ADAPTIVE CLUSTER BASED ROUTING PROTOCOL WITH ANT COLONY OPTIMIZATION FOR MOBILE AD-HOC NETWORK IN DISASTER AREA

E. Budianto[1], A. Hafidh[1], M.S. Alvissalim[1], and A. Wibowo[2]

[1]Faculty of Computer Science, University of Indonesia, Kampus Baru UI Depok, West Java,16424, Indonesia
[2]Informatics Dept. Faculty of Mathematics and Natural Science, Universitas Diponegoro, Jl. H. Prof. Sudarto, Semarang, 50275, Indonesia

E-mail: enrico.budianto@ui.ac.id

Abstract

In post-disaster rehabilitation efforts, the availability of telecommunication facilities takes important role. However, the process to improve telecommunication facilities in disaster area is risky if it is done by humans. Therefore, a network method that can work efficiently, effectively, and capable to reach the widest possible area is needed. This research introduces a cluster-based routing protocol named Adaptive Cluster Based Routing Protocol (ACBRP) equipped by Ant Colony Optimization method, and its implementation in a simulator developed by author. After data analysis and statistical tests, it can be concluded that routing protocol ACBRP performs better than AODV and DSR routing protocol.

Keywords: *adaptive cluster based routing protocol (ACBRP), ant colony optimization, AODV, mobile ad-hoc network*

Abstrak

Pada upaya rehabilitasi pascabencana, ketersediaan fasilitas telekomunikasi memiliki peranan yang sangat penting. Namun, proses untuk memperbaiki fasilitas telekomunikasi di daerah bencana memiliki resiko jika dilakukan oleh manusia. Oleh karena itu, metode jaringan yang dapat bekerja secara efisien, efektif, dan mampu mencapai area seluas mungkin diperlukan. Penelitian ini memperkenalkan sebuah protokol *routing* berbasis klaster bernama *Adaptive Cluster Based Routing Protocol* (ACBRP), yang dilengkapi dengan metode *Ant Colony Optimization*, dan diimplementasikan pada simulator yang dikembangkan penulis. Setelah data dianalisis dan dilakukan uji statistik, disimpulkan bahwa protokol *routing* ACBRP beroperasi lebih baik daripada protokol *routing* AODV maupun DSR.

Kata Kunci: *adaptive cluster based routing protocol (ACBRP), ant colony optimization, AODV, mobile ad-hoc network*

1. Introduction

Computer networks and robotics technology has developed significantly with the increasing needs of people in several related areas. Computer network that was originally developed to connect multiple computers with a static topology can then be implemented in a dynamic topology. It also happens in the world of robotics, where the mobile robot was developed as an alternative solution to the problems that cannot be resolved by the static robot. One of the problems that can be solved by those two technologies is the use of these technologies as a means of improving communication networks in disaster areas [1].

Efforts to rehabilitate communications network needed as communication takes important role in human life, especially in cases where existing communication networks damaged. However, the process to improve the communication network at the time of the disaster is very dangerous and risky if done manually by humans. This is because of the possibility of subsequent disasters and various things that endanger human safety. That is why methods for network repairing needs to be fast and reliable communication is required so that the disaster-hit areas can be linked back to the communication network. Moreover, after network rehabilitation finished, the process of data transferring needs to be as fast as before, even faster.

In this study, we introduce a method for adaptive restoration of communication networks using mobile technology ad-hoc network (MANET). This technology can adapt to environmental disasters automatically in the configuration and routing aspects, in accordance with changes in the area when the disaster occurred [2].

This is done by building a communications network that uses ad-hoc routing protocol in mobile robot as a set of decision makers in the development process of communication networks. This study focused on the development of an adaptive routing protocol and can handle the movement of the robot dynamics in the disaster area.

Some of the things that is characteristic of MANET include the ability to configure itself to adapt to the environment in which he walked and the ability to seek and maintain a network of routes, although the host of the MANET topology changes [3]. MANET has several characteristics, namely dynamic topologies, bandwidth-constrained, energy-constrained operation and limited physical security [4].

The rest of the paper is organized as follows: section 2 talks about simulation characteristics and routing protocol development. Section 3 contains results and analysis from simulations of routing protol. Section 4 concludes the paper with some remarks.

2. Methodology

Problem that is often encountered in the mobile network is its unpredictable character. Therefore, Dolev et al. [5] publish a Virtual Node Abstraction, which contains a virtual node that can be predictable and reliable. In the paper, we also discuss several algorithms to implement the abstraction of the virtual mobile node. Given this virtual mobile nodes, each person can use it to design a distributed algorithm for mobile ad hoc networks.

