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QoS Based on Ant Colony Routing for Wireless Sensor Networks

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***Abstract*— The wireless sensor networks (WSNs) are composed of nodes communicating over a wireless media, without the need for physical infrastructure. In this type of topology, all nodes cooperate to ensure the proper management of the network (control, routing, ...). Fully distributed nature of such networks is the problem of performance (due to the calculation of routes) as well as problems related to the security of exchanges between nodes. In regard to performance due to packet routing, we distinguish protocols inspired by ant colonies that give in most cases, better results. In this paper we present a protocol based on an ant colony to calculate dynamic routes and a cooperation mechanism which allows better quality of service (QoS) management problem in WSNs. Thus, we proposed Qos_Aco a routing protocol based on Ants colony with QoS support requirements in WSNs. Our approach allows to find the path with the least delay (end to end), the more bandwidth, and the shortest number of hops for data transmission.**

***Index Terms*— WSN, Qos_Aco, Delay, Bandwidth and Number of Hops**

I. INTRODUCTION

THE progress made in recent decades in the fields of microelectronics, micromechanics, and wireless communication technologies have yielded a reasonable cost of the components of a few cubic millimetres in volume [1]. The latter are called sensor nodes, they include: an acquisition unit responsible for collecting physical quantities (heat, humidity, vibration, etc…) and transform them into digital quantities, a processing and data storage unit and a module for wireless transmission. As a result, the sensor nodes are real embedded systems. The deployment of several of them, to collect and transmit environmental data to one or several collection points, in an autonomous way form a wireless sensors network (WSNs). This technology is currently developing an emerging area of research and has been the subject of numerous studies in recent years. The WSNs raise fundamental problems for the scientific community. These problems, in addition to those encountered in ad-hoc networks, are due to wireless communications, the density of nodes distribution, the constraints of resources (energy, processor, and memory), the low reliability of nodes, the highly distributed nature of the application and the supported mobility of nodes. These features specific to sensor networks systems are unreliable and their behaviour is hardly predictable.

The rapid development of multimedia technology and the commercial interest of companies to popularize this type of application have made the quality of service (QoS) a sector of great importance. In addition, ensuring QoS in such networks is very delicate. However, the unexpected change of topology may affect the continuity of service and make it extremely difficult if not impossible. It is therefore legitimate to consider the reliability of roads as the main constraint of QoS to be considered for the transmission of video streams. The routing is a method of delivery of packages to the correct destination through a network. The mission of routing is to determine the best path between the source and destination in the network according to a certain performance criterion.

Because of the limitation of radio transmission, the packets in the network can be transported through multi-hops. The search for paths and routing become essential mechanisms to support multi-hops radio transmission. In addition, the change in the topology makes the problem of connectivity and routing real challenges. The chosen orientation is to proposed Qos_Aco approche to ensure the QoS, found the path with the least delay (end to end), the more bandwidth, and the shortest in terms of number of hops.

II. ROUTING IN WSN

The problems with routing in wireless sensor networks (WSNs) are related to their unpredictable, dynamic and limited resources of nodes. The routing algorithms proposed must take into account certain constraints [2] [3]:

- Lack of infrastructure prevents any centralized control and requires a distributed resolution;
- The dynamics of the network and the rapid loss of validity of the roads that require mechanisms for appropriate updating;
- The limited resources forcing to limit the volume and frequency of routing information exchanged.

Roads constructed must also comply with the constraints of WSNs. Indeed, the low flows push to limit the number of intermediaries between two stations so as to minimize transit time information. The shortest path in number of hops is likely to also be the fastest transmission time [4] [5].

In addition, the path that uses the least amount of nodes is probably the most energy efficient. So there is an interest in determining the shortest paths to build roads. Indeed, more than the communication itself the synchronization between nodes is time consuming. In a communication path, if link breaks [6], while a process is necessary to rebuild all or part of the path. We therefore seek to minimize the number of new connections change in the path when the network changes.

III. THE FAMILY OF ACO

Recently, researchers have studied the behavior of insects to be inspired to organize networks [8] [9]. Indeed, the collective intelligence in social insects is reflected in the emergence of a macroscopic collective behavior intelligent due to simple interactions at the microscopic level. The functioning of ant colonies is the best example.

The behavior of ants is a collaborative and collective behavior. Each ant is a priority for the well being of the community [10]. Each individual of the colony is a priori independent and is not supervised (completely distributed system)). This concept is called heterarchy (opposing the hierarchy), where each individual is helped by the community in its development and in turn helps the proper functioning of the latter. The colony is self-controlled through relatively simple mechanisms to be studied. By projecting the behavior of these insects on the characteristics of WSNs, we see that the behavior of ants is well suited to this type of networks, particularly when calculating routes.

