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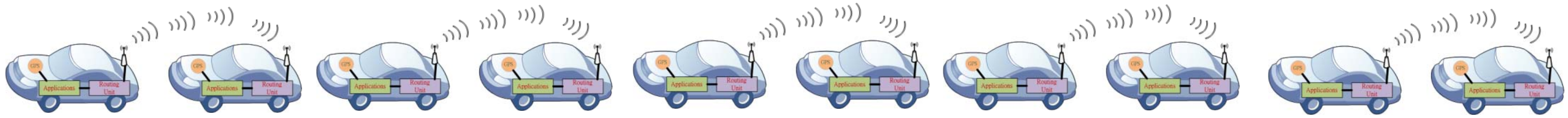

Chapter 11: Routing Protocols in Vehicular Ad Hoc Networks (2)

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National Taipei University

Why the need of “Vehicular Networks” ?

- Safety
  - On US highways (2004):
    - 42,800 Fatalities, 2.8 Million Injuries
    - ~$230.6 Billion cost to society
  - Combat the awful side-effects of road traffic
    - In the EU, around 40’000 people die yearly on the roads; more than 1.5 millions are injured
    - Traffic jams generate a tremendous waste of time and of fuel
  - Most of these problems can be solved by providing appropriate ***information*** to the driver or to the vehicle

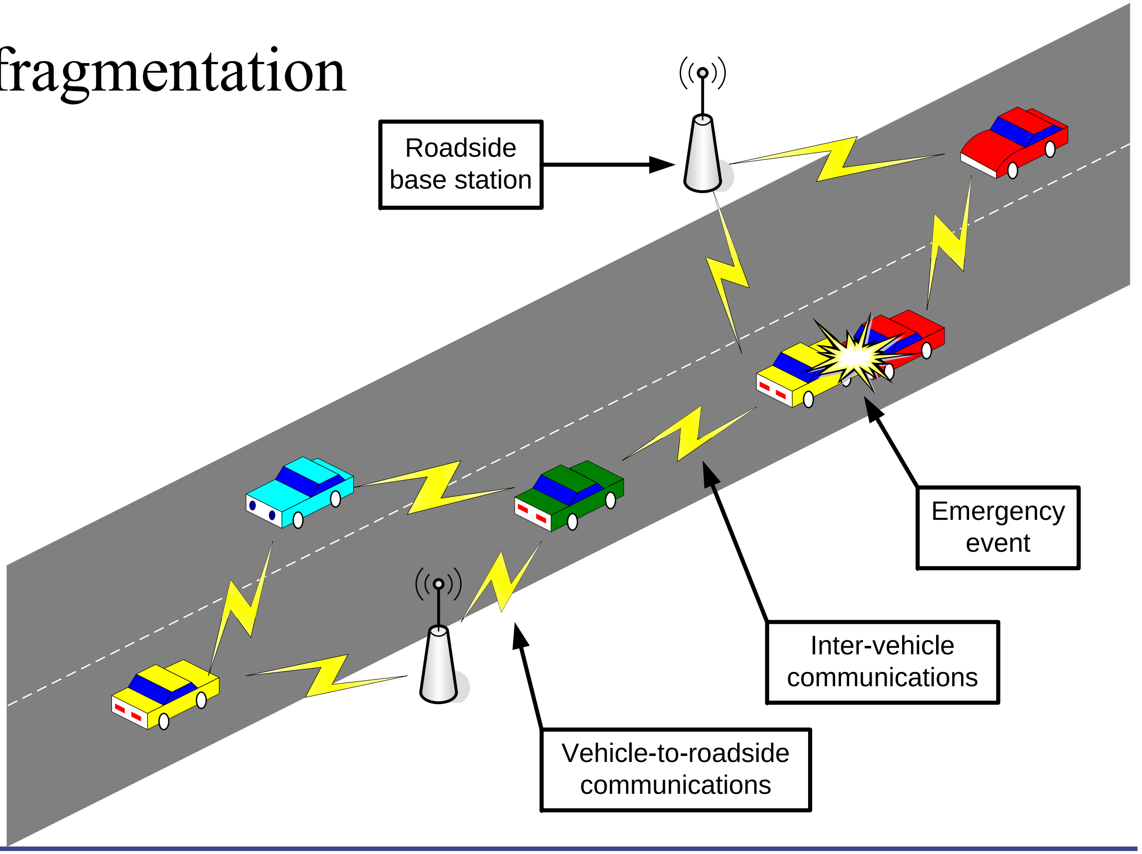
cont'd

- Efficiency
  - Traffic jams waste time and fuel
  - In 2003, US drivers lost a total of 3.5 billion hours and 5.7 billion gallons of fuel to traffic congestion
- Profit
  - Safety features and high-tech devices have become product differentiators

Examples

What is a VANET (Vehicular Ad hoc NETwork) ?

- Property of VANETs
  - Highly changeable network topology
  - High mobility pattern
  - Frequent network fragmentation



Routing protocols in vehicular ad hoc networks

- **Min-delay** routing protocols
  - Data packets should be transmitted to destinations as soon as possible
  - The transmission delay time is the major concern
  - Apply to real time services
- **Delay-bounded** routing protocols
  - Data packets can be delivered to destinations within a given constrained delay time
  - Provide the low overhead in wireless communication
  - Apply to non-real time services

Routing protocols in vehicular ad hoc networks

- Min-delay routing protocol
  - A Mobicast Routing Protocol in Vehicular Ad-Hoc Networks
    - Yuh-Shyan Chen, Yun-Wei Lin, and SingLing Lee, ACM/Springer Mobile Networks and Applications (MONET), Vol. 15, No. 1, pp. 20-35, Feb. 2010
- Delay-bounded routing protocols
  - A Mobicast Routing Protocol with Carry-and-Forward in Vehicular Ad-Hoc Networks
    - Yuh-Shyan Chen, Yun-Wei Lin, and SingLing Lee, CHINACOM'10, Beijing, China, 2010
  - Delay-Bounded Routing with Linear Regression in VANETs
    - Yuh-Shyan Chen, Chih-Shun Hsu, and Yi-Guang Siao, IEEE VTC-2010-Spring, Taipei, Taiwan, 2010

- Routing Protocols in Vehicular Ad Hoc Networks
  - Min-Delay Routing Protocol
    - Mobicast Routing Protocol
  - Delay-Bounded Routing Protocols
    - Mobicast Routing Protocol with Carry-and-Forward
    - Delay-Bounded Routing with Linear Regression

A Mobicast Routing Protocol in Vehicular Ad-Hoc Networks

Yuh-Shyan Chen, Yun-Wei Lin, and SingLing Lee

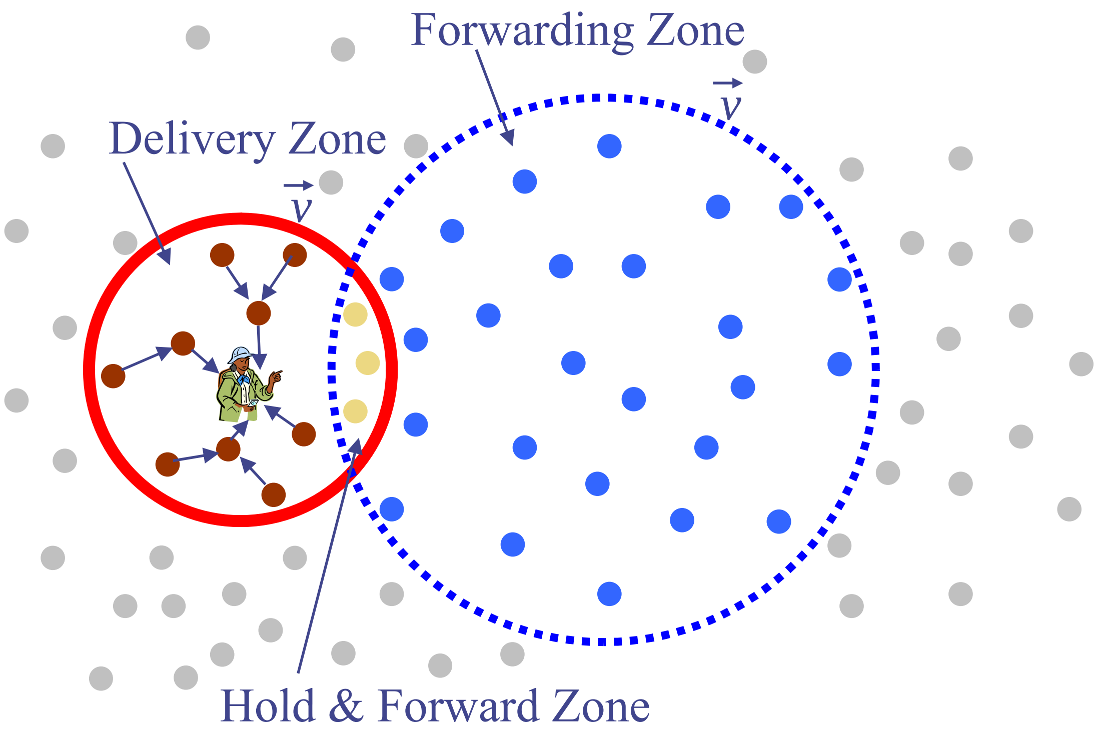
1. **IEEE GLOBECOM 2009**
2. **ACM/Springer Mobile Networks and Applications (MONET), 2010**

Mobicast Routing Protocol

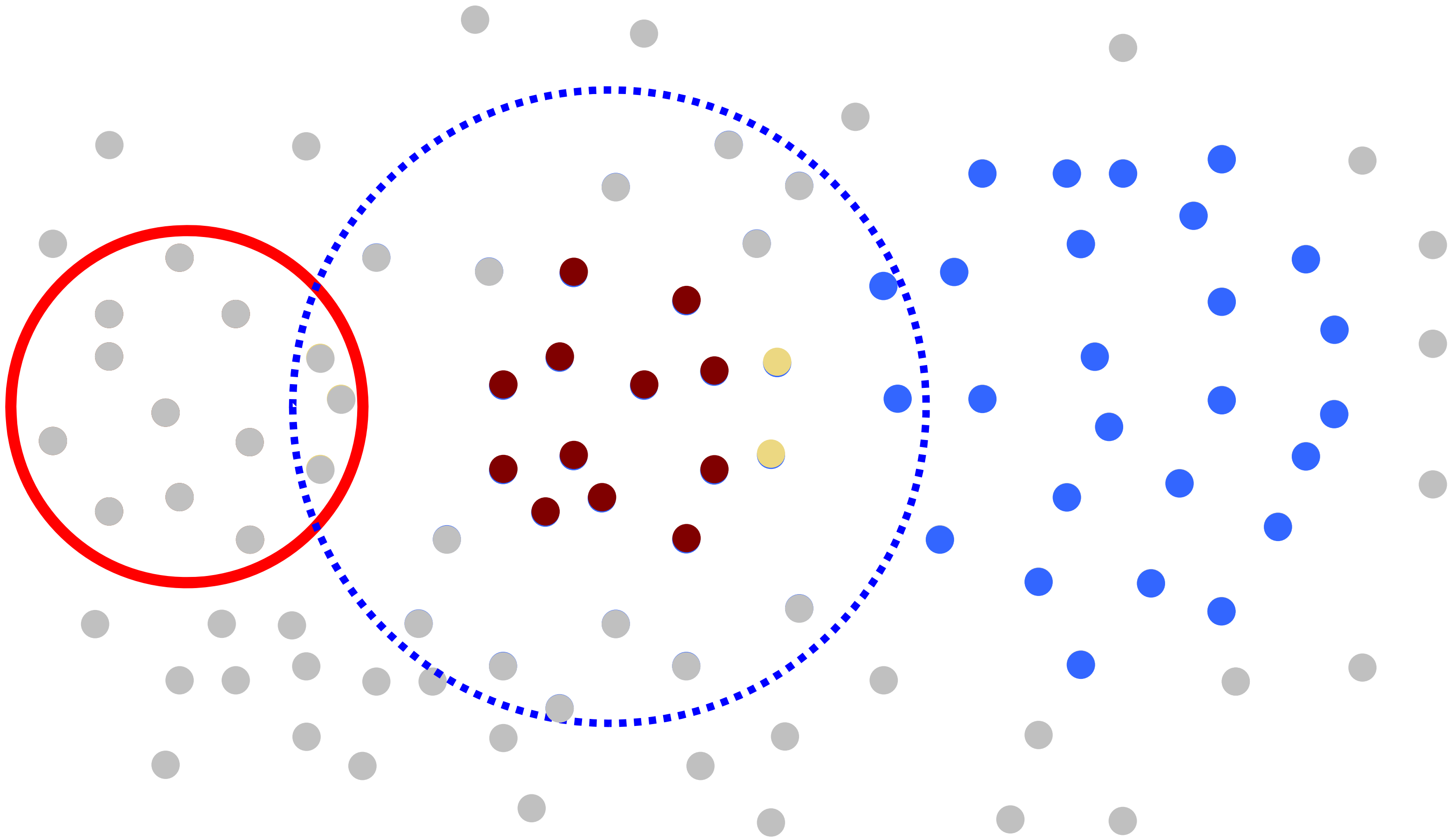
- To monitor mobile phenomena is always an important issue
- That can be facilitated by a spatiotemporal multicast protocol which calls “mobicast”
  - Provide just-in-time message delivery to mobile delivery zones
  - Need to transfer the multicast message to the “right **place**” at the “right **time**”

Mobicast in Sensor Network

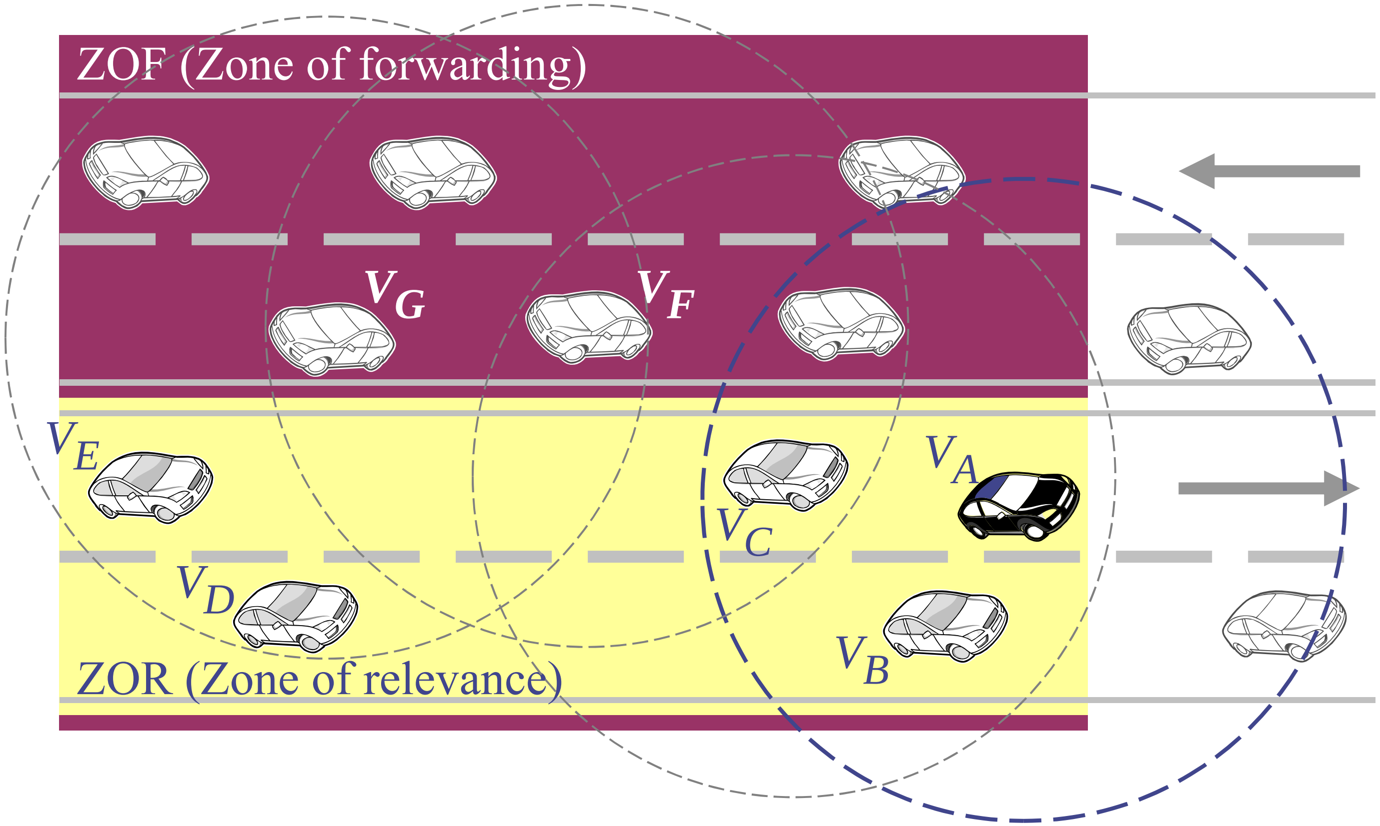
- Huang *et al.*, "Reliable Mobicast via Face-Aware Routing," INFOCOM, 2004
- Chen *et al.*, "VE-Mobicast: A Variant-Egg-Based Mobicast Routing Protocol for Sensornets," ACM Wireless Networks (WINET), 2008.



