On Site-Specific Propagation Models for the Evaluation of V2X Applications

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***Abstract*—In this paper, we investigate the use case of an approaching emergency vehicle warning, considering site-specific propagation characteristics. Especially in urban environments, the presence of buildings leads to shadowing properties of the radio signal. In traditional propagation models, these properties are described with stochastic processes. However, for the evaluation of warning use cases where every individual message is important, stochastic models may be too simplistic. Therefore, we implemented efficient ray tracing techniques to identify the specific locations of buildings in the surrounding of the transmitter. Then, we employed adopted models that consider the effects of shadowing, penetration and diffraction to achieve a more accurate result. The comparison of the stochastic and the site-specific models showed that the stochastic models lead to overoptimistic propagation conditions in our scenario. In turn we can rely on a more credible result for the performance of the approaching emergency vehicle warning, when the site-specific models are applied.**

I. INTRODUCTION

Vehicle-to-X communication is a promising technology that gains in importance to improve future mobility. According to the common understanding, mainly three different areas of use cases can benefit from information exchange among vehicles each other, or vehicles and other stationary nodes [1]. The two areas of driving-related Traffic Efficiency and Safety use cases directly address the conditions caused by the vehicle movements. In contrast, the third area of Comfort applications (e.g. applications for multimedia streaming or e-mail access) is more passenger-related and depends to a lesser extent on the traffic situation.

Generally, V2X applications need to operate in different environments with their individual characteristics on the signal propagation. In highway scenarios, higher vehicle speeds involve higher Doppler shifts of the signal. However, highways are commonly located rural environments, where a smaller number of scatterers can be assumed. In contrast, especially in inner-city environments, buildings cause multipath propagation and also include strong shadowing characteristics.

The preferable communication properties of Safety and Traffic Efficiency applications exhibit contrary requirements regarding the range and the latency. Traffic Efficiency applications typically demand a higher communication range to inform vehicles extensively about the certain traffic conditions. However, the latency requirements are less stringent when vehicles receive information at higher distances and have sufficient time to take action. Additionally, traffic efficiency information (e.g. signage information, lane regulations or information about traffic jams) have a more static character in relation to the vehicle movement. In contrast, high vehicle mobility directly involves the requirement for short latencies and regular updates of safety information. From the perspective of the individual vehicles, the relevance area for safety use cases is limited to the own and nearby adjacent roads with an upcoming intersection. Certain use cases as the warning of Approaching Emergency Vehicles (AEV) demand to cover more than the own road as the dissemination area for the appropriate and safe information of other traffic participants. Yet, this use case can cope with medium latencies between other Safety and Traffic Efficiency use cases. Particularly in urban environments, AEV warning applications exhibit critical conditions. Due to buildings and their shadowing characteristics, the reception quality can be low even at shorter distances. For this reason, we will investigate the performance of the AEV warning with the regard of a detailed modeling of shadowing properties.

The rest of this paper is organized as follows. The subsequent Section II resumes the phenomena of radio wave propagation and introduces related approaches to treat especially the shadowing effect. In Section III, the selected models are presented to regard shadowing in different levels of detail. A comprehensive simulation study on the AEV warning use case is conducted in Section IV. Finally, the paper results are concluded and an outlook on future work is given in the last Section V.

II. FUNDAMENTALS AND RELATED WORK

Basically, the radio transmission is characterized by the time variation of the channel and the properties of multipath reception [2]. Multiple paths arise by the three phenomena of reflection, scattering and diffraction of electromagnetic waves on objects in the environment (see Fig. 1).

Reflection occurs when the wave hits a planar surface with large dimensions compared to the wavelength. According to Snell's Law the emergent angle is proportional to the incident angle. The effect of *Penetration* denotes that a part of the energy enters the material of the surface. *Scattering* is a special case of reflection. It occurs when the wave hits a rough surface or one with small dimensions compared to the wavelength. In

