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5G V2X map-based hybrid channel model implementation

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Abstract

With the more and more maturity of 5G V2X technology, the wireless channel model based on stochastic is unable to conduct accurate channel emulation for a specific scene, which makes the current communication OBU performance evaluation of ADAS system difficult. As a deterministic modeling method, raytracing (RT) can theoretically achieve accurate simulation based on digital map. However, due to its high computational load, it cannot simulate vehicular networking channels, especially in multi-user/link scenarios. In recent years, graph theory, as an effective and accurate semi deterministic model, has the characteristics of high computational efficiency and modeling accuracy. This paper introduces a new multiusers V2X channel simulator based on digital map using graph theory. In the end, we present some test result to verify the system.

1 Introduction

With wireless network evolution, cellular network provides more and more capacity to support more vehicle communication function. In recent years, the design goal of 5G V2X standard is to solve the multiple communication mechanisms brought by autonomous vehicles. It is very important to introduce a channel model which can be used to V2X performance verification. The current wireless channel models can be divided into the stochastic and deterministic model. The widely used stochastic channel model is geometry-based stochastic channel models (GSCM) model. According to the difference of cluster modeling method, the GSCM model can be further divided into Winner-type and COST-type. The former includes 3GPP spatial channel model (SCM), extended SCM (SCME) [3], Winner, Winner II [4], Winner+ (WIM+) and QuaDRiGa [5]. The latter is COST-type GSCM [7]. The main problem with stochastic models is that they cannot perform accurate channel analysis for the specific scenario. According to the current vehicles signaling layer protocol, such as upper V2X stack for CSAE (CN), optional for DSRC WAVE (US)* and ETSI ITS-G5 (EU)*, a series of application scenarios are specified, including cooperative lane change, cooperative cross pass, perception data sharing, vehicle-road coordination perception, etc. These specific scenarios have been integrated into the scenario simulation software for current vehicle OBU test. However, the main problem of the test is that the stochastic channel model, which results in the mismatch between the specific simulation scene and the emulated channel. To solve the following problem, map based deterministic channel model is taken into consideration. On the other hand, another major requirement for vehicle network channel model is the joint emulation of multi-user. It requires that the channel model can support simultaneous emulating channels of multi users. The channel model based on GSCM is difficult to model the correlation of channel parameters among multiple terminals. In the past few years, deterministic channel models such as Raytracing (RT) have been used increasingly. It can accurately model the direct propagation path, specular reflection, diffraction and other propagation paths according to the principle of geometrical optics. In recent years, the method has also been extended to model diffuse scattering of building walls, such as diffuse components (DC) with the “effective roughness” (ER) approach [1], [7]. Ray models including DCs yielded more realistic simulation results than models accounting for the SC only when compared to measured data. The main problem of Raytracing is its difficulty to model the accurate power delay spectrum (PDP) [1], [2]. This is mainly because the calculation of scattering scenes based on RT will lead to a significant increase in the calculation time. According to the passage [9], as the test results show, using RT to take into account multiple bounces (for precise simulation of PDP trailing) results in an exponential increase in simulation time. Re-

Table 1. TIME CONSUMING FOR RT AND GRAPH MODELLING

Method \ Bounces	0	1	2	3	∞
Ray-tracing	0.17	1.2	175	2.98×10^4	N/A
Graph modelling	N/A	3.5	54	55	82

cently, a new geometric–stochastic channel modeling approach based on graph theory has been proposed, which can simulate multiple-bounce scattering to several interactions in a very efficient way. In graph theory channel models, propagating paths are represented as sequences of branches (edges) connecting nodes (vertexes, representing scatters) [8]. Traditional graph theory is based on statistical scheme for scene modeling, which does not belong to deterministic channel model. Paper [9] proposes the geometric model and node extraction based on digital map, and CIRs are calculated by proposed scattering theory which makes the scheme have the advantage of accuracy of deterministic model. Coupled with the advantage of fast simulation speed, the graph theory-based approach becomes an ideal choice for V2X channel. In the paper, we propose a graph theory-based channel model implementation for V2X. The channel emulator can realize the emulation of specific channel for multiple users which make it easy to be integrated into the vehicle scene test for verification of communication performance. This paper is consisting of the following parts. The second part mainly introduces the basic principles of the hybrid deterministic channel model based on graph theory. The third part introduces the realization scheme of multi-user channel model. The fourth part shows some test results of the real scene for verification of the implementation.

