Routing in Vehicular Ad Hoc Networks: A Survey

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Outline

- 1. Motivation and overview
- 2. Routing Protocols
  - Ad Hoc Routing
  - Position-Based Routing
  - Cluster-Based Routing
  - Broadcast Routing
  - Geocast Routing
- 3. Mobility Model
- 4. Application
- 5. Summary

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Motivation

- Vehicular Ad Hoc Network (VANET):
  - integrates *ad hoc network*, *wireless LAN (WLAN)* and *cellular technology*
  - to achieve intelligent inter-vehicle communications
  - to improve road traffic safety and efficiency
- Distinguish from other kinds of *ad hoc networks*:
  - Hybrid network architectures
  - Node movement characteristics
  - New application scenarios

Major Application

- Co-operative traffic monitor
- Control of traffic flows
- Real-time detour routes computation
- Blind crossing prevention of collisions

- Nearby information services
- Internet connectivity to vehicular nodes while on the move, such as streaming video, email etc.

Standards

- The formal 802.11p standard is scheduled to be published in April, 2009 *(this is a 2007 paper)*
  - *IEEE Std 802.11p-2010*, now incorporated in *IEEE Std 802.11-2012*
  - Use 5.85 – 5.925 Ghz
  - 75 MHz of sprectrum
- WAVE: Wireless Access in Vehicular Environments
  - IEEE 1609 protocols suites
    - IEEE 1609.2: Security
    - IEEE 1609.3: Management Control
    - IEEE 1609.4: Multichannel Operation

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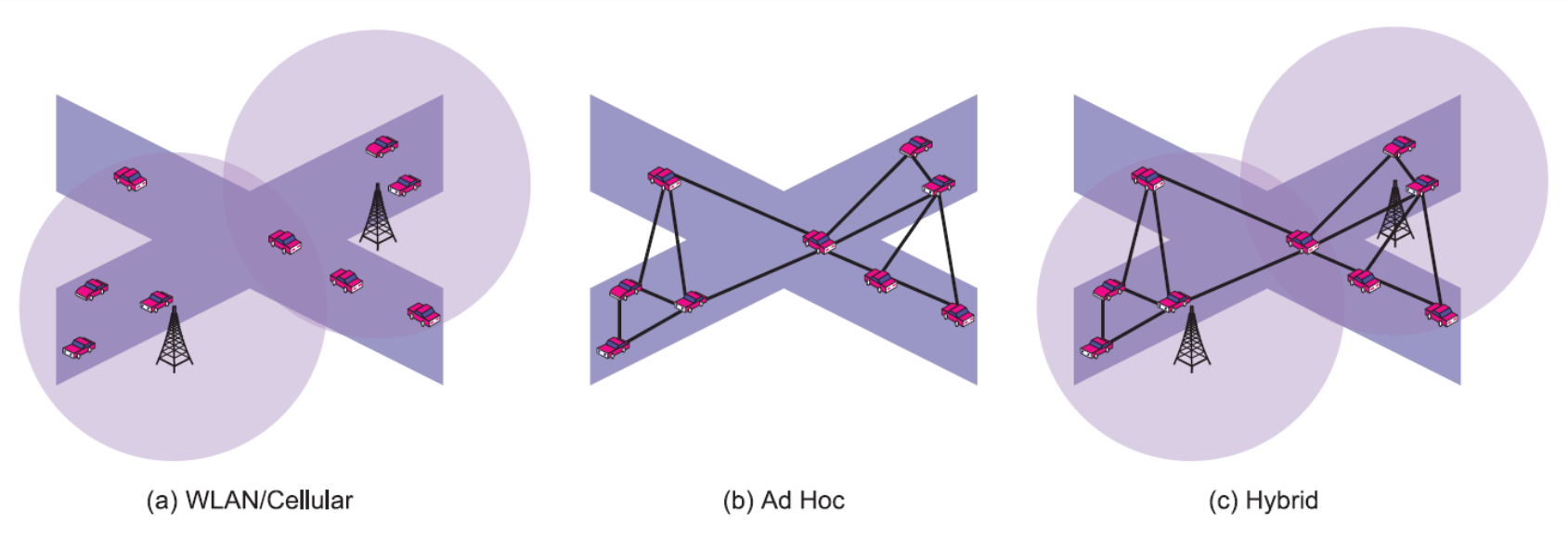
Routing Protocol for VANETs

