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Energy Efficient MANET based Emergency Communication Module for Post Disaster Recovery

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Abstract: **In recent years the world has experienced several catastrophic natural calamities such as earthquake and tsunami. When stricken by a catastrophic natural disaster, the efficiency of disaster response operation is very critical to life saving. Deployment of Mobile Ad Hoc Network (MANET) plays a very important role in post disaster situations where fixed network infrastructure is unavailable due to widespread destruction and devastation. It is important to configure a communication network that offers sufficient quality of service after a catastrophic disaster using an ad hoc network to help protect people. Routing is one of the key issues in MANET due to their highly dynamic and distributed nature. In particular, energy efficient routing is the most important design criteria for MANET since mobile nodes will be powered by batteries with limited capacity. In this paper evaluation of the energy efficiency of the MANET routing protocols in terms of their energy consumption and performance is carried out. This paper mainly focuses on the low power consumption of MANETs deployed in emergencies intimates the need for energy aware routing concept and performance comparison of AODV, DSR protocols with GAF algorithm in such scenario. The objective of this paper is to investigate the energy consumption and performance of routing protocols through simulations. The simulations are carried out using the Network Simulator 2(NS2) tool. The results obtained from the simulation provide both qualitative and quantitative analysis of the routing protocols for MANET used in emergency communication system.**

1. INTRODUCTION

A general mobile network consists of wireless access networks and interconnecting backbone networks. The mobile terminals are connected to the base stations (access points) by wireless access networks, and the base stations are connected to the wired backbone networks. There are drawbacks to these systems when large-scale disasters, such as earthquakes, occur: if the base stations or other elements of the infrastructure comprising these networks are damaged by disasters, communications may be impossible. Communication and sharing of information in emergencies are also possible via ad hoc networks, which take full advantage of the features of wireless communication including rapid and temporary setup and outstanding terminal portability and mobility.

An ad-hoc network is a collection of wireless mobile hosts forming a temporary network without the aid of any stand-alone infrastructure or centralized administration. MANETs are self- organizing and self-configuring multi hop wireless networks where, the structure of the network changes dynamically. This is mainly due to the mobility of the nodes. The node in the network not only acts as hosts but also as routers that route data to/from other nodes in network.

Routing in ad-networks has been a challenging task. The major reason for this is the constant change in network topology because of high degree of node mobility. In particular, energy efficient routing is the most important design criteria for MANETs since mobile nodes will be powered by batteries with limited capacity. Power failure of a mobile node not only affects the node itself but also its ability to forward packets on behalf of other nodes and thus the overall network lifetime. The power conservation monitoring in areas of emergency is vital. The victim in a catastrophic disaster struck area should be able to communicate even with a low battery power and also the power transmitted at the base stations should be monitored.

Many protocols are available in the literature such as Distance Vector Routing (AODV, DSDV, DSR). Distance Vector routing protocol has an option of using Table-driven or On-demand routing algorithm. Table-driven is proactive protocol as the route information is maintained even before it is needed. It periodically updates the routing tables by sending broadcasting signals to all the other nodes in the network. It maintains route information for each and every node in the network. In on-demand routing protocol, the route information needed are found on-demand by exchanging HELLO message with the neighboring nodes. The main drawback in such a protocol is that the power conservation is not monitored.

One more approach is geographic routing in which the location information of a particular node is used to route the packets. The location information can be obtained by various available localization schemes such GPS etc. This category of geographic routing comprises routing protocols such as GAF, GEAR etc. In this paper an attempt has been made in studying and analyzing one such protocol, GAF.

The rest of the paper is organized as follows: Section II gives an insight on the challenges in MANETS. Section III presents the performance evaluation of the routing protocols. Section IV gives the simulation results and analysis. Finally Section v gives the concluding remarks of the paper.

2. CHALLENGES AND SYSTEM ANALYSIS

Communication and sharing of information in emergencies are also possible via ad hoc networks, which take full advantage of the features of wireless communication

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including rapid and temporary setup and outstanding terminal portability and mobility

It is obvious that loss of communication and information systems may have a big impact on the disaster response to a catastrophic disaster.