2 MODELLING ALGORITHM OF CHANNEL MODEL

In the section, we firstly introduce propagation graph algorithm which is original proposed in [8]. The propagation

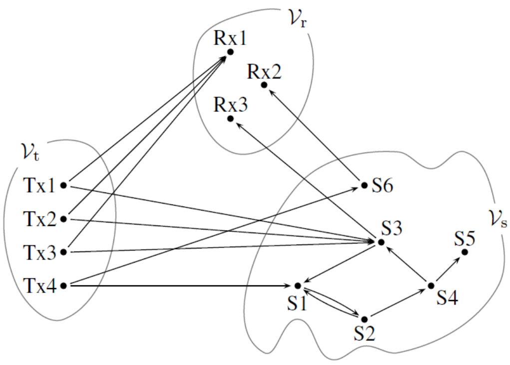

Figure 1. vertices and edges set for graph method

graph method model buildings and objects, environment scatters, transceiver device as a series of vertice and edge sets. For example, as shown in Fig. 1, the position and visibility information of m = 4 transmitters (Tx), n =3 receivers (Rx), and s = 6 scatters have been configured. Considering the transfer function between two nodes, it can be expressed as follows:

$$A_e(f) = g_e(f)\exp\left(-j2\pi\tau_e f + j\phi\right). \tag{1}$$

Where $A_e(f)$ can be represented as one of the four transmission types, which are respectly TX/RX, TX/Scatter, Scatter/Scatter, Scatter/Rx. τ_e is the propagation delay or time of arrival, and ϕ is random phase rotation, which is uniformly distributed on the interval [0, 2π), and $g_e(f)$ is the propagation coefficient depending on following equations [9]:

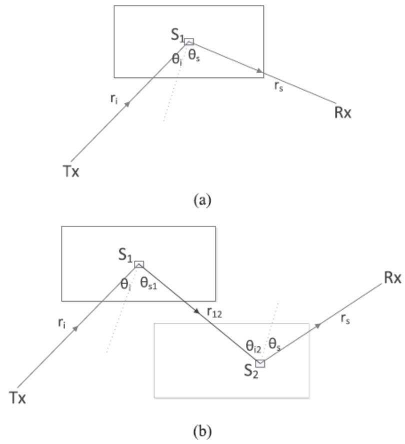

Figure 2. Illustration of a) single-bounce scattering and b) double-bounce scattering.

$$y_e^2 = \begin{cases} \left(\dfrac{\lambda}{4\pi r_d}\right)^2 & e \in \varepsilon_d \\ \dfrac{dS\cdot cos\left(\theta_i\right)}{4\pi r_i^2} & e \in \varepsilon_t \\ \dfrac{S^2\cos\left(\theta_s\right)}{\pi r_s^2}\cdot\dfrac{\lambda^2}{4\pi} & e \in \varepsilon_r \\ \dfrac{S^2 dScos\left(\theta_{i2}\right)cos\left(\theta_{s1}\right)}{\pi r_{12}^2} & e \in \varepsilon_s \end{cases} \tag{2}$$

The transfer function can be calculated in the frequency domain as:

$$\begin{aligned} Y(f) &= Y_1(f) + \sum_{k=2}^{\infty} Y_k(f) \\ &= D(f)X(f) + \sum_{k=2}^{\infty} R(f)B^{k-2}(f)T(f)X(f) \\ &= \left[D(f) + \sum_{k=0}^{\infty} R(f)B^k(f)T(f)\right]X(f) \\ &= \underbrace{\left[D(f) + R(f)(I-B(f))^{-1}T(f)\right]}_{H(f)}X(f) \end{aligned} \tag{3}$$

Where Y(f) represents frequency domain representation of the signal received by the receiver. $Y_1(f)$ represents the received signal of the direct path, and $Y_k(f)$ represents the received signal after k times of transmission. A(f) is expressed as the weighted transfer matrix of the whole propagation graph vertices set. The weighted transfer between any two elements are expressed as:

$$[A(f)]_{nn'} = \begin{cases} A_{(v_n,v_{n'})}(f) & if\,(v_n,v_{n'}) \in E \\ 0 & otherwise \end{cases} \tag{4}$$

v and E represent the set of vertics and the set of edges respectly. $(v_n, v_{n'})$ means the edge from n_{th} to n'_{th} vertics in the set v The whole transition matrix can be expressed as:

$$A(f) = \begin{bmatrix} 0 & 0 & 0 \\ C & 0 & R(f) \\ T(f) & 0 & B(f) \end{bmatrix} \tag{5}$$

