Implementation of the AODV Routing Protocol for Message Notification in a Wireless Sensor Microgrid

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Abstract. This paper analyzes the behavior of the AODV routing protocol applied in a telecommunication network that transmits information for the management of the energy resources of an electric microgrid. Each node represents a sensor that captures primary data on voltage, current, phase, and frequency to be sent to a central node; in the opposite direction it receives instructions to activate or deactivate loads or sources. The implementation was performed with Raspberry Pi3 devices, encoding the routing protocol in Python 2.7. The network tests involve two topologies (trees and mesh). Through the tests, service quality metrics such as delay, throughput, and PDR were compared.

Keywords: AODV · Microgrid · Raspberry Pi3 · Python · Delay Throughput · PDR

1 Introduction

Wireless networks are currently used in a variety of applications, and this technology is spreading rapidly. However, most depend on infrastructures such as access points and routers; this makes communication in dynamic topologies difficult. As a result, ad-hoc networks have emerged, that is, decentralized networks that allow better communication even when there is mobility at the nodes; they provide flexibility and autonomy as there is no need for central management.

With the emergence of these networks, there is a need to implement routing protocols that can easily adapt to changes that may occur. The choice of these routing protocol to be implemented on communication networks on microgrids is fundamental, as it is necessary to satisfy the network system requirements for Neighborhood Area Networks (NAN) applications on microgrids, such as low

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latency and high reliability. The distribution of information in these networks depends principally on node quantity and the network topology, by which it is necessary to analyze the most appropriate routing protocol that ensures compliance of communication requirements for smart grids and microgrids. To achieve this goal there are two types of routing protocols, on the one hand, proactive protocols are proposed; each node maintains routes to the other nodes available on the network, and the creation and maintenance of these routes is carried out through periodic updates. On the other hand, there are reactive protocols, which calculate the routes as they are needed and in their tables store only information on the active communications.

This paper shows the analysis of the time delay and the throughput obtained in the implementation of the reactive AODV protocol in two communication network topologies such as tree and mesh topologies, in order to analyze the performance of the data routing protocol applied to the operating conditions in an isolated rural microgrid. These results are compared with the latency parameters acceptable to data transfer in a microgrid and with the values obtained when simulating the routing protocol with the NS2 tool.

To this end, the paper is divided into six sections distributed as described below: Sect. 2 shows the characteristics of isolated rural microgrids and their operating parameters as a function of the time of data collection for their control. Section 3 details the operation of the reactive protocol to be analyzed. Section 4 presents the parameters and configurations of the implementation. Section 5 presents an analysis of the results obtained. Finally, Sect. 6 presents the conclusions of the study.

2 Rural Microgrids

An electric microgrid is a system composed of loads and generators that works independently of the electrical distribution network, created in order to supply energy to a certain local area.

The main elements of microgrids are loads, distributed generators, and storage devices or controllable loads that allow them to operate in a coordinated manner [1]. The objective is to save energy, to minimize costs, and to increase reliability through the use of digital technology and the integration of renewable sources [2].

Due to the high economic and technical costs of traditional electricity networks in the electrification of hard-to-reach areas, rural microgrids are emerging [3]. These are a good alternative when what is required is greater reliability and quality of energy, also allowing these small communities to control energy use [4].

2.1 Operation Parameters in Rural Microgrids

Factors such as the quality, size, characteristics of the electrical distribution, number of generating sources, and power demand define the technical principles and architecture of a microgrid. To define the type of current to be operated by the system (direct or alternating), the technology used and the energy management strategy must be considered; for example, while batteries and photovoltaic generation provide direct current (DC), others such as generators and hydroelectric power stations provide alternating current (AC). There are also hybrid microgrids, in which a bidirectional inverter is installed to control the power supply between the alternating current bars and the battery [5].

The routing protocols to be implemented in this type of wireless network must coincide with the latency requirements according to the application to be used in the microgrid. Table 1 shows the applications and their latency.

