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A Bayesian network approach to a biologically inspired motion strategy for mobile wireless sensor networks

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ABSTRACT

Mobility strategies for wireless sensor networks (WSNs) are presented. We introduce a grazing mobility strategy for mobile WSNs, inspired by the foraging behaviour of herbivores grazing pastures. We present Bayesian network GRAZing (BNGRAZ) that implements the proposed WSN grazing strategy. BNGRAZ uses local neighbourhood information to predict coverage and connectivity performance changes related to sensor node motion characteristics. This enables a sensor node to predict the performance implications related to its direction of movement. We implement the BNGRAZ approach to grazing in a custom built mobile WSN simulator. The WSN performance criteria considered during the validation process include coverage, redundancy, connectivity, and network lifetime.

1. Introduction

Recent advances in sensor technology (in terms of size, power consumption, wireless communication and manufacturing costs) have enabled the prospect of deploying large quantities of sensor nodes to form wireless sensor networks (WSNs). These networks are created by distributing large quantities of usually small, inexpensive sensor nodes over a geographical region of interest in order to collect data relating to one or more variables. These nodes are primarily equipped with the means to sense, process and communicate data to other nodes and ultimately to a remote user(s). WSN nodes can also have mobility capabilities which enable them to roam the region of interest to harvest information. Sensor nodes may cooperate with their neighbours (within communication range) to form an ad-hoc network. WSN topologies are generally dynamic and decentralized. WSNs have a wide range of applications including military, environmental monitoring, health, home, space exploration, chemical processing, and disaster relief.

The majority of WSN research has assumed that the nodes are static and that once deployed they are unable to relocate. This limits the ability of WSNs to adapt to changing operating environments. A large number of applications involve a dynamic environment and/or do not necessarily need the deployment of large quantities of static nodes.

A mobile WSN varies from traditional static WSNs in the obvious sense. A fraction of the sensor nodes can have motion capabilities which enable the WSN to change position over time according to some strategy. This motion may be achieved by including motors and servos onto the node platform. Mobility capabilities may also be possible by attaching the nodes to other mobile entities. This gives the nodes the ability to physically change position in relation to neighbouring nodes and also the environment in which the nodes are situated. The nodes may move

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individually to optimize the performance of the network. Mobility strategies aimed at this have been presented by Kansal et al. [5–7], and Rao and Biswas [9]. Nodes may also move cooperatively around the geographical region of interest to adapt to the environment and/or application criteria.

When deploying a WSN in a region of interest a number of alternative approaches can be adopted. The region could be covered with a large quantity of static nodes, which achieve the desired coverage criteria at initial deployment. The network would generally incorporate a high level of redundancy in order to extend its lifetime, with redundant nodes providing a level of fault tolerance. The drawback of this approach is that optimum deployment is required to achieve the desired level of performance. When considering deployment to unmanned remote regions, optimum deployment becomes difficult to achieve.

An alternative approach is to deploy a smaller quantity of mobile nodes. These nodes would not achieve the desired level of coverage at any instantaneous point in time; however, over a finite period of time total coverage (specified coverage criterion) could be achieved. In order to achieve this nodes migrate around the geographical region collecting data and thus providing total coverage. This concept will be referred to as a grazing strategy, by analogy to a herd of herbivores feeding off pastures.

This paper presents a mobility scheme based on a decentralized Bayesian network GRAZing (BNGRAZ) algorithm that adopts the proposed WSN grazing strategy. BNGRAZ uses discrete Bayesian networks to predict the likelihood of deterioration in performance given that the sensor node moves in a particular direction. The evidence used for prediction is obtained from local neighbourhood information, which minimizes the communication overheads and provides scalability. The performance criteria considered under the BNGRAZ algorithm include connectivity and coverage. The paper also presents a distributed coverage approximation (CA) algorithm. This algorithm enables the sensor nodes to approximate the collective coverage of the WSN using only local knowledge of neighbouring node configuration. The CA algorithm is required for the successful operation of the BNGRAZ algorithm.

The simulation results have been obtained by implementing the proposed BNGRAZ algorithm using a custom built simulator which allows the evaluation of the performance of mobile WSNs.

Section 2 of this paper outlines related work on mobile WSNs, and their inherent performance implications and benefits. Section 3 discusses the grazing strategy in detail outlining the performance implication and benefits. Section 4 discusses the proposed decentralized BNGRAZ algorithm that aims to achieve the grazing motion behaviour in WSNs. In Section 5 we present the simulation results and compare the results to a generic fixed path approach. Finally, 6 concludes the paper and discusses future work.

2. Related work

WSN are currently a widely researched topic. For a detailed review of architecture, management, communication protocols, and their current and potential applications, see [2].

Mobility as a control primitive for self-deployment of WSNs has been investigated. For example [18] proposes a distributed self-deployment protocol which uses Voronoi diagrams to discover coverage holes caused by non uniform deployment. The paper proposes three movement-assisted sensor deployment protocols which essentially relocate sensor nodes from densely deployed regions to areas with sparse coverage. In [14] a self-deployment protocol for heterogeneous WSNs is proposed.

Mobility as a control primitive for improving network performance has also been investigated. For example [6] proposes a distributed coverage fidelity (Co-Fi) algorithm that controls the relocation of a sensor node in order to repair coverage holes which are assumed to be a consequence of node failure. In [13] a dynamic coverage maintenance (DCM) scheme is proposed that also exploits the limited mobility of sensor nodes for active fault repair of the WSN. Four distributed rule based DCM algorithms are proposed which rely on local neighbourhood topology information for coordinating the sensor relocation.

In [4] an event based mobility scheme is proposed that coordinates the relocation sensor nodes to areas that require a higher sensing resolution. Using single dimensional mobility for improving sensing resolution and overcoming unpredictable environmental influences has also been investigated. In [5] a low complexity single dimension mobility strategy is proposed which has low energy actuation primitives. The nodes move along a single dimension to counteract a loss in coverage caused by environmental influences such as the presence of obstacles.

Low complexity mobility was also investigated in [10] and [11] through the development of the Network InfoMechancial System (NIMS). NIMS's integrate distributed, embedded sensing and computing systems with infrastructure – supported mobility.

Using mobility as a control primitive to extend the network lifetime by balancing the energy discharge rate (EDR) between all sensor nodes has also been investigated. For example [9] proposes a biologically inspired mobility model for balancing the energy overhead related to communication.

The group migration of a WSN has also been investigated. For example [19] presents a mobility management protocol for group migration of sensor nodes. The paper suggests that in order for a WSN to provide the specified coverage or track moving targets, it should incorporate some level of mobility. In [15] a centralized group migration strategy is proposed. The commander (user) controls the motion of a cluster of mobile sensor nodes. The nodes are deployed to monitor a square area at a certain distance ahead of the commander's motion direction. As the speed and direction of the commander changes, the new positions of the sensor nodes are calculated by the proposed movement control algorithm. Other work assumes alternative infrastructures with nodes acting as commanders (referred to as actors) Vassis et al [25]. In this work, we assume that the WSN has a single commander node which is essentially a sensor node capable of aggregating and forwarding all sensing data to an eventual recipient via a network gateway.