Mobile Agent Itinerary Planning Approaches in Wireless Sensor Networks- State of the Art and Current Challenges

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Abstract. A ubiquitous embedded network, such as wireless sensor network (WSN), is characterised by its capability to carry out common tasks by sharing resources that are placed in-node or in-network domains. One of the most critical properties of mobile agent (MA) based wireless sensor network is how to design the itinerary through the WSN for mobile agent. In addition to that, a huge amount of redundant data is generated by sensors due to node density and placement. This consumes network resources such as bandwidth and energy, thus decreasing the life time of sensor network. Several studies have demonstrated the benefits of using mobile agent technology as an effective technique to overcome these limitations. MA itinerary planning techniques can be classified into three categories depending on the factors that define the route of the MA: static-itinerary, dynamic-itinerary, and hybrid-based. This paper presents a survey of the state-of-the-art MA itinerary planning techniques in WSN. The benefits and shortcomings of different MA itinerary planning approaches are presented as motivation for future work into energy efficient MA itinerary planning mechanism.

Keywords: Wireless sensor networks (WSN) · Mobile agent (MA) · Itinerary planning · Static-itinerary · Dynamic-itinerary · Hybrid-itinerary

1 Introduction

The main purpose of a wireless sensor networks (WSN) is to provide users with access to the information of interest from data collected by spatially distributed sensors. In real-world applications, sensors are often deployed in high numbers to ensure a full exposure of the monitored physical environment. Consequently, such networks are expected to generate enormous amount of data [1]. The desire to define and route mobile agents in an energy efficient manner makes the success of WSNs applications, largely, determined by the methods used for mobile

L.A. Maglaras et al. (Eds.): INISCOM 2016, LNICST 188, pp. 143–153, 2017.
DOI: 10.1007/978-3-319-52569-3_13

agent itinerary planning. The principal concerns when dispatching a mobile agent include the selection, determination, and migration cost of the mobile agent itinerary planning and the methods used for defining such a plan. Practical constraints on sensor node implementation such as power consumption (battery limits), computational capability, and maximum memory storage, make MA itinerary planning a challenging distributed task [2].

One of the most important features of WSN is collaborative information processing i.e. exploiting the relationship between the data of spatially correlated nodes so as to reduce the total data transmitted to the sink [3].

There has been sustained research into Mobile agent technology (MA) for WSNs over the last few years [4–7]. For a comprehensive literature review, we refer the interested readers to [8] and the references therein. Such research efforts focused on itinerary planning based on specific architectures, data dissemination, data collection and data fusion. However, there has been little attention on grouping sensor nodes, such that the efficiency of the itinerary planning and the quality of the returned information is maximized. MA brings a relatively new trend in distributed computing, which mainly comes in response to enable flexibility and scalability problems of centralised models. The term mobile agent refers to a piece of software that performs data processing autonomously while migrating between nodes [9].

Mobile Agents (MAs) are primarily used in the field of WSNs for data collection and in-network processing. They can perform data aggregation and make local decisions autonomously without human cooperation. Consequently, most of the works are applied towards the optimization of energy consumption in nodes through planning of mobile agent itinerary. The itinerary followed during the migration of the mobile agent can have a significant impact on energy consumption. Finding an optimal sequence of visited sources is a difficult problem to solve (NP-hard problem) [4]. Itinerary planning is defined as the route followed during MA migration [10]. It determines the order of source nodes to be visited during agent migration.

In terms of dispatching Mobile Agents to collect information that is required by an application, itinerary planning of MA in WSNs can be classified into three broad categories: static, dynamic, and hybrid. In a static itinerary, the route is computed at the dispatcher prior to the MA migration. In a dynamic itinerary, the route of MA is determined by the MA on the fly. In a hybrid itinerary, the sensor nodes to be visited by the MA are selected by the dispatcher, but the visiting sequence is determined by the MA on the fly.

