

# Mobility–Aware Grid Computing

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## INTRODUCTION

Grid computing has emerged as a paradigm for coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations (Foster, 2001). A grid computing system is essentially a large-scale distributed system designed to aggregate resources from multiple sites, giving to users the opportunity to take advantage of enormous computational, storage, or bandwidth resources that would otherwise be impossible to attain. Current applications of grid computing focus on computational-expensive processing of large volumes of scientific data, for example, for earthquake simulation, signal processing, cancer research, and pattern search in DNA sequences.

At the same time, the recent advances in mobile and wireless communications have resulted in the availability of an enormous number of mobile computing devices such as laptop PCs and PDAs (personal digital assistants). Thus, it is natural to extend the idea of resource sharing to mobile and wireless computing environments. Resource-sharing collaboration between mobile users appears as a promising research direction toward the alleviation of the inherent resource constraints present in mobile computing environments. Either in the context of mobile ad hoc networks (MANETs) or in wireless networks based on fixed infrastructure (i.e., cellular networks, wireless local area networks (WLANs), small- or large-scale communities of mobile users can form mobile grid systems and collaborate in order to either achieve a common goal (otherwise impossible to achieve) or simply overcome their individual limitations. In the following, we highlight the fundamental issues toward the realization of a computational mobile grid system.

## BACKGROUND

The research area of mobile grid is relatively new compared to the traditional (fixed) grid and mobile and wireless computing research areas. A consensus on the exact character of mobile grid computing has not been reached yet. Hence, a classification of the existing approaches is provided in the following, aiming at the clarification of the mobile grid

concept. At the same time, the most significant research directions within each approach are described.

As mentioned earlier, a primary distinction is made between various research efforts in the area based on whether mobile devices act exclusively as resource consumers or as resource providers as well.

### Mobile Devices as Resource Consumers

In this case, research is motivated by the fact that mobile devices are considered to have limited computational and/or storage capabilities (Banavar, Beck, Gluzberg, Munson, Sussman, & Zukowski, 2000; Migliardi, Maheswaran, Maniymaran, Card, & Azzedin, 2002; Park, Ko, & Kim, 2003; Srinivasan, 2005). The grid, in this case, can provide the resources missing in mobile devices on demand. The emerging problems here stem from the mobile and wireless character of the devices and include intermittent connectivity, device heterogeneity (in terms of hardware and operating system), and limited battery life. The use of proxies is proposed in Park et al., which act as gateways to the grid. These proxies undertake the role of the mediator between the mobile device and the grid system, and try to hide device heterogeneity and intermittent connectivity by acting on behalf of the mobile device.

Other approaches target the provision of a “smart” environment for pervasive computing (Banavar et al., 2000; Srinivasan, 2005). Here, mobile devices are considered as pure access devices with no need for enhanced processing and/or storage capabilities (Migliardi et al., 2002). The role of the grid is to provide all the functionalities required by users, pushing this way the complexity of the system to the network rather than to the edges.

### Mobile Devices as Resource Providers

In this case, mobile devices participate in grid systems as resource providers as well (Kurkovsky & Bhagyavati, 2003; Li, Sun, & Ifeachor, 2005; Litke, Skoutas, & Varvarigou, 2005; Park et al., 2003; Phan, Huang, & Dulan, 2002). Strong emphasis is given to two important factors. First, even though mobile devices have limited resources compared to their

stationary counterparts, they seem to increasingly gain sufficiently powerful CPUs and storage means. In effect, they are considered capable of providing useful resources. Second, since the number of mobile devices continuously increases, their aggregate resources cannot be considered negligible (Phan et al.). Again, mobility and device heterogeneity pose significant challenges, especially due to the mobility of the resource providers. Moreover, an important problem rises here: Since mobile devices are strictly personal and at the same time resource constrained, it is not a given whether their resources will be offered by the device owners for the sake of collaboration or not.

In a second-level classification, two fundamentally different architectures have been proposed in an effort to exploit resources relying on mobile devices. Their difference concerns the underlying networking topology.

### Mobile Grids on Site

In mobile grids on site (Katsaros & Polyzos, 2007a; Kurkovsky & Bhagyavati, 2003; Kurkovsky, Bhagyavati, & Ray, 2004; Park et al., 2003; Phan et al., 2002), mobile devices residing in a well-defined area, such as a cell in cellular networks or a WLAN hot spot, are coordinated by a central entity (residing at the access point or base station, BS) in order to perform a task (computational grid). The advantage of this approach is that the BS does not suffer from the constraints imposed by mobility. Therefore, it is considered suitable to act as a mediator capable of hiding the heterogeneity of the participating devices from the requesting node, coordinating the overall execution of the submitted job, and even allowing the grid system to appear to the rest of the network as an ordinary grid node (Phan et al.). What is more, these networking environments are characterized by the concentration of a large number of mobile nodes yielding a potentially large amount of aggregated resources, usually under a single administrative domain (Katsaros & Polyzos).

### Mobile Ad Hoc Grids

In the case of mobile ad hoc grids (Gomes, Ziviani, Lima, & Endler, 2007; Li et al., 2005; Marinescu, Marinescu, Ji, & Boloni, 2003), there is no stationary entity responsible for the coordination of the overall job execution. In environments such as MANETs, the absence of fixed nodes imposes difficulties in resource discovery, job scheduling, and monitoring. The instability of the network topology induces further difficulties due to unique ad hoc characteristics such as network partitioning and multihop routing. An approach toward overcoming this limitation is the formation of a virtual backbone consisting of a number of possibly more powerful

mobile nodes responsible for coordinating the mobile nodes residing in a certain area of the overall ad hoc network (Li et al.; Marinescu et al.).

## TOWARD THE REALIZATION OF A MOBILE GRID

### Collaboration and Contribution

As implied earlier, the very essence of a mobile grid system depends on the actual availability of the existing mobile resources. Given that mobile devices are in principle personal devices with limited resources, at least in comparison to stationary ones, a critical issue concerns the willingness of the mobile users to offer their resources, that is, the willingness to collaborate. Therefore, a crucial target for the realization of mobile grids is to ensure this willingness, and this is subject to the incentives given to the owners of the mobile devices.

In the simplest case, the incentives may be inherent in the community of the collaborating mobile users; that is, mobile users may collaborate in order to achieve a common goal. However, mobile nodes may participate in a community where no common goal exists. In this case, mobile nodes would possibly engage in a mobile grid system to overcome their individual limitations, but it is not straightforward why they would also provide their own resources as well. Hence, in environments where users are considered rational (or selfish), proper incentive schemes are required to motivate collaboration. A simple approach, borrowed from the context of peer-to-peer systems, is based on reciprocity; that is, mobile users may consume resources offered by other mobile users as long as they also provide their own resources (Katsaros & Polyzos, 2007a). Apparently, a balance between consumed and offered resources must be struck for each participant in order to eliminate free riding (see also the “Security Issues” section).

This balance is strongly influenced by the fact that the willingness for collaboration is directly affected by the actual amount of the resources that are required to be offered. Special care must be given in order not to drain the already limited resources of mobile nodes as this would inevitably discourage users from participating in the mobile grid. In effect, the power of a mobile grid system must come from the aggregation of small amounts of resources from multiple mobile devices at a time. Additionally, mobile-device owners must be given the flexibility to control the degree of actual contribution to the mobile grid with respect to several criteria, such as available power and current device workload.

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