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A SURVEY ON MOBILE AGENT ITINERARY PLANNING IN WIRELESS SENSOR NETWORKS

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Abstract-- It has been proven recently that using Mobile Agent (MA) in wireless sensor networks (WSNs) can drastically help to obtain the flexibility of application-aware deployment. Normally, in any MA based sensor network, it is an important research issue to find out an optimal itinerary for the MA in order to achieve efficient and effective data collection from multiple sensory data source nodes. In this paper, we firstly investigate a number of conventional single MA itinerary planning based schemes, and then indicate some shortcomings of these schemes, since only one MA is used by them. Having these investigations and analysis, novel Multi-agent Itinerary Planning (MIP) algorithms to address the shortcomings of large latency and global unbalancing of using single MA and its effectiveness is proved by conducting the extensive experiments in professional environment.

Keywords *— Wireless sensor networks, Mobile Agents, Multi-agent itinerary planning, Local Closest First.*

I. INTRODUCTION

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The development of WSNs was motivated by military applications, such as battlefield surveillance. They are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control. Wireless sensor networks (WSNs) have attracted much attention in the research community over the last few years, driven by a wealth of theoretical and practical challenges and an increasing number of practical civilian applications. "One deployment, multiple applications" is an emerging trend in the development of WSNs, due to the high cost of deploying hundreds and thousands of sensor nodes over a wide geographical area and the application-specific nature of tasking a WSN [1]. Such a trend requires sensor nodes to have various capabilities to handle multiple applications. However, it is infeasible to store the programs required to run every possible application in the local memory of

Embedded sensors, as these devices generally have tight memory constraints. The use of mobile agents to dynamically deploy new applications in WSNs is proving to be an effective method to address this challenge. A mobile agent is a special kind of software or computer program that migrates between the nodes of a network to perform a task (or tasks) autonomously and intelligently, in response to changing conditions in the network environment, to realize the objectives of the agent dispatcher. Mobile agents have been found to be particularly useful in facilitating efficient data fusion and dissemination in WSNs.

MA system has been proven to be an efficient approach to enhance such capabilities of WSNs. Normally, the MA design in WSNs can be decomposed into four components, i.e., 1) architecture, 2) itinerary planning, 3) middleware system design and 4) agent cooperation. Among these four components, itinerary planning determines the order of sensory data source nodes to be visited during the MA migration, which has a significant impact on the performance of the MA systems. Thus, find out an optimal itinerary for the MA to visit a number of source nodes is critical. However, finding an optimal itinerary had already been proven to be NP-hard, generally heuristic algorithms are proposed and applied to compute competitive itineraries with sub-optimal performance.

I. APPLICATION OF WSN WITH MOBILE AGENT'S

The benefits of applying mobile agent systems in WSNs are mainly twofold. First, they can potentially reduce bandwidth consumption by moving the data processing elements to the location of the sensed data, whose transmissions in the raw otherwise would incur most of the energy expenditures of the nodes. This is highly appealing when large amounts of data have been collected and must be disseminated to the sink. In addition, mobile agent systems introduce a higher degree of WSN re-tasking flexibility, compared to other approaches, and facilitate collaborative information processing. In light of these aspects, we describe two archetypal WSN applications in which the use of mobile agent technology proves to be an efficient solution. In practice, several other WSN issues, such as routing and data fusion can be effectively tackled by mobile agent systems.

