Vehicular Transmission Reliability over Blind Intersections

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Vehicular Transmission Reliability over Blind Intersections

Mouhamed Abdulla and Henk Wymeersch

Vehicle-to-vehicle (V2V) communication can improve road safety and traffic efficiency, particularly around critical areas such as intersections. We analytically derive V2V success probability near an urban intersection, based on empirically supported line-of-sight (LOS), weak-line-of-sight (WLOS), and non-line-of-sight (NLOS) channel models. The analysis can serve as a preliminary design tool for performance assessment over different system parameters and target performance requirements. The most interesting outcome of this research is the ability to design the network and explicitly quantify the tolerated number of simultaneous transmissions that could occur at the same time-frame of the wanted transmission, while still meeting the pre-determined target reliability. Meanwhile, we will also discuss means to determine the fraction of vehicular traffic realizations that achieve the target reliability. This is a more granular finely detailed analysis, and it will basically builds on the results presented earlier.

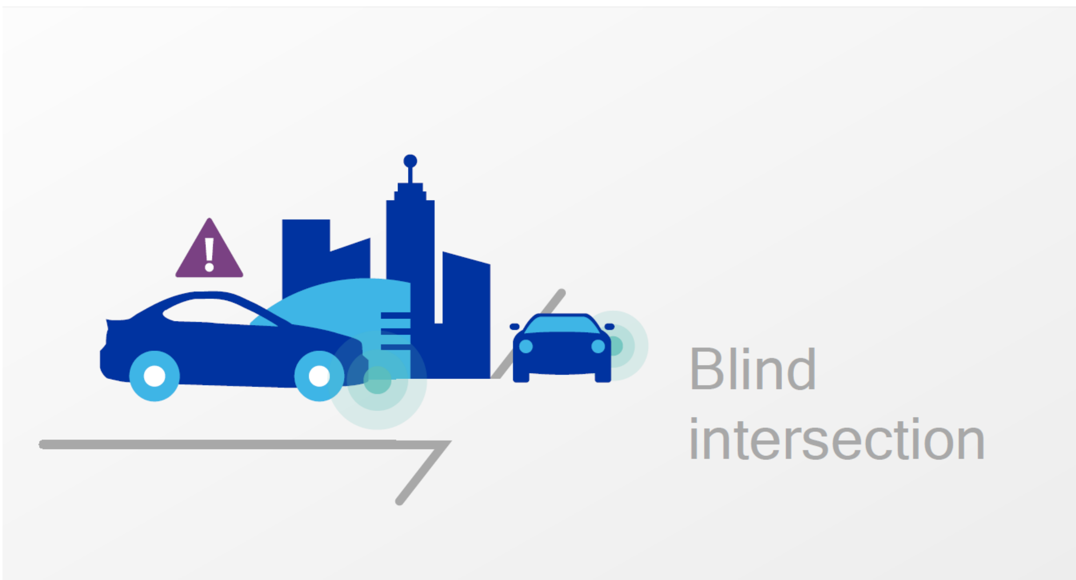

Fig. 1. Blind intersections are estimated to cause $\sim 47\%$ of all accidents. V2x can overcome this challenge, since packet reliability can lead to road-safety.

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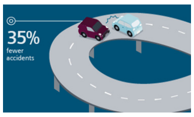
CHALMERS UNIVERSITY OF TECHNOLOGY

MARSS-5G
European Commission Project

Motivation

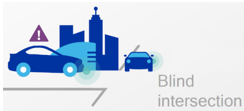
5G Use-Cases

V2x Communications



packet reliability
↓
road-safety

Intersections/Corners



~ **47%** of all accidents

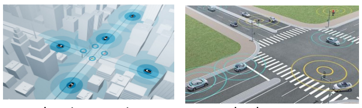
Target Reliability

reliability ≤ 10^{-5}

Vehicle to Vehicle
transmission distance ~ **100m** [urban]
~ **200m** [suburban]

Research Questions

1. How to **quantify/evaluate** V2V **packet reliability** in blind intersections?
2. How to **design vehicle ad hoc network (VANET)** to meet a fail-safe target reliability?
3. How to go beyond **misleading averages** and explicitly study **reliability of each vehicular traffic realization**?



urban intersection　　suburban corner

*our research attempts to **uncover** the collection of these important **unknowns**!*

Quantifying Reliability

$$\mathcal{P}_c(\beta, \mathbf{x}_{tx}, \mathbf{x}_{rx}) = \mathcal{P}_{\text{noint}}\mathcal{P}_x\mathcal{P}_y$$

system parameters	
transmit probability	p_I
transmit power	P_o
AWGN floor	N_o
RX sensitivity	β

TX/RX Geometry	
TX position	$\mathbf{x}_{tx}$
RX position	$\mathbf{x}_{rx}$

propagation parameters	
operating frequency	f_o
reference distance	d_o
break-point distance	$\triangle$
path loss (PL) exponent	α
PL coefficient for LOS/WLOS	A_o
PL coefficient for NLOS	A'_o

dimensions and traffic	
road dimensions	R_x, R_y
vehicular traffic	λ_x, λ_y

horizontal interferers

$$\mathcal{P}_x = \exp(-p_I\lambda_x\zeta\mathcal{X}(R_x))$$

vertical interferers

$$\mathcal{P}_y = \exp(-2p_I\lambda_y\zeta\mathcal{Y}(R_y))$$

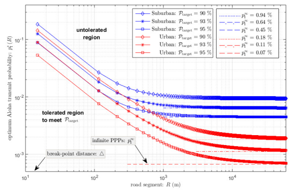
road segment　path loss exponent　Gauss's hypergeometric

