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AODV routing protocol performance assessment for wireless sensor network scenarios

Luay Abdulwahid Shihab, Manhalmohammed Basher

Nursing college - Basrah University - basrah – Iraq
Agricultural technical college , Northern technical university

Abstract
Emerging WSN applications include a wide selection of traditional situations with many nodes. The messages are propagated through intermediate nodes, in order to ensure correct contact between the network nodes with the base station, so that a path has many connexions. Generally speaking, the nodes on the sensor network are distinguished by their minimal resources, so protocols must be used that not only guarantee connectivity but also conserve the most energy while maintaining scalability. Different protocols for routing wireless sensor networks have been suggested, however, reactive routing algorithms have been shown to be energy efficient and adaptable to wireless sensor networks. In this paper, under the OMNeT + + simulation platform, the performance of the reactive protocol will be tested, evaluating different scripts. In contrast to the supplementary responsive protocols stated in literature, the AODV protocol has been selected for supremacy in performance. The following parameters have been evaluated: the transmission rate of packets, average delays, overhead routing and energy usage. The findings show that AODV decreases its efficiency with the growth in the number of nodes. As a result, its usability limits the network scalability and the outcomes demonstration that the spatial distribution of nodes affects protocol performance. The standardised delivery shows the best outcomes for our particular works.

Key Words: *WSNs, AODV protocol, IEEE802.15.4, Zig Bee, Energy consumption, Packet delivery rate*

1. Introduction

The Wireless Sensor Network (WSN) is a wireless communication technology that uses low-power network devices[1]. These network devices, also called sensor nodes, transmit data collected by sensors, allowing to sense the environment in which this equipment is inserted, with little or no physical impact in that environment. WSNs are systems made up of a set of sensor nodes that communicate with each other to cooperatively monitor physical signals[2]. In general, the nodes of a sensor network are characterized by the limitation in power, memory and processing resources, consequently, the use of protocols that guarantee communication between the nodes of the network, optimize performance and save the most energy while providing scalability.[3]

Wireless sensor networks performance is closely linked to that of the protocol routing, because routes can change dynamically over time. The energy restraint imposed by these networks nodes is not taken into account in the traditional approaches so that they consume a substantial amount of energy by intensive messagerial exchange. In the literature[4], different routing protocols were proposed for wireless sensor networks[5]. A great range of features such as the routing method, routing techniques and protocol operation can be classifying the routing protocols. According to the route establishment process, three types of protocols are available[6]: 1) Proactive style protocols, which create routes until there is a real traffic requirement, are ideal for real-time traffic, because they have low latency, however, they waste bandwidth due to intermittent changes and are not energy efficient; 2) Reactive protocols, which configure routes on demand, turn out to be good for low-traffic networks, saving power and bandwidth during times of inactivity, making them ideal for wireless sensor networks, however, the node source experiences a significant delay until being able to send data packets, due to route discovery latency; 3) hybrid protocols, which combine the best of both approaches. We have DSR, AODV and DYMO between reactive routing protocols for wireless sensor networks. In general, some authors accepted that AODV worked better than DSR and DYDO in high mobility, increase network density and lower traffic. The efficiency of this protocol depends on the scenario. This article aims to evaluate the performance of the IEEE802.15.4 standard under the AODV reactive routing protocol for different scenarios using the OMNET ++ simulation platform. All wireless networks, such as cellular telephone networks and wireless local area networks, or WLANs, rely on broadcasting stations that transmit signals. These stations, which include large cellular antenna towers as well routers, transmit signals at particular radio frequencies[39]. A network has a certain carrying capacity, denoted by the maximum number of packets that it can hold at any point in time[40].

