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Measurement Based Ray Launching for Analysis of Outdoor Propagation

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Abstract—Clustering is a key concept of existing MIMO channel models, such as the COST 2100 model. Parameter based clustering has been studied for a while, but how parameter based clusters relate to the physical environment is not well known yet. A measurement based ray launching tool is developed and used for studying clustering and its relation to physical scatterers. By using estimated angles and delays of multi-path components as input to the ray launching tool, the physical scatterers along the propagation paths are visualized. After the physical scatterers are grouped, we notice that when the receiver moves, some physical scatterers continue to contribute to the channel response while others disappear and sometimes also later re-appear as represented by the cluster life time and common clusters in the COST 2100 model. Our measurement based ray launching tool shows significant advantages for further channel analysis and modeling.

Index Terms—Channel modeling, Clustering, Ray launching, Ray tracing, Scatterer, Multi-path components.

I. INTRODUCTION

Ray launching and ray tracing are attractive tools for wireless propagation investigations since they can provide predictions of propagation characteristics with high accuracy. Varieties of ray launching and tracing algorithms have been developed [1][2], generally based on models of the same propagation mechanisms such as reflection, diffraction and transmission. In order to make even better channel characterization, a combination of channel measurement results and ray launching can give valuable insights. Measurement can provide additional information such as angle of arrival (AOA), angle of departure (AOD), delay and power of multi-path components (MPCs), which helps identifying the most likely propagation paths and reduces the complexity of calculations.

An indoor scenario is analyzed with a simple measurement based ray launching tool by Poutanen et al. in [3]. New concepts for multi-user MIMO channel modeling and analysis such as common clusters [4], single/multiple interactions with the environment have been studied with such a ray launching tool. The indoor investigation in [4] shows the advantage and necessity of a ray launching tool for multi-user channel modeling.

The objective of this work has been to develop a new ray launching tool for outdoor scenarios based on channel measurement results and three dimensional (3D) maps. With this ray launching tool we are aiming to visualize the most likely propagation paths according to the measured information. The visualized geometrical propagation paths can then be used for further channel analysis, such as clustering, finding common clusters and identifying interaction processes and so on. It should be noted that our purpose is not to provide a tool competing with sophisticated ray tracing tools in performance and accuracy but rather, to help interpreting and analyzing measurement results.

The paper is organized as follows. The modeling assumptions are studied in Section II. Section III explains the main approach of the ray launching tool. The development platform and parameter choice are discussed in Section IV. Ray launching results are shown and analyzed in Section V. Section VI gives a short conclusion of this work.

II. MODELING ASSUMPTIONS

To visualize propagation paths, good models of objects in the environment are required. For outdoor scenarios, the most important objects are buildings and vegetation, which directly influence direction and power of propagation paths. Vehicles, lamp posts and street signs can also be of interest, but they are generally not available in commercial 3D maps, and are therefore excluded in this paper.

A. Building model

Building models are usually defined by reflection, transmission and diffraction properties [1]. The transmission through buildings is usually not considered for outdoor scenarios. The walls of buildings are often modeled as flat surfaces, however, real buildings are in general not totally flat. For example, in [5] a building model including windows has been discussed. Only one specular reflection is not enough to describe the building reflection process in general. Therefore a cone of scattered rays is launched around the specular reflection ray to represent rough wall reflections in our tool, see Fig. 1a. These scattered rays are generated by rotating the specular reflection ray in angles.

There are many models describing the diffraction around the edges or corners of buildings, such as Bullington’s model, Epstein-Petersen model and so on [6]. To reduce the complexity of the building model, in our ray launching tool, rays are launched from both sides, and diffraction is only considered when rays from two sides can be matched though diffraction.
Both single edge diffraction and diffraction from two parallel edges are taken into account.

B. Vegetation model

Existing vegetation models generally focus on describing attenuation through a vegetation area. For example, in the ITU-R model [7], an attenuation factor based on frequency and distance is derived. Some research has been also carried out to give more advance vegetation models for ray-based propagation prediction tools. In [8], an expression for incoherent scattered field when rays are coming out from the vegetation areas is derived. However, these models do not fulfill the requirements in our ray launching tool design, since they usually only consider attenuation and forward scattering processes caused by the vegetation area. No modeling of the backward scattered rays from the vegetation area is given, and the vegetation scattering processes are not fully described.

In our tool, a slightly modified vegetation model is used, see Fig. 1b. The vegetation area is described by its size and shape as well as its height. When an incoming ray has an intersection point with an edge of the vegetation area, backward scattered rays with different azimuth and elevation angles are generated at this intersection point. At the same time, the incoming ray continues straight ahead until it reaches the other edge of the vegetation area. There, at the second intersection point, additional forward scattered rays are launched. Again, those scattered rays have varying azimuth and elevation angles around the direct ray. We try to cover the sphere around the vegetation area since the scattering of the vegetation area is quite complicated. It should be noted that this is a very simplified vegetation model, but good enough to fulfill its purpose here.

