Modeling of VANET for BSM Safety Messaging at Intersections with Non-homogeneous Node Distribution

June 7, 2016

Nets4Car 2016

Xiaomin Ma, Gregory Butron
Department of Engineering, Oral Roberts University
Kishor S. Trivedi
Department of Electrical and Computer Engineering, Duke University

Outline

- Introduction and Research Background
- Related Work for BSM Safety Services at Intersection
- Problem Formulation and Assumptions
- Analytic model and QoS Metrics Derivation
- Numerical Results and Discussions
- Conclusions

Introduction

- Dedicated Short Range Communication (DSRC) vehicular ad hoc networks (VANETs) can support many safety-related applications:
  - one-hop or multi-hop broadcasting
  - Strict QoS requirements
- Two types of Safety messages:
  - Basic Safety Message (BSM) or cooperative awareness message (CAM): blind spot avoidance, Intersection collision avoidance, etc.
  - Event-driven Safety Message (ESM) or decentralized environmental message (DENM): braking of a leading vehicle, rear-end vehicle crashes and other hazardous road conditions, etc.

Introduction: Channel Allocation

- Channel Allocation Strategies
  - New DSRC deployment option by DOT CAMP VSC2: CCH (Ch. 178) for WSAs, Ch. 172 dedicated to V2V BSMs, channel for ESM not specified
  - ETSI: CAMs and DENMs are normally transmitted on a CCH (Ch. 180)
- Analysis of VANET for Safety Applications
  - Motivations: evaluate if and how the current system can meet the QoS requirements for respective safety applications
  - Experimental testing vs. Simulation vs. Analytic models
  - Intersections are very important and common situations for vehicular communications

Previous Related Work

- Many analytical models on 1-D VANETs
  - Packet Reception Probability (PRP), Packet Reception Ratio (PRR) and Packet Delivery Ratio (PDR)
  - Transmission Delay
- Very few of models on 2-D broadcast
  - Simulations
  - Two parallel lane highway
  - Simple models without considering impact of non-perfect channel, hidden terminal and other possible collisions

Previous Related Work

X. Ma, M. Wilson, X. Yin, K. S. Trivedi, Performance of VANET safety message broadcast at rural intersections. IEEE IWCMC, 1617-1622, July, 2013

- Propose an analytic mode for VANET safety applications at intersections with uniform node distribution
- Derive performance and reliability indices: Packet reception rates, message transmission delay
- Simple assumption of uniform node distributions makes the analytic models fail to characterize realistic traffic situations and uneven node distributions

Main Contributions

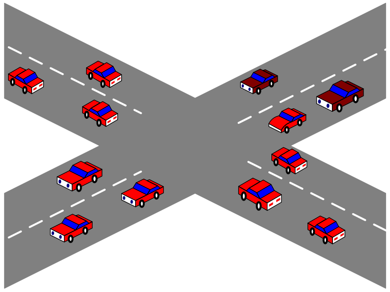
- Propose a new analytic model to characterize VANET BSM-based safety services at general intersection with non-homogeneous Poisson node distribution
- Evaluate the performance and reliability of safety message broadcast VANETs at 2-D intersections
- The model accounts for impact of IEEE 802.11p CSMA, hidden terminal, fading and path loss, and node distribution at intersection

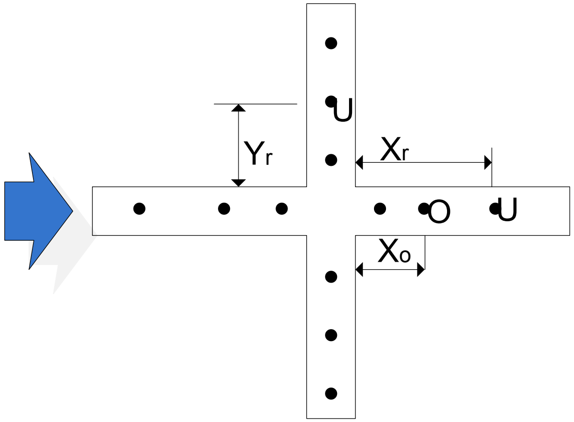
Problem Formulation

- We consider a VANET with nodes distributed randomly on cross roads at intersections.
- Nodes communicate under IEEE 802.11 protocol for broadcast
- The channel fading and path loss effect follow Nakagami model
- Given a node broadcasting on any position at an Intersection, how do the other vehicles on different locations of the intersection receive the message

