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Modeling of Energy-efficient Applicable Routing Algorithm in WSN

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Abstract

Recent advances in WSN (Wireless Sensor Networks) have led to many routing protocols designed for more efficiency of energy utilization in the WSN field. While many routing protocols have been proposed in this field, a single routing protocol cannot be energy-efficient if the environment of the sensor network varies. This paper presents a FAR (Fuzzy logic based Adaptive Routing) algorithm that provides energy-efficiency by dynamically changing the protocols installed at the sensor nodes. The algorithm changes protocols based on the output of the fuzzy logic which is the fitness level of the protocols for the environment. A simulation is performed to show the usefulness of the proposed algorithm.

Keywords: *Adaptive routing, Fuzzy inference system, Wireless sensor network, Simulation*

1. Introduction

Recent advances in wireless communication and electronic technology can develop small-scale sensor nodes which can make short distance communication with low cost, low power, and multiple functions [1]. As a result, WSN (Wireless Sensor Network) appeared as a new tool for applications, such as tracking pollutants, monitoring natural environment or traffic volume, and tracking enemies in a battlefield, etc [2].

WSN is composed of small-scale sensor nodes which have abilities of perception, calculation, and wireless communication. Each sensor node is composed of a sensor, processor, memory, transceiver, location measurement system, and battery. A sensor node not only collects and transmits data but also performs a routing function which transmits received data to another node. These sensor nodes are generally arranged and scattered in the center field. Each sensor node transmits the perceived data to BS (Base Station) outside the center field. The BS enables a user to collect the data, connecting the sensor network with an existing communications infrastructure like the Internet [3].

In most applications, supp1ying energy in the sensor node is 1imited [2, 3]. To enlarge the sensor's node's survivability, it is very important to minimize the design of the routing algorithm. A key issue is that there is no single routing protocol which can guarantee the efficiency in a11 network situations [2, 4]. For examp1e, using a LEACH (Low Energy Adaptive Clustering Hierarch) [5] routing protocol with a cluster base in a broad area is difficult, as the cluster head uses a sing1e hop routing method which directly transmits data from sensor nodes in the cluster to the BS [4]. If the distance between the cluster head and the BS grows larger than radio scope, the data cannot be transmitted, or the energy consumption must be increased. The saving a human life at an earthquake site, when using a sensor node loaded with LEACH, might become impractical if the node's range is increased due to a secondary shock.

This study suggests the FAR routing algorithm to solve the problem in this case. The FAR algorithm sets the goa1 to secure efficiencies in energy consumption when changes in situation make a sensor node use a routing protoco1 chosen by the BS, using a fuzzy inference system. The FAR algorithm minimizes the energy consumption by switching energy effective routing protocols as needed with changes in the current and network situation. Lastly, this study shows that the FAR algorithm is more energy effective than the existing technique by using the routing protocol and performing simulations with a changing sensor network.

2. Background Theory

2.1. Active Networks

An Active Network [6, 7, 8] is a newly presented concept to overcome limitations on usage of new technologies and services due to the static characteristics of middle nodes. This active network makes it possib1e to economically introduce new protocols or application programs to networks by transferring and executing program codes on the se1ected middle nodes.

There are two ways to embody active networks: the discrete approach, and the integrated approach. In the discrete approach programs are installed on the active midd1e node, separated from actual data packets and on another host, which transmits the packet with data and identification for the active program to the target node, and accomplishes the service. In the integrated approach the program and data are combined and transmitted to the active node, which executes the program and the service.

2.2. TEEN

TEEN (Thresho1d sensitive Energy Efficient sensor Network protocol) [9] is a routing protocol based on c1usterinng, similar to LEACH. The sensor nodes in TEEN decide whether to transfer on the sensed data based on Ht and St, the critical values received from the cluster head. On the other hands, if the va1ue of the sensed data first exceeds Ht, TEEN will store the corresponding data to the node’s interna1 variable called SV (Send Value) and transfer. Subsequently, it will only transfer when the value of the sensed data is bigger than Ht and when the discrepancy between SV and the value of the sensed data is bigger than St. TEEN is more adaptive to a reactive sensor network because of reduced data transfer based on the critica1 va1ue broadcast by the cluster head. This is different from LEACH, where the sensors transfer sensed data regularly, even though TEEN uses the cluster formation technique of LEACH [10].

