

Enabling Efficient and Accurate Large-Scale Simulations of VANETs for Vehicular Traffic Management

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- » Many papers on Vehicular Ad Hoc Networks (VANETs) that intend to optimize QoS-parameters like ‘packet delivery ratio’
- » Our claim: There is a need to prove the impact of VANETs in metrics directly related to the aimed goals

‘Traffic Safety’ and ‘Traffic Efficiency’

- » Simulations will be the first method to accomplish this task
- » This paper addresses the problem of realizing efficient and large-scale simulations of VANETs to evaluate the impact on ‘traffic efficiency’

» Traffic management

- Evaluate effects on traffic behavior
- Results should be available “in time”

» Conduct simulations

- VISSIM: traffic simulator
- NS-2: discrete-event network simulator

» Problem:

- Large-scale discrete-event network simulations are computational much too intensive



» Possible remedy: Hybrid simulation

- Well known since the 1970s

“By combining, in a hybrid model, discrete-event network simulation and mathematical modeling, we are able to achieve a high level of agreement with the results of an equivalent simulation-only model, at a significant reduction in computational costs.”

Schwetman, 1978

» Idea is already present in today’s packet-level network simulators, e.g., *radio wave propagation*

- No simulation of various path
- Execution of macroscopic model

» Separate data traffic

- Traffic belonging to application under evaluation
- Traffic constituting ‘background noise’ on channel

» Examples

- Emergency messages for active safety
 - Background data traffic: beacon messages
- Application in urban environments
 - Background data traffic: commercial advertisements (e.g., Hotel, Fast Food, etc.)

» Background data traffic impairs evaluation of application

» Save computation time via hybrid simulation: instead of simulating background data traffic use accurate model

Outline

- 1. Cost analysis of large-scale discrete-event network simulations**

- 2. Statistical model**
 - a. Derivation**
 - b. Evaluation**

- 3. Simulation architecture**
 - a. Hybrid simulation**
 - b. First large-scale scenario**

- 4. Summary & Conclusion**

1. Cost analysis of large-scale discrete-event network simulations

» Runtime performance related to number of scheduled events

- Communication events (e.g., transmission of a packet) need to be considered at each potential receiver
- Number of events depends on the amount of packets to be transmitted and on the density of nodes