- Goal: to achieve **minimal communication time** with **minimum consumption** of network resources.
- The performance of the existing routing protocols developed for MANETs *(Mobile Ad Hoc Networks)* suffer from poor performance due to:
  - Fast vehicles movement
  - Dynamic information exchange
  - Relative high speed of mobile nodes

VANET Architectures



- (a) Vehicular to Infrastructure (V2I)
- (b) Vehicular to Vehicular (V2V)
- (c) Hybrid of V2I and V2V

VANETs Characteristics

- **Highly dynamic topology**
  - High speed of movement between vehicles results in topology change.
  - *eg: Distance of two cars: 250m; Speed: 60 mph in opposite directions; Link will last only for 10 seconds.*
- **Frequently disconnected network**
  - The connectivity of the VANETs could be changed frequently.
  - One solution is to pre-deploy several relay nodes or AP along the road to keep the connectivity (V2I).
- **Sufficient energy and storage**
  - The nodes have ample energy and power
- **Geographical type of communication**
  - VANETs address geographical areas where packets need to be forwarded

VANETs Characteristics

- **Mobility modelling and predication**
  - Mobility model and predication play an important role in VANETs protocol design.
- **Various communications environments**
  - In highway traffic scenarios, the environment is simple and straightforward;
  - In city, *direct communication* is difficult because the streets are often separated by buildings, trees and other obstacles.
- **Hard delay constraints**
  - Delay has to be considered;
  - eg: when brake event happens, the message should be transferred and arrived in a certain time to avoid car crash.
- **Interaction with on-board sensors**
  - On-board sensors is to provide information which can be used to form communication links and for routing purposes.

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Ad Hoc Routing

- AODV, PRAODV, PRAODVM
- LAR

Routing: Ad Hoc Routing

- A.k.a. Topology-based routing
- Similarities with MANET:
  - not relying on fixed infrastructure; self-organization; self-management; low bandwidth and short radio transmission range.
  - AODV: Ad-hoc On-demand Distance Vector
  - DSR: Dynamic Source Routing
- Differences from MANET:
  - Highly dynamic topology
  - AODV evaluation
  - PRAODV
  - PRAODVM
  - ZOR and LAR

Ad Hoc Routing

- AODV (Ad-hoc On-demand Distance Vector) in VANET:
  - Unable to quickly find, maintain and update long routes in a VANET.
  - TCP is impossible because of the excessive lost of packets.
  - Even when the scalability is not a problem with path lengths of only a few hops, AODV still breaks very quickly due to the dynamic nature.
- PRAODV and PRAODVM:
  - Prediction-based: predict the link lifetimes.
  - PRAODV builds a new alternate route before the end of the ***predicted lifetime***, while AODV does it when route failure happens.
  - PRAODVM: select the ***max*** predicted lifetime instead of selecting the shortest path in AODV and PRAODV
  - Results: Slightly improvement and heavily depend on the accuracy of the prediction method.

Ad Hoc Routing

- LAR (location-aided routing):
  - AODV is modified to only forward the route requests within the Zone of Relevance (ZOR).
  - ZOR can be rectangular or circular range determined by the application
  - For example: ZOR covers the region behind the accident on the side of highway where the accident happens.

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Position-based Routing

- GPSR
- GSR
- GPCR
- A-STAR

Routing: Position-Based Routing

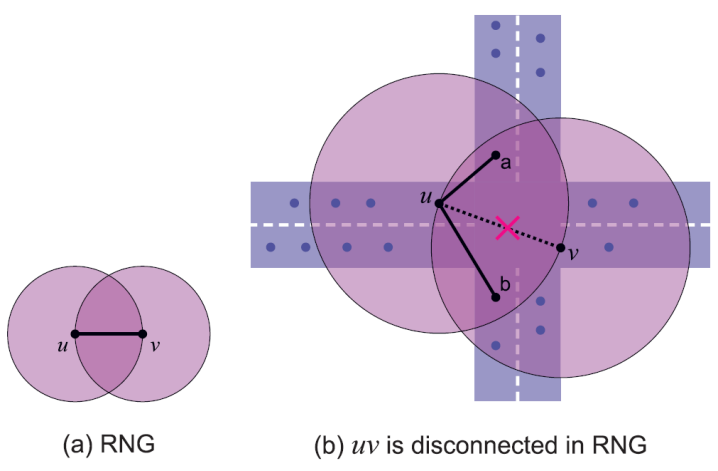
- Node movement in VANETs is usually restricted in bidirectional movements
- Obtaining geographical location information from street maps, GPS is feasible.
- More promising routing paradigm for VANETs.