2.3. Directed Diffusion

Directed Diffusion [11] is a data-centric routing protocol, base on a BS query. Inquiry in Directed Diffusion is displayed as interest, composed of property and va1ue pairs [10]. Such interest is regularly pumped into the sensor network from the BS; a gradient will be set up for sensor nodes to transfer data to the BS. After the setting of the gradient, a multi-path route is created between the BS and the sensor nodes. Data sensed by the sensor nodes is transferred to the BS through this route. One or more paths among the multiple-path route will be enhanced by the BS, and data wi11 be transferred through the enhanced paths, decreasing the consumption of energy of the sensor network and preventing unnecessary flooding. The directed diffusion design can be a1tered or modified as needed; it is adaptive for query-driven sensor networks, but a1so adaptable for event-driven sensor networks [11, 12].

3. Fuzzy Adaptive Routing Algorithm

3.1. Assumption

Various compositions are possible for wireless sensor network, depending on the application. Assumptions about the wireless sensor network for the FAR algorithm are as follows:

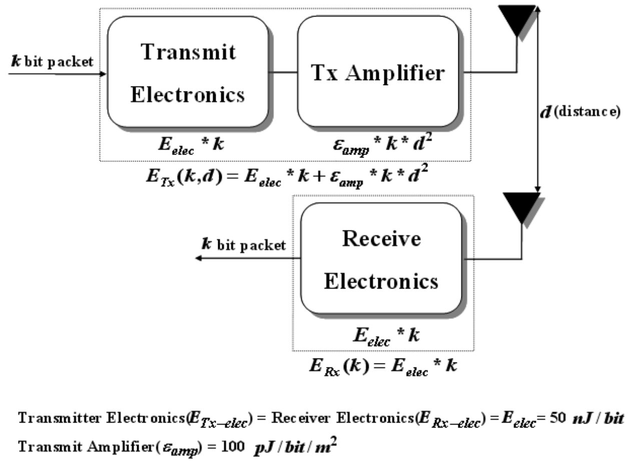


Figure 1. Radio Model

- All nodes use the Radio Model in Figure 1, the same as LEACH and TEEN. In this algorithm the BS uses an amplifier when it broadcasts messages to a sensor node. Using this Radio Model, the BS could distribute protocol code indirectly to a sensor node, or transmit it directly to a remote node. In that case the sensor node traffic will not be routed, and the energy consumption is greatly reduced. This study sets the direct transmission range of the BS and sensor node to be 300m.
- The BS is continuously powered. The wireless sensor network BS collects information from the sensor nodes, and sends it to the task management node through the Internet [1, 3]. The BS needs a continuous power supply to accomplish fuzzy operation, and broadcast protocol code and switch messages to the sensor node.
- All nodes know the general location of themselves. In order to reduce an expense, either low power GPS (Global Positioning System) or Triangulation [14] which is able to grasp general locations of nodes, affixing GPS to only a few node.
- All nodes will be able to load any routing protocol dynamically. For this algorithm, all sensor nodes should load the routing protocol dynamically. One technique is to use Active Networking technologies [15]. These technologies have not only routing functions, but also calculation functions. Using active networking technologies it wou1d be possible to use a sensor node to load the routing protocol, since a sensor node also has these functions.

3.2. Algorithm Execution Process

FAR algorithm basically consists of four steps: Initialization, Protocol Selection, Direct Code Distribution, and Direct Protocol Switching. Additionally, in an exceptional situation, Request-response Code Distribution, and Local Protocol Switching are added.

• Initialization

The task administration node, which the user manages, transmits configuration data including suitable routing protoco1 codes, hash codes, parameters, fuzzy membership functions, and fuzzy rules, to the BS through the Internet. The BS initiates the work with data received from the task administration node. The hash code for each routing protocol can be created by hash algorithms MD5, or RIPEMD-160. This study uses a hash code as a protocol switching message, since the hash code is the only thing identified for each routing protocol. If there is an environmental change in the network, such as an additional arrangement or arrangement scope of a node during this task, the task administration node transmits new parameters in this step. Figure 2 is an example of the initialization step showing the transmission of routing protoco1 code, such as TEEN, and Directed Diffusion, hash code, parameters, fuzzy membership functions, and fuzzy rules to the BS.

