An Efficient Message Dissemination Technique in Platooning Applications

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Introduction

Objective:
- Delay-sensitive data traffics are sent with high reliability
- Considering the co-existence of both time-triggered and event-driven control messages

Current approach:
- CSMA IEEE 802.11p: unbounded channel access delay and multiple consecutive packet drops
- Time-triggered messages: congestion control, rate control
- Event-triggered messages: algorithms to mitigate broadcast storms
- Collision-free phase together with contention-based phase, using a separate SCH
A platoon consisting of $N$ nodes communicating through an *ad hoc* network, using a separate SCH

- Time is slotted (TDMA) and every packet is transmitted in exactly one time-slot
- In each superframe, a subset of the available time-slots are dedicated to periodic time-triggered messages
System Model (Cont’d)

- Channels between nodes are characterized by an $N \times N$ stationary matrix $P$
- Each event-driven message is assigned a set of $K + 1$ time-slots
- Time-slot 0 is always allocated to the source $R_0$ and the remaining $K$ time-slots to a set of $K$ distinct relayers $R_1, R_2, \ldots, R_K$
- After overhearing in time-slots numbered $0, 1, \ldots, k - 1$, relay $R_k$ will transmit at time-slot $k$ or being quiet
- How to choose an optimal combination of $R_k$, $i = 1, 2, \ldots, K$?
ANALYTICAL EXPRESSIONS

▶ Defining

\[ e_i = \begin{cases} 
  T & \text{if } R_i \text{ transmits at time-slot } i \\
  Q & \text{if } R_i \text{ remains quiet at time-slot } i,
\end{cases} \]

▶ For a specific sequence \( e = \{e_i\}_{i=0}^K \in \{T, Q\}^K \), defining

\[ \Phi_T(e) = \{i|e_i = T\}: \text{the set of time-slots where transmissions occur} \]
\[ \Theta_Q(e) = \{j|e_j = Q\}: \text{the complimentary set of time slots where the corresponding relay nodes remain quiet} \]

▶ The probability that the destination cannot receive the packet after \( K \) transmission attempts

\[ \Pr\{e_{K+1} = Q\} = \sum_{\forall e \in \{T,Q\}^K} \Pr\{e_{K+1} = Q|e\}\Pr\{e\} \] (1)
Analytical Expressions (cont’d)

- Applying the chain rule

\[
\Pr \left\{ \cap_{i=0}^{K} e_i \right\} = \Pr \left\{ e_0 \right\} \prod_{k=1}^{K} \Pr \left\{ e_k \mid \cap_{i=0}^{k-1} e_i \right\}
\]

(2)

- in which

\[
\Pr \left\{ e_k = T \mid \cap_{i=0}^{k-1} e_i \right\} = 1 - \prod_{\begin{subarray}{l} l \in \Phi_T(e) \\ l < k \end{subarray}} P_{R_l \rightarrow R_k},
\]

(3)

\[
\Pr \left\{ e_k = Q \mid \cap_{i=0}^{k-1} e_i \right\} = \prod_{\begin{subarray}{l} l \in \Phi_T(e) \\ l < k \end{subarray}} P_{R_l \rightarrow R_k}.
\]

(4)

- Assuming that \( P_{R_u \rightarrow R_l} = 0 \) when \( l = 0, u < l \)

\[
\Pr \left\{ e \right\} = \prod_{\begin{subarray}{l} l \in \Phi_T(e) \\ k \in \Theta_Q(e) \\ k > l \end{subarray}} P_{R_l \rightarrow R_k} \left( 1 - \prod_{\begin{subarray}{l} u \in \Phi_T(e) \\ u < l \end{subarray}} P_{R_u \rightarrow R_l} \right)
\]

(5)
Analytical Expressions (cont’d)

\[ \Pr \{ e_{K+1} = Q \} = \sum_{\forall e \in \{ T, Q \}^K} \Pr \{ e_{K+1} = Q | e \} \Pr \{ e \} \]

\[ = \sum_{\forall e \in \{ T, Q \}^K} \prod_{\forall l \in \Phi_T(e), k \in \Theta_Q(e) \cup \{ K+1 \}} P_{R_l \rightarrow R_k} \left( 1 - \prod_{u \in \Phi_T(e) \cap u < l} P_{R_u \rightarrow R_l} \right) \tag{6} \]
NUMERICAL RESULTS

Simulation parameters, $N = 12, D = 20m$

Parameter $m$ in Nakagami-$m$ distribution, $PL = 2.32$

<table>
<thead>
<tr>
<th>Distance between vehicles (meter)</th>
<th>Parameter $m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.94</td>
</tr>
<tr>
<td>40 to 60</td>
<td>1.86</td>
</tr>
<tr>
<td>80 to 160</td>
<td>0.45</td>
</tr>
<tr>
<td>180 to 240</td>
<td>0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Power</td>
<td>20 dBm</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Cable loss</td>
<td>3.4 dB</td>
</tr>
<tr>
<td>Noise floor</td>
<td>$-99$ dBm</td>
</tr>
<tr>
<td>SNR decoding threshold</td>
<td>8 dB</td>
</tr>
</tbody>
</table>


A message that needs to be propagated to a specific receiver

ES = Exhaustive Search, GS = Greedy Search
Numerical Results (Cont’d)

A message that originates from one node and needs to be received by the entire platoon, minimising the largest error rate in the platoon

ES = Exhaustive Search, GS = Greedy Search
CONCLUSIONS I

- Provide a centralized TDMA approach where dissemination of event-driven messages is assisted by a set of relay nodes
- Give full analysis on the targeted error probability which also includes the best set of relay nodes for a specific dissemination model
CONCLUSIONS II

- Verified by Monte Carlo simulation using the channel model as suggested from literature.
- Evaluate the performance of the proposed scheme, it is useful to determine how a message should be spread within a platoon given a strict time-limit.
- Future works
  - Generalize the probability analysis, not only for distinct relayers
  - Consider other channel models instead of using a stationary matrix $P$
Thank you for your attention