Position-Based Routing: GPSR

- GPSR (Greedy Perimeter Stateless Routing)
  - Greedy routing always forwards the packet to the node that is geographically closest to the destination.
  - GPSR combines the greedy routing with face routing.
  - Using face routing to get out of the local minimum where greedy routing failed.
  - Suitable for free open space scenario with evenly distributed nodes.

Position-Based Routing: GPSR

- GPSR's failure



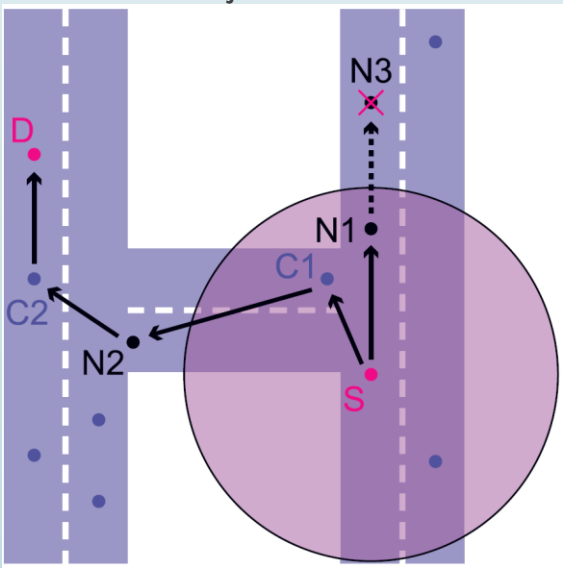
- a. The relative neighborhood graph (RNG) is a planar topology used by GPSR. A link uv will exist if the intersection of two circles centered at u and v does not contain any other nodes.
- b. Link uv is removed by RNG since nodes a and b are inside the intersection of two circles centered at u and v. However, due to obstacles there is no direct link ua or ub. Thus the network is disconnected between u and v

Position-Based Routing: GSR

- GSR (Geographic Source Routing) assumes the aid of a ***street map*** in *city environments*.
- Use Reactive Location Service (RLS) to get the global knowledge of the city topology.
- Given the above information, the sender determines the junctions that have be traversed by the packet using the *Dijkstra's shortest path algorithm*.
- Forwarding between junctions is then done by ***position-based fashion***.

Position-Based Routing : GPCR

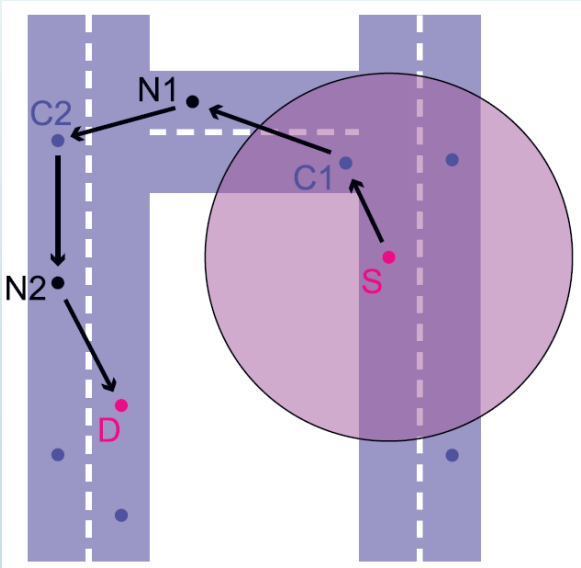
- GPCR (Greedy Perimeter Coordinator Routing) does not use either *source routing (DSR or GSR)* or *street map*.
- It utilizes the fact that the nodes at a junction follow a natural planar graph.
- Thus a ***restricted greedy algorithm*** can be followed as long as the nodes are in a street.
- Junctions are the **only** places where routing decisions are taken. Therefore packets should be forwarded **on** a junction rather than **across** the junction.



- Restricted greedy routing
- S wants to forward the packet to D.
- For regular greedy forwarding, the packet will be forwarded to N1, then N3.
- For greedy routing, the packet will be forwarded to C1, then N2,C2,D.