1. In a catastrophic disaster, regular rescue teams including trained professional rescue squads, police, army, and fire fighters were far from sufficient for the disaster response operation.
2. Transportation system was paralyzed not only by broken bridges and roads, but also by a large number of disorganized voluntary vehicles.
3. Trained and skill-specific professional rescue squads were misplaced to wrong stricken zones.
4. Some injured victims died on the way being transferred from hospitals to hospitals after been rescued from under tons of rubbles. This is because the loss of cellular network inhibits the victim arrangement system (i.e. ambulance) to follow up rapid changing hospital capacity.
5. Streets were blocked by collapsed buildings so that the rescue workers were divided into isolated groups.

To many people's surprise, cellular networks that were thought highly dependable in an emergency were completely wiped out in many cases.

1. A few base stations were crashed.
2. The power lines and backhaul links that connected base stations to their controllers (BSC) or Mobile Switching Centers (MSCs) were broken almost everywhere, especially broken roads and bridges.
3. Power was out because of backup battery exhausted or fuel for power generator exhausted.
4. Critical hardware equipments were knocked down because of cooling towers fallen or cooling pipes broken by the quake.
5. Cell phone batteries ran out of power and couldn't be recharged because of power line failure or simply compatible chargers not available.
6. Communication systems were overwhelmed by extremely huge traffic.

Figure 1 Damage to Communication Backhauls due to Earthquake

Among the causes mentioned above, the most vulnerable one is not the physical structure of base stations, but rather the cables of power lines or backhaul links. When roads and bridges were broken everywhere in a disaster, cables were broken everywhere consequently as we can see from Fig.1, which are the photographs taken in one of the earthquakes.

MANET communication module can transmit information from a node to any other node within its radio range. If the destination node is not within the range of the source then an intermediate node acts as a router to route to the destination node and is termed as hop-by-hop. In the scenario of a catastrophic natural disaster struck area, all the centralized networks would crash and it is difficult for victims to communicate for finding safe zones. Deployment of MANET in such decentralized areas is of great help.

Other main factors that affect the functionality of MANETS are,

1. Routing Overhead: In wireless ad hoc networks, nodes often change their location within network. So, some stale routes are generated in the routing table which leads to unnecessary routing overhead.

2. Battery constraints: This is one of the limited resources that form a major constraint for the nodes in an ad hoc network. Devices used in these networks have restrictions on the power source in order to maintain portability, size and weight of the device. By increasing the power and processing ability makes the nodes bulky and less portable. So only MANET nodes has to optimally use this resource.

3. Time-varying wireless link characteristics: The wireless channel is susceptible to a variety of transmission impediments such as path loss, fading, interference and blockage. These factors resist the range, data rate, and the reliability of the wireless transmission.

4. Hidden and Exposed terminal problem: When a node is receiving the data if at the same time other node in its transmission range should send the data to that node, .which may result in packet loss.

Followings are a few options based on conventional technologies.

Walkie-Talkie

Perhaps the most convenient and reliable communication system for emergency is walkie-talkie. It doesn't rely on any infrastructure to operate and is very easy to use. Unfortunately, the popularity of walkie-talkie in many countries is far less than laptops, not to mention cell phones. Although regular rescue squads may already be equipped with similar equipments, most volunteers may not. In reality, it may take several days to collect and deliver a large number of walkie-talkie units to the stricken zones (probably by airdrop or helicopter).

Mobile Base Stations for Cellular Networks

Cellular operators usually have some mobile base stations that use satellite links as backhauls and can be deployed to a demanded zone in a few hours. However, there are several problems. First, cellular operators may not have sufficient number of such equipments for a large scale

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disaster. Secondly, mobile base station is too heavy to drop from air and have to rely on a good transportation system to deliver to the stricken zones. The help is limited.

Specialized Emergency Mobile Communication Systems

Various equipment vendors are offering special emergency mobile communication systems. Specially designed systems are expensive and can offer only a limited number of handsets under limited funding. It is prohibitively expensive to deploy sufficient capacity for a large scale disaster. Thus, the capacity of current specially-designed emergency communication systems may be able to support only a few regular rescue squads, but may be far from sufficient for a large number of volunteers. Similarly, it relies on a good transportation system to deliver to the stricken zones. Finally, the equipments made by different vendors may fail to interoperate, or even interfere, with each other.

