Bloom Filter for Double Counting Avoidance in Radio Frequency Ray Tracing

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Many ray-tracing algorithms have been proposed since the first ideas by Ikegami et al. in 1991. From the ray handling perspective, most of them fall into three computationally distinct groups: discrete rays, ray tubes and imaging. Algorithms in the first group trace a large number of rays from the transmitting source in all directions into the scene. The concept of a reception sphere is needed to detect rays passing by the receivers. Even if we use variable-sized reception spheres, we will fail to detect exactly one ray per wavefront due to the geometry of ray distribution in space. Here we propose an efficient filtering of rays to avoid double counting at minimal space requirements, thus improving channel modelling accuracy while significantly reducing algorithm memory requirements. Instead of approximate solutions proposed in the past, we put forward space-efficient probabilistic Bloom filters and show their near-optimal wavefront differentiation properties. The contributions of this paper are as follows:

1. Near-optimal double counting avoidance at significantly reduced space cost and lower time complexity than any known solution is proposed by the introduction of versatile Bloom filtering as a wavefront differentiation technique as shown in Fig. 1.
2. Analytical bounds on the reception sphere radius are provided for the two common icosahedral grids used as the ray launching templates. Bounds suggested in the literature are vague, usually quoting approximate average separation angle.
3. Irregularities in wavefront ray spacing are observed for refracted and diffracted rays if rays are traced in full compliance with Snell's law and geometrical theory of diffraction is employed.
4. The effect of double counting is studied in the context of synthetic channel impulse responses and evaluated against measured and analytical path losses as demonstrated in Fig. 2 and 3. Indoor and outdoor cases were presented.

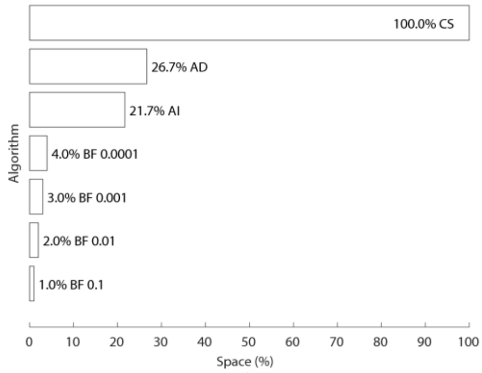

Fig. 1 Relative amount of memory required by the double hit avoidance algorithms with respect to the optimal CS while simulating 30 indoor interactions per ray, given in descending order

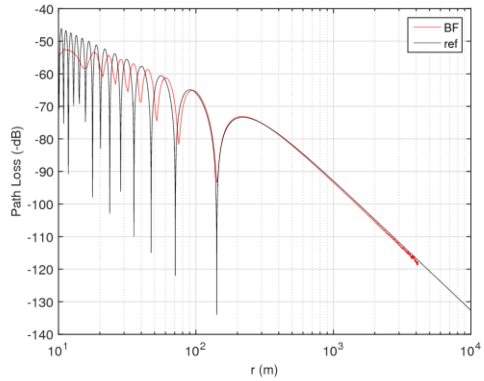

Fig. 2 Analytical plane earth loss is compared to simulated values using double counting avoidance by Bloom filtering at 900 MHz, with transmitter and receivers placed 14.6 m and 1.6 m above the ground, respectively.

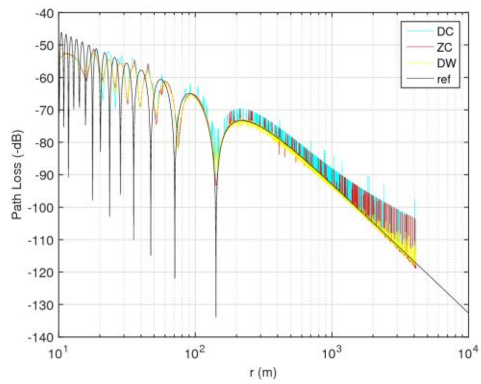

Fig. 3 Double counting error in the plane earth scenario shows as frequently underestimated path loss of other approximate solutions.