Developed Ad Hoc On-demand Distance Vector Routing Protocol for Wireless Sensor Networks

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Abstract— **Ad hoc On-Demand Distance Vector (AODV) is a routing protocol used in numerous networks, such as ad hoc wireless sensor networks and mobile ad hoc networks (MANETs). In this paper we seek to develop AODV routing protocol to reinforce network performances and overcome network problems such as path destroying in ad hoc wireless sensor networks. The proposed developed method considers the possible paths between source and destination node are discovered. Each path has three metrics: packet loss, bit rate and delay to be considered in path selection instead of single metric. The developed AODV protocol aims to finding the robust path between source and destination node by minimize packet loss, maximize the bit rate and minimize delay using weighted sum multi objective optimization method in path selection decision. Simulation results performed in Matlab (2017a) prove that the effectiveness of the developed AODV in terms of end-to-end packet loss, bit rate and delay. There is important decrease in end to end delay, packet loss and increase in bit rate by the developed AODVprotocol under the varying sensor nodes.**

Index Terms— **AODV, ad hoc wireless sensor network, developed AODV, weighted sum multi objective optimization, Matlab 2017a.**

I. Introduction

Wireless sensor networks consist of a large number of sensor nodes connected in ad hoc style and can be defined as a self-configured, decentralized and without infrastructure. Wireless sensor networks are used to monitor material or environmental events, such as humidity, vibration, temperature, pressure, motion or pollutants. Additionally, they are employed to cooperatively pass their data over the network to base stations or sink nodes through multi hop environment. Therefore the process of finding the robust path between source and destination node is very essential. Due to the limited feature of the ad hoc wireless sensor networks, such as hardware breakdown, environmental factors and path destroying, etc., routing in this network is much more challenging. In addition, routing protocol in ad hoc wireless sensor network must be able to meet the quality of service (QoS) requirements.

For the time being, many of applications require a high bit rate, low delay and packet loss rate to transmit videos, voices, and routing data. Therefore, routing protocols that supply high bit rates and very small delay and very small packet loss are very essential. In the literature, there is a large number of WSN protocols. Ad hoc On Demand Distance Vector (AODV) protocol is adopted to be developed. They discover and maintain routes only when needed [1].The major drawback of traditional ad hoc on-demand distance vector protocol (AODV) is the absence of the QoS conditions. Another drawback of traditional AODV protocol, when a link failure is discovered, a route error message will be created and must be sent to a source node. As a result, the route discovery process must be initiated again. In [2] the author proposed approach for selecting the best path between source and destination node for data transmission, and results in less end-to-end delay with high packet delivery ratio and low routing overhead. Two routes are discovered between source and destination nodes, if the primary route fails then alternate route is immediately used for data transmission. Author [3] proposed An Energy Saving Multi-path AODV routing protocol considered the node energy and total path energy as the routing metric. Simulation results shows that it shows better performance in terms of Packet Delivery Ratio and End-to-End delay in comparison to AODV routing protocol. The work in [4] proposed a heuristic mechanism in WSNs to provide multiobjective QoS routing (MQoSR) as link, and path-based metrics. In this paper, we propose a developed ad hoc on-demand distance vector routing protocol improves the QoS conditions and to overcome the network problems, such as path destroying in ad hoc WSNs. The developed AODV protocol includes all possible paths between source and destination node in calculations. Each path is attached with packet loss and bite rate and delay values as a path-based metrics. Using weighted sum multi objective optimization method, the robust path is selected.

II. Ad Hoc On Demand Distance Vector (AODV)

The AODV is a reactive routing protocol in which a route is established only when it is needed. When the source node wants to transmit data to the destination node, first it checks its routing table, if the path is exist, then the node uses that path, otherwise, it initiate rout discovery process by broadcast a RREQ packet to its neighbor node. When a node receives RREQ packet, it ensures that the received RREQ is not a duplicated RREQ, in order to prevent looping paths. A RREQ packet is determined by a source IP address, a source sequence number, a broadcast ID, a destination IP address, a destination sequence number and hop count [5].

