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A Routing Optimization Based on Ant Colony for Wireless Multimedia Sensor Networks (WMSNs)

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Abstract: Routing process in Wireless Multimedia Sensor Networks (WMSNs) has its own challenges to pass multimedia applications from source nodes to a sink. The WMSNs have specific characteristics consisting of multi-hop network, restricted bandwidth, and limited power resources in the WMSNs. Additionally, multimedia applications require specific Quality of Service (QoS). This paper proposes a routing optimization based on the Ant Colony Optimization (ACO) for multimedia transmission in the WMSNs. The routing optimization can deliver multimedia data within an average throughput of 164.65 kbps and provide better QoS than DSDV and AODV routing protocols.

Keywords: Routing optimization; Ant colony; Wireless Multimedia Sensor Networks

1. Introduction

The unique needs of Wireless Multimedia Sensor Networks (WMSNs) such as multi-hop network, restricted bandwidth, limited power resources, and quality of service (QoS) pose a new challenge to perform an optimization of routing protocols that is appropriate for the WMSNs. Routing protocol optimization is a process to improve the performance of existing routing protocols to have good quality and high working results. The WMSNs have the characteristics of energy resources that are limited because of the small and limited node. In addition, multimedia data such as audio, videos, images and scalar data require a certain QoS compared to the data that do not require QoS. The WMSNs consist of many nodes, and each data from multiple sources is passed through intermediary nodes to the sink to form a multi-hop network. All the WMSN characteristics and the change of channel bandwidth all the time make routing optimization become crucial. Unfortunately, popular protocols which are available in the wireless networks have not been able to meet the unique needs of the WMSNs as they only focus on energy efficiency and have not considered the multimedia data transmission via the WMSNs yet [1-3].

In the literature, there are several studies related to multimedia transmission via wireless multi-hop manner in unpredictable wireless networks. The routing protocol in the Wireless Sensor Networks (WSNs) can be classified into four main schemes, namely: Network Structure, Communication Model, Topology, and Reliable Routing [4, 5]. The new communication protocol for the WSN called Energy-Efficient Ant-Based Routing Algorithm (EEABR) [6] is proposed that the protocol is based on the Ant Colony Optimization (ACO). Improved Energy Efficient Ant-Based Routing (IEEABR) [7] protocols are used to improve the energy efficiency of the WSNs. The ant colony routing algorithm based on cross-layer architecture [8] is used to increase throughput in the WSNs. This algorithm is made to focus on energy levels, link quality, and speed to get the best service from the WSN and is managed to increase the overall data throughput, especially the real-time data. The ACO [9] and the AntHocNet application [10] have been implemented in a mobile ad-hoc network. Cross-layer approach based on

EDCA and H.264/SVC is used for video transmission in the WMSNs [11]. Real-time routing protocol with load distribution (RTLD) ensures high throughput with packet overhead that is minimized, thereby it extends the lifetime of the WSN. However, this routing protocol that is implemented and investigated only uses constant bit rate (CBR) traffic in the simulation program [12]. The ACO for routing protocol has been implemented in the WSN [13]. The QoS requirements in wireless networks have been discussed in [14]. The Cluster based approach to Ad-hoc On Demand Distance Vector (CAODV) has increased the life time and QoS of the WSN [15].

The previous WSNs and WMSNs protocols routing only focus on energy efficiency and are not suitable for multimedia applications that require tight deadlines, low delay, high throughput, and reliability. While images and video sensors of the nodes in the WMSNs require guaranteed throughput and high Packet Delivery Ratio (PDR) for the transmission and continuity of operation of the network nodes (lifetime). For that routing protocols existing in the WSNs and WMSNs need to be optimized to suit the needs of the PDR and high throughput of the WMSNs.

In this paper, a routing optimization is proposed to give guaranteed bandwidth or Quality of Service (QoS) for multimedia application in WMSNs. The routing optimization uses ACO routing protocol to determine best selected paths between sensor nodes and a sink. Since wireless sensor networks has varying bandwidth channels, a routing protocol must adapt to the varying bandwidth conditions. The ACO routing protocol has main characteristic features, namely robust and adaptive connectivity. In ACO routing protocol, there are pheromone tables of ACO which always updated by forward and backward ants. The forward and backward ants always try to find the best selected paths based on higher routing possibilities. Through this way, the routing tables will be updated based on the varying bandwidth conditions. Therefore, multimedia application will get guaranteed bandwidth or Quality of Service (QoS) during transmission in WMSNs.

The rest of this paper is organized as follows. Section II explains the WMSNs, Section III explains Ant Colony Optimization (ACO), Section IV explains Simulation Results. Last, the Conclusion is presented in Section V.

2. Wireless Multimedia Sensor Networks

In the WMSNs, intermediate nodes must forward packets from the source node to the destination node or sink. In these conditions, the intermediate node must decide which an incoming packet will be forwarded or transmitted to neighboring nodes.