$D(f), R(f), T(f), B(f)$ are respectively expressed as:

$$\begin{aligned} D(f) &\in \mathbb{C}^{M_2 * M_1} && \textit{connects transmitters to receivers} \\ R(f) &\in \mathbb{C}^{M_2 * N} && \textit{connects scatterers to receivers} \\ T(f) &\in \mathbb{C}^{N * M_1} && \textit{connects transmitters to scatterers} \\ B(f) &\in \mathbb{C}^{N * N} && \textit{interconnects the scatterers} \end{aligned} \tag{6}$$

Where f is the specific frequency band, D(f) represents the line-of-sight (LOS) part of the transmission, and T(f) R(f) and B(f) denote the transmission matrices with entries representing respectively the propagation coefficients of the links e from individual transmitter to scatters, from scatters to individual receiver, and among scatters.

3 CHANNEL MODEL IMPLEMENTATION

A. Overall architecture of the channel model

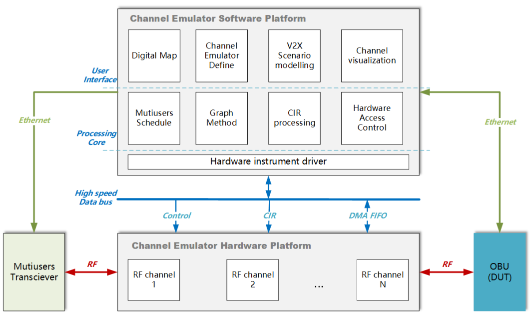

Figure 3. Architecture for the channel emulator

Figure 3 is the V2X map-based channel emulator architecture. Generally, the emulator is divided into two parts, which are software part and hardware part. In the software part, the channel emulator mainly realizes the process of user setting, channel coefficient calculation and hardware access control. In the hardware part, channel emulator completes multi-user CIRs reloading, real-time TDL channel filtering and some of hardware accelerating. User setting is mainly completed by the user interface layer, including the digital map module which is the interface to digital map of some specific scene to be tested, channel emulator define module which is used to configure basic parameters of channel emulator, such as frequency point, bandwidth, number of users and antenna parameter information, and V2X scene simulator module whose role is selection and configuration of typical application scenarios defined by V2X, including configuration of the transceiver type of each link of V2X, movement path and speed, terminal number, etc. When user setting is finished, the software system executes the processing core layer. Processing core layer is used to calculate the instantaneous channel coefficients based on propagation graph for multiple users. It includes several modules. Multi-user scheduler module, which realizes the generation of transceiver slot of multiple users and the corresponding relationship of channel coefficients based on the output of V2X scenario modeling module. The output of this module will also be given to the multi-user signal transceiver for the generation and reception of multiple terminal V2X protocol signals by Ethernet link. Then the output from three modules of the user interface layer including the digital maps, channel emulator define, V2X scenario modelling will be input to the Graph method module. During the analysis and processing of the graph method module. The transmission path and electromagnetic factor of each propagation path have been calculated based on the scattering theory. After that, the channel propagation function matrix for each user will be calculated, and the transfer matrix will be updated dynamically according to the user terminal's movement along the trajectory. The output of the Graph method module will be input to the CIR processing module, which will calculate the final time-varying CIR coefficient and input it to the hardware platform. At the same time, according to the results of multi-user scheduling, the transceiver slot of each user is input into the hardware access control module to generate hardware control instructions, to realize collaborative control of hardware resources. After that, the Processing Core layer call the hardware device driver to realize the transmission to the hardware platform resources through the high-speed data bus. The transmission includes sending control information, real-time CIR reload information transmission, and using DMA-FIFO to carry out information interaction accelerated by some hardware modules. Meanwhile, the Processing Core layer also sends the generated transmission path information to the User interface layer in real time, to realize the dynamic display of transmission path in the scene simulation module. The hardware part of the channel simulator adopts multi-channel transceiver equipment, and uses re-definable FPGA resources to realize flexible configuration of multi-channel RF signal path, multi-user loading, CIRs dynamic update, multi-channel baseband filtering, etc. The parallel and time division channel fading emulating is realized.