The rest of this paper is organised as follows: Sect. 2 describes the Anatomy of Mobile Agent. Section 3 looks at static Itinerary planning approaches and presents sample developments. Section 4, describes dynamic itinerary planning and recent successful deployments. Section 5, describes and identify recent advances in hybrid itinerary planning and present some of the recent approaches. In Sect. 6, a summary on future research direction for MA Itinerary planning is discussed. In Sect. 6.1 an energy efficient itinerary planning mechanism is introduced. Section 7 concludes this paper.

2 Anatomy of Mobile Agent

Mobile Agent technology has the capability of performing data aggregation and ability to make local decisions autonomously without user input. MA consists of four components as shown in Fig. 1.

- Identification: is a number used to uniquely identify a MA as well as the dispatcher. Identification comes in the format of a 2-tuple (i : j) where i represents the IP address of the dispatcher, and j is a serial number the dispatcher assigns to each MA. However, due to the sheer number of sensor nodes in WSNs it is infeasible to assign individual nodes with a unique identification, e.g. IP address. Instead of addressing nodes with ID, it is natural to access data directly via content, attribute, e.g., location of node.
- Data space: The agent's data buffer, which is responsible for carrying results of data integration. The results should provide a progressive accuracy as the agent migrates from node to another.
- Itinerary: is defined as the route followed during mobile agent migration. In general, itinerary planning can be classified into three categories: static, dynamic, hybrid.
- Method: is the execution code that is carried by the agent.

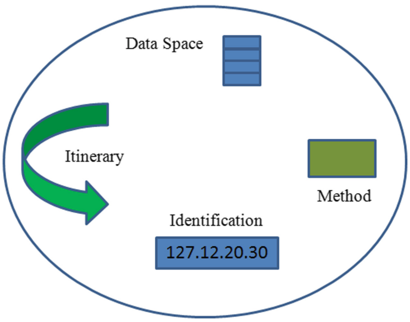

Fig. 1. Components of mobile agent.

Nodes organisation plays an important role in MA Itinerary planning because it defines, among other factors, the cost (amount of energy), accuracy (level of coverage), reliability (e.g. timeliness) of Itinerary planning [2]. The organisation of nodes can be either centralised or hierarchical. In the centralized approach, data collected by all nodes are sent towards a sink node using single or multi-hop communication [11]. However, this approach does not provide scalability, which is a main design factor for WSN. Also, it causes communication bottlenecks and transmission delays due to congestions especially in areas around the sink [12]. To overcome the problems in the centralised approaches, hierarchical techniques have been proposed as an effective solution for achieving longer network lifetime and better scalability.

Since the number of existing MA Itinerary planning approaches is significantly large, it will not be feasible to provide a detailed description of each approach. Instead, we have selected recent approaches that particularly represent directions of future research without focusing on the details of these approaches. However, characteristics of various approaches that are common for the approach they apply will be presented. Table 1 lists the reviewed approaches for mobile agent itienray planning techniques. In Sects. 3, 4 and 5 the approaches are presented based on the categorisation so as related sub-categories are discussed in the common context. To make the analysis of different approaches more logical and to set up a common base for their comparison and connection we consider some qualitative criteria.

Table 1. Overview of the selected approaches to MA Itienrary Planning

Static-itinerary	[13–16]
Dynamic-itinerary	[17–20]
Hybrid-itinerary	[13, 21–23]

3 Static Itinerary Planning to MA

3.1 Description and Operation

In static itinerary planning of MA approaches in WSN, the global information of the network is used in identifying an efficient agent route at the dispatcher prior to mobile agent dissemination. In the simplest form, a dispatcher (gateway, sink) determines the route, and the number of nodes to be visited before agents are sent.

Static itinerary planning approaches uses a single MA that introduces long itinerary distance and increases the packet length. This leads to longer task duration and consumes energy. Among the benefits of this class of approaches are: they are efficient in computing, in an environment as dynamic as the sensor network, in which connections between nodes can be lost or the sensor node may be malfunctioning, they may not respond to the changes in real time; they are easy to implement and configure; they have satisfactory performance for small WSNs; and they are suitable for monitoring applications, e.g. environmental monitoring. However, there are a number of limitations to Static itinerary planning. First, they do not respond to the changes in real time. Second, increased MA state size, leads to energy consumption.

