# A Tracking Range Based Ant-Colony Routing Protocol for Mobile Wireless Sensor Network

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## Abstract

*Mobile wireless sensor network (M-WSN) is wireless sensor network without infrastructure, and includes mobile nodes. According to certain mobility models, mobile nodes move around in the network, and change their locations continually. Because the paths between nodes are not fixed any more, it normally takes nodes longer time to communicate each other. To solve this problem in the M-WSN, this paper presents a new ant-colony routing protocol. The new protocol uses the tracking range of mobile nodes to split the path between source node and destination node into two parts: indefinite path and definite path. The indefinite path is almost the same as the path of probabilistic search in the traditional ant-colony routing protocols. The definite path is the path in the tracking range of mobile nodes. The message from source node is first sent through indefinite path until the tracking range of mobile destination node is reached. Then the message is sent through definite path to reach the destination node. Simulation results showed that our protocol speeded the procedure of message delivery.*

## 1. Introduction

Recent development in wireless communications and manufacture has enabled the wide use of wireless sensor networks (WSN) [1], which consist of large number low-cost, low-power nodes with sensing ability. These nodes are often deployed in the specific environment, and organized by themselves into a large sensing platform through wireless channels. By cooperation between them, sensor nodes can detect, sense, and gather environmental data, such as temperature. Then the data is sent back to the base station to facilitate people's query.

Mobile wireless sensor networks (M-WSN) are wireless sensor network without infrastructure, and include two kinds of nodes. One is router nodes, which are fixed and responsible for forwarding messages. The other is mobile sensor nodes. These mobile sensor nodes move around in the networks according to certain mobility models, and sense environmental data. Typically, because of high cost of localization services (such as GPS), all nodes in a mobile sensor network have no knowledge of their own locations. In a mobile wireless sensor network, one special router node is called base node. The responsibility of base node is to gather environmental information from mobile sensor nodes and/or send command message to mobile sensor nodes. Since mobile sensor nodes change their locations frequently, it is very difficulty to maintain routing information between base node and mobile sensor nodes. So designing a routing protocol for M-WSN becomes a new challenge.

In the early 90s, M.Dorigo discovered Ant-Colony Optimization Algorithm (ACO) [2-5]. The inspiring source of ACO algorithms is the foraging behavior of ants in the real world. When searching for food, ant first searches randomly around its nest, returns back to the nest once food is found, and drops chemical pheromone along the trip to help other ants find the food. After a period of time, ants can find the shortest path between their nest and food. The ACO algorithms are stochastic search procedures, and can be used to solve some hard combinatorial optimization problems. Many researchers have applied ACO algorithms to solve network routing problems[6]. By emulating the procedure of food searching of real ants, the path between a pair of nodes can be constructed.

Essentially, the ACO algorithms are cumulative procedures of past information. The path information between the nest and food is updated and/or corrected

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by the continuous search of ants. This strategy is feasible for static networks whose topologies are not changed repeatedly. But it is not appropriate for mobile wireless sensor networks. In mobile wireless sensor networks, frequent network topology changes may invalidate past information quickly. Meanwhile, the mobility of sensor nodes in the network makes the search procedure a “Hide & Find” game. It will take ants a longer time to reach the “food”- mobile sensor nodes. In other words, it will increase the time of message delivery.

This paper presents a tracking range based ant-colony routing protocol (TRAC) for mobile wireless sensor networks. The protocol uses the tracking range of mobile sensor nodes to split the search path into two parts: indefinite path and definite path. The message from base node is first sent probabilistically through indefinite path until the tracking range of mobile destination sensor node is reached. This procedure is the same as that of traditional ant-colony routing protocols. Then the message is sent through definite path in the tracking range. With the mobility of mobile sensor nodes, the tracking range information is gradually known by more and more router nodes. This will help decrease the length of indefinite path, thus speed the procedure of message delivery.