Abstraction of the VMN consists of mobile client nodes and the virtual mobile nodes, which communicate with each other using local cast service. Each mobile node is prone to failure, one of which is a state in which the nodes can fail and recover. When a node recovers, the node will start again from the initial state. Every node receives notification of Geo-sensor on a regular basis at that time, and location of these nodes.

Virtual mobile node has two main components [5]. The main components include VMN.val that represents an abstract state of the VMN I/O automation and VMN.buffer, an outgoing message buffer distorted until the messages are ready for delivered. The components of the VMN abstraction shown in figure 1.

A schematic flow of simulation process is essential to show the process and give more understanding about this action. Diagram of the simulation process of routing and data transfer can be seen in figure 2. Stages of simulation consist of several phase: requirement, implementation, verification, execution, debug & improvement, statistical test, and result storage phase.

Requirement is a process to obtain the information needs of testing the developed model. The results at this stage form the basis for the planning scenario simulation and verification of the model developed. In routing protocol implementation, each implementation of each routing protocol is put in its place to facilitate the developer in putting the results of their implementation of the routing protocol.

In verification, a scenario is planned to run a comparison simulation of routing protocol. This stage also provides input to the simulator so it can work in accordance with a predetermined scenario. Simulation execution is a process to run the simulation by using scenarios that have been determined. Debug & Improvements is conducted by develop and improve the program by removing the bugs and shortcomings.

After debugging process finished, a statistical testis being performed to measure how big the influence of differences in treatment is given in the simulation. Statistical tests based on the nature and types of comparisons are made.

The result of research conducted for research purposes is stored for future reference.

In addition to virtual mobile node, the routing protocol simulation application development also involves a simulated environment, as a supporter of the mobile node. There are several components that are developed to support the application of this simulation. Those components are field, activity log database, and scheduler (figure 3). In general, the view of the routing protocol simulation environment that was developed is shown in figure 4.

In this experiment, we use a robot called Al Fath as the mobile node model in simulation. We assume that this robot has already equipped with MANET technologies that allows them to communicate. The display of this robot can be seen on figure 5.

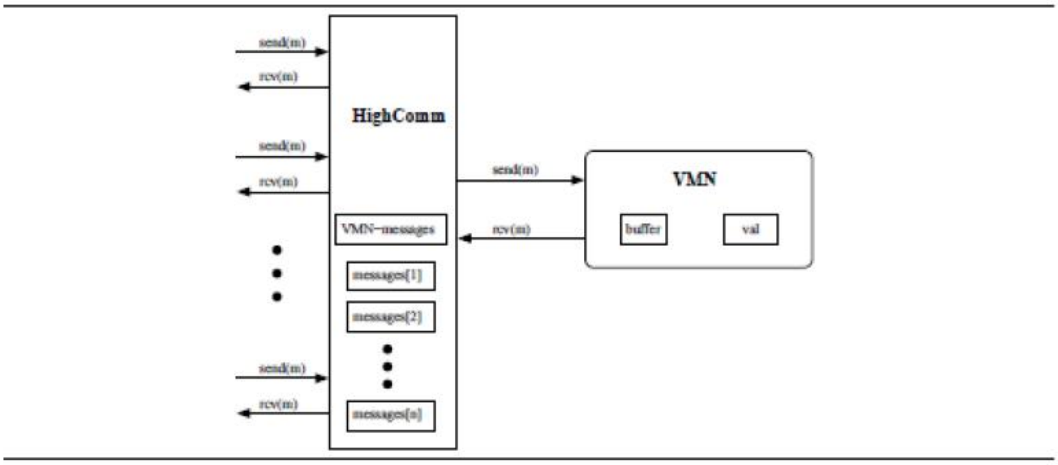

Figure 1. Component of VMN abstraction [5].

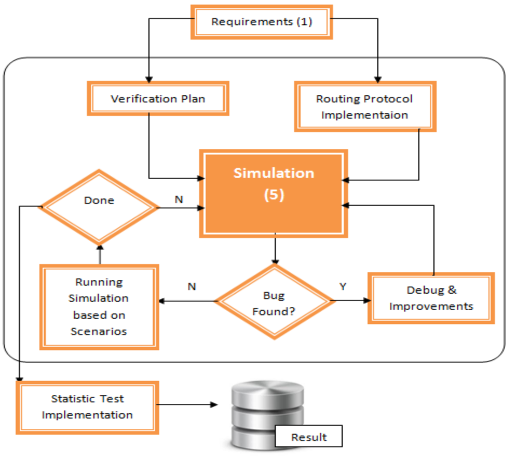

Figure 2. Simulation process diagram.