Mobicast in Sensor Network



- ***Zone of relevance*** (**ZOR**) and ***zone of forwarding*** (**ZOF**) are first defined
- The typical geocast routing: static sender, fixed region and size

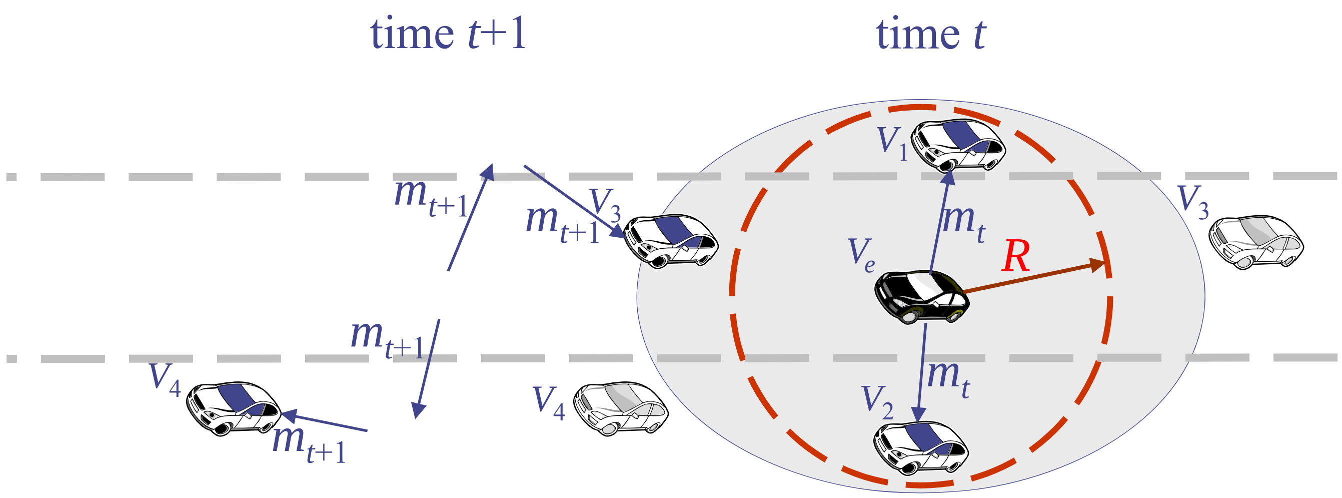


Mobicast Routing Protocol in VANETs

- Existing multicast/geocast protocols in VANET
  - They can not apply to transmit real-time messages to a dynamically prescribed region
  - They are difficult to handle an emergency traffic situation, such as warning notifications initiated from a suddenly braking failure vehicle
- Mobicast routing protocol can disseminate mobicast messages m_t to all vehicles in the prescribed region at time t

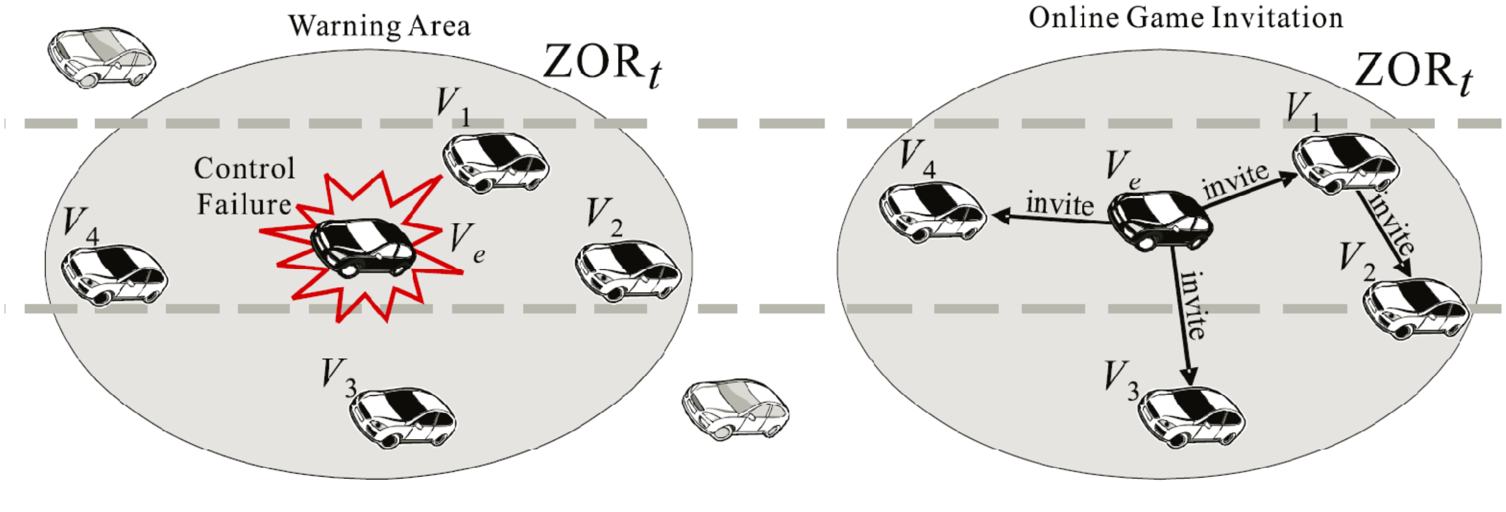
Mobicast Routing Protocol in VANETs

- Develop for **safety applications**
  - Emergency messages should be delivered in time
- The message m_t is sent at time t and expected to deliver to all relevant vehicles before time $t+1$



Application of Mobicast

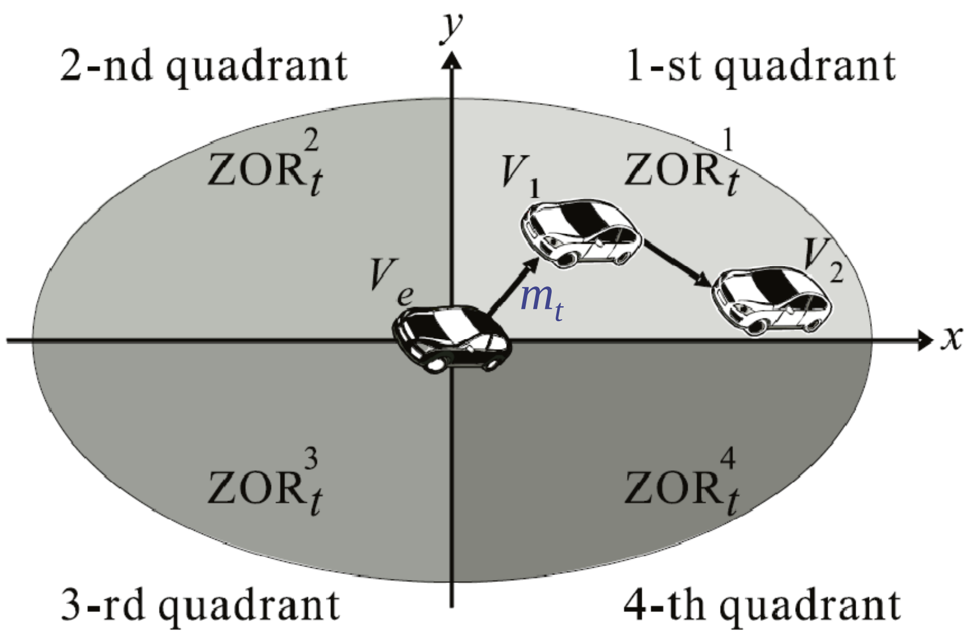
- Emergency warning
  - Emergency electronic brake lights
  - Vehicle states announcement
  - Collision warning
  - Intense changed velocity notice
- Online game



(a) (b)

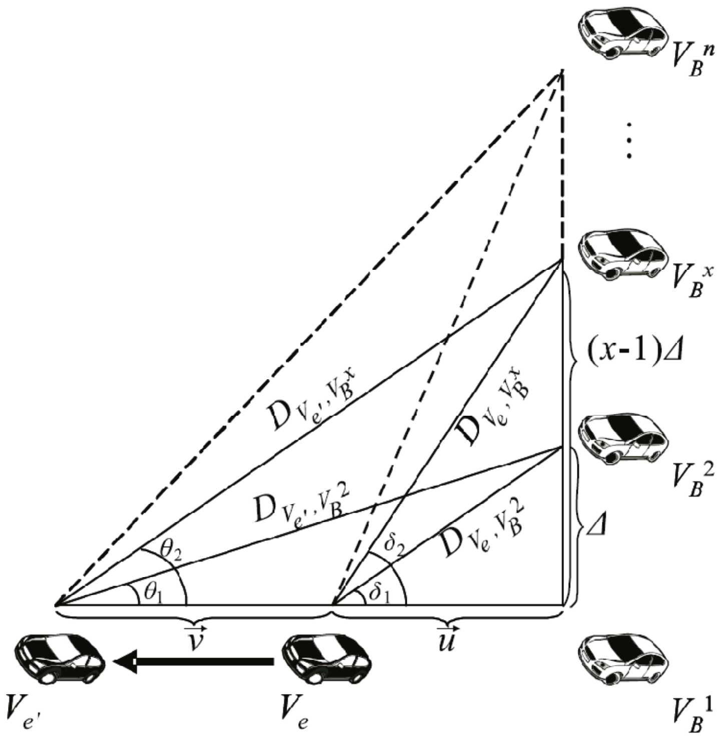
Zone of Relevance (ZOR_t)

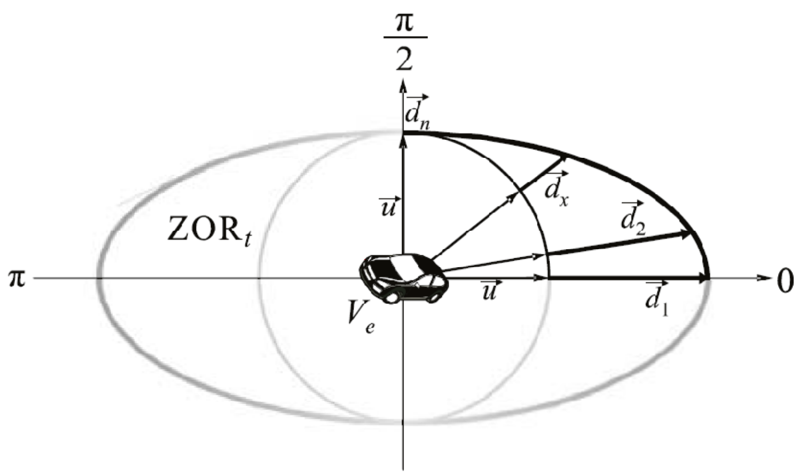
- ZOR_t is the prescribed region to indicate which vehicle is relevant to the event occurred on V_e
- V_e announces the real-time information of event to those vehicles by disseminating the mobicast message m_t at time t



The Shape of ZOR_t

- The shape of ZOR_t in existing results* in WSNs are assumed to a circle
- In VANETs, the shape of ZOR_t for an event vehicle V_e is an ellipse

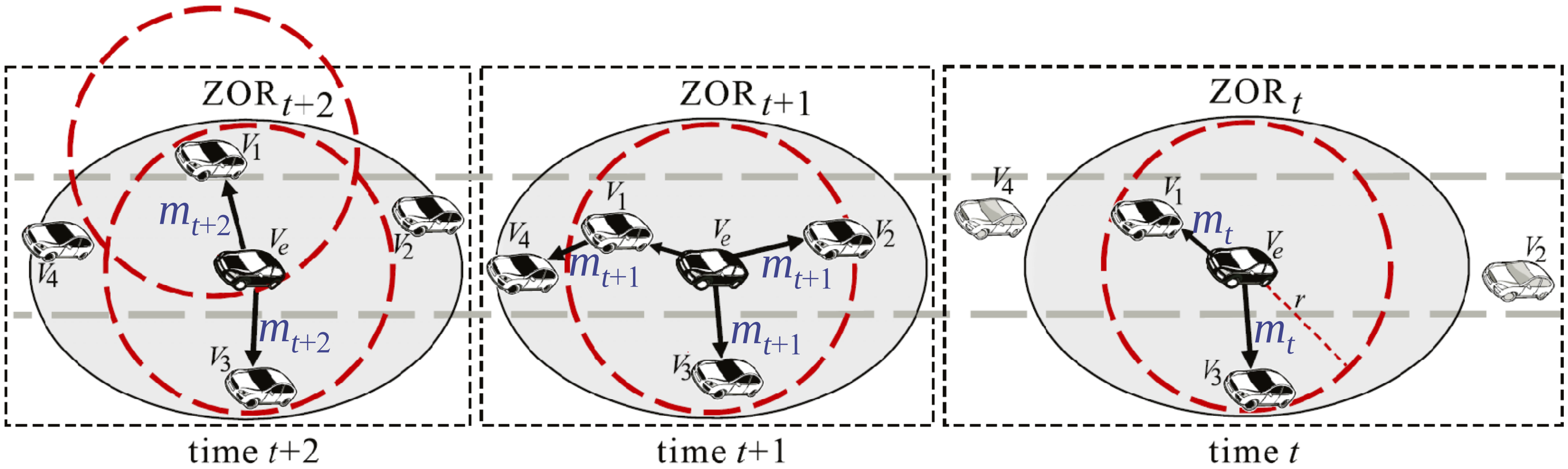




*Q. Huang, C. Lu, and G. C. Roman, "Spatiotemporal Multicast in Sensor Networks," ACM Conference on Embedded Networked Sensor Systems, pp. 205–217, Nov. 2003.
*Q. Huang, C. Lu, and G. C. Roman, "Design and Analysis of Spatiotemporal Multicast Protocols for Wireless Sensor Networks," Telecommunication Systems on Wireless Sensor Networks, vol. 26, pp. 129–160, Aug. 2004.

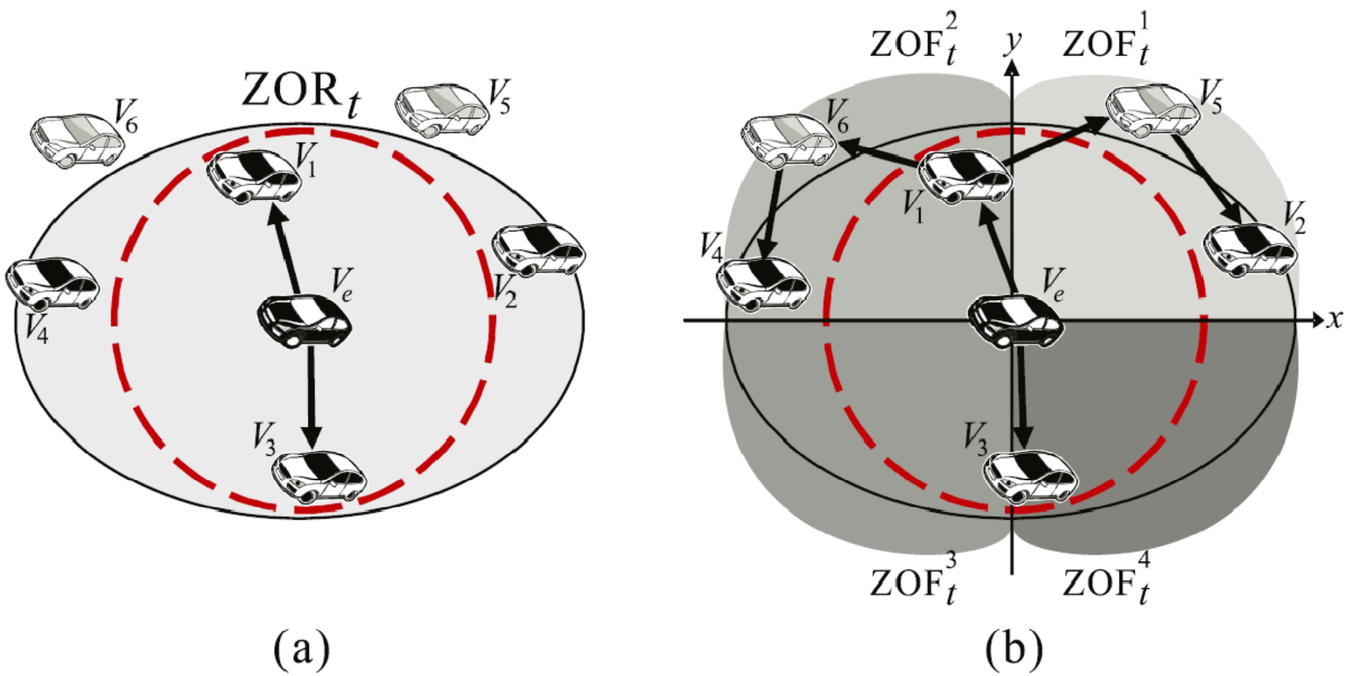
Key Problem: The Temporary Network Fragmentation Problem

- Temporary network fragmentation problem is incurred due to the velocity variation between each pair of vehicles
  - Temporary network fragmentation problem causes that some vehicles did not receive the mobicast message
- **Zone of forwarding** (ZOF_t) is a geographic region to overcome the temporary network fragmentation problem