Through receiving the RREQ packet, every node includes a reversed path entry in its routing table for the source node. Broadcasting of the RREQ packet continues until it arrives to the destination node. Broadcasting is done via the flooding mechanism [6]. When a destination is reached, it sends the Route Reply Packet (RREP) to the source node, and every intermediate node sets up its routing table a forward path entry to the destination. It contains a destination IP address, an IP address from which an entry arrives, a hop count and a lifetime.

Consequently, once the packet receives the destination, using the routing table entries, the data can be sent. However, the performance of traditional AODV has been influenced when a node or a connection fails. In this case the node detecting this problem sends a Route Error (RERR) message to the source node and the route discovery process must be restarted [7]. The route discovery stage may be started several times yet it is ad hoc WSN where the battery of sensor nodes is always exhausted. The network has some restrictions i.e. low bandwidth, power consumption and communication limits, etc. Therefore it is important that the route lifecycle should stay steady in a routing operation of ad hoc WSN.

Furthermore, there are another drawback of traditional AODV protocol that is the path between source and destination node can be found with the minimum length (cost), but not necessarily it is the best path. Whilst, the proposed approach can find the best path between source and destination node.

III. Multi Objective Optimization

Optimization problems are normally divided into two types: single-objective optimization and multi-objective optimization. Single-objective type optimizes (minimize / maximize) single objective function according to a set of constraints given by the problem to be optimized. Multi-objective optimization problems optimizes (minimize all objective functions / maximize all objective functions / minimize some and maximize others) multi objective function according to a set of constraints given by the problem to be optimized. Therefore, it will find set of solutions for conflicting objective functions. The problem of multi-objective optimization can be described mathematically as follows [8]:

$$min\ \mathrm{F(x)} = [\boldsymbol{f_1}(\mathbf{x}), \boldsymbol{f_2}(\mathbf{x}), \boldsymbol{f_3}(\mathbf{x}), \dots, \boldsymbol{f_n}(\mathbf{x})] \quad (1)$$

$$\text{s.t.} \quad \boldsymbol{g_i}(\mathbf{x}) \leq \mathbf{0}, \boldsymbol{i} = \mathbf{1}, \mathbf{2}, \dots, \boldsymbol{n},$$

where $\mathbf{x} = [\boldsymbol{x_1}, \boldsymbol{x_2}, \boldsymbol{x_3}, \dots, \boldsymbol{x_N}]^T \in \boldsymbol{R}^N$ is the vector of variables that must be optimized, $\boldsymbol{f_j}$, $j = 1, \dots, n$, are the objective functions, $\boldsymbol{g_i}$, $i = 1, \dots, n$, are the constraints on the functions.

The problems with multiple objective functions, may occur conflicting between them, i.e. when we improve one objective function, other objective functions may be worsen. Thus, there is no a single solution that can optimize all objective functions together. Instead, the best compromised solutions, called the Pareto optimal solutions, which was proposed by Edgeworth and Pareto [9], and is officially defined in the minimization case as follows [10]:

Definition 1. A vector $v = (v_1, \dots, v_n)^T$ is said to dominate another vector $u = (u_1, \dots, u_n)^T$, denoted as $v \prec u$, *if and only if* $\forall i \in \{1, \dots, n\}$, $v_i \leq u_i$ and $v \neq u$.

Definition 2. A solution x is said to be Pareto optimal solution if and only if there is no $\acute{x} \in \Omega$ such that $\acute{x} \prec x$, where Ω is the search space, x is the decision variable vector. The target of multi-objective optimization methods is to produce a various set of Pareto-optimal solutions to enable the user from evaluation the trade-offs between the conflicting objectives.

IV. Formulation Of The Proposed System

A. Modeling of the network: Ad hoc WSN can be modeled as an undirected graph, G = (V, E, Q), with N nodes, where V denotes the set of vertices that represent the nodes, E denotes the set of edges that represent the links between nodes, and Q is the Quality of Service vector for each link. The distance of a link $l(s_i, s_j) \in E$ between the adjacent nodes s_i and s_j is $d_{s_i s_j}$, A path is a series of links between the source node and the destination node.