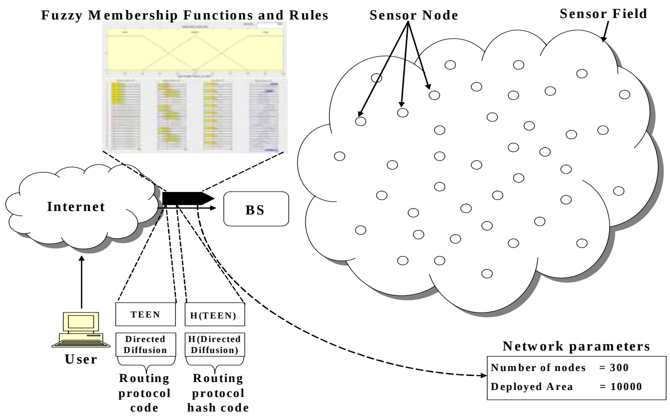


Figure 2. Initialization

Parameters are as follow:
- Number of nodes = 300; Number of the sensor nodes arranged in the sensor field.
- Deployed Area = 10000 ㎡; Area of the territory containing sensor network.

• Protocol selection

When the BS receives parameters from the task administration node, FBPS, which is inside of the BS, selects the suitable degree of each protocol. Then the maximum suitable degree is selected from among the suitable degrees. If there are more than two, then all protocols are selected. Figure 3 shows an example where the FBPS received the parameters (Number of nodes = 300, Deployed Area = 10000 ㎡), and select TEEN as the most efficient routing protocol. More detailed facts used to select the most efficient routing protocol for a situation will be discussed in part 3.3.

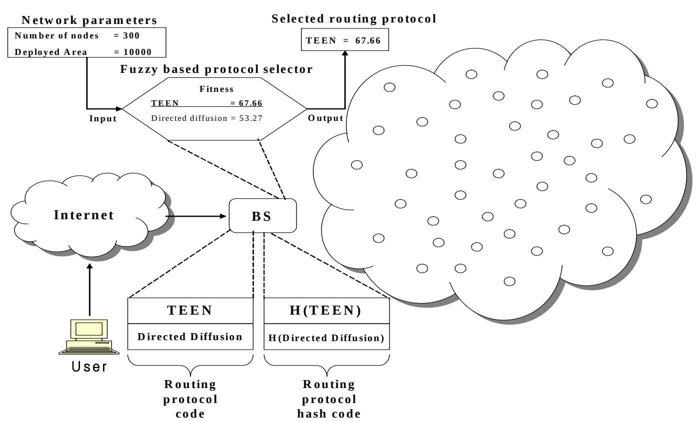


Figure 3. Protocol selection

• Direct code distribution

The BS confirms the existence of hash code in record of the cached routing protocol selected by FBPS, and checks whether BS has distributed the selected routing protocol to the sensor node or not. If the routing protocol was already distributed, go to the next step, direct protocol switching. Otherwise, the BS broadcasts it to all sensor nodes in radio range, and stores the hash code of the corresponding protocol in the protocol distribution record. The sensor nodes which received the routing protocol code from the BS initiate routing, loading additional protocol routing. Figure 4 is an example which shows the BS broadcasting TEEN code, which was selected in the protoco1 selection step, to the sensor nodes.

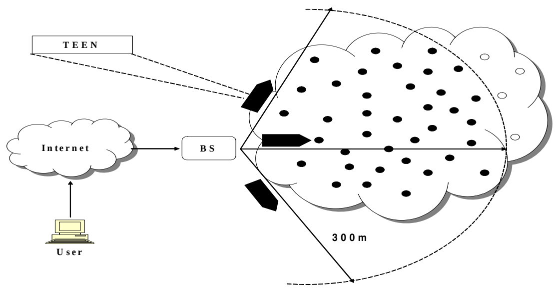


Figure 4. Direct code distribution

• Direct protocol switching

The BS compares the hash code of the protocols selected by the FBPS with those stored in cache. If they match the protocols in use, the selected routing protocols are in accord, and the BS does not perform a protocol switch. Otherwise, the BS broadcasts the hash code and stores it in the cache. Sensor nodes receiving the hash code from the BS replace the routing protocol in use with a corresponding protocol and perform the routing. Figure 5 shows the BS broadcasts the hash code of TEEN, which is then selected in the protoco1 selection step by the sensor nodes. In this step, energy consumption is reduced by using the smaller sized hash code, rather than the protocol code, as a protoco1 switching message. Sensor nodes which are rearranged or out of radio scope of the BS (300m) cannot receive either routing protocols or switching messages. Additional steps are necessary to solve this problem.