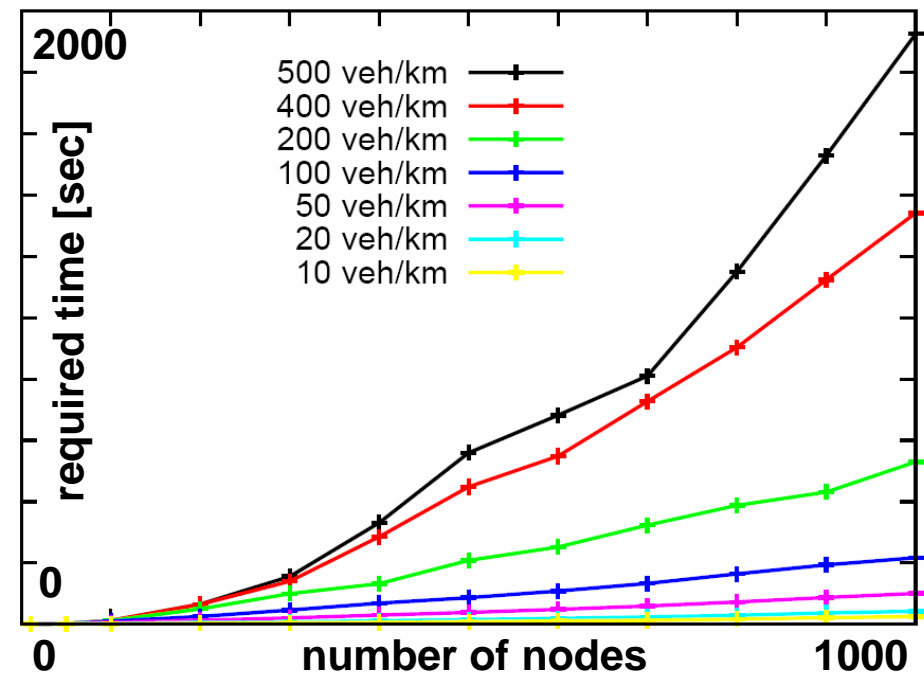
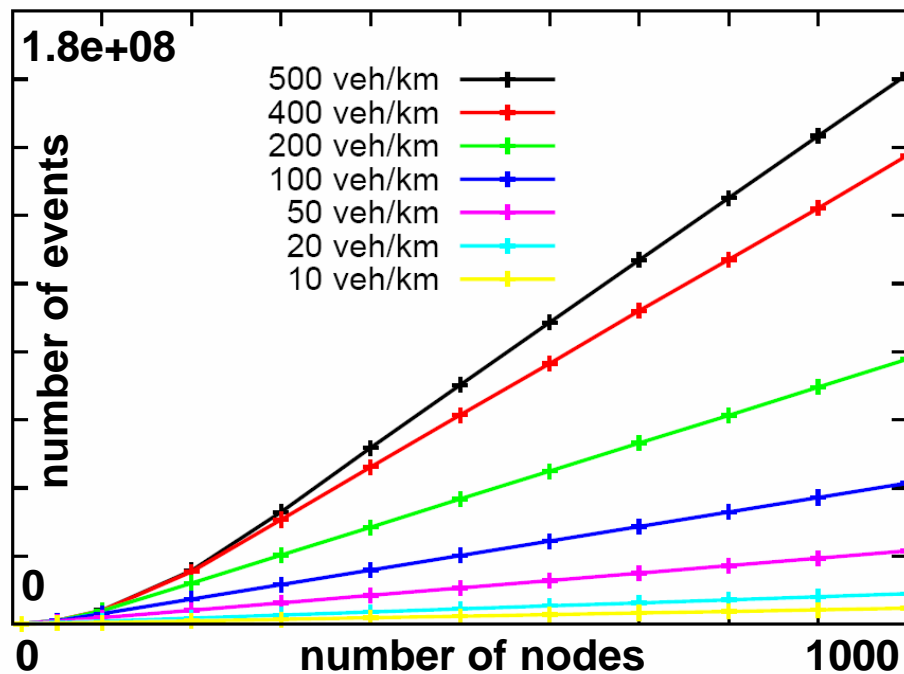
» How much background data traffic do we expect?

- Depending on the number of vehicles in the surrounding
- Traffic densities up to 400 vehicles per km
 - Traffic jam
 - 3 lanes highway

1. Cost analysis of large-scale discrete-event network simulations

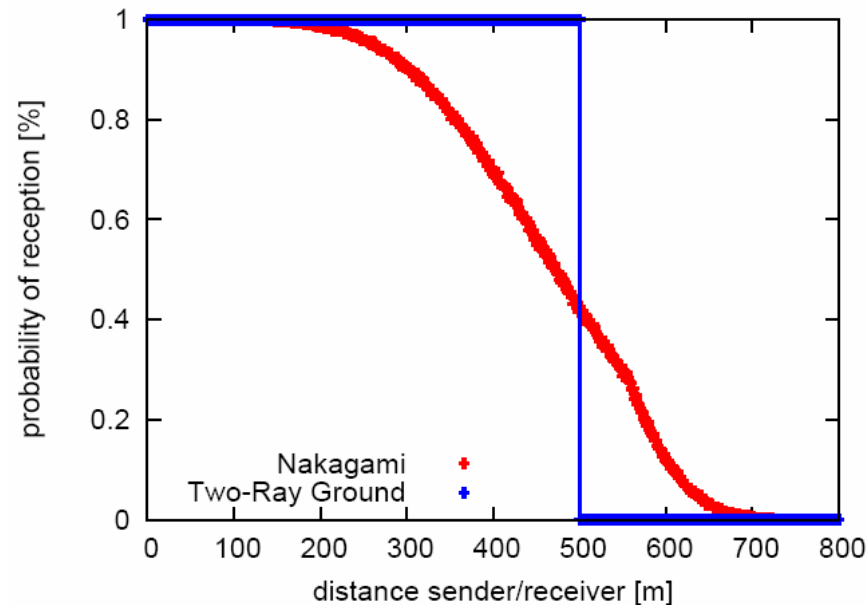
II

» NS-2 example: 100sec, 1 packet (500 bytes) per second and node, varying traffic densities on a straight lane, IEEE 802.11p



2. Statistical model – Assumptions

- » ***Nakagami m-distribution*** seems to be a suitable model for the radio propagation in VANETs [Taliwal et al. VANET'04]



