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

INTRODUCTION(1/2)

- Safety applications are attracting a lot of attention because of improving driver's awareness of surrounding environment.

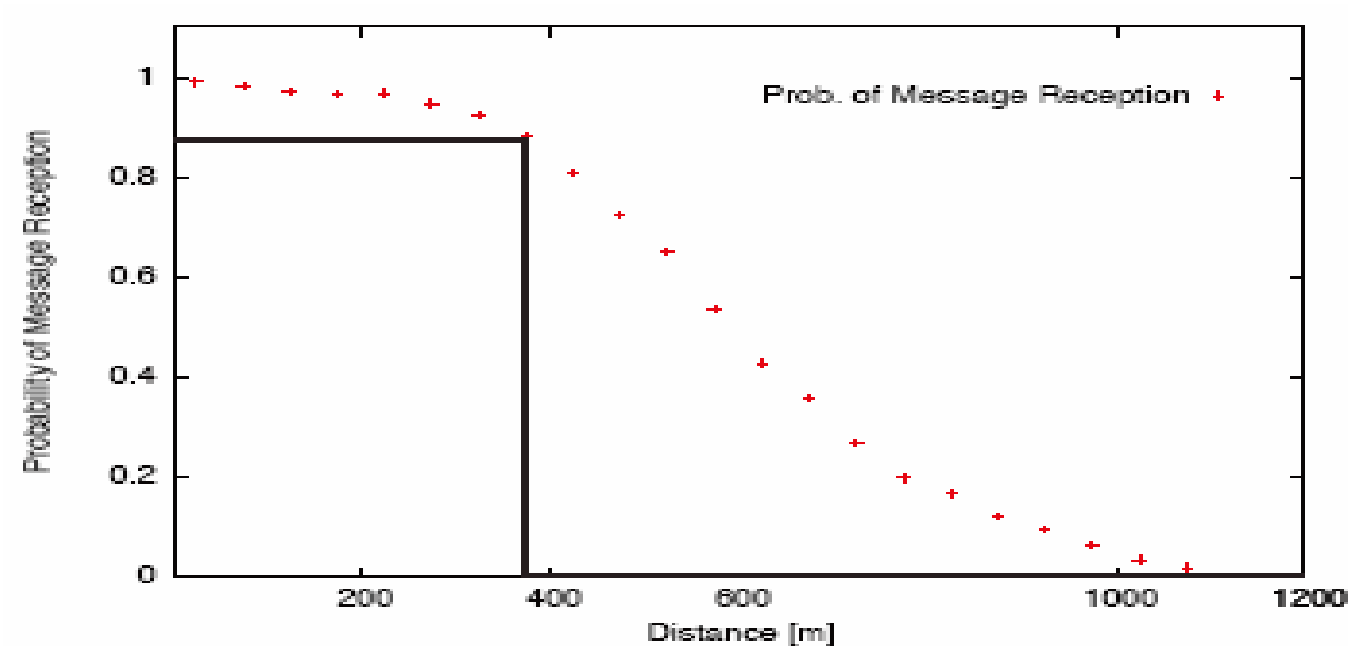
- We can improve reliability of 1-hop emergency message by devoting more resources to safety-related message dissemination, like setting the transmit power level [13, 14].

INTRODUCTION(2/2)

- 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**.

