EE299 Project Course

Vehicular Ad Hoc Networks (VANET)

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# Routing in Sparse Vehicular Ad Hoc Wireless Networks

Authors: Nawaporn Wisitpongphan, Fan Bai, Priyantha Mudalige, Varsha Sadekar, and Ozan Tonguz

## Describe Problem

From the Abstract statement: Study of disconnected network phenomena and its network characteristics. Average time taken to propagate a packet to disconnected nodes (i.e., the re-healing time ). For safety applications need something better than Dynamic Source Routing (DSR) and Ad Hoc On-Demand Distance Vector Routing (AODV) which have long re-healing times.

Introduction:

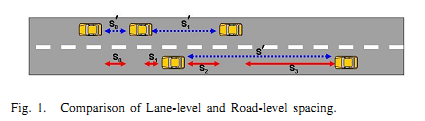
* Problem with VANET is wireless links and strengths constantly changing. Example: Bumper to bumper highway traffic has highly dense networks, night time and rural area experience network fragmentation.
* Focusing on “disconnected network” situation which deserves more attention.
* Three questions straight from the paper:
  + Is the network disconnection problem a severe problem prohibiting vehicles from successfully delivering safety messages to other vehicles?
  + What are the key characteristics of the network disconnection in VANETs and how do they affect the network performance?
  + How can we solve or mitigate this disconnected VANET problem?
* Will show that network fragmentation is a real issue, but will show some solutions (“store-carry-forward” mechanism)
* Look at some traffic models (inter-arrival time and inter-vehicle spacing between roads and vehicles) from I-80 freeway on June 27, 2006.
* Stats: Inter-vehicle spacing is exponential distribution when effective traffic volume is less than 1000 veh/hr. Even with 100% market penetration, network disconnection is 35% during night but well connected network during rush hour. Small market penetration then network disconnection is a problem during rush hour too.
* Characteristics to analyze:
  + Probability of disconnection from another vehicle
  + Cluster size
  + Cluster lengths
  + Intra- and inter-cluster spacing
* Show how re-healing time affects safety applications based on how well connected a network is.
* Key Contributions of this study:
  + Observed that inter-arrival time and inter-vehicle spacing can be approximated by exponential distributions. Validates network fragmentation conjecture about VANETs.
  + Quantify metric of re-healing time, quantifying average delay needed to deliver messages between disconnected vehicles.
  + Potential Solution: “store-carry-forward” for disconnected VANETs. Use Monte Carlo simulations. Use store-carry-forward with broadcast mechanisms in disconnected VANET then the average re-healing time is on the order of a few to several seconds.