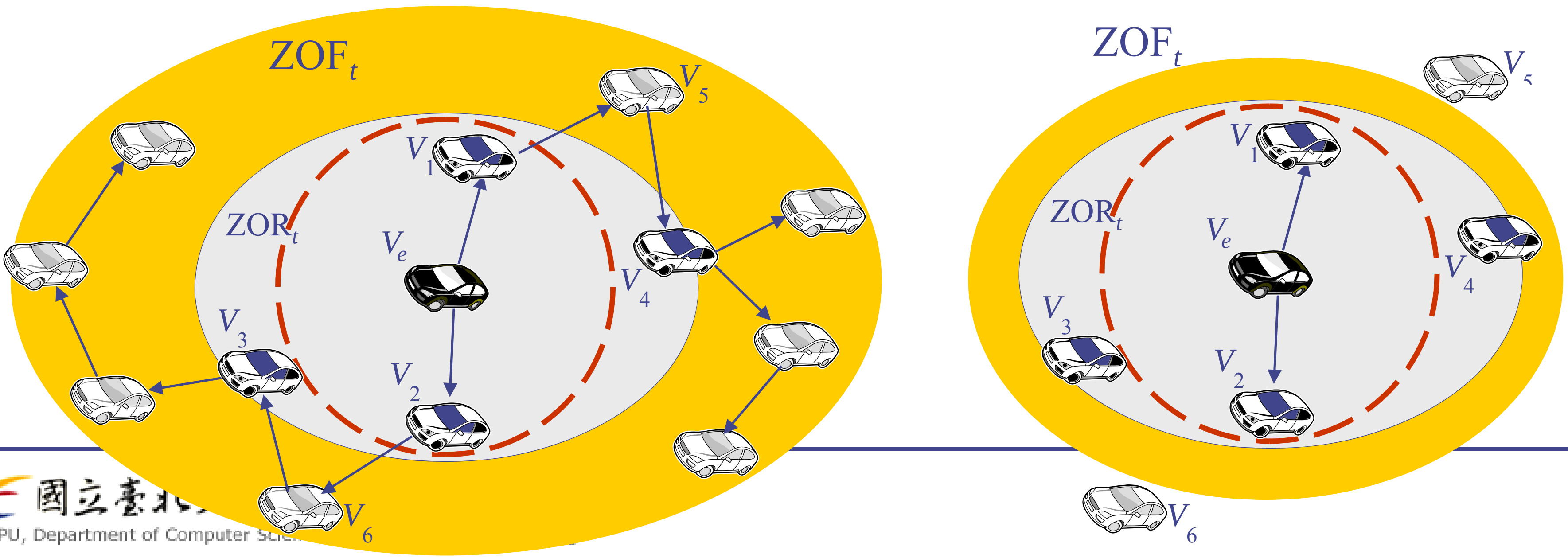
Zone of Forwarding (ZOF_t)

- ZOF_t is used to disseminate the mobicast message to all vehicles located in the ZOR_t
- ZOF_t indicates which vehicle should forward the mobicast message to other vehicles located in the ZOR_t



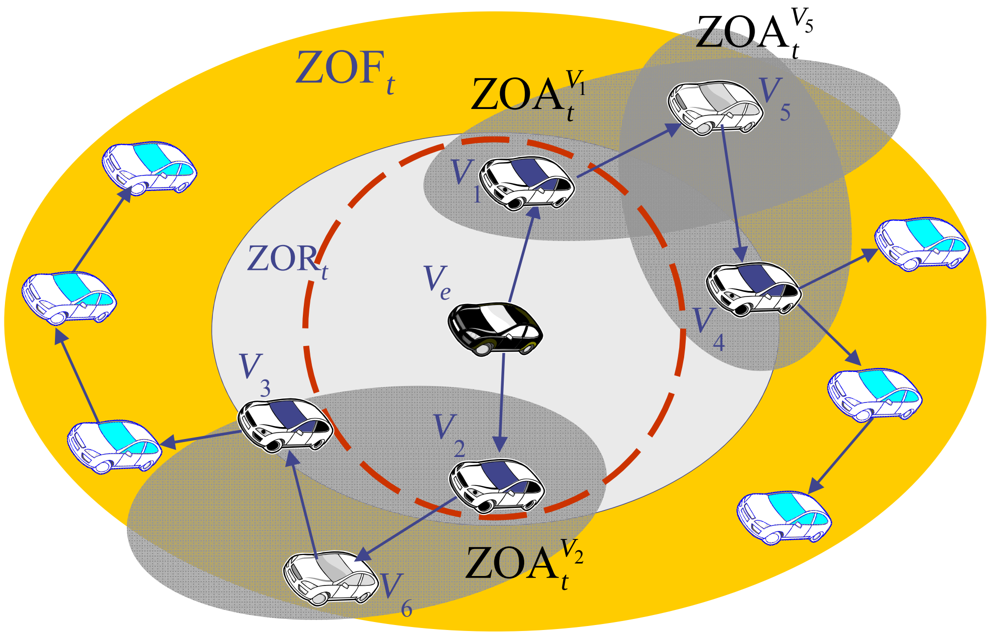
The Size of ZOF_t

- Normally, the size of ZOF_t may be larger or smaller than the optimal size of ZOF_t
  - If the size of ZOF_t is larger than the optimal size of ZOF_t
    - Some irrelevant vehicles are asked to uselessly forward the mobicast message
  - If the size of ZOF_t is smaller than the optimal size of ZOF_t
    - The temporal network fragmentation problem is incompletely overcome



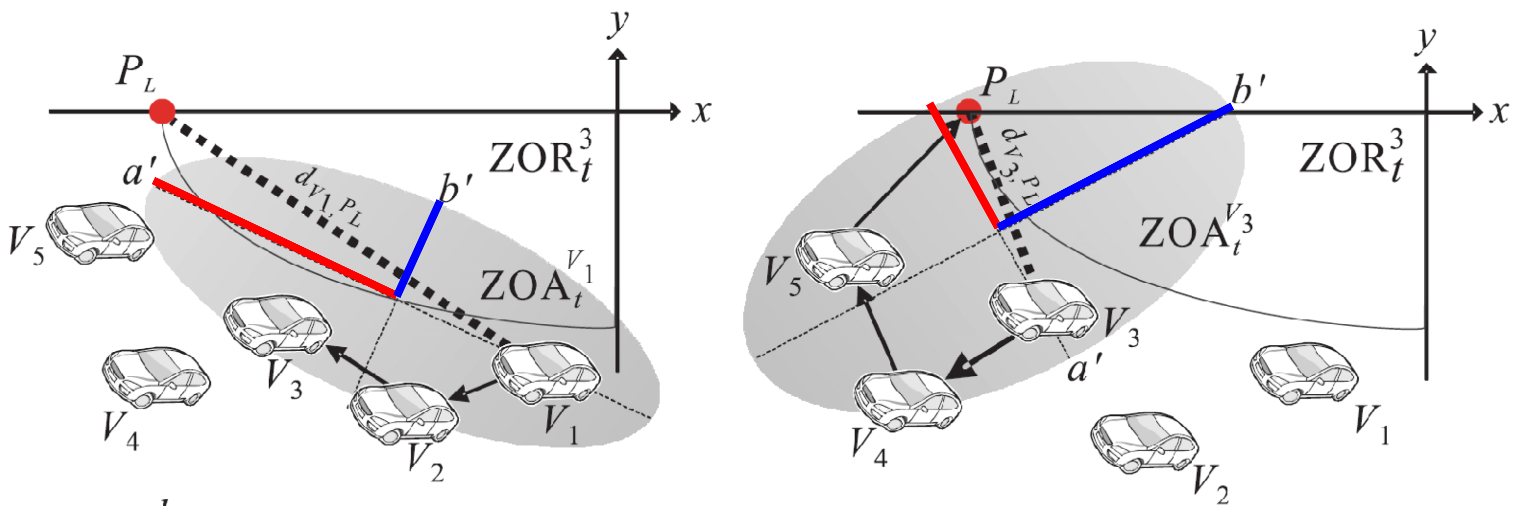
Zone of Approaching (ZOA_t)

- The size of ZOF_t is difficult to predict and determined under the high speed environment
  - The network resources are easily wasted
- *Zone of approaching* (ZOA_t) is proposed to accurately predict the ZOF_t



The shape of ZOA_t

- The shape of ZOA_t^{Vi} is different depended on different distance to P_L
  - The narrow shape ZOA_t^{Vi} reduces number of ZOA_t^{Vi} growing
  - The wide shape ZOA_t^{Vi} can be discovered more possible paths to P_L



d_{V_1,P_L} is long, then $a'>b'$

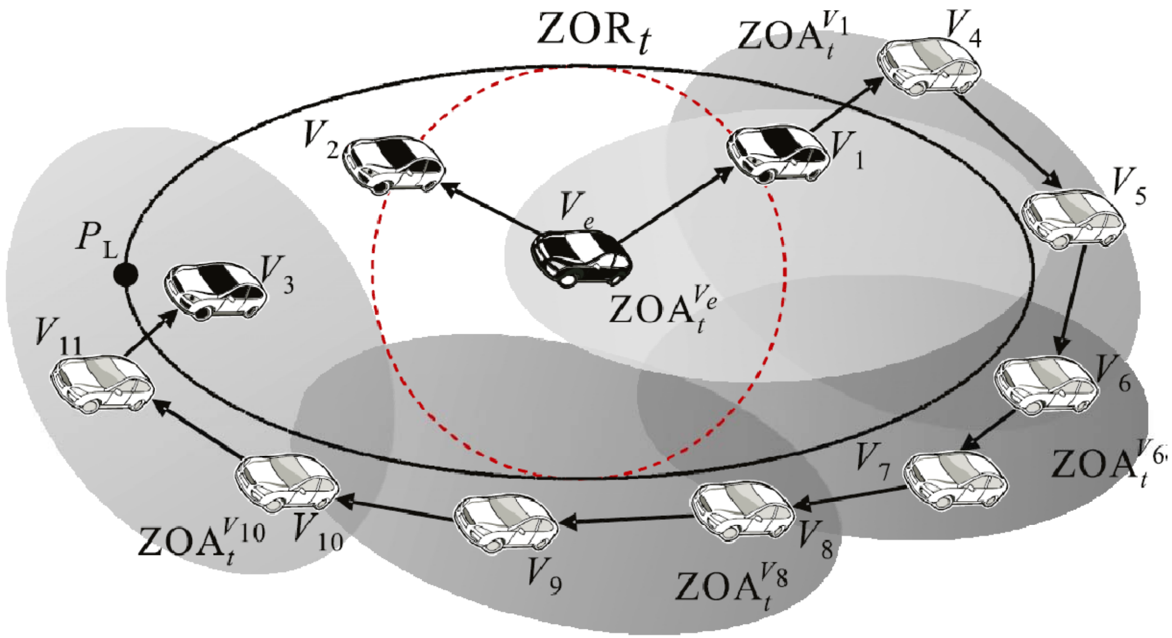
d_{V_3,P_L} is short, then $a'<b'$

$a' = \frac{d_{V_1,P_L}}{v_1 \times \alpha}$ $b' = \frac{v_1 \times \alpha}{d_{V_1,P_L}}$

$a' = \frac{d_{V_3,P_L}}{v_3 \times \alpha}$ $b' = \frac{v_3 \times \alpha}{d_{V_3,P_L}}$

Multiple Quadrants

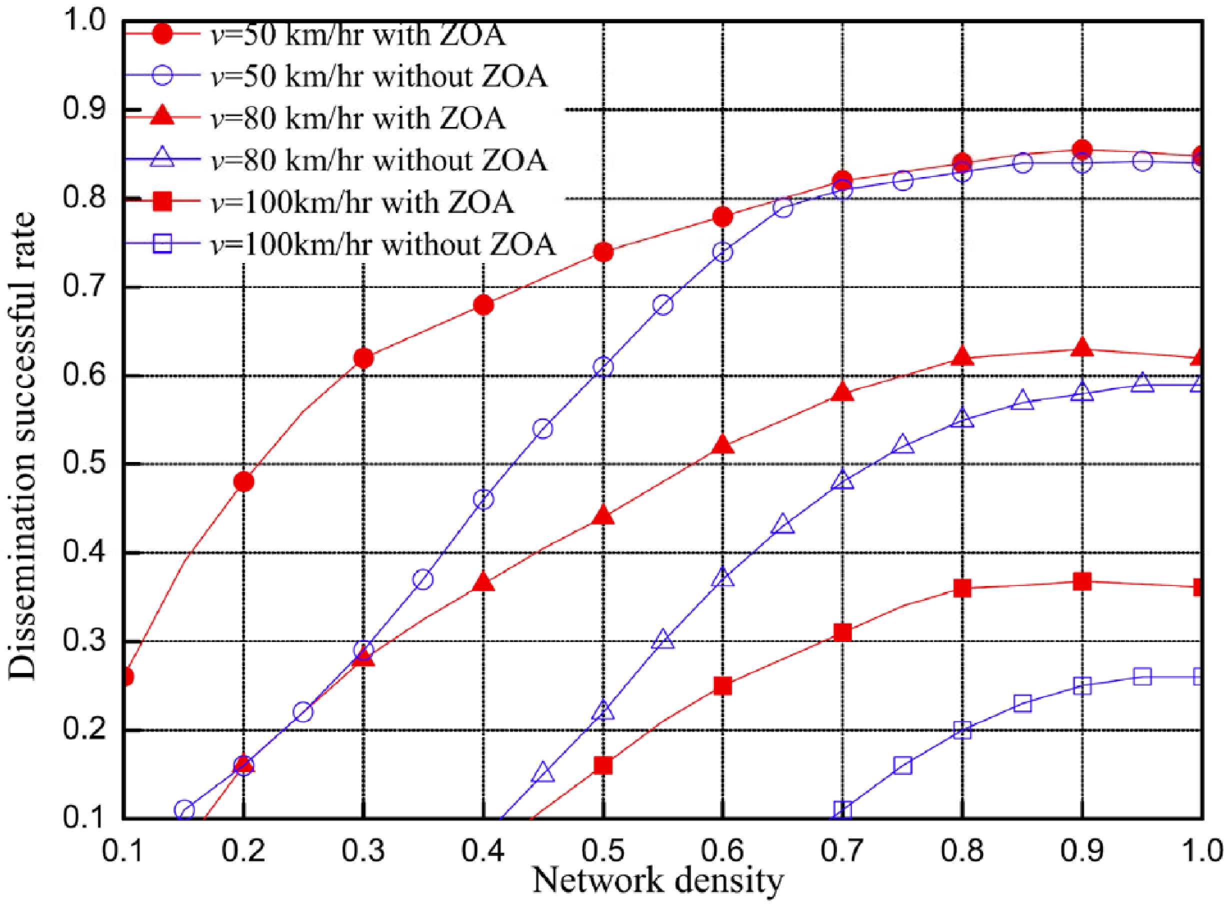
- The mobicast message can be disseminated from one quadrant to another



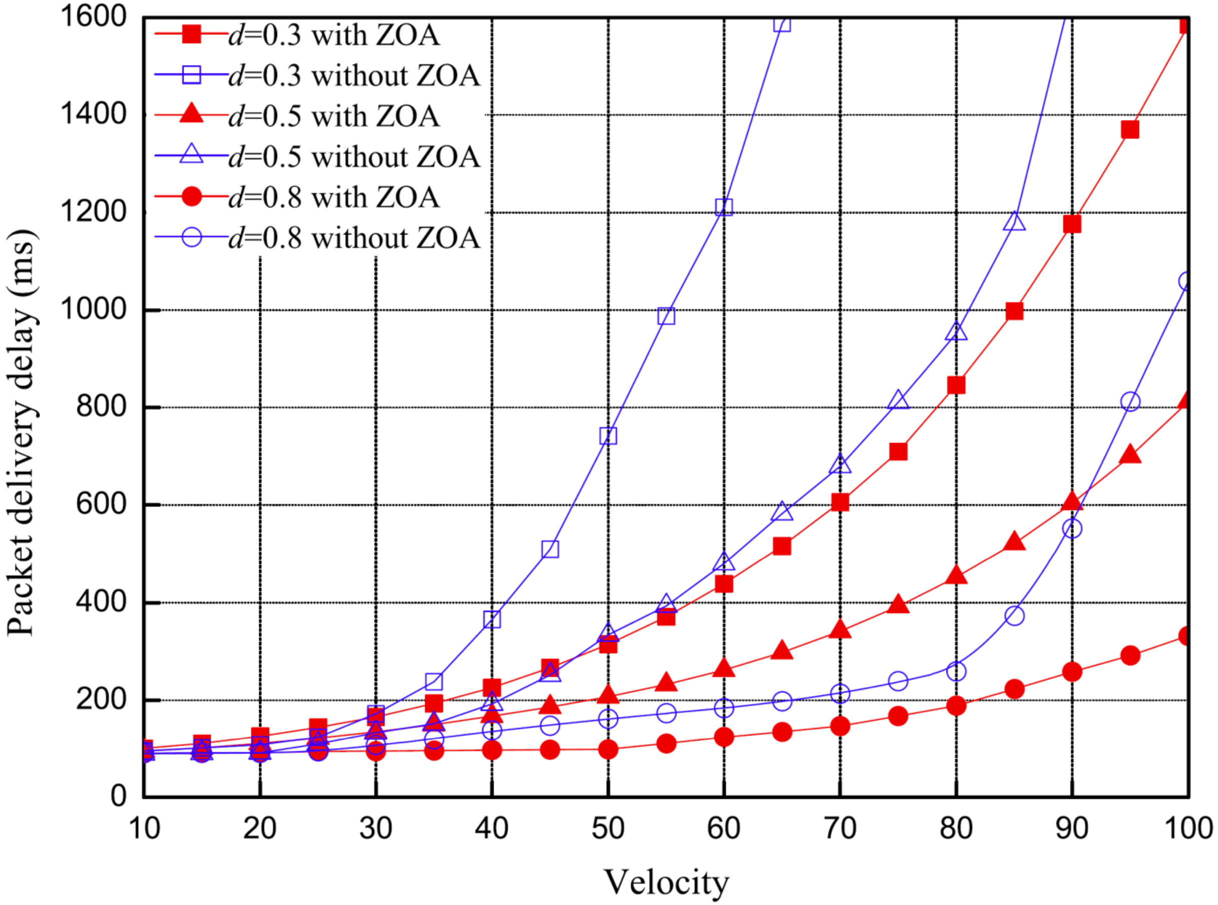
Simulation Result

- This protocol is mainly implemented using the NCTUns 4.0 simulator and emulator.
- The simulation environment
  - The physical and MAC layer adopts 802.11b protocol
  - The path-loss model adopts “Free Space and Shadowing”
  - The fading model adopts “Ricean Fading”
  - The environment is a 2000 × 20 m2 highway scenario
  - The numbers of vehicles is ranging from 40 to 400
  - The communication radius of each vehicle is 100 m
  - The velocity of each vehicle is assumed from 10 to 100 km/hr