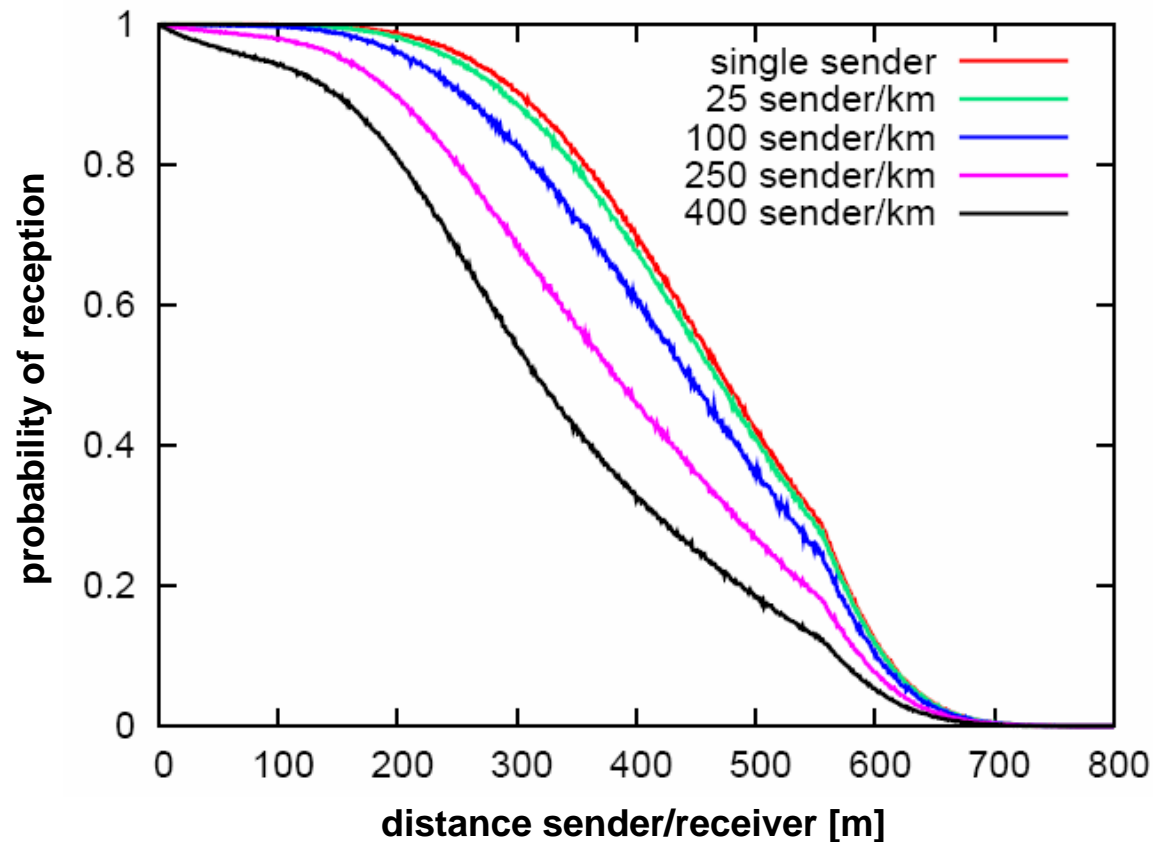
» ***Nakagami*** model

- Average power according to deterministic Free space/Two-ray model
- Additional fast-fading component
→ probability distribution of reception power

2. Statistical model

» We look at application data traffic

» What is the impact of ‘background data traffic’?



Several simulation runs:

extended ns-2.31,
nodes on a straight lane,
IEEE 802.11p,
1 packet (500 bytes) per second
and node

Goal:

find analytical term for
‘probability of reception’
taking account for varying
traffic densities

2. Statistical model – derivation

I

» Easy case: single sender

- No interferences from packet collisions
- Limited CSMA/CA mechanisms
- Probability of packet reception derives from probabilistic radio propagation

» Nakagami m-distribution (here: $m = 3$)

- For distance d smaller than crossover distance

$$P_R(d, \omega) = e^{-3\left(\frac{d}{\omega}\right)^2} \left(1 + 3\left(\frac{d}{\omega}\right)^2 + \frac{9}{2}\left(\frac{d}{\omega}\right)^4 \right)$$

