Routing in Sensor Networks based on Symbolic Coordinates

Matthias Gauger, Pedro José Marrón, Marcus Handte, and Kurt Rothermel

IPVS, Universität Stuttgart, Universitätsstr. 38, 70569 Stuttgart, Germany
{gauger, marron, handte, rothermel}@informatik.uni-stuttgart.de

Abstract. The routing of messages between mobile nodes and a sensor network is an important but challenging task. In this paper we present our approach for this problem that is based on the use of symbolic coordinates and that divides the task among client and sensor nodes.

1 Introduction

Sensor networks have the potential to play an important role in ubiquitous computing scenarios as sources of environmental data and context information. A variety of such data is required by typical ubiquitous computing applications for providing their services to the user. However, the expected large number of nodes in deployed sensor networks as well as their strong resource constraints make the interaction with the mobile ubiquitous computing devices a challenging task.

One fundamental problem is the communication between the mobile client devices and the sensor nodes. The client devices should be able to address a specific area of the network and the sensor nodes should then efficiently route such request messages to the appropriate nodes. Global routing tables are not well suited to this task due to the potentially large size of the network, the limited resources of the sensor nodes and due to the frequent topology changes. Flooding the network with request messages and building routing structures on-demand as done by classic source routing approaches [1] also conflicts with scalability requirements and resource constraints.

In this paper we present our approach for routing messages between mobile client nodes and sensor networks that is based on the use of symbolic coordinates. The basic idea is to have the client nodes calculate and provide a symbolic route to the destination and then let the sensor nodes transform this symbolic route into individual node-to-node routing steps.

Symbolic coordinates – in contrast to geographic coordinates – do not represent exact geographic locations but rather certain geographic areas of different sizes. In many cases, symbolic coordinates represent areas which are directly meaningful to applications like rooms in a building or streets and buildings in a city scenario. However, symbolic coordinates by themselves do not allow to infer spatial information like the distance or the spatial relationship between two coordinates. For such tasks, a symbolic location model is required.

In the rest of this paper we first give a short overview of related work and then describe our routing algorithm, its advantages and problem fields and some solution approaches for the problems.

2 Related Work

The use of symbolic coordinates has been widely discussed in the area of ubiquitous computing and different symbolic location models have been developed [2][3][4]. Our approach is largely independent of the specific location model and its properties so that most of these location models can be used.

Using symbolic coordinates in sensor networks has received much less attention so far. The general idea has been formulated by Fekete et al. [5] who propose to automatically create clusters and organize these clusters in a weighted graph structure expressing their neighborhood relations. They argue that such graphs of symbolic coordinates should in most cases be small enough to allow the distribution and use in all nodes of the network. This provides the nodes with some abstract location awareness based on the position of their cluster in the graph. The authors describe routing as one possible application of graphs of symbolic coordinates. However, they do not elaborate on how routing to specific nodes or areas could be achieved.

One alternative routing approach quoted in many sensor network publications is geographic routing [6]. However, geographic routing can only be used when all nodes in the network know their exact geographic coordinates. The required precision of this location information rises with the node density in the network. In many cases requests also first need to be mapped to a destination coordinate with some kind of location service before sending out messages.

3 Routing with Symbolic Coordinates

Assumptions We build upon a small set of assumptions concerning the system model. First, we assume that there is a symbolic location model available in the system that allows determining symbolic coordinates for all locations covered by the sensor network. We do not require special properties of the location model other than the availability of some kind of `neighborOf`-relationship among symbolic coordinates.

Concerning the sensor network, we only assume that the sensor nodes are able to maintain local neighborhood information without any knowledge of the global topology. Additionally, we require each sensor node to store its own symbolic coordinate. Note that aquiring this coordinate should be much simpler than determining the exact geographical coordinate making it relatively easy to, for example, assign the coordinate at deployment time. We are currently working on different methods for semi-automatically assigning symbolic coordinates to sensor nodes.