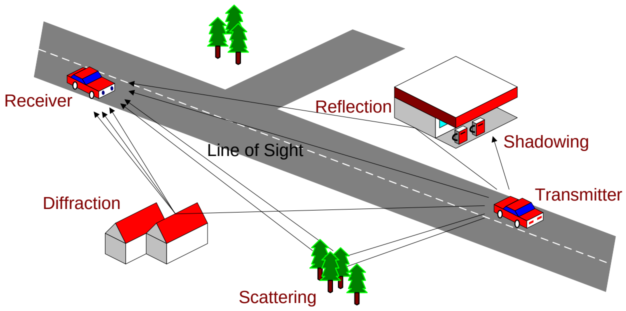

Fig. 1: Phenomena in a Multipath Propagation Scenario

this case, multiple reflections superpose to an emergent wave with an angle orthogonal to the surface. *Diffraction* occurs when the wave is refracted on a sharp edge. According to the Hyugen's principle, a new wave source emerges in this case. Fig. 1 includes two additional paths. The *Line-Of-Sight (LOS) path* is the direct path between the transmitter and the receiver. It does not experience any deflections and arrives at the receiver with the highest amplitude and the shortest delay. In contrast, the *Shadowed path* is reflected in such a way that it never reaches the receiver at all. On the LOS path, the freespace pathloss $\overline{PL}$ takes effect on the decrease of the amplitude during the transmission Eq. (1). It is proportional to the frequency of the radio wave (reciprocal to the wavelength λ) and also depends on the distance d from the transmitter.

$$\overline{PL} = \left(\frac{4\pi d}{\lambda}\right)^2 \rightarrow \overline{PL}[dB] = 2 \cdot 10log\left(\frac{4\pi d}{\lambda}\right) \qquad (1)$$

The Log-distance representation of the Pathloss - Eq. (2) introduces a calculated or measured reference pathloss at a selected distance d_0 and a more generalized pathloss exponent n (with $n = 2$ in free space).

$$PL(d)[dB] = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) \qquad (2)$$

At receiver side, the so-called partial waves with different amplitudes, delays and phases are superposed to combine one arriving signal. Due to the time variation, continuous fading properties arise. Fast fading is considered by Rayleigh, Ricean or Nakagami Models. Slow fading due to the presence of clutter in the surrounding is accounted with the Log-normal Shadowing Model (Eq. (3)). This model extends Eq. (2) with a Gaussian distributed random variable X_σ with the standard deviation of σ.

$$PL(d)[dB] = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) + X_\sigma \qquad (3)$$

Empirical models that account for the channel parameters as the number, the powers and the delays of the paths introduce further details. An according model was presented in a larger scale simulation in [3]. However, many system-level scenarios are not sensitive to this high level of detail, which in turn slows down the simulation time substantially. The same applies for full-featured ray-tracing implementations. Thus, geometry-based approaches are developed that are computationally efficient, still yielding a high grade of detail [4], [5], [6], [7].

III. PROPAGATION MODELS FOR BUILDINGS

In the following section, we present the models we implemented to consider shadowing properties of buildings. Prior to this, we give a brief introduction about the representation of buildings in our environment.

A. *Building Representation*

We use OpenStreetMap (OSM)[1] as the source for all map data in our simulations. These data include certainly the street network for the vehicle movement simulation as well as the buildings, which we use for the radio propagation simulation. OSM basically implements a two-tier concept to represent the location and the shape of any map object.

1) It locates *Nodes* with defined position using geographic latitude and longitude coordinates.
2) It defines *Edges* by referencing an ordered list of Nodes.

In particular, for buildings the first and the last entry of the ordered list refer to the same node to complete the loop for the polygon. The accordingly defined edges correspond to the walls of the building. For our simulation models, we adopt this representation. Furthermore, we augment the building information with a so-called abstracted area. The abstracted area can be seen as a rectangle with the maximum expansion of the building. When the following simulation models need to calculate the signal reception, they initially fetch all buildings in the vicinity of the transmitter. More specifically, they query all buildings where the abstracted area is within the area with the of the sender.

The vector based representation of the building and respectively the map geometries allows reducing the number of rays heavily for the following models. Hence, the impact on the computing effort is still within reasonable limits.

B. *Shadowing Model*

The Shadowing Model is the simplest model, we present in this work. It draws one single ray between the transmitter and possible the receiver. This technique is also referenced as *primary ray tracing* [2]. In geometrical sense, it calculates a line segment $[TxRx_n]$ between the current positions of the transmitter and the receiver. The actual determination of the reception consists of a nested loop over all walls of all fetched buildings in the vicinity. When an intersection of the line segment $[TxRx_n]$ and an according wall is calculated, the signal is considered as shadowed. For this reason, the Shadowing model returns the most restrictive reception conditions. The advantage of the Shadowing Model lies in its computing efficiency. When the first intersecting wall is found, the nested loop can break and skip further calculations. In the case when the ray is unobstructed, the receive power is calculated by the Log-distance Pathloss (Eq. (2), introduced in Section II). Fig.