3.2 Static Itinerary Planning Approaches to MA

In earlier studies, MA itinerary planning solution was based on the use of single MA [13, 14], the authors in [24] proposed two heuristics algorithms for MA itinerary. It is assumed that both algorithms start at the same sensor node closest to the dispatcher. In Local Closest First (LCF) algorithm, MA searches for the next destination with the shortest distance to the current location. In Global closest First (GCF) algorithm, MA searches for the next node closest to the sink. The two algorithms are mainly associated with low computational complexity. However, both LCF and GCF involves the use of a single MA that sequentially visits all sensor nodes and do not scale acceptably when thousands or millions of sensor nodes are to be visited by a single MA. This indicates that they are suitable for small WSNs. Also, when the agent migrates between sensor nodes the size of a MA increases continuously. The growing size of the MAs results in increased consumption of the limited wireless bandwidth, and also consumes the limited energy supplies of sensor nodes.

To overcome some of the inherent problems in the use of a single MA, [16] introduced a source grouping scheme and an iterative algorithm for multi-agent-based itinerary planning. The idea of their work is to divide source nodes into several sets and minimize the number of agents while achieving the required coverage of source nodes. However, their idea of selecting the centre of area with a high source node density is similar to that of clustering-based method, so a different set of source nodes may cause great difference in numbers. The unbalanced set numbers will lead to the unbalanced task duration of agents and unbalanced energy consumption.

Another MA itinerary planning approach based on genetic algorithm is proposed by [15], which uses the global information of sensor detection signal levels and link power consumption. The algorithm main components include an encoding mechanism, crossover and mutation operations, and an evaluation function. It assumes that each node cannot be visited repeatedly to shorten the search space. Although global optimization can be achieved using the genetic algorithm, it is not a lightweight solution that is suitable for sensor nodes constrained in energy supply.

4 Dynamic Itinerary Planning to MA

4.1 Description and Operation

In a dynamic- itinerary planning approaches of MA in WSN, the mobile agent has no prior path knowledge. A special node dispatches a MA after the route is designed and the sequence of nodes to be visited is determined on the fly during MA migration.

Dynamic- Itinerary planning approaches reduces the long route caused by utilising a single-MA and maximise the aggregation ratio during MA migration, they have the ability to respond to faults that might occur during its migration by changing its itinerary on the fly, they scale to handle millions of nodes, they are suitable for time critical applications such as, target tracking application, in which the trajectory of a moving object is initially unknown, they explicitly incorporate resource capacity, and highlights unused resources. However, there are a number of limitations to the Dynamic- Itinerary planning approaches.

First, they are limited to specific set of applications where consistent changes occur across the network, e.g. agricultural applications. Second, they are more difficult to design and complex to execute, as they need to group sensor nodes at first into subsets in a way that will create itineraries of approximately equal cost. Third, they require more time due to the fact that the decision about the next node to be visited is taken at each sensor node. Finally, they require a careful selection of the number of MAs and the number of nodes in a different groups to achieve an optimised task duration.

4.2 Dynamic Itinerary Planning Approaches to MA

In Dynamic-itinerary planning for MA in WSN, most of the published work in the literature considers MA has no prior knowledge of their path. Additionally, they use multi-agent that dispatches a multiple agent to collect data. For example, the authors in [17] applied the directed acyclic graph to model referral process in which node stands for agent, edge denotes relationship. The weights on nodes and edges represent the social ability and referral strength of agent respectively. Since it needs knowledge of the whole system structure prior to give weights, this method cannot adapt to the open environment. To overcome these limitation, [25] proposed a dynamic building method of mobile agent path with minimum payment based on referral. By referral, the next workplace (host) of mobile agent can be recommended by the current workplace provider based on his acquaintance knowledge. They claim that their proposed techniques do not require pre-fixed system, thus, it can adapt to open environment.

