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Cooperative Diversity Selection Protocol Using Pareto Method with Multi Objective Criterion in Wireless Ad Hoc Networks

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Abstract

In cooperative diversity of ad hoc networks, the selection of the path pair becomes very important to achieve optimum performance. In this paper, it was created the cooperative diversity protocol by using Pareto method for multi objective criteria problems namely the signal to noise ratio (SNR) and load variance. Pareto method was used to find a non-dominated solution by way of Continuously Updated. The non-dominated solution was chosen based on the smallest euclidean distance. The advantage of this protocol is to provide fair and the best path pairs of cooperative diversity. From the simulation results, it was obtained the path pairs for cooperative diversity is path S-11-D and S-28-D selected by the smallest value of euclidean distance that is 0.108 and 0.379. Furthermore, the reliability of protocol with Pareto method was compared with the scalarization method in the form of value of cumulative distribution function (CDF).

***Keywords**: Cooperative diversity, path pair, Pareto method, Continuously Updated, multi-objective criterion, scalarization, SNR, load variance*

1. Introduction

Relay in ad hoc networks is needed because nodes in ad hoc networks have limitations in terms of transmission range and battery capacity [1]. To overcome these limitations will require cooperative diversity communication. Cooperative communication is a system where the source node cooperates and coordinates with nodes that function as relay before reaching the destination node. Cooperative communication that uses a single antenna in multi-node scenario can utilize the antenna of each node to create cooperative diversity systems such as multi-input multi-output (MIMO) [2]. Thus cooperative diversity can improve transmission quality.

Selection of path in cooperative diversity can be done depending on the criteria used. Selection of path in cooperative diversity can be done by SNR [3-7], the outage probability [8-10], mutual information [11], and the symbol error rate [12]. But papers in [3-12] implementing cooperative diversity by using a single-objective criterion. Whereas in the selection of path in cooperative diversity using a combination of several criteria. Selection of path pairs in cooperative diversity using the criteria of power consumption, SNR, and load variance that uses Pareto and scalarization methods [13].

To implement cooperative diversity in wireless ad hoc network, then it needs protocols and criteria that must be met in the communication from source to destination. The authors in [3] making simple cooperative diversity protocols to configure source to destination and source-relay-destination. Protocols made have a weakness of not taking into account the performance of the transmission from source to destination. Problems arise when the signal quality from source to destination cannot be received well so that the transmission directly failed. This causes the full diversity cannot be achieved which effect on the declining performance.

Next cooperative diversity protocol is a protocol that guarantees the full diversity to always check the condition of S-D. The protocol uses the problem criteria such as SNR

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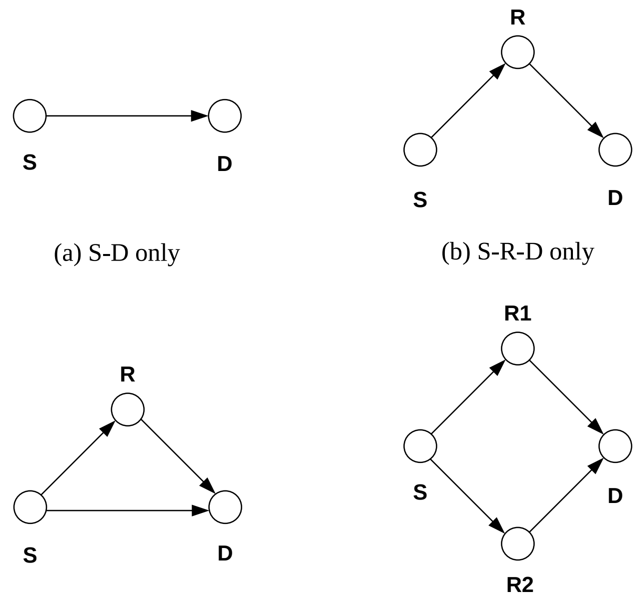
and load variance that are optimized using methods of scalarization [14]. Although the protocol made has already guaranteed the full diversity but the results of the selection of path for cooperative diversity was still inequitable and performed in stages. It was made in the study, cooperative diversity protocol with Pareto methods, which was not only for guaranteeing the full diversity but also for path selection for fair and simultaneous cooperative diversity. The results obtained are path-pairing that consists of the best paths for the two problem criteria.