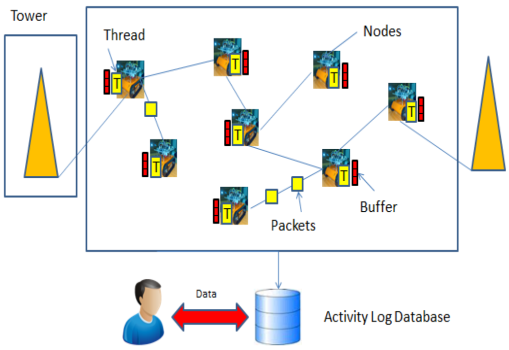

Figure 4. Simulation schema.

Figure 5. Al Fath robot.

In this simulation development, we develop a mobile node that mimics the specification of Al Fath robot; the complete specification of this robot is described on table I.

Based on specification that has been described on table I, several characteristic that will be implemented in this simulation can be seen from several factors: base energy, distance from sensor, and buffer size.

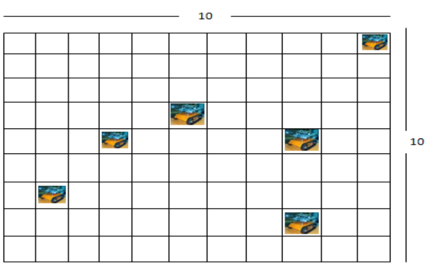

Figure 3. Field illustration.

Adaptive Cluster Based Routing Protocol is a routing protocol developed to make improvements over the lack of a routing protocol that ever existed, a combination of excess multiple routing protocols, and the addition of new features that make the routing protocol performance is better. There are several improvements that have been done comparedwith other existed routing protocol. Those improvements are in the multiple source routing concept, the parameter that is used in cluster head selection, change of cluster head mechanism, route discovery process, and route maintenance steps

TABLE I
AL FATH ROBOT SPECIFICATION

Name	Values
Voltage	5v
Current	15mA Typ. 3mA Standby
Frequency	40 KHz
Maximum Range	6 m
Minimum Range	3cm
Max Analogue Gain	Variable to 1025 in 32 steps
Connection	Standard IIC Bus
Light Sensor	Front facing light sensor
Timing	Fully timed echo, freeing host computer of task
Echo	Multiple echo – keeps looking after first echo
Units	Range reported n uS, mm, or inches
Weight	0.4 oz
Size	43mm w x 20mm d x 17 mm h

There are two phases in Adaptive Cluster Based Routing Protocol, namely the cluster head election and transmission phase. The cluster head election phase aims to form a cluster of a group of interconnected mobile. From a group of mobile nodes, a mobile nodes will be selected as cluster head. Cluster head will organize the data transmission, as well as being a gateway from internal cluster members to the outside cluster. The cluster head also serves as the backbone that connects to cluster head from the entire clusters. Afterwards, a set of clusters and number of cluster head nodes that are connected will be formed. Once all nodes are ready and have formed a cluster, then the routing process has been completed and the ad hoc network can be used to send data. There are three type of routing packets in ACBRP: RREQ, RREP, and RERR. Those routing packet modes will be appended by data packets.

Al Karaki et al. [6] said that there are several parameters used to build a routing techniques, those are tiered architecture and self-configuration. Tiered architecture is a layered network architecture which has several layers and a node that serves as controlling node. As a tiered network, cluster-based concept can lead to scalability and efficiency. Multitier network architecture display can be seen on figure 6.

Adaptive Cluster Based Routing Protocol also implements self-configuration. Self-configuration is the ability from each agent node to adapt with dynamic topology to maintain connectivity within nodes in the network. When there is a node that comes to failure or leave the network, reconfiguration and update process must be conducted.

This algorithm modifies the previous NCBR protocol, and adds several features that makes this protocol more optimize than before. As stated on point A, there are two steps that a node must takes place, named cluster head election and data transmission phase. For cluster head election phase, the steps taken by a node is as follows on figure 7.

