Full-wave Moment Method Simulation of Large-scale Antenna Arrays on High Performance Computing Platforms

Donghoon Chun* and Kazem Sabet

EMAG Technologies Inc., 1340 Eisenhower Place, Ann Arbor, MI 48108
*Email: donghoon@emagtechnologies.com

I. Introduction

Simulation of large-scale antenna array structures is a very challenging task in that the simulation requires excessive amount of memory and creates heavy computational load. Typical large-scale array problems involve modeling and discritization of hundreds of radiating elements and very complex feeding networks [1], which can easily create more than 100,000 unknowns in Method of Moments (MoM) computations. Therefore, full-wave simulation of such large-sized problems is very difficult or impossible on conventional workstations due to their hardware limitations. Parallel computers provide one of the ultimate solutions for this difficulty with exclusive computing capacity through thousands of Giga Bytes (GB) of memory and thousands of processors connected by high-speed switches. However, efficient parallel algorithms for a given numerical technique have to be carefully developed to simulate the problem correctly and maximize the capacity of parallel systems.

This paper presents simulation of large-scale antenna arrays on parallel platforms with a conventional MoM technique (such as Mixed Potential Integral Equation [MPIE] [2]). In specific, we discuss parallel schemes for partitioning large-sized geometry files, computation and storage of system matrix, and parallel solution process. In addition, we briefly explain a parallel algorithm for radiation pattern computation in the partitioning scheme. Lastly, we demonstrate application of the developed schemes to a 256-element slot-coupled patch antenna array with 101,555 unknowns. The size of partitioned geometry files, simulation time, and computed radiation pattern are presented as results.

II. Algorithm

One of the first obstacles to encounter when treating large-scale problems is the loading of huge geometry files. Such files whose size typically reaches to several hundreds of MB occupy most of system memory and, therefore, do not allow enough memory space for the system matrix. In this paper, the problem is resolved by partitioning the large geometry file into small pieces for each processor of a parallel system. The partitioning is started from assignment of antenna and circuit elements (objects) to the processors and finished after extracting necessary geometry information for the assigned objects from the large geometry file.

After partitioning, parallel matrix computation is performed in the processors using partitioned geometry information. Each processor computes and stores part of MoM system matrix that corresponds to its assigned objects. In this way, a huge MoM matrix can be distributed over system memories attached to the processors in a parallel machine. Due to the nature of task parallelization, almost linear speedup can be achieved in this process.

Parallel matrix-vector multiplication is the most critical part one should delicately handle to reduce overall simulation time because it takes nearly 90% of the computational load in the solution process for large-sized problems. In order to achieve minimum multiplication time, the processors should store similar number of matrix elements to make the multiplication time uniform across the processors. Matrix balancing [3] is performed by migrating matrix elements between the processors until the number of matrix elements reaches to a certain level of similarity among the processors. Once the balancing is completed, one can begin parallel matrix-vector multiplication by sending a solution vector from master processor to slave processors (step 1) as shown in Fig.1. Local matrix-vector multiplication is then performed in each processor and the results are gathered (step 2) to master processor to produce a final result of the multiplication (step 3).