2. Theoretical Framework Zigbee/Ieee 802.15.4

IEEE 802.15.4 protocol: The IEEE 802.15.4 protocol was ratified by the Institute of Electrical and Electronics Engineers (IEEE)[7] as a standard for low speed and low power consumption networks, and for this reason it is used in WSN. IEEE 802.15.4 networks operate in the 2.4 Ghz frequency range - from 2400 to 2483.5 Mhz, and with a transmission rate of 250 kbps. Other frequency ranges are allowed by the protocol, with variation in the number of communication channels and transmission speed[8]. The IEEE 802.15.4 protocol implements physical layers and Medium Access Control (MAC), leaving the network and upper layers free for implementation according to use. The physical layer is responsible for the interconnection of the protocol with the communication radio and provides services for the immediately upper layer, which controls access to the network, the MAC layer[9]. The IEEE 802.15.4 protocol operates with two types of physical devices[10]: the Full Function Device (FFD), which is responsible for routing the network, with an FFD node being used as the network coordinator, controlling the topology and addressing of the nodes and also as a router, forwarding messages; and the Reduced Function Device (RFD), which is a low-cost device, does not route and can only connect to one FFD node at a time. Routing allows a node to forward a message from an RFD or FFD node to other FFD nodes to the coordinating node and normally both the routing FFD nodes and the coordinating FFD nodes need a constant power source, as they need to be active at all times for message transmission, unlike RFD nodes that are normally powered by batteries and need to save as much energy as possible. As IEEE 802.15.4 defines only these two layers, it allows other protocols to use it as a basis for the implementation of higher layers, as is the case of the ZigBee protocol as follows.

How ZigBee works: The ZigBee protocol was defined by the ZigBee Alliance in 2006 and uses IEEE 802.15.4's physical and MAC layers[11], incorporating network and device layers in addition to 128-bit AES encryption, and can address up to 65535 nodes per subnet. An example of this type of topology can be seen in Figure 1, where ZigBee Coordinator (C) and ZigBee Router (R) are implemented as FFD nodes and ZigBee End System (E) is implemented as an RFD node since routing is not finished. ZigBee End Device node is called a sensor node in this work. ZigBee network operation is listed below. The coordinating node initialises the network, selecting a communication channel and an identifier for the network called PAN ID[12]. The coordinating node allows router nodes and sensor nodes to join the network, supporting data routing and packet storage for non-active (dormancy) nodes. Therefore, the coordinating node must always be active with a constant power supply. Router nodes may begin sending, receiving, or routing data after entering a coordinator-initiated network. It also allows other routers and sensor nodes to access the network. Like the coordinating node, the router nodes must still be involved due to routing and storing packets for non-active nodes.

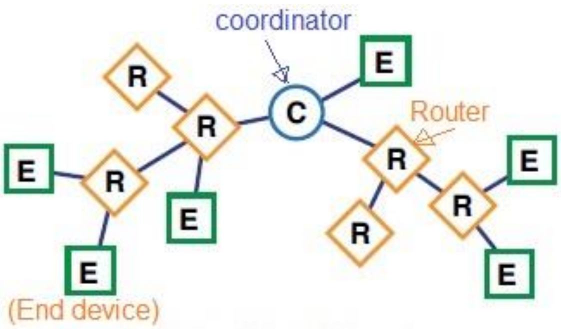


Figure 1: Example of a ZigBee Network Topology

There is only one coordination node in the ZigBee network, regardless of the form of topology used. The coordinating node defines a special network identifier (PAN ID). This identifier is common to all other nodes entering this network. ZigBee devices are typically pre-configured to add a PAN ID address to an existing network, but can also select a PAN ID from a nearby network to request entry[13].

ZigBee layers: This section presents the layered architecture of the ZigBee network, which is important to understand the operation of the protocol and its implementation over the IEEE 802.15.4 protocol.[14] The work of Farahani (2008)[15] describes the functioning of the physical and MAC layers of the IEEE 802.15.4 protocol, in addition to mentioning how the network layer is implemented in conjunction with the ZigBee protocol. Both the IEEE 802.15.4 protocol and the ZigBee protocol were subjected to analysis and simulation in large-scale scenarios in the work by Pekhteryev, et al. (2005)[16]. Figure 5 shows the layer structure of the ZigBee network, where the implementation of the ZigBee standard over the IEEE 802.15.4 protocol can be viewed.