Cellular Phone Feature Extension

Perhaps cell phone has become the most popular personal “sticky” electronic devices. A cell phone user is very likely to have his/her own cell phone in hand when a disaster strikes. If most cell phones are embedded with a walkie-talkie functionality, the demand for the emergency communication can be approximately fulfilled. A major concern is that cellular operators may not like this idea due to the concern of revenue damage. Therefore, an alternative idea is to embed walkie-talkie functionality into laptops, Apple’s iPAD, or anything similar.

Existing cellular triangulation systems are doom to fail if cellular networks are paralyzed. It will be beneficial to embed into cell phone a SOS feature that can emit wireless SOS signals on both cell phone band and WiFi band. A trapped victim can then be easily located using a corresponding triangulation system. A large number of cell phones can also be activated for emergency communication if the following option is implemented.

Due to the disadvantage of these systems deployment of MANET which is self configuring, self organizing and cost effective is preferred.

4. PERFORMANCE EVALUATION OF ROUTING PROTOCOLS

Routing protocol in MANET can be classified into several ways depending upon their network structure, communication model, routing strategy, and state information and so on but most of these are done depending on routing strategy and network structure. Based on the routing strategy the routing protocols can be classified into two parts:

1. Table driven,
2. Source Initiated (on demand).

Figure 2 describes the general classification of routing protocols based on routing strategy.

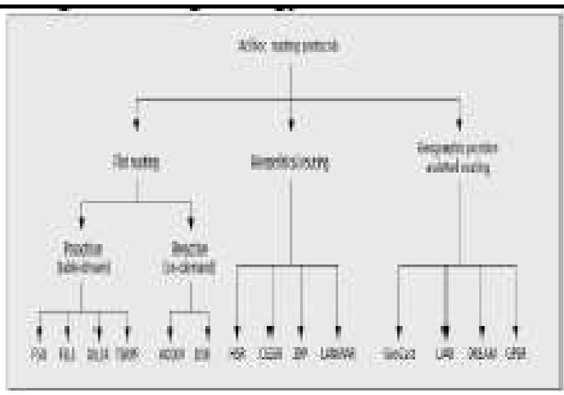

Figure 2 Classification of Adhoc Routing Protocol

A. Adhoc On-Demand Distance Vector (AODV)

AODV (Adhoc On Demand Distance Vector Routing) routing classified as a pure on demand routing protocol system, when a node want to send a message to another destination node and does not have a valid route to that destination its initiates a path discovery process to find the destination node. The source node broadcast a route request (RREQ) packet to its neighbors, and these neighbors forward the request to their neighbors, and so on until reach to destination node or reach intermediate node have a information about the route to destination node.

The AODV routing protocol is a reactive routing protocol; therefore, routes are determined only when needed. Figure 3 shows the message exchanges of the AODV protocol.

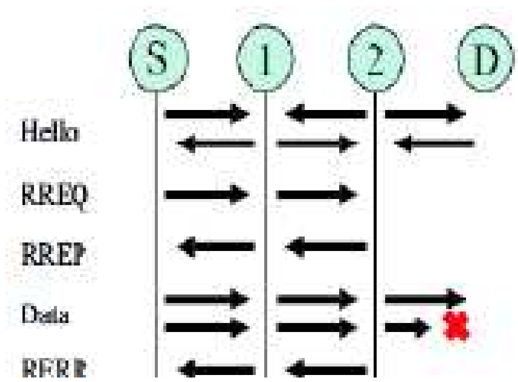

Figure 3 Working of AODV Protocol

Each node records its own sequence number known as a broadcast ID, The broadcast ID is incremented for every RREQ the node initiates, and record also the nodes IP address , a RREQ with its own sequence number and the broadcast ID, the source node includes in the RREQ the most recent sequence number it has for the destination, Intermediate nodes can reply to the RREQ only if they have a route to the destination if the destination sequence number is greater than or equal to that contained in the RREQ . During forwarding process the intermediate node records the address of the

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neighbors, from which node first copy of RREQ is broadcasted, is received, if additional copy is received from same RREQ, these packets are discarded to avoid looping problem. When the RREQ reached the destination node or intermediate node with recent route to destination, the destination or intermediate node responds by unicasting a route replay (RREP) packet back to the neighbours that received the first RREQ. Routes are established on demand and destination.

