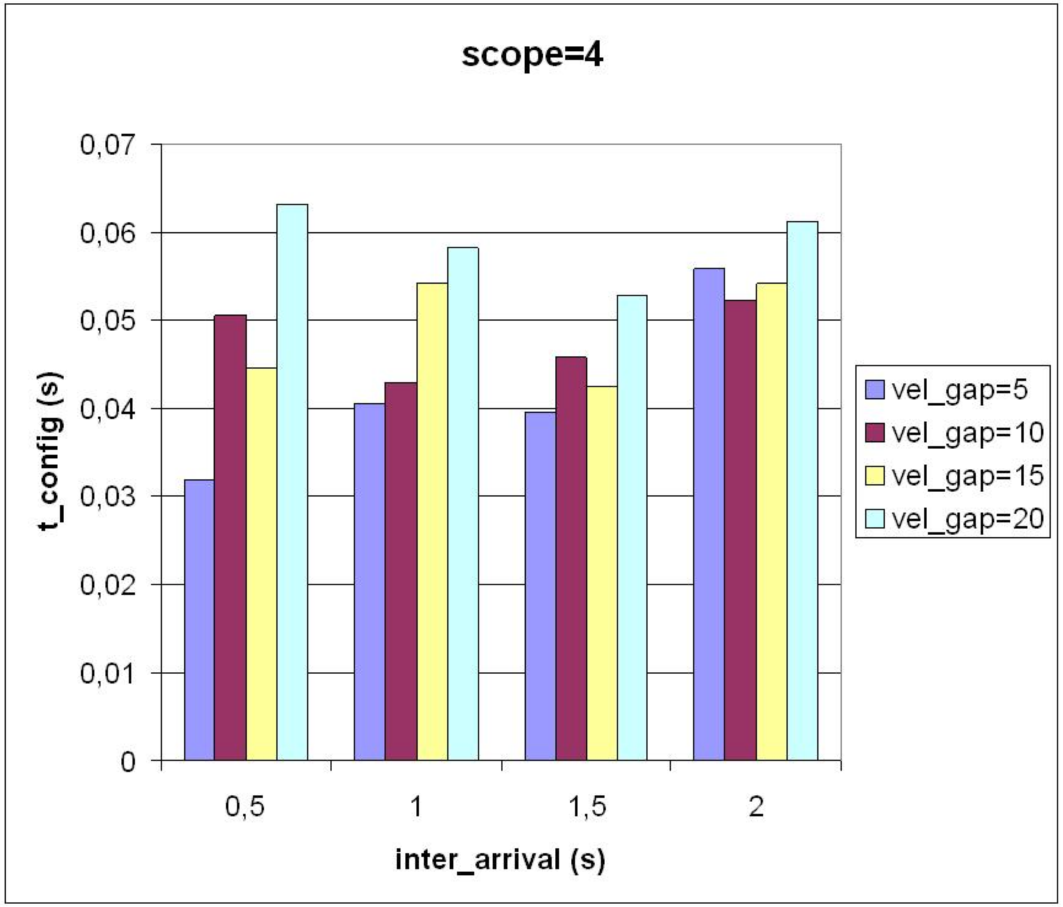


vel_gap: the gap between the minimum and the maximum speed of nodes in the scenario.

inter arrival time: this parameter allows changing the node density in the network.
D

Configuration Time In Seconds

- Configuration time per inter_arrival time for several values of vel_gap and with constant scope.



vel_gap: the gap between the minimum and the maximum speed of nodes in the scenario.

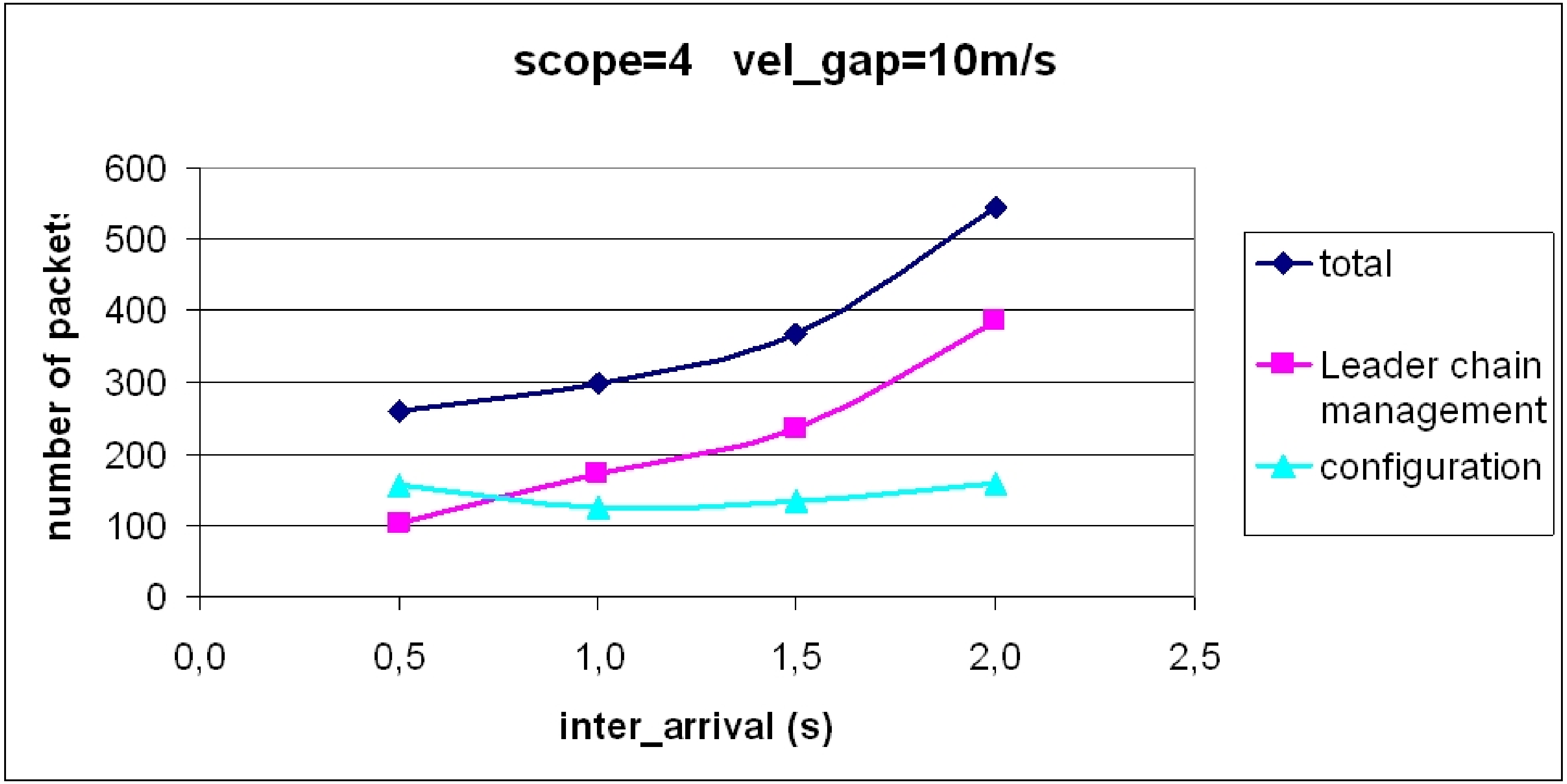
inter arrival time: this parameter allows changing the node density in the network.
D

Evaluation: Overhead

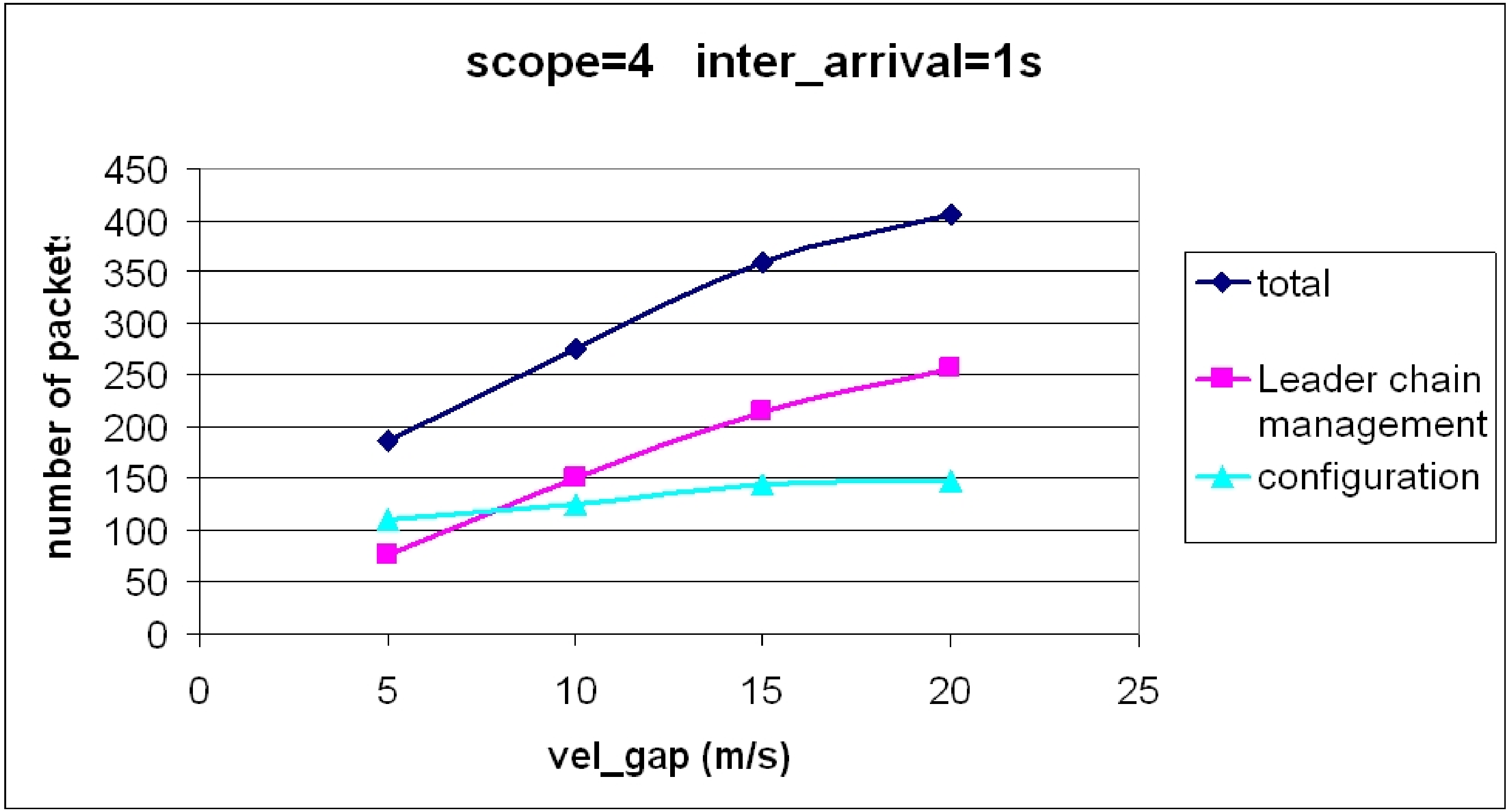
- Leader chain management is more affected by vehicles' density and speed than address configuration.
  - VAC address assignment is very stable.

- Cross-layer techniques could be exploited to piggyback messages for Leader chain management on beacons periodically sent by routing algorithms.

- Number of signalling packets per inter_arrival time for several values of vel_gap and with constant scope.



- Number of signalling packets per vel_gap for several values of inter_arrival time and with constant scope.