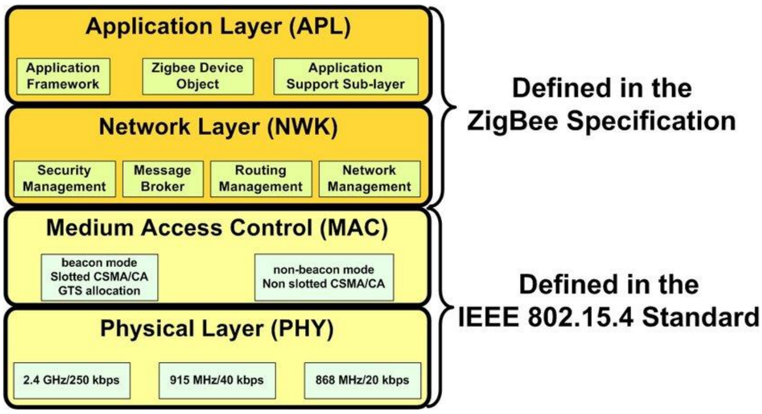


Figure 2: ZigBee and IEEE 802.15.4 layers

In the physical layer, the reception sensitivity, number of channels, rejection of a channel and the specification of the data transmission rate are defined. ZigBee networks operate in the 2.4 Ghz frequency range and with a transmission rate of 250 kbps, the same as the IEEE 802.15.4 protocol as given in Maurya, et al.,(2015)[17]

At the MAC layer, data transmission between neighboring nodes is managed by diffusion, including transmission resend service and collision prevention techniques Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA)[18], providing also services for association and disassociation of nodes in the network. The network layer adds routing capability, allowing data packets to travel across multiple devices, from source to destination. Only coordinating nodes and routers have the ability to discover routes, choosing the best path for the data from the sensor nodes. In the coordinating node, the network layer is responsible for the initial establishment of the network, for the definition of the topology used, such as mesh, star or tree (figure 3), and for the allocation of network addresses to all participants. The ZigBee network works with several types of routing. In the work by Zayani et al. (2012),[19] a description of the mesh, star and tree topologies is presented, as well as the routing protocols AODV, Cluster Tree and integrated routing, in addition to making an analysis of the protocols focusing on the routing mechanism, cost and maintenance. Basmer et al. (2011)[20] present an analysis of the operation of network topologies in the IEEE 802.15.4 protocol, making a simulation in scenarios with a single destination and with multiple destinations, for packets that travel on the network.

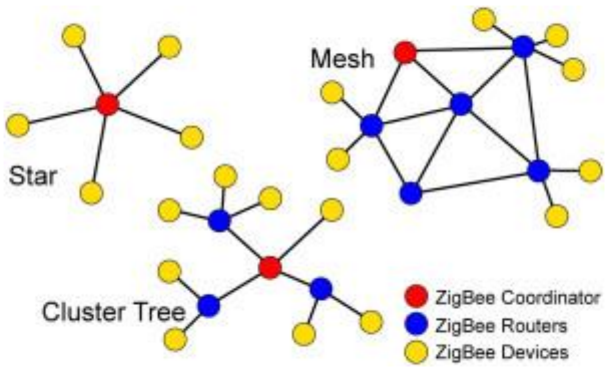


Figure 3: Types of ZigBee network topologies

Reactive Routing Protocols for Wireless Sensor Networks

Reactive routing protocols are also known as demand routing protocols, as they do not maintain route information on nodes on the network if there is no communication. One protocol may perform better than another, the selection of a particular routing protocol will depend on the type of application and the intended use of the network. The three reactive routing protocols DSR, AODV and DYMO studied[21] in this work are explained in detail below:

• **DSR Routing Protocol:** The DSR (Dynamic Source Routing) protocol is based on routing from the origin, that is, the data packets include a header of information about the exact nodes that must pass through. It does not require any type of periodic messages (reactive), thus reducing overhead and wastage of bandwidth at the level of control messages[22]. It also offers the possibility of obtaining, with the request for a route, multiple possible paths to the destination as long as feasibility conditions are guaranteed. In order to carry out the routing at the source, each data packet is inserted a DSR header of options that will be placed between the header of the transport layer and the IP datagram, the purpose of which is to include the route that the node-to-node packet must follow node. Each data switching equipment maintains a route cache in which the routes obtained through route discovery processes are stored, whether they are its own or obtained through network shipments detections. In the processes of discovery of new routes to destinations, request, response and error messages are generated, these messages being "Route", "Request", "Reply" and "Error" respectively according to the provisions of[23].