Table 1. Latency requirements in the operation of a communication network on a microgrid (Source: [6])

Application	Latency
AMI (Advanced Meter Infrastructure)	2–15 s
Demand response	500 ms–few minutes
Knowledge of behavior on wide area	20–200 ms
Storage and distributed energy resources	20 ms–15 s
Power transmission	2 s–5 min
Distributed management	100 ms–2 s

3 Reactive Wireless Routing Protocols

There are currently numerous routing protocols for wireless networks [7]. Depending on the topology, the scenario in which that topology is proposed, and the information to be transmitted, the appropriate protocol to be implemented is chosen.

The grid proposed in this paper, a microgrid capable of obtaining information on the power generated, the state of the batteries, and the consumption of the loads were analyzed in order to notify a coordinating node for the subsequent management of the energy resources of that grid, a reactive protocol is chosen to be used considering that there is data transfering on real time, it is necessary the calculation of routes on demand, that is, the route establishing will only be accomplished with a request sent from a sensor node.

With the use of this type of protocol, network resources are optimized, avoiding the sending of unnecessary packets [8]. This kind of scenario has been simulated previously, however as of today, it has not been implemented on a real-case rural microgrid. The AODV reactive protocol implemented for the communication of the nodes of this microgrid is described below.

3.1 AODV Routing Protocol

AODV is one of the most commonly used protocols in mobile ad-hoc networks. It is reactive, works on demand, and generates only a routing table when it is necessary to transmit a message to a particular destination. Therefore, it reduces control messages and regulates the energy consumption of the devices that use the protocol; the routing table is stored on each node to reduce the use of bandwidth [9] (Table 2).

The fields stored on the routing tables are described below [10].

Table 2. Routing table (Source: own elaboration)

Destination IP address	It is the IP address of the node to which information will be sent
Next hop	This entry identifies the next node necessary to reach the destination node
Destination sequence number	It refers to the sequence number of the destination node, obtained from the control information
Hop count	It represents the number of hops required to arrive from the source node to the destination node
Status	It identifies whether the route is active or inactive, by determining whether a new route can be used or should be discovered
Lifetime	Through this attribute, routes are discarded and deleted from the table once their useful life has expired, in order to avoid network overloads

This algorithm has two main phases: route discovery and route maintenance. Both phases are represented globally in Figs. 1 and 2 respectively.

3.1.1 Route Discovery

This phase occurs when a node needs to send a message to a destination node and does not have any valid route in its routing table. Then it broadcasts a route request packet (RREQ) to the destination node via broadcast; the neighbors of the originator node will receive this RREQ message. If there is no route to the destination, the number of hops must be increased and this packet must be also broadcasted. At the same time, they must store a route to the node that caused the request on their routing table, taking into account the information they receive in the packet. If it does have a route to the destination, it generates a route response packet (RREP) [11]. Table 3 shows the structure of the RREQ message.

In order to avoid repeated information, each RREQ will be identified with an unique number (which increases each time a node issues a new packet) and with

Table 3. RREQ message format (Source: own elaboration)

Message type
Sender
Originator IP address
Originator sequence number
Unique identifier
Destination IP address
Destination sequence number
Hop count

the sequence number of the originator of the request. Thus, when an intermediate node processes this packet, it will discard it if it notices that it has already analyzed the same request from the same sender [12].

If an RREQ packet arrives at the destination node, it must create or update the route as appropriate and diffuse an RREP via unicast. When an intermediate node receives this RREP, it also diffuses the packet via unicast, considering the reverse routes stored on the routing tables through which the RREQ was transmitted. Table 4 shows the structure of the RREP message.

The protocol uses two sequence numbers: the sequence number of the source keeps information updated for the route contrary to the source, and the sequence number of the destination helps determine whether the route submitted can be accepted by the source or whether a more recent route exists [13].