The remainder of this paper is organized as follows. In section 2 we introduce the related work on ant-colony algorithms. In section 3 we present the network model. In section 4 the overview of TRAC protocol is presented. Subsequently, in section 5 TRAC protocol is presented in detail. Then in section 6 simulation results are shown. Finally, a conclusion is drawn in section 7.

## 2. Related work

Ant-Colony Optimization algorithms [7-8] are a kind of meta-heuristic search algorithms. In this kind of algorithms, a set of cooperated artificial ants find feasible solutions to optimization problems by searching the graphs denoting the problems. Let $G=(V,E)$ denote the graph. Pheromone value $\tau^{i,j}$ is associated with every edge $e(v^i,v^j)\in E$ in the graph. It represents the degree of the use of the edge in the process of solving problem. The bigger the pheromone value is, the larger the probability of the edge included in the solution is.

In general, the ACO algorithm includes three steps: initialization, search solution, and pheromone value update. In the initialization phase, the pheromone value on every edge is set to a constant value. Then, a repeated search procedure starts. In the each iteration, there are $n^a$ artificial ants probabilistically searching the problem graph to find a solution. When an ant is at node $v^i$, the probabilities of choosing the next visited nodes (transitions probabilities) are defined as follows:

$$P^{i,j}=\begin{cases}\dfrac{\tau^{i,j}}{\sum\tau^{i,j}}, v^j\in N^i \\ 0, otherwise\end{cases} \tag{1}$$

Where $N^i$ denotes the neighboring nodes of node $v^i$. After the each iteration, the pheromone value on every edge of the solution is updated. The update rule is defined as follows:

$$\tau^{i,j}=\tau^{i,j}+\Delta\tau \tag{2}$$

The aim of the update rule is to increase the probabilities of the use of these updated edges, which have been found in a feasible solution. After update, the ACO algorithm starts another round iteration until good enough solution is found.

The key components of the ACO algorithm are transitions probabilities and pheromone value update rule. Variants of the ACO algorithm generally differ from each other in these two aspects. G.D.Caro and M.Dorigo presented the AntNet protocol [9] to be used in data network routing. Their transitions probabilities take into account link conditions of the current node. If the queue of link toward some node is long (i.e. the link is congested), the probability of choosing this link is low. When ants return from $v^i$ to $v^j$, the pheromone value on the edge is updated as follows:

$$\tau^{i,j}=\tau^{i,j}+\gamma\times(1-\tau^{i,j}) \tag{3}$$

Where $\gamma$ is the parameter of the AntNet protocol. The ARA algorithm [10] is a routing protocol based on ant-colony algorithm. This protocol computes the pheromone value according to the number of hops ants travel, and the update rule is very similar to the equation (2). It also simulates the evaporation process of the nature by decreasing the pheromone values regularly.

## 3. Network model

Two kinds of nodes exist in the network: fixed router node and mobile sensor node. The router nodes have fixed positions, and theirs only tasks are to forward messages. The mobile sensor nodes walk in the network according to certain mobility models, such as Random Waypoint model. Base node is a special router node communicating with mobile sensor nodes. We assume that all nodes in the network have no knowledge about their locations. Every node’s sensing radium is the same.

For the sake of convenience, we define the following symbols. Let $N=(V,E)$ denote the network, $V$ denotes all nodes in the network, $n=|V|$ denotes the number of nodes, and $E$ denotes communication links between nodes. For node $v^i$, $N^{i,t}$ denotes all neighboring nodes at time $t$:

$$N^{i,t} = \left\{ v^j \,\middle|\, d(v^j, v^i) \le r(v^i), i \ne j \right\} \quad (4)$$

Where $d(v^j, v^i)$ denotes the distance between node $v^i$ and node $v^j$, and $r(v^i)$ denotes the sensing radium of node $v^i$. $N^{i,t,k}$ denotes the set of neighboring nodes $j(1 \le j \le k)$ hops away from node $v^i$. Finally, we define the tracking range function:

$$range : V \rightarrow N \quad (5)$$

The input parameter is a node (called as input node), and the output of the function is the hop number of the tracking range of the input node. The tracking range can be considered approximately as a circle, and the input node is the centre. The radium of this circle depends on the hop number of the tracking range. All nodes in the tracking range represent the input node, and can be regarded as an entity. We use $\sigma(v^i)$ to denote the entity representing node $v^i$:

$$\sigma(v^i) = \left\{ v^j \mid v^j \in N^{i,t,range(v_i)} \right\} \cup \left\{ v^i \right\} \quad (6)$$

For example, range($v^i$)=3 means all nodes three hops away from node $v^i$ can be regarded as an entity, and can be used to represent node $v^i$.