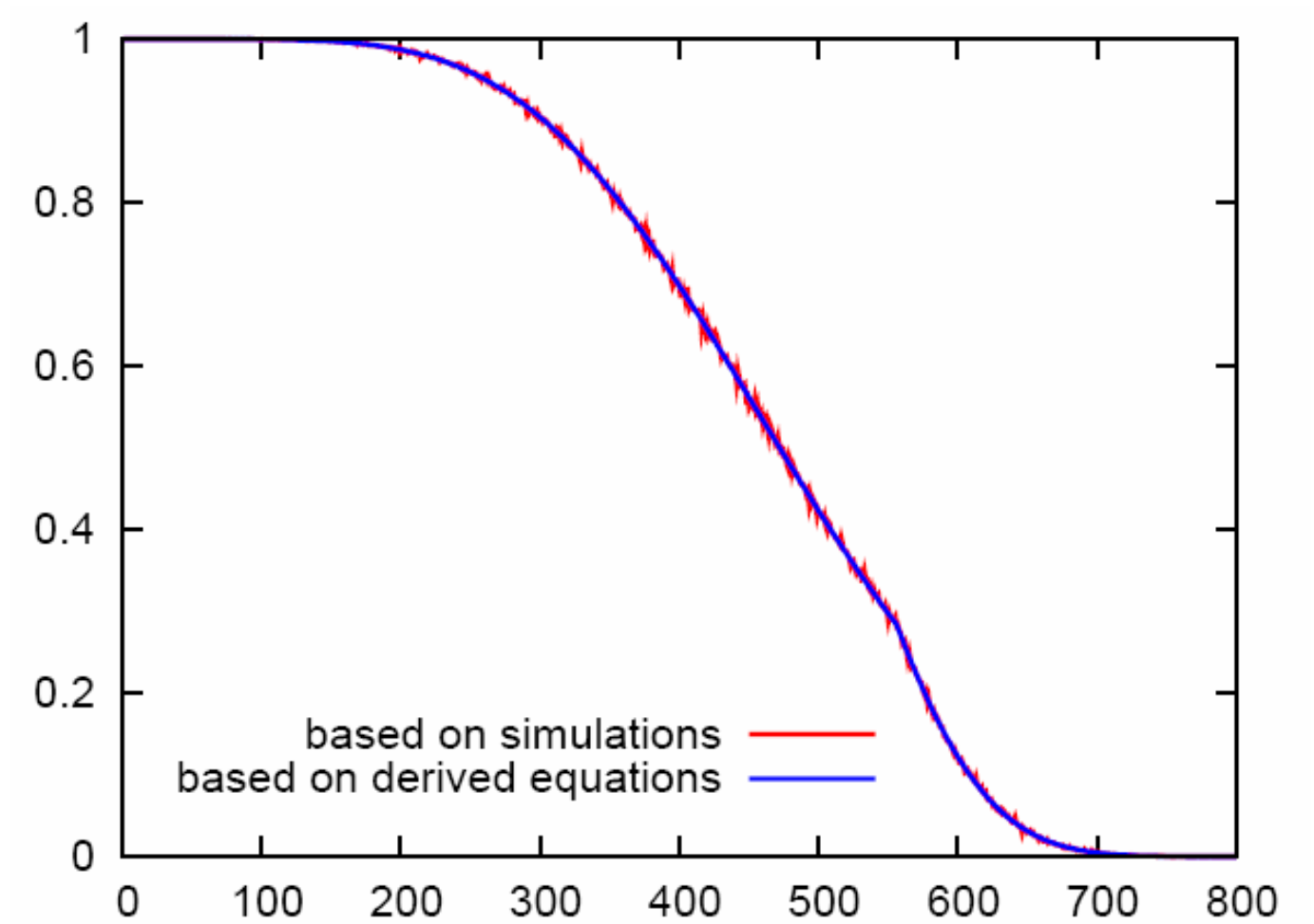
- For d greater than crossover distance

$$P_R(d, \omega) = e^{-3\gamma\left(\frac{d^2}{\omega}\right)^2} \left(1 + 3\gamma\left(\frac{d^2}{\omega}\right)^2 + \frac{9}{2}\gamma^2\left(\frac{d^2}{\omega}\right)^4 \right)$$

γ depends on the antenna heights and on the radio wavelength

2. Statistical model – derivation

I



2. Statistical model – derivation

II

» More difficult: many senders

- Several effects determine probability of reception: packet collisions, radio propagation, hidden terminal, etc.