Mobile nodes are typically less resource-constrained than the nodes of a sensor network. For that reason, it is reasonable to assume that mobile nodes have access to the symbolic location model either by storing model data on the node or by dynamically loading required information from an infrastructure. They are also able to process and use this information for querying the sensor network.

Mobile client nodes and sensor nodes share a common communication interface so that a mobile node is able to communicate with any sensor node in its direct neighborhood.

Basic concept The basic idea of our approach is to divide the task of routing messages from mobile nodes to specific areas in the sensor network among clients and sensor nodes. The mobile client nodes are responsible for the global routing task whereas the sensor nodes manage the local node-to-node routing of messages.

All sensor nodes periodically exchange beacon messages that contain their own symbolic coordinate and hop distance information to neighboring symbolic coordinates they have heard of. Based on such beacon messages received from neighbors, a sensor node fills a routing table with next-hop (and distance) information to symbolic coordinates in the neighborhood of the node's symbolic coordinate. Note that this list of neighboring coordinates isn't preconfigured but only learned from beacon messages.

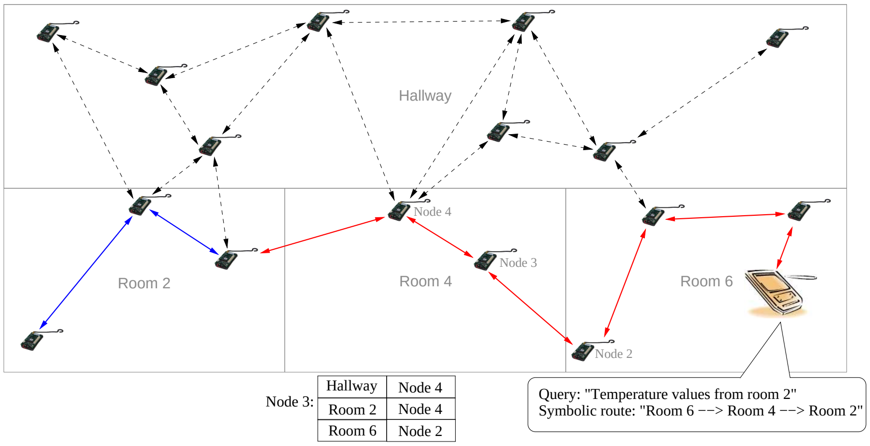
When a client node wants to send a message to a specific symbolic area of the network it first has to calculate the symbolic route from its current position to the destination coordinate based on the stored symbolic location model. The client node then includes this route information in the message and passes it to an arbitrary sensor node in its neighborhood.

When a sensor node receives a message from a neighboring node it investigates the symbolic route stored in the message header. Based on its own symbolic coordinate, the node can retrieve the next symbolic coordinate the message should visit. It then queries its local routing table to retrieve the next-hop node on the route to this next-hop symbolic coordinate and forwards the message to this node.

When the message reaches the first node lying in the destination area three different message distribution semantics are possible: The message can be delivered to this node only (**area anycast**), to all nodes in the area (**area broadcast**), or to a specific node identified by a node identifier (**area unicast**). Area broadcast and area unicast can be implemented using a broadcast limited to the respective symbolic area.

Figure 1 shows an example of a query forwarded from symbolic coordinate "Room 6" to coordinate "Room 4". At the bottom it also shows as an example the local routing table of node 3.

Advantages The main advantage of our approach is the division of the routing task among client and sensor nodes with both parties contributing based on their respective strengths. Sensor nodes do not have maintain global routing information as they only have to perform local routing decisions. The amount of state a single sensor node has to manage neither depends on the size of the



Node 3:

Hallway	Node 4
Room 2	Node 4
Room 6	Node 2

Query: "Temperature values from room 2"
Symbolic route: "Room 6 --> Room 4 --> Room 2"

Fig. 1. Message routing example

network nor on the number of nodes in its neighborhod but only on the number of symbolic areas adjacent to the symbolic area the node resides in.