Sequence numbers are used to find the latest route to destination. If data is owing and a link break is detected, a Route Error (RERR) is sent to the source of the data in a hop-by hop fashion. As the RERR propagates towards the source, each intermediate node invalidates routes to any unreachable destinations. When the source of the data receives the RERR, it invalidates the route and reinitiates route discovery if necessary.

B. Dynamic Source Routing (DSR)

Dynamic Source Routing, DSR, is a reactive routing protocol that uses source routing to send packets. It uses source routing which means that the source must know the complete hop sequence to the destination.

Each node maintains a route cache, where all routes it knows are stored. The route discovery process is initiated only if the desired route cannot be found in the route cache. To limit the number of route requests propagated, a node processes the route request message only if it has not already received the message and its address is not present in the route record of the message.

As mentioned before, DSR uses source routing, i.e. the source determines the complete sequence of hops that each packet should traverse. This requires that the sequence of hops is included in each packet's header. A negative consequence of this is the routing overhead every packet has to carry. However, one big advantage is that intermediate nodes can learn routes from the source routes in the packets they receive. Since finding a route is generally a costly operation in terms of time, bandwidth and energy, this is a strong argument for using source routing. Another advantage of source routing is that it avoids the need for up-to-date routing information in the intermediate nodes through which the packets are forwarded since all necessary routing information is included in the packets. Finally, it avoids routing loops easily because the complete route is determined by a single node instead of making the decision hop-by-hop.

The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance", which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR to scale automatically to only what is needed to react to changes in the routes currently in use.

C. Geographic Adaptive Fidelity (GAF)

Geographic Adaptive Fidelity or GAF is an energy aware location-based routing algorithm designed primarily for mobile ad hoc networks, but is used in sensor networks as well. This protocol aims at optimizing the performance of wireless sensor networks by identifying equivalent nodes with respect to forwarding packets. In GAF protocol, each node uses location information based on GPS to associate itself with a "*virtual grid*" so that the entire area is divided into several square grids, and the node with the highest residual energy within each grid becomes the master of the grid. Two nodes are considered to be equivalent when they maintain the same set of neighbor nodes and so they can belong to the same communication routes. Source and destination in the application are excluded from this characterization.

Nodes use their GPS-indicated location to associate itself with a point in the virtual grid. Inside each zone, nodes collaborate with each other to play different roles. For example, nodes will elect one sensor node to stay awake for a certain period of time and then they go to sleep. This node is responsible for monitoring and reporting data to the sink on behalf of the nodes in the zone and is known as the master node. Other nodes in the same grid can be regarded as redundant with respect to forwarding packets, and thus they can be safely put to sleep without sacrificing the "*routing fidelity*" (or routing efficiency).

The slave nodes switch between off and listening with the guarantee that one master node in each gridwill stay awake to route packets. For example, nodes 2, 3 and 4 in the virtual grid B in Figure 4 are equivalent in the sense that one of them can forward packets between nodes 1 and 5 while the other two can sleep to conserve energy. Hence, GAF conserves
energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid.

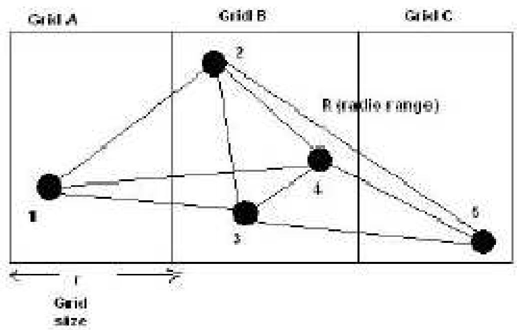

Figure 4 Virtual Grid Structure in the GAF Protocol

The grid size r can be easily deduced from the relationship between r and the radio range R which is given by the formula:

$$r \leq R/\sqrt{5}$$

There are three states defined in GAF as shown in Figure 5. These states are discovery, for determining the neighbors in the grid, active reflecting participation in routing and sleep when the radio is turned off. In order to handle the mobility, each node in the grid estimates it's leaving time of grid and sends this to its neighbors. The sleeping neighbors adjust their sleeping time accordingly in order to keep the routing fidelity. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active. The state transitions in GAF are depicted in Figure 5.

