AN EXTENSION OF PUBLISH/SUBSCRIBE FOR MOBILE SENSOR NETWORKS

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Abstract: The miniaturization of computing, sensing and wireless communication devices enable the development of wireless sensor networks (WSNs). One of interesting research in sensor networks is utilizing moving nodes. The benefit of the moving sensor nodes is to measure wide-ranging area by small number of nodes. Despite of the rapid development of the network protocols in mobile sensor nodes, the application platforms for moving sensor nodes have not been much discussed. In this context, Publish/subscribe model is one of reasonable solution with sensor networks. Publish/subscribe model has become a prevalent paradigm for delivering data/events from publishers (data/event producers) to subscribers (data/event consumers) across large-scale distributed network. In sensor networks, a user who is interested in the specific location and attributes can send subscription to the system to receive all desired events. This paper proposes a novel schema that allows us to control sensor nodes for location-based publish/subscribe system. In our schema, sensor nodes can be deployed to the most effective location for event delivery.

1 INTRODUCTION

The miniaturization of computing, sensing and wireless communication devices enable the development of *wireless sensor networks (WSNs)* (Estin et al., 2001; Akyildiz et al., 2002), an new form of distributed computing where sensors deployed to gather and report information about real world phenomena. One of interesting research in sensor networks is utilizing *moving sensor nodes*. For example, it allows us to cover wide sensing area by mobility, to observe surroundings of 360 degrees with swiveled cameras, and to receive reflections by on-demand signal transmitters. The benefit of the moving sensor nodes is to measure wide-ranging area by small number of nodes. Since the moving sensor nodes generally consume much energy by positive movement, the most important challenge is to develop the control schema regarding with wide-ranging area sensing and energy efficiency. Several works have been developed in moving sensor nodes such as (Zhao and Ammar, 2003; Zhao et al., 2004). These works are mainly dedicated in data dissemination and simple round-trip-like movement. Despite of the rapid development of the network protocols in moving sensor nodes, the application platforms for sensor nodes have not been much discussed.

In this context, Publish/subscribe model is one of reasonable solution with sensor networks. Publish/subscribe model has become a prevalent paradigm for delivering data/events from publishers (data/event producers) to subscribers (data/event consumers) across large-scale distributed network. In typical Publish/subscribe system, subscribers register their interests to the system using a set of subscriptions, and publishers can simply submit information to the system using a set of publications. Once receiving a publication, the system matches it to the subscriptions and then delivers it to the interested subscribers. In sensor networks, a user who is interested in the specific location and attributes can send subscription to the system to receive all desired events. Conventional researches of sensor networks which publish/subscribe architecture is applied have been focued on routing algorithm (Costa et al., 2005) or data manegement (Yang and Hu, 2007).

This paper proposes a novel schema that allows us to control moving sensor nodes for location-based publish/subscribe system. In our schema, sensor nodes can be deployed to the most effective location for event delivery. For example, the mobile sensor node can move to where the subscriptions are con-

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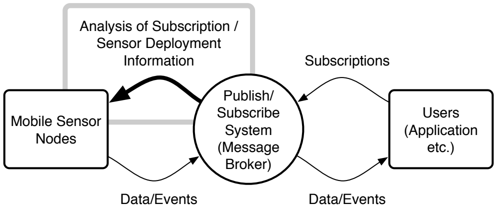

Figure 1: Extention of Publish/Subscribe Model.

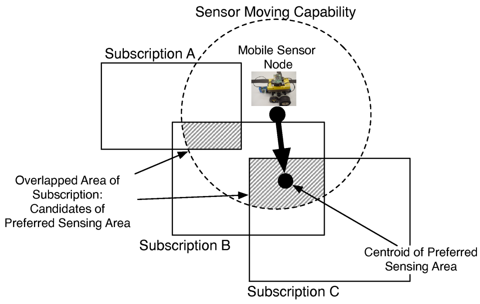

Figure 2: Candidate of preferred sensing area.

verged on. Also the swiveled 360 degrees camera sensor can always focus to the center of the subscriptions.

