A Framework for Intelligent Data Gathering and "Triage" Techniques in Self Maintaining Ad Hoc Wireless Sensor Networks for a Martian Environment

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Abstract

The deployment and operation of self-organizing and autonomous ad hoc sensor networks is envisioned as playing a key role in exploration of Mars and space exploration in future. Ad hoc sensor networks have stringent energy requirements, and this problem of managing energy consumption across sensor nodes in order to increase the longevity of the network is important. This paper focuses on sensor networks on a Martian surface where human intervention is either impossible or risky and costly, and as a result the network might be short-lived and unable to fulfill its objective. Past research has shown that routing software protocols that are distributed and location aware can result in power savings in an ad hoc wireless sensor network. This research moves beyond routing protocols, to consider how an autonomous ad hoc sensor network could use all available resources to extend its useful lifetime. We analyze the current state of research, and propose a new framework for intelligent data gathering and the use of "triage" techniques in the form of a tool known as TRIAGE (Tool for Resource and Information mAnaGement in Extreme environments). TRIAGE is used to coordinate the self-repair and maintenance of a wireless ad hoc sensor network, and specifically attempts to address the remote operation of sensor nodes in a self-maintaining wireless ad hoc sensor network. Such a system would be ideal for data gathering in a remote, extreme environment, such as the Martian surface.

Key words: Triage, Ad hoc, Sensor networks, Robot, Routing Protocol

I. Introduction

"One of the JPL Sensor Web Project major objectives is to support the NASA goal of establishing a virtual presence throughout the solar system. Sensor Webs may play a critical role in meeting this objective. Like remote planetary measurements obtained by satellites and telescopes today, the webs allow large areas to be monitored in the future."- NASA [11]

Our research project supports this vision of future by advancing the state of the art of distributed, scalable, energy efficient, self-configurable, and self-diagnostic wireless ad hoc sensor networks, suitable for deployment in inhospitable environments, such as the Martian surface. This network is made up of sensor units that record measurements such as temperature, humidity, pressure, luminous intensity, wind speed, solar radiation, and so on, and which are capable of communicating with one another and transmitting data to a base station. Each sensor unit is independent, with some form of onboard power supply in form of batteries, and has enough processing power to carry out its routine tasks. The mobility of these sensor units is very low but the data forwarding strategy is robust enough to be fault tolerant and to allow occasional (perhaps accidental) mobility among units.

A real life sensor network can be composed of hundreds of nodes. Typically, the nodes are battery powered, so the first research challenge is getting data back with minimal energy expenditure, by choosing energy-efficient paths and by minimizing the routing overhead. The second challenge is to maintain connectivity in case some nodes are moved to a different location or fail to participate due to lack of power, though overall mobility is likely to be more limited than in a network of laptops. The third challenge is that sensor networks can be expected to grow to many thousands of nodes, so any routing algorithms used in these networks must be scalable. Finally, the routing algorithms in sensor networks should use multiple paths whenever possible, both for redundancy and to distribute the energy expenditure of forwarding packets. These requirements distinguish ad-hoc wireless sensor networks from mobile ad-hoc networks (MANETs).

In medicine, *triage* is a mechanism for deciding in what order casualties will receive medical treatment, according to urgency and chance for survival. We can apply the same principle of triage to the problem of salvaging individual nodes in a sensor network, thus improving the ability of the network to be more productive and useful over a longer time. Sensor units in an ideal sensor network are self-deploying, self-monitoring and capable of repairing themselves – in other words, the network is autonomous. It is able to reason strategically about how best to maintain itself in order to achieve its goal of acquiring quality data over a long period of time. In this project, we integrate advances in artificial intelligence research areas, such as mobile agents and autonomous robotics, with recent work on sensor network protocols, in order to build a framework for a network that meets all the requirements given above.

II. Background

Wireless ad hoc sensor networks are basically energy and bandwidth starved. Current research in this field is focusing on means of designing energy aware routing protocols [3,8,1,2,10,4]. One of the major constraints of these networks is that they require regular human or robot intervention. This problem becomes more serious if this network is in an inaccessible or inhospitable location, such as the surface of another planet, where human intervention is either impossible or risky and costly, and as a result the network is short-lived and is unable to fulfill its objective. We propose to approach this problem in a new way: by using triage techniques to coordinate the self-repair and maintenance of a wireless ad hoc sensor network, specifically attempting to address the kinds of situations that might be encountered on, for example, a Mars mission. Here, we use "triage" to refer to the task of intelligently planning and scheduling self-maintenance, repair requests, power up and down, data transmissions, and so on, in order to maximize the useful life of the network, and secure the maximum amount of useful data. Here we envisage a large number of sensor nodes capable of minor self-repair, a smaller number of robot nodes capable of more sophisticated repairs, and possibly a very small number of humans. The challenge is to use these resources intelligently.