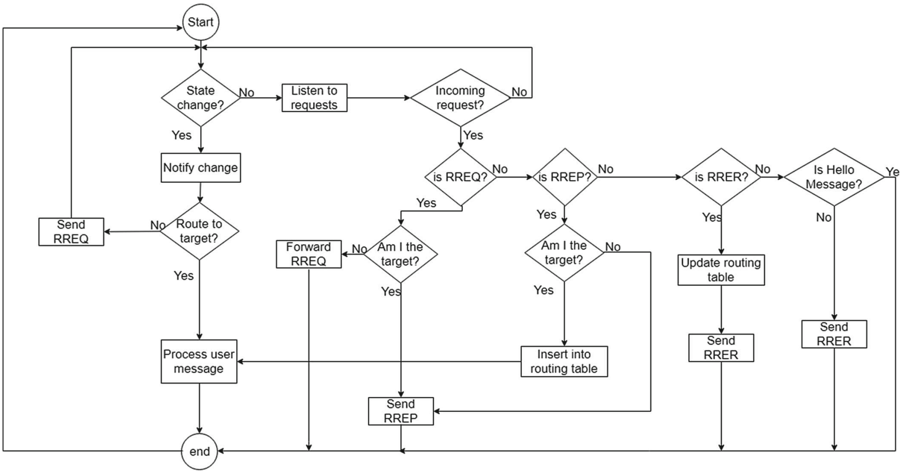

Fig. 1. Flowchart: route discovery (Source: own elaboration)

Table 4. RREP message format (Source: own elaboration)

Message type
Sender
Originator IP address
Hop count
Destination IP address
Destination sequence number

3.1.2 Route Maintenance

In this phase periodic messages called hello messages are used. These are transmitted to the neighboring nodes in order to notify that a node is still present in the network. When after a while a "hello" is not received from a neighbor, a route error packet (RERR) is generated to the source node: the RERR contains the IP address of the node that has become inaccessible. Each intermediate node that processes the RERR will update the routes used by the node that is now inaccessible and continue to propagate the packet until the broken link notification has been communicated to all nodes in the network [14,15]. Table 5 shows the structure of the RRER message.

Table 5. RRER message format (Source: own elaboration)

Message type
Sender
Destination IP Address
Destination sequence number
Extra destination IP address
Extra destination IP sequence number

If a node needs to send a message even after receiving a broken link or RERR notification, it can initiate a route discovery [16].

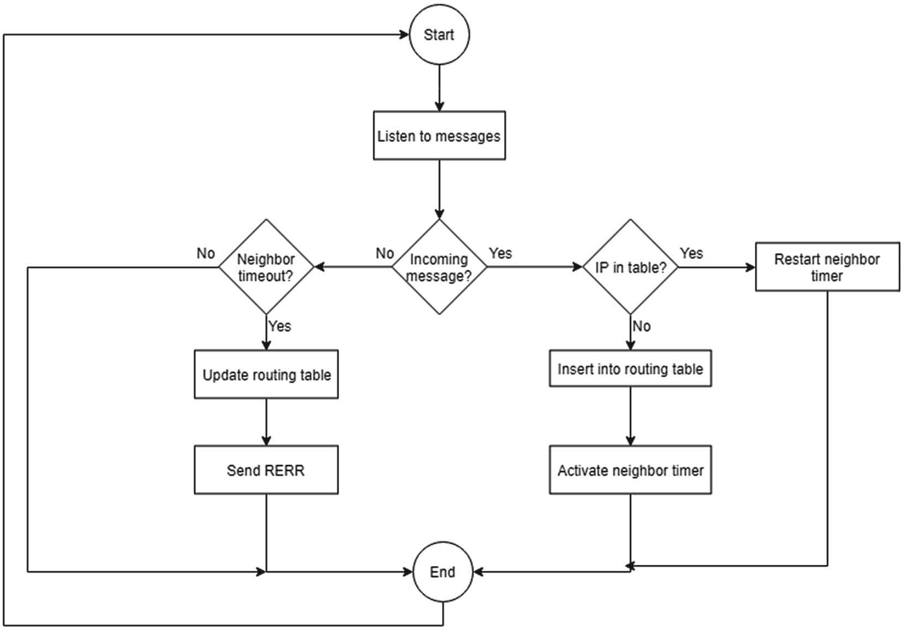

Fig. 2. Flowchart: route maintenance (Source: own elaboration)

4 Methodology

The network topologies used correspond to the configuration of an isolated microgrid, where a sensor node needs to communicate a change of state in its energy source to the others, so that each one can store this information and make decisions that affect the supply from the microgrid. Figure 3 shows the tree topology and Fig. 4 shows the mesh topology. In both topologies, nodes are tagged with the last byte of their static address corresponding to the network address 192.168.0.0. Both scenarios include static nodes with static IP addresses, that is, the topology is not modified unless a node is shut down or external conditions prevent connection to it; in either case, inactive routes will only change state (RRER) but will not be deleted. For this purpose, a SQLite database was used; it stores the routing tables in order to maintain the routes to the different nodes.