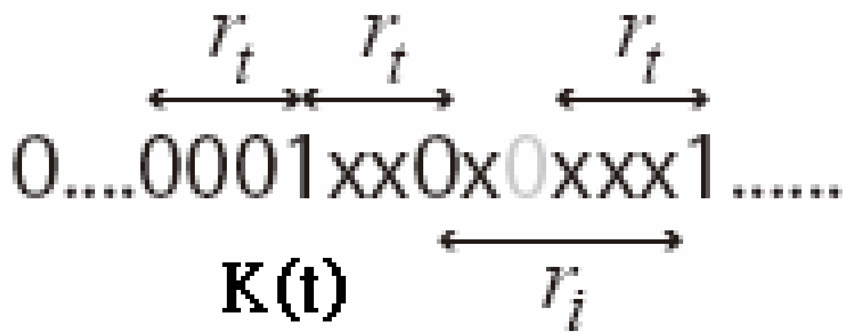
NETWORK AND CHANNEL MODEL

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



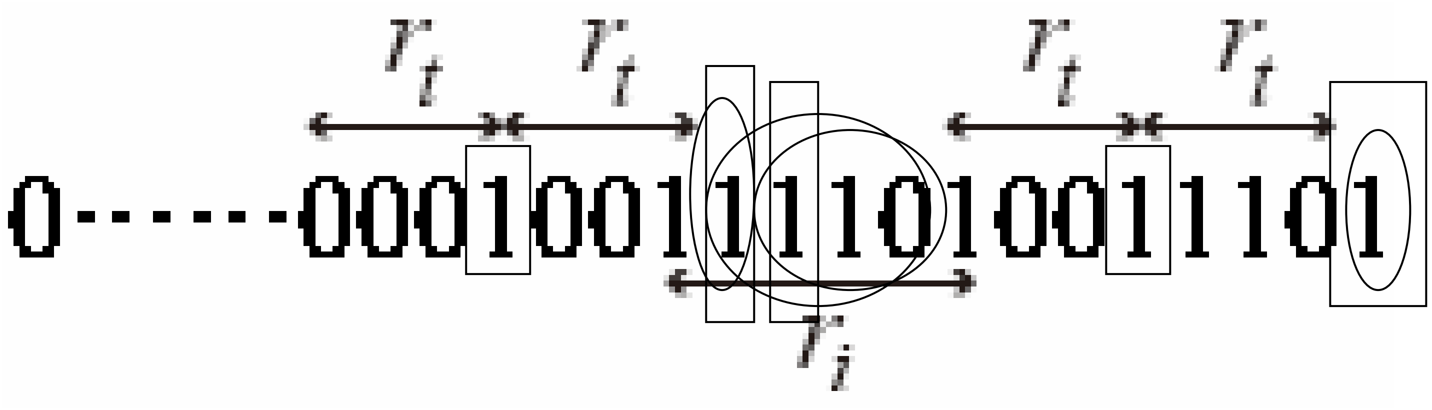
THEORETICAL ANALYSIS(1/8)

- 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.**



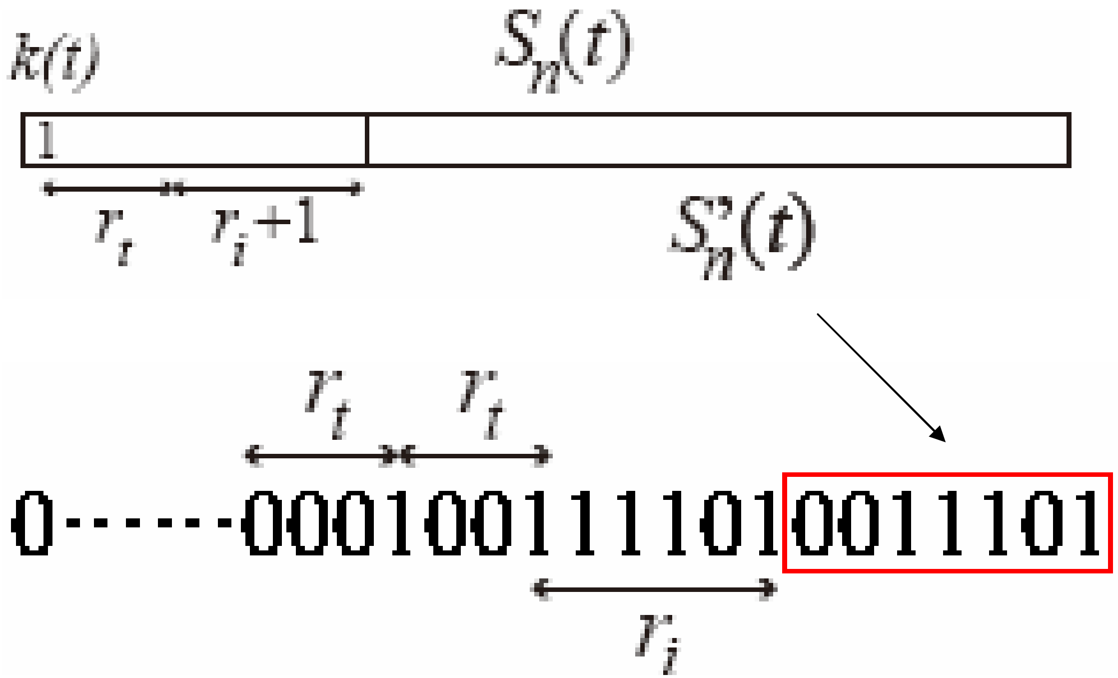
THEORETICAL ANALYSIS(2/8)