VISUAL SENSOR NETWORK

Recent advances in hardware miniaturization have allowed the implementation of sensor devices that support the use of specialized add on modules for imagery applications. For example, the Cyclops image capturing and inference module can be interfaced with popular WSN devices, such as Crossbow's MICA2 and MICAz for image sensing applications [11]. The availability of such lightweight and inexpensive imaging hardware has fostered the development of visual sensor networks that enable retrieval of video streams and still images from sensor nodes. In fact, mobile agents have been found especially useful in visual sensor networks [1]. Because the amount of data generated by an image sensor is generally very large, transmitting whole pictures not only consumes much bandwidth and energy, but also may be unnecessary if the sink must evaluate only a certain region of interest (ROI) in the picture. Figure 2 illustrates an application of mobile agents in visual sensor networks. Here, a mobile agent that carries image segmentation codes is dispatched to the target region to visit the image sensors one by one, collecting image data from their corresponding ROI. Thus, the large volume of imagery data at each sensor node in the target region is reduced to a much smaller one. When the circumstances surrounding the environment being sensed have changed substantially, new mobile agent(s) that carry different image segmentation algorithm(s) can be dispatched to re-task specific image sensors to keep the image processing code working efficiently.

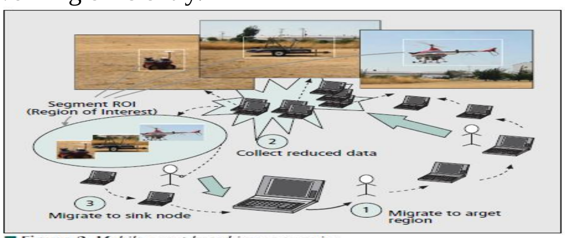


Figure 2. Mobile-agent-based image querying.

TARGET TRACKING

In [2], mobile agents are employed to track the location of a target and report it to a location server periodically by employing a simple localization algorithm called trilateration. In this approach, a node relies on location measurement information from itself and two of its Neighbours to estimate the target location, as illustrated in Fig. 3a (1). Here, the three circles indicate possible target positions based on measurements from three mobile agents. One is the mother agent, and the other two are child agents that have been invited by the mother agent to cooperatively position the object. In Fig.3a (1), the mother agent residing at node A dispatches child agents to nodes B and C to help locate the target. When the target moves away from node B, the received signal level at B will be reduced, and when the signal level falls below a threshold, the child agent at B is revoked, and a new child agent is dispatched to D, as shown in Fig. 3a (2). As the target passes node C, the mother agent itself will lose the tracking, in which case it will migrate to C. All old child agents are revoked, and new child agents will be dispatched by the new mother agent to nodes D and E, as shown in Fig. 3a (3).

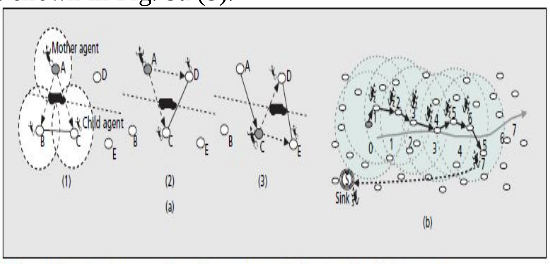


Figure 3. Illustration of two target tracking applications: a) geographical location tracking; b) object recognition.

While Fig. 3a shows the case in which the mother agent cooperates with only two child agents, more child agents can be employed to improve the positioning accuracy. By comparison, Xu et al. [3] proposed a different application of mobile agents for target tracking. As illustrated in Fig. 3b, after a new target is detected, a mobile agent is dispatched to track the roaming path of the target. When the agent migrates to a sensor node, it gathers data to progressively increase the accuracy of recognizing the object. After the achieved accuracy exceeds a certain threshold and satisfies the requirement of object recognition, the mobile agent terminates the tracking process and returns the collected results to the sink node. Thus, the overhead associated with unnecessary data gathering and agent migration is avoided.