• **AODV:** The *Ad Hoc on Demand Distance Vector Routing* (AODV) has characteristics such as dynamic topology, which undergoes constant changes[24]. It is a reactive protocol in order to build your routes when necessary[25]. Thus, there is a process that uses measures such as sending a large number of packets to discover possible routes, thus showing a great feature of the protocol that is trying to increase the available bandwidth, trying to minimize the flow of messages issued to update your routes. This discovery allows each mobile on the network to act as a specialized router and routes are obtained when needed, thus making it a self-parting network. Each node in the network maintains a routing table with the routing information entries for the neighbouring nodes, where the next hop to the destination is saved[26].

The main messages used by AODV are requests for RREQs (Route Requests), responses for RREPs (Route Replies) and errors on RERRs (Route Errors). When it is necessary to create a route for a node, the route discovery process is initiated, in this process the originating node sends an RREQ message to all its neighbours. The route is determined when the RREQ reaches the destination node or an intermediate node that knows the path to the destination node and the sequence number is recent, that is, the route is valid as long as the sequence number is greater than that sent in the message of RREQ. The route is constructed by sending the RREP message by the reverse path to that taken by the RREQ message. In AODV there are two route maintenance processes. The one based on whether or not to receive ACK acknowledgment signals (acknowledgment) and the one based on sending and receiving hello messages. Both are intended to validate the routes contained in the route table. In the hello-based process, packets called hello are periodically sent between the nodes to check for the existence and rupture of routes. When a hello packet is not received, an RERR message is sent to the originating node signalling that an error has occurred. Upon receiving a RERR message the routing table is updated by removing the routes related to the error. More details on the route discovery and maintenance process in AODV can be found in Atto et al (2020).[27]

Dynamic MANET On-demand (DYMO)

• DYMO is a simplified successor to the AODV protocol: For networks with various mobility and traffic patterns, DYMO protocol is constructed. It offers a reduced consumption of bandwidth and computer processing as packets are not shipped unless needed. In big networks, it has a stronger role in situations where only small portions of the others interact with each node[28]. DYMO includes two activities, the discovery and maintenance of roads, like other reactive protocols. Routes are available whenever a node must deliver a packet to a destination other than its chart. A notification of path requests (RREQ) is sent to all nodes to verify that the endpoint is in their routing table on request. Check if the target node is still active in the table. Where the destination node receives an RREQ, the path reply message is launched (RREP) and the intermediate-hop number and route are sent hop by hop to the origin node. Contrary to the AODV protocol, which produces only routing table entries for the destination node and the next node, the node receiving the requested destination route provides information of all intermediate nodes along the newly discovered route[29]. As shown in the AODV figure 4, node A is only familiar with node B roadways, its next-hop neighbour and destination nodes D, while nodes A are initiating a road-discovery process for nodes D. Node A is also familiar with node C and node B tracks for DYMO (Figure 5). DYMO’s path accumulation is called this function. DYMO's only reference to active sources and targets is to keep routing knowledge[30], but it refers to small memory modules. A reduced version for DYMO-LOW sensor networks that are intended to minimise the consumption of energy is currently being developed[31].

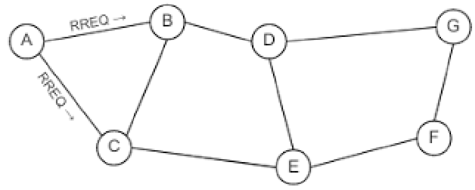


Figure 4. Operation of the AODV protocol.

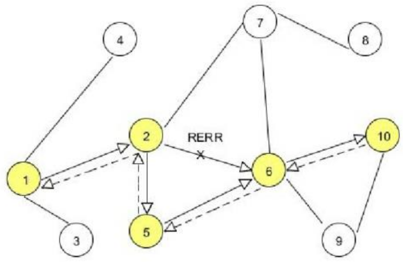


Figure 5. DYMO protocol operation.

3. Methodology

After the study carried out in the previous section, the AODV protocol was selected to be evaluated by simulation. Its choice is due to the fact that, according to the AODV literature, it presents better performance under scenarios of high mobility, increased network density and low traffic loads, which makes it suitable for wireless sensor networks[32].