Problem Statement

- Assumptions





  - Vehicles on 1-D line: non-homogeneous Poisson node distribution with density $\beta(x)$

$$P[i,(x,x+l)] = \frac{\left(\int_x^{x+l} \beta(y)dy\right)^i e^{-\int_x^{x+l}\beta(y)dy}}{i!}$$

  - Packet arrival: Poisson process with rate λ
  - Only one channel for contention
  - Queue length: unlimited, discrete time M/G/1 queue

Semi-Markov Process (SMP) Model for IEEE 802.11 Broadcast

- SMP is introduced to characterize behavior of channel access in IEEE 802.11 broadcast
- Why SMP: more precise through introducing time duration for each state
- Solution to the SMP: Channel performance
  - The steady-state probabilities, π_{XMT} and P_{XMT}
  - Mean and variance of transmission service time
  - Channel busy probability: p_b

[redacted]

Performance Evaluation: Delay

- Packet Transmission Delay: the average delay a packet experiences from the time at which the packet is generated until the time at which the packet is successfully received by all neighbors
  - The expected queuing delay (M/G/1)

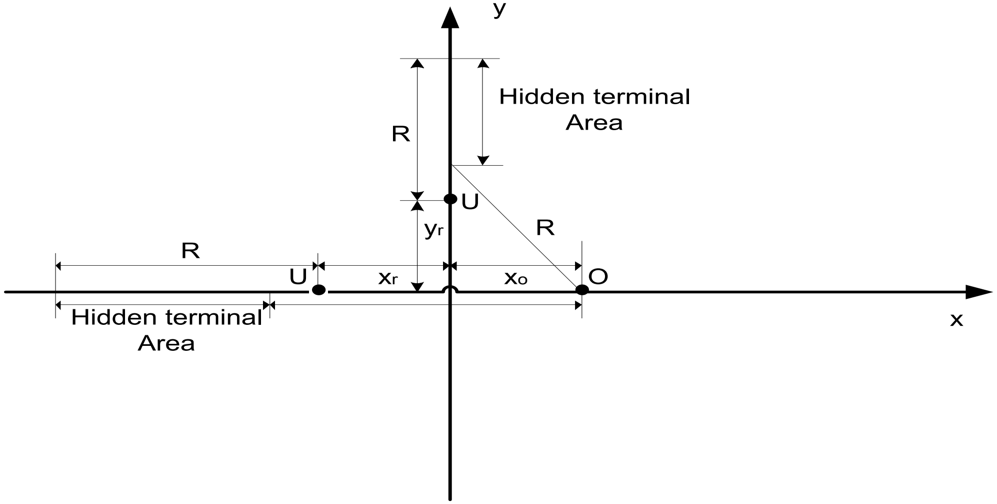
$$E[D_q] = \frac{\lambda Var[S] + \lambda (E[S])^2}{2(1 - \lambda E[S])}$$