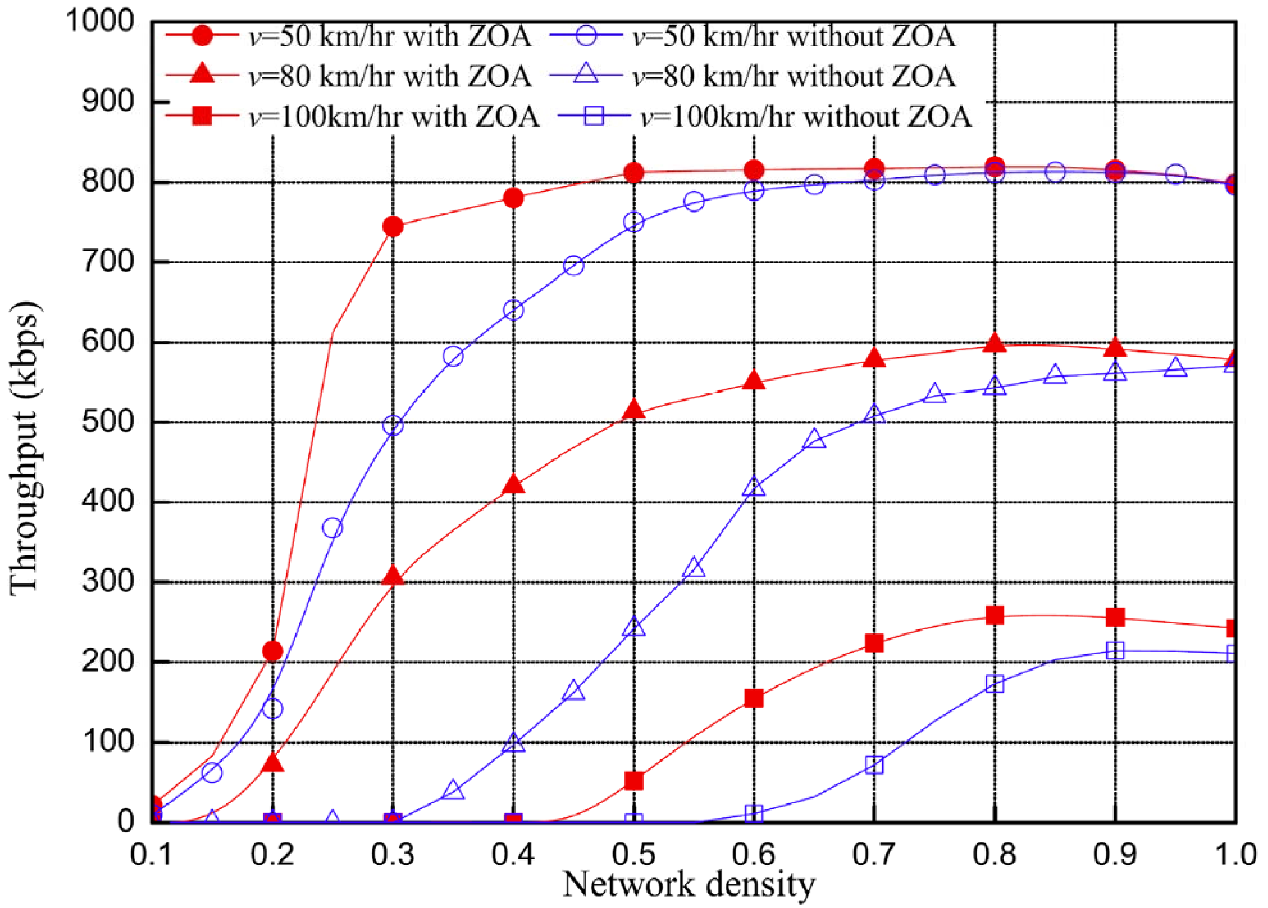
Dissemination Successful Rate vs. Network Density



Packet Deliver Delay vs. Velocity



Throughput vs. Network Density



Mobicast Routing Protocol

- A new adaptive and dynamic shape ZOF_t is proposed to adaptively determine the size, shape, and location of the forwarding zone under highly changeable topology
- This protocol is a fully distributed algorithm which effectively reduces the communication overhead of constructing the ZOF_t
- High dissemination successful rate with low communication overhead is achieved

A Mobicast Routing Protocol with Carry-and-Forward in Vehicular Ad-Hoc Networks

Yuh-Shyan Chen, Yun-Wei Lin, and SingLing Lee

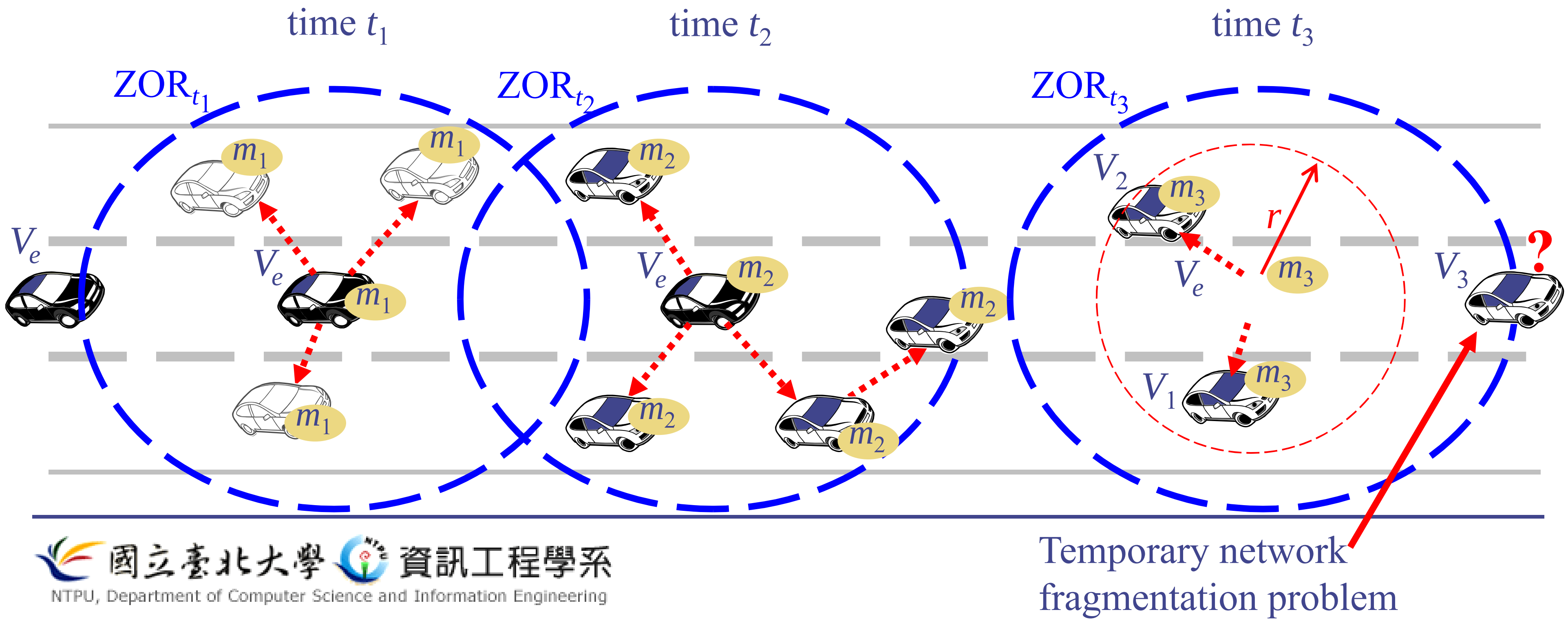
CHINACOM 2010

Applications in VANETs

- Safety applications
  - For example: emergency electronic brake lights
  - The notification should deliver to destined vehicles as soon as possible
- Comfort applications
  - For example: short message, map information
  - The comfort applications usually keep the delay-tolerant capability
  - The message can be delivered within a **constrained delay time λ**
- This work focuses on the comfort applications to provide the mobicast routing service

Mobicast

- Mobicast is a mobile geocast protocol which provides just-in-time message delivery to mobile delivery zones (zone of reference, ZOR_t)
  - Need to transfer the mobicast message to vehicles at the "**right place**" at the "**right time**"
- Rapid changed topology causes the *temporary network fragmentation problem*
  - Some vehicles may not receive the mobicast message



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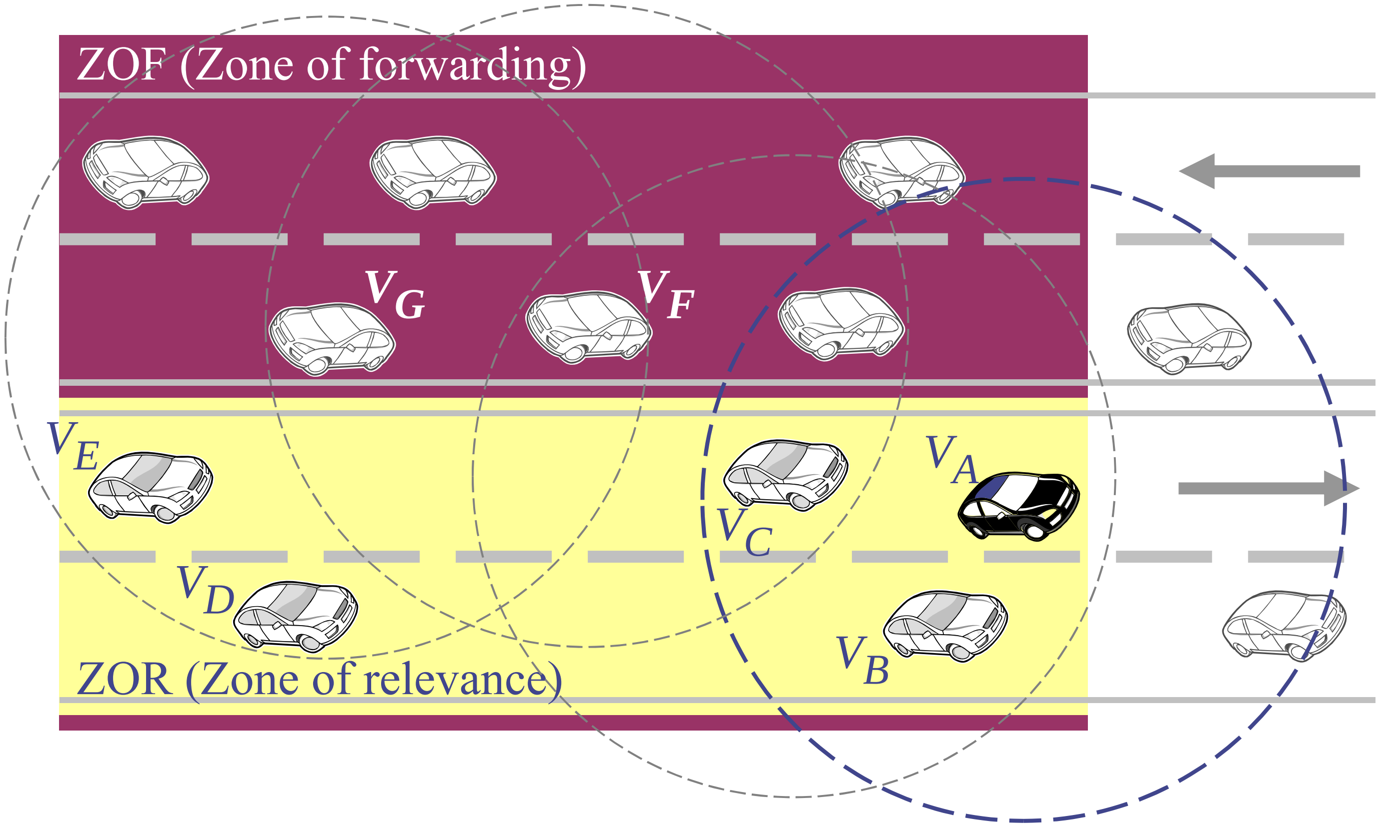
- The typical geocast routing: static sender, fixed region and size



Motivation

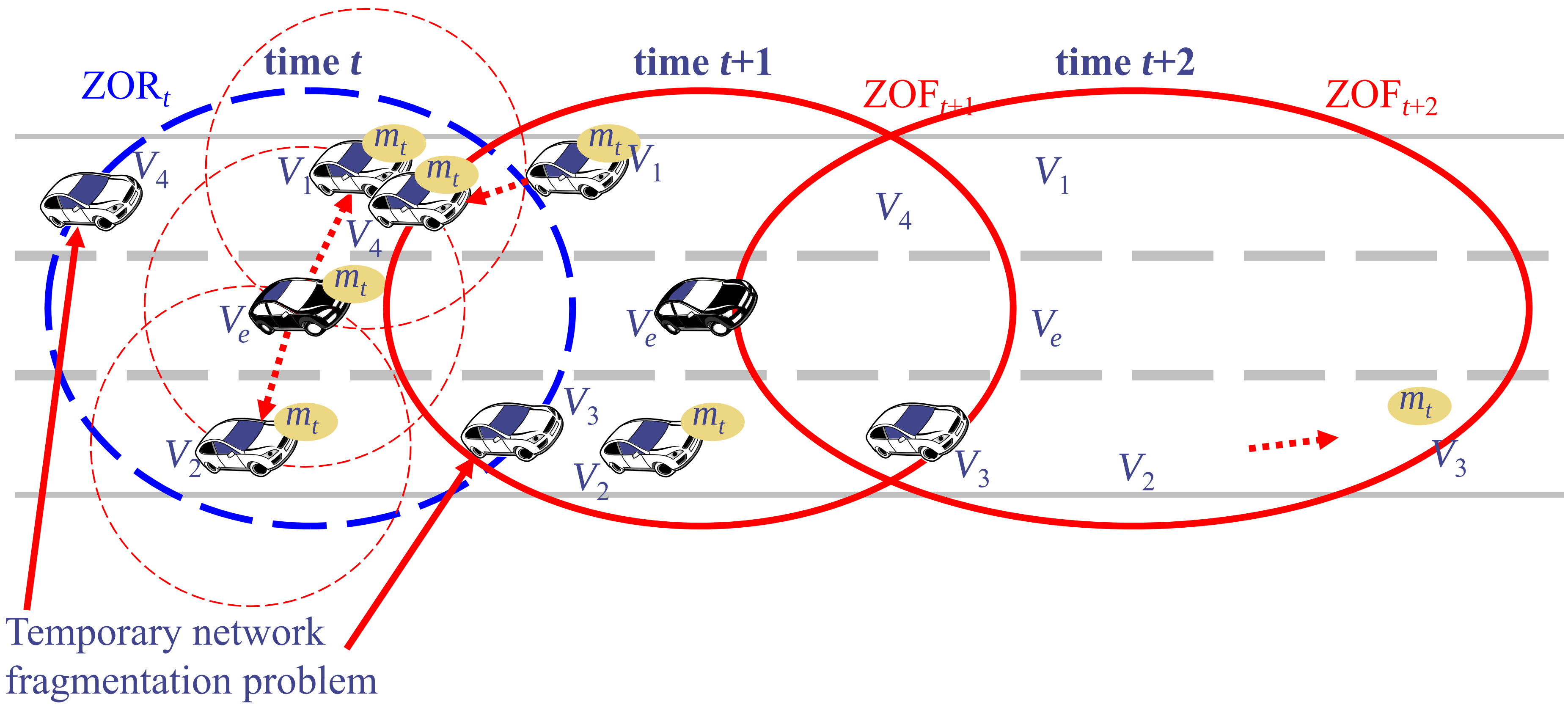
- Existing multicast/geocast protocols in VANET
  - Many channel resources are used to handle the rapid changed topology.
- Our goal of mobicast routing for comfort applications
  - Overcome the temporary network fragmentation problem
  - Achieve high dissemination successful rate
  - Maintain a low degree of channel utilization
    - Reserve the channel resource for safety applications

