Communication Characteristics of VANETs

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***Abstract*—The standardization work for Vehicle-to-Vehicle (V2V) communication based on IEEE 802.11p has advanced enough for the start of application development. Future providers of V2V communication applications need to know the technical boundaries of their products to be able to keep their promises towards the customers. As these applications are based on the information received from other road users, their successful operation depends on the communication quality provided by the surrounding setting. With many obstacles such as buildings, foliage and infrastructure, urban scenarios pose a challenge to the communication quality for Vehicular Ad-Hoc Networks (VANETs). This paper investigates the communication characteristics of different urban environments in terms of Line-of-Sight probability. We find a strong correlation between the chance of a building blocking the line of sight not only based on the distance but also on the angle between two vehicles. The latter property has not yet received wide attention from the research community, however, we believe it opens interesting ways both to design future applications and to stochastically model urban V2V communication.**

I. Introduction

Future services and applications based on V2V communication require a certain amount of information in a certain time and/or over a certain spatial expansion to provide their envisioned quality of service. If these requirements are not met and the promised effect cannot be reached, the comfort or even the safety of a driver suffers. In order to prevent the client from disenchantment and the provider from an image loss, technical limitations need to be taken into account when developing new applications. These requirements depend on the communication quality available in the field. For that purpose, this paper introduces preliminary investigations to automatically estimate the communication characteristics of a specific urban scenario.

The surrounding environment of a VANET determines the communication characteristics and thus defines the communication quality. In this paper we introduce and examine the hypothesis, that urban scenarios do have a deterministic communication characteristics based on their topology. In the following, these characteristics will be represented by the probability for a Line-of-Sight (LOS) link between two communication partners depending on their distance and their angle to each other. We found out that the angle between vehicles is a crucial parameter for the differentiation between scenario topologies' influence on VANETs. In every situation a object leads to a Non-Line-of-Sight (NLOS) condition between communication partners, it potentially attenuates the radio signal and thereby negatively affects the communication quality. Hence a LOS condition will always provide better communication quality than NLOS. Karedal [1] for example shows with measurements that the absence of LOS is a severe problem for collision avoidance applications. Focussing solely on LOS probabilities, we can isolate effects caused by the topology of a scenario, as this probability is not dependent on communication parameters such as the transmission power.

II. Related work

The effect of urban scenarios on vehicular communication has been studied by both industry and academia. Oishi et al. examined the influence of the building density within a scenario on channel characteristics [2]. The paper uses the building density to describe the influence of the inter-vehicular angle on the LOS probability between communication partners. For that purpose, it considers an artificial road network with solely 90 degree angles and rectangular buildings. This simplified synthetic scenario, however, cannot be transferred to real urban scenarios that have different topologies.

Samimi et al. [3] and Sun et al. [4] define a model describing the influence of an urban scenario on millimeter-wave outdoor communication and 5G communication, respectively. In contrast to Oishi [2], Samimi [3] and Sun [4] conducted their investigations with real urban scenarios, but they did not examine the difference in the impact on the communication of various urban scenarios and the important role of the inter-vehicular angle.

In this paper, we want to give a more realistic and a broader view on the communication characteristics of Inter-Vehicle Communication (IVC) depending on the setting of urban scenarios. We do that by investigating various typical categories of real urban scenarios in Germany.

III. Evaluation Parameters

Our hypothesis is that different categories of urban scenario settings have different LOS probabilities. Additionally, we suppose that this relation is deterministic and can be modeled.

To examine this hypothesis, both the influencing factors, that is, the parameters of a scenario, as well as resulting communication characteristics, need to be evaluated. These are introduced in the following two sections.

(a) Historical Center of Ingolstadt, Germany (HistCtr)
(b) Feselenstraße, Ingolstadt, Germany (Urban1)
(c) Richard-Wagner-Straße, Ingolstadt, Germany (Urban2)

Figure 1. Three scenarios of 800 m x 800 m, buildings are colored in red.

A. Scenario Attributes

For our investigations we selected urban scenarios from four different categories: historical center, rural residential area, urban residential area and industrial area. Concerning the topology, we tried to capture the highest variance between the urban settings and considered preferably homogeneous scenarios to avoid ambiguous results.