II: Related Work

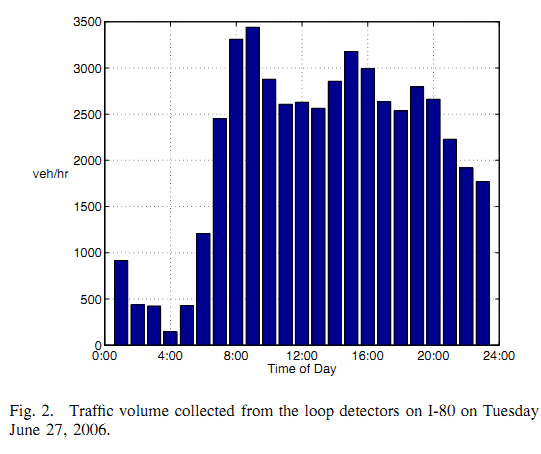
* The data is collected in real-world setting
* Most existing models not mathematically tractable.
  + Random Way Point (RWP) mobile nodes randomly select destinations with a randomly chosen velocity. Doesn’t capture all characteristics of true traffic.
  + Reference Point Group Mobility (RPGM) emulates grouping behavior of battlefield scenarios.
  + Freeway/Manhattan model captured impact of geographic restriction (ie road) on vehicular mobility
  + Simplified car-following model is used to restrict vehicular movements on a road at lane-level defined by real map data.
* Most models are over simplified with assumptions necessary to make the analysis tractable which results in models that fail to adequately represent the extreme complexity of the real-world mobility patterns.
* Emphasis on fact that VANETs are prone to network fragmentation due to uneven nature of vehicle traffic and market penetration.
* Delay Tolerant Networks (DTN) is synergistic with the problem formulation of disconnected VANETs.
* DTN framework proposed to analyze and interconnect challenged networks where end-to-end routes between mobile nodes may not exist:
  + Wildlife tracking sensor networks
  + Inter-planetary networks
  + Military ad hoc networks
* Requires asynchronous message forwarding paradigm based on **“store-carry-forward”** concept to achieve interoperability among different challenged networks.
* Some models that fall into DTN framework
  + DataMules: mobile messengers which promote the network connectivity in a sensor network by providing access between the virtual backbone and sensor nodes
  + Epidemic Routing: relies on mobile nodes to exchange they data they possess whenever they encounter new neighbors
  + Role-based multicast approach: proposed to achieve maximum reach ability in a sparsely connected or fragmented network by using the store-carry-forward mechanism
  + Single-copy and Multi-copy “Spray and Wait” are shown to be efficient alternatives for message delivery
* **Focus on network fragmentation scenarios of VANETs with realistic vehicular mobility models. Main objective in this paper is to establish comprehensive analytical framework for understanding the fundamental characteristics of disconnected VANETs in addition to studying the feasibility of the store-carry-forward approach.**
* Developed analytical framework which can be used to derive several network characteristics and key routing performance metrics such as per-hop delay (re-healing time) in sparsely connected VANETs

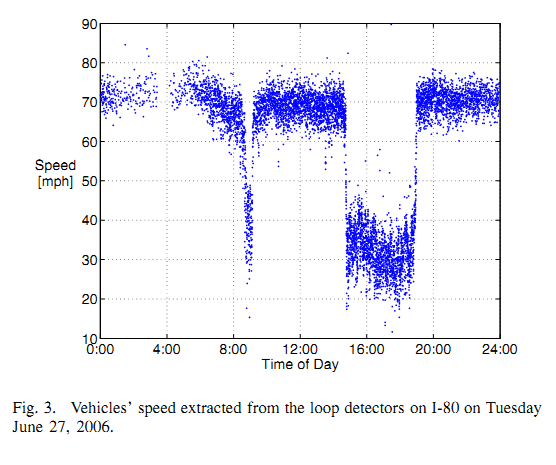
III. Vehicle Traffic Model

* Car following model, single-lane behavior under both free-flow and congested traffic conditions. Assumes drivers maintains safe distance from leading vehicle. Takes into account deceleration factor for braking performance and drivers behavior.
  + Complete mathematical model:
    - S’ headway spacing between rear bumper to rear bumper
    - L effective vehicle length in meters
    - V vehicle sped in meters/second
    - driver reaction time in seconds
    - reciprocal of twice the max average deceleration of a following vehicle (ie approximately 0.075 )
  + and introduced to ensure sufficient spacing so that following vehicle can come to a complete stop if the leading vehicle suddenly brakes.
  + Simplified Model: Good driving assumption, similar braking performance () 🡺
* Limitations of the car following model:
  + Describes headway spacing between 2 adjacent vehicles in same lane (lane level spacing). From network perspective most relevant metric is spacing from leading vehicle to the nearest following vehicle on a multi-lane road (road level spacing), regardless if following vehicle is in same or different lane. Distance to nearest neighbor determines whether wireless link between vehicles exist or not.
  + Car following model appropriate under free flow traffic or heavy traffic scenarios where **driver reaction time** is believed to be a dominant factory.
    - typically small that represents reaction time of driver following a log-normal distribution
    - can be large as 50-100 seconds in light to moderate traffic, **CAN NOT** be interpreted as driver reaction time. In this case, **inter-arrival time** is used to describe vehicle spacing. Represented by exponential distribution (not sure if there is evidence to justify the distribution)
  + Address both limitations by replacing with road-level inter-arrival time . Reduces model to . By focusing on road-level inter-vehicle spacing S, proposed model accounts for rush-hour heavy traffic and captures sparse or intermediate traffic.
    - inter-arrival time of vehicles on any lane from fix observation point
    - is minimum spacing between any two adjacent vehicles



* Incorporate empirical data into traffic model from Berkeley Highway Laboratory (BHL)
  + Shows when network disconnection occurs.
  + How serious the disconnected network problem could be in real traffic situations.





