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非意図的な移動に適応するセンサーネットワークのホットスポットクラスタ生成と維持方式

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本稿では、アドホックセンサーネットワークにおいてのホットスポットクラスター方式のクラスタ生成と維持手順を提案する。PDA や携帯電話のような携帯端末にセンサーネットワーク機能を導入すると、端末を持ち歩ける人間の移動は制御不可能である。このような環境においては観測やシンクノードとセンサーノード間のデータ転送のため極端な柔軟性を持つ制御方式を必要とする。ホットスポットクラスタ管理では対象エリアの実時間にノードの入れ替えが可能である。対象エリアにはセンサーノードが一時的に存在しないときにシンクからの flooding を削減するため、対象エリアへの設定に潜伏期間を提案する。なお、ノード移動によって不連続な観測が生じても完全失敗を防ぐクラスタ維持方式を提案する。

Hotspot Cluster Set-up and Preservation in an Ad-hoc Mobile Sensor Network with a High Degree of Unintentional Movement

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This paper discusses the set-up and keep-alive procedures for a hotspot cluster configuration of sensors in an ad-hoc sensor network where the nodes are moving dynamically in unintentional ways. To integrate a sensor network over embedded devices such as cell phones or PDAs, the nodes that are carried around by the users keep moving in a completely uncontrollable way. This fluctuating environment demands a very robust scheme for controlling sensor activities and for transmission of interest and gathered data between the sink and the sensor nodes. The hotspot cluster method allows several nodes to enter and exit the interest area without interrupting the task. We introduce latency in the set-up of the sensor field to avoid repeatedly flooding of interests from the sink in the case there are no nodes nearby the event in the initial configuration of the network. Also, we introduce a keep-alive function where the interest area tolerate a certain level of interruptions in the case no sensor nodes are able to continue the task for certain time period.

1. Introduction

Sensor networks provide an extension to the perception range for human individuals. We are now approaching an area where computers will be embedded everywhere, providing a truly ubiquitous environment supporting everyday activities. With small, reasonable processors available all around us, new possibilities that are different from the traditional computer networks start to appear.

Wireless sensor ad-hoc networks are different than communication networks. Rather than focusing on the communicating nodes, the focus is on collecting and processing the data interests. Which node carries out the task is not important. To achieve better results several nodes might carry out a task cooperating with each other. Also, depending on the movement of the sensor nodes or of the objective, the active nodes will replace each other dynamically.

So far a lot of work on sensor networks has focused on deploying specialized networks for predefined tasks. The usage of these networks can be applications such as environmental observation, exploration of extreme environments like Polar Regions and deep space etc., locating and rescuing survivors after a disaster, and military applications.

However, one can also imagine another kind of sensor networks, making use of technology developed for personal area networks (PAN). PANs are developed for users to let their electronic devices interact with each other over wireless links. To construct PANs short range wireless ad-hoc protocols are used.

With ad-hoc protocols such as IEEE802.11 and Bluetooth implemented in virtually every electronic device, devices belonging to different persons not knowing each other could interact and open up possibilities for new services. For instance, a third party could use a fraction of the resources of many wireless personal devices to organize a sensor network to achieve information available at locations at a distance from the user. This kind of network structure can then be used to located objects and people, or retrieve only locally available information from electronic tabs and tags available everywhere.

This paper is organized as follows. First we discuss the problem of unintentional node movement in a sensor network in section 2. Then we discuss the hotspot cluster concept in section 3.

2. Unintentional node movement in sensor networks

Issues concerning the movement of sensor nodes in a sensor network that is programmed for a special task are different from the issues for a sensor network that utilizes devices originally intended for other usage. For a specialized network node mobility can be considered beforehand. In the best case the nodes can move in an intelligent way, enhancing sensing. In other cases there is little mobility at all, or at least unintentional mobility can be predicted in such a way that the application layer can take the necessary precautions.

This is different in an environment where the nodes are carried around by people not aware of the task at hand. In this situation intentional movement of the nodes to enhance sensing is not possible, and mobility patterns of the sensor nodes will be difficult to predict without information about the environment where the network is deployed.

When the nodes in a sensor network move about randomly, the software needs to cope with unpredictable movement of the nodes. This makes routing of information very difficult. As the network needs to completely reconfigure itself at very short intervals, ensuring a steady flow of data between the event that is observed and the sink node becomes a challenging task. This problem can be split up in to two components.

- Continuously sensing of an event

With highly rapid movement of the nodes, the sensors might move out of range of the event before the scan is completed. This complicates continued sensing over a longer interval as no nodes will stay put long enough to finish the task. If all the nodes move away from their objective so that they are out of range with their sensors, data can not be provided, and the sensing task fails. On the other hand, as nodes continuously come and go, other nodes might approach the event, allowing them to take over the task. In order to take advantage of the new nodes that enter the area of interest when a sensing task is in process, there is a need for some way of transmitting the sensing task between nodes in real time.

- Propagating data back to the sink node

When data from the sensors have been gathered, the data must propagate through the network to a sink node. However, the path to transmit the data might be compromised as nodes move away from each other. The path taken by the initial interest to reach the area where an event is to be observed will probably not be available when the resulting data are transmitted back. For continuous sensing of a phenomenon, the path between the sensors and the sink might continue to change rapidly. Thus, a robust scheme for data transmission back to the sink node is also necessary.

To overcome these issues, the system can be split into three layers. The field layer represents the area where we want to make an observation. The mobile node layer represents the position and movement of the individual mobile devices that make up the sensor network. On top of that we have the software layer that represents the eventual collection of data. The objective of the system is therefore to represent the field layer in the software layer to as an accurate degree as required by the application, independent of the changing situation in the mobile node layer.