Conclusion

- High reliability
- Low configuration time
  - Can support even vehicles engaged in real-time applications
- Low overhead

4-3: Network Mobility Protocol for Vehicular Ad Hoc Networks

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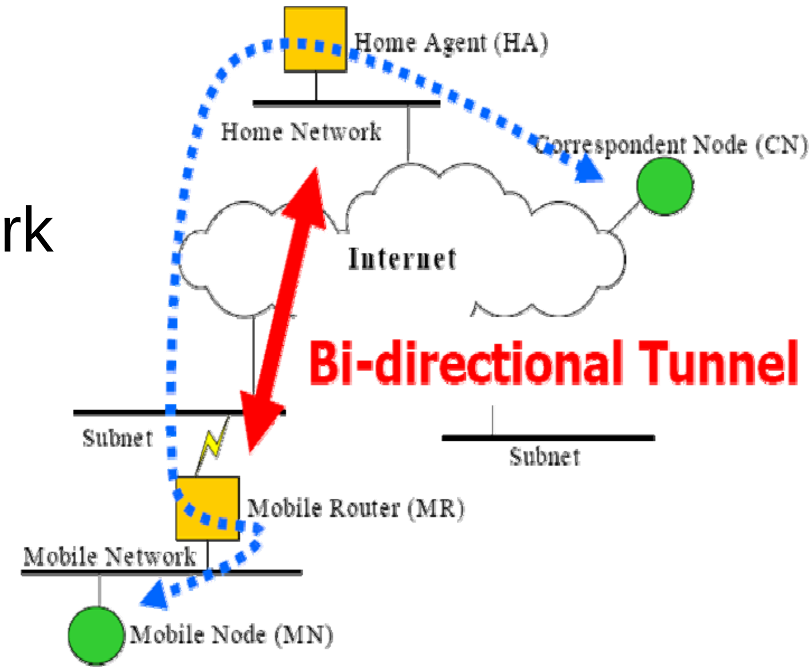
IEEE WCNC 2009

Outline

- Introduction
- Related works
- Motivation
- System architecture and basic idea
- Network mobility protocol for vehicular ad hoc networks
- Simulation results
- Conclusion

Introduction (1)

- VANET characteristic
  - High mobility, network topology changes at any time
  - Trajectory
- Mobile Router (MR)
  - Gateway of a mobile network
  - Bi-directional tunnel



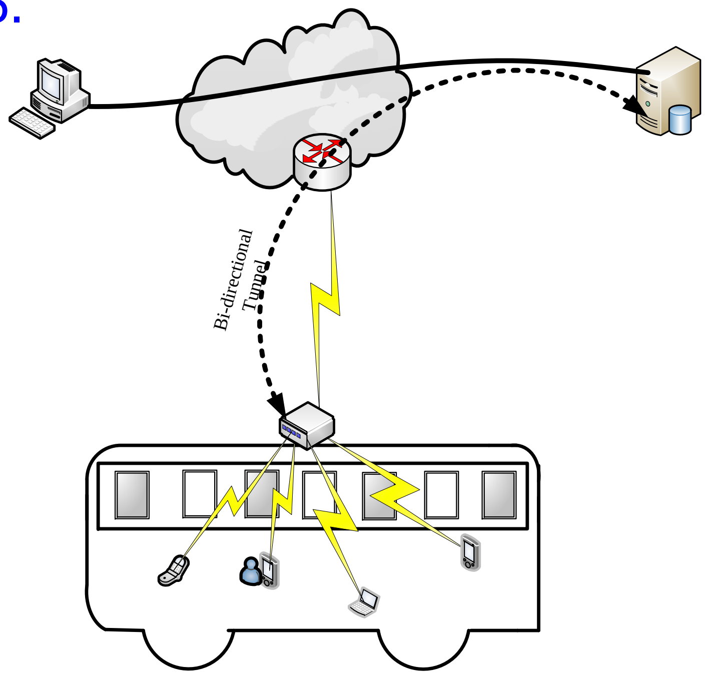
- Drawbacks
  - Long packet delay
  - High handoff latency
  - Not suitable for high mobility environment
  - To complex to acquire IP address

Introduction (2)

- Existing results can be divided into
  - Layer-3 (Mobile IPv6)
  - Layer-7 (SIP Mobility)
- This work provides a network mobility protocol for vehicular ad hoc networks
  - This work integrates the IP address passing into the network mobility for VANETs
  - The cooperative mobile router assists vehicle to perform the layer-3 pre-handoff procedure

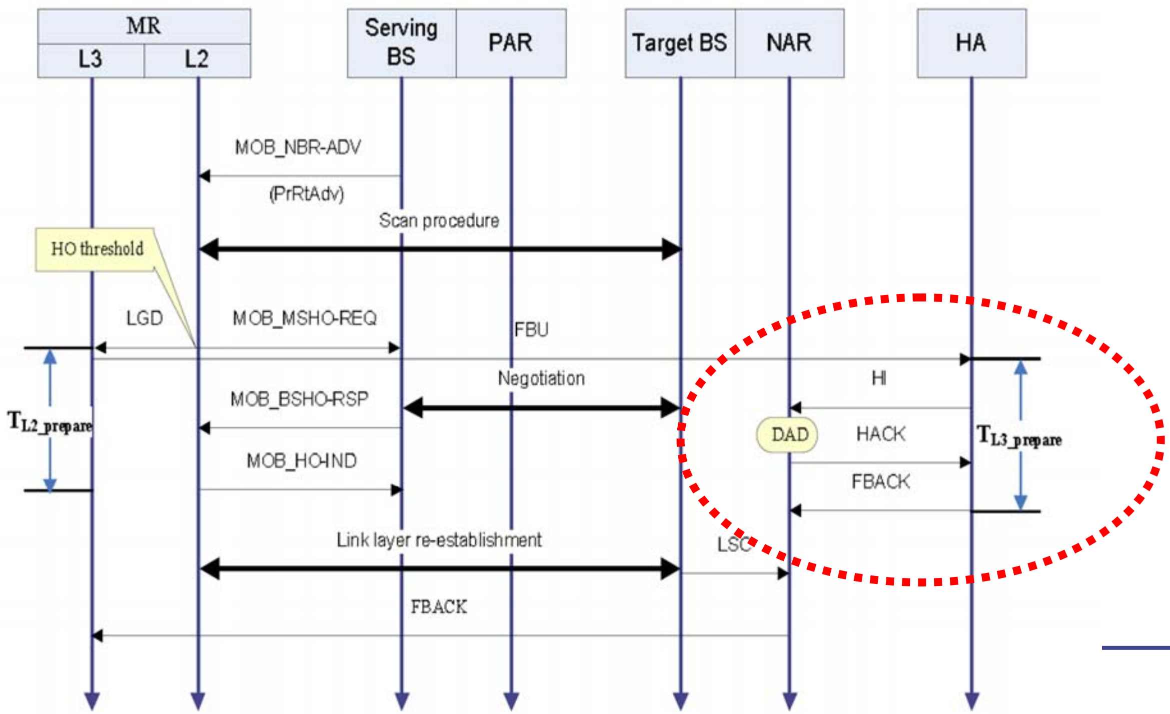
Related Works (1)

- Network mobility (RFC-3963)
  - Network mobility mobile IPv6 (MIPv6-NEMO) provide permanent Internet connectivity to all mobile network nodes.
  - A. Petrescu V. Devarapalli, R. Wakikawa and P. Thubert. "Network Mobility (NEMO) Basic Support Protocol". *Internet Engineering Task Force* (IETF), RFC-3963, 2005.



Related Works (2)

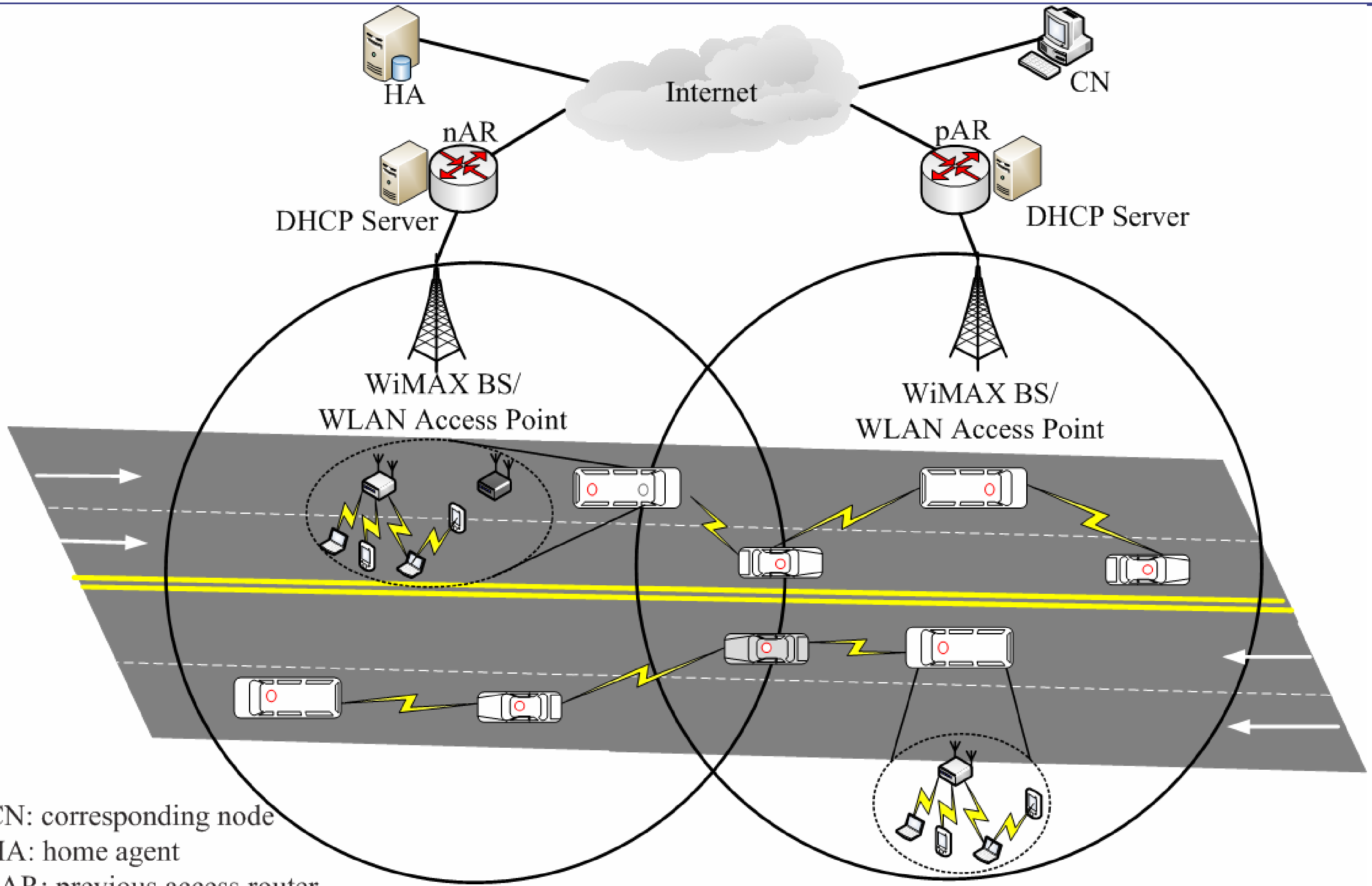
- Solution of network mobility handoff
  - Zhong Lei, Liu Fuqiang, Wang, Xinhong and Ji, Yusheng. " Fast Handover Scheme for Supporting Network Mobility in IEEE 802.16e BWA System ", *IEEE International Conference on Wireless Communications, Networking and Mobile Computing* (WiCOM 2007).
    - Duplicate address dection (DAD) procedure still spend lots of time.



Motivation

- Traditional IP-mobility is not suitable due to high mobility of vehicle in vehicular environment.
- Even though **Network Mobility (NEMO) Basic Support** protocol can operate in vehicular network but suffers a long latency for real-time service.
  - DAD time for MR's CoA occupies most of the layer-3 handoff delay.