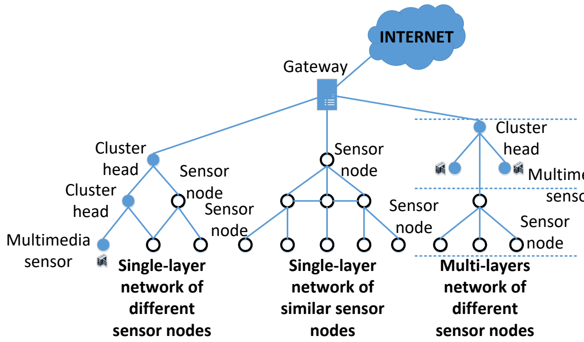

Figure.1 A model of Wireless Multimedia Sensor Networks (WMSNs)

Rules are used to forward packets depending on information about the suitability or fitness of a neighboring node in forwarding packets.

Conformity is calculated as a cost that determines packet delivery decisions through certain nodes to its destination. This cost can be measured in a variety of metrics, such as the minimum number of hops, the minimum total energy, high throughput, and low delay. Each node collects these costs in the routing table. Thus, the routing table will register most of the neighboring nodes and is used as a guide to forward data packets.

A model of the WMSNs is shown in Fig. 1, in which three sensor systems with diverse qualities indicated, may be put in distinctive physical areas. On the left, the first network constitutes a single-layer network of the different sensor nodes. The network in the middle is a single-layer network of similar sensor nodes. The network on the right is multi-layer networks with different sensors [1].

3. Ant Colony Optimization (ACO)

The ACO is based on the behaviors of ant colony cooperation to find the shortest path from the nest to get to the food source. Ants are social insects that live in colonies and behave in the interests of the colony. One of interesting things of ants' behaviors is the ability to find the shortest distance between their nest and the food source. Suppose there is a swarm of ants in front of them, they have to choose a specific track to skip. At the time of the first ant is walking, this ant leaves pheromone hormones that can be detected by the next ants, so that they know if the place is already passed or not. Furthermore, each running ant will leave pheromone on the path.

An ant that passes a short track will leave pheromone scent sharper on the track that is longer. This occurs because the pheromone that is left can evaporate. When an ant follows an ant in front of him, the ant will choose a path based on the strength of the pheromone scent and track distance. The more ants travel on a certain path, the pheromone scent on the track will get stronger. Therefore, the next ants will follow the same trajectory. The shortest path will be encountered because more ants will pass through the pathway [16].

The ACO process can be explained by plotting multiple layers of optimization problems faced. As shown in Fig. 2, where the number of layers is equal to the number of the variables of the problems faced and the number of the nodes in a particular layer is equal to the number of discrete values allowed for variables related. Therefore, each node is associated with a possible discrete value for a variable. Fig. 2 shows a problem with four variables and four possible values for each variable.

The stages of the ACO algorithm to solve the problem of minimizing the function can be described by the following summary:

1. Step 1: Assume the number of ants is N. Specify the number of discrete values as p is used to search for variable values that exist in the problem to solve. This value is expressed as $x_i = x_{i1}, x_{i2}, .., x_{ip}$, ($i = 1, 2, .., n$), where n is the number of variables. Determine the number of initial pheromone τ_{ij}^{1}. Determine the number of initial pheromone which is the same for all segments in the multi-layer network as shown in Fig. 2. Notation (1) on τ_{ij}^{1} shows iteration 1. For an easy calculation, it can use starting value $\tau_{ij}^{1} = 1$ for all segments *ij*. Set iteration, $t = 1$.
2. Step 2:
   a. Calculate the probability, p_{ij}, to select segments or discrete values, x_{ij}, using the formula:

$$p_{ij} = \frac{\tau_{ij}}{\sum_{j=\in N_i^{(k)}} \tau_{ij}}; \quad (1)$$

$$i = 1, 2, .., n; 1, 2, ..., p$$

   b. Certain sections will be selected by an ant k based random number in the range (0, 1). For that reason, we must also determine the cumulative probability range associated with options segment. Thus, if there is a possibility (p) of the variable, then there will be a number of options (p) of the range of probability. Special section selected by the ant k is determined by roulette-wheel selection.