Position-Based Routing: GPCR

- GPCR also uses a repair strategy to get out of the local minimum, i.e., no neighbor exists which is closer to the destination than the intermediate node itself.
  - 1. decides, on each junction, which street the packet should follow next, by right hand rule.
  - 2. applies greedy routing, in between junctions, to reach the next junction.



- S is the local minimum since no other nodes is closer to the destination D than itself.
- The packet is routed to C1, which chooses the street that is the next one counter-clock wise from the street the packet has arrived on.
- The packet is forwarded to C2 through N1.
- Then C2 forward the packet to N2. Now, the distance from N2 to D is closer than at the beginning of the repair strategy at Node S.
- GPCR switches back to modified greedy routing.

- GPCR has higher delivery rate than GPSR with large number of hops and slight increase in latency

Position-Based Routing : A-STAR

- Challenge:
  - in a built-up city, vehicles are not evenly distributed;
  - the constrained mobility by the road patterns;
  - difficult signal reception due to radio obstacles such as high-rise buildings may lead VANETs unconnected.
- A-STAR (Anchor-based Street and Traffic Aware Routing)
  - Use street map to compute the sequence of junctions (anchors) through which a packet must pass to reach the destination.
  - Unique:
    - Use statistically rated maps by counting the number of city bus routes on each street to identify anchor paths.
    - Or use Dynamically rated maps by monitoring the latest traffic condition to identify the best anchor paths.
    - The packet is salvaged by traversing the new anchor path. To prevent other packets from traversing through the same void area, the street is marked as *out of service* temporarily.
- Results: A-STAR shows the best performance compared to GSR and GPSR with traffic awareness.

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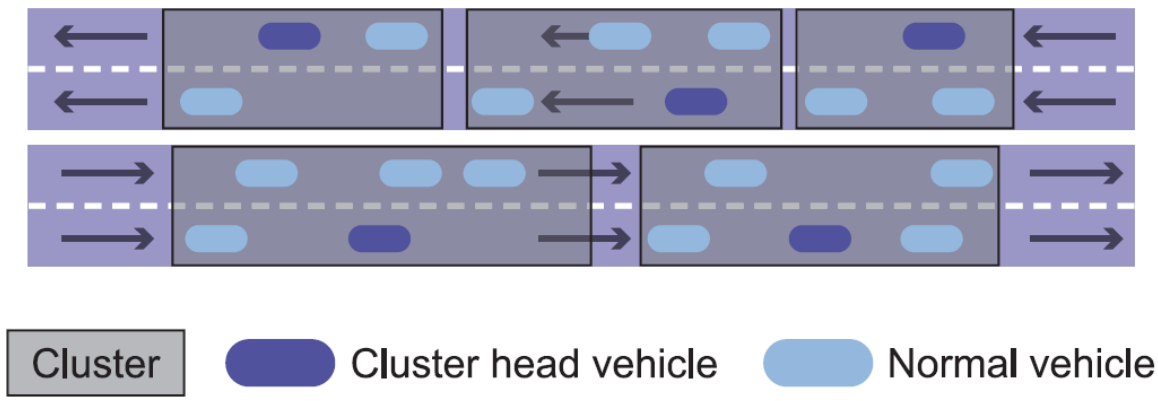
Cluster-based Routing

- COIN
- CORA_CBF

Routing: Cluster-Based Routing

- A virtual network infrastructure must be created through the clustering of nodes.



Vehicles from multiple clusters in cluster-based routing

- Each cluster can have a cluster head, which is responsible for intra- and inter-cluster coordination in the network management function.
- Nodes inside a cluster communicate via direct links.
- Inter-cluster communication is performed via the cluster-heads.

Cluster-Based Routing: COIN

- Current MANETs clustering techniques are unstable in VANET because the clusters are too short-lived to provide scalability with low communications overhead.
- COIN (Clustering for Open IVC Networks)
  - Cluster head election is based on vehicular dynamics and driver intentions, instead of ID or any classical clustering methods.
  - Accommodate the oscillatory nature of inter-vehicle distances.
- Results:
  - COIN increases the average cluster lifetime by 192%;
  - reduces number of cluster membership changes by 46%.