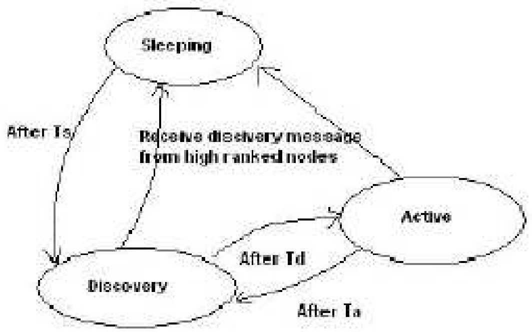

Figure7. State Transition in GAF

Master election rule in GAF is as follows. Initially, a node is in the discovery state and exchanges discovery messages including grid IDs to find other nodes within the same grid. A node becomes a master if it does not hear any other discovery message for a predefined duration *Td*. If more than one node is in the discovery state, one with the longest expected lifetime becomes a master. The master node remains active to handle routing for *Ta*. After *Ta*, the node changes its state to discovery to give an opportunity to other nodes within the same grid to become a master. In scenarios with high mobility, sleeping nodes should wake up earlier to take over the role of a master node, where the sleeping time *Ts* is calculated based on the estimated time the nodes stays within the grid. Which node will sleep for how long is application dependent and the related parameters are tuned accordingly during the routing process.

GAF strives to keep the network connected by keeping a representative node always in active mode for each region on its virtual grid. Simulation results show that GAF performs at least as well as a normal ad hoc routing protocol in terms of latency and packet loss and increases the lifetime of the network by saving energy.

5. SIMULATION RESULTS AND ANALYSIS

In order to evaluate the performance of these three protocols simulation is done in Network Simulator 2.34 and results are analyzed in nam and xgraph.

A. NAM Outputs

35 nodes are considered as the victims in the disaster struck area, they are allowed to freely move around the area. Also 2 access points, 3 rescue choppers and 7 rescue brigades are considered. The rescue teams are constantly moving around and helping the victims to move to the safe area. The trace file and NAM file results provided by the ns2 gives enormous amount of information about the victims. It specifies position of the node, number of nodes within the network of access point and also visualizes in detail about the packet transmission amongst the victims, rescue team, access points, and base station is simulated.

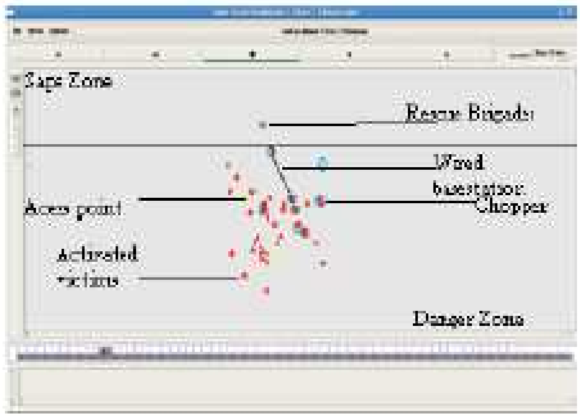

Figure 6. NAM Simulation of Wireless Disaster Scenario

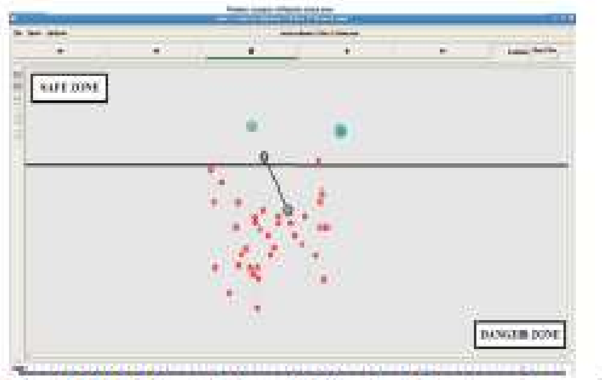

Figure 9. NAM Simulation of Wireless Disaster Scenario

Figure 6 shows the disaster area. It shows the connection between the nearest base stations and temporary base station created near the disaster struck area, airdropped access points, rescue choppers and rescue brigades.