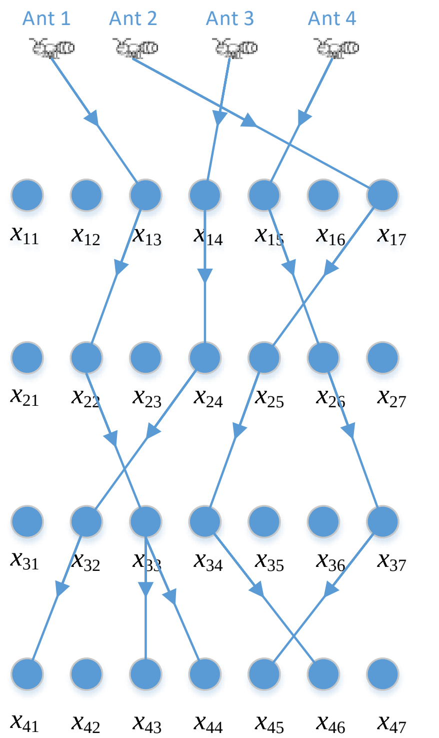

Figure.2 An ant colony based optimization

3. Step 3
   a. Generate N random numbers $r_1, r_2, \ldots r_N$ in the range (0, 1), one for each ant. Determine the discrete values that represent segments for ant *k* for the variable *i* by using a random number from step 2 and the cumulative probability area in the roulette wheel.
   b. Repeat step 3(a) for all variables $i = 1, 2, 3, , n$.
   c. Evaluate the objective function value by entering the value of x_{ij} that has been selected for all variables $i = 1, 2, 3, \ldots, n$ by ant k, $k = 1, 2, \ldots, N$: $f_k = f(X(k)); k = 1, 2, \ldots, N$. Specify the best and worst path between in *N* segments or tracks that have been selected by the different ants:

$$f_{best} = min_{k=1,2,\ldots,N}\{f_k\} \quad (2)$$

$$f_{worst} = max_{k=1,2,\ldots,N}\{f_k\} \quad (3)$$

4. Step 4: Test the convergence of the process. In this case the convergence could mean if all ants take the best same tracks. If not convergence, the ant colony will return to the nest and start foraging again. Set iteration, $t = t + 1$, and update pheromone for each segment with:

$$\tau_{ij}^{t} = \tau_{ij}^{old} + \sum_k \Delta\tau^{(k)} \quad (4)$$

Where τ_{ij}^{old} states the number of the pheromone from the previous iteration is left after the evaporation.

$$\tau_{ij}^{old} = (1-\rho)\tau_{1j}^{(t-1)} \tag{5}$$

$\Delta\tau_{ij}^{k}$ is the number of pheromone written by the best ant k in the segment and summed for all the ants taking the same segment (if there is more than one ant takes the same path). One best path consists of only one segment ij of the segments ρ that are likely to variable i. Evaporation rates or factor pheromone decay ρ is assumed between 0.5 to 0.8 and the amount of pheromone is added $\Delta\tau_{ij}^{k}$ calculated by the formula p_{ij}. With the value of τ_{ij}^{k} we go to step 2. Step 2, 3, and 4 are repeated until the process of convergence that is when all the ants choose the best same path or we can stop when the maximum number of iterations is reached [17].

4. Simulation and Results

This simulation was carried out using NS2 simulation which consisted of two ways. The first, UDP data flows with 512 bytes packet size were sent through the WMSN with speeds of 400 kbps from the sensor node 1 to the sensor node 11 (sink). The second, TCP data flows were sent through the WMSN after UDP data flow at 10 seconds from the sensor node 1 to the sensor node 11. Among the first node and the sink, there were 9 intermediate nodes forming a multi-hop network as shown in Fig. 3. The simulation began at t = 5 seconds.

In this simulation, three different routing protocols were used alternately, namely Ad hoc On-Demand Distance Vector (AODV), Destination Sequenced Distance Vector (DSDV), and the Ant Colony Optimization (ACO). The simulation results of the three routing protocols were compared and shown in Table 1.

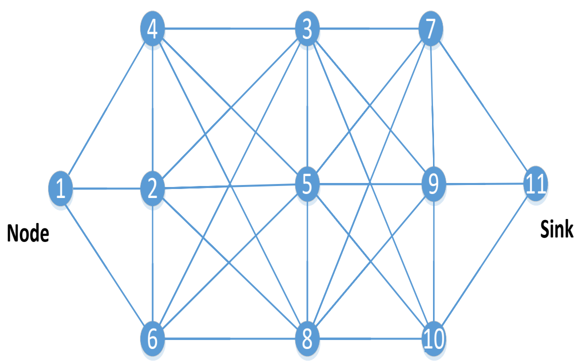

Figure.3 System model

Table 1. Simulation results of the first way

Results	DSDV	AODV	ACO
Generated Packets	14357	14161	14161
Received Packets	9019	11776	11548
Packet Delivery Ratio	62.82	83.16	81.55
Average Throughput (kbps)	254.78	332.67	326.24