Cluster-Based Routing: LORA_CBF

- LORA_CBF Process:
  - Each node can be the cluster head, gateway or cluster member.
  - Each cluster has exactly one cluster-head.
  - If a node is connected to more than one cluster, it is called a ***gateway.***
  - The cluster-head maintains information about its members and gateways.
  - If the destination is unavailable, the source will send out the location request (LREQ) packets.
    - It is similar to AODV, but only the cluster heads and gateways will disseminate the LREQ and LREP (Location Reply) messages.
- Results: Network mobility and size affect the performance of AODV and DSR ***more significantly*** than ***LORA_CBF***.

Cluster-Based Routing

- Cluster-based routing protocols can achieve good scalability for large networks

- But a significant hurdle for them in fast-changing VANET systems is a ***delay and overhead*** involved in forming and maintaining these clusters.

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Broadcast Routing

- Flooding
- BROADCOMM
- UMB
- Others

Routing: Broadcast Routing

- Broadcast is frequently used in VANET
- Flooding is the simplest routing way by using broadcast.
- **Advantages:**
  - Each node re-broadcasts messages to all of its neighbors except the one it got this message from.
  - Flooding guarantees the message will **eventually** reach all nodes.
  - Easy and suitable for small number of nodes.
- **Disadvantages:**
  - When network increases, the performance drops quickly and the bandwidth requested increase exponentially.
  - Also cause contentions and collisions, broadcast storms.

Broadcast Routing: BROADCOMM

- BROADCOMM:
  - The high way is divided into virtual cells, which moves as the vehicles move.
  - The nodes are organized into two level of hierarchy:
    - First level includes all the nodes ***in the same cell.***
    - Second level included ***cell reflectors***, which are nodes located closed to the geographical center of the cell.
  - Cell reflectors
    - can act as a temporary base station (cluster head) to handle the emergency messages coming from neighbor cells.
    - can also decides which message will be the first to be forwarded.
  - Limitation: Only works with simple highway networks.

Cluster Routing: UMB

- UMB (Urban Multi-Hop Broadcast)
  - Designed to overcome interference, packet collisions and designed to overcome interference, packet collisions and hidden nodes problems.
- In UMB:
  - The sender select the furthest node in the broadcast direction.
  - At the intersection, repeaters are installed to forward the packets to all road segment.
- Results:
  - UMB has much higher success percentage at high packet loads and vehicle traffic densities than CSMA/CA.

Cluster Routing: Others

- Vector-based TRAcking Detection(V-TRADE), History-enhanced V-TRADE (HV-TRADE) are GPS based message broadcasting protocols.
- Based on position and movement information, they classify the neighbors into different forwarding groups.
- For each group, only a small subset of vehicles (border vehicles) is selected to rebroadcast the message.
- Significant improvement of bandwidth utilization with slightly loss of reachability as fewer vehicles will rebroadcast themessage.

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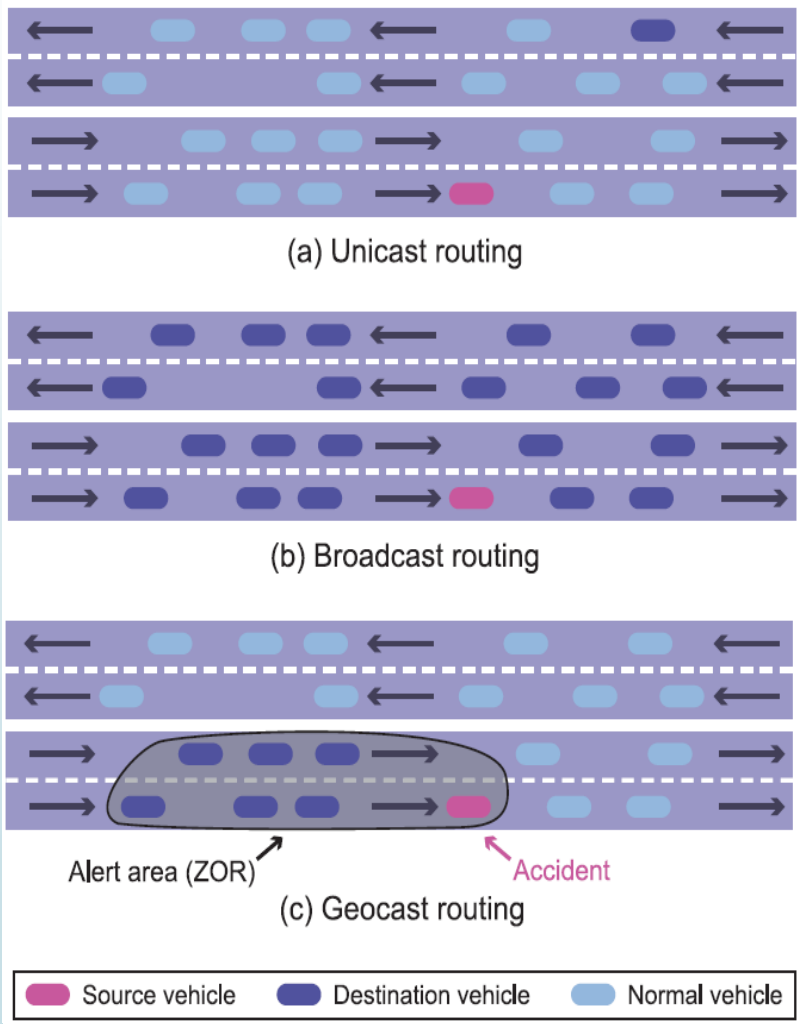
Geocast Routing