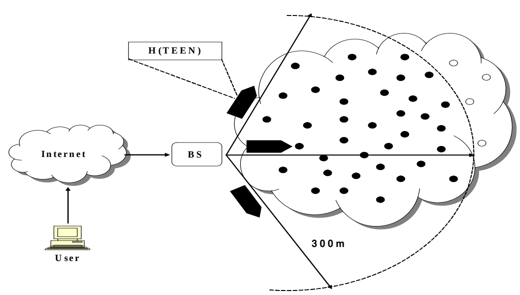


Figure 5. Direct protocol switching

• Request-response code distribution

The sensor nodes which perceived events or received data from neighbor nodes investigate whether the routing protoco1 is inside of cache or not. If there is no routing protocol in the node, it broadcasts a request message to a neighbor node. The neighbor node which receives the request message transmits to the requesting node. Figure 6 shows the nodes which do not receive the routing protoco1 code from the BS receiving TEEN protocol code via Request-response.

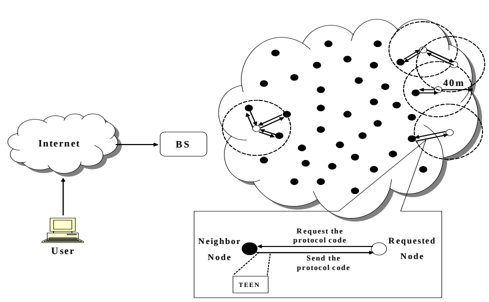


Figure 6. Request-response code distribution

• Local protocol switching

The node received routing protocol switching message from BS, within the radio scope of BS (300±5m), broadcasts a protocol switching message. In this manner the sensor nodes out of radio scope of the BS can receive protocol switching messages. Figure 7 shows a sensor node near the radio scope limit broadcasting the hash code of the TEEN protoco1. The FAR algorithm performs the 6 steps mentioned above. It repeats the 6 steps whenever the number of nodes increases due to rearrangement of the sensor nodes or network changes due to extension of the arrangement scope.

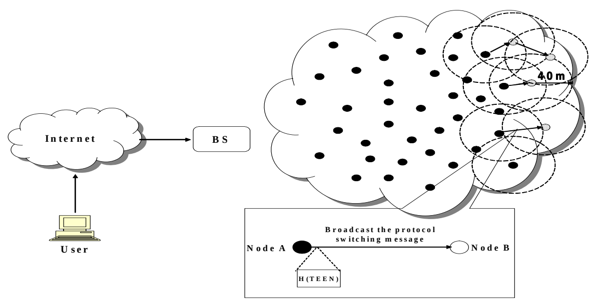
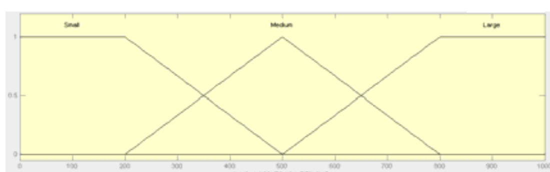


Figure 7. Local protocol switching

3.3. Fuzzy Based Protocol Selector

The FBPS selects the routing protocol for the most efficient energy utilization using a decision-making system based on fuzzy inference, under the current network situation. The FBPS has “Number of nodes”, and “Dep1oyed Area” as input variables, and “Fitness” as an output variable. Input variables are: the fuzzy set, which expresses the components of the network environment; “Number of nodes”, the number of sensor nodes arranged in the sensor fie1d, and “Deployed Area”, which is the area of the square territory of the dep1oyed sensor network. “Fitness”, the output variable, shows how suitab1e the routing protocol is to the current situation. The composition and scope of the input-output variables are set up as in Figure 8.



