Towards a Real-Time Solution of Extreme-Scale Electromagnetic Problems

Brian MacKie-Mason and Zhen Peng
Department of Electrical & Computer Engineering, University of New Mexico, NM 87131-0001, USA

Modern electromagnetics engineering problems often involve large and complex high-fidelity models that push the limits of state-of-the-art computational tools. Domain decomposition methods have proven to be a very useful tool for such problems. In our previous work, we have demonstrated the scalability of a geometry-adaptive domain decomposition method for the integral solution of a large aircraft carrier with hundreds of millions of degrees-of-freedom. However, when the problem size is pushed beyond this threshold, new computational challenges are discovered. The framework for this method is a Schwarz preconditioned Krylov subspace iterative method that is well-suited for distributed high performance computing architectures.

A common class of problems solved with the surface integral equation is that of antennas mounted on large platforms. One bottleneck of traditional domain decomposition methods is the coupling between sub-domains of varying distances. If each sub-domain is thought of as either a receiving or transmitting antenna, then the entire computational domain, for a given radiating sub-domain, can be divided into three distinct regions based on the distance between the receiver and transmitter. A skeletonization representation is used in the near-field, the multi-level fast multipole method is used for mid-range interactions, and the fast far field algorithm is used for long distance computations.

A graph partitioning algorithm is used to ensure the computational load is balanced across the high performance computing environment. It assigns an equal number of degrees-of-freedom to each computational sub-domain as a best initial guess as to the ideal load balancing. This approach does not fully accomplish the goal of having a load balanced domain decomposition solution method due to irregular discretization of the mesh and poor conditioning of the matrix. This issue will be attacked with a sequence of load balancing algorithms. First, during the pre-processing stage, data will be gathered on the time to solution for each sub-domain. The computational sub-domains whose solutions take significantly longer than the average time will be further partitioned into smaller sub-domains. The second load balancing technique implemented will be a dynamic task queue in which the *first-in-first-out* principles are used to assign tasks to the next available MPI process.

The success of this method will be demonstrated through numerical experiments on the convergence, scaling, and efficiency of the implemented algorithms. We will also demonstrate the power of this method by presenting the solution to a real-world antenna problem of a few billion degrees-of-freedom. Finally, a path to achieving the real-time simulation of antenna design problems will be discussed.