LOS probability values are determined by the road network and the arrangement and extension of buildings. The roads define possible geometrical setups of VANETs in relation to the buildings within a scenario. Hence, the geometrical properties of buildings and roads represent the scenario attributes decisive for the communication characteristics. For the sake of comparability, these attributes need to be measurable and extractable, e.g., from maps described in XML.

The road network attributes are given in the following list:

1) average length of road segment in [m]
2) number of roads
3) percentage area covered by roads
4) number of curves
5) number of intersections

A road consists of several lane segments and ends as soon as there is no consecutive lane that forms an angle between the next and the current lane segment, that lies in the range of $20°$ and $160°$. This definition is based on the assumption that no building along a road can intersect a communication link of two vehicles. The number of curves is indicated by the number of angles between two roads within the range of $20°$ and $160°$. An intersection is any junction of two roads with an angle between $45°$ and $135°$. These definitions should be perceived as indicators to capture the differences in various urban scenarios.

Concerning the buildings in a given scenario, we consider the following list of attributes:

6) average building area in $[\mathrm{m}^2]$
7) number of buildings
8) percentage area covered by buildings

The attributes in Table I show the distinction in topology between the three scenarios depicted in Figure 1. The scenario attribute values of the two urban residential scenarios are similar and differ significantly from the value for the historical center. In contrast to the urban residential areas, the historical center is characterized by short yet many roads with a large number of curves and intersections. Although the buildings within the historical center are smaller, the amount of the buildings is so high that the percentage area covered by buildings is twice as high as in the urban residential area.

Table I
SCENARIO ATTRIBUTES OF THE HISTORICAL CENTER AND TWO URBAN RESIDENTIAL AREAS IN INGOLSTADT, GERMANY

Attributes	HistCtr	Urban1	Urban2
average length of road segment	87 m	143 m	104 m
number of roads	127	67	79
perc. area covered by roads	10.4%	9.2%	7.9%
number of curves	258	162	159
number of intersections	1117	57	66
average building area	304 m^2	400 m^2	567 m^2
number of buildings	1035	413	251
perc. area covered by buildings	46.4%	24.7%	21.3%

It is important to state that this list is not complete as it does not, for example, capture the shapes and constellations of the given buildings. The consideration of more detailed influence factors is left to future work.

B. Parameters of Communication Characteristics

This paper focuses on the impact of the geometrical scenario setting on VANETs characteristics. Thus this influence factor needs to be isolated from other influencing factors like the material a radio wave penetrates through (i.e. the facade of buildings or the air humidity). The focus on the geometry of a scenario happens by the evaluation of the chance to meet a LOS constellation, which offers communication conditions far better than NLOS constellations. The presence of a LOS gets evaluated between a sender and all potential receivers for every sent message. As introduced in Section I, the LOS probability serves as an indicator for the communication quality expectable for the examined link. The distance and angle between possible communication partners are decisive parameters for the geometrical description of VANETs. Hence the LOS probability was investigated regarding those two parameters. The results are discussed in the following section.

IV. COMMUNICATION CHARACTERISTICS

To examine the LOS probability of urban scenarios we used the Veins framework [5]. Simulations of several scenarios were done with the same simulation setup. Periodic beacons were sent with a constant rate of 10 Hz, a transmission power of 20 mW and a receiver sensitivity of -89 dBm. The size of each simulated scenario was 800 m x 800 m with a VANET of 100 vehicles in it. The vehicles were randomly placed on routes, which were automatically generated weighted by the length and the number of lanes of a street. We conducted extensive simulation runs for each selected scenario and also computed the scenario parameters presented in Subsection III-A. The output of one simulation run consisted of about 5 Mio. data sets, one for every simulated communication link. For each

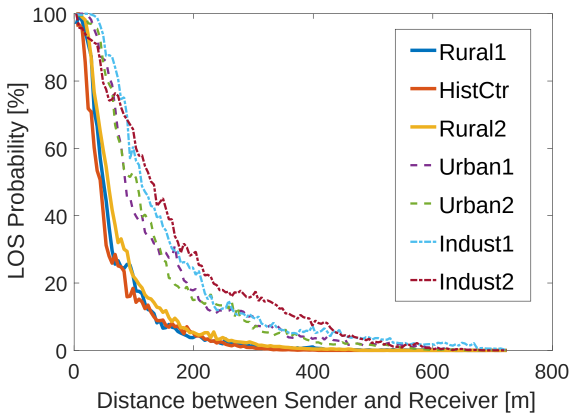


Figure 2. LOS probability over distance between sender and receiver for seven scenarios in and around Ingolstadt, Germany.