A new approach to routing in WSNs was born: this approach is based on algorithms inspired by the functioning of ant colonies [11]. These algorithms are based on the ability of simple ants to solve complex problems by cooperation. All methods using this paradigm are now called ACO [12] [13]. Each new contribution made improvements to the original model or specialized for particular problems.

IV. DESCRIPTION OF THE PROPOSED APPROACH

The idea is to design an algorithm based on decentralized operation of ants, using their natural ability to find shortest paths between source and destination by moving through the network. The first constraint to consider with this approach is that the number of individuals. Indeed, algorithms like ant colony are known for their effectiveness on the condition of using a sufficient number of entities. This implies a certain computing power and large volume of information exchanged. But the computing power and bandwidth are the main weaknesses of WSNs.

We are nevertheless convinced that there is a compromise between the efficiency of research and the volume of communication that passes through both the optimization of the number of individuals and by optimizing the data structures exchanged. The general idea used in this proposal concerning the use of ant colonies on the basis of purely local information in a decentralized environment. Ants of our system are not intended to construct explicit solutions to the problem considered even if they build the road. The deposition of pheromone in the environment (by the network nodes) that defines the solutions seeks. Indeed, the solutions are roads in the traditional sense in traditional networks; the road leading from one point to another is discovered in the course of the stations. The decentralized operation of our proposal inherits from previous work such as Ant-Based Control [7] for load balancing in telecommunications networks, AntHocNet [14] for routing in mobile ad hoc networks. Our approach uses the same mechanisms for selecting local neighborhood. Thus, the formula for choosing a next neighbor of Ant System with the joint attraction of pheromone trails. The proposed approach consists of two phases route discovery and route maintenance phase. When a source node wants to send data to a destination with QoS requirements, it begins with the route discovery phase. Once the route is found, the data transfer can begin. During data transmission, it is also necessary to maintain the path to the destination.

A. Format of Control Messages

To implement our proposed approach, four control messages are used.

1) Hello Message

The Hello packet (Hello_Ant) is distributed periodically to all the neighbors of the current node, containing its starting time. When neighbors receive this packet, they react by answering an acquired reception (ACK_Ant). Based on starting time and receiving time of hello packet and also size of hello packet, current node will calculate available bandwidth of outgoing links. For each node from which hello packet receiving time has been reported, an entry is created in neighbor table along with calculated available bandwidth and initial pheromone of the neighborhood links. For subsequent hello messages, available bandwidth as well as pheromone will be updated to indicate current status of outgoing links.

2) Route Request Message

A packet Route_Request_Ant is broadcasted upon receiving a route request to the destination. At each node, the hop count will be incremented and the node id is entered in to the stack of visited nodes. In addition to exploring shortest path from source to destination, Route_Request_Ant additionally senses the network environment-related factors like nodes visited, end-to-end delay from source to destination, and available bandwidth of the path through which it is propagated.

3) Route Reply Message

Upon the receipt of Route_Request_Ant, the destination will convert this to a Route_Reply_Ant. From starting time and Route_Request_Ant arrival time, end-to-end delay experienced by Route_Request_Ant is found and converted as the parameter, delay.This Route_Reply_Ant will be unicasted to the original source. While forwarding Route_Reply_Ant, the intermediate nodes will not alter the hop count and starting time. At each node, the stack is also popped to see the next node to which the reply has to be forwarded. This is because the Route_Reply_Ant will be forwarded along the path through which the Route_Request_Ant was forwarded but in reverse direction.

4) Route Error Message

Whenever a node learns that it cannot reach a particular destination for which it has an entry in its routing table, the node updates its routing table and sends route error message (Route_ error _Ant). Upon receiving this message, intermediate nodes will update their routing table and path preference probability table for the unreachable destination.

B. Mathematical Model

The objective function of proposed work is to find a path from source to destination through a neighbor with maximum path preference probability. As in [14], path preference probability from source *i* to destination *d* through *i*'s neighbor *j* is calculated as:

$$P_{ijd} = \frac{[\tau_{ijd}]^{\alpha}[D_{ijd}]^{\beta}[\eta_{ijd}]^{\chi}[BP_{ijd}]^{\delta}}{\sum_{l\in N_i}[\tau_{il}]^{\alpha}[D_{ild}]^{\beta}[\eta_{ild}]^{\chi}[BP_{ild}]^{\delta}} \qquad (1)$$

Where **α**, **β**, **γ** and **δ** (>=0) are tunable parameters that control the relative weight of pheromone trail $\boldsymbol{\tau_{ij}}$, Delay $\mathbf{D_{ijd}}$ and hopcount considered as heuristic value $\boldsymbol{\eta_{ijd}}$, bandwidth $\mathbf{BP_{ijd}}$ respectively, Also, $\mathbf{N_i}$ is the set of neighbors of **i** and **l** is neighbor node of **i** through which a route is available to destination **d**.