II. ITIERNARY PLANNING

We define an itinerary [3] as the route followed during mobile agent migration. Itinerary planning includes the following two issues that can be addressed by the sink or by the mobile agent autonomously:

- Selection of the set of the source nodes to be visited by the mobile agent
- Determination of a source-visiting sequence in an energy-efficient manner

The order in which a mobile agent visits the selected source nodes can have a significant impact on energy consumption. Finding an optimal source-visiting sequence is a non-deterministic polynomial-time

(NP)-complete problem. The sequence can be fixed, dynamic, or a combination thereof based on the information of one hop neighbors and/or the information from previously visited nodes piggybacked by the mobile agent. Itinerary planning can be categorized as:

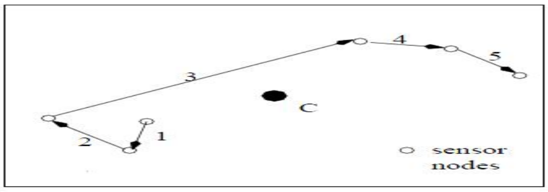
- **Static planning**, where the agent itinerary is totally determined by the sink node before the agent is dispatched.
- **Dynamic planning**, where the mobile agent autonomously determines the source nodes to be visited and the route of migration according to the current network status.
- **Hybrid planning**, where the set of source nodes to be visited is decided by the sink and the source-visiting sequence is determined dynamically by the mobile agent.

III. SINGLE AGENT ITINEARY PLANNING ALOGRITHMS

A. LOCAL CLOSEST FIRST ALGORITHM

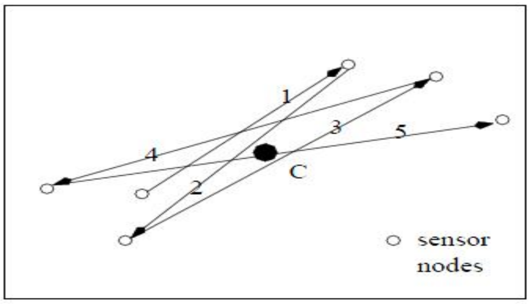
Algorithm makes use of Static planning where current global network information and derives an efficient agent path at the dispatcher before the mobile agents are sent Assuming both algorithms start at the same sensor node closest to the dispatcher, LCF searches for the next node with the shortest distance to the current node. Local Closest First (LCF), the MA starts its itinerary from a node and searches for the next destination with the shortest distance to its location [12].

This has the computational complexity of $O(n2)$ if the closest neighbor node is obtained by comparing the distances with the remaining nodes at each step.



B. GLOBAL FIRST SEARCH ALOGRITHM

As far as the Global Closest First (GCF) algorithm is concerned, the MA starts its itinerary from a node and selects the next destination with the closest to the center of the surveillance zone. When source nodes intend to form multiple clusters with similar distance to the sink, GCF causes zigzag routing due to the itinerary fluctuations among those clusters. This essentially utilizes sorting the distances (between the sink and other sources) to compute the MA path. Its computational complexity is O(n log n) if using a comparison-based sorting algorithm (e.g., quick sort).

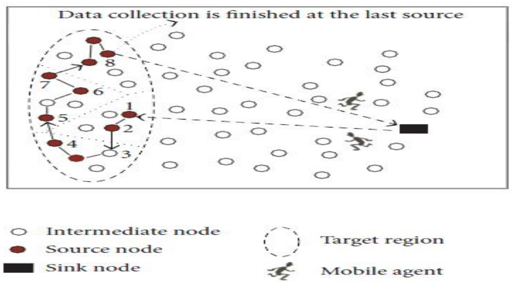


An optimal list of nodes Li;j is searched such that the cost of computation time and the relative power consumption with respect to each node itself reaches the minimum. An objective function as Eq. 1 is derived, where HT is the time consumed and HP is the relative power consumed, ® is a positive real number that is less than 1. It indicates the tradeo® between HT and HP.

H(Li;j) = ®HT + (1 ¡ ®)HP

C. MOBILE-AGENT BASED DIRECTED DIFFUSION ALGORITHM

In a hybrid planning scheme called mobile agent-based directed diffusion (MADD) is proposed. In MADD, if the sources in the target region detect an event of interest, they flood exploratory packets to the sink individually. Based on these exploratory packets, the sink statically selects the sources that will be visited by a mobile agent, which autonomously decides on the source-visiting sequence as it migrates among the nodes in the source-visiting set. As a result, the mobile agent follows a cost-efficient path among target sensors in MADD.The MA aggregates individual sensed data when it visits each target source. Though this kind of aggregation technique is typically used in clustering or aggregation tree-based data dissemination protocols, the aggregation in MADD does not need any overhead to construct these special structures.