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[1] http://www.openstreetmap.org

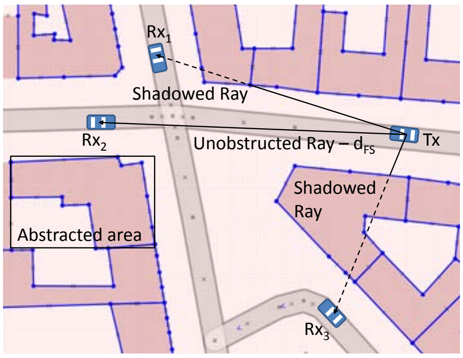

Fig. 2: Shadowing Model Propagation

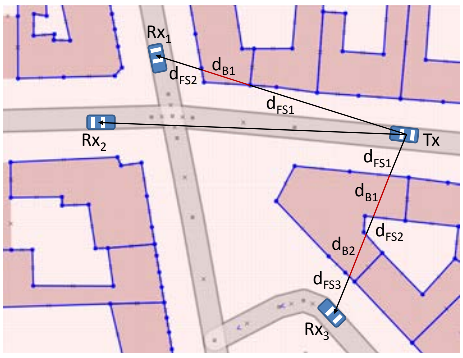

Fig. 3: Penetration Model Propagation

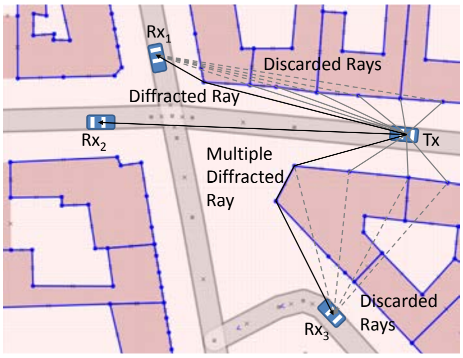

Fig. 4: Diffraction Model Propagation

2 shows an example where the Rx_1 and Rx_3 will not receive the signal. For Rx_2, in the LOS condition, the reception will depend on the pathloss over the freespace distance d_{FS}. Moreover, the abstracted area for one building is included. The abstracted area was used for fast queries of the buildings in the surrounding of the transmitter. The Shadowing Model is comparable to the model presented by [6].

C. Penetration Model

The Penetration Model uses the same technique with the launch of single rays between Tx and all Rx and the calculation of wall intersections. However, it does not skip the evaluation upon the detection of the first intersection but calculates all intersections. In this manner, the model can count all penetrated walls w and determine the individual distances through the buildings d_B. Accordingly d_{FS} is the distance, the signal travels through the free space (see Fig. 3). The Pathloss formula is extended to sum up all partial losses along the primary ray and turns out like Eq. (4).

$$PL(d)[dB] = PL(d_0)+10nlog\left(\frac{d_{FS}}{d_0}\right)+\alpha d_B+\beta\sum w \quad (4)$$

Compared to the restrictive Shadowing Model, the Penetration Model includes more physical details, yet it is computationally still inexpensive. In fact, [2] reports that this model yields very accurate results, when the attenuation factors α (signal loss per meter of the building interior) and β (signal loss at one building wall) are selected appropriately. [2] also gives a wide range of attenuation factors, measured at different frequencies for cellular systems. [8] realized a detailed measurement campaign and collected further factors, preferably at 5.85 GHz. Moreover, the Penetration Model shows similarities to the model presented by [5], with a slightly different usage of the attenuation factors.

D. Diffraction Model

The Diffraction Model is already more complex. The Fresnel geometry of diffraction requires multiple rays to determine the diffraction corner when the direct path between transmitter and receiver is obstructed (see Fig. 4). The Huygen's principle states that a new wave source originates at the point of diffraction. According to this, the Diffraction Model assumes a tuple of an initial ray from the Tx to the building corner and a second ray from the corner to the Rx for all potential corners in the setting. Most of the ray tuples can be discarded at this step as they would end in an obstruction again. The remaining tuples are used to calculate the Fresnel-Kirchhoff diffraction parameter v [2]. The v-value is then applied to the Knife-Edge Diffraction Model provided by Lee [9] to receive the diffraction loss L_d for the individual corner. Finally, the path with the smallest diffraction losses on the way is selected to be applied in the modified Pathloss Equation (5).

$$PL(d)[dB] = PL(d_0) + 10nlog\left(\frac{d_{FS}}{d_0}\right) + \sum L_d(v) \quad (5)$$

Concluding this section, we presented the computationally efficient Shadowing and Penetration Models that require only one single ray. The Diffraction Model already includes multiple rays. If all Reflection paths would be considered, a full-featured ray tracing approach needs to be applied.