C. Transmitter and receiver model

The transmitter (TX) and receiver (RX) are represented by their orientation and location. In the 3D map, they are only single points, and dummy cylinders are introduced and centered at the coordinates of the TX and RX. The cylinder has 1 meters radius and a height of 2.8 meter above the ground. The rays passing through the cylinders do not change any properties and directions. The purpose of the dummy cylinder is to “capture” incoming rays in the matching process described below. To account for measurement and positioning inaccuracies, rays from TX and RX are launched in a cone centered around the measured AOA/AOD. Since it is a 3D ray launching tool, rays are also launched with slightly varying elevation angles, see Fig. 1c.

III. MEASUREMENT BASED RAY LAUNCHING APPROACH

Two important concepts are used for the measurement based ray launching tool: intersection points and rays launched from these intersection points, see Fig. 2. The intersection points are where rays intersect with objects. Rays are launched at the intersection point according to the specific propagation mechanisms and they are characterized by their coordinates, propagation direction, power, traveling distance and the next intersection point. Rays, objects and intersection points are all processed in 3D.

Based on these two concepts, ray launching processes are implemented from both TX and RX sides to increase accuracy and efficiency, see Fig. 3. First, two points at TX and RX coordinates, respectively, are created. Dummy cylinders are placed around these two points respectively and cones of rays from these two points are launched according to the measured AOA/AOD as described in Sec. II-C. Secondly, the tool processes all rays launched from the TX and RX points. For each ray, if there is an object at the propagation path, a next intersection point is determined. Otherwise, this ray continues propagating until it reaches the maximum traveling distance defined by the measured delay, including some extra margin (10%). The dummy cylinders around TX/RX are also taken into account and the corresponding intersection points are called dummy intersection points. Different objects change the propagation properties according to the building and vegetation models described above. New intersection points
are determined until all the rays are processed. The tool continues launching new rays from these new intersection points and determining next intersection points again. It keeps generating rays and intersection points until either the number of reflection or scattering processes for the rays exceeds a certain limit or the traveling distances of rays are larger than the maximum traveling distance.

There is one important consideration when rays travel a long distance without any intersection points. Over a long distance, even a little angle inaccuracy at TX or RX side can lead to a large distance offset, which might lead to missed intersection points. To account for this, ray splitting is implemented, where a dummy intersection point is added at the position of ray splitting. Once the traveled distance of a ray exceeds a predefined ray splitting distance, a new cone of rays is released from this dummy point, centered around the propagation direction.

The last step of the algorithm is to check if rays launched from the TX and RX can be matched or not. Since rays are launched from two sides, they can only be matched at intersection points corresponding to physical objects or the dummy cylinders around TX/RX. Two parameters are checked: the measured delay for a certain MPC and the intersection angles of rays. In future versions, power will likely also be checked. The total traveling time from TX to RX has to be close to the measured delay.

$$| \frac{D_{TX} + D_{RX}}{c} - \tau_{MPC} | < 0.1 \times \tau_{MPC}$$

where $D_{TX}$ is the distance from the TX to the matching point, $D_{RX}$ is the distance from the RX to the matching point, $\tau_{MPC}$ is the delay for this particular MPC (from the measurement) and $c$ is the speed of light. Similarly rays from TX and RX have to meet in a valid angle at the dummy cylinders. For example, the LOS ray departing from the TX should reach the RX with an angle matching the AOA of this MPC. After the matching processes there might be more than one candidate path for one particular measured MPC, the one who has shortest delay difference compared to the measured value is chosen as the final visualized propagation path.

Three matching scenarios are considered in this tool. 1) Matching at buildings. Reflection and diffraction are both investigated for the matching process at buildings. Rays can match through reflection when their intersection points with a building are on the same side and close to each other. Diffraction is more complicated, not only single edge diffraction but also multiple diffraction is considered. Rays can match when they are close to the same edge of a building or they intersect with two parallel edges. 2) For the matching at a vegetation area, simple rules are applied. Rays can be matched when they intersect with the same vegetation area and the distance between the two intersection points is within the capture range. 3) Matching can occur when rays intersect with the cylinder around the TX or RX. As mentioned in previous paragraph, the angles are also checked here.

IV. DEVELOPMENT PLATFORM AND PARAMETERS SETUP

The ray launching tool is developed based on the C++ application built by E. Olsson [9] and A. Stranne. This application provides a graphical user interface (GUI), see Fig. 4, and we can easily import a 3D map. The map is shown by its 2D projection, elevation information is represented by color. The measurement results can also be handily imported into this application. With proper parameter setup, we are able to visualize the propagation path and intersection points on the map.