B. The principle of software part

The core part of software for this channel emulator includes parameter setting, geometric path calculation, propagation coefficient calculation and CIR acquisition. The simulator setup module includes map importing section, V2X scene setting up for typical V2X scene type, wireless channel setting which including wireless channel type, frequency, antenna attributes, number of users, and path or location planning for each user and roadside facilities. After the parameters setting has been done, the system software discretizes the building surface according to the input digital map and abstracts it as vertice sets. The software records

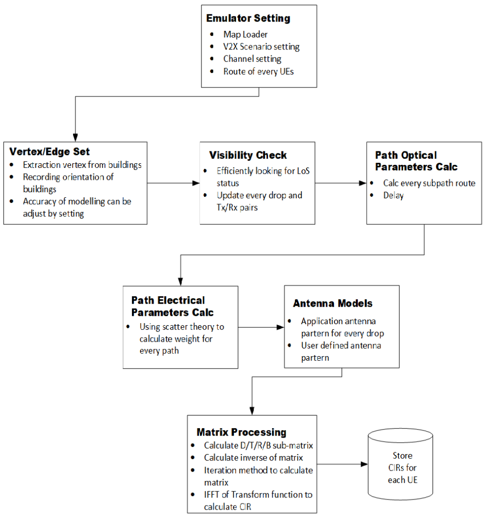

Figure 4. Architecture and workflow for the core part of software platform

the coordinates of each vertices and the normal direction of the surface. Here, the number of vertices used to simulate the building can be set according to the precision level requirements of the emulation. When the vertice sets are accomplished, visibility analysis among different vertices is dynamically generated based on the position of the vertices and the movement trajectory of the communication transceiver terminal. The visibility of each pairs of two nodes (i.e., one Tx and one scatter, one scatter and one Rx, or two scatters) is realized by detecting whether the vector connecting the two nodes intersects the surface according to their position and the position of the surface. After finishing visibility analysis, the propagation diagram has now been established. Different terminals will retain their own sets of visible vertices. After determining the sets of vertices, the geometric optical parameters calculation module determines the transmission graph path according to the visible vertices and calculates the transmission delay according to the geometric path of the propagation path. After the geometric propagation path is determined, the propagation coefficient $g_e(f)$ of each available link is calculated, and matrices D(f) R(f) T(f) and B(f) at a specific frequency are calculated according to equation (5). During the calculation of matrix T(f) and R(f), the antenna radiation patterns are also embedded into calculation, which configured and changed dynamically according to different user terminals, different antenna orientation alongside movement of the user. When D, T, R, and B sub matrices are generated, the matrix inverse can be calculated, and the channel transfer function can be achieved based on the formula (3). Because this part is the most computation time consuming one in the whole system, the system uses the acceleration algorithm and combination with hardware to improve the efficiency. Due to the inverse calculation of matrix is complicated, the system can consider limited finite scattering iteration steps as an optional approximate calculation method. By using this method, only finite iterative matrix multiplication operations are considered instead of matrix inverse calculation, thus greatly reducing the operation complexity. Finally, after Fourier inverse transformation (IFFT) to the transfer function (from equation 3), the final CIR is obtained. The CIRs of multiple users will be stored in the corresponding storage space, and the CIRs reloading and hardware emulation will be conducted based on the fact that the schedule controller will download the corresponding CIR to the hardware part of the channel emulator at the corresponding sending time of the user.

C. The principle of hardware part

The hardware solution uses the SDR platform of National Instruments (NI). The architecture of the solution show as figure 5. PXI-8135 is an industrial grade embedded controller installed with windows OS. PXIe-5646s are Vector Signal Transceivers (VST) which execute AD/DA and RF up and down convert as the core components of the channel emulator. PXIe 7965R are the coprocessor of the VST which add channel fading to input signal in baseband by Xilinx Vertex-5 FPGA in the card. Multi-cards of PXIe 7965R form computation pool which process the data from all VST channels linked by PXIe bus. All these components are intergrade in a PXIe bus in a chassis named PXIe 1085. The embedded controller completes the software part of the channel emulator. On the other hand, it completes the configuration of different RF hardware resources, including real-time reloading of multi-user CIR coefficients, selecting and switching of RF channels. In the FPGA module, FIR filter is used with the overloadable CIR coefficient to realize the updated channel TDL model. At the same time, some matrix operation and IFFT operation are also implemented in FPGA, to realize optimization of computing efficiency. The real hardware platform shows as Figure 6. Features of the hardware solution are included in the following table.