» Nonlinear curve fitting to each simulated traffic density

- ‘Nakagami-equation’ extended to 4th polynomial
- Fitting variables x_1 through x_4

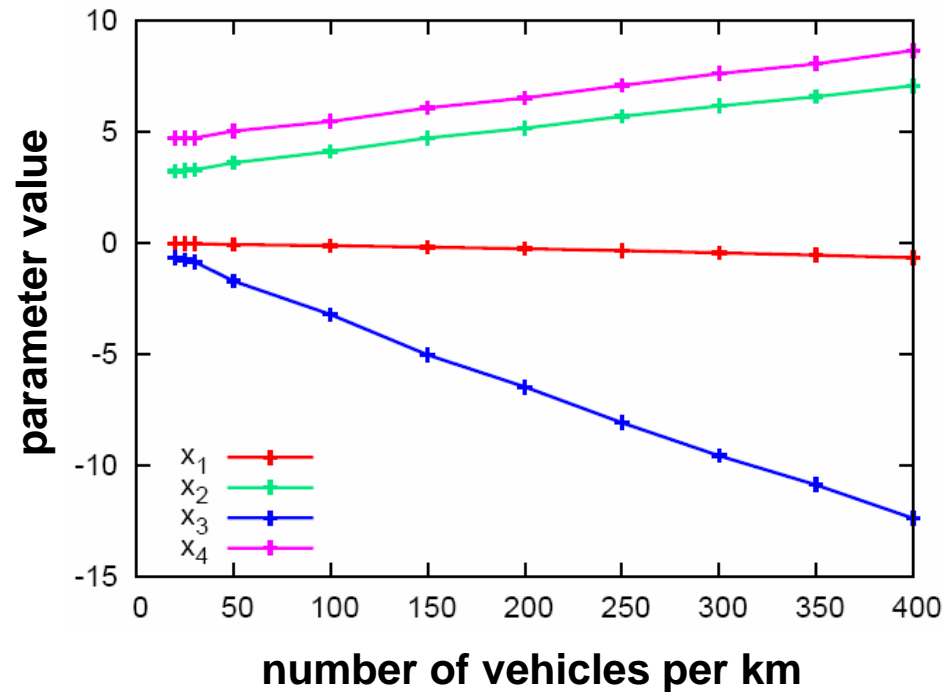
$$\tilde{P}_R(d, \omega) = e^{-3\left(\frac{d}{\omega}\right)^2} \left(1 + \sum_{i=1}^4 x_i \left(\frac{d}{\omega}\right)^i\right)$$

» In dependency of the traffic density x_1 through x_4 show linear behavior

2. Statistical model – derivation

II

$$\tilde{P}_R(d, \omega) = e^{-3\left(\frac{d}{\omega}\right)^2} \left(1 + \sum_{i=1}^4 x_i \left(\frac{d}{\omega}\right)^i\right)$$



» Deviation between approximation and simulation results

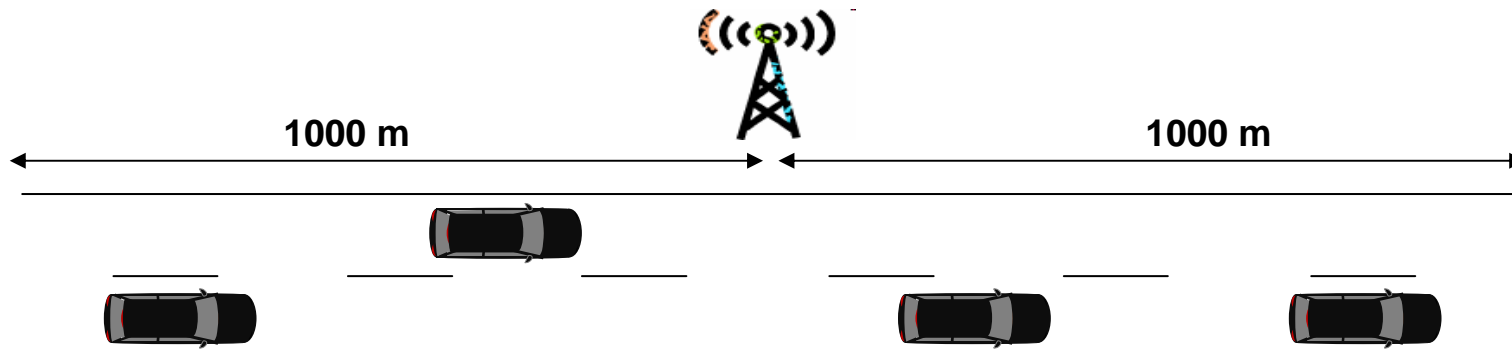
- Average error of 0.25%, maximum error 2.5%

