Mobile Agents' Itinerary Analysis and Planning in Wireless Ad-hoc Sensor Networks

Purnendu Dubey	**Archana Pandey**
Dept. of CSE, MANIT, Bhopal	*Dept. of CSE, TIT, Bhopal*
Bhopal, India	*Bhopal, India*

Abstract— Wireless Sensor Networks are highly definite in nature when it comes to their different applications and their pattern of energy consumption is highly discussed research issue. In order to deal with above issues, mobile agents are introduced to the network. These agents are movable codes that roam around the network for data gathering related tasks. The route followed by these agents is called as itinerary whose significance lies in lowering down the overall energy usage so that the overall network life span is increased. This paper deals with various issues and techniques related to the itinerary analysis and planning, and also provides a new mechanism to plan the routes for these mobile agents. We conclude with further open problems and possible directions for future.

Keywords— energy efficiency, mobile agent (MA), optimal itinerary, wireless sensor networks (WSNs).

I. INTRODUCTION

Emerging trend of numerous applications for a single deployment has attracted a lot of interest among researchers in the field of Wireless Sensor Networks (WSNs). As WSNs are highly specific in nature in terms of their applications, the limited storage capacity and the requirements for larger capabilities on a sensor node makes it impractical for storing a chunk of programs in its local memory to sense and process accordingly. To deal with the above issue, mobile agent introduction in the network is proving to be very efficient and effective. A Mobile Agent (MA) is a movable chunk of code that roams in a network among sensors to perform its predefined tasks with autonomy and intelligence, with respect to the changing conditions in the network environment, in order to achieve the objectives of the sink (or the agent dispatcher). Using mobile agents is proved to be beneficial as it can potentially reduce the bandwidth consumption by transferring the data processing codes to the sensor node itself, which inherently reduces the energy consumption of the nodes as most of the energy is wasted in transferring the raw data to the sink when mobile agent is not applied. But the above policy can also incur large overhead if an efficient agent migration approach is not employed. A mobile agent system also provides re-tasking flexibility and cooperative information processing. Regarding the above benefits, mobile agents find various applications in Visual Sensor Networks (VSNs) and in Target Tracking scenarios using sensors. In case of VSNs, image retrieval from various nodes requires heavy image preprocessing and high bandwidth usage leading to steep decrease in the energy content of sensor nodes. Here mobile agents can be effectively applied for image preprocessing tasks and taking back only the processed images' data to the sink. In target tracking, to remove uncertainty about moving objects, data from a number of sensor nodes is to be retrieved, and hence mobile agents can be flexibly used here to retrieve data for tracking objects. But in order to apply mobile agents effectively in sensor networks, proper design functionality and related issues are to be taken care of, for efficient completion of tasks. In [2], the agent modelling and designing has been divided into four categories, i.e., architecture, itinerary planning, middleware system design and agent cooperation. Among these categories, itinerary planning deals with determining the list of sensor nodes to be visited by a mobile agent and planning the order in which these nodes are visited by the mobile agent in energy-efficient way. Here, itinerary is defined as the route to be followed by mobile agent during its journey in the network. This sequence of nodes to be visited has a larger effect in the efficient usage of energy by the network.

Various heuristic techniques are proposed to compute sub-optimal itineraries, since determining an optimized route for a mobile agent is a non-deterministic polynomial-time hard (NP-Hard) problem. Itinerary planning can be categorized [2] as:

- Static Planning, where itinerary for each agent is calculated purely by the sink or base station before transmitting the agent;
- Dynamic Planning, where itinerary for each agent is autonomously determined by the agent itself ,i.e., the agent itself select the sensor nodes and their visiting sequence according to the network conditions;
- Hybrid Planning, where the list of source nodes to be visited it predetermined by the sink statically and the sequence of visiting them is calculated by the agent dynamically while roaming in the network.

According to the above planning categories and the infusion of a single mobile agent or multiple mobile agents in the network, various proposed algorithms are categorized as Single-Agent Itinerary Planning (SIP) and Multiple-Agents Itinerary Planning (MIP) problems. SIP algorithms basically constrained when large networks comes in scenario because of larger delay and unbalanced load due to the mobile agent's migration and increasing, respectively. Above issue is dealt

with MIP algorithms, where basic design issues include, a) quantity of MAs to be used; b) sources nodes' grouping for each MA; and c) the itinerary planning for each MA. This paper focuses on the itinerary planning issues of mobile agents and provides study of various methods being proposed in the same field. We then present a new approach for itinerary planning for these agents. Section 2 studies various solutions to SIP solutions and MIP problems, Section 3 provides our proposed algorithm with expected performance analysis and Section 4 points conclusions with future directions.