The communication energy of a candidate itinerary is estimated by

$$E_{ma} = E_p / n_{data} + E_{roam} + E_{back}$$

D. ITINERARY ENERGY MINIMUM FOR FIRST-SOURCE-SELECTION ALOGRITHM

We focus on designing energy-efficient itinerary planning algorithms while relaxing the aforementioned assumption. We first propose an Itinerary Energy Minimum for First-source-selection (IEMF) algorithm, which extends LCF by considering the estimated communication cost. In IEMF, the impact of both data aggregation and energy efficiency is taken into account to obtain an energy-efficient itinerary[15]. The scheme is quite general in the sense that relies on no specific network architecture (e.g., [2] assumes a cluster-based networking environment). LCF performance can be improved by carefully choosing the first source node in the itinerary, which is one of the motivations for us to design the IEMF algorithm. IEMF is deemed to have n times the complexity of LCF, i.e., O (n3). Although our proposed IEMF approaches exhibit higher performance in terms of energy efficiency, compared with the existing solutions, the limitation of utilizing a single agent to perform the whole task makes the algorithm un-scalable with a large number of source nodes to be visited.

E. ITINERARY ENERGY MINIMUM FOR FIRST-SOURCE-SELECTION ALOGRITHM

We then propose an Itinerary Energy Minimum Algorithm (IEMA), which is an iterative version of IEMF. During each iteration, IEMA selects the best node according to IEMF as the next source to visit among the remaining set of source nodes. We show that, with more iteration, the suboptimal itinerary can be progressively improved and that the major reduction in average energy consumption is achieved for the first few iterations. We can thus tradeoff between energy efficiency and computational complexity based on specific application requirements. IEMF selects the first source as the one whose corresponding itinerary is estimated to have the smallest energy cost among n candidate itineraries. Once it is determined, the corresponding itinerary is actually determined by the LCF criterion [2]. In this section, we propose an iterative version of IEMF called IEMA. Compared with IEMF, in addition to IEMA seeks to optimize the remaining itinerary to a certain degree. Although our proposed IEMA approaches exhibit higher performance in terms of energy efficiency, compared with the existing solutions, the limitation of utilizing a single agent to perform the whole task makes the algorithm un-scalable with a large number of source nodes to be visited. The complexity of IEMA with κ iterations is O(κ .n2 log n).The communication energy of a candidate itinerary is estimated by

$$EI = E\text{conv} + E\text{roam} + E\text{back}$$

F. ADVANTAGES AND DISADVANTAGES OF SINGLE-AGENT ITINEARY PLANNING

In this section, Single agent itinerary planning algorithms have high efficiency in the applications with the following characteristics:

a) The source nodes are distributed geographically close to each other.

b) The number of source nodes is not large.

For large scale sensor networks, with many nodes to be visited, single agent data dissemination exhibits the following pitfalls:

1) Large Delay: Extensive delay is needed when a single agent works for networks comprising hundreds of sensor nodes.

2) Unbalanced load: There are two kinds of unbalancing problems while using a single agent. First, in the perspective of the whole network, the entire traffic load is put on a single flow. Therefore, sensor nodes in the agent itinerary will deplete energy quickly than other nodes. Secondly, from the perspective of the itinerary, the agent size increases continuously while it visits source nodes, and so the agent transmissions will consume more energy in its itinerary back to the sink node.

3) Insecurity with large accumulated size: The increasing amount of data accumulated by the agent during its migration task increases its chances of being lost due to noise in the wireless medium. Thus, the longer the itinerary, the higher risky of the agent-based migration becomes.

