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A Fast and Accurate Method for Modeling of Millimeter-Wave Propagation and Scattering in Rain

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A new method for accurate modeling of propagation and scattering of electromagnetic wave through a random media is presented. In the context of automotive radar, the random media is rain and the method enables performance evaluation of mm-wave radars in presence of rain. Utilizing full-wave numerical methods for analysis of propagation of mm-waves within a range of hundreds of meters is not feasible in terms of simulation time and the required computation resources. The existing approximate methods such as Foldy's method only provide an upper bound for estimation of attenuation rate introduced by the random medium and cannot be applied for accurate statistical modeling of phase front aberration and scattering. The new proposed method is fast but yet very accurate and similar to full-wave methods, can be applied for analysis and statistical modeling of propagation of waves through any random media whether it is sparse or dense.

The proposed method is based on S-matrix approach in spectral domain [1]. In this method, the three-dimensional random medium is divided into slabs with thickness of tens of wavelength. As illustrated in Figure 1, the incoming waves at the two interfaces of the slab are expanded and represented by a number of plane waves traveling in different directions. Within each slab, the incoming plane waves interact with the scatterers such as rain droplets and the resulting scattered fields are again expanded by plane waves. These plane waves are added to the incoming plane waves to form the outgoing plane waves at the two interfaces of the slab. Propagation of the plane waves within the slab and between the boundaries and scatterers can be done either by tracing the plane waves or using Green's function of a homogeneous medium. The latter increases the computation complexity but requires much less memory. Matrix representation of the relation between amplitude and phases of the incoming and the outgoing plane waves, which is equivalent to scattering matrix in network theory, enables exact analyses of the multiple interactions between the adjacent slabs. By cascading the scattering matrices of different slabs, all the interactions between scatterers located at different slabs, which are significant, are captured resulting in a very accurate modeling of scattering and propagating in random media.

Using the proposed method, the statistical distribution of the received scattered waves generated by the randomly distributed droplets with different sizes can be derived for different length of the random media (distance between the radar and the target) and different rain rates. With this statistical distribution, the scattered waves can be generated by a random number generator and added to the radar data for performance evaluation of the radars. Using a simplified model based on the model introduced in [2], it is shown that the phase and amplitude distribution of the scattered waves are defined by three parameters which are functions of rain rate and range.

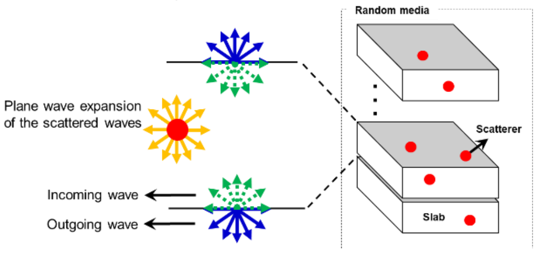

Figure 1. Method for analysis of the propagation and scattering in random media. The random medium is divided into slabs. Each slab is represented by a matrix relating incoming and outgoing waves at the interfaces.

References

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[2] K. Sarabandi, "Derivation of phase statistics from the Mueller matrix," *Radio Sci.*, vol. 27, no. 5, pp. 553–560, 1992.