From the client's point of view, the main advantage is that the routing can be done independent of knowledge about the current sensor network topology. The failure of nodes or communication links only affects local routing within the respective area. The global routing from a client to a symbolic destination area does not change and is therefore relatively insensitive to node failures.

Problem Fields Three types of problems can prevent a successful communication when using the basic algorithm described above. First, not all neighboring symbolic areas have to be connected by sensor node communication links (**communication hole**). Secondly, complete symbolic areas might lack coverage by sensor nodes (**coverage hole**). Thirdly, the subgraph formed by the nodes inside of a symbolic coordinate might be disconnected although the complete graph is connected (**area partitionings**). In all three cases message forwarding can fail because the next-hop symbolic coordinate cannot be reached. Coverage holes and area partitionings can also prevent successful completion of area broadcasts and area unicasts once the destination coordinate is reached.

Figure 2 shows examples of all three types of problems with a communication hole between room 1 and room 2, a coverage hole in room 6 and an area partitioning in room 4.

Several ways of preventing or reacting to these problems are possible. The most simple way of preventing holes and partitionings is to assume or rather require an extremely dense topology that makes holes or partitionings extremely unlikely. Alternatively, static information about holes and partitionings might be available in the location model so that the client can plan its routes accordingly. A related method is to maintain weight values for all symbolic areas that represent the (expected) density of nodes in this area. The larger the accumu-

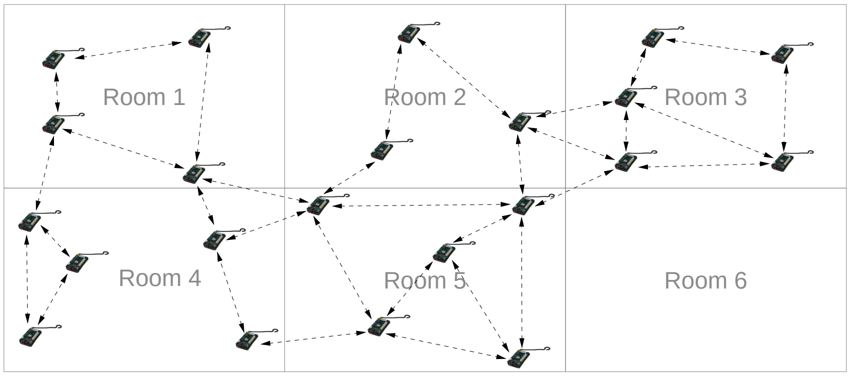


Fig. 2. Example showing communication holes, coverage holes and area partitionings

lated weight of a symbolic route the higher the probability that a message can be forwarded to the destination without getting stuck in holes and partitionings.

If none of the prevention methods works or the required information is not available then the sensor network must react to communication failures caused by holes and partitionings. We are working on two possible reactions: First, the sensor node detecting the problem can send a feedback message to the original sender of the message by following the symbolic route of the message backwards. Notified of this routing failure, the original sender is then able to resend the message specifying an alternative route. It can also buffer information about where the communication failed so that subsequent messages directly circumvent the hole. A second possible reaction for the node detecting the problem is to try to find a by-pass locally. For doing this it needs to broadcast the message to all of its neighboring symbolic coordinates which can then reinvestigate the symbolic route and either find the required symbolic next-hop in their neighbor list or broadcast the message to their neighbors. How deep such a symbolic broadcast is allowed to propagate determines both the likelihood that the original route can be taken up again but also the cost for distributing the message in multiple directions.

4 Conclusions

In this paper we described our approach for the use of symbolic coordinates in sensor networks. We concentrated on their use for a better integration of sensor networks in ubiquitous computing scenarios. We presented the basic concept showing both the advantages as well as potential problem fields. We are currently working on an in-depth evaluation of the concept including different solutions for the described problem fields and aim to improve the algorithm based on these results as part of future work.

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