Abstract—In this paper we present a geometry-based stochastic channel model (GSCM) for mobile urban scenarios. GSCMs are very use case specific and high effort is needed to transfer existing ones to other scenarios. We propose to use OpenStreetMap data bootstrapping the geometry including the automatic placement of static, mobile and diffuse scatterers. We propose a method to distribute diffuse scatterers along buildings and roads. Our goal is to model complete city areas having the use case of real-time emulation of the wireless channel for vehicle-to-everything (V2X) communication in mind. In order to achieve this ambitious goal we propose a novel active scattering set selection based on locality-sensitive hashing (LSH). We show the trade-off between the number of selected diffuse scattering points by comparing the resulting power delay profile and Doppler spectral density to a measurement campaign.

I. INTRODUCTION

Geometry-based stochastic channel models have been successfully applied to a variety of scenarios ranging from simple to highly mobile scenarios [1]. GSCMs use simplified ray tracing methods (e.g., 2D ray tracing, 2.5D ray tracing) and model the non-line-of-sight components, such as those caused by diffuse scattering, penetration/refraction, and diffraction at edges by stochastic scatterers. The statistics of the scatterers’ distributions are obtained by measurements. Due to the nature of GSCMs these models can be computed very fast, even satisfying the constraints for real-time channel emulation, recently shown in [2]. However, real-time capable GSCMs represent small areas with a low number of scatterers leading to a low accuracy.

An approach to reduce the computational complexity of diffuse scattering in GSCMs is presented in [3]. The complexity reduction of diffuse scattering has been mainly accomplished by the use of discrete prolate spheroidal sequences (DPSS) and their approximate basis coefficient calculation introduced in [4]. In [5] a GSCM for high speed railway is presented and the active scattering region (ASR) and geometry clusters are introduced. The introduced active scattering regions shall provide means to model the (diffuse) scattering from the environment within certain geometry clusters holding a certain type of scatterers. However, the parameters (e.g., life time/distance, size/shape, energy distribution) of such geometry clusters and ASRs are derived by a measurement.

The scenarios modeled with GSCMs and measured were rather limited in extend (e.g., short highway sections, simplified intersections, etc.). We provide a GSCM which is capable of simulating urban areas directly taken from OpenStreetMap in real-time. This includes automatic placement of diffuse scatterers along buildings, vegetation, tram rails and roads as well as the placement of static discrete scatterers which represent traffic signs, traffic lights and other objects. We further support the import of GPS trajectories for mobile discrete scatterers, receiver(s), and transmitter(s). Following this approach, a vast amount of diffuse scatterers are placed for even rather small inner-city areas. Therefore, we present an approach to restrict the number of active diffuse scatterers with only a minor impact on the obtained power delay profile (PDP) and Doppler spectral density (DSD). The scientific contributions of this paper are as follows:

- We present a GSCM which can be initialized using OpenStreetMap data.
- We formulate the search and selection of active diffuse scatterers as an approximate nearest neighbor problem and solve it using locality-sensitive hashing (LSH).
- We compare our GSCM with the active diffuse scattering selection to the results obtained from a measurement campaign.

II. GEOMETRY-BASED STOCHASTIC CHANNEL MODEL

In order to model urban areas, the correct representation of buildings and objects on and aside the road is a must. We speed up the tedious task of reconstructing the area of interest and placing diffuse, static, and mobile discrete scatterers as well as defining their movement. We use OpenStreetMap data to automatically import and instantiate our GSCM which is implemented using MATLAB. Besides buildings, roads, rail tracks, traffic lights/signs and vegetation, we also provide the possibility of importing GPS trajectories for defining the mobility of mobile discrete scatterers (e.g., cars, pedestrians, etc.), receivers and transmitters. If the GPS sampling rate is lower than the assumed stationarity region duration [6] we interpolate...
known that the search can be efficiently solved by using minimal spanning trees (MST). However, in our case the query point(s) move over time and even some diffuse scattering points may change their position (mobile scatterers). Thus, we would have to rebuild the MST for every time instant which takes $O(n \log n)$. Therefore, it is desirable that we build a data structure only once such that we have to recompute only the time-varying points. These thoughts instantly lead to hash functions. More specifically, in our case we need hash functions which are locality sensitive with respect to a metric according to Def. 3.1 [10].

Definition 3.1: A family $\mathcal{H} = h : S \rightarrow U$ of hash functions is called $(r, cr, p_1, p_2)$-sensitive for a metric $d : S \times S \rightarrow R^+$ if $\forall v, q \in S$:

i) if $q \in B(v, r) \implies P(h(v) = h(q)) \geq p_1 \forall h \in \mathcal{H}$,

ii) if $q \notin B(v, cr) \implies P(h(v) = h(q)) \leq p_2 \forall h \in \mathcal{H}$.