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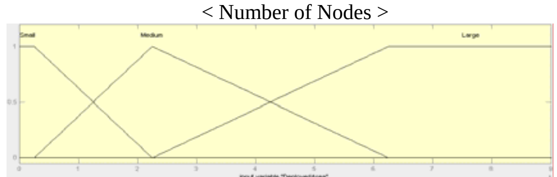

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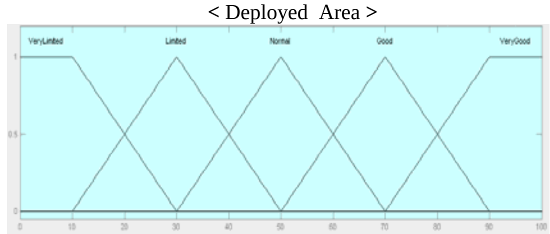


< Fitness >

Figure 8. Fuzzy input-output variable of FBPS

Directed Diffusion and TEEN are selected as the switching candidacy protocols in this study. Although the number of sensor nodes increases, the energy consumption in the entire network does not increase proportionally, because TEEN is a single hop routing protocol, However, as Directed Diffusion is a process utilizing flooding, the more the number of sensor nodes increases, the more energy consumed in the entire network.

The BS could be placed outside of the radio scope of the cluster head, when sensor nodes are arranged in a broad area, since cluster head in TEEN is selected randomly. Therefore, energy is wasted when the BS cannot receive al1 data from the cluster head. Consequently the energy efficiency decreases when TEEN is used in a broad area. Directed Diffusion, however, is a hop routing technique which can transmit data to the BS without the above problem when sensor nodes are arranged in a board area.

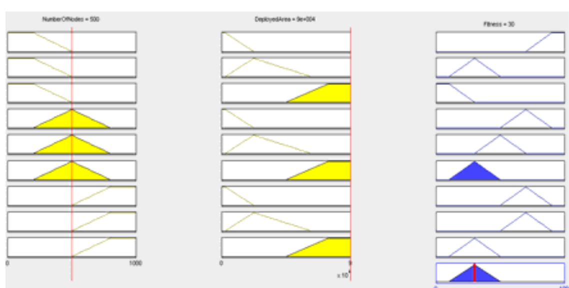
Table 1. Fuzzy Rule for TEEN

Number of nodes / Area	Small	Medium	Large
Small	Very Good	Good	Good
Medium	Normal	Good	Good
Large	Very Limited	Limited	Limited

Table 2. Fuzzy Rule for Directed Diffusion

Number of nodes / Area	Small	Medium	Large
Small	Good	Limited	Very Limited
Medium	Good	Good	Good
Large	Very Good	Good	Good

Table 1 and **Table 2** are the fuzzy rules considering these facts, and show the fitness of the routing protocol, as "Number of nodes" and "Deployed Area" are changed.



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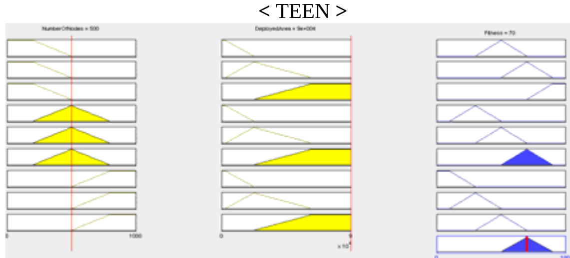

< Directed Diffusion >

Figure 9. Fuzzy inference system of FBPS

Figure 9 is a fuzzy inference system composed of the concepts mentioned thus far. This inference system has 9 if-then rules regarding the protoco1. It uses the min-max Composition of Mandani [16] model and CoA (Center of Area) method as a defuzzification method to get a result value.

4. Simulation

4.1. Setting the Simulation Environment

To evaluate the efficiency of the proposed algorithm our research team organized a simulation environment using the simulator DEVS Object C, developed by ourselves. The first energy of the sensor node was set as 1J, and the radio scope was from 40m for Directed Diffusion to 0-300m for TEEN. The BS was set (0, 0), and the sensor nodes were distributed randomly inside a square deployment area. Events occurred every 20 seconds in the area with the sensor nodes. The simulation was performed for 1000 seconds. Initially, 100 nodes were arranged in 10000 ㎡ (100m x 100m). Then 200 more sensor nodes were added, for 300 seconds. Finally, for the last 600 seconds, the arrangement area was extended to 90000 ㎡ (300m x 300m), and 200 additional nodes were added.