  - The average packet transmission delay

$$E[D] = E[D_q] + E[S]$$

Performance Evaluation: PRP and PRR

- Impact of hidden terminals

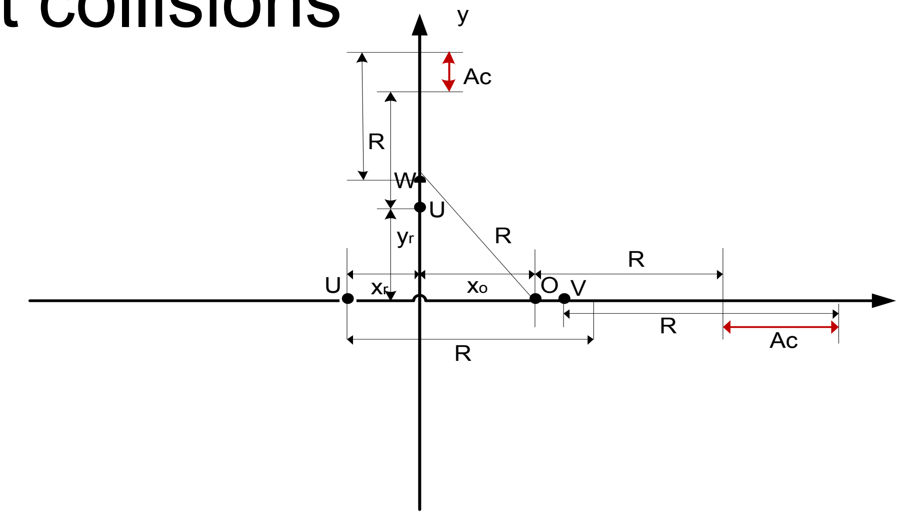


- Main ideas
  - 1-D model for hidden terminal nodes
  - Probability that node U's receiving the broadcast message from node O is free from the hidden terminals

$$P_H(x_o, x_r or\ y_r) = \sum_{i=0}^{\infty}(1-\pi_{XMT}^{(1)}\frac{2(T-DIFS)}{T})^i \frac{(\Delta)^i}{i!} e^{-\Delta} = e^{-\frac{2(T-DIFS)\pi_{XMT}^{(1)}\Delta}{T}}$$

Performance Evaluation: PRP and PRR

- Impact of concurrent collisions



- Main ideas
  - SMP model for channel performance: p_b, π_0 and P_{XMT}
  - Channel performance is calculated through setting the tagged node in the center of the intersection.
  - Two cases: (1) U in (x_r,0); (2) U in (0, y_r)

Analytical Models

- Impact of fading with path loss
  - The channel fading and path loss effect follow Nakagami model
  - At each node, emergency message arrival is bursty
  - ROI for each safety application is less than *R*

$$P_s(r_0) = 1 - \frac{m'^{m'}}{\Gamma(m')} \int_0^{(r_0/R)^{\gamma}} z^{m'-1} e^{-m'z} dz$$

Performance Evaluation: PRP and PRR

- Probability that no nodes within the reception range of U start transmission during the slot that collides with the transmission from O is

$$P_{con}(x_o, y_r) = q_b \frac{(\bar{n}_{\Sigma 2})^0}{0!} \exp(-\bar{n}_{\Sigma 2}) + 1 - q_b$$
$$= q_b \exp(-\bar{n}_{\Sigma 2}) + 1 - q_b$$

- Packet Reception Probability (PRP)

$$P_s(x_o, x_r or y_r) = P_H(x_o, x_r or y_r) P_{con}(x_o, x_r or y_r) P_{cf}(r_o)$$

- Packet Reception Ratio (PRR)

$$PRR(x_0, x) = \frac{\int_0^x \beta(x_r) P_s(x_o, x_r) dx_r}{\int_0^x \beta(x_r) dx_r}, d(x, x_o) \le R \qquad PRR(x_0, y) = \frac{\int_0^y \beta'(y_r) P_s(x_o, y_r) dy_r}{\int_0^y \beta'(y_r) dy_r}, \quad \sqrt{y^2 + x_0^{\,2}} \le R$$

