Parallel, Distributed-memory MLFMA for Large-scale Electromagnetic Simulations

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The current trend to advance computational power is to incorporate more and more parallelism: multi-processor/core nodes are assembled and connected through fast intercommunication networks. In order to take full advantage of such infrastructure, parallel algorithms need to be designed such that compute workload is evenly distributed among processes and interprocess communication is minimized.

In the case of the Multilevel Fast Multipole Algorithm (MLFMA), this has proven to be a notoriously difficult task. One of the major difficulties is that the nature of the computations changes from level to level in the MLFMA tree. At the lower levels, there are many but smaller radiation patterns whereas at the top levels, few but large radiation patterns come into play. Consequently, in state-of-the-art parallel MLFMA implementations, the parallelization strategy differs from level to level.

In recent work, three existing parallelization strategies (i.e., spatial, hybrid and hierarchical partitioning) were studied in the asymptotic case of large problem sizes \(N\) and number of parallel processes \(P\). The conclusion of that study is that all of these schemes suffer from bottlenecks (i.e., load imbalances) that become apparent for a sufficiently high \(N\) and \(P\) and that become more stringent when further increasing \(N\) and \(P\). As a consequence, this puts a limit on the number of processes \(P\) and hence the problem size \(N\) that can be handled in practice.

Additionally, a modification to the hierarchical partitioning scheme was proposed in which radiation patterns are distributed in a two-dimensional fashion, i.e., both in azimuth and in elevation. This scheme distributes the load among processes in an even fashion, at the cost of a more complex implementation. We report on the performance of this algorithm on a Tier 1 computational cluster with 4,096 CPU cores and 32 TByte of RAM, in which a full-wave simulation with over three billion of unknowns was successfully completed.