Basic Idea

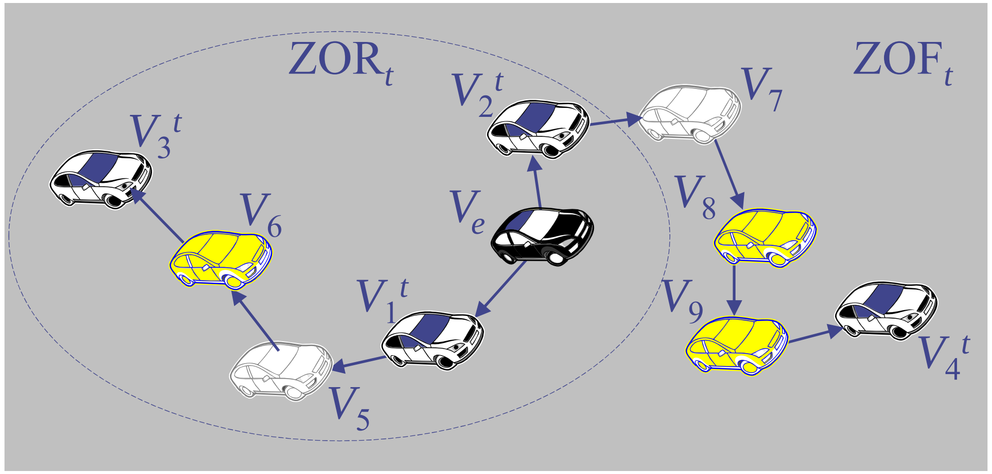
- Mobicast messages delivery
  - Vehicles have ever been in the ZOR_t at time *t* should receive the mobicast message
- The method to deliver message can be divided into two techniques:
  - **Multihop forwarding technique**
    - Delivers messages by wireless multihop transmission
    - The delivery delay is short
  - **Carry-and-forward technique**
    - Some possible vehicles carry the message to forward to other vehicles
    - Overcome the temporary network fragmentation problem
    - Maintain a low degree of channel utilization
    - The delivery delay is comparatively long compared to multihop forwarding
- Our basic idea is to carefully choose the delivery techniques between multihop forwarding and carry-and-forward techniques before the constrained delay time λ

Protocol Overview

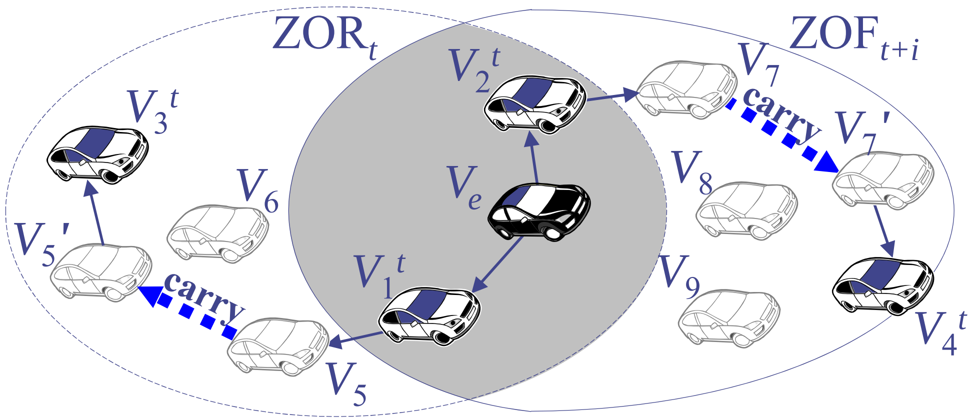
- Vehicles located in ZOF_{t+i} (zone of forwarding) should carry the message and forward to other reference vehicles.
  - ZOF_{t+i} is moving with V_e at the same speed and toward the same direction



Protocol Comparison



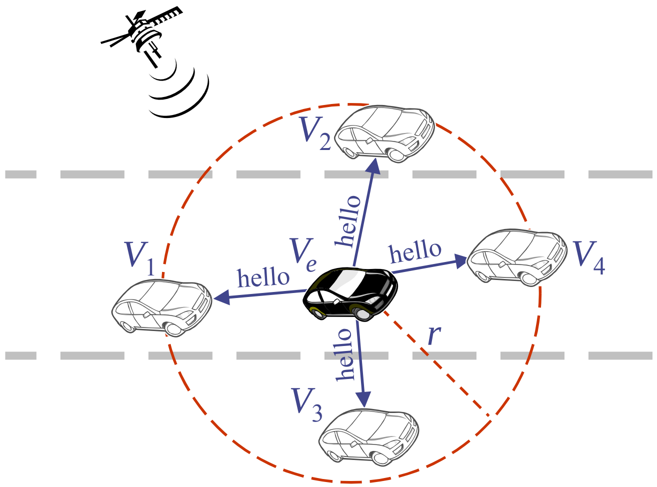
Distributed robust geocast multicast routing protocol (DRG)



Our mobicast routing protocol

System Architecture - Assumption

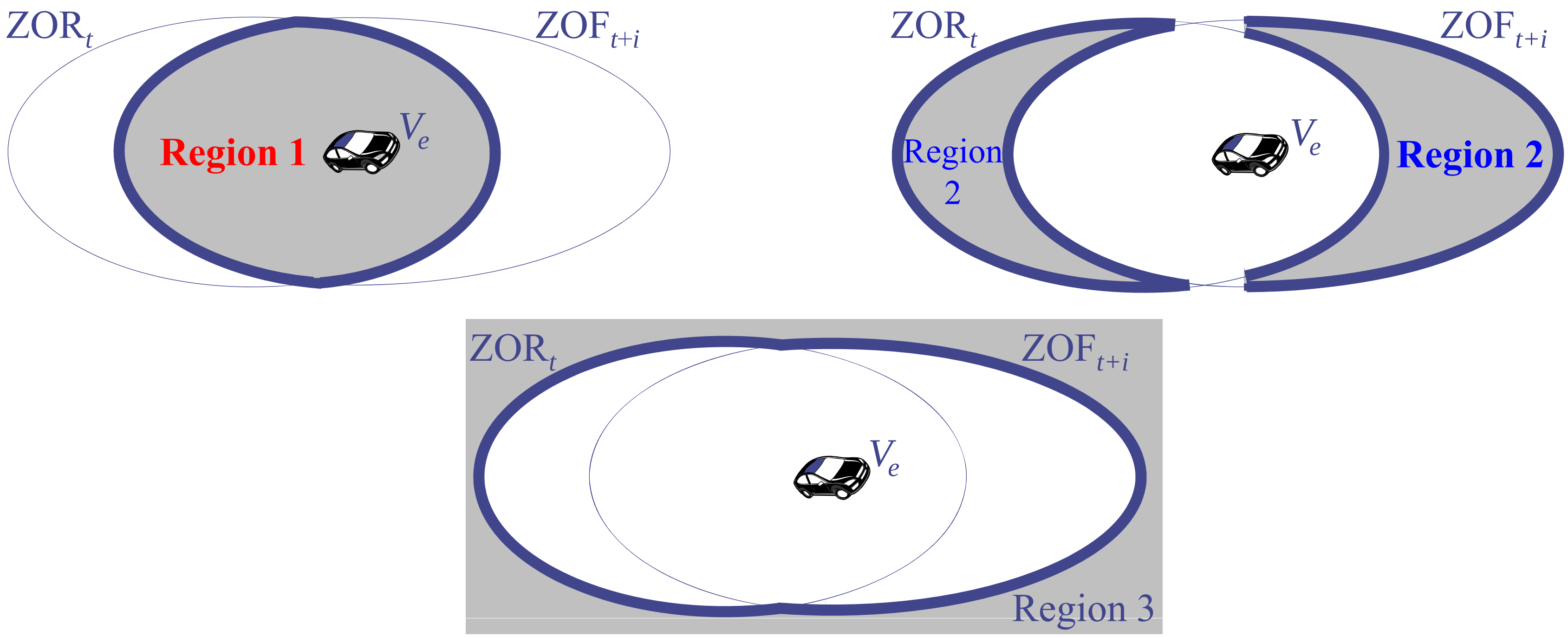
- The mobicast protocol is to support comfort applications in a highway scenario
- Vehicles send hello messages to neighbors when they first meet
- Hello messages include the vehicle state information, such as velocity, location



Each car equips GPS and communication range is *r*.

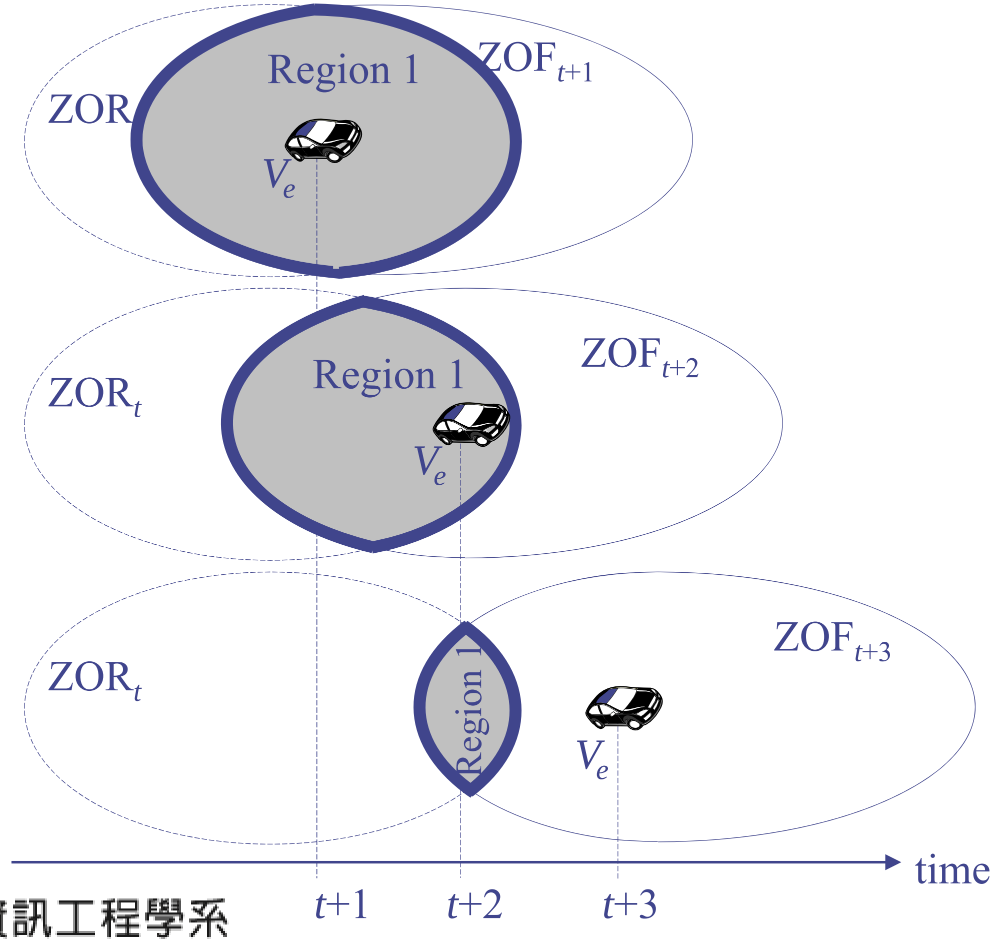
Mobicast Routing Protocol

- The delivery technique is decided according to the region
  - Region 1: the message delivery with multihop forwarding technique
  - Region 2: the message delivery with carry-and-forward technique
  - Region 3: the message is dropped



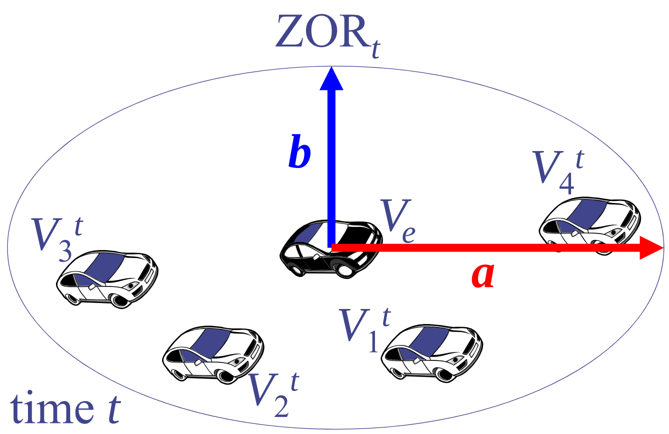
Channel Resource Suppression

- Region 1 is decreasing as time goes by
- Fewer and fewer vehicles use the multihop forwarding technique
  - The channel resource can be reserved



Zone of Relevance (ZOR_t)

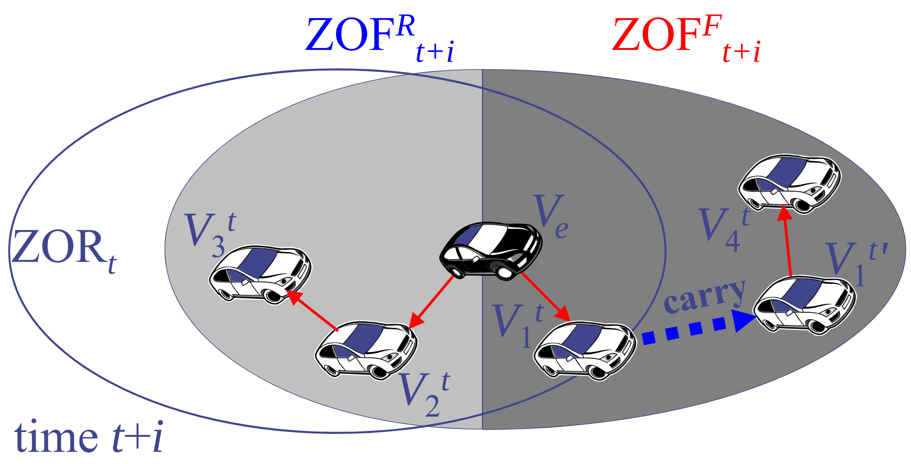
- ZOR_t is the prescribed region to indicate which vehicle is relevant to the event occurred on V_e
- Major axis *a* is determined by the requirement of comfort application and minor axis *b* is determined by the width of lane



$$ZOR_t = \frac{(x_t^{Vj} - x_t^{Ve})^2}{a^2} + \frac{(y_t^{Vj} - y_t^{Ve})^2}{b^2} - 1 = 0$$

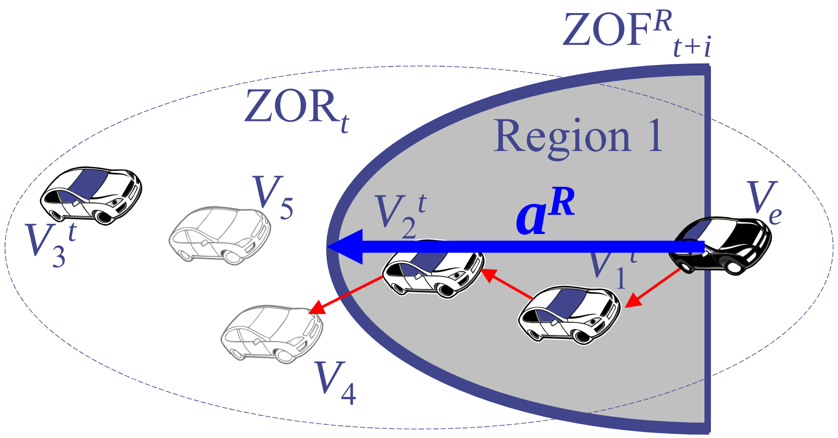
Zone of Forwarding (ZOF_{t+i})

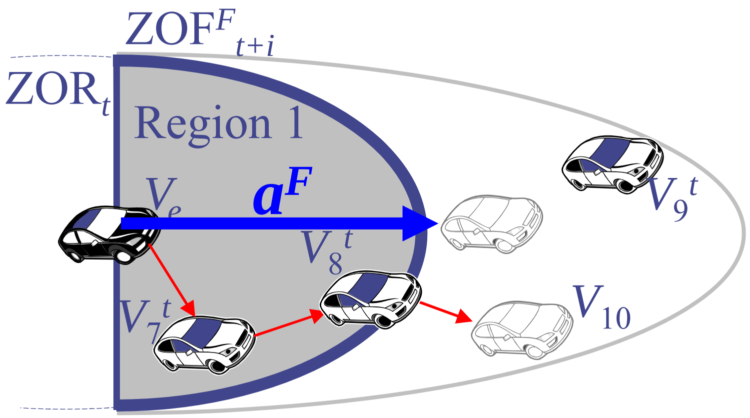
- ZOF_{t+i} is used to disseminate the mobicast message to all vehicles have been in the ZOR_t
- ZOF_{t+i} indicates which vehicle should carry and forward the mobicast message
- ZOF_{t+i} is composed of two parts, ZOF^R_{t+i} and ZOF^F_{t+i}



The Construction of ZOF$_{t+i}$

- The rear zone of forwarding, ZOF$^{R}_{t+i}$
  - The major axis a^R is determined by the harmonic velocity of vehicles behind of V_e
- The front zone of forwarding, ZOF$^{F}_{t+I}$
  - The major axis a^F is determined by the harmonic velocity of vehicles in front of V_e