II. RELATED WORK

A. Single-Agent Itinerary Planning (SIP)

Itinerary planning calculates the sequence in which an MA visits the sensor nodes. It has a significant impact on the system performance. Thus, how to find the optimal itinerary for the MA to visit particular sensor nodes is a critical problem. Also, finding an optimal itinerary for an MA is NP-hard [7]. So, certain heuristic algorithms are proposed.

Itinerary related issues that can be tackled by the sink or the MA autonomously includes the following:
- Selecting the list of source nodes to be visited by the MA.
- Computing an energy-efficient source-visiting sequence.

Two static algorithms are being proposed in [1] to calculate the MA itinerary: local closest first (LCF) and global closest first (GCF). Both the algorithms assume a cluster-based network environment. Also, both start from a central node or the sink and plan the itinerary in static manner, i.e., before the MA is dispatched in the network. Both the algorithms assume high redundancy among sensory data, so requires perfect data aggregation model to be used. The LCF scheme searches for the node with the shortest distance from the current node. The GCF scheme always searches for the node having shortest distance from the sink. These schemes only consider the spatial distance between the sensor nodes for the computation purposes and hence, may not be considered as energy-efficient in many cases. The computational complexity and space complexity of LCF are same, i.e., $O(n^2)$ and those of GCF are $O(n \log n)$ and $O(n)$, respectively [6]. Another method called Mobile Agent based Directed Diffusion (MADD) was proposed in [4] as a hybrid scheme for itinerary planning. MADD is based on the routing mechanism of Directed Diffusion (DD) [5], which is a data-centric dissemination protocol. In DD, firstly, the sink floods the interest packets or query in the network to determine the sensor nodes having the interest-related data and secondly, the intermediate nodes sets up the gradients to send the data back to the sink. The value of these gradients is basically used to select the suitable neighbour node as next hop in the route to be followed. Similar concept is followed in MADD, where the sensor nodes flood the exploratory packets towards the sink when an event of interest is detected. Based on these packets, the sink statically selects the nodes to be visited and dispatches the MA, which autonomously and dynamically selects the next hop or node among the source-visiting set on the basis of the gradient values. The MA then aggregates the individual sensed data when it visits each source node. Now comparing to DD, MADD is highly reliable and consume lower energy. But when the source nodes are increased steadily, MADD's integrated performance (in terms of delay and energy consumption) is observed to be worse than LCF [8]. Two energy-efficient algorithms, Itinerary Energy Minimum for First-source-selection (IEMF) and Itinerary Energy Minimum Algorithm (IEMA) have been proposed in [6]. Methods discussed above like LCF, GCF, MADD do not take into consideration the estimated communication cost while an MA migrates in the network. Unlike LCF and GCF, IEMF and IEMA do not assume any specific network environment. IEMF extends the LCF functionality by taking into account the energy cost estimation. According to the authors, the choice of first node of the itinerary is of utmost importance as it can lead to an unbalanced itinerary altogether. The IEMF idea is quite general, where it chooses an arbitrary source node as the First node from the set of nodes to be visited by MA and applies LCF on remaining nodes in the list. Same process is followed by choosing each node as First node and applying LCF on remaining ones. This gives us *n* different itineraries for *n* different nodes taken as First node. Out of these *n* itineraries, the one with the lowest energy cost is selected to be followed by MA.

IEMA, on the other hand, is an iterative version of IEMF. It applies IEMF in order to select every next source node of the itinerary in an energy-efficient manner. Performance analysis shows that due to the high computational and space complexity, IEMA should be used to compute a certain number of nodes of the itinerary and the remaining nodes may be chosen by applying LCF. This will provide with a sub-optimal path while making a trade-off between the computational complexity and the energy-efficiency. Thus, IEMA seeks to optimize the itinerary up to a certain degree. The computational complexity and space complexity of IEMF are $O(n^2 logn)$ and $O(n^2)$, and those of IEMA are $O(k \cdot n^2 logn)$ and $O(n^2)$, respectively [6]. In terms of iterations, a single iteration of IEMF can outperform LCF/GCF in terms of energy and delay, while suitable *k* iterations of IEMA can lead to an improved itinerary and quality of service.