The simulation results obtained the best path pair selection from non-dominated solution by finding out the smallest euclidean distance. The best path pairs was P_1' path (S-11-D) and P_2' path (S-28-32) with euclidean distance of respectively 0.108 and 0.379. Furthermore, the reliability protocol of Pareto method was compared with the scalarization method [14] in the form of value of CDF.

The remainder of the paper is organized as follows. Section II describes the formulation of the two criteria of the problems. Section III describes the ad hoc network models and the Pareto method protocol. Section IV describes the parameters and results of simulation and it is concluded with the conclusion in Section V.

2. Formulation of Multi-Objective Criterion

Selection of the relay to be used is based on a combination of two criteria, namely SNR and the variance of traffic load for every possible relay node. The formulation of the two criteria together with Pareto method can be explained as follows: There are 4 possible outcomes of the selection of path *i.e.* S-D only, S-R-D only, S-D and S-R-D, as well as S-R1-D and S-R2-D. The possible outcomes of the path selection can be seen in Figure 1.



(a) S-D only (b) S-R-D only (c) S-D and S-R-D (d) S-R1-D and S-R2-D

Figure 1. Possibilities of Path Selection Results

2.1 SNR

The success of communication by the configurations of S-D and S-R-D with AF relay determined the value of the channel capacity on the spectral efficiency of r. The value of channel capacity of AF methods can be calculated by the following equation [15]:

$$C_{AF} = \frac{1}{2}\log(1+\gamma) = \frac{1}{2}\log\left(1+\gamma_{s,d}+\gamma_{r_i,d}\right) = \frac{1}{2}\log\left(1+\gamma_{s,d}+\frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}\right) \quad (1)$$

From equation (1), the channel capacity will achieve the optimum value when the value $\gamma_{s,d}$ and $\gamma_{r_i,d}$ obtained from non-dominated solution. These values respectively are the SNR value of direct path and relay path. So as to achieve optimum value of $\gamma_{r_i,d}$ then it requires relay which gives the optimum value. The best relay was given by optimum value of γ_i . Mathematically it can be formulated as follows:

$$\gamma_i^* = \arg\max\left(\frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}\right) \quad (2)$$

Where the sign (*) means the optimum value.

2.2. Load Variance

Load variance, the variance of the traffic load of all nodes, is inversely proportional to the load balance or fairness [16]. In the wireless ad hoc network, load balance is very important because some of the nodes may have a greater chance to be a relay. In pair path where node i is used as a relay, then the load of node i can be formulated as:

$$B_i = B_{oi} + B_{di} \quad (3)$$

With B_{oi} and B_{di} respectively is the traffic load itself and traffic load that heading to the the node i.

After the load of each node is known, then the load variance of the pair path of non-dominated solution can be analyzed based on the variance of the load of each node which is calculated for all nodes in the pair path. The load variance value can be determined by calculating the load balance by the following equation [16]:

$$V_p = \frac{1}{M}\sum_{i=1}^{M}\left(B_i - \left(\frac{1}{M}\sum_{i=1}^{M} B_i\right)\right)^2 \quad (4)$$

2.3. Pareto Method

If the total number of nodes (including source and destination pair) is M, then there is 1 solution of single-hop and $(M-2)$ is a 2-hop solution. Mathematically both these problems can be formulated as follows [17] :

$$\gamma_{opt} = \max\left(\gamma_1, \gamma_2, \dots, \gamma_{(M-2)}\right) \quad (5)$$
$$V_{opt} = \min\left(V_1, V_2, \dots, V_{(M-2)}\right)$$

In the Pareto method, Pareto optimal solution (POS) on the solution to every problem is done separately for optimization. At POS there is the concept of domination, to distinguish dominated and non-dominated solutions. For optimization of two problems, then the non-dominated solution can be described in Pareto optimal front (POF) of flat plane (two dimensions) as shown in Figure 2. The dominated and non-dominated solutions can be seen from comparing the two solutions, for example p3 and p9, contained in POS. Solutions p3 is said dominated of the p9 solution when both conditions are true. First, the p3 solution is not bad compared to p9 in all objective functions. Finally, the p3 solution is better than the p9 solution for at least one objective function [18].