B. Packet loss rate metric: The packet loss rate is an important QoS parameter, and used to measure the probability of transmission failures and can be expressed in terms of data delivery ratio. If the node *i* sends total packets of $\mathbf{Pkt}_i$ and the number of packets received by the node j is $\mathbf{Pkt}_j$, then the data delivery ratio (packet loss rate) of the link , denoted as $\mathbf{PLR}_{link}$, can be written as:

$$\mathbf{PLR}_{link} = \frac{\text{number of packets received at the node j}}{\text{number of packets generated by the node i}} = \frac{\mathrm{Pkt}_i}{\mathrm{Pkt}_j} \quad (2)$$

We assume PLR_{link_l} is the value of the packet loss rate for each link, then the end-to-end packet loss rate for path p, can be calculated as follows :

$$PLR_{e2e_{path_p}} = \prod_{l=1}^{hop_p} PLR_{link_l} \quad (3)$$

C. Bit rate metric: In telecommunications and computing, bit rate is the number of bits that are conveyed or processed per unit of time. We assume the value of bit rate for each link as BR_{link}, then the end-to-end bit rate for path p:

$$BR_{e2e_{path_p}} = \min(BR_{path_p}) \quad (4)$$

D. Delay metric: Delay is the time elapsed from the travel of a data packet from the source to the destination node. The delay metric between two nodes represented as $\boldsymbol{D_{link}}$ is the summation of processing, queuing, transmission, and propagation delay. Many of the WSNs applications are sensitive to real-time delay constraints, therefore must use an efficient routing technique that reduces delay in packet delivery. The end-to-end delay of a path p, $D_{e2e_{path_p}}$, is the summation of the delays between all of the intermediate nodes along the path p:

$$D_{e2e_{path_p}} = \sum_{l=1}^{hop_p} D_{link_l} \quad (5)$$

V. The Proposed System

The proposed method is introduced to improve the network performance by selecting the path with the best

Quality of service parameters. In addition, it finds several backup routes to avoid another route discovery process when the link failure occurs as shown in Figure (1), represented as flow chart. When source node wants to send data to destination node, first it checks the routing table. If the path is existed, then the node uses that path. Otherwise, it initiates a route discovery process by broadcast a RREQ packet to neighbor nodes in order to find the path. After the source node finds the first path to destination, then the source node uses Yen's algorithm [11] for finding other possible paths between the same nodes. For all paths between source and destination node, we calculate the QoS parameters as shown in section 4. After that, the source node contains all the route reply messages (Each message contains a particular path information in terms of QoS parameters), and must build the source decision table, shown in Table (1), from the information that it collected in each message. Then, the source node selects the robust path from its decision table that satisfies the following objective functions:

$$f : \min(f_{PLR_{e2e_{path_p}}}), \min(-f_{BR_{e2e_{path_p}}}), \min(f_{D_{e2e_{path_p}}}). \quad (6)$$

Where, p (number of paths) = {1, 2, . . . ,n} .

The first expression ($f_{PLR_{e2e_{path_p}}}$), in the objective function (6) specifies the packet loss rate to measure the probability of transmission failures, the second expression ($-f_{BR_{e2e_{path_p}}}$) specifies the bit rate for transferring the data, while the third expression ($f_{D_{e2e_{path_p}}}$) specifies the delay that they occurs in the transmission of data. Hence, the objective function is to minimizing the probability of transmission failures, maximizing the data transferring rate while minimizing the delay.