IV. MULTIAGENT ITINERARY PLANNING ALOGRITHMS

We propose a novel Multi-agent Itinerary Planning (MIP) algorithm to address the above issue. Traditionally, Single-agent Itinerary Planning (SIP) includes the following two challenges:

1) Selecting the set of the source nodes to be visited by the mobile agent.

2) Determining a node visiting sequence in an energy efficient manner.

Compared to existing SIP proposals, the main contributions of this paper are listed as follows:

We introduce a novel source-grouping algorithm. Note in [11], clustering based architecture is utilized to facilitate mobile agent based data dissemination. Though our source-grouping algorithm partitions source nodes into several sets, which have a similar effect of grouping source nodes in clusters, we do not set up a hierarchical structure. Thus, our algorithm does not have any control message overhead for the clustering process. We propose an iterative algorithm for MIP solution. We propose a generic framework to design a MIP algorithm. Within this framework, any SIP algorithm can be extended to the corresponding MIP algorithm, where the SIP algorithm will be carried out iteratively until the source list is empty.

We state our assumptions and define a generic MIP algorithm in this section as follows:

1) Primary itinerary design algorithms are executed at the sink, which has relatively plenty of resources in terms of energy and computation.
2) The sink node knows the geographic information of all the source nodes. Note that in our algorithm only source locations are needed, while the other algorithms [4], [5] need all of the nodes' geographical positions.

B. GA-MIP

Genetic Algorithm [14] (GA) is adaptive heuristic search algorithm based on the evolutionary theory of genetic and natural selection, which will produce the fittest survival. In a GA system, each solution to the problem was described as an individual with genetic information in the nature. The solutions produce children that inherit mixture characteristics from their parents. Meanwhile, an opportunistic mutation may happen to generate new individuals. Through the evaluation by a fitness function, the better individuals could survive. As time goes on, the survivals contain the excellent genes which represent the better solutions to the problem.
A novel genetic algorithm (GA) based multiple MAs itinerary planning (GAMIP) scheme is proposed, which mainly aims at optimizing the number of MAs and planning an efficient itinerary for each MA. To realize the GA-MIP algorithm, we encode the Source Node Sequence and the Source Node Group into numbers as the genes for genetic evolution. First, we set up a searching space filled with randomly selected genes.
Then, we perform an iterative evolution approach. In each iteration, evolution operators such as crossover and mutations are applied to increase the variety of the genes. After these procedures, the selection operator selects the better genes to survive for the next generation, which is analogous to the natural-selection in the real world. After a number of evolution iterations, the solution corresponding to an efficient strategy of itinerary planning will be obtained. During the GA evolution, the ith gene corresponds to a planned itinerary, whose cost is denoted by **EI (i), i = 1...k**, where k is the size of the search space. After the crossover and mutations, the number of genes is increased to **(1+α) k.5**. In our implementation, the select operator select first k genes according to the their better EI s
The scientific research contributions of this research work include the following points:
• **Novelty**: To the best of our knowledge, this research work is the first effort that tries to solve the MIP problem based on the genetic algorithm.
• **Optimization**: Different from previous MIP solution [11], which divide the MIP solution into 3 components: 1) finding the optimal number of MAs 2) grouping source nodes for MAs 3) determining the visiting sequence for each MA, the proposed GA-MIP scheme consider finding the optimal number of MAs, subsets for source nodes and the visiting sequence for each MA as ONE problem. It provides sub-optimal solution with shorter task duration and lower communication cost while the computational complexity is not relevant to the number of source nodes

V. CONCLUSION

In this paper, we addressed the problem of itinerary planning for multi-agent based data dissemination, facilitating concurrent sensory data collection to reduce task duration extensively. The proposed multi-agent itinerary planning (MIP) algorithm has the similar complexity with most of single agent based itinerary (SIP) algorithm, and can be flexibly adaptive to network dynamics in various network scales. We will propose more efficient source-grouping algorithm in our future work.

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