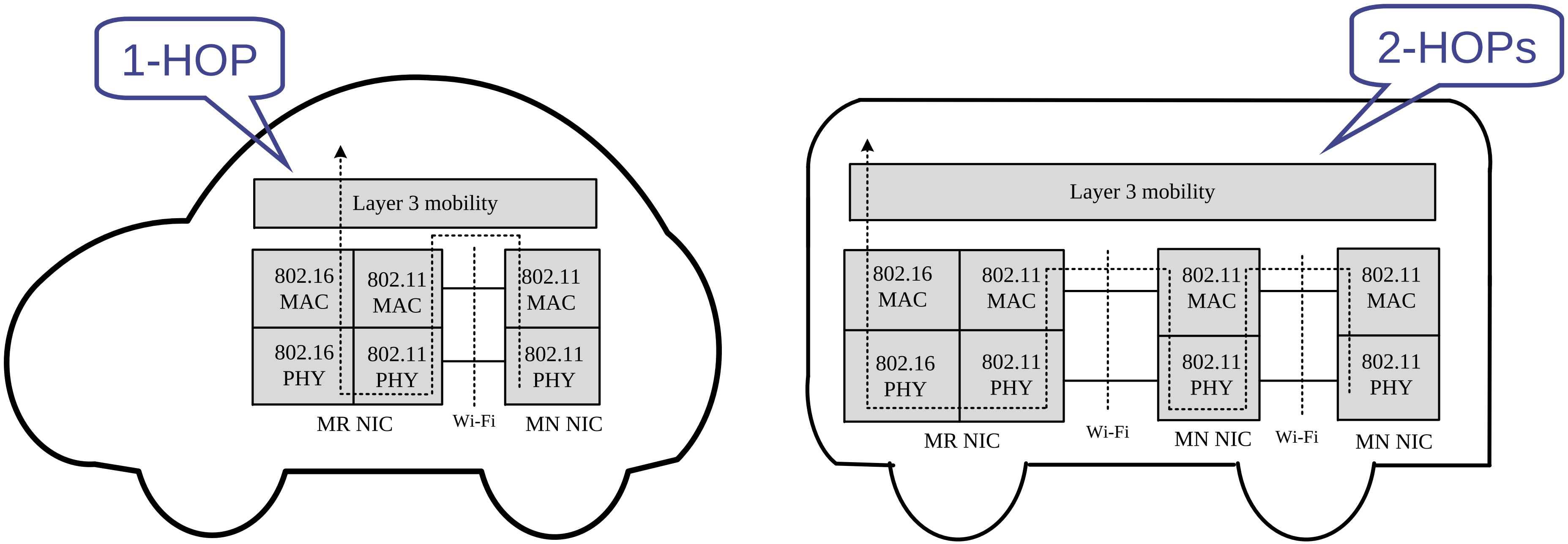
System Architecture



CN: corresponding node
HA: home agent
pAR: previous access router
nAR: new access router
MR: mobile router

802.11 connection

Mobile Router Protocol Stacks



MR NIC: Mobile Router Network Interface Card

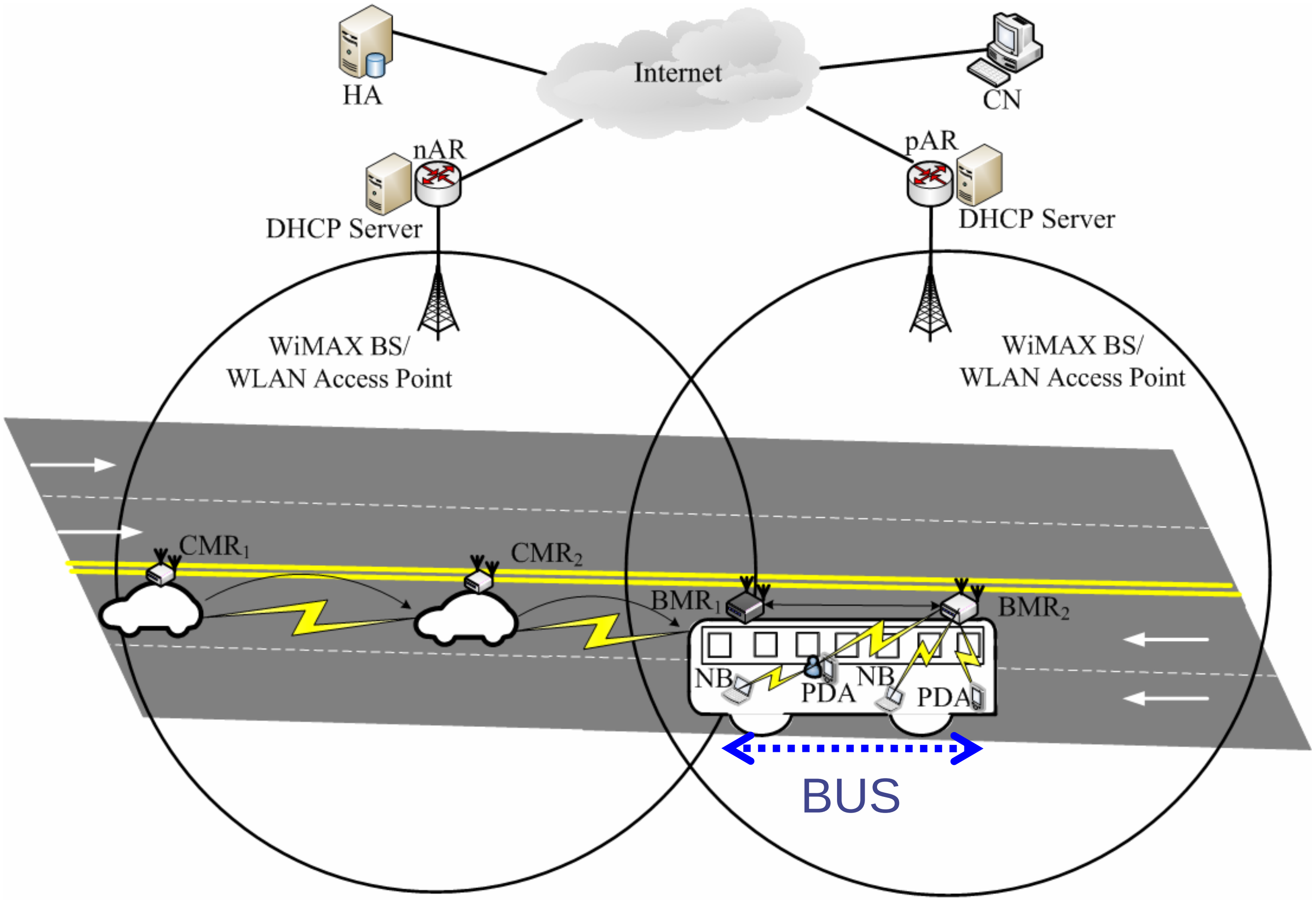
MN NIC: Mobile Node Network Interface Card

Basic Idea

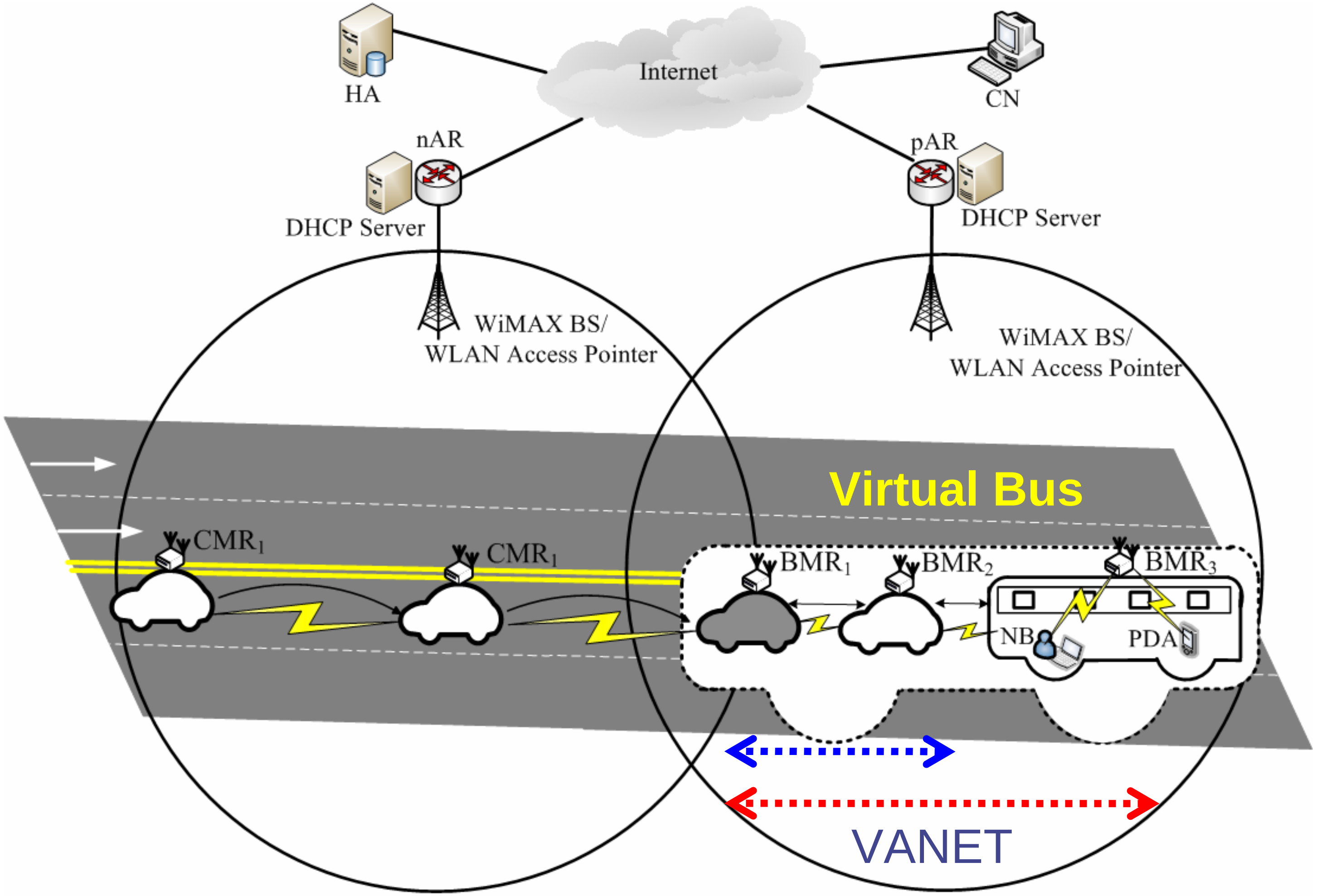
- Tradition IP acquirement approach
  - DHCP server
- Novel IP acquirement approaches
  - IP Address Passing
    - Acquire IP address from the lanes of the same direction.
    - Acquire IP address from the lanes of the opposite direction.
- Using cooperative mobile router assists handoff mechanism in layer-3.
  - Pre-handoff by cooperative mobile router for getting IP address and pre-binding update to HA (home agent).