Similar approaches have been suggested in [18,19]. In [18] the authors build upon their previous work by introducing a dynamic planning method for mobile agent path based on the Markov Decision Process (MDP) and social acquaintance recommendation variable decision space. The path planning model is described with MDP, and social acquaintance recommendation, assuming that every social member can provide workplace and service recommendation for mobile agent in a cooperative work manner. However, their technique is time consuming and complicated to apply in practice.

Recently, [16] presented an itinerary planning scheme using multi-agent by building a spanning tree of WSN nodes. They have introduced an itinerary algorithm called disjoint multi-Agent Itinerary planning (DMAIP). Simply, the algorithm builds a network topology graph based on WSN, and then it generates a spanning tree of the connected graph to increase weigh and traverse the spanning tree recursively to find disjoint paths of all the sub trees.

Another approach proposed in [20] in which the authors concentrate on the computation side of an itinerary planning to enable an agent to achieve its mission while respecting a time deadline. The mission is characterized by a subset of resources that the agent should collect from the network servers while respecting a partial order. Resource is an abstract concept that could mean processing capacity, a data base, and a device, among other things. The network servers provide resources of varying kinds and qualities, giving rise to the problem of deciding which servers and the order in which they should be visited to maximize mission quality, while meeting the deadline. The work presented in [19] takes the computation itinerary work one step further by developing a graph theoretic model for itinerary computation under time constraints that enables the design of provably optimal, dynamic-programming (DP) algorithms and approximation algorithms.

5 Hybrid-Based Itinerary Planning to MA

5.1 Description and Operation

A hybrid approach is an approach that combines the functionality of two or more algorithms from different MA itinerary planning. The selection of the sensor visiting set is static, whereas the decision of the sequence for nodes to be visited is dynamic.

Hybrid approaches aims to minimise the effect of the disadvantages of individual MA itinerary planning categories described above.

5.2 Hybrid Approaches Itinerary Planning to MA

Many hybrid approaches for MA itinerary planning in WSN have been recently proposed in the literature. In [13], a hybrid planning mechanism 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 work presented in [21] uses an Angle Gap-based MIP (AGMIP), this approach provides a new way of grouping source nodes that do not use the circle shape. In AG-MIP the nodes within a particular angle gap threshold around one central location should be included in the same group. The idea of AG-MIP is to connect the sink and all source nodes with beelines and the angle gaps between beelines become a critical factor to describe the relevant degree among the source nodes. The importance of AG-MIP is their way of grouping; it uses angle gap to divide the network into sectors, which lead to a contention and interferences potentially reduced among mobile agent. However, the open interrogation in this approach is to find an optimal angle gap threshold remains a challenge.

The authors in [22], applied a tree structure with branches for planning the itineraries (CBID). The main idea of CBID is to include the node that makes the total cost minimal. The MAs are dispatched in parallel a number of MAs that sequentially visit sensor nodes arranged in tree structures. The proposed work has a significant result to reduce the overall energy consumption and response time. However, their work lacks scalability with the increasing number of nodes.

In [23], a Genetic Algorithm for Multi agents Itinerary Planning (GA-MIP) is proposed. The main idea is to encode the Source Node Sequence and the

Source Node Group into numbers as genes in the genetic evolution with randomly selection. After a number of evolution iterations, the solution corresponding to an efficient strategy of itinerary planning will be obtained. Although, extensive simulations were performed to show the performance of the GA-PMI in terms of time and energy consumption. However, the complexity of higher GA-PMI calculation makes the implementation of GA-MIP still debatable.

6 Discussion and Possible Future Directions

Before concluding this paper, this section provides a discussion about research issues, and future directions in the area of MA itinerary planning in WSNs. This short survey revealed that most of the existing approaches to MA itinerary planning suffer from inherent problems that limit their applications including: they are application specific [19,24]; some approaches indicate that they are suitable for small WSNs [24]; most algorithms assume that high redundancy exists among sensor data, which requires the use of a perfect data aggregation model [16]; they introduce overhead due to imperfect migrations, and access to legacy systems [21,23]; consume high power [16,25]; some techniques assume a constant size for the MA [24]. This is unrealistic due to the fact that MA grows in size while collecting data from sensor nodes. Furthermore, they mostly limit the MAs technology to a particular architecture. This restricts the use of the MAs on anything other than the architecture it was designed for.