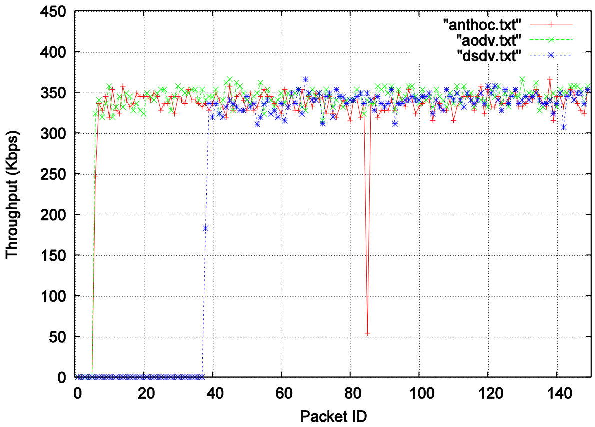

Figure.4 The throughput of UDP data flows over WMSN

The Packet Delivery Ratio (PDR) and the throughput of the ACO routing protocol were better than the DSDV and nearing the AODV. While PDR and the throughput of the DSDV routing protocol were the lowest and began transmitting the data at t = 38 seconds. It indicates the ACO and AODV routing protocol has the higher reliability of the data reception when multimedia data is delivered from the sensor nodes to the sink node.

Fig. 4 shows the throughput of the UDP data flows over the WMSN. The UDP data streams using the AODV and ACO routing protocols obtain almost the same throughput at t = 6 seconds. Additionally, the UDP data streams using the DSDV routing protocol obtain throughput at t = 38 seconds. Then, the throughputs of the UDP data streams using the ACO, AODV, and DSDV routing protocols are almost the same until the end of simulation.

Table 2 shows the results of the simulation when the TCP data sent at t = 10 seconds in conjunction with the UDP data from sensor node 1 to sensor node 11 via the WMSN. The average throughput of the UDP data streams using the ACO routing protocol is better than the DSDV and AODV routing protocols. It indicates the ACO routing protocol can adapt to the change of bandwidth channels along the simulation. So that the entire multimedia data has the highest rate when using ACO protocol compared to DSDV and AODV protocols.

Table 2. Simulation results of the second way

Results	DSDV	AODV	ACO
Average Throughput (kbps)	102.61	163.29	164.65

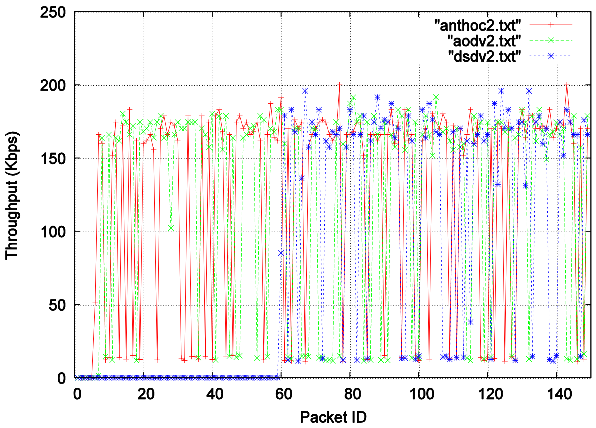

Figure.5 The throughputs of the UDP and FTP data flows over the WMSN

Fig. 5 shows the throughputs of the TCP data flows sent through the WMSN after the UDP data flows. The TCP and UDP data streams using AODV and ACO routing protocols obtain almost the same throughput at t = 6 seconds. While the TCP and UDP data streams using DSDV routing protocol obtain throughput at t = 60 seconds. The throughput of the TCP and UDP data streams using the ACO routing protocol is more stable than the DSDV and AODV routing protocols especially after t = 60 seconds. ACO routing protocol has characteristic features that it can provide robust and adaptive connectivity between sensor nodes and a sink. Although wireless sensor networks has varying bandwidth channels, pheromone tables of ACO are always updated by forward and backward ants through the varying bandwidth channels. In addition, ACO routing protocol usually uses multiple paths to deliver multimedia data packets based on higher routing possibilities. So that ACO routing protocol can give guaranteed bandwidth or throughput for multimedia application in WMSNs.

5. Conclusion

Routing optimization approach has been made to transmit multimedia data with guaranteed QoS in the Wireless Multimedia Sensor Networks (WMSNs). This approach uses the Ant Colony Optimization (ACO) and was simulated in NS2 simulation software environment. The simulation results show that the routing optimization can achieve a better performance in terms of the throughputs and Packet Delivery Ratio (PDR) than the DSDV and AODV routing protocols. Thus, the ACO has an ability to optimize routing techniques for multimedia applications over the WMSNs.

In the future, the routing optimization based on the Ant Colony Optimization (ACO) will be combined with a cross-layer design method. Since data transmission will be influenced by the varying bandwidth channels in WMSNs, a routing decision need to consider the datalink layer. So the cross-layer design will be combined with the Ant Colony Optimization (ACO) to give the best routing decisions in accordance with conditions of wireless environment and needs of multimedia applications in wireless multimedia sensor networks (WMSNs).

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