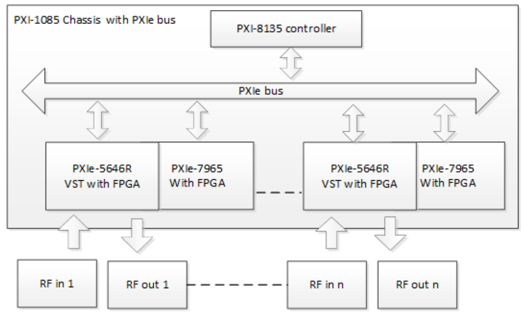

Figure 5. Architecture of the hardware

4 CALIBRATION FOR THE CHANNEL MODEL

Several main results of generating channel coefficients for a channel emulator based on graph theory are shown in figure 7. The digital map in figure 7a shows part of the main block in Xuhui district of Shanghai, China. The area is a crossroads in a dense urban area. Figure 7b is the 3D

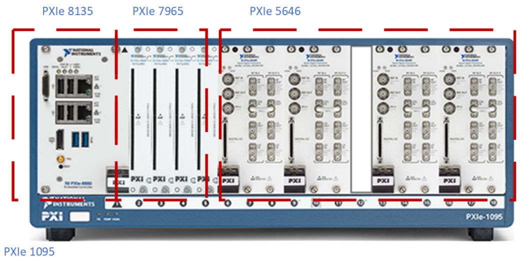

Figure 6. Hardware solution with 5646

Table 2. HARDWARE SYSTEM SPECIFICATION

Parameter	Value	Comments
Multi-channel	4×1by1	4 channels synchronization processing. Each one is 1by1.
Maximum RF Bandwidth	200 MHz	200 MHz
Taped-delay-line sampling rate	200 MSPS	5646R ADC and DAC have 16-bit resolution.
Delay resolution	5 ns	This is currently implemented as a sample-based tapped-delay-line. Fractional Delay filters would not use.
Maximum delay	20.6 µs	Maximum tap delay
Power normalization		Power normalization of all paths

model after vertex extraction. The buildings of different heights are abstracted into a large set of vertexes which will store coordinate and normal direction information. At the same time, transmitter and receiver antennas are also represented by different vertices. Figure 7c is the result after real-time decision of the visibility among vertices for updated TX/RX positions, and the transmission paths and coefficient for each path are calculated based on the scattering model defined in Figure 7b. The module can set different bounces levels, which will determine the complexity of the processing. Figure 7d is the CIR calculation results based on the transmission path of figure 7c. The CIRs are obtained by IFFT processing based on frequency domain channel coefficient. By setting different bounces levels, different accurate results of PDP can be obtained.

5 CONCLUSION

In this paper, a new channel simulator based on graph theory is proposed, and the reliability of the system is verified by some test results. In the future, this system will further optimize for the multi-user V2X scenario.

6 ACKNOWLEDGMENT

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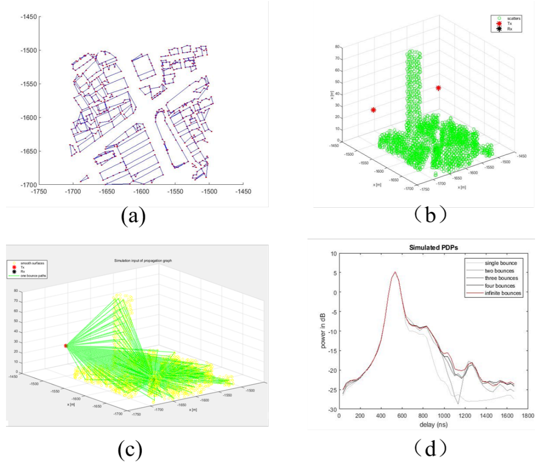

Figure 7. Test result of the channel emulator