First Solution – Pre-handoff and Binding

- High handoff latency and packet loss

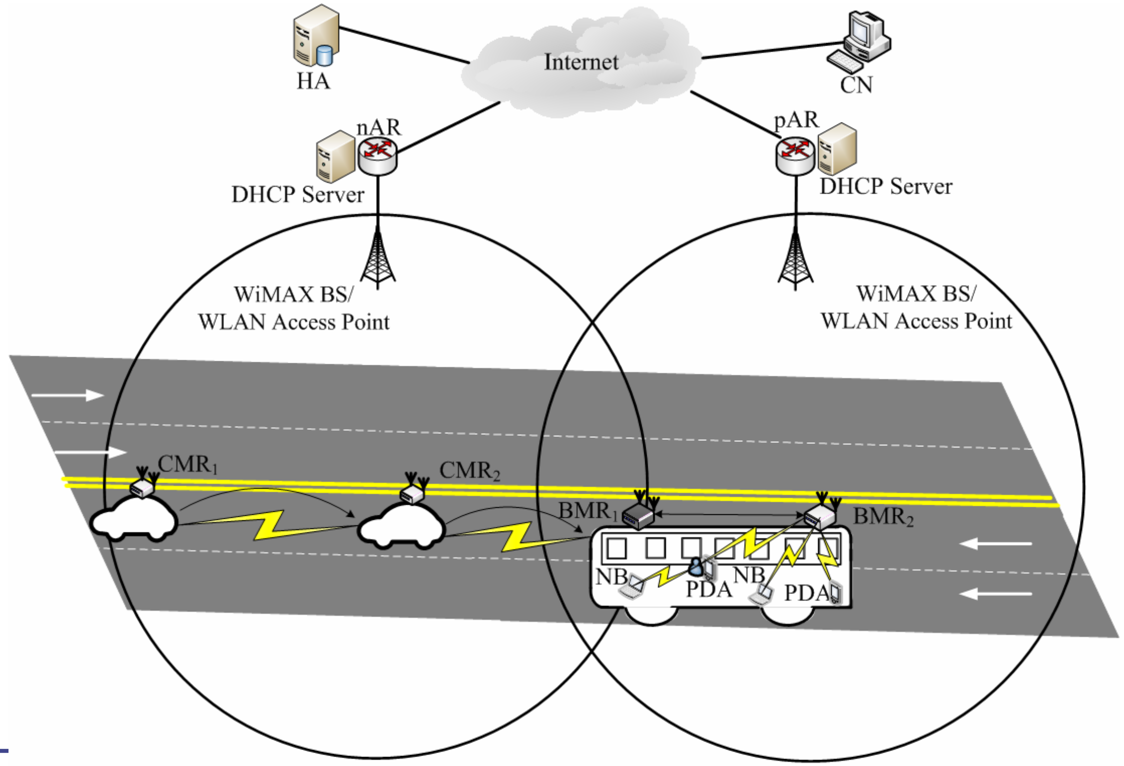


Virtual Bus Solution



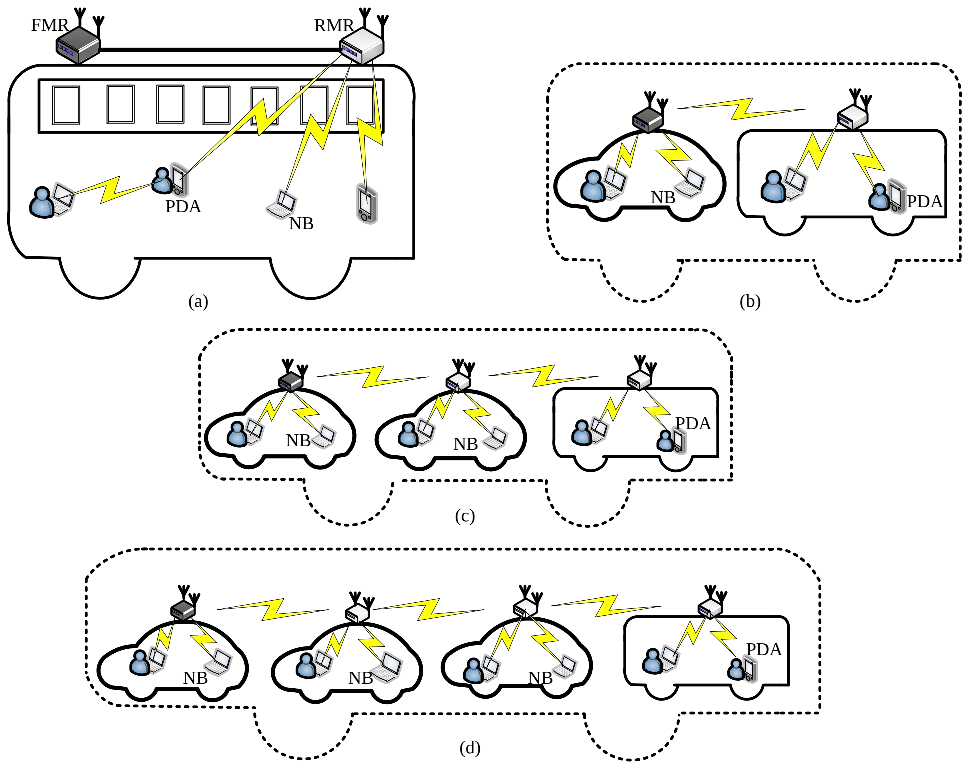
Challenge

- High hardware cost
- BMR1 cannot offer a seamless handoff under high mobility



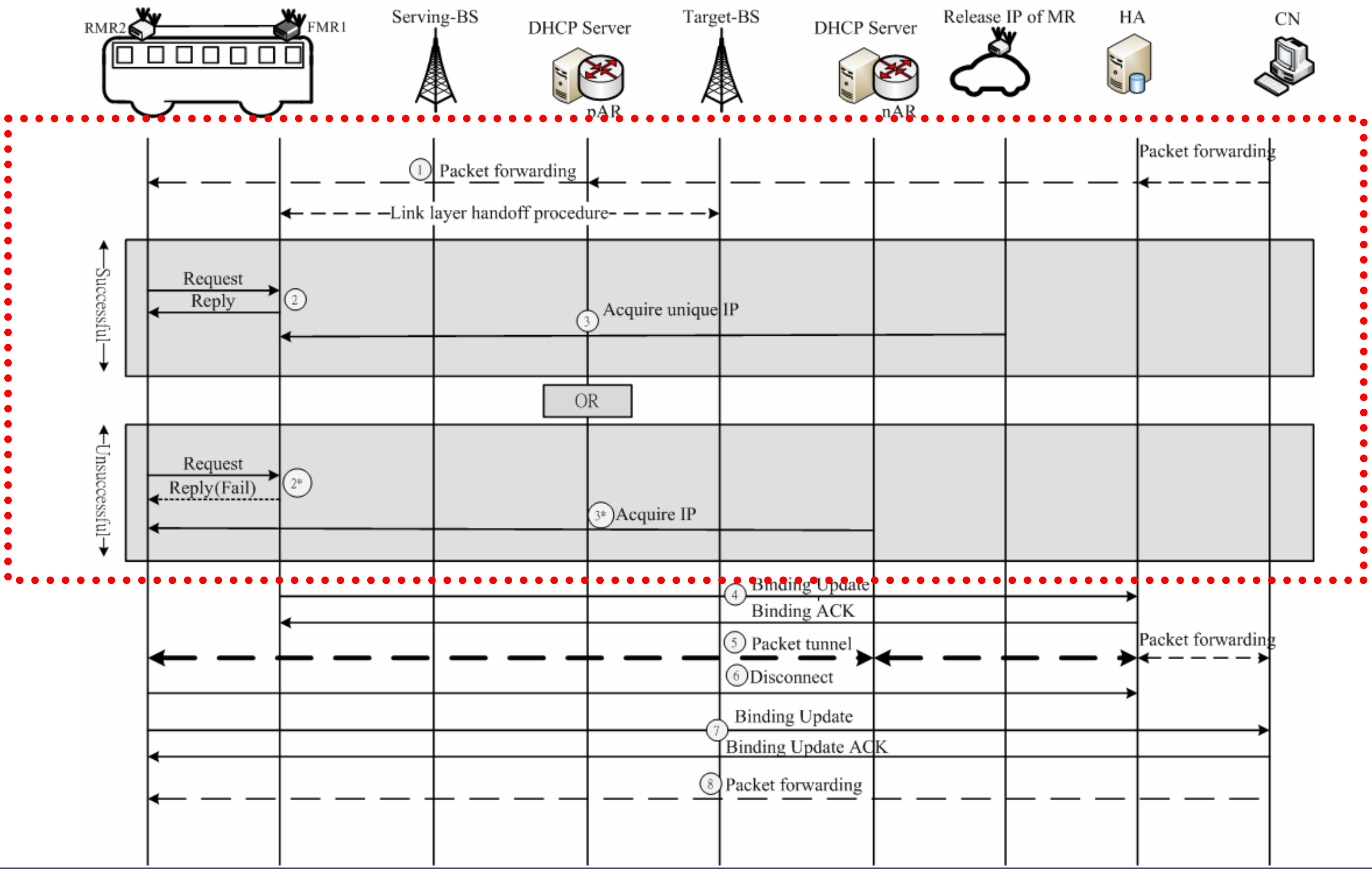
NEMO Protocol for VANETs

- (a) NEMO by bus
  - FMR: Front mobile router
  - RMR: Rear mobile router
- (b) NEMO by 1-hop on **virtual bus**
- (c) NEMO by 2-hop on **virtual bus**
- (d) NEMO by multi-hop on **virtual bus**



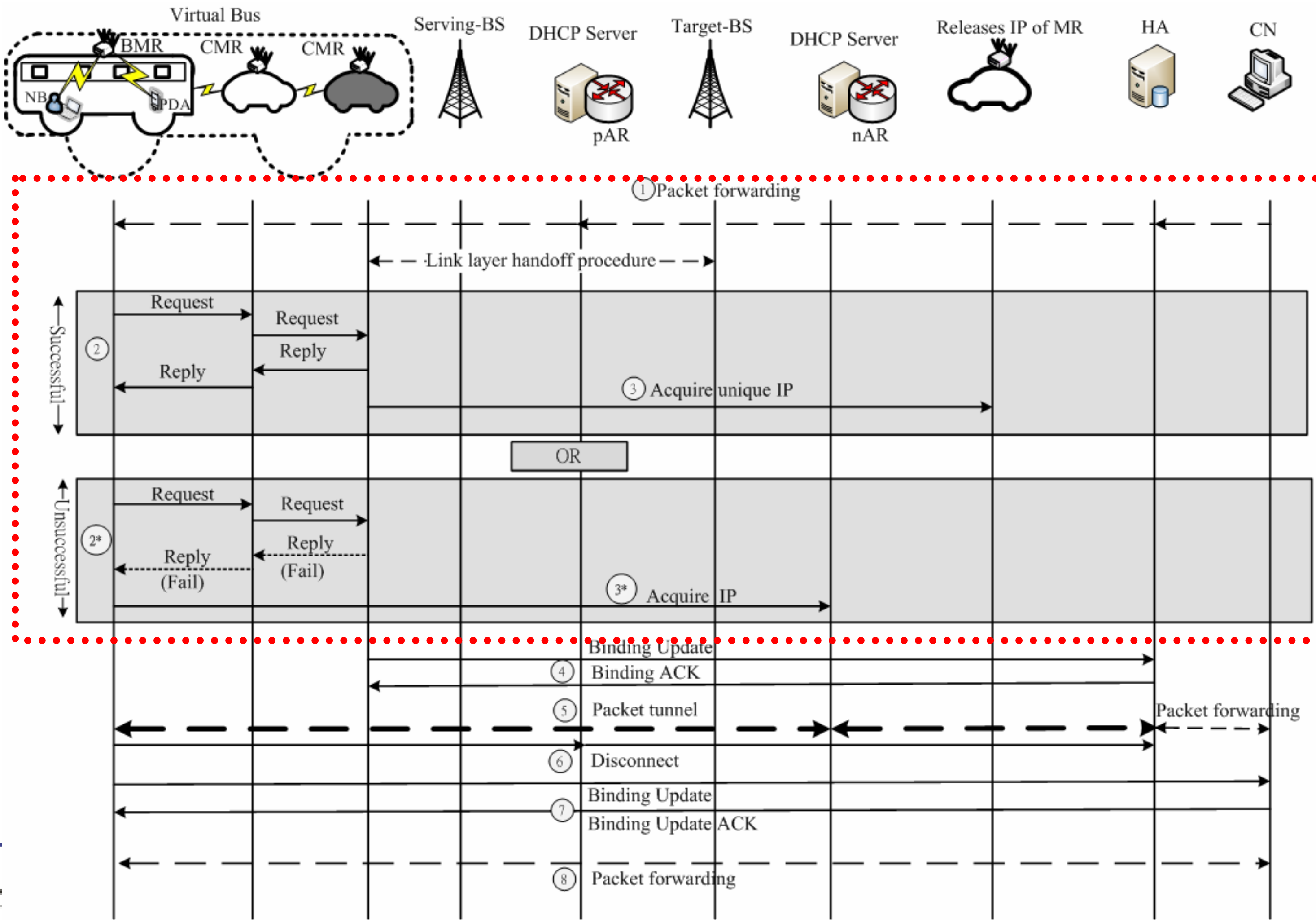
NEMO Scheme for a Real Bus over VANETs

- Difficultly acquire IP address under high speed environment
- Acquiring IP address from DHCP causes high handoff latency