Network Design

- road dimension: $R \geq \triangle$ (channel: breakpoint distance)
- target reliability: $\mathcal{P}_{\text{target}} < \mathcal{P}_{\text{noint}}$ (success probability (with no interference))
- requirements: $\mathcal{P}_{\text{noint}}\mathcal{P}_x\mathcal{P}_y \geq \mathcal{P}_{\text{target}}$ (success probability; worst-case scenario)
- design guidelines:

$$p_I^*(R) = \frac{-\beta N_o/(P_o\ell(\mathbf{x}_{tx}, \mathbf{x}_{rx})) - \ln(\mathcal{P}_{\text{target}})}{\zeta\lambda(\mathcal{X}(R) + 2\mathcal{Y}(R))}$$

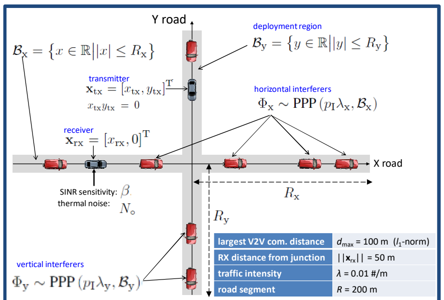
input #2　input #1



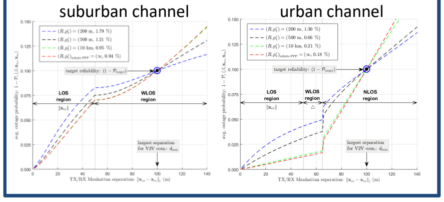
$p_I \leq p_I^*(R)$

transmit probability　optimum

Average Reliability

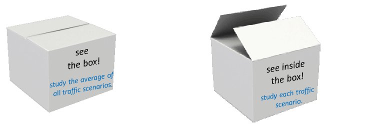


largest V2V com. distance	d_{max} = 100 m (l_1-norm)
RX distance from junction	$\lVert\mathbf{x}_{rx}\rVert$ = 50 m
traffic intensity	λ = 0.01 #/m
road segment	R = 200 m



Meta Distribution

basic analysis (averages)　　**advanced granular analysis** (Palm Calculus)

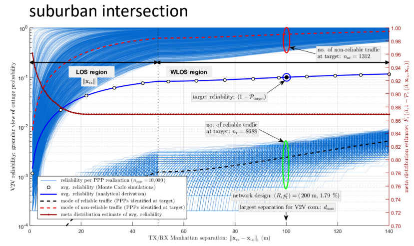


$\mathbb{P}(\text{SINR} < \beta) \leq p$　　$F_r(\beta, p) = \mathbb{P}^o(\mathbb{P}(\text{SINR} < \beta \mid \Phi_x \cup \Phi_y) \leq p)$

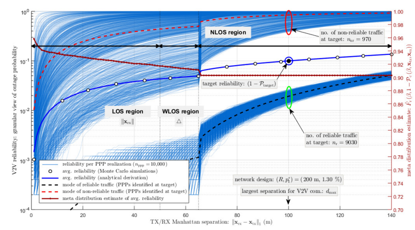
$$\bar{F}_{P_s}(x) = \frac{1}{2} - \frac{1}{\pi}\int_0^\infty \frac{e^{-C\Gamma(1+\delta)\Re(D_{jt})}\sin(t\log x + C\Gamma(1+\delta)\Im(D_{jt}))}{t}dt$$

Fine-Grained Reliability

suburban intersection



urban intersection

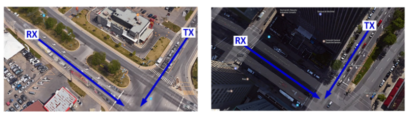


System Parameters

target reliability	$\mathcal{P}_{target}$ = 0.9
transmit power	P_o = 20 dBmW
AWGN floor	N_o = − 99 dBmW
RX sensitivity	β = 8 dB

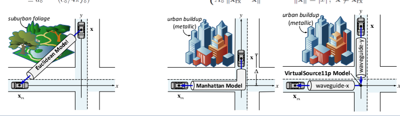
Channel Propagation

suburban channel　　urban channel



suburban channel	
operating frequency	f_0 = 5.9 GHz
reference distance	d_0 = 10 m
path loss (PL) exponent	α = 2.0
PL for LOS/WLOS	A_0 = − 17.86 dBm

urban channel	
operating frequency	f_0 = 5.9 GHz
reference distance	d_0 = 10 m
break-point distance	$\triangle$ = 15 m
path loss (PL) exponent	α = 1.68
PL for LOS/WLOS	A_0 = − 21.06 dBm
PL for NLOS	A'_0 = − 6.8 dBm



Conclusion

- ❑ Metrics for packet reliability are necessary for network analysis & design.
- ❑ Traditional metrics based on averages are not precise enough for ultra-reliable and delay-sensitive applications such as V2x com.
- ❑ Fine-grained reliability per traffic realization reveals a bimodal distribution outcome.
- ❑ Smaller road-segment "R" results in a more polarized reliability outcome.
- ❑ This striking revelation would have never been obvious by simply exploring averages for reliability.

European Commission　MARIE CURIE ACTIONS　erc European Research Council　HIGHTS　SAFER VEHICLE AND TRAFFIC SAFETY CENTRE AT CHALMERS　ERICSSON　VINNOVA