## 4. Overview

The TARC protocol includes four phases: setup, path search, pheromone value update, and delivery. The pheromone value update and delivery phases are carried out simultaneously after message reaches the entity of mobile destination node.

In the setup phase, every edge in the network is assigned a constant value $C$, which represents the initial pheromone value. When the protocol starts, the probabilities of choosing every edge are the same.

In the path search phase, artificial ants from base node use the path information collected in the past to probabilistically select the next direction. Meanwhile, mobile destination node $v^t$ broadcasts its tracking range information to surrounding nodes. These surrounding nodes form the entity $\sigma(v^t)$. Also the paths from the surrounding nodes to the mobile destination node are constructed. When artificial ants reach the nodes at the border of the entity $\sigma(v^t)$, the path search phase is finished, and the messages contained in the artificial ants are passed to the nodes.

The pheromone value update phase follows the path search phase. Artificial ants take the same path as they came, but in the opposite direction. Along the path, artificial ants increase the pheromone value on the edge by some amount of pheromone value $\Delta\tau$ to strength the edge.

After the nodes at the border of the entity $\sigma(v^t)$ receive the messages, the delivery phase begins. The messages are delivered along the path constructed in the path search phase until they reach the mobile destination node.

All phases are shown in the figure 1, except the setup phase. The hop number of the tracking range of the mobile destination node $v^t$ is 3, i.e. range ($V^t$) = 3.

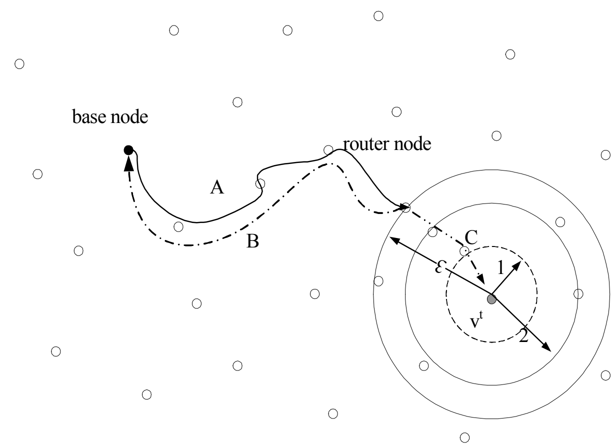


**Figure 1. The TRAC protocol phases: (A) the path search phase; (B) the pheromone value update phase; (C) the delivery phase**

Figure 1 shows that the path travelled by the message is split into two parts: one is outside of the $\sigma(v^t)$, the other is inside of the $\sigma(v^t)$. The outside part is travelled by artificial ants probabilistically, called as indefinite path. The inside part is constructed in the path search phase, called as definite path. By splitting the path into indefinite and definite paths, the time of probabilistic search is reduced, thus messages are delivered faster.

## 5. TRAC Protocol

The artificial ant in the TRAC protocol is a kind of message, and includes information that the base node wants to sent to the mobile destination node. Router node contains two routing tables: $T^R$ and $T^r$. The routing table $T^R$ is used by the nodes in the tracking range to record the paths toward the mobile destination node. The paths travelled by the artificial ants before they reach the entity $\sigma(v^t)$ are recorded in the routing table $T^r$, which directs the artificial ants back to the base node. We describe the TRAC protocol in detail in this section.

