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Maximizing connected coverage via controlled actor relocation in wireless sensor and actor networks

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ABSTRACT

Wireless sensor and actor networks (WSANs) have recently emerged with the idea of combining wireless sensor networks (WSNs) and mobile ad hoc networks (MANETs). In addition to resource constrained sensors, resource rich and mobile actor nodes are employed in WSANs. These actors can collect data from the sensors and perform appropriate actions as a result of processing such data. To perform the actions at all parts of the region in a timely manner, the actors should be deployed in such a way that they might be able to communicate with each other and cover the whole monitored area. This requires that the actors should be placed carefully prior to network operation in order to maximize the coverage and maintain the inter-actor connectivity. In this paper, we propose a distributed actor deployment algorithm that strives to maximize the coverage of actors without violating the connectivity requirement. The approach applies repelling forces between neighboring actors and from the sensors that sit on the boundaries in order to spread them in the region. The spreading of the nodes is done using a tree of actors which can provide more freedom for the movement of the nodes but at the same time maintain the required connectivity among the nodes. We present two techniques for creation of such an actor tree which are based on local pruning of the actor links and spanning tree of the inter-actor network. The performance of our approach is validated both analytically and experimentally.

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1. Introduction

With the idea of eliminating human intervention from the wireless sensor networks (WSNs), wireless sensor and actor (actuator) networks (WSANs) have received a growing attention from the research community in the past years [1]. Such networks employ large number of miniaturized low-cost sensing nodes that are responsible for measuring ambient conditions and reporting such measurements to some actor nodes over wireless communication links. Actors have the capability for processing the sensed data, making decisions and then performing the appropriate actions. Robots, rovers and unmanned autonomous vehicles (UAVs) are some examples of possible actor nodes [1–4]. Example of WSAN applications include facilitating/conducting urban search and rescue (USAR), detecting and countering pollution in coastal areas, performing in situ oceanic studies of bird/fish migration and weather phenomena, detection and deterring of terrorist threats to ships in ports, destruction of mines in land and under water, and monitoring the environment for unusually high-level of radiation [1].

Coverage is one of the most important design goals in most applications of WSANs [3]. It is often required for the network to provide services at every part of the deployment area. For instance, in USAR applications [3] in case of events such as fires, earthquakes, disasters, etc. various robots, designated as actors, can be employed in places where rescue workers and search dogs cannot enter. Such actors will have the ability to sense, move, and hence

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recognize the victims or survivors who can be at any location in the event area. In such a case, the actors need to make a decision in terms of how many and which actors to employ for efficient rescue operation. For instance, the survivor can be in desperate need of oxygen gas, water, or even some sort of medicine within a short period. Therefore, the decision making process should be fast and result in the best possible solution in terms of the number of actors to employ, their traveling time, and distance to the survivor. This interaction among actors requires that actors stay reachable to each other. In other words, actors should form a connected network among themselves in order to perform such collaboration. Therefore, actor placement has to not only maximize the area coverage but also ensure inter-actor connectivity.

In this paper we investigate the problem of actor relocation for increased connected coverage while maintaining inter-actor connectivity. We present a Relocation algorithm for Connected Coverage, namely RCC, for post-deployment of actors which will increase the connected actor coverage through relocation of actors based on repelling forces from neighboring actors and boundary sensors. RCC is completely distributed; relying only actors' interaction with each other in their neighborhoods. The main idea is to apply repelling forces among neighboring actors, similar to molecular particles in Physics, in order to spread them in the deployment area. Furthermore, sensors which sit on the boundaries of the monitored area also impose forces to actors so that they will not move outside the targeted region where no sensors exist. The forces are applied in steps until there is no further movement in the network. In that case the inter-actor network is said to be converged.

When applying the forces, we make sure that the initial connectivity is maintained at each step so that the inter-actor network is not partitioned when the network converges. This is achieved by restricting the movement of each actor when they are being relocated. Specifically, each node is responsible for keeping its connectivity with its current neighbors even after its relocation. However, this will not give enough room for the node to improve its coverage as there may be multiple nodes connected to it. Therefore, we present two mechanisms, namely local pruning (LP-RCC) and spanning tree-based pruning (ST-RCC) to minimize the number of links that has to be maintained by a particular actor. While LP-RCC performs this by looking at only 2-hop neighbors of an actor, ST-RCC creates a spanning tree for such purpose. The spanning tree contains the minimum number of links which will span all the nodes in the network and thus will give chance to provide more freedom to the actors nodes when relocations are performed. The performance of LP-RCC and ST-RCC are evaluated both analytically and through simulations and are shown to be effective in achieving almost the same connected actor coverage of the optimal solution.

This paper is organized as follows. The next section describes the system model that we consider throughout the paper. The related work is discussed in Section 3. Section 4 discusses the connected actor coverage relocation problem in details and describes LP-RCC and ST-RCC. In Section 5, we analyze the performance of RCC algorithm in terms of movement, message complexity and convergence time. Experimental validation of LP-RCC and ST-RCC is done in Section 6. Section 7 concludes the paper with a summary and a highlight of our planned future extensions.

2. System model and assumptions

In this paper, we assume a set of sensors and actor nodes that are spread randomly throughout an area of interest to detect and track events and take necessary actions in that area. While sensors are deployed in abundance, the number of actor nodes is limited since robot-like nodes are usually used and they tend to be very expensive. The actors are both less-energy constrained and have larger radio range than the sensors. While an actor can in theory reach other actors through a satellite, the frequent inter-actor interaction required by the application would make the often-intermittent satellite links unsuitable. We also assume that actors can discover each other in the area trough repeated beacons. Actors aggregate their individual set of neighbors in order to establish a core inter-actor network. Fig. 1 articulates the considered WSAN model. An actor collects sensors' data in its neighborhood and collaborates with other actors. Some of the actors can interact with a remote command center through a long haul communication link, e.g., through a satellite, to report on their activities and detected event/targets.

In addition to the radio range, the action range of an actor is defined as the maximum distance it can act. This is similar to the sensing coverage range of sensors and assumed to be equal for all actors. We considered the coverage to be based on the area under the control of a particular actor. The distribution and the number of sensors are not considered when action range is defined. Nonetheless, as will be explained later, we detect the

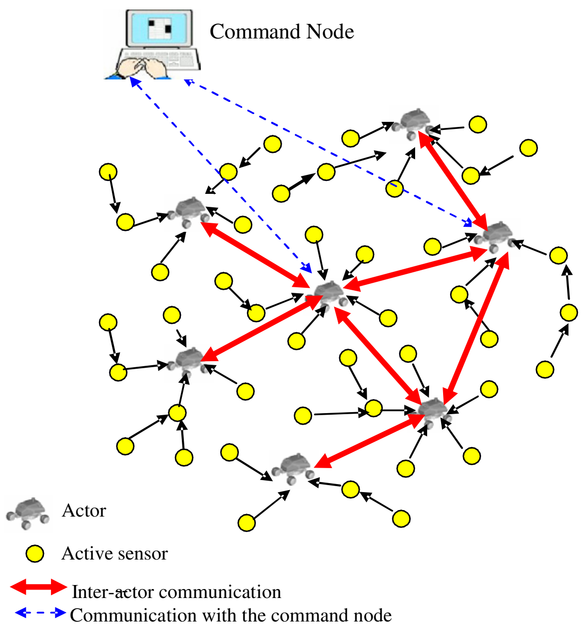

Fig. 1. WSAN with a connected inter-actor network.

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