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A store-carry-process-and-forward paradigm for intelligent sensor grids

Carlos Borrego [a,*], Sergi Robles [b]

[a] Institut de Física d'Altes Energies, Universitat Autònoma de Barcelona, Barcelona, Spain
[b] Departament d'Enginyeria de la Informació i de les Comunicacions, Universitat Autònoma de Barcelona, Barcelona, Spain

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A B S T R A C T

Store-carry-and-forward DTN (Delay/Disruption Tolerant Networking) protocols offer new possibilities in scenarios where there is intermittent connectivity, asymmetric bandwidths, long and variable latency and ambiguous mobility patterns. In this article we propose a new paradigm – *store-carry-process-and-forward* – based on mobile code to improve the integration of wireless sensor networks and grid computing infrastructures. We describe the implementation of a delay tolerant grid service, the computer element, to give computing access to an intermittently connected wireless sensor network. The result is an intelligent system which adapts dynamically to intermittent disconnections and improves multi-application coexistence. Finally, we present as an example a real case application which provides general purpose grid access to a multi-application mobile robot node sensor network.

1. Introduction

Grid computing [33,15] has consolidated as a technology capable of solving some of the most challenging scientific projects of our century. The needs of these projects usually include complex computation of data obtained from different sources and stored in large storage resources. The main goal of grid computing, precisely, is to share these resources among different institutes and virtual organizations across high-speed networks and distribute and coordinate its processing.

Wireless sensor networks (WSNs), on the other hand, is a technology that can be very useful when it comes to acquiring and transporting data collected in widely spaced areas. These networks consist of different nodes carrying different sensors along with autonomous computational devices which transmit data through the network to some specific locations or data sinks.

This article analyzes how both technologies, grid computing and wireless sensor networks, can be combined into an integrated WSNs and computer grid infrastructure allowing new functionalities. The corner stone of this conjugation is using delay and disruption tolerant networking (DTN) concepts [14] along with mobile code to create an intelligent grid network capable of routing and managing processes depending on the context. Some other recent proposals, which will be further described in Section 2, integrate WSNs and grid computing, as well. However, our proposal comes from the network perspective. We consider WSNs nodes as intermittent connected nodes, containing asymmetric bandwidths, long and variable latencies and ambiguous mobility patterns. This new perspective contributes to the creation of a novel concept of intelligent grid computing networks, going beyond the possibilities of the reviewed literature in some current scenarios, and providing promising prospects for supporting future grid services.

The routing decision making and execution policies travel with the messages, instead of being static and exactly the same for all nodes. These policies, in the shape of mobile code, can take into account the context of the nodes to choose the behav-

* Corresponding author.
E-mail addresses: cborrego@ifae.es (C. Borrego), sergi.robles@uab.cat (S. Robles).

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ior that fits best in each situation. All in all, the system acts more like an ant colony, with differentiated autonomous parts acting locally but with a cooperative aim, rather than a traditional and more inflexible system. Thus, using mobile code makes the grid network an intelligent system, pliable enough to adapt to new scenarios of grid computing. However, the proposed system cannot be considered a silver bullet for all grid computing; in highly connected grids, with low latencies and where data does not need to be processed before getting to the execution destination, mobile code would introduce an unnecessary extra overhead and other unwanted side effects.

The original contributions of this paper are: a grid computing model based on mobile code to allow intermittently connected wireless sensor networks to seamlessly coexist with other traditional connected services and a grid computer service which transparently gives access to a general purpose multi-application mobile robot node sensor network.

This paper is organized as follows: Section 2 is a state of the art of the combined use of grid computing and wireless sensor networks, having a closer look at those ones which suffer from intermittent connections and those using mobile code. Section 3 presents our proposal, an intelligent system following the store-carry-process-and-forward paradigm. In Section 4 we present a delay tolerant architecture for grid services which are transiently unavailable. In Section 5 we analyze how to include intermittent connected networks in traditional grid computing systems using mobile code. Services such as computing, storage, information service and monitoring will be discussed in detail. Finally, Section 6 presents the conclusions we have come to.

2. Background

There are several efforts already published on the integration of wireless sensor networks and grid computing. Studies like [30] and [23] propose different ways of extending the computing grid paradigm to allow the integration of wireless sensor networks and grid computing infrastructures. This section analyzes the state of the art of other technologies: mobile code and DTN protocols which we believe can extend and improve this integration. In Fig. 1, research overlapping of the four technologies is depicted.

The widespread use of portable devices, generally equipped with wireless enabled communications, GPS receiver, and touch screen, has remarkably improved outdoor applications in a great variety of scenarios. Although the most common network configuration is adhoc, or mobile adhoc (MANET), new communication paradigms are emerging to fill the void for some specific settings. This is the case of delay and disruption tolerant networking (DTN) [14], extremely useful when no concomitant network links connect source and ultimate destination at transmission time.

Unfortunately, although DTN has strong foundations and many groups have been working on its formalities for some years [35,36], there is still a number of issues to be solved. Several interesting proposals have been already proposed and implemented which cover problems like routing [17], congestion [28], and security [3].

Some of these topics need solutions quite different from the ones used normally in the Internet. The rationale for this is that the diverseness of applications running on such limited connected networks calls for a number of different mechanisms to solve the specificities of each one. In opposition to what happens in the Internet, no general purpose mechanisms exist satisfying the requirements of all applications at once.

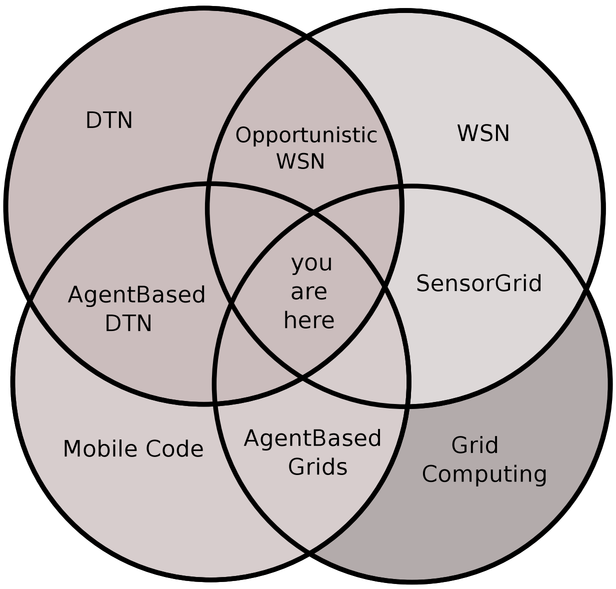

Fig. 1. State of the art.