2 PROBLEM STATEMENT

2.1 Moving Sensor Nodes

We assume that moving sensor nodes are deployed to sensing space and are available to move to where users desire to know (Dahlberg et al., 2005; Sibley et al., 2002), and assume that all sensor nodes can communicate to a base station. For example, sensor nodes have the following features: (1) **Mobile sensor nodes** enable to move directly to sensing point. (2) **Moving camera sensor nodes** are fixed sensor nodes which the observation camera is equipped. The camera can focus to target object by swiveled it and zooming. (3) **Active signal detection nodes** are fixed sensor nodes that receive reflections by on-demand signal transmitters.

2.2 Publish/Subscribe Model

As described in (Fabret et al., 2001), a publish/subscribe schema can be defined as: **PS** $= \{A_1, A_2, ..., A_n\}$, where each A_i represents an *attribute*. Each attribute is defined by a *name*, a *type* and a *domain*. An *event* is a set of equalities on all attributes in schema **PS**. A *subscription* is a conjunction of predicates on one or more attributes, where each predicate specifies a range for an attribute. An event e is sent from a publisher, if a predicate of subscription s is satisfied by value corresponding attribute contained in event e, it matches a subscription s. In the publish/subscribe model mentioned above, the content space of a publish/subscribe schema can be modeled as a multi-dimensional space, where each dimension represents an attribute.

3 EFFICIENT SENSOR DEPLOYMENT SCHEMA

Figure 1 shows our concept of the extention of publish/subscribe model. In conventional publish/subscribe model, publishers generally are not aware of subscribers and data/events transfer, and publishes simply send data/events. Compared with that, in our schema, publishers are positively controlled with subscribers.

It allows us to control moving sensor nodes which can be deployed to the most effective location for event delivery. In our schema, sensor nodes positively measure the area where subscribers is interested in.

3.1 Location-based Map

It is necessary to consider a suitable data structure for publish/subscribe system in location-based sensor networks. In our schema, a multi-dimensional subscription space is divided into location-based sensor maps.

Consider a n-dimensional content space $\Omega = \{L, A_1, A_2, A_3, ..., A_n\}$, where L is range of location, and A_i is type of data and range of sensed data which subscriber is interested in. Ω is divided into the maps of each attribute and uniform location, that is, the location-based map Λ_n is defined as $\Lambda_{A_i} = \{L, A_i\}$, for each $A_i \in \Omega$ $(1 \leq i \leq n)$.

3.2 Analysis for Preferred Sensing Location

Since sensor nodes have the sensing range where it can move, the method for estimating a preferred sensing area is required. The following conditions should be satisfy to determine preferred location where sensors are deployed:

- The location where many subscribers are interested in.
- The largest area where subscribers are interested in.

To determine the preferred sensing area which satisfies the conditions, the following procedure is performed:

1. For each sensor, let **S** to set of subscription which is exist within range of sensing capability *R*.
2. For each subscription **S**, calculate the intersection of **S**, let **I** to set of the most overlapped area.
3. Consider $\mathbf{I} = \{I_1, I_2, I_3, ..., I_n\}$, for each I_i, calculate the intersection of I_i and the sensing capability *R*. The largest area of the intersection is *preferred sensing area*.

For example, figure 2 shows the overlap of subscriptions and sensing capability. Each rectangle represents the subscriptions, and the circle represents the sensing capability of the sensor node. There are two overlapped areas of the subscriptions within the sensing capability. These become candidates of the preferred sensing area. Since the intersection of Subscription B and C is wider than another intersection, the preferred sensing area is the intersection of subscription B, C and the area of the sensing capability. Then, the centroid of the preferred sensing area is calculated, the sensor node move to the sensing point.

3.3 Algorithms

To install a subscription, the first of all, a multi-dimensional subscription is divided *location-based subscription* by its location and data types. The following algorithm is to produce location-based subscriptions $SL_{Ai} = \{L, A_i\}$ (L and A_i represent location and attribute respectively) from spliting a subscription $S = \{L, A_1, A_2, ..., A_n\}$.