4.2. Results and Analysis of the Simulation

In this study the average energy consumption was established as a performance index in order to evaluate energy efficiency when using only a single routing protocol and using the FAR algorithm. The average energy consumption is a value calculated by dividing energy consumed by each sensor node comprising the sensor network with a unique event number received by the BS. In other words, the average energy consumption means the average energy value consumed by each node for transferring one event to the BS. Therefore, as this value becomes smaller, an event can be delivered to the BS with less energy.

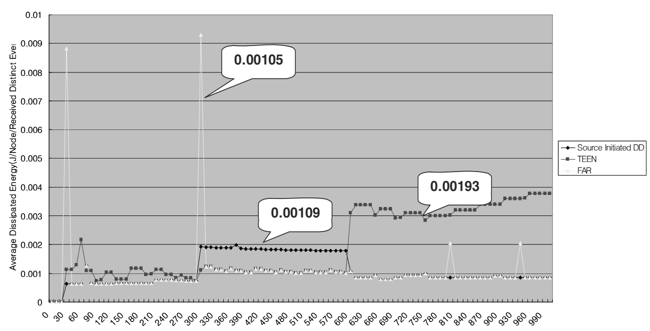

Figure 10. Comparison of average energy consumption of FAR algorithm

Figure 10 illustrates TEEN, Directed Diffusion, and the average energy consumption of a node in the sensor field when using the FAR algorithm, with changes in the number of nodes and the placement of the nodes. As for the FAR a1gohthm, when a task is initiated the directed diffusion protocol code is activated; in 300 seconds the code is switched to TEEN. After 600 seconds an active routing protocol is exchanged using directed diffusion again. Figure 10 indicates that when the FAR algorithm performs protocol diffusion considerable energy is consumed. On the other hand, switching a protocol takes relatively less energy than performing protocol distribution. This is because a message used for exchanging the protocol with the FAR algorithm is the 128 bit MD-5 hash code, which is very small. Figure 10 also shows the average energy consumption after the completion of the simulation is the smallest with the FAR algorithm. Although energy consumption is high when distributing protocol code using the FAR algorithm, this is infrequently done. Thus such energy consumption is not very influential. When it is necessary to switch protocols after protocol code distribution the small 128 bit

MD-5 hash code is used to highly reduce energy consumption. Hence, it was proven that energy consumption was lower when using the FAR algorithm rather than using only a single routing protocol.

5. Conclusion and Future work

In this study, the FAR a1gohthm was proposed as a way of improving the energy efficiency of a sensor node in a dynamic network environment. It was shown that proposed algorithm was more energy efficient than when a single routing protocol was used. Depending on the environment where a sensor node is placed, the proposed algorithm also includes a technique for dynamically placing a routing protocol on a sensor node so the algorithm may use more appropriate routing protocols. In this study only “Number of Nodes” and “Deployed Area” were considered as fuzzy input variables. In order to further improve energy efficiency additional input variables for a node failure rate and a packet size may also be added, as appropriate.

With the FAR algorithm, when the network environment changes then the FBPS reduces overhead due to exchange message transfer by se1ecting an energy efficient protoco1, and controlling the transfer of protoco1 code and switch messages. However, the energy efficiency may be lowered due to exchange protocol message traffic in an environment where there should be frequent protocol changes. In that case, an operator needs to determine whether or not to use the FAR algorithm, after considering the impact to energy efficiency. In addition, a sensor node needs to load diverse protocols in the FAR algorithm. The sensor node performance may vary, depending on use. For the proposed algorithm, the sensor node used needs to have better performance than a genera1 sensor node. In order to determine the suitability of the FAR algorithm to an actua1 situation the number of candidate routing protocols applicable and the price of a sensor node with sufficient memory to contain the protocols must be considered.

In conclusion, the energy efficiency of the FAR algorithm depends on selecting appropriate routing protocol candidates for an app1ication field and a given network environment. In order to enhance the va1ue of the FAR algorithm the features, advantages, and disadvantages of the routing protocols must be analyzed.

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