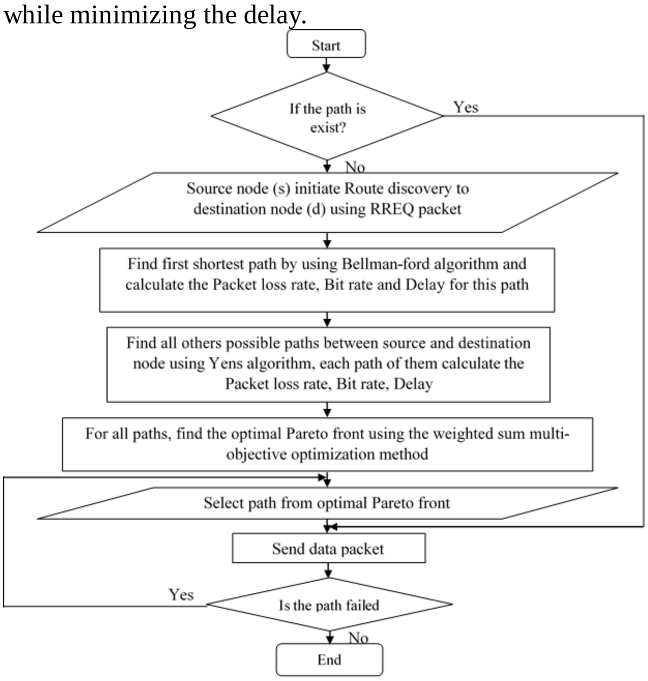

Figure 1: Flow chart of the proposal approach.

Finally, we use the weighted sum multi-objective optimization method [12] to find the Pareto optimal solution [9]. Furthermore, the objective functions in (6) can be rewritten according to this methods as follow:

$$f = \min \sum_{p=1}^{n} f_p \times w_i \quad (7)$$

Subject to

p = {1, … , n }, p must be integer value.

$0 \leq w_i \leq 1$, i = {1, … , m }

$$\sum_{i=1}^{m} w_i = 1$$

This method consists of combining the three functions in (6) to become a single-objective function model as expressed in equation (7). The n objective functions is assigned with a weight to each of the functions. For various values of weights, we can experimentally obtain optimal Pareto solutions. This can lead to select one solution that represents the path used for sending the data. In the case of route failure occurs, the proposed method selects other path form optimal Pareto solution. Therefore, in our proposal, the proposed approach avoids the route discovery process again.

Table 1: source decision table

Path No.	Packet loss rate	Bit rate(b/s)	Delay (Ms/s)
1	$PLR_{e2e_{path_1}}$	$BR_{e2e_{path_1}}$	$D_{e2e_{path_1}}$
2	$PLR_{e2e_{path_2}}$	$BR_{e2e_{path_2}}$	$D_{e2e_{path_2}}$
.	.	.	.
.	.	.	.
.	.	.	.
N	$PLR_{e2e_{path_n}}$	$BR_{e2e_{path_n}}$	$D_{e2e_{path_n}}$

VI. SIMULATION TOOLS USED AND RESULTS

In this section the simulation results are evaluated in terms of the simple AODV routing protocol and the proposed developed AODV routing protocol using MATLAB 2017a. The total number of nodes are 50 nodes, and are deployed randomly in an area of 50m x 50m. Transmission range for each node is 8.5m. Performance is measured on the basis of three performance matrices which are described previously in section 4 (packet loss rate, bit rate and delay).

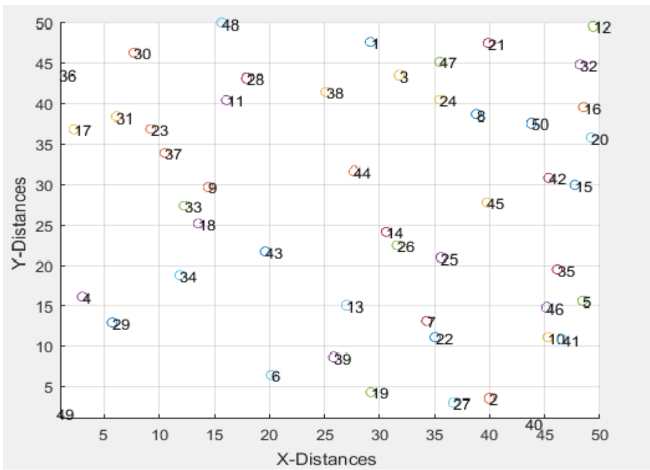

Figure 2: Simulation Environment

First step of the adopted simulation is to deploy the network as shown in Figure (2). Second step is to find the path from the source to the destination node using simple AODV as well as the proposed approach. Figures (3) and (4) show the finding of a path from the source to the destination node in the same area of network.