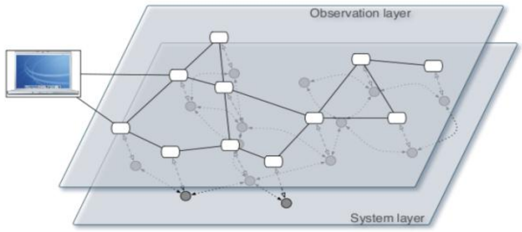

Figure 6. Multitier network architecture [6].

```
    for every node i that is not member of
cluster
    Compute CHSV value of i
    Choose Node I as parent
    for (neighbors of node i)
    if ACO initialization is finished
    do randomization using transition
probability of pheromone
    choose the node as cluster head
    else
    find neighboring node with lowest CHSV
and is not child or parent from other
cluster
    Choose node as the parent
End for
```

Figure 7. Step for cluster head election phase.

```
    Source node determines destination,
create RREQ
    If node is node child or parent of
cluster
       Broadcast RREQ to all neighboring
nodes
    If node is a child of a cluster
       Check if destination is on our
neighbors
       If so, broadcast RREQ to that node
       If not, throw RREQ to parent of
cluster node
    If node is a parent of the cluster
       Check if a child as destination
exists
       If so, broadcast RREQ to that node
       If not, throw RREQ to other cluster
head
    If current node is the destination
    Create RREP as the response of RREQ to
source node
Send RREP following the precursor node that
has been created during RREQ propagation
```

Figure 8. Pseudocode of aata transmission process.

After cluster head election process finished, the next step is conducting data transmission. The data transmission process is described by pseudo-code on figure 8. The flowchart of ACBRP routing protocol is displayed on figure 9. There are two steps in the routing protocol : Cluster formation mechanism (equivalent to cluster head election) and data transmission mechanism.

There are several possible scenarios that might happen in the real world and its resolution using ACBRP routing protocol. The first possible scenario is when the source node is outside the cluster. This condition happens on the node that just join the cluster and then try to send the data. This condition is illustrated on figure 10. On the illustration, node 8 tries to send data to node 10. To handle such condition, source node will use AODV mode to send the data, since the node is not joining any cluster.

The second scenario that is put into account is a condition when the destination node is outside the cluster. This scenario might happen when there is a node that just join the network and not yet assigned to any cluster. The illustration can be seen on figure 11. On the illustration, the source is node 0 and the destination is node 9.

One of the improvement of this protocol is its ability to do multiple source routing. Hence, this protocol can handle data transfer from more than two towers.This algorithm implements the ability for multiple source routing, which sends a message from some sender node, and then send it to some destination node. In order to implement this capability, each mobile node is equipped with a buffer to hold data packets that come to each mobile node. Any period of time, the contents of the buffer will be checked, and the package is in the buffer will be forwarded to the destination. Illustration of this scenario is shown in the figure 12. In the above case, a data packet is sent from tower 1 to tower 3, from tower 2 to tower 1, and from tower 3 to tower 2. Because it’s ability to handle multiple sources, this algorithm requires a buffer to store packets to the node. For example, node 1 may just take delivery of packets sent from tower 1 to tower 2, and from tower 3 to tower 2 simultaneously, but it will not cause packets to be lost, because the node already has a buffer to store the data packets before then taken.