Leading directly from the discussion above, we intend to investigate the usefulness of the watershed gradients to define the itinerary planning of the mobile agents. The order in which sensor nodes are visited by the mobile agent and the number of nodes it migrates to can have a significant impact on energy consumption. Furthermore, to select an optimal subset of sensor nodes and to decide on an optimal order of how to allow the MA to visit these nodes can be equally well supported by the Watershed gradients [26], and a Self Stabilizing algorithm [27].

6.1 An Energy Efficient Itinerary Planning Mechanism

The benefits of restricting the number of nodes that the MA will visit in a task are to reduce energy consumption, MA migration cost, and improve information accuracy by removing task-irrelevant nodes readings from a task computation. For instance, allowing a MA to collect temperature data over the whole network might end up getting the amount of data that is linked with the density of sensors but not necessarily pertinent to the monitored phenomena. The combination of the MA and Watershed algorithm will help answering the following questions:

1. How is a MA routed from node to node in an efficient way?
2. How does a MA decide a sequence to visit multiple nodes?
3. How the integration of the MA and the watershed reduces the cost of migration?

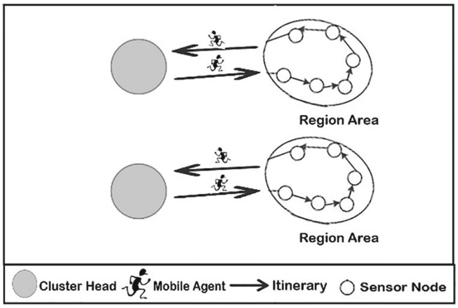

Fig. 2. MA Itinerary planning technique for WSNs.

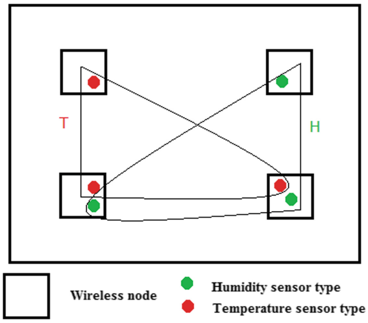

Fig. 3. Heterogeneous grouping scheme.

The Watershed Segmentation approach [26] groups nodes sharing some common group state into segments. A segment is described as a collection of spatially distributed nodes with an example being the set of nodes in a geographic area with sensor readings in a specific range. A network segment formed with a logical notion of proximity determined by applicative information is, therefore, capable to return specified information with high confidence.

A key contribution of the work presented in this research paper is the creation of logical groups of nodes, called segments (region), within the network. These segments are used as a scoping mechanism that is used for defining the itinerary planning of the MA. The user can exploit segments to be used by the system to autonomously make decisions on where a MA should be disseminated efficiently.

Figure 2 shows an illustration of the described MA itinerary planning scheme utilising watershed segmentation approach. It shows how MAs will be directed to only to a subset of the networks and the sequence of the nodes to be visited during migration. Figure 3 shows the grouping scheme based on heterogeneous sensor type.

7 Conclusion

To conclude, the main objective of this paper is to provide an understanding of the current issues in this area for better future academic research and industrial practice of MA Itinerary planning. We have presented a review of the state of the art for MA Itinerary planning approaches in WSNs. We discussed various approaches to Mobile Agent Itinerary planning. We also discussed the challenges as well as future research directions in developing a complete MA Itinerary planning mechanism.

The majority of MA Itinerary planning techniques focus on a particular architecture type. In the authors opinion, the next step is to integrate the mobile agent with the gradients of the watershed algorithm to generate an energy efficient itinerary planning mechanism. The group is a key concept for defining MAs itinerary planning. When implementing this integration it is important that new vulnerabilities are not introduced into the system.

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