2. Statistical model – evaluation

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» Simulation using statistical model integrated into VISSIM

- Presented on following slides



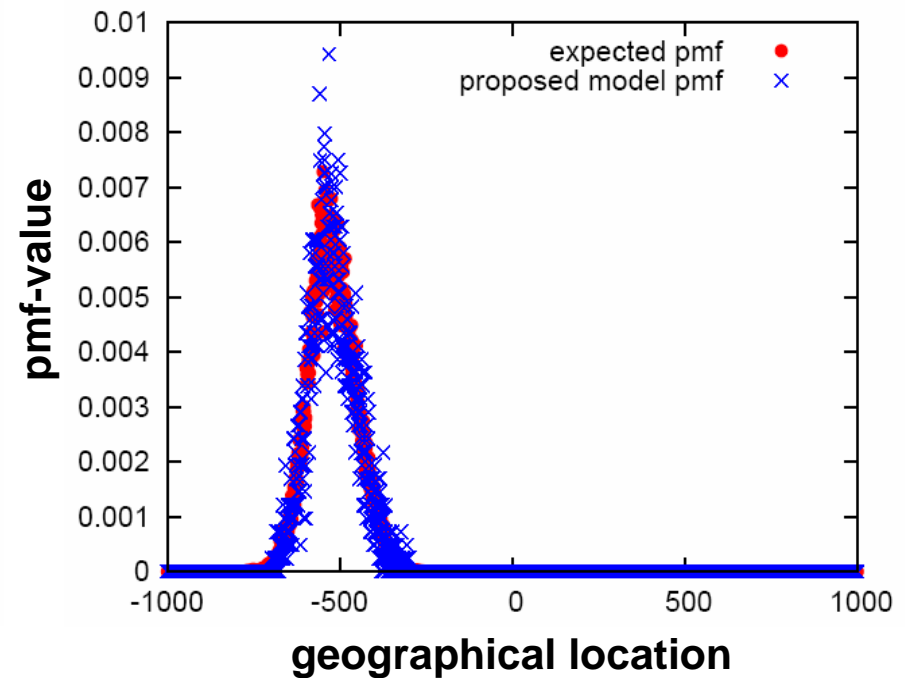
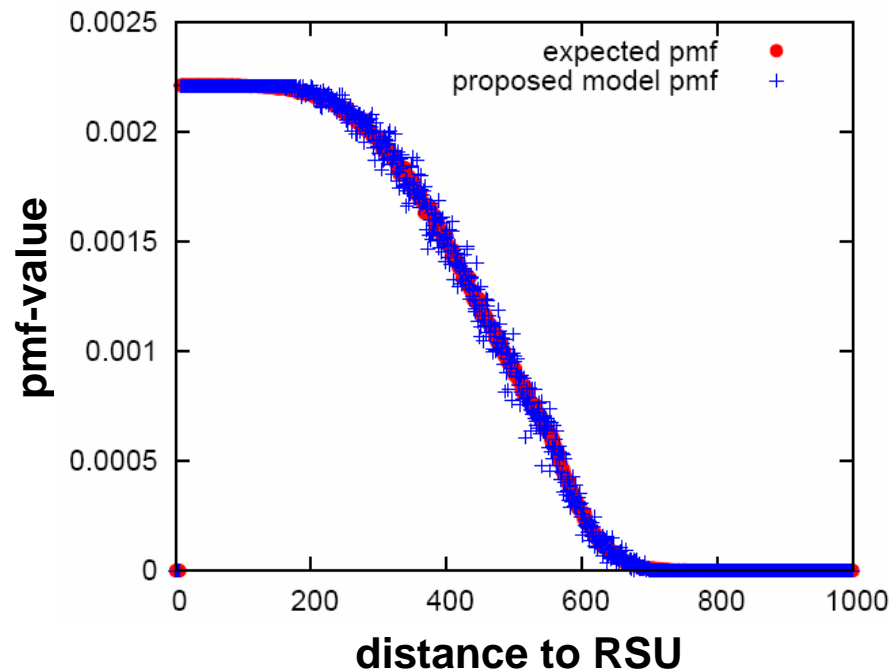
» Simulation details