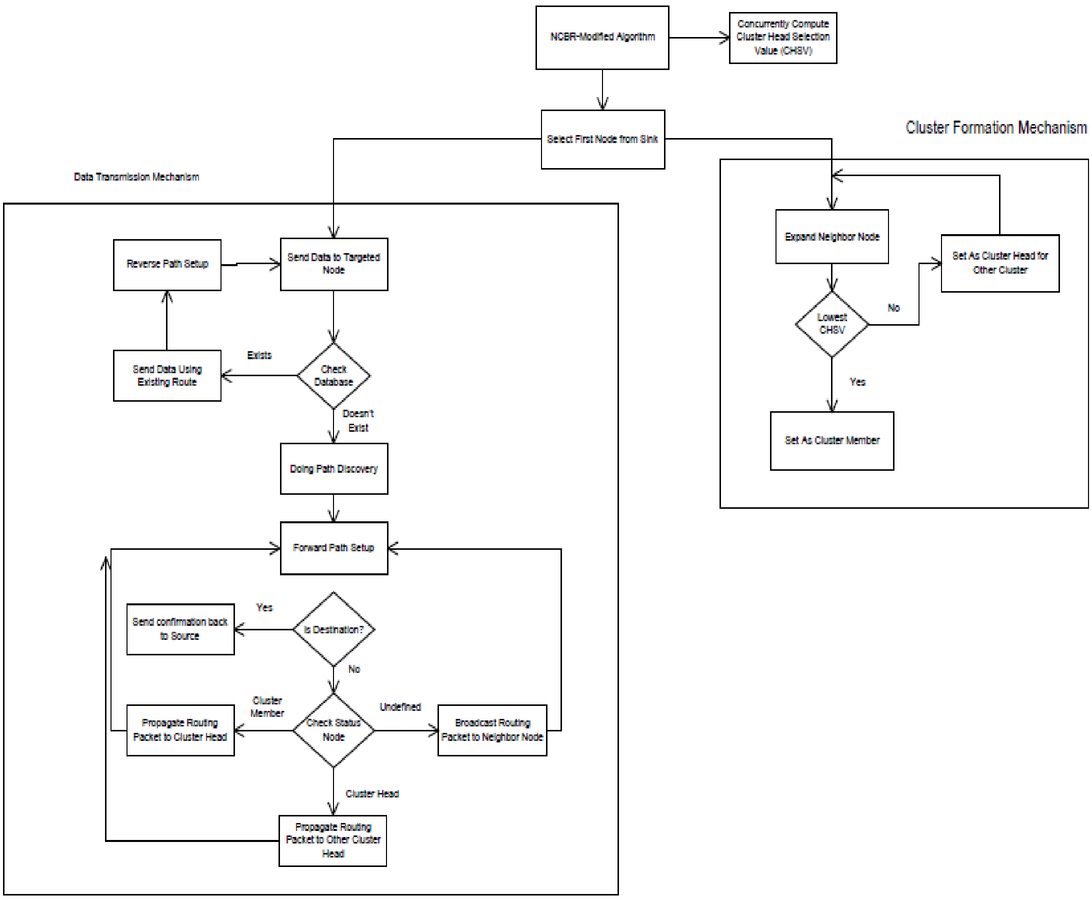

Figure 9. ACBRP protocol design.

The last possible scenario is failure/dead nodes.This problem has a lot of cases encountered in mobile ad hoc network, where each node has high mobility and network topology changes. One illustration of this scenario is shown in figure 13. Assuming that the data will be sent from node 0 to node 7, because it goes to the second node in a cluster, then node 0 will have data about the node 7. Therefore in this scenario the first time the package will be delivered based cluster. However, since node 4 suddenly dead, then the packet may not be able to get to node 7. Therefore, each node has a wait time, where the waiting period is intended to give pause for a long time for the sender node, before sending node decides that the packet transmission fails, and the packet must be resent. In the process the second packet transmission, data transmission will be done in AODV. After the node sending a new route towards the destination node, the data later be updated Thus, the new route can be used to communicate.

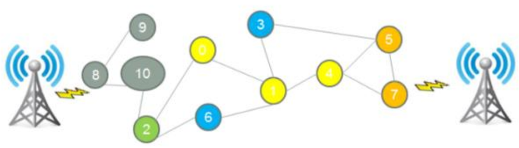

Figure 10. Illustration of first scenario.

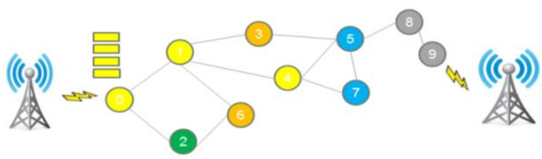

Figure 11. Illustration of second scenario.

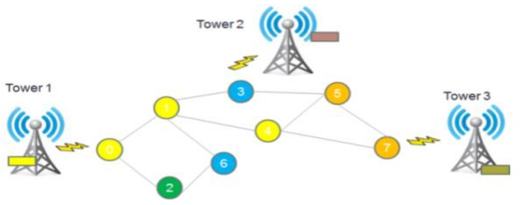

Figure 12. Illustration of third scenario.

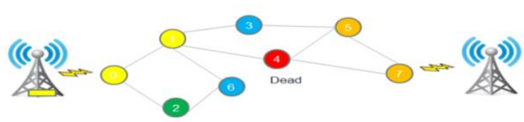

Figure 13. Illustration of third scenario.

One improvement in Adaptive Cluster Based Routing Protocol is in cluster head selection process. This process uses ant colony optimization, an approach proposed by Dorigo and Theraulaz [7]. This approach combines the ant colony with local search and other optimization methods. The basic idea of all ant-based algorithm is a positive feedback mechanism. Above mechanisms take the analogy of a trail Following from ant to encourage good solution so as to encourage improved quality of the solution [7]. The illustration of trail following in ant colony systems can be seen on figure 14.

This routing protocol is equipped with additional features to improve optimization by using ant colony optimization. In the implementation of this algorithm, data packetsand routing packets will also serve as artificial ants. Artificial ants will work to establish the optimization process in the selection of the next cluster head. The optimization process starts by putting ant *k* at random node. Then, the artificial ant which is a packet routing and data packet will be forwarded to another node, by using a routing protocol ACBRP. After a number of data packets and routing successfully delivered to each destination node, cluster head can be selected using this algorithm.