In searching for non-dominated solution is done by Continuously Updated. Continuously Updated is a continuously updated approach in finding non-dominated solution. Continuously Updated approach can be described as follows [18]:

a. Initialization of the set of non-dominated path $P' = \{1\}$. Set counter $i = 2$.
b. Set $j = 1$.
c. Compare solution i with j contained in P' to find a more dominant solution.
d. If the solution i dominates solution j, remove member to j from P'. If j is less than the number of members of P' add P' by one and go back to step c. Otherwise, then proceed to step e.

If the member to j from P' dominates solutions i, add i by one and go back to step b.

e. Insert the solution i into P' or updated $P' = P' \cup \{i\}$. If $i < N$, where N is the number of the solution, then add i by one and go back to step b. Otherwise, the process stops and determine P' as the non-dominated set. The non-dominated set that makes POF.

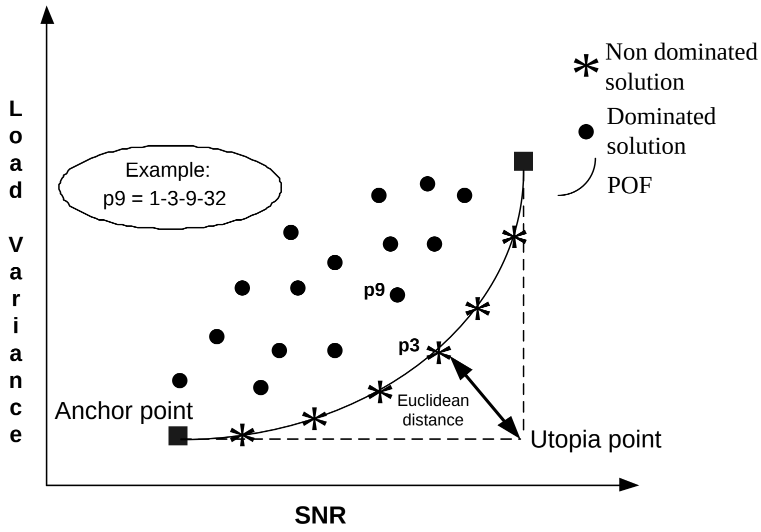


Figure 2. POF of SNR and Load Variance

In finding the optimal value of POS, first, determine the point of Utopia. Utopia point is made from the intersection of the maximum value of the first objective function and minimum value of the other objective functions. Optimal value can be determined by finding the shortest euclidean distance [19] by the equation [20]:

$$d_E = \min \sqrt{\left(\frac{\gamma-\gamma^*}{\gamma_{norm}}\right)^2 + \left(\frac{V-V^*}{V_{norm}}\right)^2} \quad (6)$$

Where $\{\gamma^*, V^*\}$ is the coordinate of Utopia solutions for variable SNR of found maximum value and variable load variance of found minimum value, $\{\gamma, V\}$ is the coordinate solutions to the POS, and $\{\gamma_{norm}, V_{norm}\}$ are the coordinates of normalization solutions to problem areas. γ_{norm} and V_{norm} are determined based on the maximum value of the non-dominated solution γ, while V_{norm} is determined based on the minimum value of the non-dominated solution V.

3. System Model and Protocol

In this study, each node can act as a source (S), relay (R) and destination (D). Properties of system models are:

- Each node uses a single antenna with omni-directional radiation.
- Relay in conducting cooperative communication using AF method.
- Package delivery method is based on half duplex.
- Transmission is done by broadcast.
- The transmit power of S and R are considered equal by P_t.
- Channel model used is path loss model *i.e.* distance power law is influenced by shadowing [14].
- The affecting noise is the AWGN noise with variance N_o.

We assume in this protocol that each node broadcasts information about the received power and the traffic load of other nodes alternately so that each node identifies the received power of each node in the form of received power table. Communication protocols initiated from the source sends packets by broadcast. Decision in the selection of the best path pair is done through the equation (5). Results of the protocol in the selection of path for cooperative diversity were determined by the smallest euclidean distance. Cooperative diversity protocol can be explained by the flowchart in Figure 3.