Numerical Results

PARAMETERS FOR COMMUNICATIONS IN DSRC

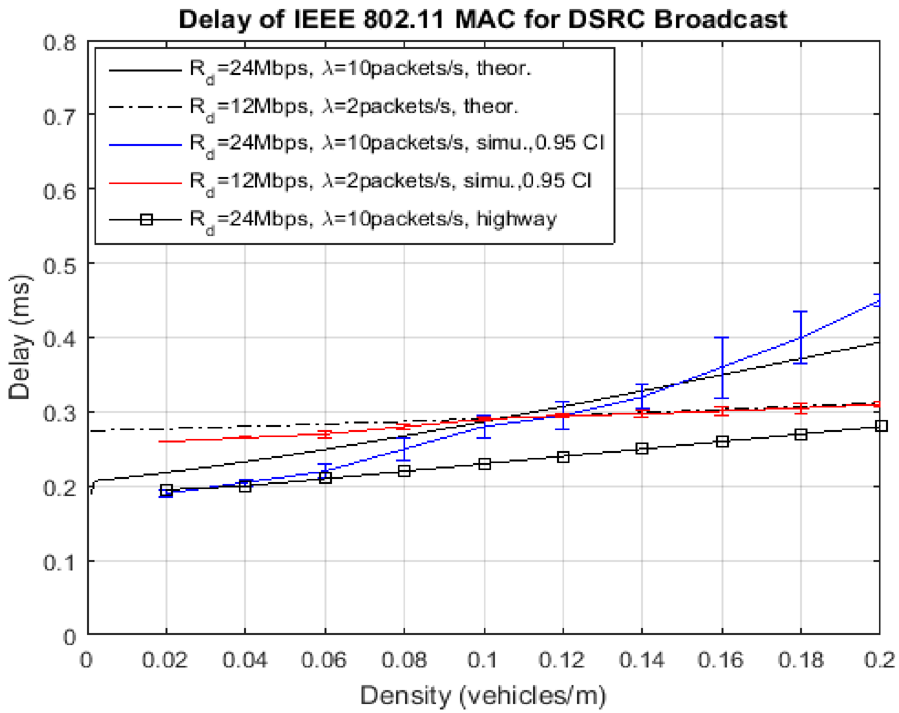
Parameter	Value
Modulation	BPSK, QPSK, 16-AM, 64-AM
Coding Rates	1/2, 2/3, 3/4
OFDM Symbol Duration	8 μs
Signal Bandwidth	10 MHz
Channel Data rate	12 Mbit/s
DIFS for 802.11a	64 μs
Slot time, σ	16 μs
SIFS for 802.11a	32 μs

Parameter	Value
Propagation delay	1 *us*
Preamble Length	40 *us*
PLCP Header Length	8 *us*
CWMin	128
Packet Payload size	200 bytes
Bit Error Rate	variable
Packet Arrival Rate	variable
Number of Stations	variable

$$\beta(x) = \begin{cases} 3\beta_{av}/2, & x \le 50m \\ \beta_{av}/2, & 50m < x \le 100m \\ \beta_{av}, & x > 100m \end{cases}$$

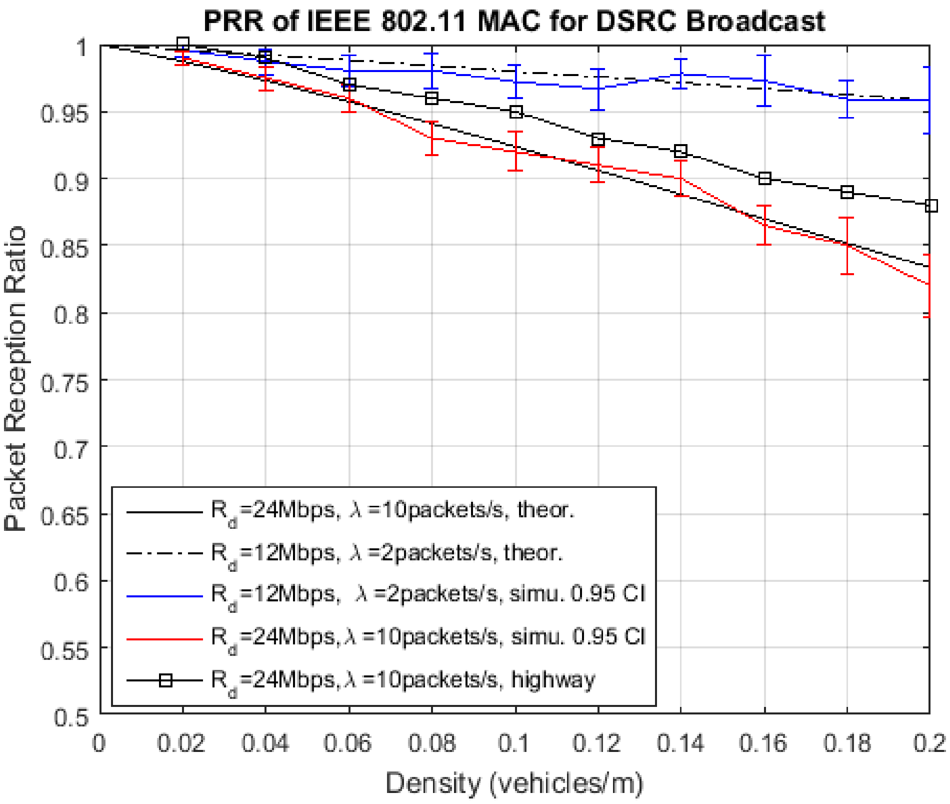
$$\beta'(y) = \begin{cases} \beta_{av}/2, & y \le 50m \\ 3\beta_{av}/2, & 50m < y \le 100m \\ \beta_{av}, & y > 100m \end{cases}$$