At the time of an ant came to a node, each ant *k* will give a value $\Delta\tau_{ij}^{k}(t)$ for every edge (i,j) where pheromone is passed. The value $\Delta\tau_{ij}^{k}(t)$ depends on the distance that is already traveled by the ant. At *t-th* iteration , the length of step that has been passed is added by 1, so the value $\Delta\tau_{ij}^{k}(t)$ is evolved as shown in equation 1. Value $L^{k}(t)$in equation 1 indicates length of route has been traversed by the *k-th* ant, and $T^{k}(t)$ declares the nodes that have been visited by ant k on the *t-th* iteration.

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \frac{100}{L^{k}(t)}, & if\ (i,j) \in T^{k}(t); \\ 0, & if\ (i,j) \notin T^{k}(t); \end{cases} \quad (1)$$

Values $\Delta\tau_{ij}^{k}(t)$ above can then be used to update the pheromone values laid down by each ant on the nodes in the network. To prevent stagnation, a condition in which only a limited section of an area being explored, we introduce the concept of evaporation, a parameter that can be used to reduce the intensity of pheromone in a series of iterations. With the evaporation, the rate of pheromone from a node can be reduced gradually so that other nodes still have the opportunity to be explored. Update pheromone values are presented in the equation 2.

$$\tau_{ij}(t) \leftarrow (1-\rho).\tau_{ij}(t) + \Delta\tau_{ij}(t). \quad (2)$$

Value ρ in the equation above states decay coefficient, that is a probability value of pheromone on reducing levels of the previous iteration. The value ρ has a range of $0 \leq \rho < 1$. In the implementation of ant colony optimization algorithm has a value $\rho = 0.9$. In the cluster head election process, the pheromone plays an important role to determine the node where the cluster head will be given. To determine the node that manages to be cluster head, a function called the transition probability proportional transition rule is used, as described in equation 3.

$$p_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{1}.[\eta_{ij}]^{2}}{\sum_{l\epsilon J_i^k}[\tau_{il}(t)]^{1}.[\eta_{il}]^{2}}. \qquad (3)$$

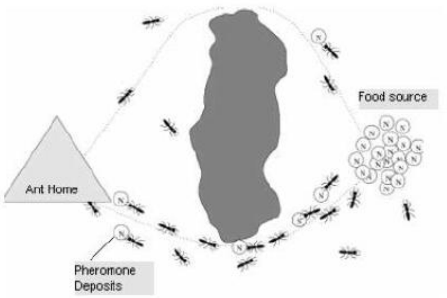

Figure 14. Ant colony optimization in food finding [8].

Random proportional transition rule states the probability of *k-th* ant for the transition from node *i* to node *j* in order to conduct tours to choose the cluster head to form an optimum cluster. Probability makes the node with the greatest $p_{ij}^{k}(t)$ value may not necessarily be the cluster head. This is done to keep giving chance to other nodes will smaller probability. Value $p_{ij}^{k}(t)$denotes the probability of transfer from the source node *i* to destination node *j* in the *k-th* ant, and at iteration *t*. The process of selecting a cluster head based on the random proportional transition rule above is done until no more nodes to be explored, or when the intermediate node has no neighbors.

3. Results and Analysis

In the implementation of the routing protocol simulation, there are three parameters to be compared: throughput, average end-to-end delay and routing overhead [3][9][10]. Throughput is the ratio between the numbers of data packets that successfully sent to the destination node with the number of data packets sent by the sender node. Average end-to-end delay states all the possible time delay caused by buffering during route exploration process, the process of lining up in the interface queue, retransmission of data packets or routing packet (retransmission), propagation of information and transfer time. In routing overhead parameter, there are two types of overhead on these parameters, namely packet overhead and byte overhead. In this study, we use the concept of packet overhead. Packet overhead is the ratio between the numbers of routing packets transmitted with a packet of data sent to the destination.

In the simulation scenarios, each parameter has 64 pieces of scenario comparison. Scenario variables and variations can be seen on table II. There are two routing protocols used to compare the performance of ACBRP routing protocol, those routing protocol are the Ad-hoc On Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) [11][12]. Those three routing protocols will be tested within the same scenario and simulator, and the result of performance will be fetched later at the end of simulation.

There are two variables involved in the process of data collection by the implementation of the ACO: number of nodes and number of ants. Variables involved and variations in the scenario of implementation of ACO can be seen in table III. After Ant Colony Optimization takes place, the process of comparing this method and the conventional one is conducted. Parameter used as comparison factor is percentage of coverage of the cluster to the overall number of nodes in the network.