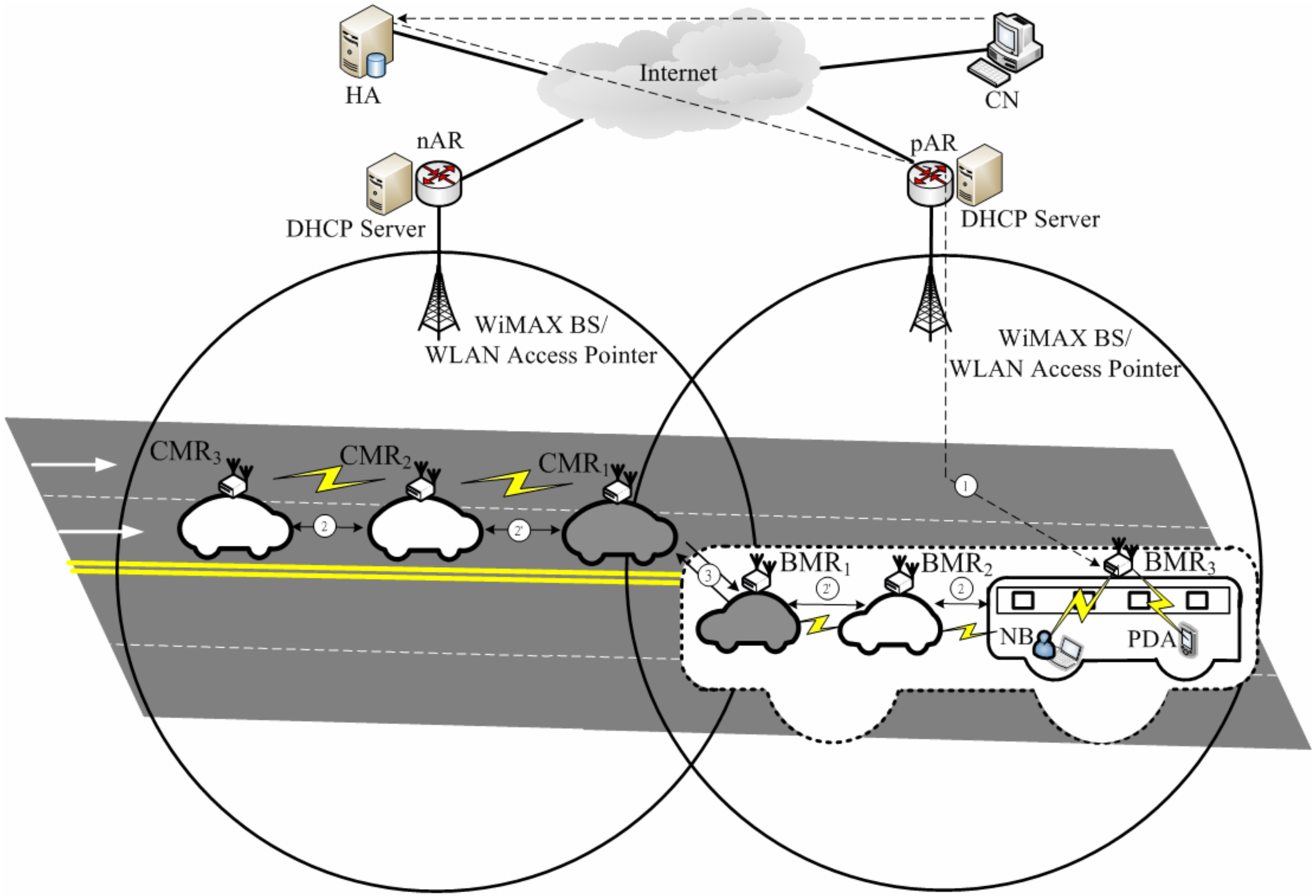


NEMO Scheme for a Virtual Bus over VANETs

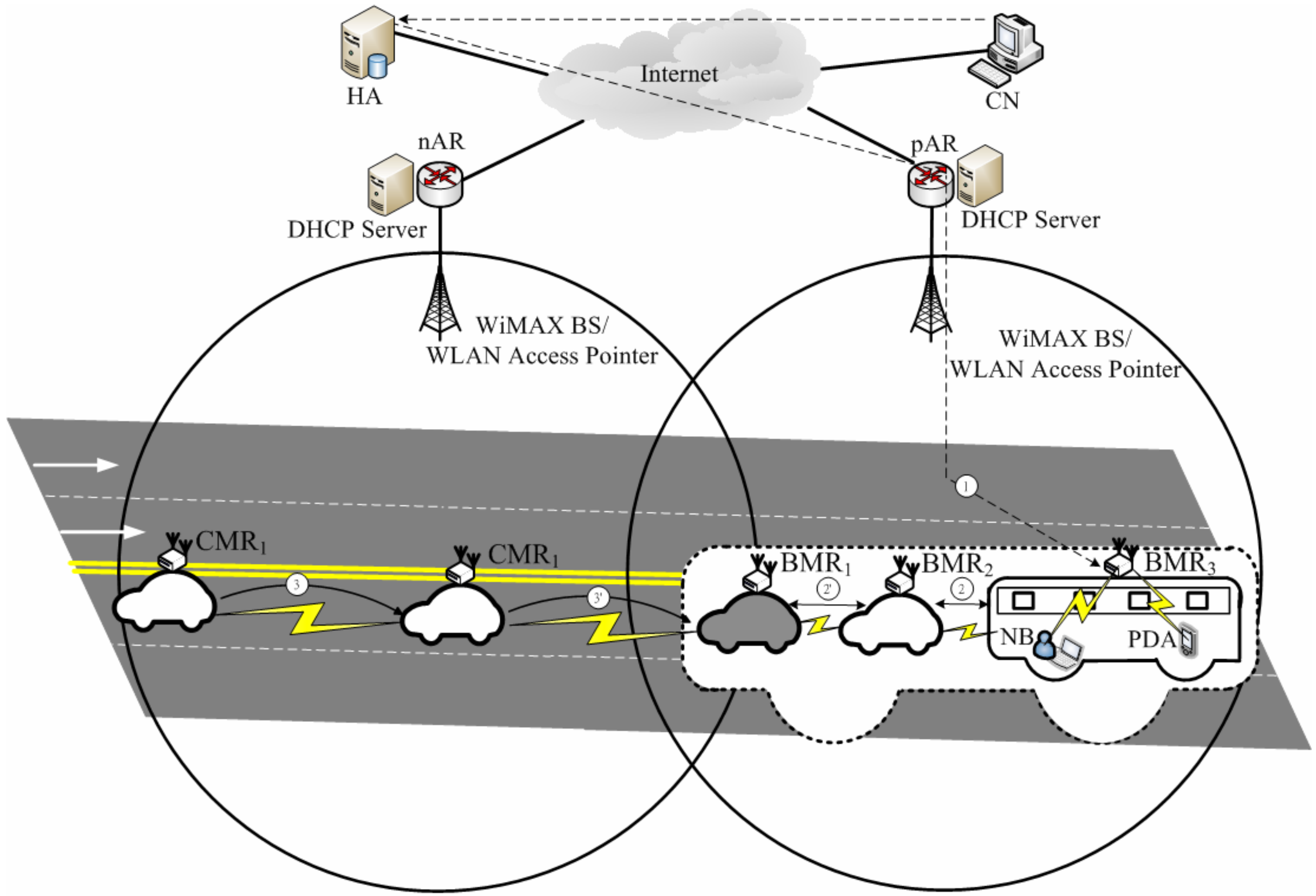
- Acquire IP address early
- Reduce handoff latency and packet loss rate



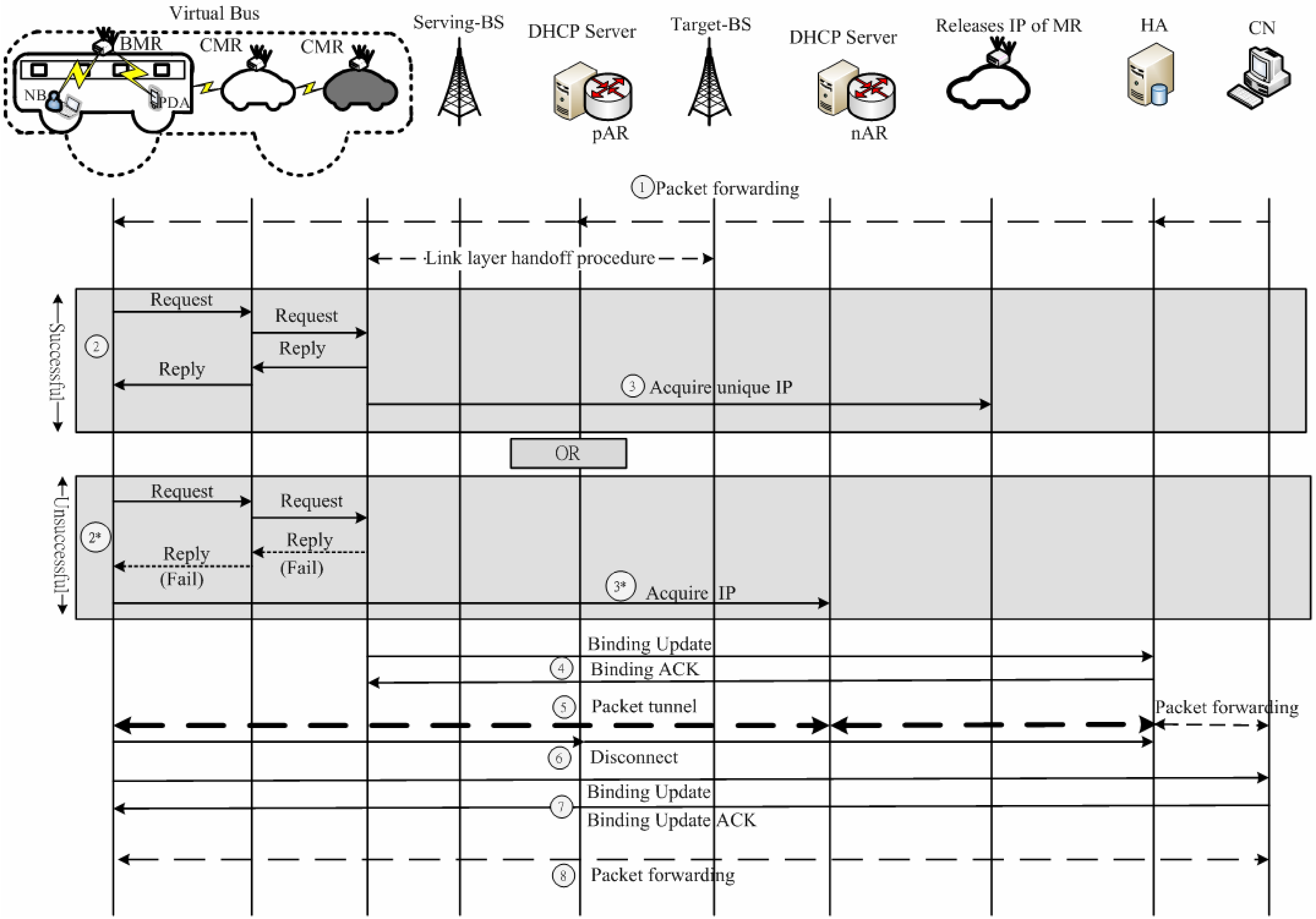
Acquire IP Address from **Opposite Direction**