Numerical Results



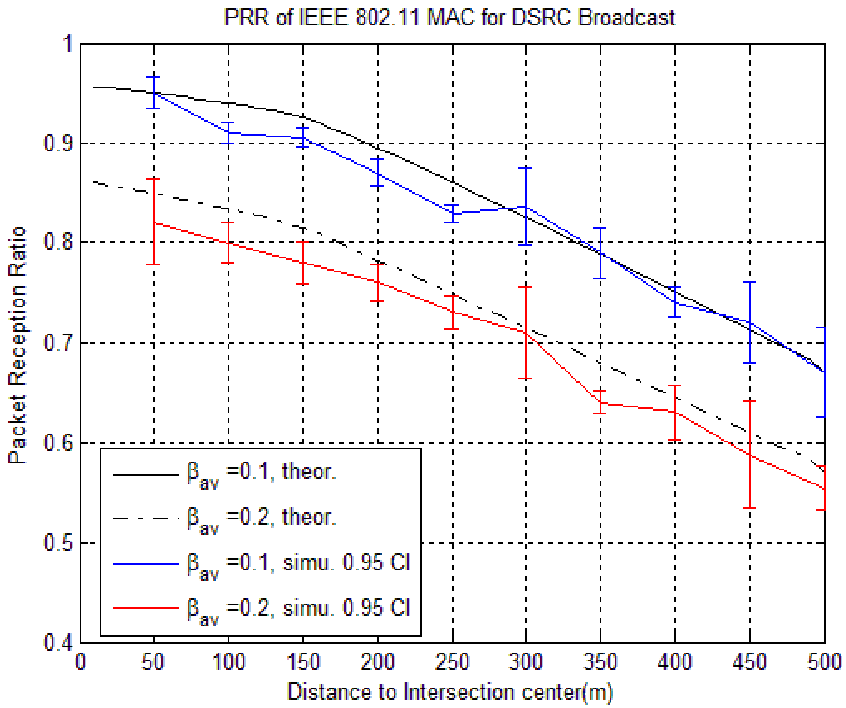
Mean transmission delay of DSRC broadcast with parameters

Numerical Results



PRR (0, 500) of DSRC broadcast with network parameters R=500m, W_0=15, $E[PA]$=200*bytes*

Numerical Results



PRRs of vehicles as function of distance to the center of intersection with different average densities and network parameters

$E[PA]$=200*bytes*, λ=10 *packets/s*, R_d=24*Mbps*, R=500*m*, W_0=15

Conclusions

- Propose an analytical model to evaluate the performance of a 2-D broadcast VANET at Intersections with more general vehicle distribution
- The model takes the impact of practical vehicular environment and applications into account
- The model can be potentially used in the design and analysis of VANETs for safety applications

Thanks and Q&A