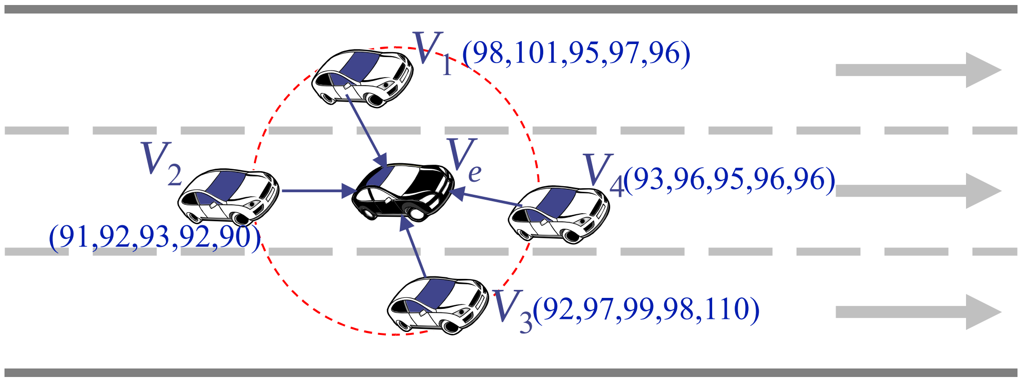


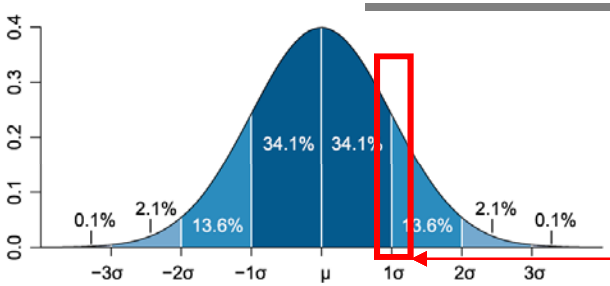
$$ZOF^{R}_{t+i} = \frac{(x^{V_j}_{t+i} - x^{V_e}_{t+i})^2}{a_R^2} + \frac{(y^{V_j}_{t+i} - y^{V_e}_{t+i})^2}{b^2} - 1$$

$$ZOF^{F}_{t+i} = \frac{(x^{V_j}_{t+i} - x^{V_e}_{t+i})^2}{a_F^2} + \frac{(y^{V_j}_{t+i} - y^{V_e}_{t+i})^2}{b^2} - 1$$

The Harmonic Velocity

- The velocity is generally assumed as normal distributed in the highway scenario*





Interval Estimation (Confidence interval=*CI*%)

$$\overline{x} - t_{Gossett} \times \frac{\hat{S}}{\sqrt{n}} \leq v_p \leq \overline{x} + t_{Gossett} \times \frac{\hat{S}}{\sqrt{n}}$$

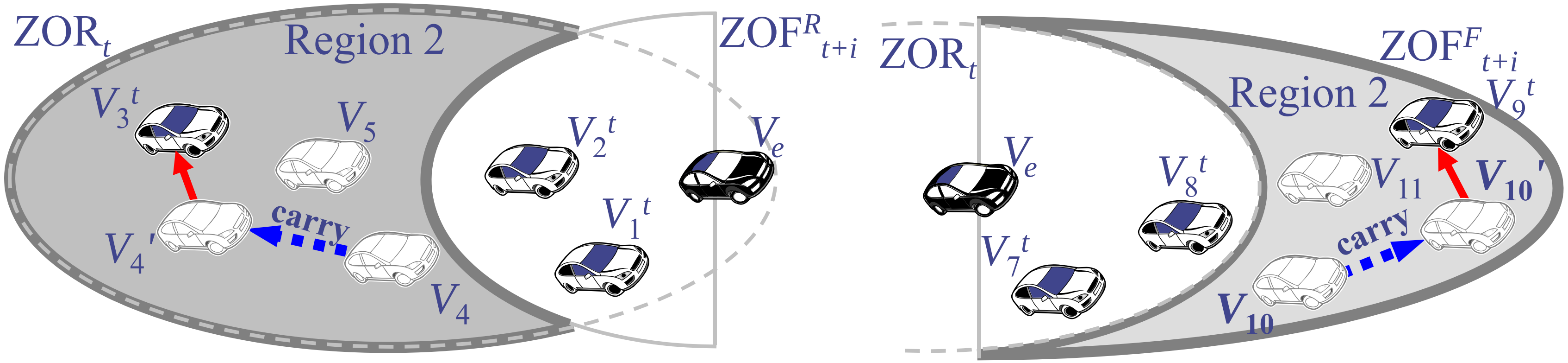
$$v_{low} \leq v_p \leq v_{up}$$

Predictive velocity (Harmonic mean) $= \dfrac{d + d}{\dfrac{d}{v_{low}} + \dfrac{d}{v_{up}}} = v_h$

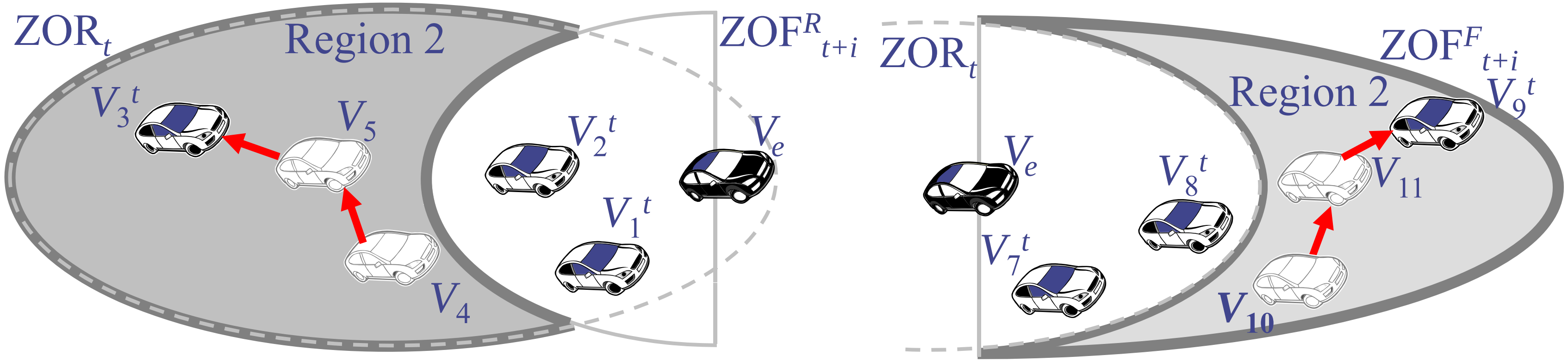
* W. Schnabel and D. Lohse, "Grundlagen der Strasenverkehrstechnik und der Verkehrsplanung," pp. Bd. 1, 2. Aufl., Verlag fur Bauwesen, Berlin, 1997.

Constrained Delay Time λ

If the delivery time can be under the constrained delay timeλ, the carry-and-forward technique is used in region 2.



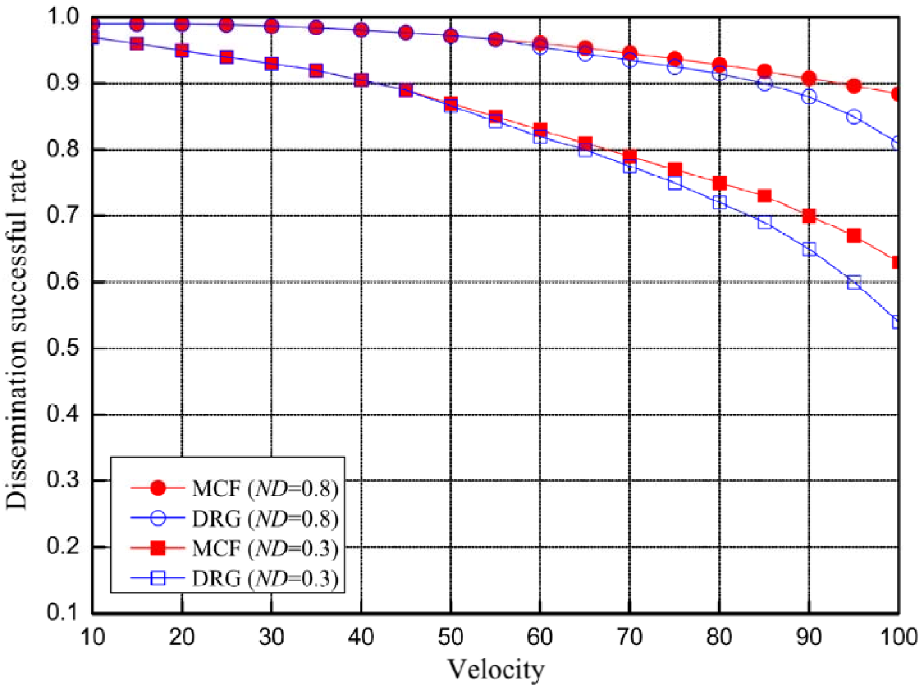
If the delivery time **cannot** be under the constrained delay timeλ, both the multihop forwarding and carry-and-forward techniques are used in region 2.

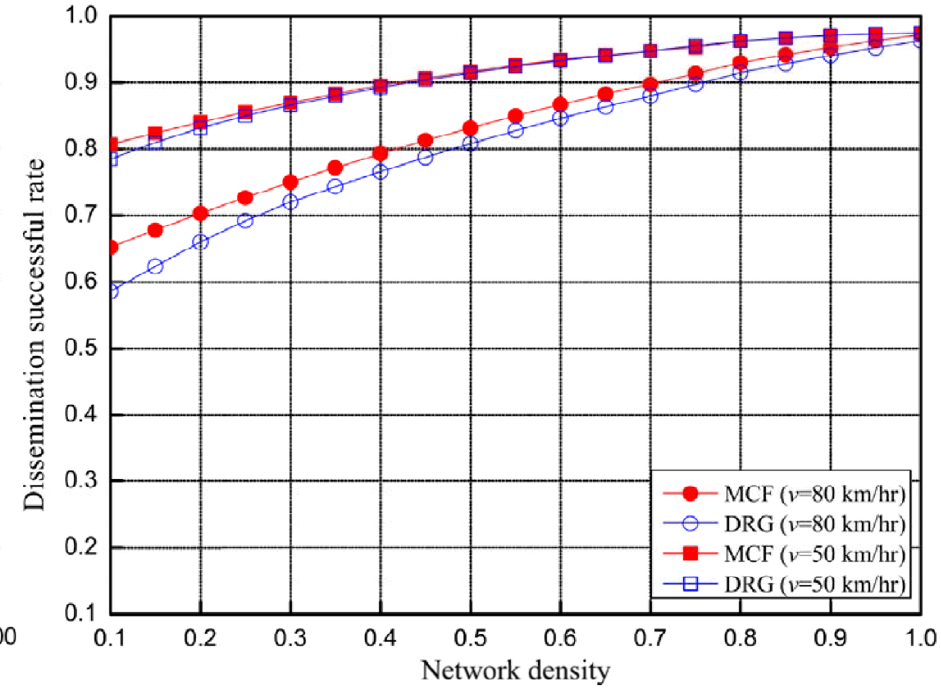


Simulation

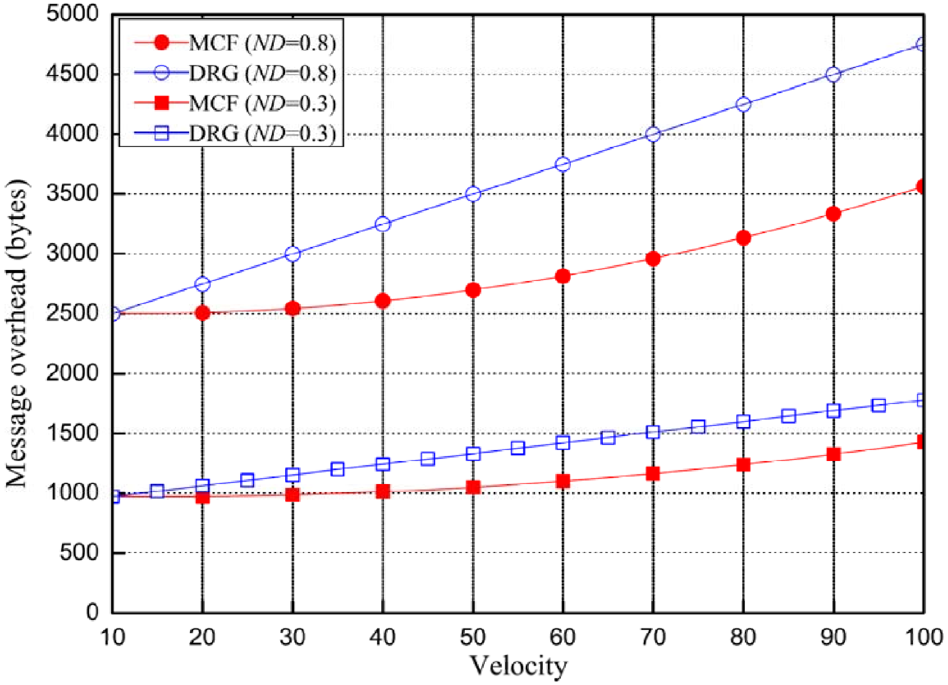
- Our mobicast routing protocol with carry-and-forward (**MCF**) is simulated compared to Distributed Robust Geocast Multicast Routing Protocol (**DRG**)
- All these protocols are mainly implemented using the NCTUns 5.0
- MAC layer uses 802.11p protocol
- The path-loss model is and ”Free Space and Shadowing”
- The fading model is ”Ricean Fading”
- A 2000×20m^2 highway scenario with various numbers of vehicles, ranging from 40 to 400
- The communication radius of each vehicle is 100m
- The velocity of each vehicle is assumed from 10 to 100 km/hr

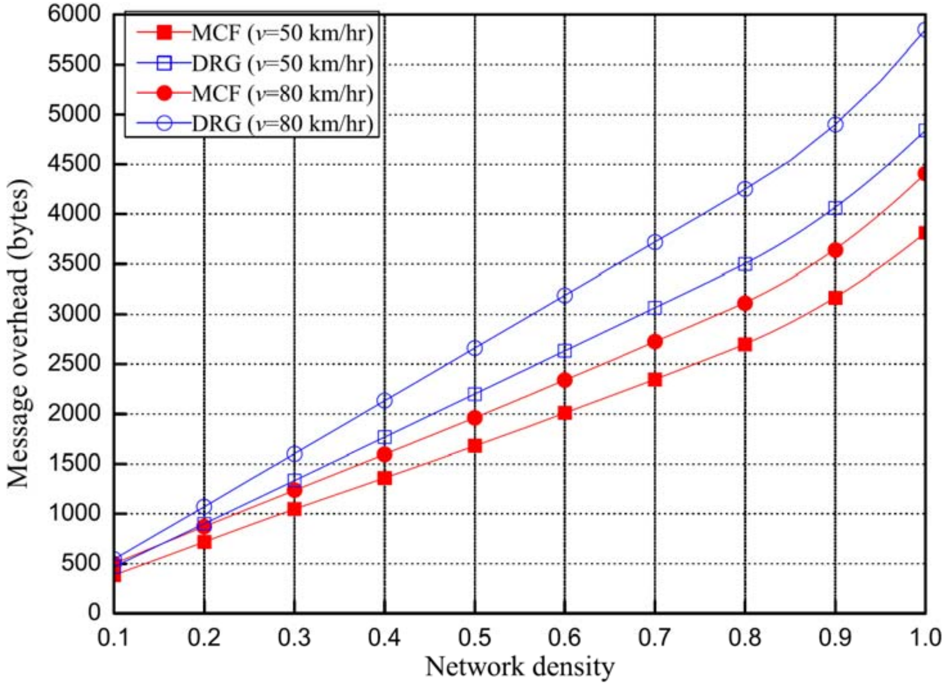
Dissemination Successful Rate vs. Velocity and Network Density





Message Overhead vs. Velocity and Network Density





Mobicast Routing Protocol with Carry-and-Forward

- A new adaptive ZOF_{t+i} is proposed to adaptively determine the size, shape, and location of the forwarding zone under highly changeable topology
- This protocol is to support the comfort applications
  - Achieve high dissemination successful rate
  - Maintain a low degree of channel utilization

Delay-Bounded Routing with Linear Regression in VANETs

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Delay-Bounded Routing with Linear Regression

- Transmit message to the destination within a limited time and minimize the usage of radio resource
- Routing delivery strategy
  - Forwarding by radio
  - Carried by vehicles

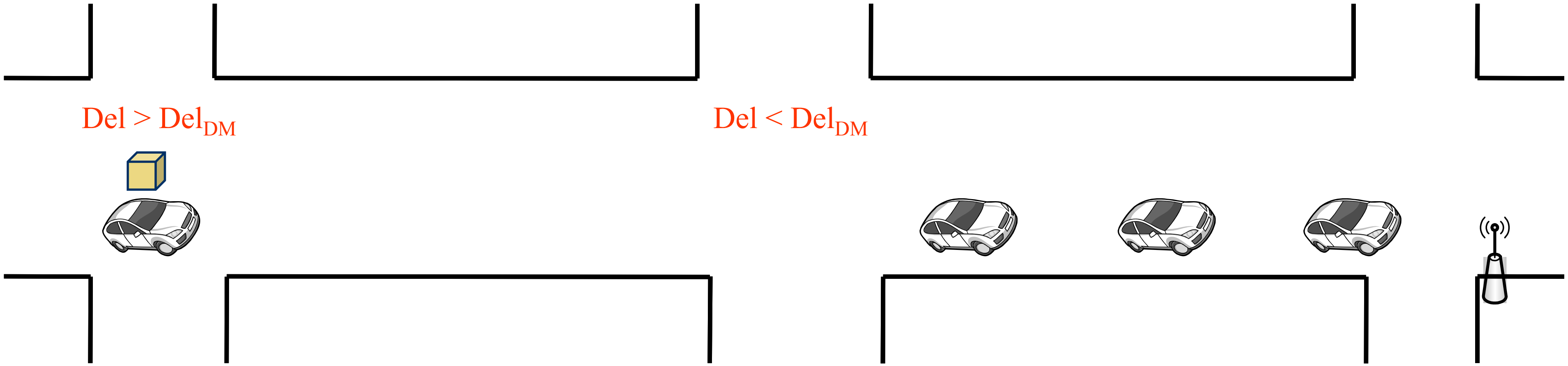
Related Works

- Skordylis *et al.*, "Delay Bounded Routing in Vehicular Ad Hoc Networks" (**ACM MOBIHOC 2008**).
  - Generated message at time t_g with a time-to-live λ
  - Message arrives AP before time $t_g + \lambda$
  - Vehicle switches delivery strategies at intersection
  - D-greedy－follow the shortest path to deliver message
  - D-MinCost－use dynamic programming to compute the best path with the minimum cost.
  - Cost : the number of message transmissions