- Global strategy：
  - 1 stage has h rounds, h = 2 if $r_t = r_i$, and h = 3 if $r_t < r_i \le 2r_t$.
  - Input： $S_n(t)$,output：set T_h of transmitters for round t + h.



THEORETICAL ANALYSIS(3/8)

- IMGlobal strategy：



THEORETICAL ANALYSIS(4/8)

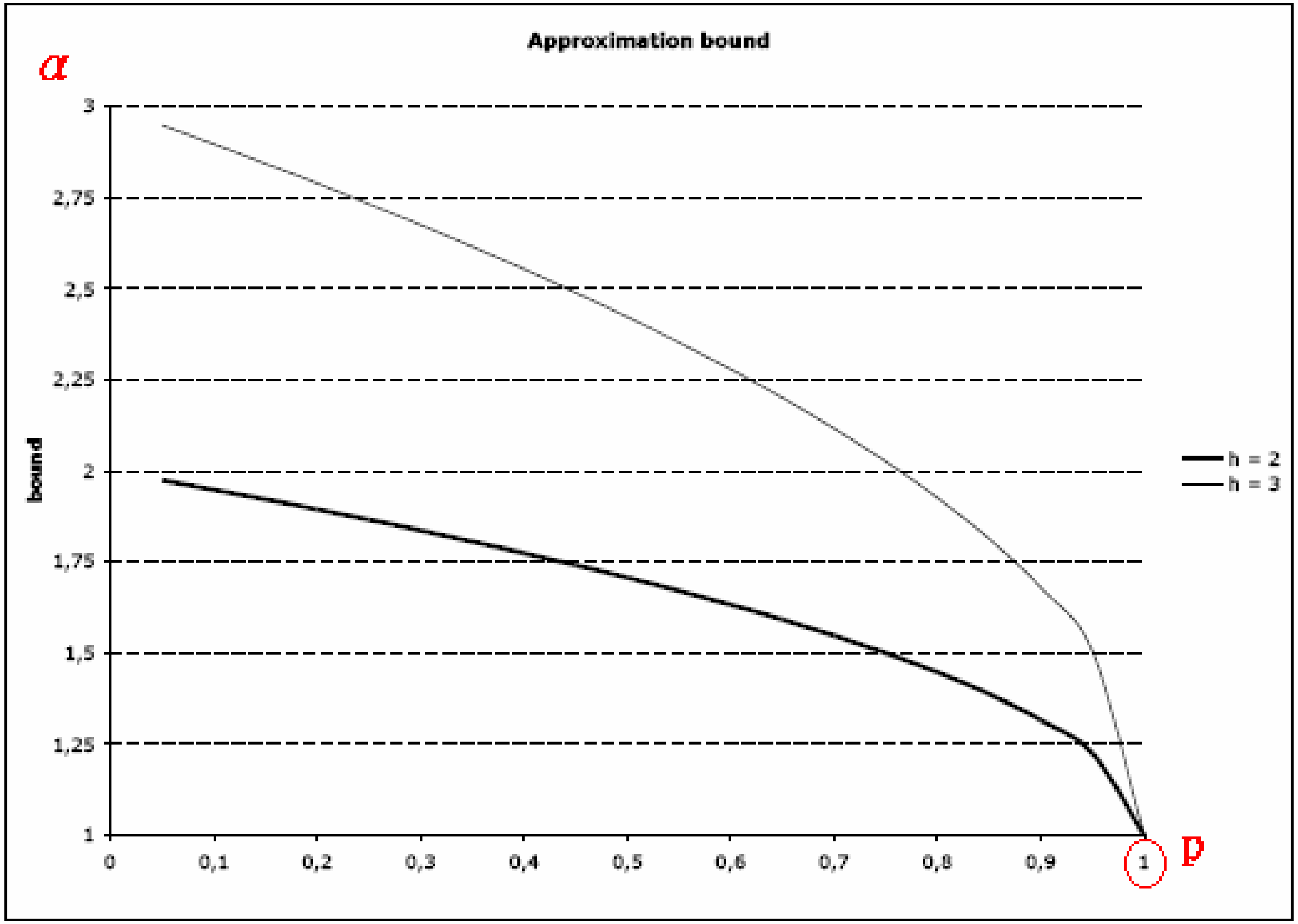
- Approximation bounds：(α , β)
  - α ：Gives chance at least p/ α of turning into 1 to all internal 0-nodes at each round.
  - β ：$E_s(k(t)) \geq \frac{E(k(t))}{\beta}$
  - GLOBAL：$\left(\frac{p}{1-\sqrt[h]{1-p}}, h\right)$ ←