Additionally, the separation of the nodes is six meters, configured at low power, in order to facilitate the implementation and obtaining of results in open field.

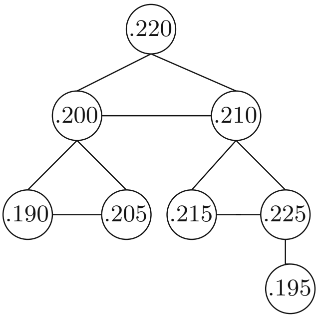

Fig. 3. Tree topology (Source: own elaboration)

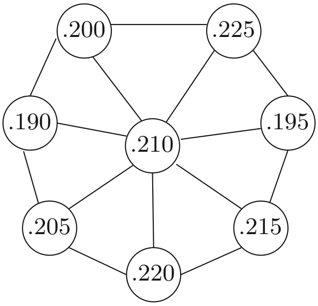

Fig. 4. Mesh topology (Source: own elaboration)

The sending of messages is performed by a single originator (.220) that constantly plays a fixed size message of 100 bytes every 30 s. This message represents a change of state at the originator node.

The algorithm is implemented and run on Raspberry Pi3 B devices, with Wi-Fi transmitters in ad-hoc mode and their power (Txpower) at 3 dBm to limit the range of coverage. For the operation of the program, different modules were developed, coded in Python 2.7.13 only. These are the modules:

- Neighbors and network node discovery script: *find_neighbors.py*, which lists the IP addresses of all the nodes found on the network through flooding (see Fig. 5).
- AODV Protocol script: *aodv_protocol.py*. It comprises the routines and subroutines for sending, receiving, and processing request messages (see Fig. 6).
- Main script: *main.py*. It is the one in charge of instantiating and integrating the functionalities of the two modules described above.

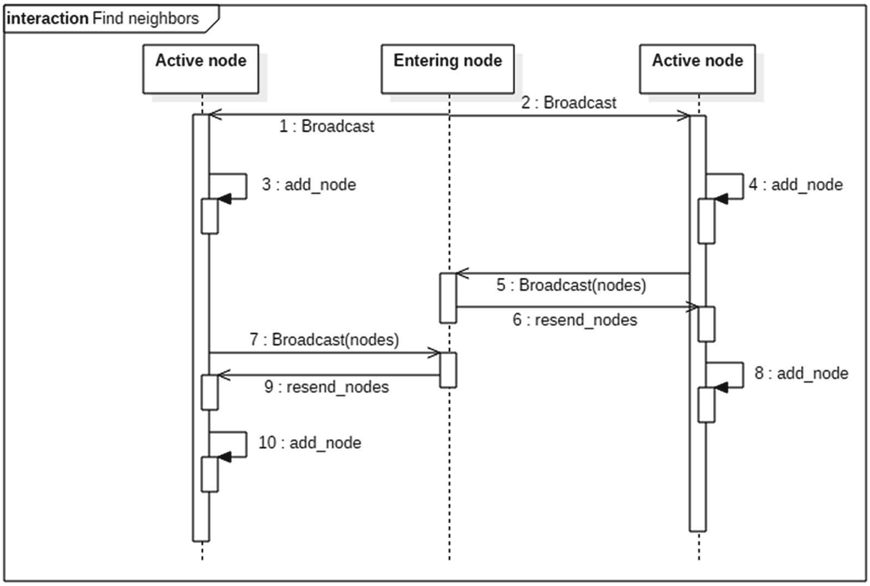

Fig. 5. Sequence diagram: find_neighbors.py (Source: own elaboration)