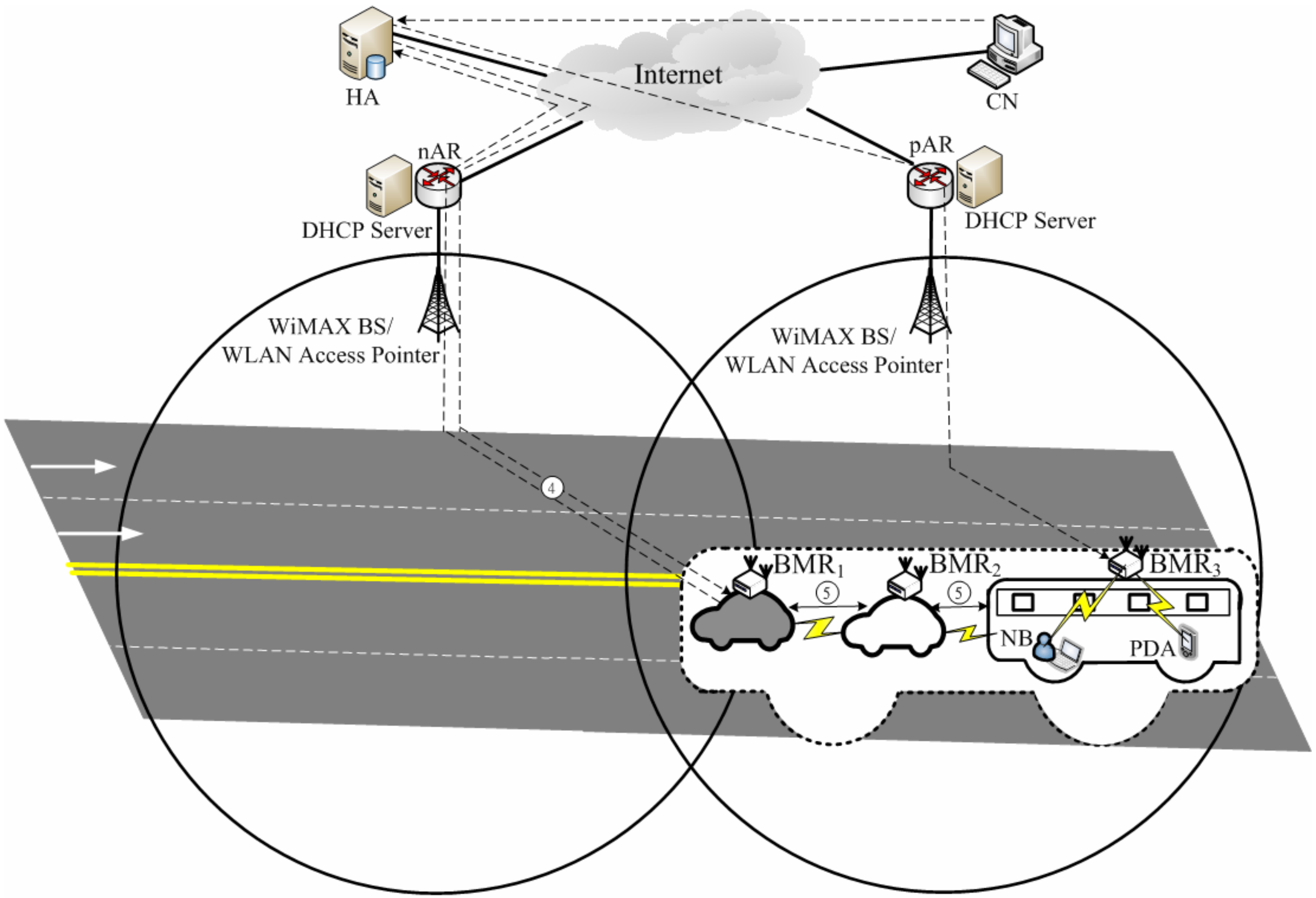
Acquire IP Address from **Same Direction**



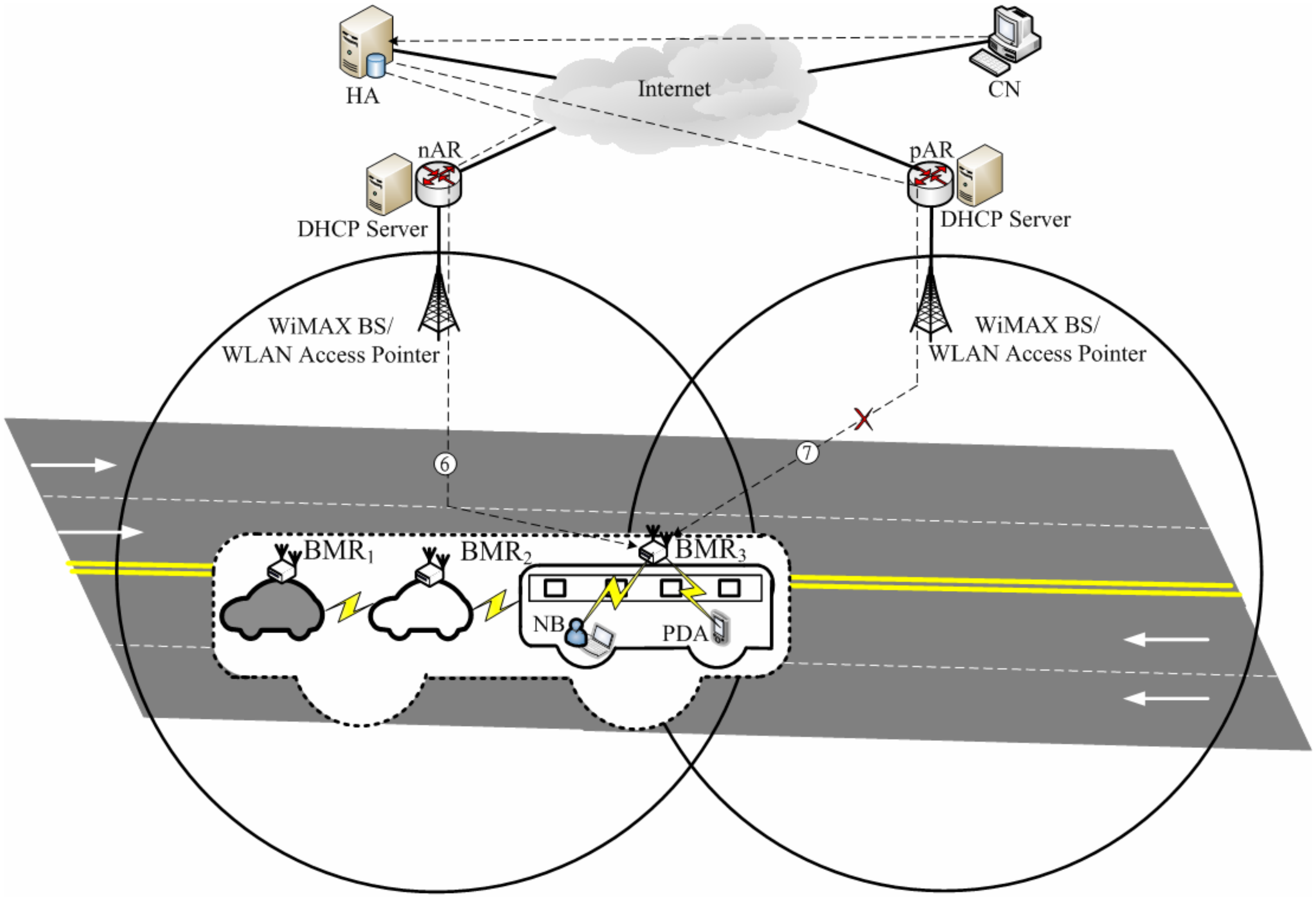
NEMO Scheme for a Virtual Bus over VANETs



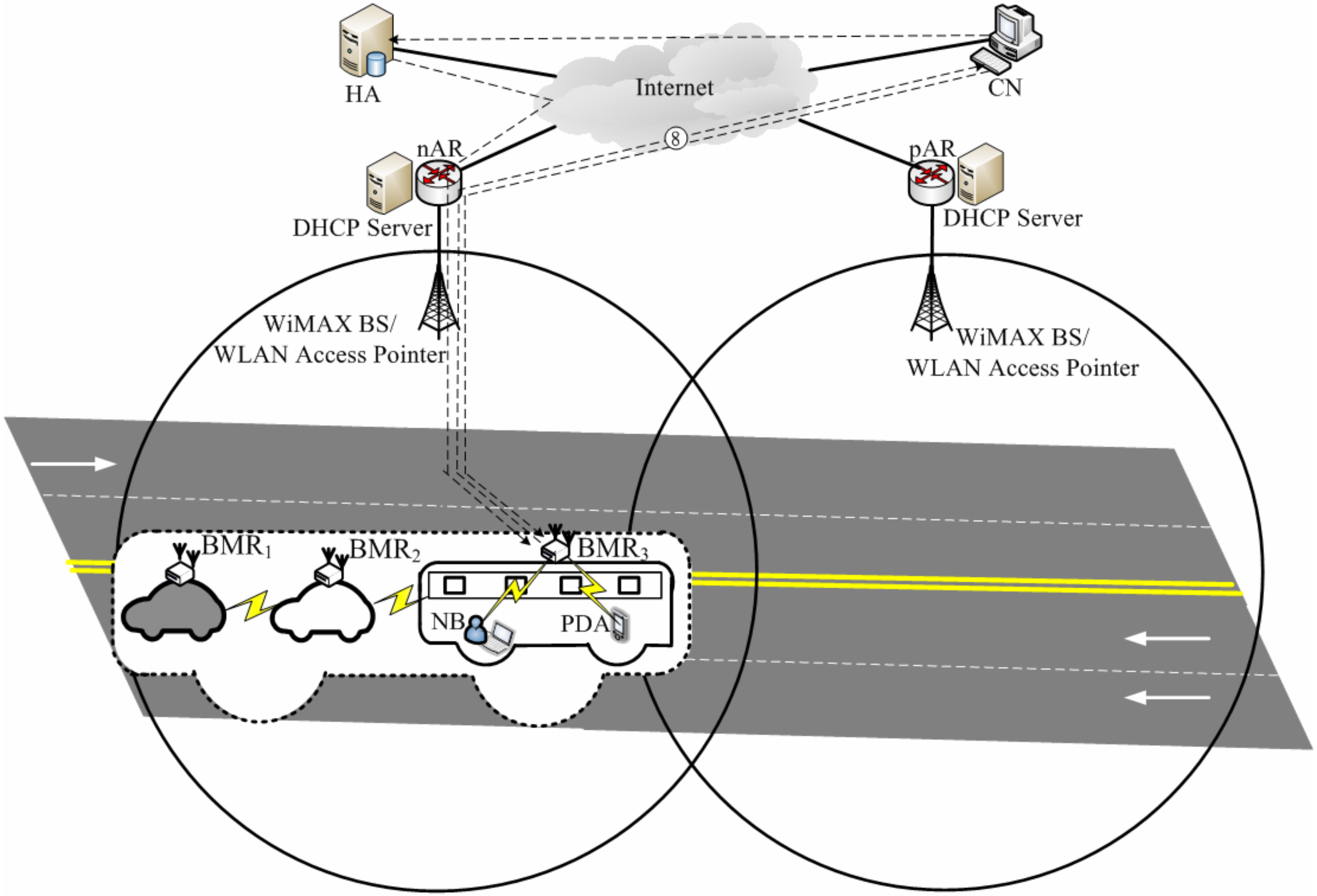
Pre-Binding Update Procedure



Soft Handoff Procedure



Route Redirect Procedure



Simulation Results

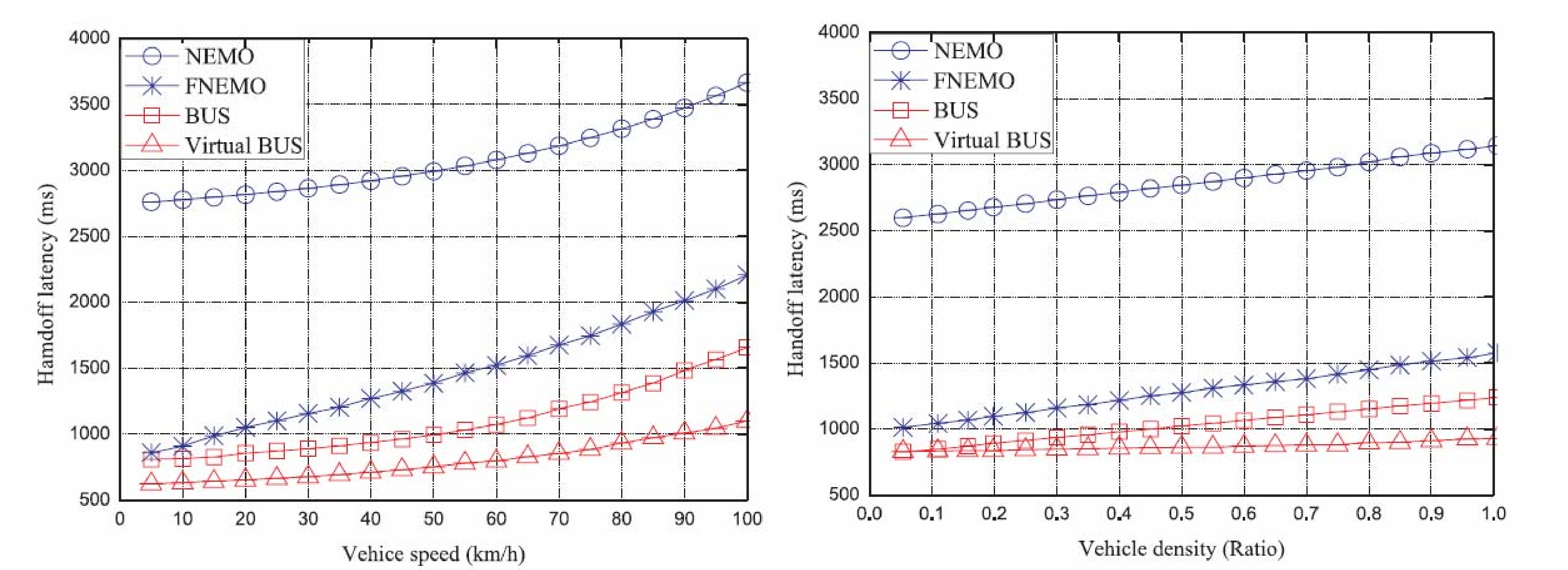
- Simulation environment
  - NS2 2.31, NEMO module, and WiMax module