Remaining delay budge (TTL)

$$Del = TTL \times \frac{\text{distance\_To\_Intersection}}{\text{distance\_To\_AP}}$$

$$Del_{DM} = \frac{\text{distance\_To\_Intersection}}{\bar{\bar{V}}}$$

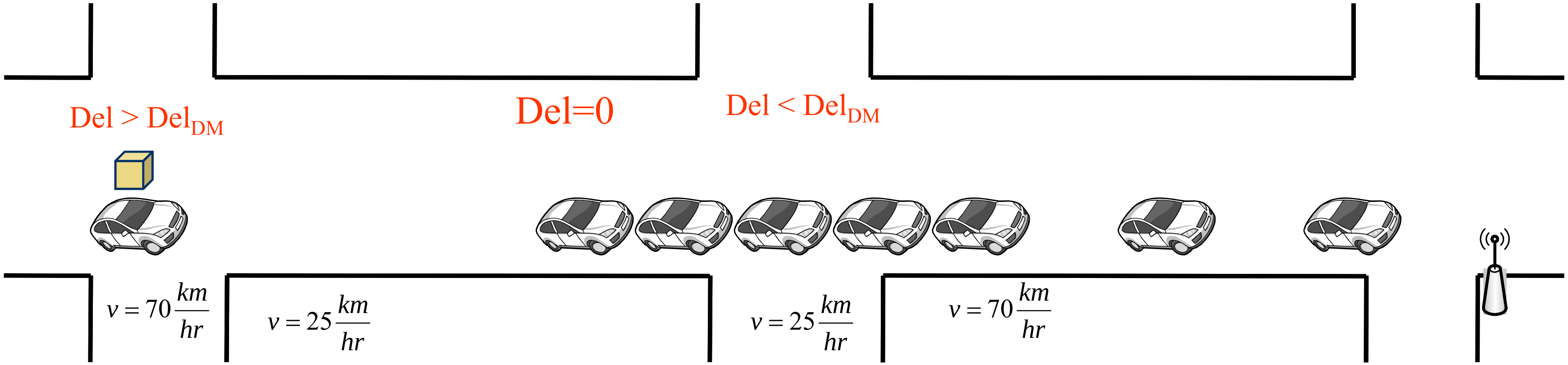


Motivation

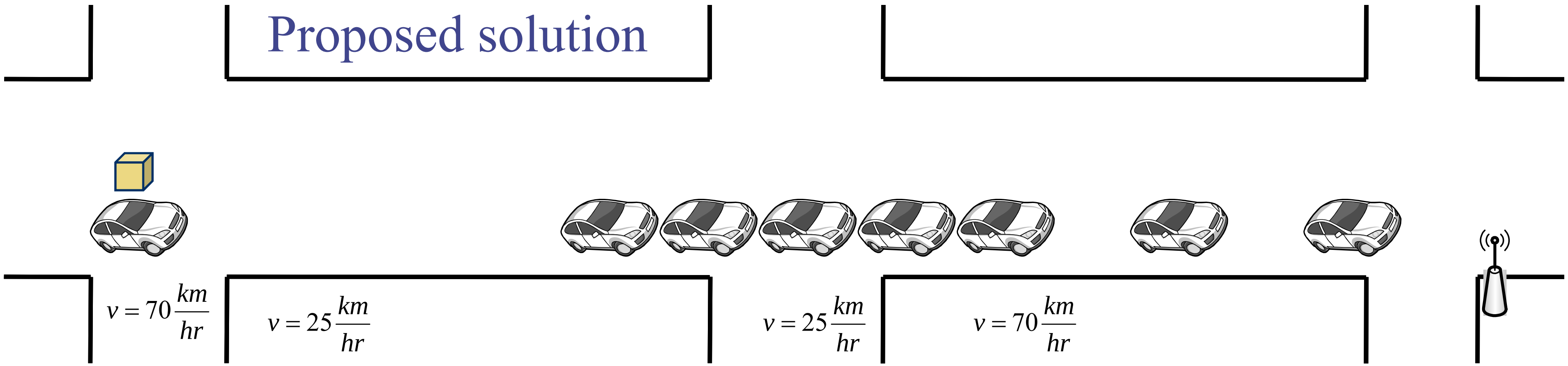
- Vehicles select the “forwarding by radio” strategy in the block, but the vehicle speed becomes high in the middle of the block
- Vehicles select the “carried by vehicle” strategy in the block, but the vehicle speed becomes low in the middle of the block
- Design a routing protocol which can select an appropriate delivery strategy at the appropriate time

Problem and Solution

Problem of D-greedy



Proposed solution



Linear Regression Formula

- Linear regression formula

$$\hat{y} = bx + a$$

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$$a = \bar{y} - b\bar{x}$$

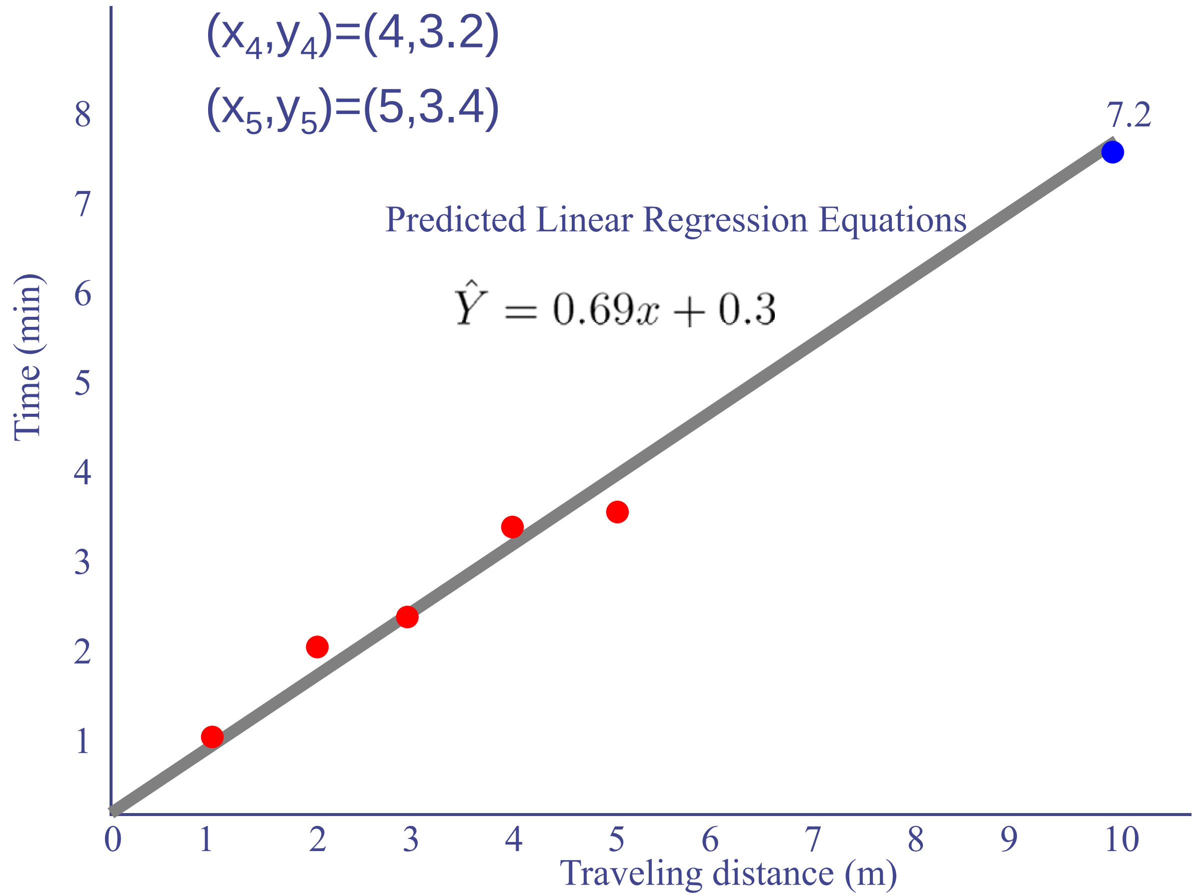
$(x_1,y_1)=(1,1)$

$(x_2,y_2)=(2,2.1)$

$(x_3,y_3)=(3,2.3)$

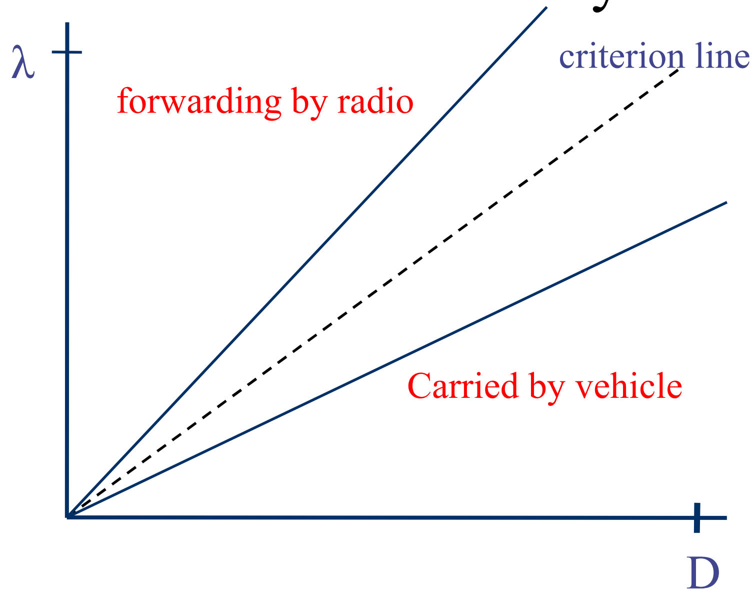
$(x_4,y_4)=(4,3.2)$

$(x_5,y_5)=(5,3.4)$



Apply Linear Regression to Our Protocol

- Record traveling distance and traveling time periodically
- Compute linear regression according recorded data
- Form a criterion line according to total distance D and λ
- If predicted line slope is greater than criterion line then forwarding by radio
- If predicted line slope is less than criterion line then carried by vehicle



Reduce Control Packets Size

- Sampling frequently would generates a large amount of data
- Reducing strategy : only transmits the necessary data

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

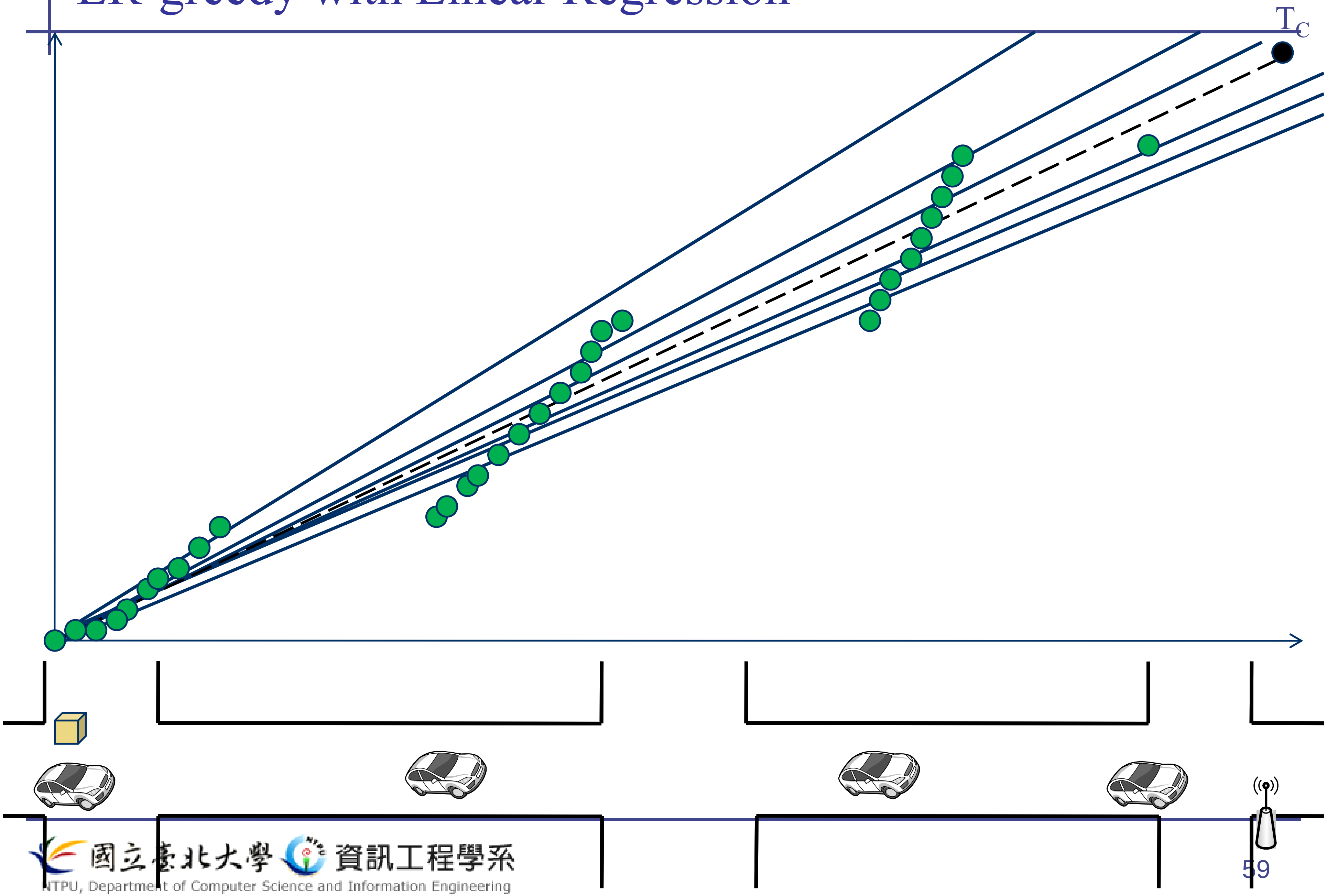
$$b = \frac{(x_1y_1 + x_2y_2 + \cdots + x_ny_n) - \bar{y}(x_1 + x_2 + \cdots + x_n) - \bar{x}(y_1 + y_2 + \cdots + y_n) + n\bar{x}\bar{y}}{(x_1^2 + x_2^2 + \cdots + x_n^2) - 2\bar{x}(x_1 + x_2 + \cdots + x_n) + n\bar{x}^2}$$

$$a = \bar{y} - b\bar{x}$$

LR-greedy

- Available information:
  - Local average velocity, digital map
- Routing path
  - Use the Dijkstra's algorithm to find the shortest path
- Message delivery strategy:
  - Use linear regression to guide the switch of the delivery strategy at an appropriate time

LR-greedy with Linear Regression



LR-centralized

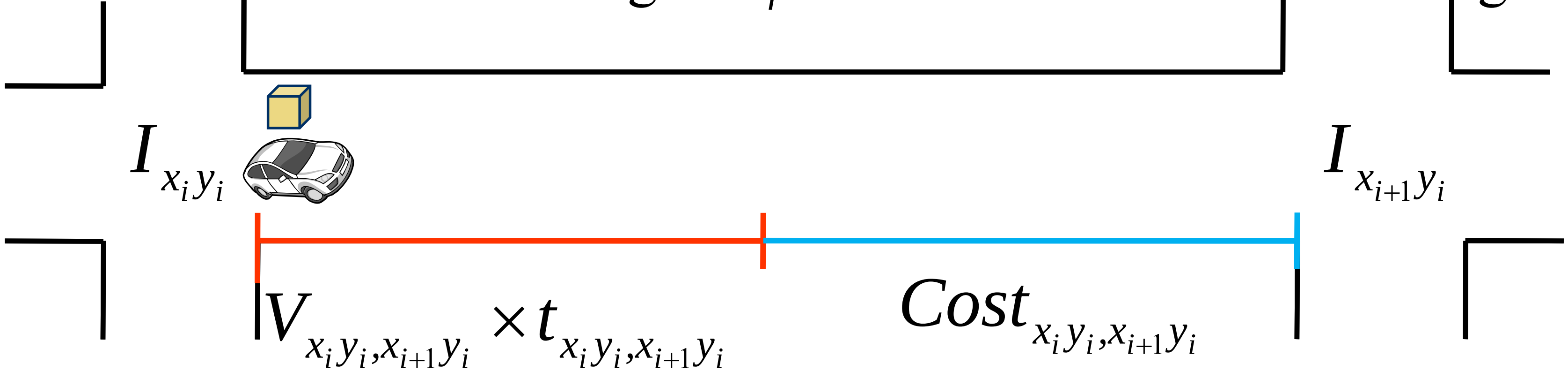
- Available information:
  - Local average velocity, history information and digital map
- Routing path
  - Use dynamic programming to find a path with the minimum cost
- Message delivery strategy:
  - Generate a criterion line of each block according history information
  - Use linear regression to guide the switch of the delivery strategy at an appropriate time

LR-centralized Count Transmission Frequency

- Compute the number of message transmissions (Cost) of each block

$$Cost_{x_i y_i, x_{i+1} y_i} = (BL - V_{x_i y_i, x_{i+1} y_i} \times t_{x_i y_i, x_{i+1} y_i})/T_r$$

- $Cost_{x_i y_i, x_{i+1} y_i}$ denotes the number of transmissions from $I_{x_i y_i}$ to $I_{x_{i+1} y_i}$
- $V_{x_i y_i, x_{i+1} y_i}$ denotes the history average speed from $I_{x_i y_i}$ to $I_{x_{i+1} y_i}$
- $t_{x_i y_i, x_{i+1} y_i}$ denotes the available time from $I_{x_i y_i}$ to $I_{x_{i+1} y_i}$
- BL denotes the block length. T_r denotes the transmission range.