As we discussed in previous two sections, parameters such as number of scattered rays, width of the cone for ray
### Table I

<table>
<thead>
<tr>
<th>Parameters Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of iterations from each side</td>
</tr>
<tr>
<td>Capture range [m]</td>
</tr>
<tr>
<td>Reflection coefficient</td>
</tr>
<tr>
<td>Path-loss exponent</td>
</tr>
<tr>
<td>Number of launched rays in Azimuth</td>
</tr>
<tr>
<td>Resolution of launched rays in Azimuth [deg]</td>
</tr>
<tr>
<td>Number of launched rays in Elevation</td>
</tr>
<tr>
<td>Resolution of launched rays in Elevation [deg]</td>
</tr>
<tr>
<td>Number of rays for ray splitting [deg]</td>
</tr>
<tr>
<td>Resolution of rays for ray splitting</td>
</tr>
<tr>
<td>Number of scattered rays for vegetation</td>
</tr>
<tr>
<td>Resolution of scattered rays for vegetation [deg]</td>
</tr>
<tr>
<td>Number of reflected rays at buildings</td>
</tr>
<tr>
<td>Resolution of reflected rays at buildings [deg]</td>
</tr>
<tr>
<td>Maximum distance before ray splitting [m]</td>
</tr>
<tr>
<td>Maximum mismatch of angle [deg]</td>
</tr>
<tr>
<td>Maximum delay offset (of $\tau_{MPC}$)</td>
</tr>
</tbody>
</table>

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Fig. 5. Visualized paths for several MPCs from one Rx position. Colors only present different MPCs.

launching and so on need to be initialized. Those are given in the initialization window and the ray launching parameters can be changed according to user requirements. The parameters are listed in Table I, the chosen values are set according to our analysis of measurements in [10], which are also used for the further analysis in next section. From the parameters, we can see the cone around the launched ray in azimuth direction is formed by 8 rays with 2.0 degree difference, so in total the width of launched cone is 14.0 degrees. Our measurement is in an outdoor scenario, which has lots of large buildings and vegetation areas. The capture range is set to 10 meter. The reflection coefficient is chosen as 3 [1]. The maximum distance controls the distance when rays start to split, 200 meter is chosen in this measured scenario. We also allow 10 degree mismatch when rays meet at the dummy cylinders. The maximum offset in delay is set to 10% for a valid match.

V. RAY LAUNCHING RESULTS

By using the parameters set in Table I and the measurement results in [10], ray launching results are analyzed and studied in this section.

In Fig. 5, the most likely paths are visualized for a particular RX position. These visualized MPCs have the strongest power among all MPCs at this RX position. It can be seen that there is a small angle mismatch at the TX side for the line-of-sight (LOS) MPC. The difference between the AOD and the propagation direction of ray is around 5 degrees. According to the estimated accuracy of the AOA/AOD and the TX and RX orientation, it is a reasonable difference, and rays can be matched. In addition, non-LOS (NLOS) MPCs are also visualized with several reflection and scattering processes that well reflect real propagation phenomena. It can also be noted that the rays going through the big vegetation area in the lower left side of the figure show a match at one side of the vegetation area, which is marked by yellow color in the figure. In fact, the ray from the TX can meet the RX ray in any place of the vegetation area. The visualized path is matched in the right vegetation area but maybe not at an accurate position. From a channel modeling point view, however, it is good enough to obtain the physical scatterers and the propagation properties.

The intersection points for different RX positions are shown in Fig. 6, both for a LOS and a NLOS scenario. The physical...
intersection points are grouped together based on their physical positions and the power and delay of their MPCs. We can see in general, the NLOS scenarios show more intersections with physical scatters compared to the LOS scenarios. Clearly in this peer to peer scenario [10], the objects around the TX and RX are the most important scatterers.

In order to take a look at the time variant properties of clusters, we also show the intersection points for two RX positions separated around 10 meters (approximately 10 wavelengths), see Fig 7. When the RX is moved, some scatterers keep contributing to the channel response, which means that the cluster is active at different RX positions and has long cluster life time. In addition, one cluster near the TX side disappeared when moving to the new position and instead, a new cluster appears near the RX side. These results indicate possibilities for further usage of this measurement based ray launching tool, such as finding common clusters, extracting cluster life time etc.

In general, the tool is able to suggest the likely propagation paths for most measured MPCs, but some exceptions can be found. A maximum number of iterations is set since in a real propagation scenario after several reflections, the power of ray highly decreases and it is not necessary to go to large number of iterations. In the peer-to-peer scenario here, the TX or RX might be surrounded by many objects. Rich reflection or scattering processes happen at these objects, and then the iteration limit can cause rays not to match. Larger number of iterations can also be considered in the future. At the same time, one MPC can have several matched candidates from the tool, and the best choice is still under discussion. In this work, the delay is chosen to be the most important criterion.

VI. CONCLUSIONS

In this paper, we have described a new measurement based ray launching tool using 3D maps. Based on the delay and angular properties of the MPCs, the ray launching tool provides a good interpretation of propagation paths and shows the physical scatterers. This tool has a good GUI for analysis of measurement results analysis and provide a good understanding of physical propagation processes, e.g., multi-user MIMO channel modeling.

ACKNOWLEDGMENT

This work builds on the framework provided by E. Olsson and A. Stranne. We would like to acknowledge their contributions to the current tool.

REFERENCES