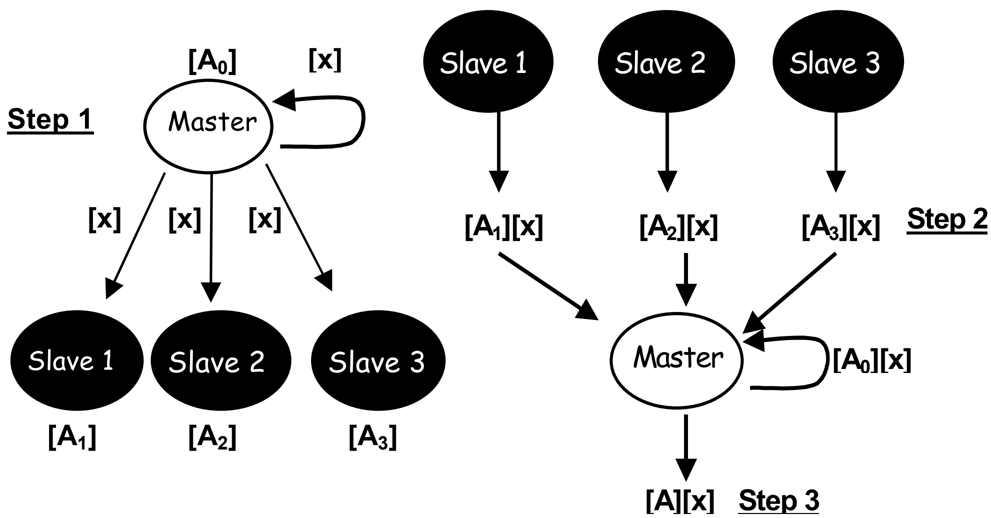


Figure 1: Parallel matrix-vector multiplication

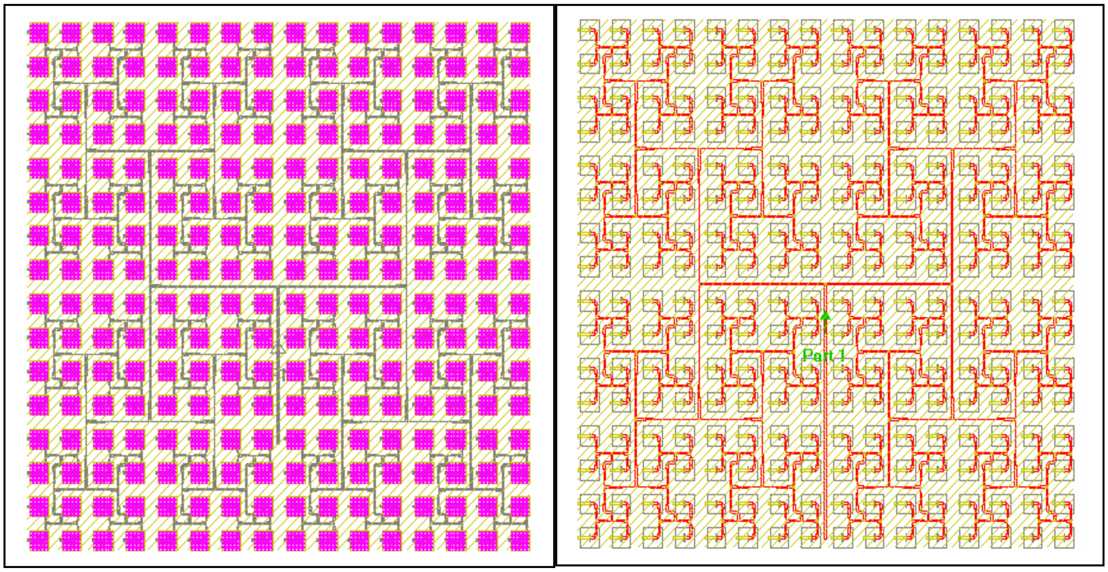
Radiation characteristics can be computed with partitioned geometry information and the solution obtained. Based on array theory [4], we linearly superimpose individual radiation patterns of partitioned geometries to produce effective radiation pattern of a given antenna array problem.

III. Application

The developed parallel algorithms were implemented using Message Passing Interface (MPI) parallel language [5-6] and applied to a 256-element slot-coupled patch antenna array shown in Fig. 2. The simulation was performed on IBM-SP3 with 136 processors at ASC-MSRC in Wright Patterson Air Force Base, OH. The measured wall-clock times for matrix filling and solution process are 250 [sec.] and 35 [hours] per frequency, respectively.

The original geometry file with the size of 870MB is partitioned into 136 pieces in the simulation. The measured sizes of partitioned files are about 23MB, yielding a 97% memory saving in the storage of the geometry information. The original file is reduced to 72MB (90% reduction) on 16 processors through the partitioning as shown in Fig. 3.

The far-field radiation patterns of the 256-element slot-coupled patch antenna array at 2.4GHz are plotted in Fig. 4. The result demonstrates correct radiation characteristics of an antenna array system.



(a) Top view (Patch antenna) (b) Bottom view (Feeding network)