Network topology size	1000m*1000m
Number of nodes	0~100 vehicles
Vehicle's basic speed	5~100km/h
Transmission Range	Wimax: 1000m WLAN:300m
Packet size	Packet Size=320bytes
Packet rate	100 packets/sec
Simulation Time	200s

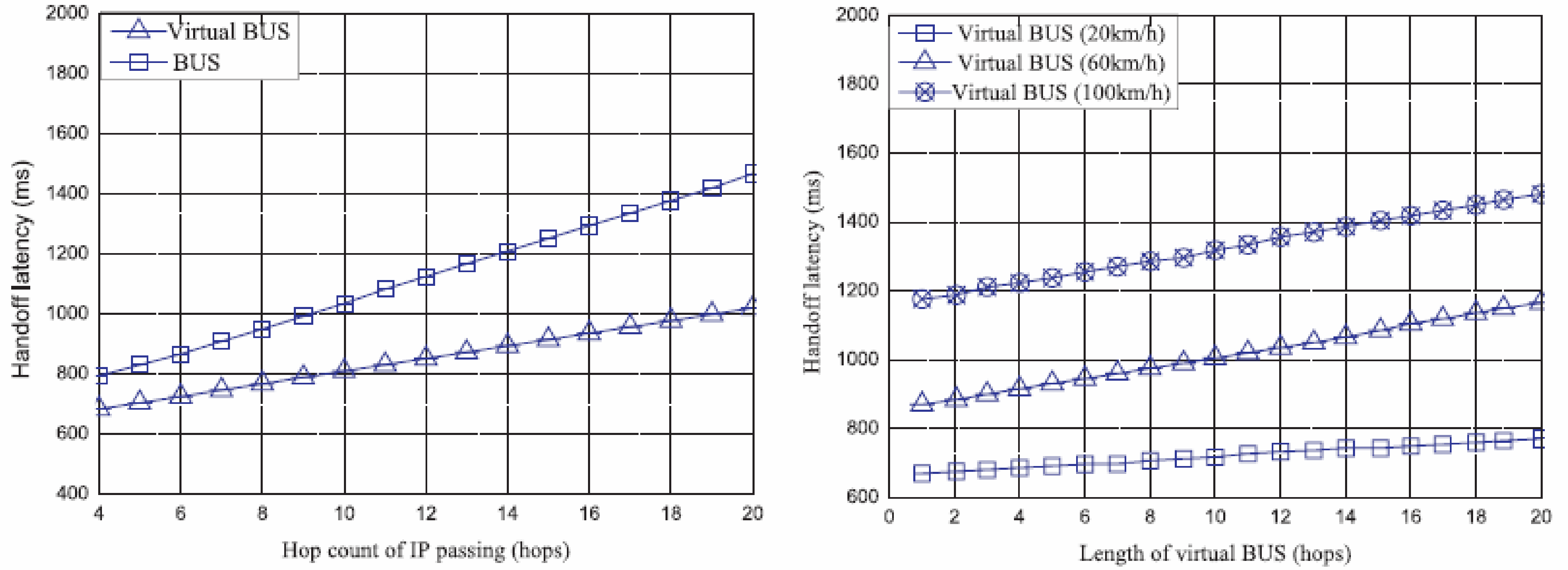
Performance metrics

- Handoff latency
  - The handoff latency is defined as the interval that the last packet is received from the pAR to the time that the first packet is received from the nAR.
- Packet loss rate
  - The packet loss counts from the MS disconnecting to old BS to receiving new packets from the new BS.
- Message overhead
  - The total number of IP-passing packets and the packets of discover CV-MR (cooperative vehicle mobile router).
- Throughput
  - The throughput is defined destination receive packets via per second.

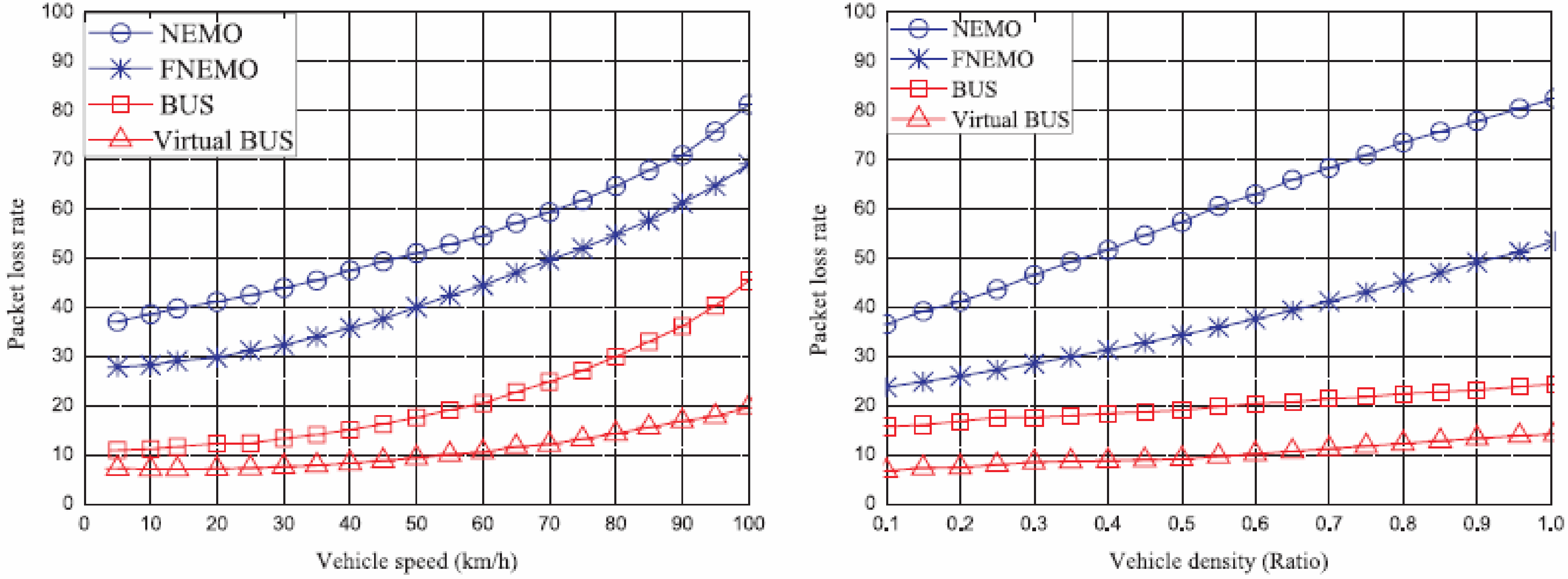
Handoff Latency vs. VS and VD



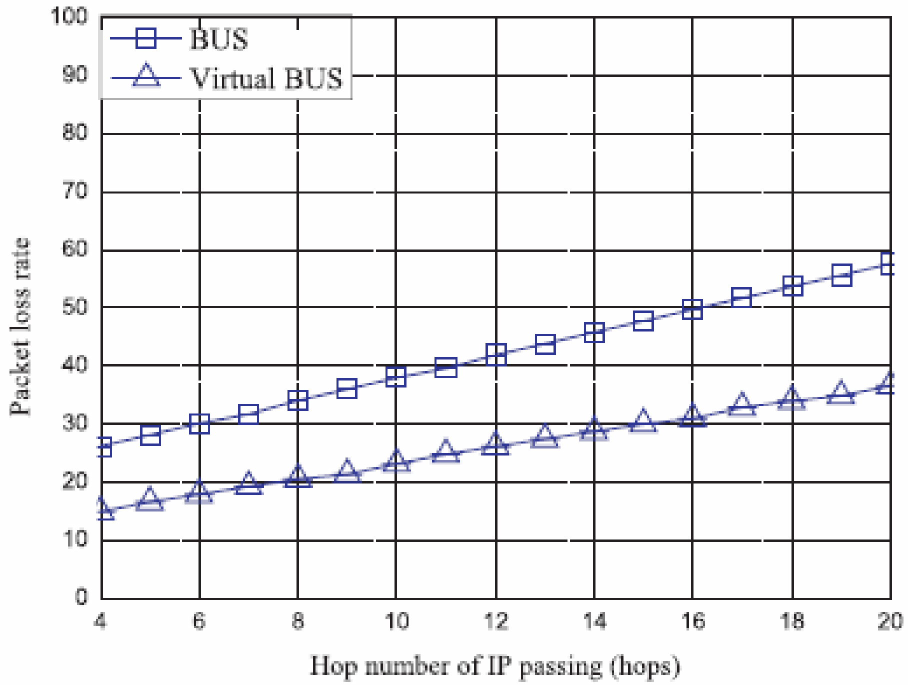
Handoff Latency vs. IP Passing and Length of Virtual Bus