$$(1-q)^h \geq (1-p)$$

$$q \leq 1-(1-p)^{\frac{1}{h}}$$

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

THEORETICAL ANALYSIS(5/8)



THEORETICAL ANALYSIS(6/8)

- Time-constrained reception probability：P(d,t,p)

$$P(\bar{d},\bar{t},p) = \sum_{h=1}^{\bar{t}-\frac{\bar{d}}{r_T}} \boxed{Prob(Succ(p,h))} \cdot Prob(EStart(\bar{d},\bar{t}-h))$$

$$\boxed{1-(1-\bar{p})^h}$$

- Lower bound of Prob(Start(d,t))：
  - Define X(t) = k(t+1) - k(t).

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

$$V(p,r_T) = \sum_{h=1}^{r_T} h^2 \cdot p \cdot (1-p)^{r_T-h} - E(p,r_T)^2$$

$$= (1-p)\left[1-(2r_T+1)p(1-p)^{r_T} - (1-p)^{2r_T+1}\right]/p^2$$

$$\mathbf{X} = \sum_{i=1}^{k} X_i$$

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

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

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

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

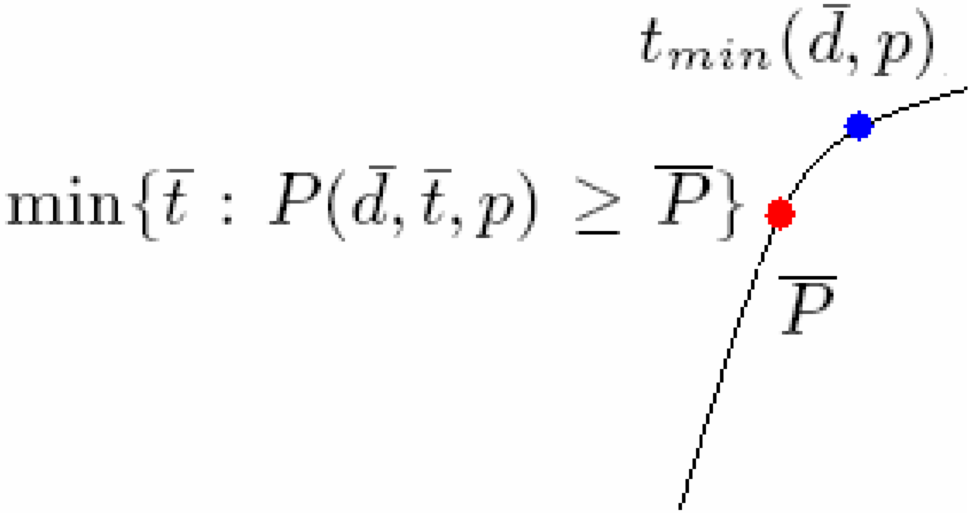
$$\lambda > 0$$

$\bar{t} > \frac{\bar{d}-1}{E(p,r_T)}$. *Then,*

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

THEORETICAL ANALYSIS(7/8)