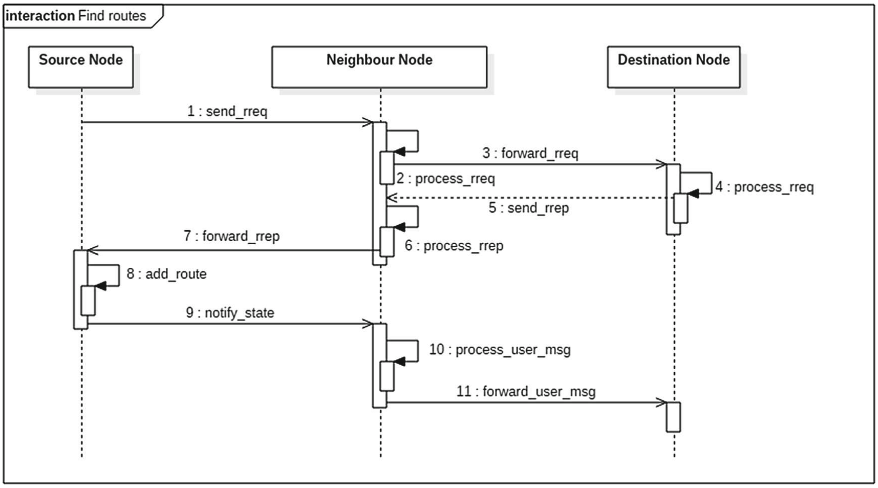

Fig. 6. Sequence diagram: aodv_protocol.py (route finding) (Source: own elaboration)

5 Results

This section presents a comparison between the results of simulations in the NS-2 tool and the implementations performed with the Raspberries Pi3 B devices.

Throughput, Packet Delivery Ratio (PDR), and latency metrics were considered to determine how the algorithm works in the different scenarios proposed.

The measurement of network reliability is performed through the Packet Delivery Ratio (PDR); this metric is defined as the percentage relation between the packets successfully received and the total number of packets transmitted. Network testing begins with PDR measurement. A set of five tests is performed on each topology, allowing the originator device to notify its status to the seven different nodes, for a total of 175 messages transmitted. It should be noted that for this measurement the sending of request messages (RREQ, RREP, RERR) was not taken into account.

Figure 7 shows the behavior of the PDR in the proposed topologies. As can be seen, in both simulation and real life, the tree topology has a higher percentage of successful packet delivery. It is also evident that in real life a lower percentage is obtained than in the simulation for the two topologies.

Additionally, it is evident that reliability requirement described by Saputro, Akkaya and Uludag in [6] is met, where it's specified that PDR for AOVD must be higher than 91.4%.

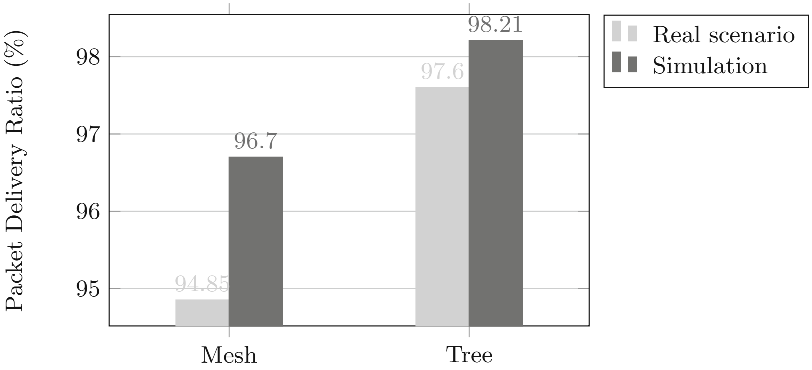

Fig. 7. Average Packet Delivery Ratio (PDR) (Source: own elaboration)

Figure 8 shows that the channel occupancy is higher in the mesh topology; this is because the central node, being directly related to seven nodes (see Fig. 4), receives, processes, and distributes more information than any intermediate node in tree topology.