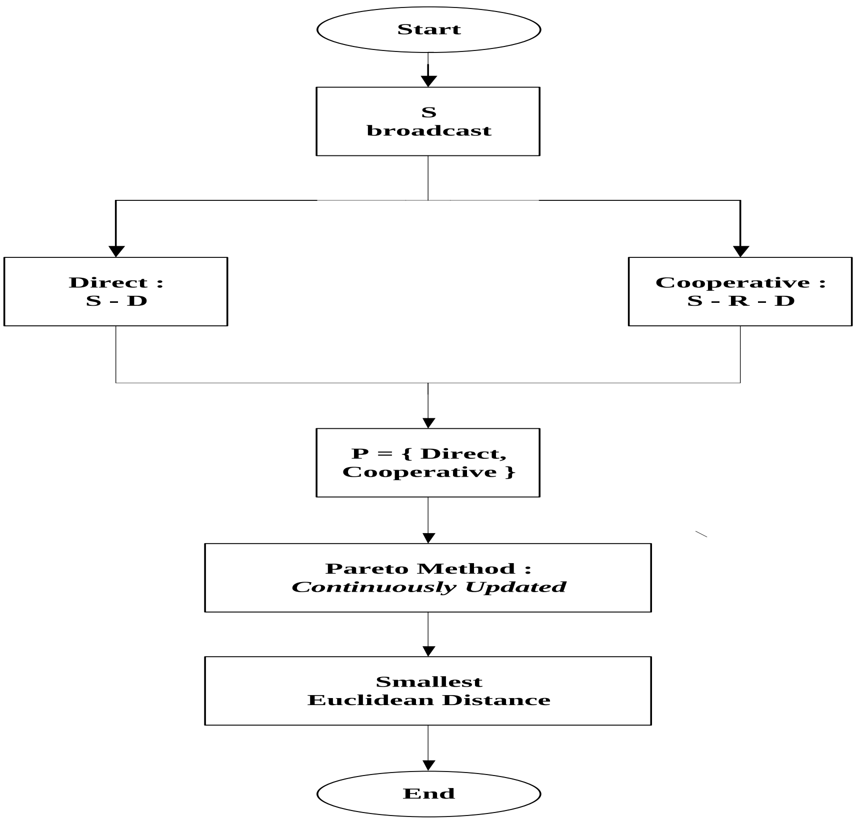


Figure 3. Flow Chart of Cooperative Diversity Protocol

Pseudocode for the flowchart in Figure 3 is as follows:

```
Algorithm :
Begin
S transmit
//direct route
route1=[S, D]
//cooperative route
For i=1:N, i≠S, i≠D
     route(i,:)=[S, I, D];
End
//Pareto optimal solution
P={[S,D],[S,I,D]}
//Pareto: continuously updated
1: Initialize P' = {1} Set solution counter i = 2
2: Set j = 1
3: Compare solution I with j from P' for domination
4: If  i dominates j, delete the j-th member from P' or
        update P' = P'\P'{j}.
   If  j < |P'|, increment j by one and then go to step 3
        otherwise go to step 5.Alternatively,
   If  the j-th member of P' dominates i, incement i by one
        and then go to step 2.
5: Insert i in P' or update P' = P' ∪ {i}. If  i< N, increment i
   by one and go to step 2. Otherwise, stop and declare P'
   as the non-dominated set.
//Euclidean distance for choice 2 non-dominated solutions
Use Euclidean distance
P'1; P'2
End
```

4. Numerical Results

The parameters of the simulation are taken based on the application of WLAN, the wireless ad hoc networks are shown in Table 1. The model of ad hoc networks used are single source, single destination, and multi relay. All nodes are in the open space, with an area of 100 m × 100 m. S sends data packets by broadcast to D assisted by multi relay node. In this study, it is determined as many as 30 nodes that have the opportunity to become relay.

Table 1. Parameters of Simulations

Parameter	:	Value
Path loss exponent , α_o	:	4
Standard deviation of shadowing, φ	:	8 dB
Power Transmit, P_t	:	1 W
Transmit antenna gain, g_t	:	2 dB
Receive antenna gain, g_r	:	2 dB
Frequency, f	:	2.5 GHz

Noise, N_0	:	- 101 dBm
Spectral Efficiency, R	:	4 Mbps/Hz

For the simulation of load variance calculation, it is assumed that in addition to the source which sends data to the destination, there are five other nodes that transmit data simultaneously to each destination node. As a result, there are some nodes that have a better chance to become relay because they have relatively lower loads. In this example, five pairs of nodes that use path 4-12-31, 7-11-25, 10-19-23, 16-12-2 and 25-20-6. It is assumed that source of node 4, node 7, node 10, node 16, node 25 respectively transmit the data successively by 5 Mbps, 3 Mbps, 8 Mbps, 7 Mbps, 2 Mbps and 11 Mbps. While other nodes are assumed to have random loads of 2 Mbps, 7 Mbps, 12 Mbps, or 17 Mbps.

