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Striving for sensing: Taming your mobile code to share a robot sensor network

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ABSTRACT

This article presents a general purpose, multi-application mobile node sensor network based on mobile code. This intelligent system can work in delay and disruption tolerant (DTN) scenarios. Mobile nodes host software mobile code with task missions and act as DTN routers following the store-carry-and-forward paradigm. Most similar proposals are unable to simultaneously run different applications, with different routing algorithms, movement models, and information retrieval strategies. The keystone of the approach in this paper is using mobile code at two levels: for the application, and for the definition of the behavior in terms of routing algorithms, movement policies and sensor retrieval preferences. The intelligence of the system lies in its ability to adapt to the environment, dynamically optimizing routing algorithms using local and global information and influencing node movement. Simulations and an implementation of a real scenario have been undertaken to prove the feasibility and usability of the system, and to study its performance. A proposal for a real-world application in the context of refugee camp management is presented.

1. Introduction

Using a network of mobile nodes as a generalization of robots for sensing purposes is not a new idea at all. Many proposals have been described or envisaged, hitherto making use of a troop of mobile devices equipped with a bunch of sensors. Some of them even use the very same mobile node network to transmit the acquired samples to a data sink. And yet, most of these systems are oriented to just one application, and all critical mechanisms, such as message routing or the physical movement pattern, are fitted with the specific actions and main goals of that particular application.

Being practical, and considering other network evolutions such as the Internet, it would be much more useful to take advantage of such a physical infrastructure, which would allow several applications to simultaneously use the mobile nodes and their sensors in their own way. The benefits are clear: a general-purpose sensor mobile node network is better when reusable, and when it allows new applications to be implemented after the mobile node network has been deployed. Unfortunately, turning such systems into multiple-application, general-purpose ones is not very easy. If several different applications coexist, which is the best message routing algorithm for them all? If mobile nodes can alter their pathways to adapt to some applications' requirements, what if there is a handful of applications striving against each other to make the node move

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under their command? These and other issues have to be considered when designing a mobile node sensor network, and can be very hard to solve.

In this paper, we propose a general-purpose sensing mobile node network, addressing the previously stated questions and many other issues surrounding the coexistence of applications and the routing of information. The rationale behind this proposal is to have mobile code at two different levels. Firstly, at the user application itself, which can move from mobile device to mobile device as it suits best the application in order to accomplish its goals. And secondly, at the message level, allowing the very same message to make the routing decision by itself, taking into account for example some context information, and independently from other messages' routing policies. The resulting system has been devised as a particular case of Wireless Sensor Network (WSN), i.e., a network of autonomous sensors aimed at monitoring physical or environmental conditions that pass their data through the network to certain locations or data sinks [32], using a DTN (Delay and Disruption Tolerant Networking) architecture [11]. In a DTN, data can be sent between any two nodes of the network, even when middle nodes are not permanently connected. This is possible by following an asynchronous store, carry and forward paradigm.

There is a wide variety of data that can be acquired by means of sensors, ranging from temperature, humidity, or noise levels, for example, to other higher level data such as object or human recognition, movement pattern detection, or plague detection; the DTN approach only broadens the scenarios of this particular WSN, allowing a myriad of applications.

One could wonder why a DTN-based network would be better in the case of a mobile node sensor network than a more traditional Ad-hoc, or while we are at it, MANET [35], network. The main reason for this is the required density of nodes. A DTN approach, for example, does not need a figure of nodes directly proportional to the sensing area to guarantee the operation of the system. Likewise, the sensing area can be extended or shrunken depending solely on the running applications. In Ad-hoc networks, communication range and sensing area determine the minimum number of nodes to be used. The maximum sensing area is determined by the range and position of the mobile nodes and extending it is very difficult without adding new nodes.

The architecture and operation of this network is presented within the paper, which also provides details on how some issues have been resolved. For instance, how population growth is controlled when cloning is considered, how dynamic multi-routing is achieved, or how mobile messages can influence node movement respectfully and fairly to other messages. Security has been considered, as well, analyzing the threats and requirements, and giving mechanisms to protect nodes.

The results are significant, and the overall performance of the system has been found very reasonable. A number of simulations have been done, from which some interesting outcomes have been drawn. It is remarkable a significant improvement in terms of message delivery ratio and latency. Furthermore, a successful proof of concept has been undertaken using real physical mobile nodes to check the feasibility of the proposal. The proposed network is suitable for use in a variety of applications such as underwater environment sensing, unmanned aerial vehicle networks, environment applications, disaster field on emergency scenarios such as earthquakes recovery or terrorist attacks, mines seeking, urban search missions, community development, machine surveillance, e-agriculture, biological attack reconnaissance and many others.

The original contributions of this paper are: a general-purpose, multi-application, mobile node sensor network based on mobile code, a dynamic multi-routing schema for allowing different routing algorithms for different applications and an application influenced movement model for minimizing node stagnation and maximizing segregation.

The rest of the paper is organized as follows: Section 2 reviews the state of the art. The core of the proposal is described in Section 3. Section 4, covers the security aspects of the system. In Section 5, the experimentation using simulations is described. In Section 6, some feasibility physical tests are presented. In Section 7, a proposal for a real-world application in the context of refugee camp management is presented. Finally, in Section 8, results and the conclusions that are drawn are presented.

2. State of the art

There is a wide range of literature concerning Wireless Sensor Networks (WSNs) [32]. The large amount of publications revolve around the different WSN's issues, such as fault tolerance [14], scalability [4], sensor placement [16], caching [9] power consumption [28], data aggregation [21] and data gathering [29].

In some particular cases, a WSN can be also seen as a collection of different sensor nodes which coexist in scenarios in which intermittent connectivity, asymmetric bandwidths, long and variable latency and ambiguous mobility patterns can be present. There are two main projects which actively study the scenarios known as delay and disruption tolerant networks (DTN) [11]. The first one is the Delay Tolerant Network Research group [42], which has defined an end-to-end protocol, abstract service description for the exchange of what they call bundles [34]. These bundles carry application information from one intermediate DTN node to another. The second project is Haggle [33]. Haggle defines an one-way communication architecture and its main purpose is to take advantage of brief connection opportunities. Both projects have a common aim: to propose solutions to scenarios in which network availability is intermittent or suffers from long delays by message-switching and opportunity-oriented behaviors.

Among all of the different DTN issues, routing [31] is probably the most challenging one. In this paper, we focus on dynamic and adaptive approaches for the routing problem. There are interesting proposals like [38] which include routing schemes to allow dynamic policies to choose from different routing possibilities. Authors of that proposal state, in concordance with this paper, that no unique routing solution can sufficiently cater to the different communication requirements.