Performance Analysis of Cooperative ADHOC MAC for Vehicular Networks

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Agenda

• Introduction
• Problem Statement
• System Model
• Performance Analysis
• Results and Discussion
• Summary and Future Work
Introduction

• State of art
  • Demand for **automation and ubiquitous connectivity**
  • Scopes are **beyond** entertainment, day-to-day organization to health/safety/financial issues, etc
  • **Better road environment**: improve road safety, increase traffic efficiency and providing on-board infotainment services
  • Vehicles are expected to be smart enough to **provide better on-board environment**

**The evolution of a smart vehicle with advanced sensors and communication devices**
Introduction

• Communication network
  • Vehicles are equipped with
    • AU: To run application(s)
    • OBU: Wireless network interface
  • RSUs are placed along the road
  • Vehicles communicate with each other (V2V) or with RSUs (V2I)
  • Wireless transmission medium

Smart vehicles equipped with AUs, OBUs and RSUs along the road, form a wireless communication network called VANET.
Introduction

• Challenges from a communication perspective
  • **Highly dynamic**: frequent link and/or connection breakage
  • **Heterogeneous data**: safety message, voice/video streaming, etc
  • **Operation Modes**: mobile-mobile, mobile-infrastructure
  • **Multi Channel Operations**: 1 control and 6 service channels
  • **Communication**: broadcast, short-range, uncoordinated

These challenges must be addressed in designing a communication protocol for VANETs
MAC Requirements

- Robust, efficient, and simple MAC protocol
  - reliable broadcast service
  - strict delay for safety messages
  - throughput sensitive application
  - multi channel operation

- Approaches
  - IEEE 802.11 Based
  - distributed TDMA MAC
  - CDMA and SDMA MAC

Protocols based on CDMA and SDMA are relatively complex
IEEE 802.11

• Advantages
  • Simple enough to implement
  • Widely considered by industries and research academia
  • P2P communication: RTS, CTS and ACK as control signals

• Limitations
  • Broadcast service: no control signals \(\rightarrow\) **Unreliable**
  • Channel is accessed randomly \(\rightarrow\) **Unbounded latency**
  • Flooding in broadcast service \(\rightarrow\) **Broadcast Storm**

*High priority safety messages have a strict delay requirement and demand reliable broadcast service*
Approaches

• **TDMA MAC**
  - ADHOC MAC\(^1\): A distributed TDMA MAC
  - Frame information (FI) acts as ACK for each packet i.e., broadcast, multicast and unicast
  - Suffers form collision due to the change in topology (mobility)
  - VeMAC\(^2\) provides a reservation scheme for highly mobile environment
    - Three disjoint time-slot groups for RSUs and vehicles moving in opposite directions

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Problem Statement

• Frame and time slots
  - Time is divided into frames and a frame into time slots
  - The number of time slots in a frame is fixed
  - Each time slot is of fixed duration

• May lead to a wastage of time slots when there are not enough nodes to use all the available time slots in a frame

• In addition, upon transmission failure, the source node has to wait until the next frame even if there are unreserved time slots

One possible solution: Utilizing an unreserved time slot for retransmission of a packet that failed to reach the target destination.
Possible Solution

• Cooperative ADHOC MAC (CAH-MAC)
  • The destination $D$ fails to receive a packet successfully from the source $S$
  • Node $H$ can cooperate to relay the packet
  • An unreserved time slot is used for the retransmission
  • Neighboring nodes are not stopped form their transmission due to cooperation
Existing Works on Cooperation

• Most of them are based on IEEE 802.11, which are not suitable for TDMA based protocols

• In TDMA based protocols, cooperation are
  • only for infrastructure based networks
  • coordinated by AP or BS
  • performed by/during fixed helpers and/or time slots

CAH-MAC : Cooperative operations such as helper selection, time slot selection, and cooperative relay transmission are performed in a distributed manner
System Model

• A VANETs consisting of $N$ vehicles
  ▪ moving in a multi-lane road
  ▪ with negligible relative movements

• Vehicles are distributed randomly on the road with an exponentially distributed inter-vehicular distance

• Counting of vehicles follows a Poisson process over a given length of road

• Link model:
  ▪ Control signals are exchanges within transmission range $r$
  ▪ Within $r$, packets are received successfully with the probability $p$

• No mobility hence, the prob. of successful transmission

\[ p_s = (1 - p_c) p = p \]
System Model

- Time $\rightarrow$ frames $\rightarrow$ $F$ time slots

- A packet is transmitted in a reserved time slot.

- Assumptions:
  - Node has already reserved its time slot
  - Sync. using 1PPS (GPS)

For reservation and ACK

Frame Information (FI) | Cooperation Header (COH) | Packet Header | Payload data | CRC
---|---|---|---|---

For offering cooperation

As in other protocols
Neighboring Nodes

- Two-Hop set
  - The group of nodes that share a frame
  - Consists of nodes that are within $r$ distance from a reference node
- Counting of the number of THS members follows a Poisson process over a road length of $2r$. 
Time Slots

- Time slots can be:
  - **Unreserved** \((UN)\): not used by any node (# of \(UN = U\))
  - **Successful** \((SU)\): reserved with successful transmission (# of \(SU = X\))
  - **Failed** \((US)\): reserved with transmission failure.