There are two methods to be compared; those are the selection of cluster head by using Ant Colony Optimization and election of cluster head using a conventional manner, where the cluster head selection is done by selecting the cluster head with the largest number of neighbors. Neighboring nodes of node *i* is a node that is directly related to the node *i* and is located within range of the sensor node *i*. After the cluster head selection process is done, each selected cluster head will expand to create a cluster in the region. The percentage of coverage will be obtained from the ratio of the number of node that becomes a cluster head or being a member of a cluster by the number of nodes as a whole.

After comparison of AODV, DSR, and ACBRP routing protocols takes place, the data throughput, average end-to-end delay and routing overhead is obtained. A routing protocol will have a better throughput if its value is closer to 1. The results of the throughput of those three routing protocols can be seen in figure 15. From the experimental results, we can conclude that the routing protocol ACBRP (in figure 15 are marked in red) has the best throughput among the three routing protocols tested.

On average end-to-end delay, a routing protocol will have a better delay if the value is getting closer to 0 millisecond, which means there is no delay at all. The results of the data average end-to-end delay from the three routing protocols can be seen in figure 16. From the experimental results, ACBRP routing protocol (in figure 16 are marked in green) has the lowest delay among the three routing protocols tested.

Routing protocol will have a better routing overhead when the value is closer to 1, which means that there is no routing packet is lost in transmission process. The results of the routing overhead from the three routing protocols can be seen in figure 17. From the experimental results, obtained data that the routing protocol ACBRP (in figure 17 are marked in green) has the best efficiency with the lowest routing overhead, compared to AODV and DSR routing protocol.

On the implementation of Ant Colony Optimization, data collection is done by running the simulation cluster formation and compare it with conventional methods. Coverage percentage of the cluster is later compared. The results of data collection can be seen in figure 18. It appears that Ant Colony Optimization method has better cluster coverage percentage than conventional methods at the beginning of the scenario with a small number of nodes with less than 40 nodes.

TABLE II
VARIATION OF ROUTING PROTOCOLSCENARIOS

Variable	Variation
Number of nodes	10, 20, 40, 50
Waiting time (milliseconds)	100, 500, 1000, 4000
Buffer size	50, 200, 500, 1000

TABLE III
VARIATION OF ACO IMPLEMENTATIONSCENARIOS

Number of Nodes	Number of Ants
10	5,10,15
20	15,20,25
40	30,40,45
50	45,50,60

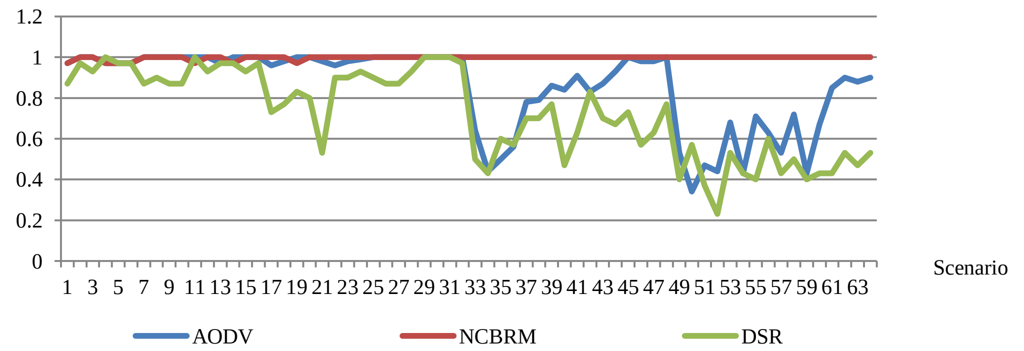

Figure 15. Throughput.

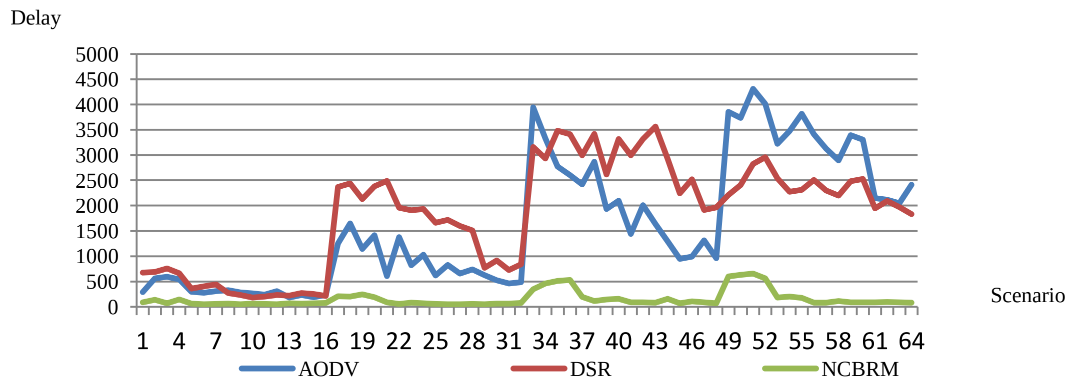

Figure16. Average end-to-end delay.

