Analysis of Multi-Hop Emergency Message Propagation in Vehicular Ad Hoc Networks

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OUTLINE

- INTRODUCTION
- NETWORK AND CHANNEL MODEL
- THEORETICAL ANALYSIS
- DISCUSSION AND SIMULATION
- CONCLUSIONS
Safety applications are attracting a lot of attention because of improving driver’s awareness of surrounding environment.

We can improve reliability of 1-hop emergency message by devoting more resources to safety-related message dissemination, like setting the transmit power level [13, 14].
Goals of this paper

- Analyze multi-hop emergency message protocols.
- Derive lower bounds on $P(d, t, p)$.
- Investigate the tradeoff between safety-level and emergency message resource wastage.
  - The relative advantage of having an increased $p$ tends to decrease as $d$ increases.
  - The efficacy of increased $p$ displays a clear dependence on the traffic conditions.
NETWORK AND CHANNEL MODEL

- All cars are equally spaced along a line: $S_n(t)$.
- Interference between concurrent transmission.
- Channel model:
THEORETICAL ANALYSIS (1/8)

IDEALIZED strategy:

- Reliability:
  - Turns every internal 0-node into a 1-node with probability $p$ at each round.

- Fast:
  - Every node $i$ such that $i > k$ and $i - k \leq r_t$ assigns probability $p$ of turning into a 1.
Global strategy:

- 1 stage has $h$ rounds, $h = 2$ if $r_t = r_i$, and $h = 3$ if $r_t < r_i \leq 2r_t$.

- Input: $S_n(t)$, output: set $T_h$ of transmitters for round $t + h$. 

\[ \text{Diagram showing transmitters and distances} \]

\[ \text{0……00010011110100111101} \]
THEORETICAL ANALYSIS (3/8)

- IMGlobal strategy:

\[ k(t) \quad S_n(t) \]

\[ \begin{array}{c}
1 \\
\overline{r_t \quad r_i+1}
\end{array} \quad S^2_n(t) \]

\[ \begin{array}{c}
0 \ldots \ldots 0001001111010011101 \\
\overline{r_t \quad r_t \quad r_t \quad r_t \quad r_i}
\end{array} \]
Approximation bounds: \((\alpha, \beta)\)

- \(\alpha\): Gives chance at least \(p/\alpha\) of turning into 1 to all internal 0-nodes at each round.
- \(\beta\): \(E_s(k(t)) \geq \frac{E(k(t))}{\beta}\)

- GLOBAL: \(\left(\frac{p}{1 - \frac{h}{\sqrt{1-p}}}, h\right)\)

- IMGLOBAL: \(\left(\frac{p}{1 - \frac{h}{\sqrt{1-p}}}, 1\right)\)

\[
(1-q)^h \geq (1-p) \quad q \leq 1 - (1 - p)^{\frac{1}{h}}
\]
THEORETICAL ANALYSIS (5/8)
THEORETICAL ANALYSIS (6/8)

- Time-constrained reception probability: \( P(\bar{d}, \bar{t}, p) \)

\[
P(\bar{d}, \bar{t}, p) = \sum_{h=1}^{\bar{t} - \frac{\bar{d}}{r_T}} \text{Prob}(\text{Succ}(p, h)) \cdot \text{Prob}(E\text{Start}(\bar{d}, \bar{t} - h))
\]

- Lower bound of \( \text{Prob}(\text{Start}(d, t)) \):
  \[
  1 - (1 - \bar{p})^h
  \]

  Define \( X(t) = k(t+1) - k(t) \).