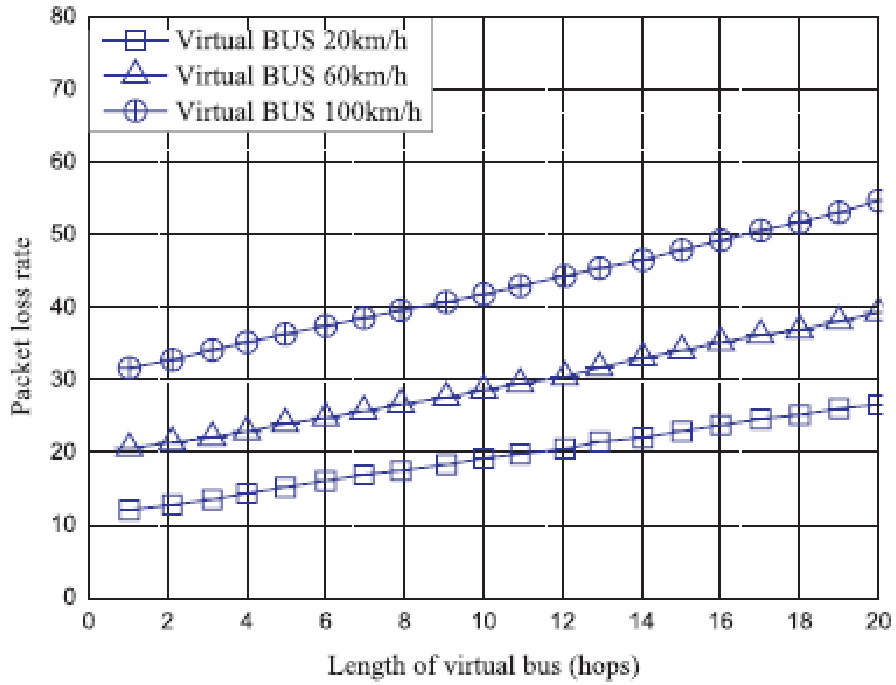


Packet Loss Rate vs. VS and VD

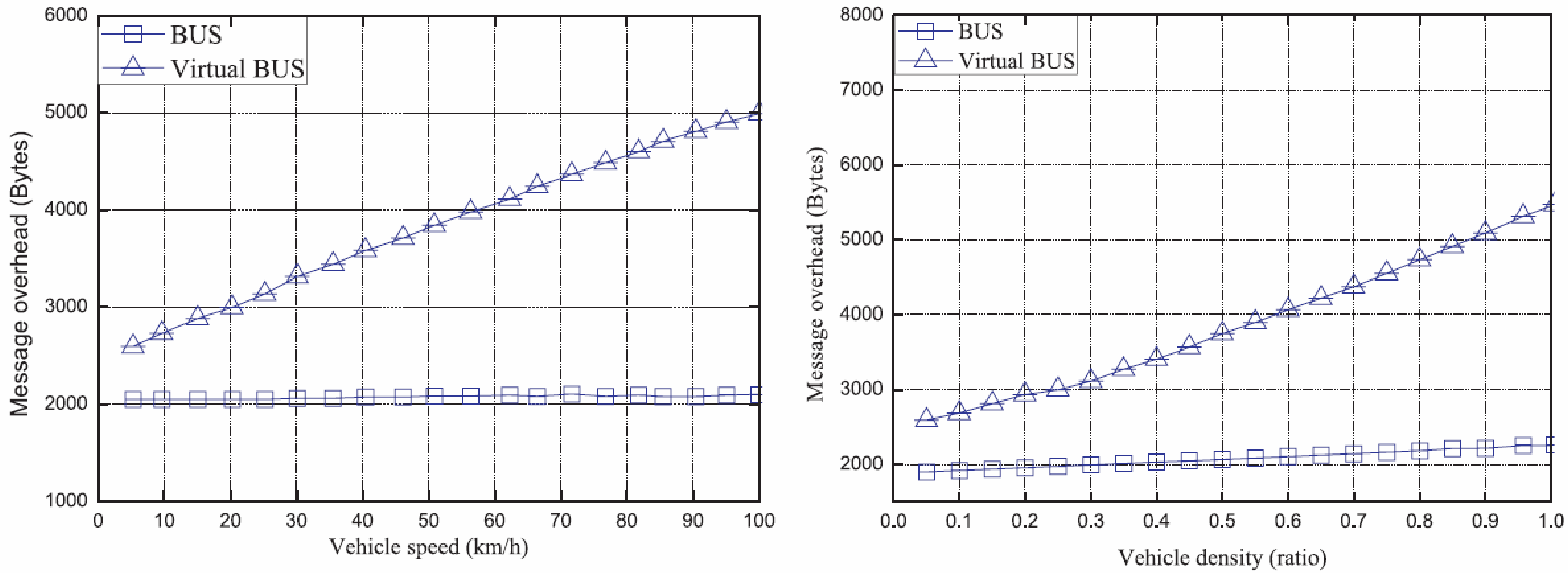


Packet Loss Rate vs. IP Passing and Length of Virtual Bus

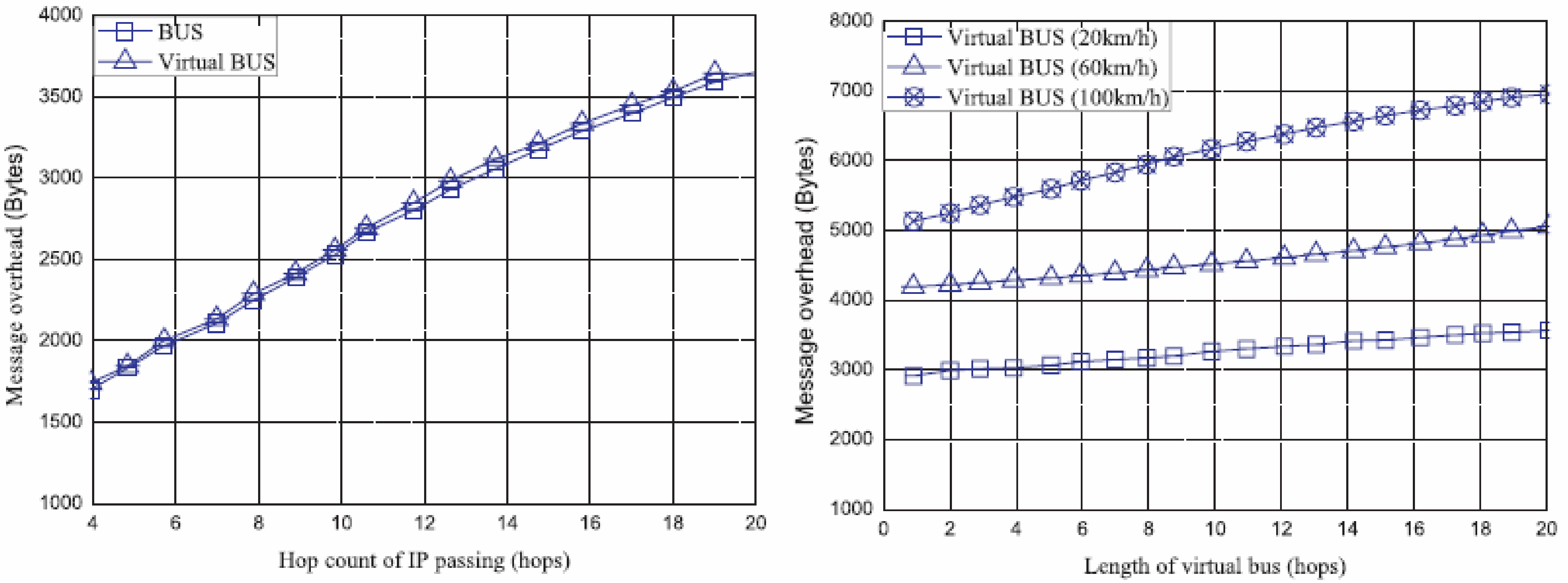




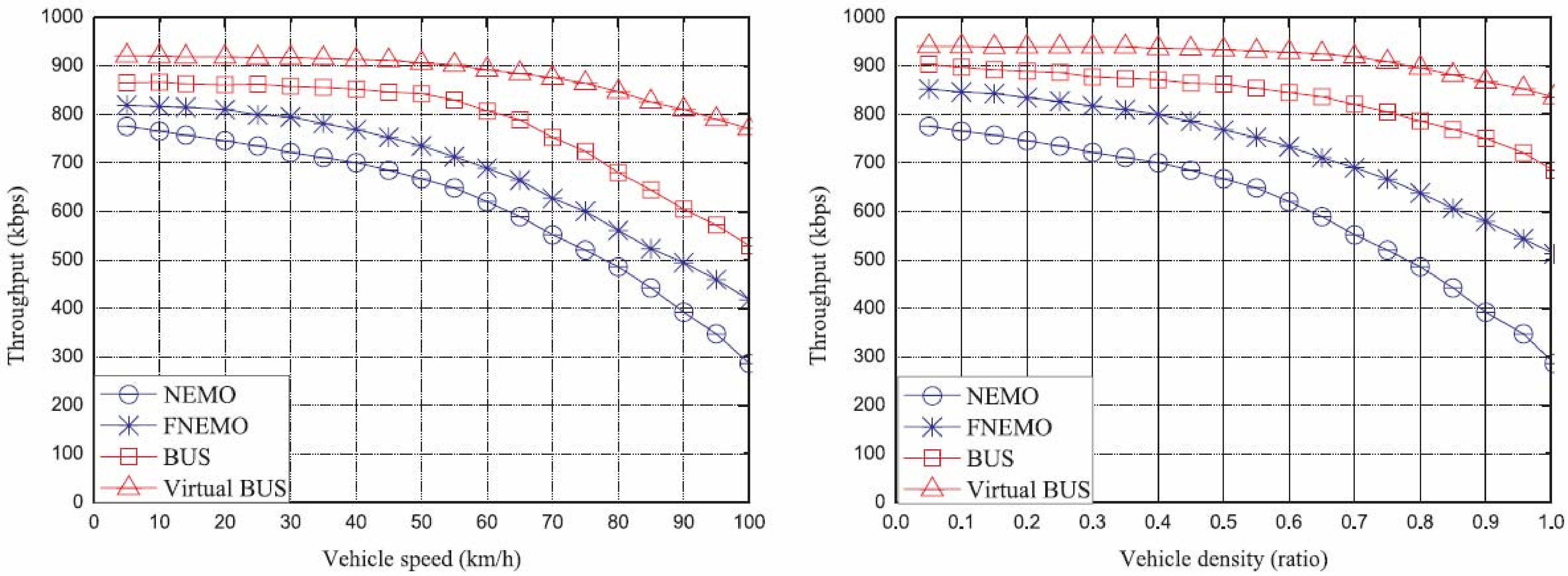
Message Overhead vs. VS and VD



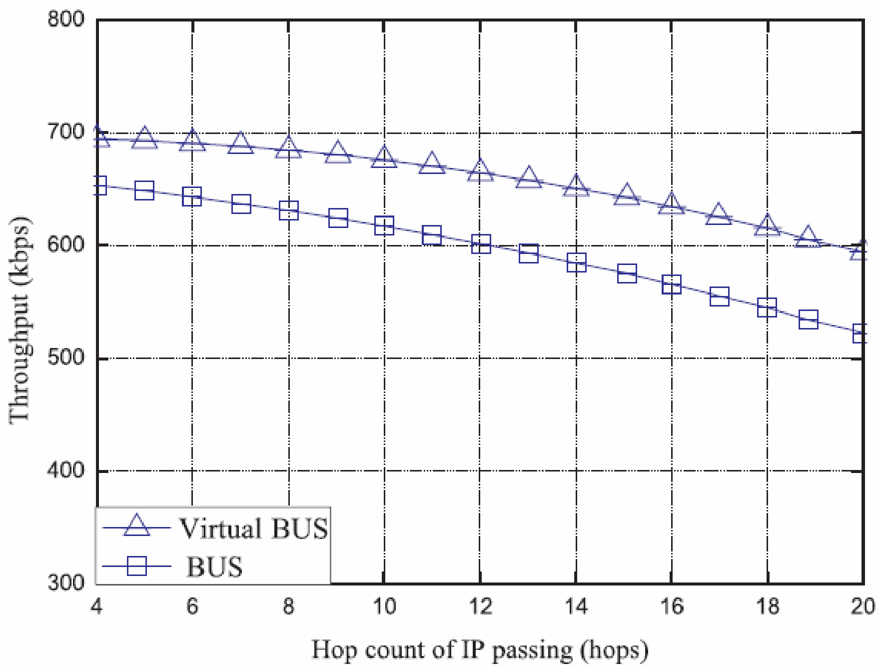
Message Overhead vs. IP Passing and Length of Virtual Bus

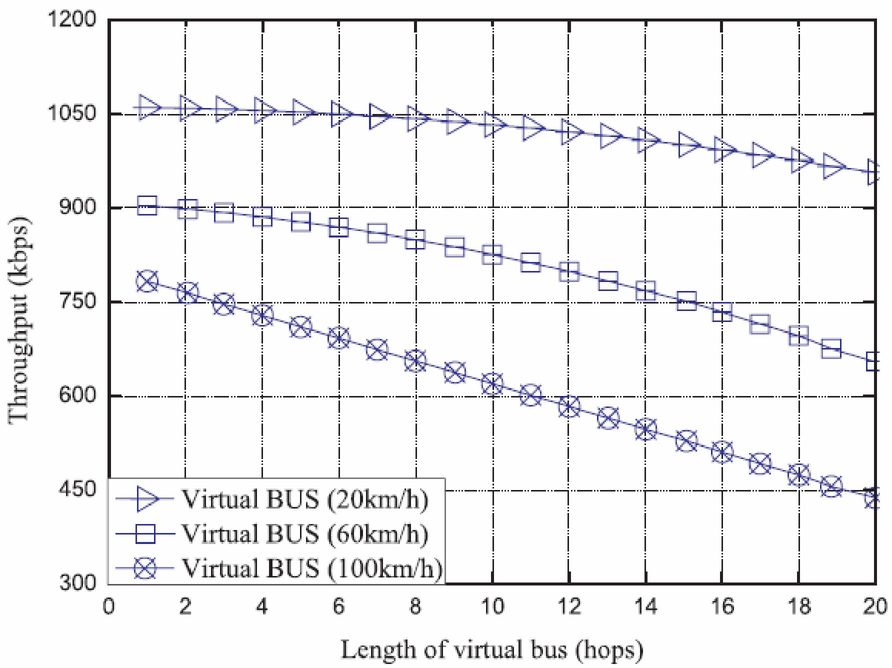


Throughput vs. VS and VD



Throughput vs. IP Passing and Length of Virtual Bus





Conclusion

- This work develops a new network mobility for VANET with the assistance of the cooperative mobile router and IP address passing technique
- Simulation results illustrate our proposed protocol significantly reduce handoff latency, packet loss, and throughput outperforms basic network mobility protocol (NEMO) and fast network mobility (FNEMO)