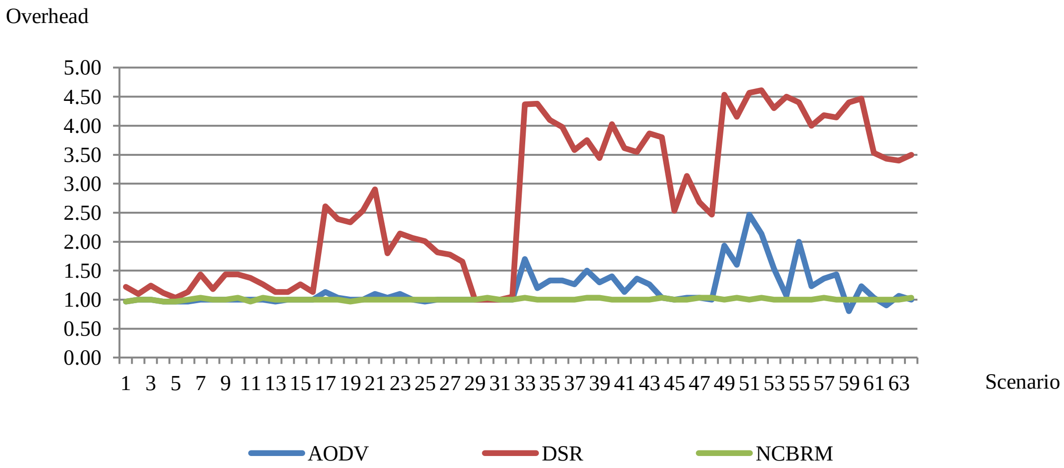

Figure17. Routing Overhead.

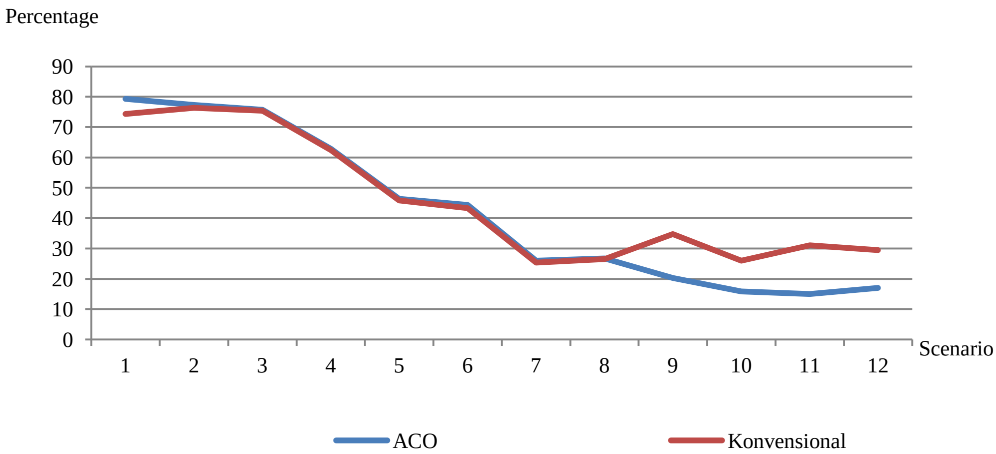

Figure 18. Cluster coverage percentage.

4. Conclusion

Adaptive cluster-based Cluster Based Routing Protocol (ACBRP) uses a cluster based routing concept with additional features to improve its efficiency. Ant Colony Optimization algorithm has been successfully implemented,tested and validated by statistical tests. From the results of data collection and test statistics, routing protocol ACBRP have better performance and more efficient routing protocol than the other compared routing protocols, i.e. Ad-hoc On Demand Distance Vector (AODV) and Dynamic Source Routing (DSR). This can be seen from three parameters, namely throughput, average end-to-end delay and routing overhead.

On the percentage coverage of the cluster, Ant Colony Optimization gives the better percentage of cluster coverage than conventional methods in the number of nodes with small and medium size, but not optimum when applied to a network topology with a large size. Further studies on the weighting of each variable of the equation is expected to make the implementation of the Ant Colony Optimization for the better.

From the results of statistical tests conducted on the experimental data, it appears that the performance of the routing protocol ACBRP is statistically better than the other tested routing protocols, namely AODV and DSR. Statistical testing performed using Mann-Whitney test for non-normally distributed data and Student's t-test distribution for the data that is normally distributed.

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