IV. SIMULATION STUDY

We have performed all simulations with our simulation framework VSimRTI that we already used for V2X successfully in previous studies [10], [11]. VSimRTI couples simulators from different field to create comprehensive simulation scenarios. For the investigations in this paper, we used mainly the following three simulators.

1) The Communication Simulator (OMNeT++ with INETMANET), which we extended with the presented propagation models (Section III).
2) The Application Simulator (VSimRTI_App) for the applications on the vehicles as well as the emergency vehicle (EV). The applications are explained in the first part of this section.
3) The Traffic Simulator (SUMO [12]) to create a realistic traffic situation. The scenarios are presented in the second part of this section.

A. Applications

The AEV warning use case comprises two different groups of actors, namely the EV itself as a sender and the other vehicles to be informed about the EV as receivers [13]. When an emergency vehicle needs to inform others about its right-of-way, the sequence of action includes four steps. The EV (1) prepares the relevant information and (2) disseminates the warning messages. Upon reception, the other vehicles (3) determine their relation to the EV and (4) possibly inform or warn the driver. On the side of the road user vehicles, a fifth step would be the message forward to further vehicles. This step is not used in the current investigation, as we especially want to evaluate the influences of the propagation models on the effectiveness of the warning application.

1) The Emergency Vehicle: (1) prepares a cooperative awareness message (CAM) and includes the information of the own position, the current speed and the heading in the warning message. Optionally, it can include its driving route. However, the message length would increase accordingly and in turn the probability of a message collision. For this reason, as well as privacy issues, [13] propose to include only a partial route. Finally, the need for right-of-way is included to distinguish the warning message from regular CAMs. (2) The messages are sent periodically via the CAM sending mechanism with regularly updated values of the included information.

2) The Road User Vehicles: (3) first calculate the own area in relation to the EV. We use a comparison of trajectories of the received information from the EV and the own current state to calculate a time-to-approach (TTA). As the trajectory comparison can contain deviations, we included tolerance margins, particularly for the speed and heading component. This means, that a set of slightly different trajectories is compared to calculate a safe TTA. Obviously, with smaller distances and a higher frequency of message receptions from the EV, the differences between the alternative trajectories also decrease and the TTA calculation gets very precise. We adopt the determined information from the AEV warning used in the German field test simTD[2]. According to this, we define the Relevance Area and the Operational Area.

- *The Relevance Area* involves all vehicles within a certain distance to the EV. Vehicles driving in the opposite direction of the EV, having an divergent trajectory or a convergent trajectory, but arriving with a time delay at the same intersection are in this area.
- *The Operational Area* involves the vehicles, which are directly affected to initiate a particular action to prevent a dangerous situation. Vehicles with a convergent trajectory are in this area.

The last step (4) of the presentation is out of scope of our investigations. This issue would depend strongly on the OEMs or aftermarket suppliers and their customers. For instance, a minor information message can be presented for vehicles in the relevance area and a remarkable warning message needs to be presented for vehicles in the operational area.

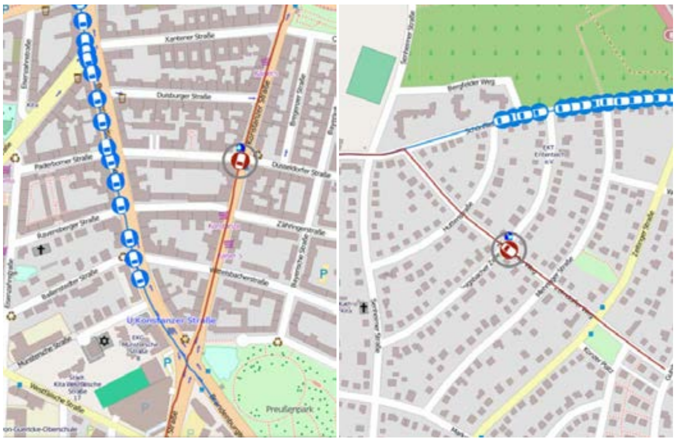

Fig. 5: Simulation Scenarios (left: inner-city, right: suburban)

B. Traffic Scenarios

In Figure 5, we present two scenarios, in an inner-city setting (on the left side) as well as in a sub-urban environment (on the right side). In this picture, the EV is the red-colored vehicle with lighting. The road user vehicles are depicted in blue-color. The number road user vehicles is 20. The vehicles routes (in red and blue) cross or join at the upcoming intersection. Both scenarios exhibit similar characteristics regarding the course of the streets. The used streets converge in an acute angle. Connecting streets allow intermediate line-of-sight conditions. The significant difference in both scenarios concerns the kind of buildings. In the inner-city setting, most buildings are erected as perimeter blocks in Wilhelminian Style. Accordingly, street intersections are mostly closed. In the suburban environment, detached houses prevail. The main intention for the scenario-selection is to identify, if more abstract propagation models lead to wrong, probably overoptimistic assumptions for the information exchange and in turn for the functioning of the application.