Figure 4 illustrates one example of the results of the simulation. The 'square' sign is source node and destination, 'star' indicates that the node is active or is under communication with other nodes, and 'circle' indicates nodes as relay.

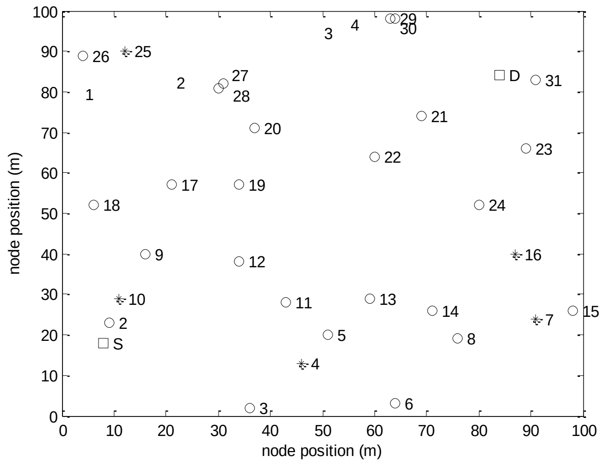


Figure 4. Wireless Ad Hoc Network Model

For the simulation of continuously update algorithm generated five non-dominated solutions namely P_1' path (S-11-D) with value of SNR = 25.55 Mbps and load variance 43,1396 Mbps^2, P_2' path (S-28-32) with value of SNR = 24.33 Mbps and load variance 41,58 Mbps^2, P_3' path (S-12-D) with value of SNR = 27.23 Mbps and load variance 45,64 Mbps^2, P_4' path (S-20-D) with value of SNR = 36.61 Mbps and load variance 46.26 Mbps^2, P_5' path (S-22-D) with value of SNR = 25.91 Mbps and load variance 44,70 Mbps^2. The non-dominated solution as a result of the simulation can be seen in Figure 5.

To select two non-dominated solutions as the pair path then it was performed by finding the smallest Euclidean distance. The value of Euclidean distance for non-dominated solutions of P_1', P_2', P_3', P_4', and P_5' are respectively 0.1087, 0.3792, 0.4251, 0.4347, and 0.4808. So the two pair paths were chosen based on the smallest Euclidean distances of P_1' path (S-11-D) and P_2' path (S-28-32). Two of the best pair path for cooperative pair path can be seen in Figure 6.