Conducting triage on the basis of role is an important component of this. The importance of a sensor is dependent on its role. For example, if the node is the only one in a region, or if it is gathering particularly important data, then its maintenance needs would be given priority over those of other nodes. The feasibility, cost and risk of doing a repair must also be taken into account. If a robot is likely to be unable to reach a node because it has fallen into a difficult-to-reach location, then that node's priority should be reduced. We propose to develop a system that can deal intelligently with these kinds of issues. There has been a considerable amount of research on intelligent networked robots and the need for intelligent data gathering has been explored to some extent. The use of smart robots for triage purposes is highlighted in one DARPA project [6] but it stops short of extending the concept to sensor networks. We propose to go a step further and design a framework for intelligent data gathering and triage techniques for ad hoc wireless sensor networks.

Current research on ad hoc sensor networks is usually focused on applying the specialized routing protocols designed for MANETS which are scalable, which support multi-path routes, and are energy efficient. Nagar and Biagioni [5] state that an ideal routing protocol for a wireless ad hoc sensor network should have these characteristics:

- Low power consumption
- Low mobility
- Supports multiple paths
- Scalable
- Self-configuring

Research into ad hoc wireless networks has been active for seven years, but only one stable routing protocol (Dynamic Source Routing, or DSR [9]) has been tested for efficiency over all different flavors of ad hoc wireless network. DSR, however, is not scalable. This suggests that it is difficult, perhaps impossible, to design an ideal routing protocol that would satisfy all the requirements given above. For this reason, here we try to take the responsibility for meeting some of these requirements off the routing protocol itself. We propose a technique by which the important characteristics of low energy consumption and self-configuration are tackled separately.

For a general sensor network a combination of the above-mentioned strategies would be sufficient to provide energy efficiency, scalability, and multi-path nature Routing algorithms using location information obtained from GPS system are not viable on Mars due to the (probable) lack of a GPS satellite system around Mars.

III. Proposed Architecture of the TRIAGE sensor network

The architecture of such a sensor network, which would be self-maintaining and have intelligent data gathering abilities, would be different from existing and theoretical ad hoc sensor networks. The network is composed of individual sensor nodes, which are basically simple self-contained computing units with sensors and a set of batteries for providing power for a fixed length of time. Sets of robots serve as mobile base nodes, and must:

- Collect data from the sensor nodes
- Monitor the data collection process and take necessary action in order to maintain node in its network
- Replenish the nodes with batteries, as necessary
- Report the data of its local neighborhood to the main base node.

There is also a main base node, which would be the final destination of the data (e.g. for transmission back to Earth).

As discussed in previous papers [5] in an ideal ad hoc sensor network, scalability is an important issue. In our network, we have decided to adopt the clustered approach, so our network has a two tier hierarchical structure.

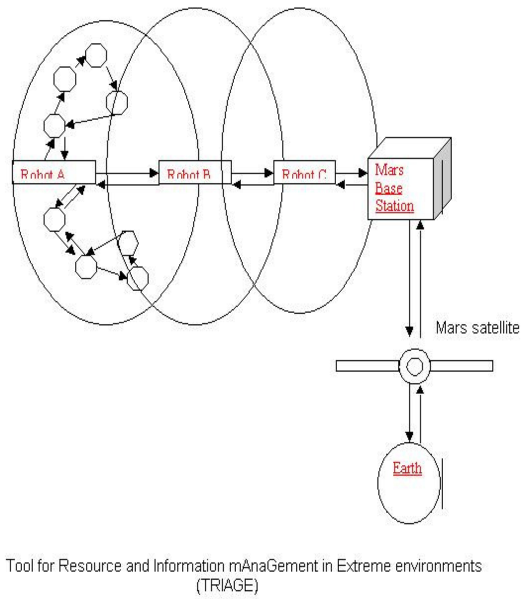

Figure 1: Describes how a sensor network made up of independent sensor units along with Robots would communicate using peer-to-peer fashion.

Our network is ad-hoc in nature, in the sense that sensors in a region report their data to whatever mobile robot nodes are accessible, which in turn monitor their performance and report their collective data to the central station. Decision-making would be distributed over all of these nodes. Individual sensor nodes make local decisions (e.g. powering down, sending a repair message), robot nodes make decisions related to their capabilities, and the main base node would coordinate overall activity.

This approach in our proposal builds upon the approach proposed by Hong [12], where base station broadcasts to all the sensor nodes. In our approach the base station broadcasts to all robots, which in turn broadcast the message to sensor units in their area of influence. Sensor units acknowledge the message and forward the acknowledgement to the robot which is also the cluster head.