- Upper bound of t : $\min\{\bar{t} : P(\bar{d}, \bar{t}, p) \geq \overline{P}\} \leq t_{min}(\bar{d}, p)$



THEORETICAL ANALYSIS(8/8)

- Define $\bar{h} = \left\lceil \frac{\ln(1-\sqrt{P})}{\ln(1-p)} \right\rceil \longrightarrow Prob(Succ(p,h)) \geq \sqrt{P}$ for each $h \geq \bar{h}$.

$$P(\quad 1 - e^{-\frac{((\bar{t}-\bar{h})\cdot E(p,r_T)-\bar{d}+1)^2}{2(\bar{t}-\bar{h})\cdot E(\mathbf{X}(t)^2)}} \geq \sqrt{P} \quad EStart(\bar{d}, \bar{t} - h))$$

$$\bar{t} - \frac{\bar{d}}{r_T}$$

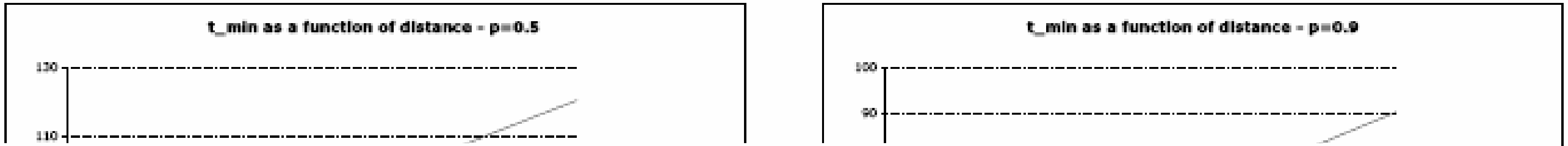
$$t_{min}(\bar{d}, p) = \frac{\bar{h}E(p,r_T)^2 + (\bar{d}-1)E(p,r_T) - E((\mathrm{X}(t)^2)\ln\left(1-\sqrt{\bar{P}}\right) + \sqrt{E((\mathrm{X}(t)^2)\ln\left(1-\sqrt{\bar{P}}\right)\left(-2\bar{d}E(p,r_T) + 2E(p,r_T) + E((\mathrm{X}(t)^2)\ln\left(1-\sqrt{\bar{P}}\right)\right)}}{E(p,r_T)^2}$$

$$\geq \sqrt{P} \cdot \sum_{h=\bar{h}}^{\bar{t}-\frac{u}{r_T}} Prob(EStart(\bar{d}, \bar{t} - h)) = \sqrt{P} \cdot \boxed{Prob(Start(\bar{d}, \bar{t} - \bar{h}))}$$

$$\geq \sqrt{P}$$

DISCUSSION AND SIMULATION(1/3)

- Dependence on distance：



	dist.	t_{min}, $p = 0.5$	t_{min}, $p = 0.9$	% reduction
Heavy traffic	$600m$	$411.4ms$	$280.43ms$	31.8%
	$1500m$	$525.61ms$	$382.76ms$	27.2%
Medium traffic	$600m$	$441.93ms$	$281.19ms$	36.4%
	$1500m$	$572.23ms$	$385ms$	32.7%
Light traffic	$600m$	$502.39ms$	$283.77ms$	43.5%
	$1500m$	$662.69ms$	$390.77ms$	41%