A locality-sensitive hash (LSH) family is only useful if the probabilities satisfy $p_1 > p_2$ and the radius satisfies $r < cr$ which we establish by setting $c := 1 + \varepsilon, \varepsilon > 0$. In order to apply the LSH scheme presented in [10] we construct $k$ hash functions $h(v) := \frac{a \cdot u + b}{r}$ using the random projection principle where $a$ is drawn from $m$ independent standard normal distributions (which are $2-$stable), $b$ is drawn from $U(0, r)$. The distance between $<a, v>$ and $<a, q>$ is distributed according to $\mathcal{N}(0, \frac{|u-v|}{r^2})$. Since we select $k$ hash functions uniformly and independently, we observe from Def. 3.1 that all $k$ hash functions have to collide which happens with probability greater or equal to $p_1^k$ to fulfill (i).

Let $P_D$ be the maximum path loss threshold for diffuse paths in $dB$. Then, we select the radius of the balls / buckets as $r := \frac{1}{2} 10^{-\frac{P_D}{10}}$, where $P_D$ denotes the path loss exponent for diffuse paths. This selection ensures that for any two points within $B(p, r)$ the attenuation is no less than $2P_D$, since for $v, u \in B(p, r) : ||u - v|| \leq ||u - p|| + ||v - p|| < 2r$ by the Minkowski inequality. Please note, that our goal is not to find the nearest neighbor of certain query points, but to find all ball centers for which the given query points are contained within their respective $r$-balls. Thus, we proceed as described in [10], [11] by selecting $L$ tables of such hash function sets with $k$ hash functions and we define $g_i(v) := (h_{i,1}(v), \ldots, h_{i,k}(v)), 1 \leq i \leq L$. For a query point $q$ we lookup $g_1(q), \ldots, g_L(q)$ and stop searching after we have encountered $\leq 3L$ points. If an encountered point $v_j \in B(q, cr)$ then we return the point $v_j$. We set $L = \frac{M}{3}$ and $k = 10$ such that with constant probability it holds that if $v \in B(q, cr)$ then there $\exists \in \{1, \ldots, L\} : g_i(q) = g_j(v)$ and $\sum_{j=1}^L ||P \setminus B(q, cr) \cap g_j^{-1}(g_j(q))|| < 3L$ (guarantees correctness).

Let $f$ be the density of our absolute standard normal distributed random variable and with transforming $x = cy$ we have

$p(c) = P(h_{a,b}(v) = h_{a,b}(q)) = \int_0^r \frac{1}{c} f \left( \frac{x}{r} \right) \left( 1 - \frac{x}{r} \right) dx.$

By our selection, $r$ is fixed and with $c = \frac{||u-v||}{r}$ it is easy to see that our selection fulfills Def. 3.1 (i) and (ii) for $p_1 = \frac{1}{2} 10^{-\frac{P_D}{10}}$.
IV. MEASUREMENT CAMPAIGN AND COMPARISON TO SIMULATION

In order to assess how well our GSCM with the proposed active diffuse scattering selection is able to reproduce measurements, we compare the results to a measurement campaign conducted in Vienna (48°16’04.9”N 16°25’56.6”E). The measurement is conducted using the AIT multi-node channel sounder [12] with a bandwidth of $B = 150$ MHz at a center frequency of 3.5 GHz. The sub-carrier spacing is $\Delta f = 250$ kHz and the snapshot interval is $500 \mu$s. The scenario of the measurement campaign is provided in Fig. 2. The antennas are mounted on the transmitting node on a Toyota Prius at a height of approximately 1.4 m. For the receiving node we mount the antenna on a Volkswagen T5 at a height of 2 m. The speed of the cars varies between 0 km/h and 40 km/h. We use $\lambda/2$ dipole antennas for the measurement and the simulation. The trajectories for the transmitter and receiver are collected during measurement, having a GPS sampling rate of 1 Hz. Thus, we assume a constant velocity between two sampling points. We interpolate the obtained GPS trajectories using splines, where we use the sampled GPS points as supporting points and interpolate points that are spaced according to the assumed stationarity region duration.

For the simulation scenario we do not model the parked cars along the streets and we do not model other mobile vehicles in the scenario. Our goal is to investigate how the proposed selection of diffuse scatterers does perform in the PDP and DSD. We use the OpenStreetMap data as it is provided online. For the placement of diffuse scatterers and for obtaining the bucket width for LSH, we set $\chi_D = 0.5$, $w_D = 0.5$, $P_D = -90$ dB and the path loss exponent for diffuse paths to $p_l = 5.0$. We further set $M = 300$ which yields at most 300 diffuse scattering paths. For the query points we use the transmitter position (TX), the receiver position (RX) and $q = TX + RX - TX/2$. Fig. 3 depicts the selection of diffuse scattering points for a single time instant during simulation before the line-of-sight check. In total we have 1536 diffuse scattering points distributed along the buildings.

We estimate the local scattering function (LSF) from the gathered discrete time- and frequency-varying channel trans-
In this paper we present a GSCM for urban areas that can be created with low effort. It reads data directly from OpenStreetMaps and places scatterers automatically in the scenario. The trajectories of mobile vehicles or entities can be defined by using any OpenStreetMap editor. The parameters of the GSCM can be provided in the OpenStreetMap data. The proposed active (diffuse) scatterer selection allows for real-time simulation and is thus appropriate to be used as channel model for real-time emulations in large geographical areas.

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