In [7], genetic algorithm for itinerary planning has been presented as a static scheme to compute the near-optimal solution by employing suitable encoding mechanism, crossover and mutation operators, and an evaluation function. It assumes that in order to shorten the search space, each node should not be visited repeatedly. Though genetic algorithms can achieve global optimizations, still they are not a lightweight solution for the energy constrained sensor network scenarios.

Employing a single mobile agent for data collection for large-scale sensor networks exhibit following drawbacks as depicted in [9]:

1) *Large Delay*: For networks having hundreds or more nodes, single agent system leads to large delays in data aggregation.

2) *Unbalanced Load*: This has two perspectives. Firstly, considering the entire network, only the nodes along the itinerary will get exhausted in terms of energy very quickly than other unvisited nodes. Secondly, with respect to the

itinerary, the agent size continuously increases (as it aggregates data) while roaming in the network, making its transmission from the itinerary back to the sink consume more energy.

3) Insecurity with large accumulated size: As more data is accumulated by the agent, it increases its chances of being lost in wireless medium due to noise during migration. The longer the itinerary, the more risk for the agent migration in the network.

Above leads to the further study of Multi-Agent Itinerary Planning (MIP) algorithms where multiple agents can be dispatched into the network, depending on various parameters like network size, number of source nodes, data aggregation ration, sensor data size, etc.

B. *Multiple-agent Itinerary Planning (MIP)*

Infusing multiple MAs in to the WSN provides benefits like scalability to deal with large network and optimization of task load by partitioning the network area among these MAs. These are the reasons behind the motivation to design MIP algorithms. Before presenting various MIP algorithms, we should discuss the design issues related to itinerary planning for multiple agents as:

1. Quantity of MAs

Introduction of multiple MAs in the network will induce more wireless transmission traffic in the network and may possibly introduce more interference and collisions and unstable energy consumption. So, the quantity of MAs is a trade-off factor for designing MIP algorithms.

2. Grouping of source nodes

The source nodes should be grouped properly according to some factors, like spatial position, and different groups should be assigned to different MAs in an optimized way. Also, a sense of balance must be preserved among the number of MAs and the number of source nodes in all groups in order to achieve optimized task period.

3. Itinerary of each MA

After the number of MAs and their subsequent groups of source nodes are decided, the routes followed by each MA are to be determined. Planning itinerary for each MA can be taken as a separate problem but the routes decided for each MA should avoid overlapping to lower the chances of collisions and interferences among the transmission flows. Among the above three issues, the third one can be addressed using different SIP algorithms. So most of the algorithms presented here differ in the way they decide the number of MAs and implement source grouping methods. Centre location-based MIP (CL-MIP) was proposed in [8], which is based on the iterative version of SIP to create MIP solutions. In CL-MIP, the source nodes are grouped together for an MA according to their geographical relevance. This visiting area generally takes circular form and a Visiting Central Location is determined among the source nodes in the group, which marks the centre of that circular area. Then the source nodes in this group are assigned to that particular MA. This algorithm is iteratively performed until all source nodes are allocated to MAs and the number of iterations mark the number of MAs in the network. Within one group, the route of an MA is planned by applying existing SIP algorithms discussed in previous sections. But here in particular, Itinerary Energy Minimum for First-source-selection (IEMF) algorithm [6] is adopted due to its low computational complexity and high efficiency.

However, the following assumptions of CL-MIP are critical:
- The source nodes' grouping is only done on the basis of their geographical locations.
- Grouping in circular area is a questionable issue which is not a generic solution when the source nodes are distributed irregularly.
- It just transforms the MIP problem into iterative version of SIP algorithms leading to sub-optimal MIP solutions.