## 5.1 Setup

Initially, the pheromone value $\tau^{i,j}$ on the every edge $e(v^i, v^j) \in E$ in the network is assigned a constant value $C$. Because at the beginning router nodes have no information about the mobile destination node, the probabilities of choosing neighboring nodes of a node are the same when the search starts.

## 5.2 Path Search

After the setup phase, the mobile destination node broadcasts the tracking range message RANGE, the format of the message is $(id, v^t, T^s, \varphi, \mu)$. $id$ is the identifier of the previous hop node (initially $v^t$). $v^t$ is the identifier of the mobile destination node. $T^s$ is the timestamp generated by the node $v^t$. $\varphi$ is the hop number from the previous hop node to the node $v^t$ (initially 0). $\mu$ is equal to range( $v^t$ ). When moving to new place, the mobile destination node broadcasts the RANGE message.

When the router node $v^i$ receives the RANGE message, it increases the $\varphi$ value by one in the message. If the new value is larger than $\mu$ (i.e. the node $v^i$ is out of the tracking range), the RANGE message is dropped. Otherwise, the router node $v^i$ marks itself, and an entry $(id, v^t, T^s, \varphi)$ is updated in the routing table $T^R$. There is only one entry for each destination node. If the router node receives several RANGE messages of the same destination node, only the information in the RANGE message with the largest $T^s$ value is used. For the RANGE messages with the same $T^s$ value, the information in the RANGE message with the minimum $\varphi$ value is used. By recording the previous hop node, the path from the router node toward the destination node is recorded. Then the router node replaces the $id$ value in the message with its own identifier, and broadcasts it. All nodes updating their routing table $T^R$ form the entity $\sigma(v^t)$.

The base node sends out the $n^a$ artificial ants, their format is $(v^t, M, \varphi, id, S^n)$. $v^t$ is the identifier of the mobile destination node. $M$ is the information that the base node wants to sent to the node $v^t$. $\varphi$ is the hop number travelled by the artificial ant, $id$ is the identifier of the previous hop node, and $S^n$ is the serial number for the destination node. When the router node $v^i$ receives an artificial ant, it first increases the $\varphi$ value in the message by one, and checks the neighboring nodes set $N^{i,t}$. Let $N^{i,t,*}$ denote the set of the marked nodes in the $N^{i,t}$. Then:

1) If $N^{i,t,*} \neq \phi$ : it means that the artificial ant has reached the tracking range of the destination node. The tracking range may be the latest one, or may be the old tracking range left by the mobile destination node after it moved to new place. The router node $v^i$ selects as the next hop node the node with the largest $T^s$ value in the $N^{i,t,*}$, and record the $T^s$ value as $T^{s,\max}$. Also the $\varphi$ value in the message is recorded as $\varphi^*$. Then the pheromone value update and delivery phases begin.
2) If $N^{i,t,*} = \phi$ : it means that no tracking range information exists. The router node $v^i$ selects the next hop node probabilistically according to the pheromone value of the neighboring nodes using equation 1. If the artificial ant is from the router node $v^j$, the router node $v^i$ inserts an entry $(v^t, S^n, v^j)$ into the routing table $T^r$ as the reverse path information when updating pheromone values. The $\varphi$ and $id$ fields in the artificial ant are updated accordingly.

The loops in the path can be detected by $(v^t, S^n)$ pairs. The TRAC protocol uses a very simple method to avoid loops. When encountering loops, artificial ants are sent back to the previous hop node, and select other node as the next hop node.

## 5.3 Pheromone Value Update

The pheromone value update phase includes two steps. First, the incremental amount of pheromone value is computed using the following equation:

$$\Delta\tau = \frac{T^{s,\max}}{\varphi^*} \tag{7}$$

The larger the $T^{s,\max}$ value is, the more recent the tracking range would be, and the less the hops travelled by artificial ant in the tracking range are. Thus the message delivery is faster.

The router node $v^i$ generates the pheromone value update message UP. Its format is $(v^t, S^t, \Delta\tau)$. The UP message is sent back to the base node by using the reverse path information recorded in the routing table $T^r$. And along the reverse path, the pheromone values of the router nodes are updated according to equation 2.