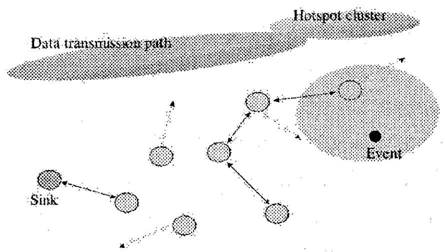

Figure 1, hotspot cluster and transmission path are independent of node structure

3. Sensing support with mobile clustering for continued sensing

To overcome the problem with lack of continuity in the area of interest as the node moves, mobile clustering can be used. Cluster management of a hotspot area allows the nodes to change configuration while the objective is being observed []. An outline of the hotspot cluster is shown in figure 3. The cluster contains two kinds of nodes, cluster-centers and cluster-frontiers. The nodes that have sensors covering the area of interest are called cluster-centers. Nodes that are located one hop away from cluster-centers are called cluster-frontiers. The cluster-centers take active part in the sensing task, while the cluster-frontiers are candidates for cluster-centers, prepared to start collecting data if they enter the sensing area. The cluster is constantly updated as the cluster-centers transmit HELLO beacons at regular intervals.

3.1. Cluster control processes

In the highly dynamic environment we are addressing, we must address how to set up the cluster in the first place, and further keep it alive, while the sensing task proceeds. Depending on the density of the sensor nodes there might not be any nodes that are close enough to the interest to qualify as cluster-centers at any given moment. However, as the mobile nodes move around, this situation changes constantly. To avoid starting all over again with a new initial flooding of interests, when an interruption of the task occurs, we consider some mechanisms to provide better robustness for the system.

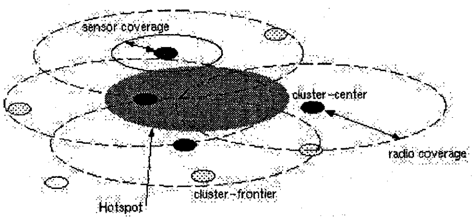

Figure 2, hotspot cluster configuration

Cluster set-up: In the case when one or more sensor nodes are able to sense the target event when the interest is flooded through the system, set-up of the cluster is straightforward. Nodes that sense the target area change state to cluster-centers and start transmitting beacons to nodes in their vicinity at regular intervals. In the case when the density of sensor nodes is relatively low, several approaches can be taken.

- A large enough area of interest is flooded through the system. This increases the chance that there exists at least one node inside the sensing area. This approach might be acceptable for some applications, but if the original area of interest is limited, this might cause nodes to unnecessary use battery power to try to detect something they are not able to gather information about anyway.
- The interest is repeatedly flooded through the system until there is a response from a node. In this scenario the sink tries to send out its interest again at regular intervals until it receives positive feedback from any cluster-center in the sensor field. If there initially are no sensors in the target area, this approach will result in flooding the same interest through the network several times. However, flooding waists a lot of resources, both communication resources and battery power, from the nodes taking part in the process.
- Introducing latency in the first probing phase. Here we suggest that sensor nodes that are not in the area of interest initially, but are not too far away, cache the interest information and keep track of their location for a timeout period. The area where these candidate nodes are to be included can be set up as an extra parameter in the original interest from the sink, or the decision can be carried out locally by each node, depending on its location, speed and direction. The first node to enter the area of interest, assumes the state of center-cluster, and starts to transmit its beacon. If no nodes enter the area of interest during the probing phase,

no result is sent back to the sink, and the task is terminated.

Cluster keep-alive: In the same way as mentioned above, during information gathering about an event, the cluster-centers might split away and leave the area of interest uncovered by any sensors. Moreover, this situation might happen regularly in the environment we are studying where there is no coordination between the highly dynamic nodes. There are several alternatives to how to solve this problem.

- The initial interest is repeated in regular intervals by the sink. In this case the sink continues to send out the same interest and thus keeping the sensor hotspot cluster alive. This is probably a good solution for a relatively static network configuration as the interest can be reinforced over a few links. However, in a configuration where the nodes are repeatedly changing position, as well as entering or leaving the network, the information must be flooded through the network. This again will take up a large amount of resources. There will therefore be a tradeoff between the update interval and the resource usage in the network.
- The cluster-frontiers and the last cluster-center cooperate in keeping the cluster alive. The hotspot cluster is originally kept updated as the cluster-centers transmit their HELLO beacons. When these beacons seize to arrive, this means that the cluster-centers have left the area of interest, and thereby changed status to cluster-frontiers and next outside nodes. The last cluster-center to leave the interest area transmits a GOODBYE message to the cluster-frontiers as it stops sensing. The GOODBYE message triggers the cluster-frontiers to start transmitting a beacon to their neighbor nodes, informing about the interest. If any of the cluster-frontiers or a new node enters the area of interest, the hotspot cluster is revitalized and starts to gather and transmit data again.

5. Conclusion and further work

In this paper we proposed a scheme for setting up a hotspot cluster of sensor nodes. The hotspot paradigm makes it possible to continue sensing an event while the configuration of the sensing nodes changes in real time. To set up the hotspot cluster when there are no nodes in the direct vicinity of the event, we suggest using latency, so that the set-up can be delayed in time. Further we also suggest a keep-alive mechanism to prevent the sensing task from failing if the center-nodes in the hotspot cluster move away from their objective.

We plan to evaluate the algorithm with simulations using the ns2 simulator. Further we are also planning to implement the sensor network with these mechanisms on PDAs. We are planning to carry out experiments where we test the protocols for different sensing tasks, when a large group of people carry these devices with them.

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