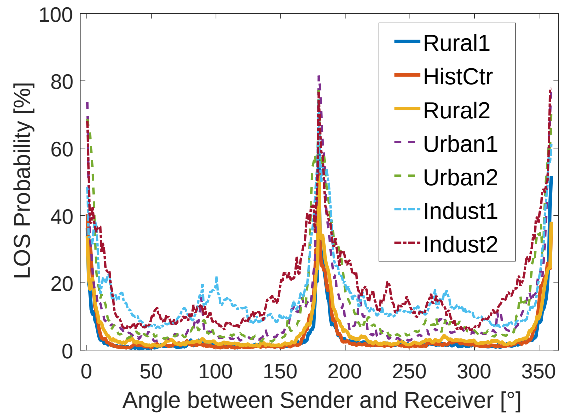


Figure 3. LOS probability over angle between sender and receiver for seven scenarios in and around Ingolstadt, Germany.

link the following information was collected: sender-receiver distance, angle between sender and receiver, LOS/NLOS.

The evaluation of the communication characteristics of VANETs depending on the surrounding scenario topology was done in three steps. For randomly distributed vehicles in an urban scenario the LOS probability decreases with increasing distance between sender and receiver. The larger the distance between two communication partners, the higher the probability for the presence of a building intersecting the communication link. This obvious relation will be investigated in the first step. Motivated by the findings presented in [6], the influence of the inter-vehicular angle on the LOS probability will be discussed secondly. Lastly, the combined impact of distance and angle is evaluated under consideration of the scenario-specific attributes.

A. LOS Probability over Distance

Our assumption is that urban scenarios with similar topologies have similar communication characteristics and vice versa. To examine the similarities and differences of the simulation results regarding the topology, scenario attributes were introduced in Subsection III-A. Table I contrasts these attributes for the historical center and the two urban residential scenarios in Ingolstadt, Germany. Figure 2 shows the simulation results for seven scenarios in and around Ingolstadt, Germany, evaluated with respect to the LOS probability over the sender-receiver distance.

At first glance there is an obvious similarity within the urban residential areas' attribute values and an obvious distance to the historical areas' values. Figure 2 shows the same behavior concerning the LOS probability, supporting our hypothesis. In comparison to the historical scenario the urban residential scenarios contain long roads, with few crossings and curves. That indicates a low level of entanglement within the road network. Due to long, straight roads without buildings intersecting a communication link, the LOS probability remains high over large distances for urban residential areas. In contrast to that, a large number of intersections and short roads decrease the LOS probability already for smaller distances in the historical center.

The average building area of a scenario and the entanglement of a road network interact, as large buildings determine long, straight roads. That relation is also observable in Table I for the urban residential scenarios. The other case, where smaller buildings lead to a more angular road network, is shown by the historical scenario. As expected, a higher building density induces an overall lower chance for LOS conditions.

Comparing all four scenario categories, Figure 2 provides the following findings: There are two obvious groups of curves. One group contains the rural residential areas and the historical center showing the same behavior. The second group consists of the urban residential and the industrial areas with a small difference between them, but not as large as to the first group. The latter provides the worst communication conditions, as the decrease of their LOS probability starts for smaller distances and proceeds with a higher gradient. The industrial areas tend to provide the best communication conditions as their LOS probability decreases with the smallest gradient over the distance.

B. LOS Probability over Angle

We introduced the entanglement as a property of road networks described by the combination of the following scenario attributes: Average road length, number of curves, and crossings. To evaluate the influence from road entanglement on the V2V communication, we analyzed the LOS probability over the angle between sender and receiver. For that purpose, we used the same angle definition as [6].

[6] describes the results of a simulation-based examination of the impact of different antenna patterns on VANETs. As mentioned before, this paper focuses on the impact of urban settings, hence it uses an idealistic isotropic antenna. In future work different antenna patterns can easily be integrated. Figure 3 shows similar results for the LOS probability over the angle as [6] does for the the number of received packets. That additionally confirms the LOS probability as a suitable

topology-based indicator for the communication characteristics of VANETs.