C. Calculation of Relative Metrics

For calculating relative metrics, the additive metrics delay, hop count, and non-additive concave metric bandwidth are considered. Since additive metrics have to be minimized for shortest paths, reciprocal values are used while calculating relative metrics. Owing to the desire of maximizing bandwidth, it is considered as in (1).

1) Delay

The delay between source and destination is considered as:

$$D_{ijd} = \frac{1}{delay(path_j(i,d))} \qquad (2)$$

Where, delay ($path_j(i, d)$) is experienced end-to-end delay from source *i* to destination *d* through neighbor *j* by route request message at the time of route exploration.

2) Hop Count

The relative metric for number of intermediate nodes between source and destination is found as

$$\eta_{ijd} = \frac{1}{Hopcount(path_j(i,d))} \qquad (3)$$

Where, Hopcount ($path_j(i, d)$) is the number of hops seen by route request message along the path *i* to *d* through j

3) Bandwidth

The available bandwidth of the path from *i* to *d* is calculated as minimum of available bandwidth of all links along that path.

$$Bp_{ijd} = \min\{available\_bandwidth(l)\} \quad \forall l \in path_j(i,d) \qquad (4)$$

Whereas available bandwidth of a link is calculated as:

$$available\_bandwidth(link) = \frac{HPS}{HPST - HPRT} \qquad (5)$$

Where HPS is hello packet size, HPST is hello packet starting time, and HPRT is hello packet receiving time. Because hello messages are frequently transmitted to keep neighborhood alive connectivity, they can better reflect current available bandwidth of outgoing links rather than route exploration messages.

4) Pheromone

Initially when there is no neighborhood relation between i and j, pheromone on link (i, j) is made as $\tau_{ij} = 0.0$. When j is detected as neighbor of i through hello message, an initial pheromone is deposited as $\tau_{ij} = 0.1$. Whenever a route reply message is received from j to i, it is considered that link (i, j) contributes to a possible path from source i to destination d. So it is positively reinforced.

$$\tau_{ij} = \tau_{ij} + \Delta\tau_{ij} \qquad (6)$$

where $\Delta\tau ij = 0.05$

There is also an implicit negative reinforcement for the pheromone values. Within every finite time interval, if there is no data toward a neighbor node, its corresponding pheromone value decays by a factor ρ as follows:

$$\tau_{ij} = \begin{cases} (1-\rho)\tau_{ij} & if \;\; (1-\rho)\tau_{ij} > 0.1 \\ 0 & if \;\; (1-\rho)\tau_{ij} \geq 1 \\ 0.1 & otherwise \end{cases} \qquad (7)$$

When node *i* losses its connectivity to its neighbor *j*, the pheromone on the link *i* to *j* will be set to 0.

D. Route Discovery Phase

The route discovery phase is as follows:

Step 1:

Let the source node **s** has data to send to a destination **d** with QoS requirements delay *D*, bandwidth *B* and Hop Count *HC*.

Step 2:

s initiates a Route_Request_Ant to destination **d** through all its neighbors which it has learned from periodic Hello_Ant messages.

Step 3:

While traveling to the destination the Route_Request_Ant collects transmission delay of each link, processing delay at each node, the available capacity of each link, the number of hops made.

Step 4:

When the Route_Request_Ant reaches the destination, it will be converted as Route_Reply_Ant and forwarded towards the original source. The Route_Reply_Ant will take the same path of the corresponding Route_Request_Ant but in reverse direction.

Step 5:

For every Route_Reply_Ant reaching an intermediate node or source node, the node can find the delay, bandwidth, hopcount from the received ant to the respective destination. Now the node can calculate the path preference probability to reach the destination.

Step 6:

If calculated path preference probability value is better than the requirements, the path is accepted and stored in memory.

Step 7:

The path with higher path preference probability will be considered as the best path and data transmission can be started along that path.

E. Route Maintenance Phase

When the data transmission is going on, the paths are reinforced positively making it more desirable for further selection. Also when session is going on, the load on the selected path may increase causing more delay and less available bandwidth; Nodes might fails (exhausted its energy) causing link rupture. In such case, the path preference probability will automatically decrease and hence alternate routes can be used which are found during route discovery phase. The alternate routes are also periodically checked for their validity even though they are not currently used.

V. SIMULATION AND RESULTS

We evaluate our algorithm QoS_Aco in a number of simulation tests. We compare its performance with the protocol AODV. Various scenarios were created by varying number of nodes. In all scenarios the nodes are static; they are deployed. The maximum transmission range of each node is 2.5 m. Channel capacity is 2 kbps. The relative values of the parameters α, β, γ, and δ are defined in Table 1.