- Simple Geocast Routing
- Cashed Geocast Routing
- Abiding Geocast Routing

Routing: Geocast Routing

- Objective: to deliver the packet from a source node to all other nodes with a specified geographical region (Zone of Relevance, ZOR).

- Different Communication Scenarios:
  - Unicast routing
  - Broadcast routing
  - Geocast routing



Different Communication scenarios in VANETs

Geocast Routing

- Simple geocast scheme to avoid collision and reduce rebroadcast:
  - When a node receives a packet, it does not rebroadcast it immediately but has to wait some time.
  - The further the distance between this node and the sender, the shorter the waiting time is.
  - Mainly nodes at the border of the reception area forward the packet quickly.
  - When the waiting time is over, if it does not receive the same message form another node then it will rebroadcast this message.
- By this way, broadcast storm can be avoided.

Geocast Routing

- Cashed Greedy Geocast:
  - to deal with high velocities in VANET.
  - Inside the ZOR, a small cache is added to the routing layer for holding packets that a node cannot forward instantly.
  - When a new neighbor comes or old neighbors left, the cashed message can be possible forwarded to the newly discovered node.
  - It chooses the closest node to destination instead of the node transmission range in the general greedy routing mode.
- Results: can significantly improve the geocast delivery success ratio and significantly decrease network load and decreased end-to-end delivery delay.

Geocast Routing

- Abiding Geocast
  - the packets need to delivered to all nodes that are sometime during the geocast lifetime inside the geocast destination region.
- Solutions:
  - a server is used to store the geocast messages
  - an elected node inside the geocast region stores the messages
  - each node stores all geocast packets destined for its location and keeps the neighbor information.

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Mobility Model

- Realistic mobility models for VANETS need to be taken into account:
  - Street conditions
  - Urban conditions,
  - Traffic speed
  - Vehicle density
  - Obstacles such as buildings

Mobility Model: RWP

- RWP (Random WayPoint Mobility) model
  - Nodes randomly choose a destination and continue to move toward that destination at a uniform speed.
  - When the destination is reached, another destination is chosen at random.
  - Widely used in NS-2.
- Saha, Johnson model
  - Use TIGER (Topologically Integrated Geographic Encoding and Referencing) US road map, and convert the map into a graph.
  - Assume each node starts at some random point on a road segment and moves toward a random destination following shortest path algorithm with a speed uniformly distributed within 5mph above and below the speed limit.
- STRAW model
  - Based on TIGER; Use a simple car-following model.
  - Consider the interaction among cars, traffic congestion and traffic controls.
- New trend of building mobility model using the realistic vehicular trace data

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Applications

- Intelligent transportation applications
  - On-board navigation;
  - co-operative traffic monitoring;
  - control of traffic flows;
  - analysis of traffic congestion on the fly
  - detour routes computation based on traffic conditions and destination.
- Comfort applications
  - allow the passenger to communicate either with other vehicles or with Internet hosts which improve passengers' comfort.
    - Download music, etc.

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Summary

- Routing Protocols:
  - Ad Hoc Routing:
  - Position-Based Routing:
  - Cluster-Based Routing:
  - Broadcast Routing:
- In general, position-based routing and geocasting are more promising because of the geographical constrains.
- The performance of a routing protocol depends on mobility model, driving environment and vehicular density.
- For certain VANETs application, we need to design specific routing protocol and mobility model to fulfill its requirements.

Thank You!