\[
E(p, r_T) = \sum_{h=1}^{r_T} h \cdot p \cdot (1 - p)^{r_T - h} = r_T + 1 - \frac{1 - (1 - p)^{r_T + 1}}{p}
\]

\[
V(p, r_T) = \sum_{h=1}^{r_T} h^2 \cdot p \cdot (1 - p)^{r_T - h} - E(p, r_T)^2
= (1 - p) \left[ 1 - (2r_T + 1)p(1 - p)^{r_T} - (1 - p)^{2r_T + 1} \right] / p^2
\]
\[ \mathbf{X} = \sum_{i=1}^{k} X_i \]

\[ \text{Prob}(\mathbf{X} \leq E(\mathbf{X}) - \lambda) \leq e^{-\frac{\lambda^2}{2 \cdot \sum_{i=1}^{k} E(X_i^2)}}, \text{ for any } \lambda > 0 \]

\[ \text{Prob}(\mathbf{k}(t) \leq t \cdot E(p, r_T) - \lambda) \leq e^{-\frac{\lambda^2}{2 \cdot t \cdot E(\mathbf{X}(t)^2)}} \]

\[ \text{Prob}(\text{Start}(\bar{d}, \bar{t})) = \text{Prob}(\mathbf{k}(\bar{t}) > \bar{d} - 1) \]

\[ \text{Prob}(\mathbf{k}(\bar{t}) > \bar{t} \cdot E(p, r_T) - (\bar{t} \cdot E(p, r_T) - \bar{d} + 1)) \]

\[ \bar{t} > \frac{\bar{d} - 1}{E(p, r_T)}. \text{ Then,} \]

\[ \text{Prob}(\text{Start}(\bar{d}, \bar{t})) \geq 1 - e^{-\frac{(\bar{t}E(p, r_T) - \bar{d} + 1)^2}{2\bar{t}E(\mathbf{X}(t)^2)}} \]

\[ \lambda > 0 \]
THEORETICAL ANALYSIS (7/8)

- Upper bound of $t$:

$$\min\{\bar{t} : P(\bar{d}, \bar{t}, p) \geq \bar{P}\} \leq t_{min}(\bar{d}, p)$$
THEORETICAL ANALYSIS

Define \( \bar{h} = \left[ \frac{\ln(1-\sqrt{P})}{\ln(1-p)} \right] \)

\[ P(1 - e^{-\frac{((\bar{t}-\bar{h}) \cdot E(p, r_T) - \bar{d} + 1)^2}{2(\bar{t}-\bar{h}) \cdot E(X(t)^2)}}) \geq \sqrt{P} \quad E_{\text{Start}}(\bar{d}, \bar{t} - h) \]

\[ t_{\min}(\bar{d}, p) = \frac{\bar{h}E(p, r_T)^2 + (\bar{d} - 1)E(p, r_T) - E((X(t)^2) \ln (1 - \sqrt{P}) + \sqrt{E((X(t)^2) \ln (1 - \sqrt{P}) \cdot (-2\bar{d}E(p, r_T) + 2E(p, r_T) + E((X(t)^2) \ln (1 - \sqrt{P})}}}{E(p, r_T)^2} \]

\[ \geq \sqrt{P} \cdot \sum_{h=\bar{h}} \text{Prob}(E_{\text{Start}}(\bar{d}, \bar{t} - h)) = \sqrt{P} \cdot \text{Prob}(\text{Start}(\bar{d}, \bar{t} - \bar{h})) \]

\[ \geq \sqrt{P} \]
DISCUSSION AND SIMULATION (1/3)

- Dependence on distance:

<table>
<thead>
<tr>
<th></th>
<th>dist.</th>
<th>$t_{\text{min}}$, $p = 0.5$</th>
<th>$t_{\text{min}}$, $p = 0.9$</th>
<th>% reduction</th>
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<tbody>
<tr>
<td>Heavy traffic</td>
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Values of $t_{\text{min}}$ for fixed values of $p$ and varying values of $d$. Medium traffic scenario
DISCUSSION AND SIMULATION (2/3)

- Dependence on traffic conditions:

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DISCUSSION AND SIMULATION (3/3)

Upper bound is accurate.

When p is high, IMGLOBAL performs as IDEALIZED.
CONCLUSIONS

- Beneficial effect of Increased 1-hop reliability tends to decrease as the distance from the initiator increases.
- Benefit on multi-hop reliability of having high 1-hop reliability tends to decrease as car density increases.
- The dissemination strategy has a major impact on multi-hop reliability, especially when $p$ is high, fast backward is more important.