C. Results

In the following, we evaluate the percentage of vehicles which successfully recorded the event of beeing in one of the previously introduced areas. A postprocessing tool, which has the knowledge of all vehicle positions of all simulations times, determines the vehicles' area with to the same algorithm as the applications. It compares, whether the vehicles have recorded the successful AEV warning or not. In particular, we have assumed a Relevance Area of 300 m distance to the EV and a Operational Area with the $TTA <= 10\ s$, similar [13]. The communication parametrization is collected in Table I.

Component	**Parameter(s)**
EV-CAMs	$f = 1\ Hz$
PHY Layer	$txPow = 50\ mW$, $rxSensitivity = -81\ dBm$
Pathloss	$n = 2\ dB$
Log-n Shadowing	$n = 2\ dB$, $\sigma = 7\ dB$
Penetration Model	$\alpha = 5\ dB$, $\beta = 2\ dB$

TABLE I: Simulation Parameters

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[2] www.simtd.org

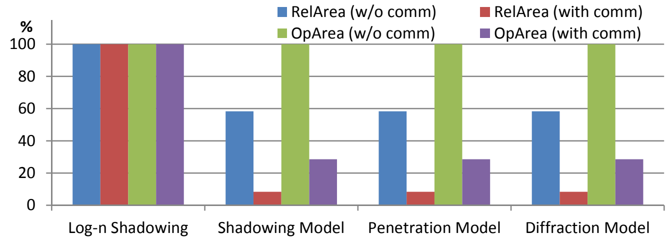

Fig. 6: Results for the inner-city setting

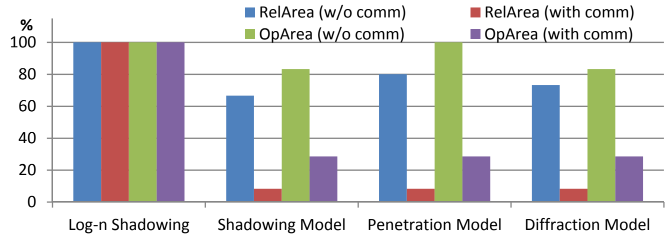

Fig. 7: Results for the suburban environment

The communication stack was based on an IEEE 802.11p compliant implementation. All CAMs were sent with single-hop broadcast without priorization, due to a relaxed load.

Fig. 6 and 7 display the simulation results for the four applied propagation models. The figures include a variation of the vehicles to be silent and just listen to warning messages (w/o comm). However, these vehicles would usually also communicate periodically via own CAMs to enable use cases apparent from AEV (with comm). Log-Normal Shadowing leads in any case to the information of all vehicles, already in the Relevance Area and also in the more important Operational Area. Even though not every message is received, it meets the requirement for at least one message to get informed. The figures turn out different and less optimistic for the site-specific models. While the applications work still sufficient without communication of the other vehicles, it degrades very strong in the case with communication. Obviously, the probability is very high that individual vehicles are shadowed from the EV message transmission and send their own CAMs to cause a collision at potential non-shadowed receivers. The well-known hidden terminal problem arises. Comparing the site-specific models among each other, the Shadowing Model is the most restrictive. The Diffraction Model allows just slightly more successful transmissions. Due to the high operating frequency of 5.9 Hz, Lee's diffraction loss gets very high. In the figures, no difference can be identified. Hence, the question arises if the computationally more expensive multiple ray launch of the Diffraction model is worth to be used in such scenarios, which are not sensitive to these details. In the inner-city setting, the Penetration Model leads to similar results as the Diffraction Model regarding the individual message transmission. The penetration loss through the buildings is many times too high, due to the perimeter block development. Consequently, no difference can be identified for the metric of informed or warned vehicles. In contrast, in the suburban scenario the probability of message reception is high enough to be visible with the presented metric. It is still far less optimistic compared to the Log-Normal Shadowing.

V. Conclusion

In this paper, we have investigated how the site-specific modeling of radio propagation effects of shadowing, penetration and diffraction influences the functioning of the approaching emergency vehicle warning. Compared to the stochastic consideration of buildings in the Log-Normal shadowing model, the results are less optimistic and reveal certain shortcomings of the application itself. In future work, the application needs to be improved with a component that forwards the warning information to other shadowed vehicles. Besides, we want to investigate a different approach that uses cellular technologies for the communication [14].

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