- 10.000 sec
- 23 veh/km in average each broadcasting 1 packet (500 byte) per second
- Average velocity 128 km/h
- RSU sends out 500 byte message once per second

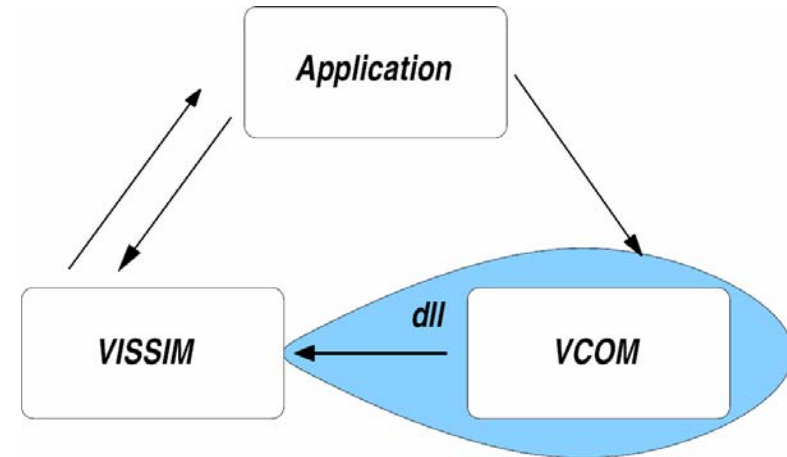
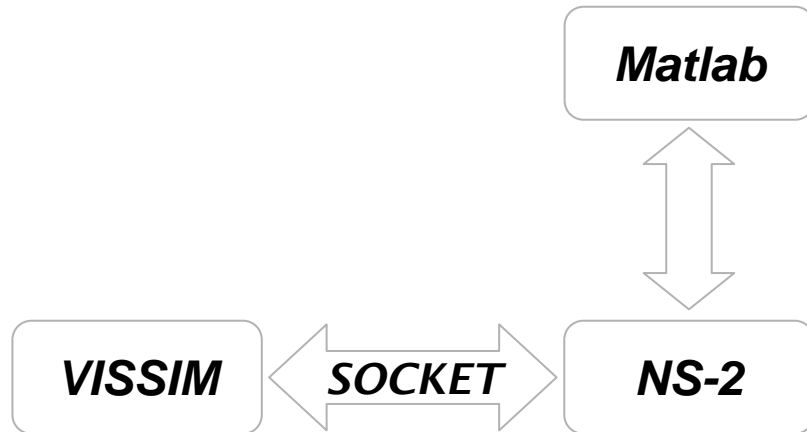
2. Statistical model – evaluation

II

- » First evaluation: message reception w.r.t. the distance
- » Second evaluation: location of first message reception



3. Simulation architecture



» Previous proposals

- Coupling of traffic and communication simulator
- E.g., VISSIM and NS-2
[Lochert et al. VANET'05]