Figure 2: 16x16 slot-coupled patch antenna array system: 101,555 unknowns

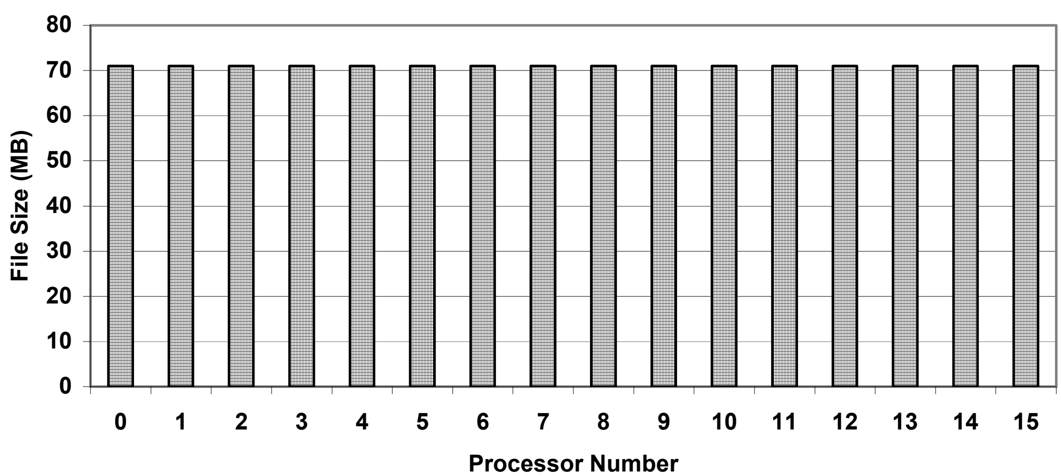


Figure 3: Size of partitioned files from 870MB of original geometry file for the 256 slot-coupled patch antenna array problem (unit: Mega Bytes)

IV. Conclusions

Efficient parallel algorithms for the simulation of large-scale antenna array are proposed in this paper. The developed algorithms are successfully applied to a 256 slot-coupled antenna array problem with 101,555 unknowns. 97% and 90% reduction of file size for 870 MB geometry file have been achieved by partitioning method on 136 and 16 processors, respectively. Parallel simulation performed on IBM-SP3 at ASC-MSRC with 136 processors has produced valid far-field radiation patterns. The results suggest that the developed parallel algorithms can be further applied to general large-scale electromagnetic circuit/antenna problems.

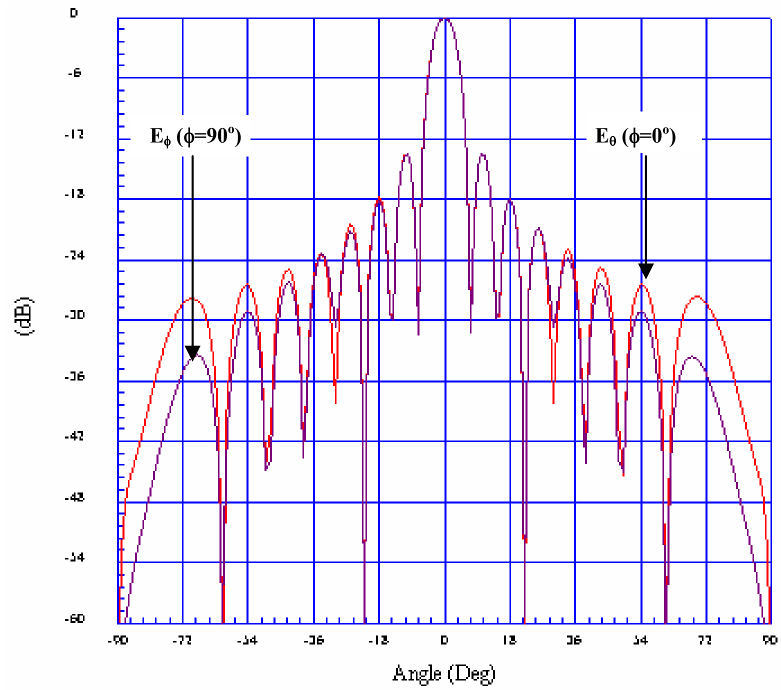


Figure 4: Computed far-field radiation pattern for the 256-element slot-coupled patch antenna array system (f=2.4GHz)

Acknowledgements

The authors would like to thank Dr. Paul Sotirelis for the parallel simulations and the Aeronautical Systems Center-Major Shared Resource Center (ASC-MSRC) for the computing facility. This work has been sponsored in part by the High Performance Computing Modernization Office (HPCMO) of the U.S. Department of Defense under the contract F3361599-C-1517.

References

[1] D. M. Pozar and D. H. Schaubert, “Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays,” IEEE Press, Piscataway, NJ, U.S.A., 1995.
[2] K.A. Michalski et al., “Multilayered Media Green’s Functions in Integral Equation Formulations,” IEEE Trans. on Antennas and Propag., vol. 45, No. 3, March 1997, pp. 508 – 519.
[3] V. Kumar et al., “Introduction to Parallel Computing: Design and Analysis of Parallel Algorithms,” Addison-Wesley Pub Co., January 1994.
[4] W. L. Stutzman and G. A. Thiele, “Antenna Theory and Design,” John Wiley & Sons, Inc., NY, U.S.A., 1998.
[5] “MPI: A Message-Passing Interface Standard,” University of Tennessee, Knoxville, Tennessee, U.S.A., June 1995.
[6] “MPI Programming and Subroutine Reference Version 2, Release 1,” IBM Corporation, Poughkeepsie, NY, U.S.A., August 1995.