Figure 9 shows that the mesh topology has lower latency than the tree topology, both in the simulation and in the tests performed on Raspberry devices, that is, less time in the transmission of messages from the originator node to the other sensor nodes. Given the latency requirements for the operation of a communication network over a microgrid described in Table 1, both topologies are in the range of applications: knowledge of wide area behavior, distributed energy resources, and distributed storage and management. In contrast, for

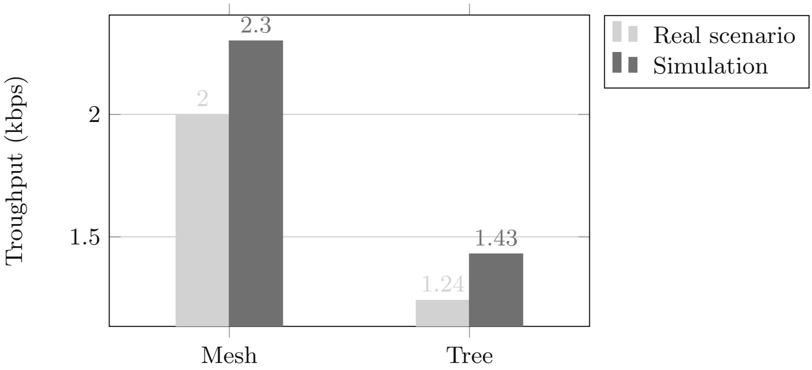

Fig. 8. Average throughput per topology (Source: own elaboration)

"AMI applications, demand response and power transmission" the topologies are in a lower range than those described.

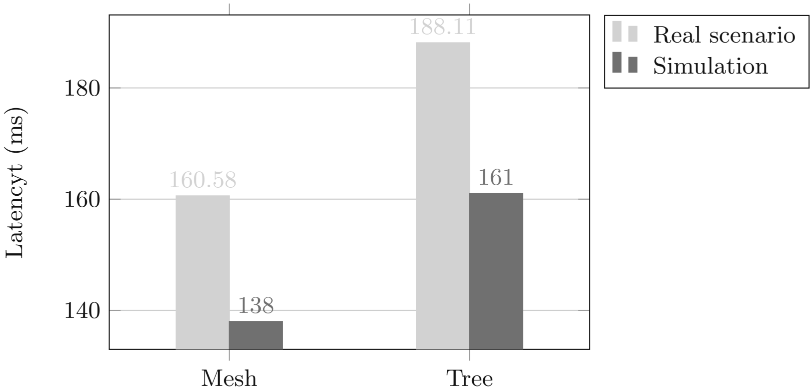

Fig. 9. Average latency per topology (Source: own elaboration)

6 Conclusions

In addition to the protocol script, it was implemented a module that let nodes know every single node within the network by broadcasting messages (flooding), in order to obtain a list with destination nodes for which a route must be found and send a message using AODV protocol. This module was proven and used together with the protocol to carry out the tests and obtain the results described below.

The AODV routing protocol presents stable latency (see Fig. 9), PDR (see Fig. 7) and throughput (see Fig. 8) metrics for both the mesh and tree topology.

Taking into account the parameters established by Saputro and Akkaya [6] for the operation of a communication network over a microgrid, it can be stated that the implementation of this protocol is appropriate for routing the data, since the objective of the microgrid is fully achieved within the established ranges.

According to Figs. 7, 8 and 9 the difference of the values obtained in the tests and simulations is not significant, so the results are coherent and equivalent. Therefore, the algorithm implemented in the tests meets its objective.

The mesh topology presents lower latency and lower PDR (94.85%) in comparison to the tree topology. For this case study, the mesh topology is chosen, since the percentage of delivered packets is above 94% and the transmission of messages is faster. In this way, the devices of the microgrid will be able to notify the changes of state that occur at the energy level in time and in an effective way. It is important to clarify that the difference between these topologies is not significant for this case, since there are few nodes and the difference in number of hops from the originator node to the other sensor nodes is minimal.

Although the tests presented represent a microgrid of eight nodes, it is expected that both the throughput in the network and the latency will increase by increasing the number of sensor nodes in the isolated microgrid. As for the PDR, the increase in the number of nodes will also increase the traffic on the network, so the number of rejected packets will be higher, thereby decreasing the PDR.

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