## 5.4 Delivery

The entity $\sigma(v^t)$ of the mobile destination node $v^t$ is determined by the function *range*, which is in turn determined by the distance between the old location and the new location of the node $v^t$. Let $L^{old}$ and $L^{new}$ denote the old location and the new location, respectively. The distance between $L^{old}$ and $L^{new}$ is $d(L^{old}, L^{new})$ that is the result of multiplying the speed of the node $v^t$ by the time the node $v^t$ moved (we assume that the mobility model of the destination node is the Random Waypoint model). The *range* function is defined as follows:

$$range(v_t) = \partial \times \left\lceil \frac{d(L_{old}, L_{new})}{r} \right\rceil \qquad (8)$$

Where $r$ is the sensing radium of the node $v^t$, and $\partial$ is the protocol parameter. The $\partial$ value normally is one. Therefore, the old tracking range centered at $L^{old}$ and the new tracking range centered at $L^{new}$ are intersected.

Every time the destination node moves, the range function is computed, and a new RANGE message containing the new range value is broadcasted.

The delivery phase in the tracking range is very simple. According to the identifier of the destination node, router nodes lookup the routing table $T^R$ to find out the next hop node. For the case that if the message is delivered in the old tracking range and the central router nodes whose hop number is one in the routing table $T^R$ have not received the new RANGE message, they hold the message waiting for the new RANGE message, and then the delivery continues.

## 6. Simulations

In this section, we conducted a set of simulations to study the performance of the TRAC protocol. The simulation scenario consists of one base node, 1088 router nodes, and one mobile destination node. The base node is deployed at location (0, 0), while the router nodes are deployed evenly over 32m×32m region. The mobile destination node is initially located at (25, 14), and move according to the Random Waypoint model. The sensing radium of the nodes is set to 1.5m.

Let $h$ denote the actual length of the path travelled by the artificial ant who first reached the entity $\sigma(v^t)$. Let $h'$ denote the straight distance between the base node and the mobile destination node when the destination node received the message. We use $h/h'$ as the performance metric. The simulation conducted compares the performance of the TRAC protocol with different ant number. Simulation results are shown in the Figure 2.

As shown in the Figure 2, the $h/h'$ values are decreased gradually. The tracking range information of the mobile destination node broadcasts to the router nodes with mobility. With the execution of the protocol, more and more router nodes know about the tracking range information, it helps reduce the length of the indefinite part of the path travelled by artificial ants, thus reduce the entire length of the path. The TRAC protocol is different from other ant-colony routing protocols in that the TRAC protocol takes account of the dynamic information of the mobile destination node.

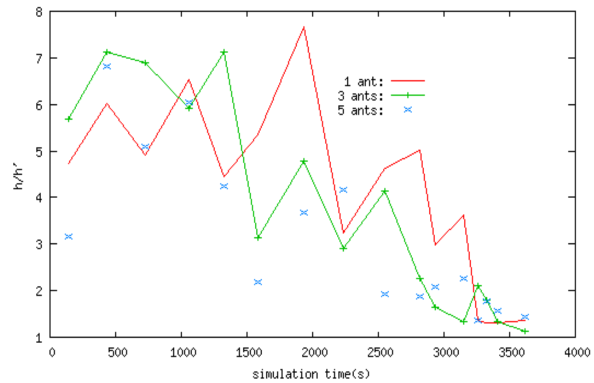


**Figure 2. The TRAC protocol with different ant number – 1/3/5**

## 7. Conclusions

In this paper, we present a tracking range based ant-colony routing (TRAC) protocol used in the mobile wireless sensor network. The TRAC protocol takes the tracking range information of the mobile destination node into account, and split the delivery path into two part: indefinite part and definite part. With the mobility of the mobile destination node, the length of the indefinite part is decreasd, thus reduce the entire path travelled by artificial ants. Simulation results showed that the TRAC protocol speeded the delivery procedure of messages between the base node and the mobile destination node.


## 8. Acknowledgements

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