In CAH-MAC, an unreserved time slot is used to retransmit a packet that failed to reach the destination
CAH-MAC

- Transmission failure detection
  - The source transmits a packet in its time slot (a)
  - The destination does not acknowledge a packet transmission from the source (b)
CAH-MAC

• Potential helpers
  ▪ Nodes which receive a packet from the source and detect the transmission failure

• Possible time slots
  ▪ Any unreserved time slot in which the helper can retransmit a packet to the destination
Existence of a Potential Helper

- Potential helper exists, if there is at least one common node of both $S$ and $D$, which has a copy of the failed packet
- $Y$ denotes the number of potential helpers

$p_1 = \Pr\{Y > 0\}$

$$= \sum_{k=3}^{F} \left(1 - (1-p_s)^{k-2}\right) \frac{(1.5\rho r)^{k} e^{-1.5\rho r}}{k!} + \left(1 - (1-p_s)^{F-2}\right) \left[1 - \sum_{k=0}^{F} \frac{(1.5\rho r)^{k} e^{-1.5\rho r}}{k!}\right]$$

Common coverage area of a $s$-$d$ pair
Existence of a Time Slot

- The source, the destination and the helpers share the same time frame
- A time slot for the cooperation exists if there is at least one unreserved time slot in a frame (i.e., $U > 0$)

$$p_2 = \Pr\{U > 0\} = \sum_{i=1}^{F-1} \frac{(2\rho r)^i e^{-2\rho r}}{i!}$$
CAH-MAC

- **Cooperation Header (COH)**
  - Used by the helper to inform
    - its decision to cooperate
    - the time slot in which transmission failure occurred
    - the selected unreserved time slot for the relay transmission
  - First come first serve
Cooperation Enabled Transmission

- Cooperation is triggered if
  - there is at least one potential helper $Y > 0$ (prob. $p_1$)
  - there is at least one unreserved time slot $U > 0$ (prob. $p_2$)
- The probability of cooperation
  \[ p_{coop} = p_1 p_2 \]
- The probability of successful transmission
  \[ p_{s_{coop}} = p_s + p_s (1 - p_s)p_{coop} \]

If direct transmission fails $\rightarrow$ Cooperative transmission
Packet Transmission Delay

- The number of transmission attempts follows a Geometric Distribution
- ADHOC MAC

\[ \Pr\{M = i\} = (1 - p_s)^{i-1} p_s \]

- CAH-MAC

\[ \Pr\{M = i\} = (1 - p_s^{coop})^{i-1} p_s^{coop} \]
Packet Dropping Rate

• A packet is dropped if it not delivered within maximum retransmission limits ($M_{max}$)

• PDR for ADHOC MAC:

$$PDR = 1 - \sum_{i=1}^{M_{max}} (1 - p_s)^{i-1} p_s$$

• PDR for CAH-MAC

$$PDR_{coop} = 1 - \sum_{i=1}^{M_{max}} (1 - p_s^{coop})^{i-1} p_s^{coop}$$
Simulation Setup

- Number of vehicles ($N$): 500 vehicles
- Number of lanes ($L$): 2 lanes
- Width of a lane ($w$): 5 meters
- Number of time slots per frame ($F$): 40 and 80 time slots
- Transmission range ($r$): 200 and 300 meters
- Vehicle density per lane ($\rho_l$): 0.01 vehicles/m
- Max. Retransmission Limits ($M_{max}$): 1 and 10 frames
- Channel characteristics ($p$): [0, 1]
Transmission Delay

- $2\rho r$ is an average number of THS members

- The larger the number of THS members $\rightarrow$ the lesser the number of unreserved time slots

- CAH-MAC uses unreserved slots for retransmission $\rightarrow$ delay decreases

- Higher the number of unreserved time slot $\rightarrow$ delay increases
Packet Dropping Rate

- The larger the $M_{\text{max}}$ value, the smaller the dropping rate.
- Dropping rate decrease with cooperation ($PDR_{\text{coop}} > PDR$).
- The higher the number of THS members and/or unreserved time slots, the smaller the $PDR$ (the gaps increases with increase in $p_{\text{coop}}$).
Summary

• We studied the performance of CAH-MAC
  • Cooperation is useful to tackle the poor channel condition
  • Uses only the unreserved slot
  • Decreases delay and packet dropping rate
Future Work

• CAH-MAC with mobility and realistic channel
  • Collision occurs with mobility
  • Reservation and cooperation contend for a time slot

• Cooperative relay and time slot reservation collide
  • Cooperation is not beneficial
  • May have a negative effects
    • Stops a node to reserve a time slot
Future Work

• Collision Avoidance
  • In CAH-MAC, a helper node transmits the FI for $\alpha$ time units, which is not necessary
  • A new node always starts its transmission from the beginning of the unreserved time slot
  • To avoid collisions, the helper node waits for $\alpha_1$ time units before starting cooperative transmission
  • $\alpha_1$ can be kept fixed
Future Work

- **Cooperative Transmission**
  - Potential helper nodes randomly select $\alpha_2 \in [\alpha_1, \alpha - \alpha_1]$, then performs cooperation
  - The best helper has the smallest $\alpha_2$ value
    - **The best helper first**
  - Other potential helpers back-off their transmission
Future Work

• Cooperation for the broadcast service
  • Mission critical and safety messages require reliable and prompt broadcast service
  • CAH-MAC works for point-to-point
    • Reactive response
    • Cooperation decision based on one receiver
  • FIs of all the one-hop nodes have to be analyze
  • Source waits for its own time slot for retransmission
  • Hence, it require a proactive cooperation scheme
  • Unreserved time slots can be use
Future Work

• Multi channel cooperative MAC
  • VANET is a multi-channel wireless network.
  • MAC must be compatible with DSRC/WAVE standard.
• Challenges
  • Channel conflict problem
  • Deaf receiver problem
  • Unfriendly with reliable broadcast or multicast
• Use of cooperation to exchange the information between neighboring nodes
  • Selection of channel (service channel and time slots)
  • Stopping any conflict between two services
  • Relaying ACK and/or NACK
Thank you!!