LR-Centralized Select Routing Path

- Use a recursive function to find the minimum cost path

$$f_{x_i y_i}(x_m y_n) = \min \begin{cases} Cost_{x_i y_i, x_{i+1} y_i} + f_{x_{i+1} y_i}(x_m y_n) \\ Cost_{x_i y_i, x_i y_{i+1}} + f_{x_i y_{i+1}}(x_m y_n) \end{cases}$$

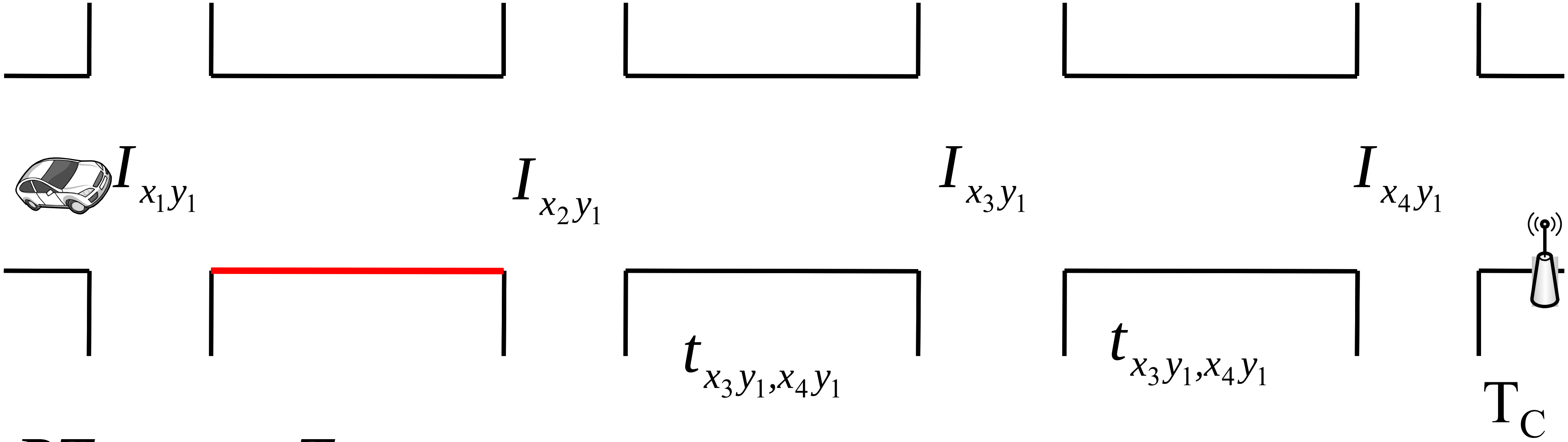
$$f_{x_{m-1} y_n}(x_m, y_n) = Cost_{x_{m-1} y_n, x_m y_n}$$

$$f_{x_m y_{n-1}}(x_m, y_n) = Cost_{x_m y_{n-1}, x_m y_n}$$

- Record each intersection of the minimum cost path

Reserve Time for Later Block

- Use history information, we can predict the traveling time and distance more accurately
- Increase the successful probability to deliver message to AP



$$RT_{x_1y_1,x_2y_1} = T_C - t_{x_2y_1,x_3y_1} - t_{x_3y_1,x_4y_1}$$

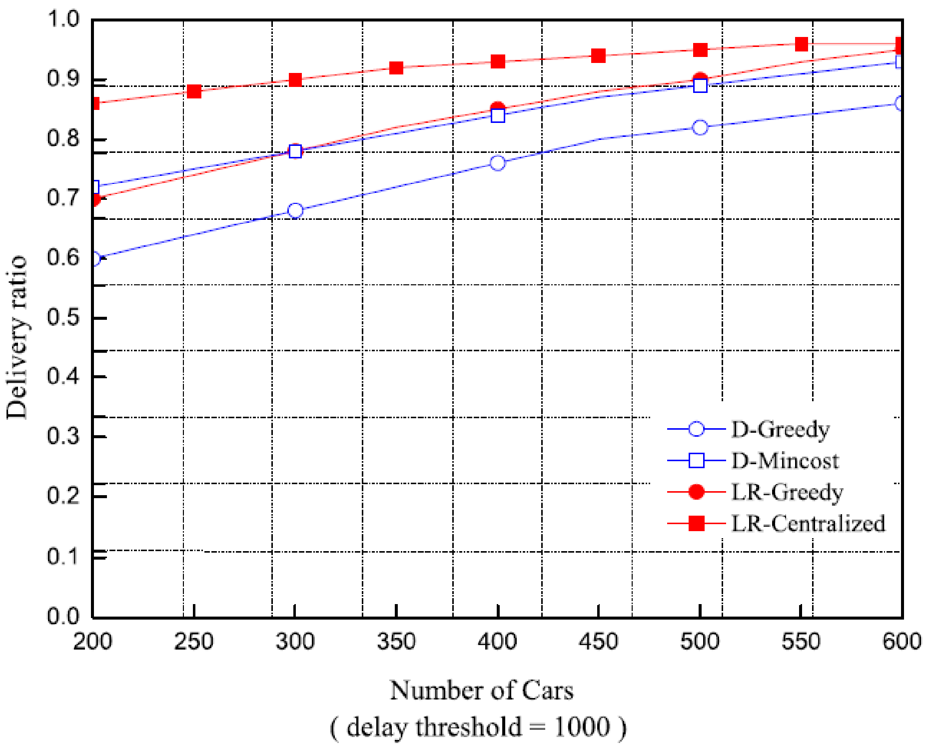
Simulation Parameters

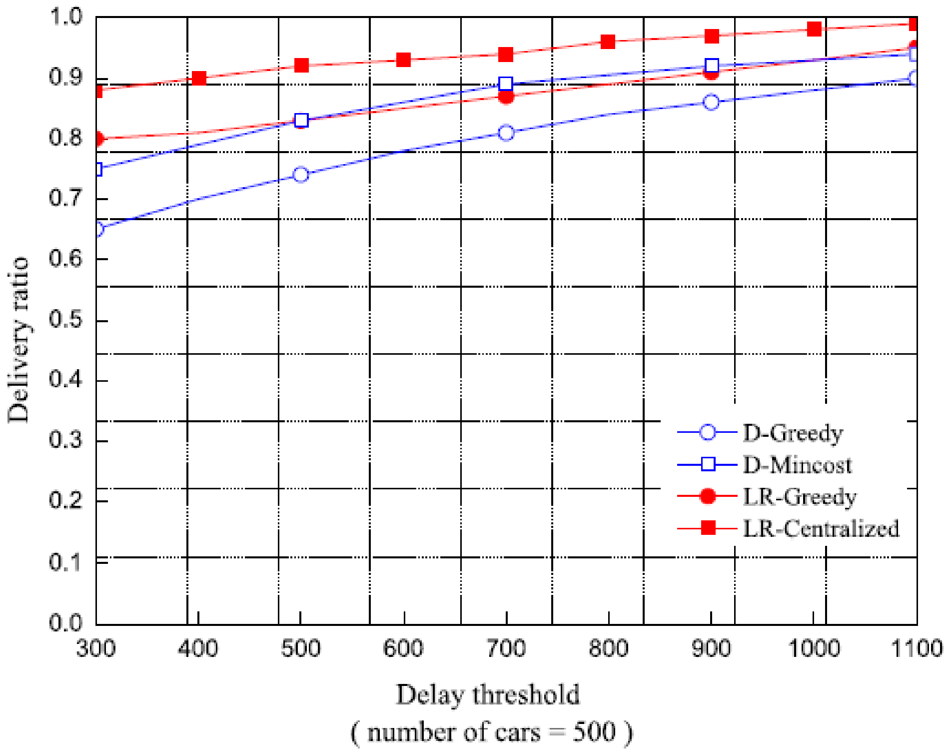
Description	Value
Simulation tool	NCTUns-5.0
Simulation area	8km x 8km
Iteration duration	1800s
Beacon period	5 sec
Number of vehicles	200 - 600
Delay threshold	200 – 1800s
Number of message generated	10
Message size	100KBs
Communication range	250m
Bit rate	1000Kbps
Sampling rate	0.5s

Performance metrics

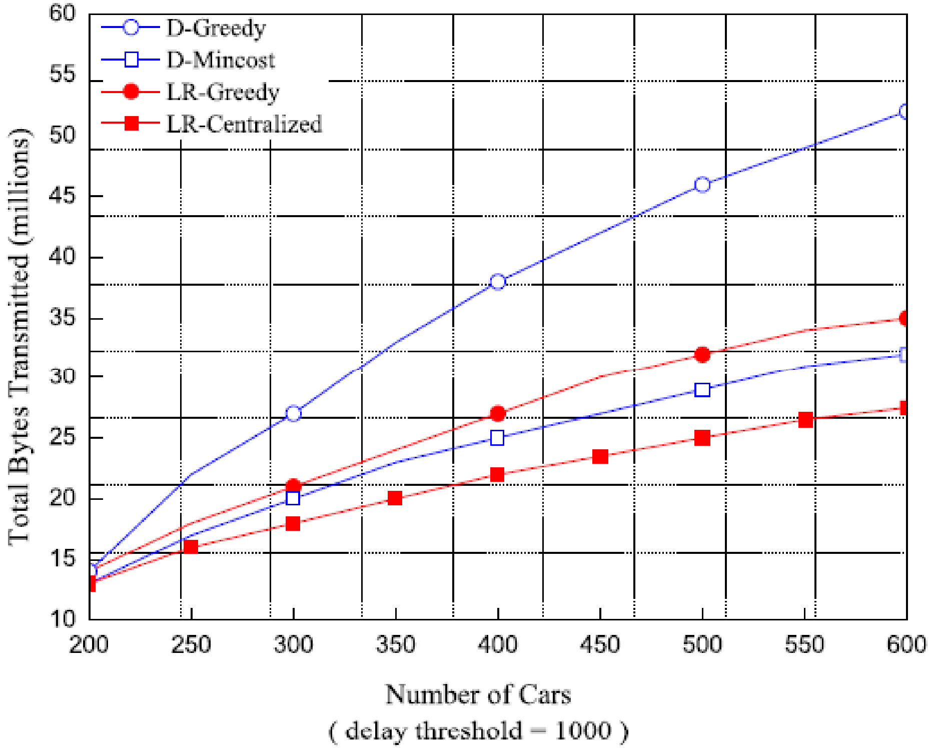
- The *total bytes transmitted (TBT)* is inclusive of any overhead incurred by control messages (e.g. beacons, acknowledgements) and protocol specific headers.
- The *delivery ratio (DR*) is measuring the messages that have reached access point without exhausting the delay threshold.
- The *average delivery delay (ADD)* is average of the delivery delay of all successfully delivered messages within the delay threshold.

Delivery Ratio



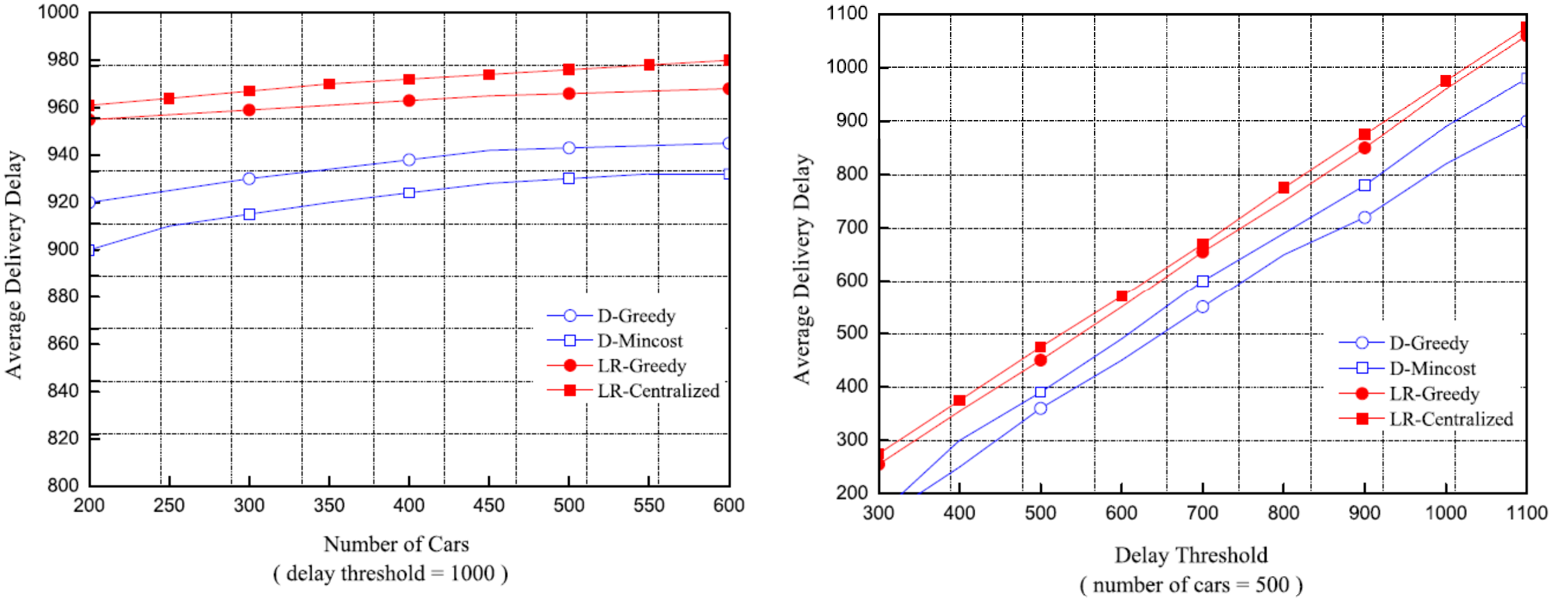


Total Bytes Transmitted

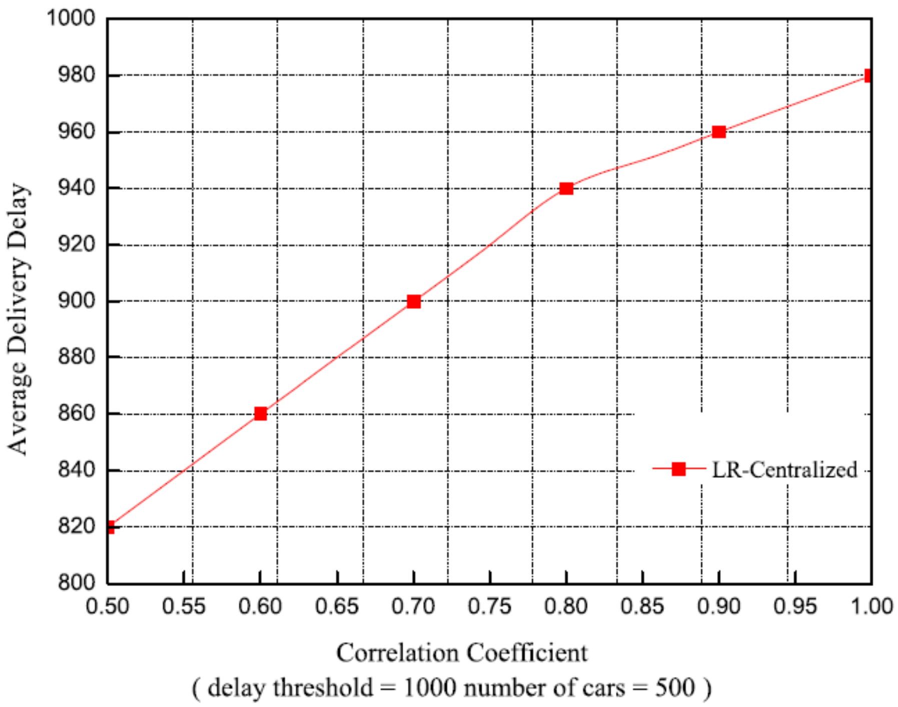


(a)

Average Delivery Delay



Average Delivery Delay



Delay-Bounded Routing with Linear Regression

- We have proposed two novel delay-bounded routing schemes for urban vehicular ad hoc networks, LR-Greedy and LR-centralized
- By the guide of linear regression, we can select an appropriate delivery strategy at the appropriate time.
- Simulation results show that our schemes perform better than previous schemes in terms of total transmitted bytes and delivery ratio

Homework #11

1. What's "Mobicast" routing protocol for WSNs ?
2. What's "Mobicast" routing protocol for VANETs ?
3. What's delay-bounded routing protocol using the "linear regression" for VANETs ?