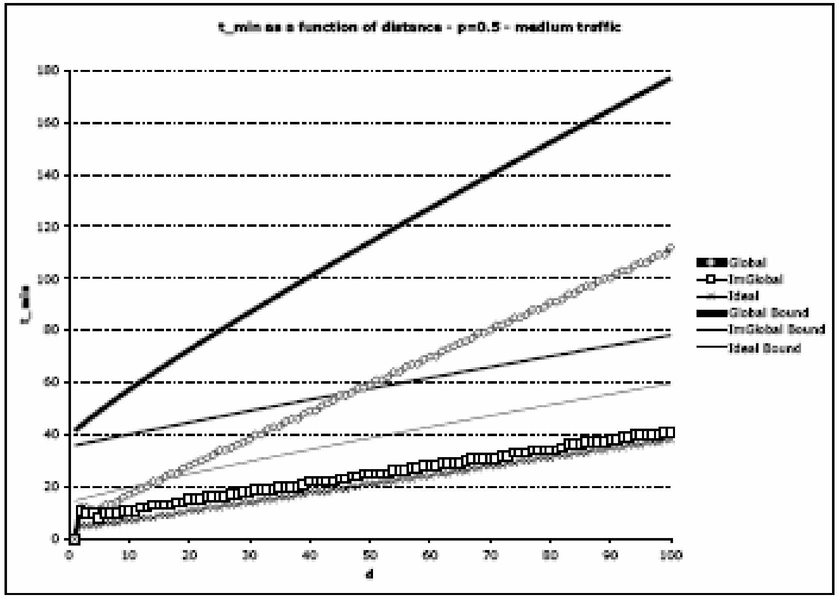
Values of t_{min} for fixed values of p and varying values of $\bar{d}$. Medium traffic scenario

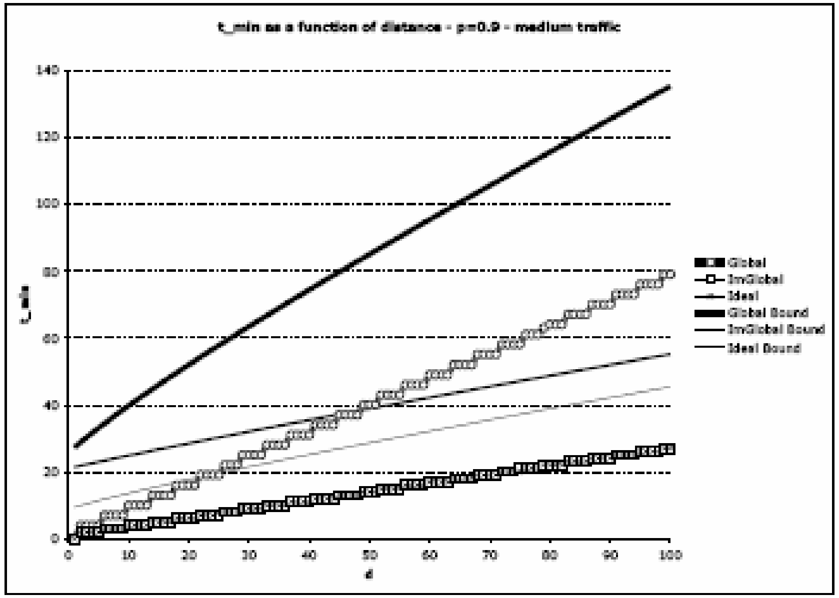
DISCUSSION AND SIMULATION(2/3)

- Dependence on traffic conditions：

	dist.	t_{min}, $p = 0.5$	t_{min}, $p = 0.9$	% reduction
Heavy traffic	600m	411.4ms	280.43ms	31.8%
	1500m	525.61ms	382.76ms	27.2%
Medium traffic	600m	441.93ms	281.19ms	36.4%
	1500m	572.23ms	385ms	32.7%
Light traffic	600m	502.39ms	283.77ms	43.5%
	1500m	662.69ms	390.77ms	41%

DISCUSSION AND SIMULATION(3/3)





Values of t_{min} for fixed values of p and varying values of $\bar{d}$. Medium traffic scenario.

- 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.