Each robot deploys TRIAGE procedures to initialize the positions of sensor units and starts monitoring sensor units in its region and collecting data. At a fixed time interval set by the base station, each robot sends consolidated data for a given region to the base station by forwarding the message through other neighboring robots using peer to peer communication.

A sensor node would conduct self-analysis, and alert a robot node if there are any significant changes, such as in battery level or position. The robot node would then take appropriate action to handle such a situation. For example, if the battery level of a node drops below 50% and it is determined by robot that the node will not have enough battery power to finish gathering a dataset at current settings, then it would automatically increase the collecting time so that

- The experiment is not disrupted and
- After the experiment is over the battery of that node can be replenished.

Meanwhile, the main base node would monitor the situation, and allocate resources appropriately over the whole network. For example, if the faulty node's data is high priority, it might schedule a replacement. Thus, decision-making is distributed over all the tiers of the network.

IV. Prototype development and evaluation

We have developed a small (toy) prototype system, and tested it in a Mars-analogue environment. We are currently testing the same prototype rather more thoroughly in simulation. Here, we describe the prototype and its evaluation. Each sensor node consisted of temperature and light sensors coupled with a GPS receiver on an IPAQ 5455 handheld computer. The nodes communicate using the 802.11b wireless protocol. A human with a laptop played the role of a robot node. Nodes were simulated to be distributed in a Mars-like' environment [7]. The system then attempted to detect a very limited range of real and simulated faults in the nodes, and conduct basic triage.

Each node collects sensor data, which is then coupled with the GPS data and the simulated battery status of the node. This data is then forwarded to the robot node on a time interval set by the robot node. The robot analyzes the information obtained from the sensor node, determines if the sensor node is capable of completing the current experiment without going down. For this purpose, it monitors the energy usage of the sensor node. It distinguishes between the energy spent to collect data from the sensors and the GPS receiver, energy spent to transmit the data to the robot, and energy spent to keep the sensor node itself up and running. The robot then calculates whether or not it will be possible for the sensor node to meet the goal of the experiment at the current rate of energy use. If not, the robot calculates the new time interval required to finish the experiment face of depleted energy resources, and changes the time interval of data collection for that specific sensor node. This way, an effective energy resource management scheme is established by using information from the sensor node. We are currently analyzing the results of this experiment, but the initial results look encouraging.

Future large-scale networks need the capability of autonomous reconfiguration, because of their sheer size and the (probable) changes in state and topology. Stadler and Karlsson [15] suggest that management operation in a network can be started from any node in the system instead of taking a top-down approach i.e., applying local parameters to control global properties. In our current research, we take an intermediate approach, and delegate the management operation of the network to clustered nodes/robots instead of each individual sensor node, thus making it more efficient.

A poll-reply communication scheme has been proposed in [16] for base stations to collect the data, whereby each base station periodically broadcasts a polling request and every sensor node returns the collected data to the nearest base station (i.e., the base station it hears from first) through the reverse path of the request delivery. In our prototype sensor network, we have implemented a clustered approach in which the base station periodically broadcasts the request to robots instead of to individual sensors, thus introducing a hierarchy in the network, improving scalability and allowing a more distributed and energy efficient operation.

V. Future work

Currently we are working towards conducting a simulated modeling analysis of this prototype network. The GloMoSim (Global Mobile system Simulator) library [CITE] would be used for modeling the "triage" concept for parallel simulation of wireless sensor networks. The library is a scalable simulation environment for wireless network systems using the parallel discrete event simulation language PARSEC .The sensor scenario we envision consists of a large sensor field (hundreds of sensor nodes randomly distributed over a geographical area) and multiple robots, which are placed randomly in this field. The robots are in charge of collecting periodic measurements from a specified region using clustered network approach [14] and sending collected data to Mars rovers which ultimately relay data and commands with Earth users. We plan to use TRIAGE in conjugation with existing routing protocols for MANETs at the robot level, such as Ad hoc On demand Distance Vector (AODV) Protocol, Dynamic Source Routing (DSR) protocol. This study will hopefully support the design of efficient and realistic protocols for self-reliant autonomous ad hoc sensor networks.

VI. Conclusion

We propose to design, implement and test a self-maintaining autonomous ad-hoc wireless sensor network, suitable for deployment in remote, inhospitable environments, such as the surface of Mars. Here we have described a new Tool for Resource and Information mAnaGement in Extreme environments (TRIAGE), to be used in conjugation with existing routing protocols for MANETs to improve overall performance and self-sufficiency of ad hoc sensor networks in harsh, remote and uninhabitable locations such as Mars.

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