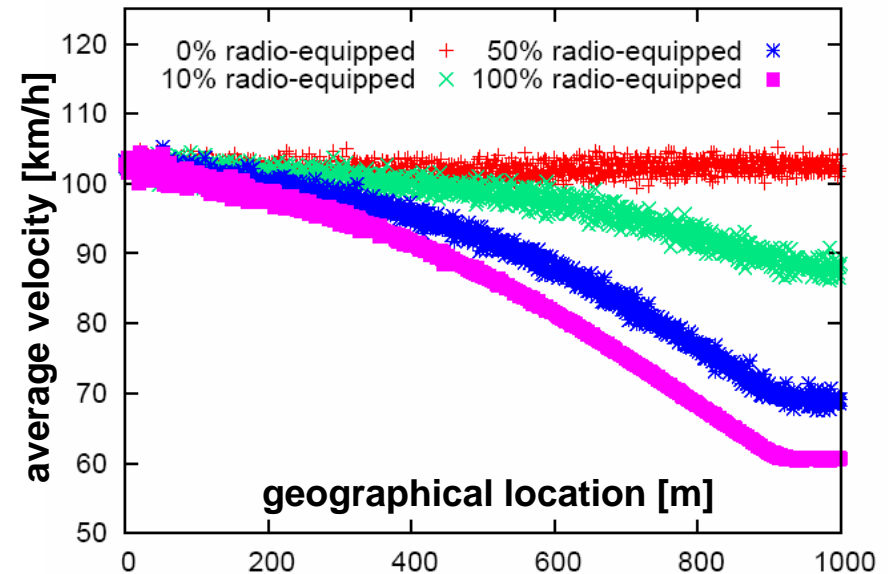
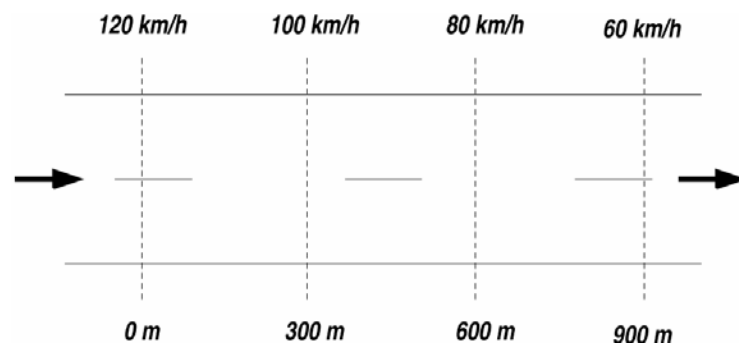
» Our approach

1. Hybrid communication simulation
2. DLL-integration into VISSIM
3. Extended control flow

3. Hybrid Simulation – First large-scale scenario

» Toy example set-up:

- 33km well-calibrated motorways in the state of Hessen, Germany
- Speed funnel sent out over 900m extract: from 120 km/h stepwise to 60 km/h
- Investigation of average velocity in dependency of equipped vehicles

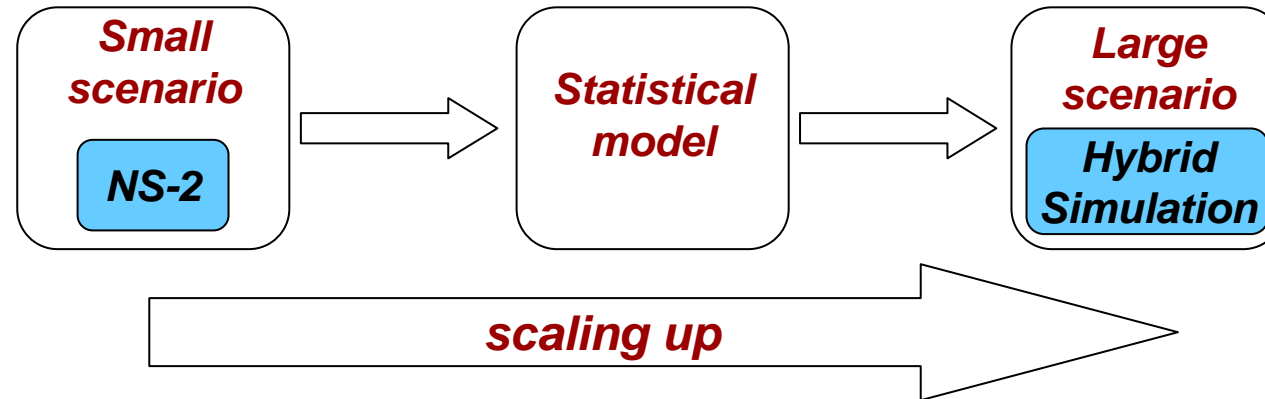


» Simulation performance:

- 2,500 to 3,000 vehicles in scenario
- 1,000sim.sec simulated in 2,200sec – only 6sec spent on application/VCOM
- Discrete-event network simulation is outperformed by a factor larger than 500 (conservative estimation)

4. Summary & Conclusion

- » Proposed hybrid simulation approach to enable efficient and accurate large-scale simulations of VANETs
- » Discrete-event simulations not replaced: required to build models



- » Integration of proposed model into VISSIM
- » Future work:
 - Varying parameters in statistical model, e.g., beacon generation rate
 - Definition of various Car-to-X applications