Directional Source Grouping-based MIP (DSG-MIP) [9] determines the visiting area of the MA by dividing it on the basis of directional sector zones. These zones have the source nodes included in the itinerary and the length of the itinerary is controlled by a threshold angle in such a way that a near-optimal itinerary can be calculated by adjusting the angle efficiently in an adaptive manner. It is based on the criterion that mainly the information significant sources are situated in same direction with respect to the sight of the sink, hence it is direction oriented source grouping and so is the role of threshold angle. The rest of the paper follows the similar procedure as CL-MIP in terms of planning the route of each MA. Furthermore, how to find the threshold angle in optimal way is still an open issue. Some Tree-based MIP algorithms are also proposed, most of which are based on the calculation of minimum spanning tree (MST) for itinerary computations. In [10], MST is calculated with the totally connected graph (TCG) and considers the sources nodes in particular sub-tree as the group. It also proposes a balancing factor used to achieve a balanced trade-off between energy cost and delays. The MST with balancing factor is named as BST-MIP method. Paper [11], [12] and [13] also proposes some tree based MIP solutions which are based on MST and greedy approaches. As an open research issue, all tree-based approaches lack dynamic recovery solutions for transmission failures. Similar to the evolutionary Genetic Algorithm, a Genetic Algorithm-based MIP (GA-MIP) is also proposed in [14], which mainly aims at optimizing the number of MAs and planning an efficient itinerary for the MAs.

Main features of GA-MIP are summarised below:
- A two-level coding scheme is proposed for MIP where the source grouping and the MA routing solution are being encoded into a gene for genetic evolution.
- Iterative evolution approach is followed. Here each of the iteration requires the evolution operators like crossover and mutation operators to be applied to produce variety of genes.
- A fitness function, also known as select operator, is applied in order to select the better genes to survive among the solutions.

- GA-MIP method considers MIP problem as a whole, rather than a four-step method as above mentioned algorithms propose.

Complexity analysis [6] shows that the computational complexity of the MIP depends on the SIP algorithm used for itinerary planning. If IEMF is used for itinerary planning, MIP's computational complexity is $O(m \cdot n^2 log n)$, where m is the number of mobile agents to be infused in the network. Performance analysis of LCF and various MIP algorithms shows that upon increasing the number of source nodes, the integrated performance (in terms of energy and delay) of LCF becomes worse than other MIP algorithms. Also GA-MIP gives better performance in terms of delay and energy consumption, but due to its higher computational complexity, GA-MIP is not a lightweight solution for the energy-constrained wireless sensor networks.

III. PROPOSED ITINERARY PLANNING ALGORITHM

A. Motivation

As a mobile agent migrates in the sensor network, its size increases from node to node. It can simply be observed that the mobile agent is of least size when it visits the first source node and its size is the largest when it leaves the last source node. Hence this constantly increasing size of MA leads to increase in transmission power consumption as MA migrates in the network. This leads to the concept of planning the itinerary on the basis of energy or battery power remaining on the sources. The simplest case could be to visit the sources in ascending order of remaining-energy factors of the sources, but it may lead to the following problems:

- Two nodes, with the lowest of the energies remaining, might be located at far ends of the network, which may lead to inefficient visits to these sources.
- There might be multiple revisits to the same nodes which may deplete their power fast and hence lower the network lifetime.

Above issues leads us to consider both the energy of the nodes and the distance between the nodes also for the itinerary planning purpose.

B. Algorithm

Our algorithm assumes the following points:

- The sink node is the most powerful node and has enormous resources for computation purposes.
- Sink node already knows the location of all the sources to be visited by an MA.
- Sink also knows beforehand the energy (in Joules) remaining on all the sources and the hop path lengths between those nodes.

Our algorithm follows a static approach to plan the itinerary, i.e., with all the assumptions stated above, itinerary is planned at the sink or agent dispatcher itself before the agent is fused into the network. Our approach uses the product of energy and hop path count between target sources in order to plan the itinerary.

TABLE I
NOTATIONS USED IN ALGORITHM

Notation	Description
V	Set of n sensor nodes to be visited by the mobile agent
n	Number of sensor nodes to be visited
s	Sink node
ID	Node identifier
E_m	Remaining energy at any sensor node m
$H_{l,m}$	Hop path length from node *l* to *m*
$f(E_m, H_{l,m})$	This function calculates the product of remaining energy of a node m to the hop path length between node l and m
A	Stores the result of $f(E_m, H_{l,m})$ for different nodes in the form of array
I	Itinerary consisting of sequence of nodes to be visited by mobile agent
I[1]	First node selected on the basis of lowest remaining energy from set V

The proposed algorithm can be summed up as:

Algorithm 1 Proposed algorithm for Single-agent Itinerary Planning (SIP) problem
---
/* First node selection */
/* Node ID with minimum remaining energy is selected as first node */
    I[1] = ID [min (E_a, E_b, E_c, …… E_n)]
/* finding the rest of the itinerary for mobile agent */
    for (node j in I)
    {
        for(every unvisited neighbor node of j in V)

```
        {
                A[i] = f(E_m ,H_j,m )
        }
        I[j+1] = ID [min (A[1],A[2],A[3], ….)]
    }
```
/* at last the array I[n] provides the itinerary to be followed by the mobile agent.*/

The sequence of nodes generated by above approach is followed by the mobile agent in order to process and collect data and return back to the sink. Our approach is basically a solution for the SIP problem. But it can also be used in various MIP techniques for planning the itinerary in case of multiple mobile agents.

IV. SIMULATION RESULTS

A. Simulation configuration

We have implemented the proposed algorithm in NS-2 simulator and performed extensive simulations. The network model adopted in [8] is used here with a uniform field of 1000m x 500m area where 500 nodes are distributed randomly to maintain the large-scale network and rest of the parameters and energy model remains similar.

B. Performance Metrics

In order to evaluate the performance of our proposed algorithm, we have considered the performance metrics, that have also been considered in some previous works in [3] and [6] as:

1) Task Duration: For an SIP algorithm, it is equivalent to average end-to-end reporting delay. But in case of MIP algorithms, since multiple agents are working parallel in the network, so the task duration is the time taken by an agent to return last, among other agents, to the sink.

2) Average communication energy: The total energy consumption including the transmission, reception, retransmission, collisions etc., in order to collect and aggregate data from all the source nodes.

3) Energy-delay product: For time-sensitive applications in energy constrained WSNs, the EDP (product of energy and delay) can give a unified view of the network performance. The lesser is the value of EDP, the better the performance of the network.
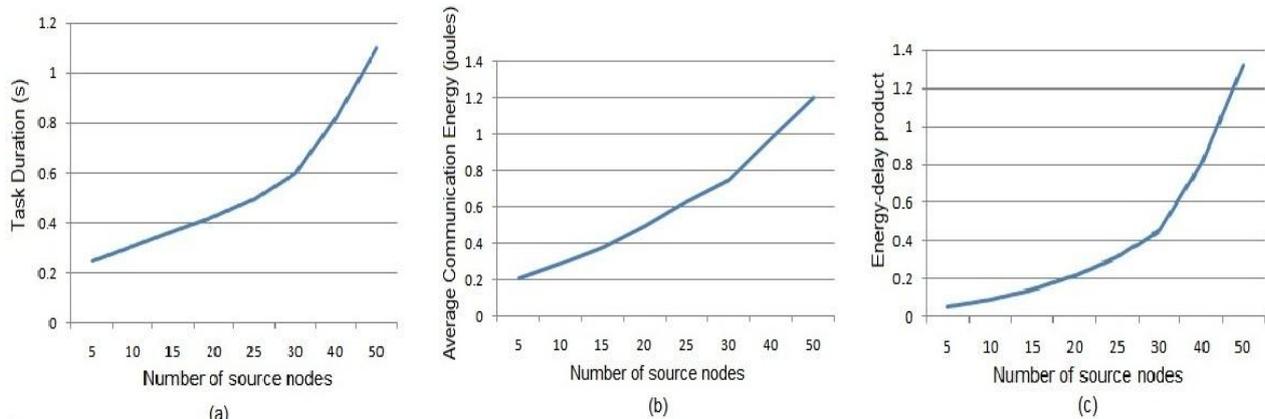
C. Performance

Fig. 1: Effect of number of source nodes on (a) Task Duration; (b) Avg. communication energy; (c) EDP

As shown in Fig. 1, as the number of source nodes increases, the EDP value increases sharply that may be a bit of concern in case of a very large network. But this can be overcome by using multiple agents in the network in parallel manner which may improve the performance of the network. Most of the algorithms studied earlier are either pure distance-based or they consider the energy consumption in communication only for the itinerary planning purposes. As proposed, our approach considers energy content remaining in the sensor nodes and is very much suitable in scenarios where there might exist some sources which sense significant data from the target region but have lesser energy remaining as compared to other nodes. So those data should be gathered first before the nodes' energy gets depleted. In terms of performance comparison, our algorithm may produce worse results than other SIP algorithms, but it tries to preserve the network nodes lifetime by parsimoniously using the energy of the nodes for communication of the mobile agents. Also our approach might not efficiently tackle the issue of revisiting the nodes, which still is considered to open research issue.