TABLE I
QOS_ACO PARAMETER SETTING

Parameters	Values
Pheromone decay factor, ρ	0.05
Pheromone	positive
Reinforcement $\Delta\tau_{ij}$	0.05
Pheromone decay weightα	1.0
Delay weight, β	1.0
Shortest hop weight, γ	1.0
Bandwidth weight, δ	1.0
Hello Interval (Hello_Ant)	1 sec
Hello Retry times (Hello_Ant)	3
Upper pheromone bound	1.0
Lower pheromone bound	0.1

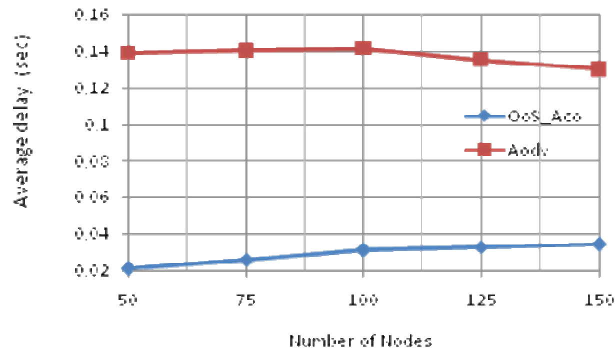

Fig. 1. Average End to End delay, density of nodes

Fig. 1 shows the effect of end-to-end average delay with various flow counts for 50 to 150 nodes scenario. In case of AODV, there are possibilities that some links might be shared by more than one shortest path. This will increase traffic on selected links which may lead to congestion and hence data packets transmitted through these links may face additional delay.

The situation is further aggravated if many traffic connections start sharing these links. In case of QoS_Aco, a path is considered as good not only based on number of hops, but also on other parameters like available bandwidth along the links on that path. So, when a link contributes itself on a shortest path of a particular traffic, available bandwidth of that link will get reduced. Since bandwidth is a kind of property to be maximized, this leads to a reduction in path preference probability of the paths which have this link as one of their intermediate links. This will lead to the selection of other possible paths which may have higher path preference probability. Though alternate paths may not be shortest in number of hops, they may have less traffic. Hence, data may be transmitted as they are received and not making them to wait in the queues.

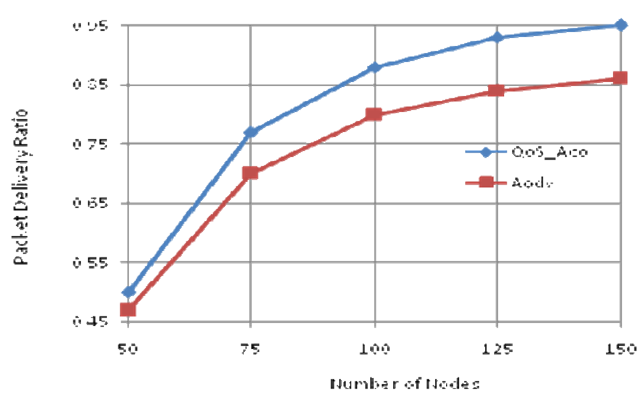

Fig. 2. Packet delivery Ratio, density of nodes

The results, presented in Fig. 2, indicate performance difference between AODV and Qos_Aco in terms of average delay and the packet delivery ratio increases with network size. This is an important result indicating that Qos_Aco is more scalable compared to the number of nodes.

The improved performance we have achieved in Qos_Aco is at a cost of routing control compared to AODV. In Qos_Aco, four kinds of control messages are used to keep neighborhood connectivity, to search for routes using request messages, to reply for routes requests, and to inform route errors. The size of request message will dynamically increase as it moves through network toward destination whereas reply message's size will decrease as it moves toward source node. Qos_Aco satisfies QoS requirements and achieves better performance by maintaining multiple paths to destinations through these dynamically size varying ant messages.

VI. CONCLUSION

WSN grant a wide range of challenges in routing and network management because of their dynamic and distributed natures. Several protocols have been proposed to address the challenges. In this article, we have proposed a Qos_Aco protocol, an ant-based routing protocol to meet the QoS requirement of WSN to support real-time traffic. In addition to considering presence of links or connectivity between nodes, network-related status of links like delay experienced through that links, available bandwidth in links, and a link's suitability for data transmission are also collected and measured. These measures provide an indication of how much a link is suitable while deciding about paths for providing QoS routing. From a given source to destination, multiple paths have been found and their path preference probability is calculated based on the above said measures. Apparently, the path with higher path preference probability offers an optimized consideration of multiple QoS metrics delay, bandwidth, and shortest hop count. Initially, data are sent over the path with higher path preference probability which can provide lesser delay, higher bandwidth, and shorter path in terms of number of hops. In case of any link failure leading to path breaks, alternate possible paths with next higher path preference probability are immediately considered and data transmission.

Future work may include testing the performance of our algorithm, Qos_Aco for various WSN applications with variety of topologies and varying load situations.

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