The figure 7 shows nodes represent the disaster struck area. They are randomly moving around. The nodes identified as the rescue team brigades moving around for victim's service. The yellow nodes represent the access points which cover the area under investigation. The deep sky blue nodes represent the rescue team choppers. continuously exchanged and the tracking of the victim is undertaken. The ns simulation also provides x graphs which provides the information regardin g residual energy of the nodes.

B. Simulation Results in X-Graph

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After the simulation for 50 nodes performed in NS-2, NAM file and trace files are generated wherein nam file represents the animated result of our scenario and trace files contains the information regarding the residual energy, throughput, packet size, source, destination nodes etc. Xgraph is X-window application used to plot the different parameters.

Trace files for AODV, DSR with GAF algorithm and unmodified AODV, DSR are analyzed and plot of residual energy v/s simulation time is plotted.

Figure 8 represents the plot of residual energy at a victim node at different simulation intervals for AODV-GAF represented by red color, DSR-GAF represented by green color, DSR represented by blue color and AODV represented by yellow color.

Figure 9 represents plot of residual energies of all the nodes at the end of simulation. Different xgraph analysis concludes that AODV and DSR protocols with GAF algorithm proves to be comparatively energy efficient than AODV and DSR.

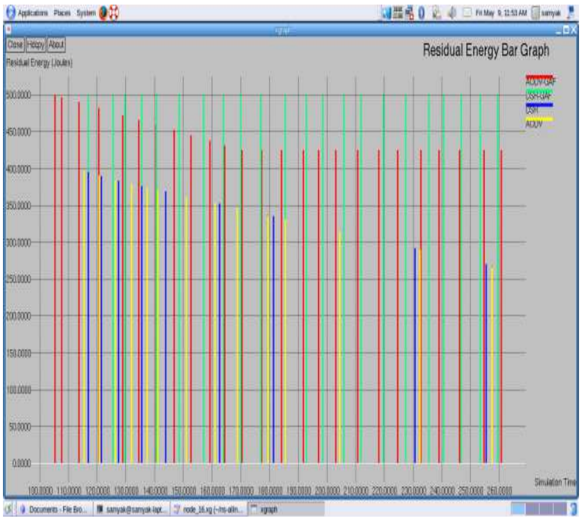

Figure 8 Xgraph Plot of Residual Energy of a Victim Node

Figure 9 Plot of Residual Energies of all Nodes at the End of Simulation

6. CONCLUSION

In this work, identification of some of the important design issues of routing protocols for MANETs is done. Also comparisons on routing protocols were made. As the study reveals, it is not possible to design a routing algorithm which will have good performance under all scenarios and for all applications. Although many routing protocols have been proposed for MANET, many issues still remain to be addressed. A detailed study on energy consumption of ad hoc routing protocols (AODV, DSR) with and without GAF algorithm were carried out with a simple traffic model in which a few nodes send data over a multi-hop path. With this energy model we found that on-demand protocols such as AODV and DSR with GAF algorithm consume lesser energy than basic AODV and DSR. This makes sense since *a* priori protocols are constantly expending energy pre-computing routes, even though there is no traffic passing on these routes. When stricken by a natural disaster, survivals and volunteers can use their own notebook PCs, laptops and other mobile devices to construct a MANET to support information network as well as emergency communication systems. Compared with other options, no extra hardware cost is needed.

In this paper, proposal for a energy efficient emergency communication module to manage disasters further investigation on performance analysis of this scheme in different network scenarios can be taken as extended network. We have investigated post-disaster communication from the viewpoint of time elapsed and classified communication based on purpose, sources and destinations, and contents of communications for each transmitter and receiver. The results gained from simulations show that performance of AODV and DSR with GAF algorithm is better than unmodified AODV and DSR in residual energy plots.

Finally, experimentation is needed to validate these results with physical hardware in actual scenarios. Therefore, more research is needed to combine and integrate some of the protocols presented in this work to keep MANET functioning for a longer duration.

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