IV: Road-Level Traffic Model: Empirical Study

1. Measurement of Empirical Data
   1. To calculate analyze data from dual-loop detector on eastbound I-80 which is a 5-lane highway immediately east of SF/Oakland Bay Bridge between Emeryvill, CA and Berkeley.
   2. Collected 24 hours by using 1/60 second timestamps starting at midnight June 27, 2006.
   3. Figures 2,3 show results for
   4. 3 time periods
      1. Night traffic low volume high speed (1am – 3am)
      2. Free flow non rush hour, moderate volume and high speed (10am-12pm)
      3. Rush hour low speed intermittent congestion, high traffic volume (3pm-5pm)
   5. Interested particularly in the time frame from 1am-3am. Normally vehicles viewed as disconnected if separated by more than 250 meters.
2. Inter Vehicle Spacing Distribution
   1. Observed that **inter-arrival time distribution**  seems exponential during early mornings (low traffic high speed time)
   2. Assume where can be derived from the average traffic volume 🡺
   3. Use Kolmogorov-Smirnov test (K-S test) which measures the goodness-of-fit in terms of where is hypothesized distribution and is empirical distribution.
   4. During early hours, inter-arrival time approximated by exponential distribution with D statistics less than 3% when traffic volume is below 1000 veh/hr.
   5. Similarly, inter-vehicle spacing can also be characterized with exponential distribution given by , where . As before, fits empirical data when traffic volume is below 1000 veh/hr. Deviation of 3% when under 1000 veh/hr.
3. Impact of Market Penetration Rate on Inter-Vehicle Spacing Distribution
   1. Don’t expect every car to have the proper equipment. Low market penetration can exacerbate severity of disconnected problem since network can be fragmented even during rush hour.
   2. PDF of spacing between equipped vehicles with x% market penetration can be approximated 🡺 , then corresponding CDF is
   3. Observed that as market penetration decreases, empirical distribution converges to exponential. K-S test approximately within 5% during rush hour and is within 3% during non-rush hour for a given 10% market penetration.
   4. Disconnected VANET problem caused by low market penetration is sthe same as disconnected VANET problem caused by sparse density.
   5. This model is good for both cases then. Via rigourous analysis of empirical highway traffic data we find that VANETs may experience network fragmentation either due to sparse traffic density and/or because of low market penetration of wireless devices.

V: Characteristics of disconnected vehicular ad hoc network: Preliminaries

* Definition 1: “Vehicles in the same direction are said to be within the same cluster if and only if they can communicate with one another in a one-hop or multi-hop fashion. Otherwise, vehicles are said to be in different clusters. From a networking standpoint, any two adjacent vehicles belong to the same cluster if they directly communicate with one another (ie within the transmission range); otherwise, these two belong to different clusters.”
* Clusters minimal separation R (ie 250 meters)
* Will show probability of being the last vehicle in the cluster, average intra-cluster spacing, average inter-cluster spacing, average cluster size, and average cluster length.

1. Probability of being the last vehicle in a cluster
   * Source vehicle can detect hazards and then transmit. If cluster boundary greater than R (250 m), then we’d want the last vehicle to transmit.
   * is the probability that there are no following vehicles within the transmission ranger R of the last vehicle.
   * Given PDF of inter-vehicle spacing ,
     + is the CDF of inter-vehicle spacing
   * is the metric used to calculate many other important characteristics of a disconnected VANET, such as, average cluster size, average cluster length, and average re-healing time.
2. Average Intra-cluster Spacing
   * intra-cluster spacing
   * Lemma 1: If inter-vehicle spacing exponentially distributed then average intra-cluster spacing is
3. Average Inter-cluster spacing

## Solution

## Analysis

## Performance Results

## Discuss Results

## Suggestion

# References

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