Figure 3 visualizes the LOS probability over the inter-vehicular angle for the same seven scenarios as Figure 2 does over the distance. Vehicles driving on the same road form angles of about 0°/360° or 180° to each other. The simulation results verify the assumption that vehicles on the same road have the significantly highest LOS probabilities within an urban scenario. The LOS probability at the angle value 180° for the urban residential scenarios are nearly 80%. Whereas the historical center provides only a 50% LOS probability. As a result, the possibility for vehicles driving the same road is higher in urban residential areas than in an historical area. That fact is also provable by the scenario attributes in Table I. Urban residential areas contain a lower level of entanglement by a larger average road length and fewer curves and intersections than the historical center. Additionally, the smaller percentage of area covered by buildings in urban residential areas facilitates higher LOS probabilities for vehicles not using the same road. These cases are represented by the angle values other than 0°, 180°, and 360°. All in all, the three groups of lines that are observable in Figure 2 are also visible in Figure 3 and they are arranged in the same order.

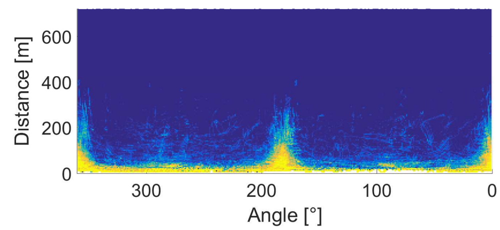
C. LOS Probability over Distance and Angle

In this section we examine the distance and angle between sender and receiver as common predictors for the LOS probability. The evaluation results, represented in Figure 4, show that there is a higher LOS probability for larger distances around the angles of 0°/360° and 180°. This points out the importance of the inter-vehicular angle. The Figures 4b and 4c demonstrate the similarity of two scenarios with a similar topology. A comparison of these two heatmaps with the one in Figure 4a shows clear differences. This supports the assumption of a site-specific influence on VANETs. In a following step, a representative cross-section of German cities, about thirty urban scenarios were evaluated, large cities, as well as small cities. The same observations were made.

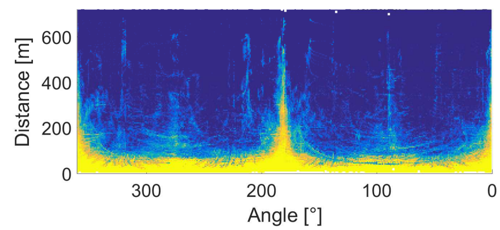
These investigations led to the following assumption: Today, due to neighbor and fire protection reasons, the arrangement of buildings is regulated by law. Areas like historical centers, that evolved over centuries, contain a high level of entanglement as they grew slowly and did not have to follow any regulations regarding the placement and dimension of buildings. However, new urban residential areas, that are artificially designed as a whole, do have to observe the law and therefore contain a low level of entanglement. In rural areas a mixture of both grown historical center and new artificial areas is observable.

V. Conclusion and Future Work

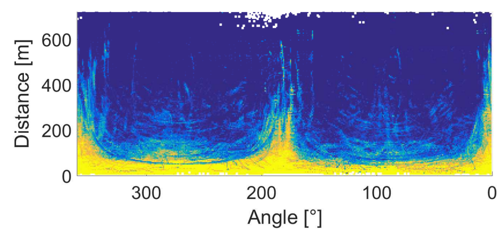
In this paper, the impact of an urban scenario topology on the communication characteristics of VANETs is presented. This is done by the evaluation of the influence that distance and angle between sender and receiver vehicles have on the LOS probability of a communication link. Furthermore, this paper proposes a measure by introducing site-specific attributes to calculate road and building characteristics of a given scenario. This can be transferred to new areas.



(a) Historical center Ingolstadt, Germany (HistCtr)



(b) Feselenstraße, Ingolstadt, Germany (Urban1)



(c) Richard-Wagner-Straße, Ingolstadt, Germany (Urban2)

Figure 4. Heatmaps for three German scenarios with the angle between vehicles on the x axis and the distance on the y axis. Lighter colors represent a higher LOS probability.

In a future step we will elaborate a model that predicts the influence of a scenario topology on the communication characteristics of a VANET by the scenario attributes for every urban scenario. For that purpose, the sufficiency of the introduced scenario attributes needs to be evaluated.

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