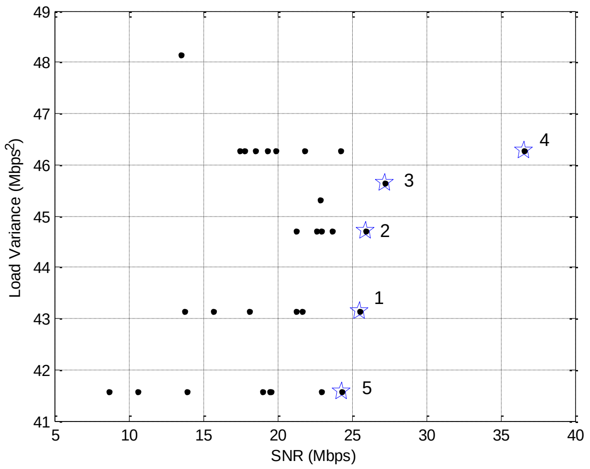


Figure 5. POF of Simulation Result

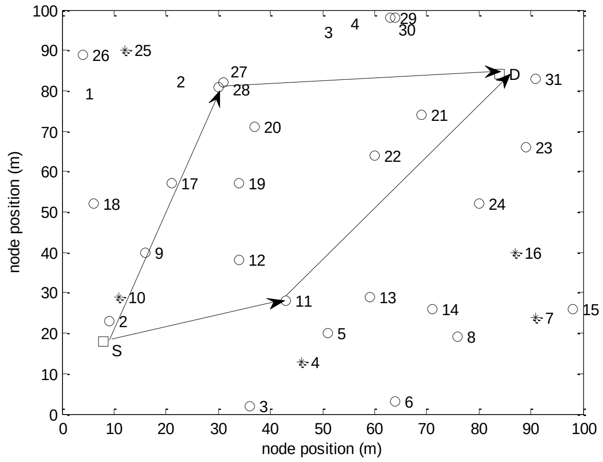


Figure 6. Cooperative Pair Path

Simulations were performed 1000 times, by random position and load of nodes to determine the distribution of each criterion and it was compared with scalarization method. The 1000-times conducted simulation result is shown in Figure 7 and Figure 8. Value of CDF of the SNR in cooperative diversity protocol can be seen in Figure 7. It can be explained from Figure 7 that the value of SNR of Pareto proposed method ranged from 23.5 up to 48.5 dB. For comparison, it is also presented the SNR values performed by scalarization method. The resulting SNR value is in the range of 18.5 to 45 dB. From these results it can be concluded that the proposed protocol obtained greater SNR value than the scalarization method.

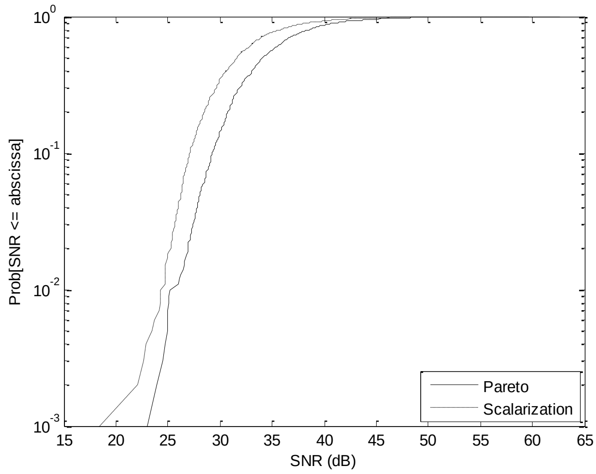


Figure 7. CDF of SNR

Then it was analyzed the value of CDF from the load variance where the simulation results can be seen in Figure 8. The value of load variance of the proposed protocol ranged from 38.51 to 50.39 $Mbps^2$. While the load variance values obtained by scalarization method ranged from 39.20 to 51.26 $Mbps^2$. Figure 8 shows that the value of load variance with the proposed protocol is smaller compared with the load variance by scalarization method. This is caused by the traffic load of the nodes on the proposed protocol is more distributed than traffic load of nodes with protocols by scalarization method.

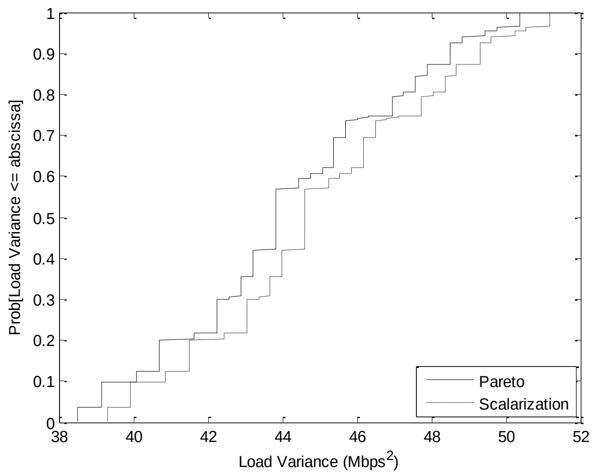


Figure 8. CDF of Load Variance

5. Conclusions

Based on the analysis of simulation results of the proposed cooperative diversity protocol hence it can be made several conclusions. First, the selection of the best path pair was done by Pareto method *i.e.* the continuously updated algorithm that based on two criteria, namely multi objective problems of SNR and load variance. Two of the best path pairs were produced by non-dominated solution which has the smallest euclidean distance. Second, the value of SNR by using the proposed algorithm was greater than the scalarization method. Finally, the value of load variance by using the proposed protocol was smaller than scalarization protocol. This means that communication with the proposed protocol resulted in more evenly distributed traffic load.

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