Algorithm 1. Divide *n*-d Subscription to Location-based Subscriptions.
Require: $\{L$: location, $A_1, A_2, ..., A_n$: attributes$\}$
for each $a \in A_1 ... A_n$ **do**
    $SL_a \leftarrow \{L, a\}$
end for
return SL_a

And then, SL_{Ai} is installed into the location-based map Λ_{Ai}. Since the location-based map should be maintained overlapped subscription for calculating the prefer sensing point, it consists of the multi-layered map. The following algorithm is to install the location-based subscription SL_a to the location-based map Λ_a.

Algorithm 2. Subscription Installation.
Require: $\{$ SL_a: location-based subscription regarding with attribute a, Λ_n: n-degree location-based map$\}$

Table 1: Simulation setup.

Size of sensed area	10,000 m × 10,000 m
Radius of moving capability in mobile sensors	50 m
Radius of visibility in swivel camera sensors	50 m
Energy for movement	1 J/m
Energy for rotation	1 J
Simulation time	10,000 sec.

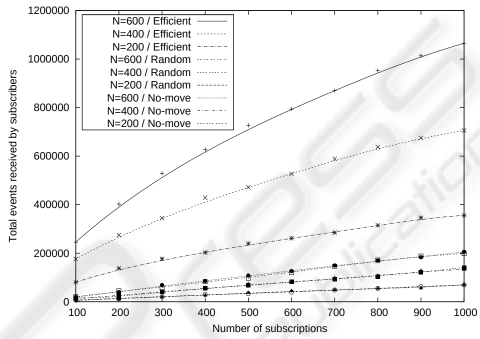

Figure 3: Received events and subscriptions.

$deg \leftarrow 0$
$S \leftarrow deg$-degree subscriptions in Λ_a overlapping with SL_a
while $S \neq \phi$ **do**
    for each $s \in S$ **do**
        $t \leftarrow$ new subscription for intersection of SL_a and s
        for each $b \in$ subscriptions linked from s **do**
            link t and b
        end for
        link SL_a *and t*
        $\Lambda_{deg}.add(t)$
    end for
    $deg{+}{+}$
    $S \leftarrow deg$-degree subscriptions in Λ_a overlapping with SL_a
end while

4 EVALUATION

We implemented the location-based publish/subscribe architecture in our simulator. We use synthetic datasets in our simulation. Subscriptions and sensor locations are generated based Zipfian distribution.

The conditions of our simulation are listed in table 1. We scheduled 100,000 sensor events and 1000 subscribers' joining/leaving generated on randomly cho-

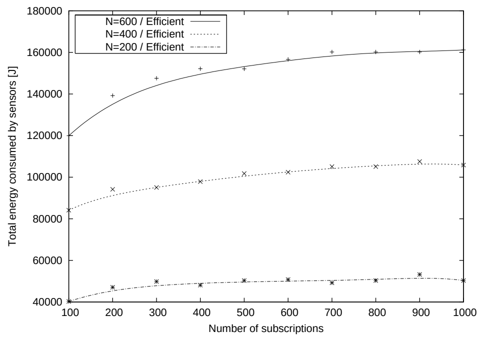

Figure 4: Consumed energy and subscriptions.

sen node/subscription.

The interval of events/joining/leaving is the poisson distribution. The cost model of energy consumption is based on (Heinzelman et al., 2000; Goldenberg et al., 2004).

We examine the following moving schema: (1) Efficient (our proposed method), (2) Random, (3) Static (No-movement) Figure 3 shows number of events received by all subscribers. *N* represents the number of sensor nodes. As compared with our model and others, our model significantly increases the sensing efficiency. Moreover, no siginifacant difference is shown between the random model and the static model. Therefore, the result shows that moving sensor nodes without user consideration is not suitable. Figure 4 shows the energy consumption in all sensor nodes concerning the number of subscription. Although rising the number of events by increasing subscriptions, the energy consumption is almost constant. Therefore, the result shows that our model is energy efficient in increasing the number of subscriptions per a sensor.

5 SUMMARY

This paper proposed a novel schema that allows us to control mobile sensor nodes for location-based publish/subscribe system. In our schema, sensor nodes can be deployed to the most effective location for event delivery. Also, to confirm its effectiveness, the simulation result are presented and discussed.

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