V. CONCLUSIONS

In this paper we discussed various issues and techniques regarding mobile agents' itinerary planning and proposed an algorithm considering the shortest remaining energy factor for itinerary planning which issues the problem for mobile agents to visit firstly the nodes with the smallest energy to handle the sensed data. It considers the data of utmost importance for concerned application of WSNs. Also, this algorithm might not tackle the issue of revisiting of nodes efficiently, which still is an open research issue.

REFERENCES

[1]   H. Qi and F. Wang, "Optimal itinerary analysis for mobile agents in ad hoc wireless sensor networks," in Proc. IEEE ICC , Helsinki, Finland, Jun. 2001, pp. 147–153.

[2]   M. Chen, S. Gonzalez, and V. C. M. Leung, "Applications and design issues of MAs in wireless sensor networks," IEEE Wireless Commun., vol. 14, no. 6, pp. 20–26, Dec. 2007.

[3]   M. Chen, V. Leung, S. Mao, T. Kwon, and M. Li, "Energy-efficient itinerary planning for mobile agents in wireless sensor networks," in Proc. IEEE ICC, Dresden, Germany, Jun. 14–18, 2009, pp. 5026–5030.

[4]   M. Chen, T. Kwon, Y. Yuan, Y. Choi, and V. Leung, "Mobile agent-based directed diffusion in wireless sensor networks" EURASIP J. Adv. Signal Process., vol. 2007, no. 1, pp. 219–242, Jan. 2007.

[5]   C . Intanagonwiwat, R. Govindan, and D. Estrin, "Directed diffusion: a scalable and robust communication paradig m for sensor networks," in Proceedings of the 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM '00), pp. 56–67, Boston, Mass, USA, August 2000.

[6]   M. Chen, L.T. Leung, T. Kwon, and L. Zhou, "Itinerary planning for energy-efficient agent communications in wireless sensor networks," IEEE Trans. On Vehicular Technology, vol. 60, no. 7, Sept. 2011.

[7]   Q. Wu, N. S. V. Rao, J. Barhen, S. S. Iyenger, V. K. Vaishnavi, H. Qi, and K. Chakrabarty, "On computing mobile agent routes for data fusion in distributed sensor networks," IEEE Trans. Knowl. Data Eng., vol. 16, no. 6, pp. 740–753, Jun. 2004.

[8]   M. Chen, S. Gonzlez, Y. Zhang, and V. Leung, "Multiagent itinerary planning for sensor networks," in Proc. QShine, Las Palmas de Gran Canaria, Spain, 2009, pp. 584–597.

[9]   M. Chen, S. Gonzalez, and V. Leung, "Directional source grouping for multi-agent itinerary planning in wireless sensor networks," in Proc. ICTC, Jeju Island, Korea, 2010, pp. 207–212.

[10]   M. Chen, W. Cai, S. Gonzalez, and V. Leung, "Balanced itinerary planning for multiple mobile agents in wireless sensor networks," in Proc. 2nd Int. Conf. ADHOCNETS, Victoria, BC, Canada, 2010, pp. 416–428.

[11]   Gavalas, D., Mpitziopoulos, A., Pantziou, G., Konstantopoulos, C.: "An approach for near-optimal distributed data fusion in wireless sensor networks", Springer Wirel. Netw. , 2009, 16, (5), pp. 1407 – 1425

[12]   Mpitziopoulos, A., Gavalas, D., Konstantopoulos, C., Pantziou, G.: "CBID: a scalable method for distributed data aggregation in WSNs", Hindawi Int. J. Distrib. Sens. Netw. , 2010, 2010, Article ID 206517, DOI: 10.1155/2010/206517

[13]   Konstantopoulos, C., Mpitziopoulos, A., Gavalas, D., Pantziou, G.: "Effective determination of mobile agent itineraries for data aggregation on sensor networks", IEEE Trans. Knowl. Data Eng. , 2010, 22, (12), pp. 1679 – 1693

[14]   Cai, W., Chen, M., Hara, T., Shu, L.: "GA-MIP: genetic algorithm based multiple mobile agents itinerary planning in wireless sensor network". Proc. Fifth Int. Wireless Internet Conf. (WICON), Singapore, 2010.