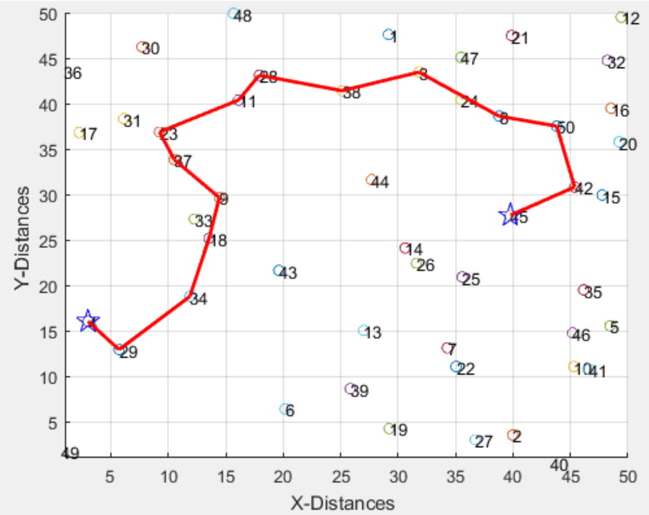

Figure 3: Finding path from source to destination using AODV

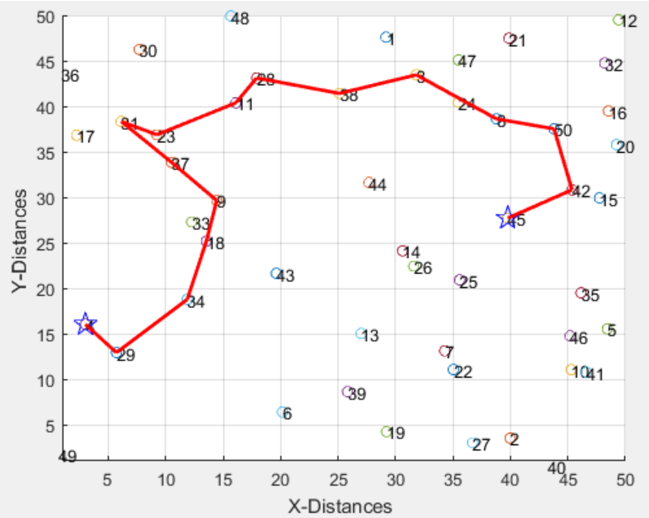

Figure 4: Finding path from source to destination using proposed system

As can be seen in Table 2, we conclude that the proposed system find the path with the best compensated metrics, where the bit rate is the best, while the packet loss and delay were being close.

Table 2: performance comparison between AODV and proposed system

Algorithm	Path no.	Packet loss rate	Bit rate (b/s)	Delay (Ms/s)
AODV	1	0.00017	163	6.27
Proposed system	5	1.06142	595	6.50

VII. Conclusions

The proposed system aimed to select the route with the higher bit rate, low packet loss rate and low delay from source to destination nodes simultaneously. In modified AODV, three parameters (packet loss rate, bit rate, and delay) were considered in routing decision. Modified AODV has better bit rate and good result in QoS parameters than AODV. But delay of modified AODV increases in the case of increasing the number of node in some scenario compared to AODV. Developed AODV protocol selects the best first path as main route for transmission data that have minimum packet loss rate value, maximum bit rate value and minimum delay value from optimal Pareto front. The other routes were reserved as alternatives for transmission in the case of frailer occur. Therefore, avoiding route discovery process saves the battery power consumed in rerouted discovery process and increase the network lifetime.

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