To carry out the simulation, OMNeT ++ is used, a free simulator for academic use available for operating systems such as Windows, Linux, Mac, among others, and which can be obtained directly from its website (https://omnetpp.org/). OMNeT ++ is a discrete event simulator, written in the C ++ programming language and based on modular components, which has two interfaces, graphical and programming. To meet our work requirements the Castalia system[33], which includes an advanced wireless channel models, radio models, node clock models, power consumption models, various MAC protocols, including IEEE 802.15.4, and routing protocols, has been used to simulate the simulation of wireless sensors networks and body area networks, which are the simulators for WSN and body zone networks (WAN). In Castalia, the nodes are also linked via the wireless channel module and through their physical processes. A contact modulus, a sensor manager, an application module, a resource handler and a mobility management are composed of each node. The communication module consists of three layers: the radio (physical layer), the MAC layer and the routing layer, and gives the application module communication capacities. The mobility manager is in charge of the sensor position in the field. The RM models local resources such as electrical consumption, memory usage and the CPU state.

The AODV simulation model used in this work is based on the implementation of the protocol carried out by the research group Kumar et al (2018)[34]. The network has been evaluated under the IEEE 802.15.4 standard for two different scenarios that include stationary conditions, different spatial distributions of the nodes and different collision models. Shading will not be used in the radio model, so the coverage will only depend on the distance of the nodes. Table 1 shows the general simulation characteristics[35].

Table 1. Simulation parameters

Topology	Value
Number of nodes	5,9,15
Topology	Star
Distribution	Circular, uniform
Simulation time [s]	100 seconds
Simulation area	140 m x 140 m
MAC and physical layer model	IEEE 802.15.4
Routing model	AODV
Radio model	CC2420
Pack size	105 bytes
Packet data rate	2 packets / sec
Transmission power [mW]	-1 dBm / 55.17
Interference model	0 to 2
Mac BO	default value Six
Mac OS	default value Four

In Castalia there are three interference models available

- ***Interference = 0,*** that is, while there have been no collisions at a time with multiple nodes, there are however some randomnesses in the radio module modelled in the form of thermal noise (packet reception probability is based on SNR).
- **Interference = 1,** simple model based on the concept of interference range, in which two partially overlapping transmissions are both discarded;
- ***Interference = 2,*** additive interference model, in which the signal interference ratio is calculated taking into account all possible interferences from other sensor nodes. For all the scenarios, the shadowing effects have been disabled and the application is used all nodes send packets to a coordinator node at a constant (configurable) rate.

The simulation scenarios are described in detail below.

• Network in star topology with 5, 9 and 15 nodes deployed in a square field in circular distribution around the coordinator node, which is located in the centre of the field. The simulations are run for all three interference models (no collision, simple collision, and additive collision).

• Network in star topology with 5, 9 and 15 nodes deployed in a square field in random uniform distribution and with the coordinating node located in the center. The simulations are run for all three interference models (no collision, simple collision, and additive collision).

The AODV protocol was evaluated under the following metrics[36]:

i) ***Packet Delivery Rate [%]*:** Number of data packets transmitted successfully to the target node (coordinator), split by a source node (other network nodes) number of packets generated.

ii) ***Average End-to-End delay [ms]:*** It takes a packet time to reach the destination node from the source node. This metric takes into account all possible delays caused by queuing delay time, packet retransmission at the MAC layer, and packet transmission and propagation times.

iii) ***Routing Overhead [%]:*** Total number of packets sent by the routing layer, divided by number of packets sent. The impact of monitoring messages on the network can be analysed. Analyzes would be carried out of the total number of control messages (RREP, RREQ, RERR) sent and of error messages.

iv) ***Power Consumption [Joules]:*** Amount of energy consumed by the network, discriminated between the energy of the coordinating node and the rest of the nodes of the network.

4. Results

Castalia involves several random processes, such as wireless channel shadows, different node start times, multiple random decisions in the MAC, and 11 random number sequences in total affecting various parts of the simulation. To have a better precision in the results, ten repetitions have been made for each scenario (each repetition is executed with a different set of random seeds). The results obtained reflect an average of 10 iterations per measure.

Package delivery rate:

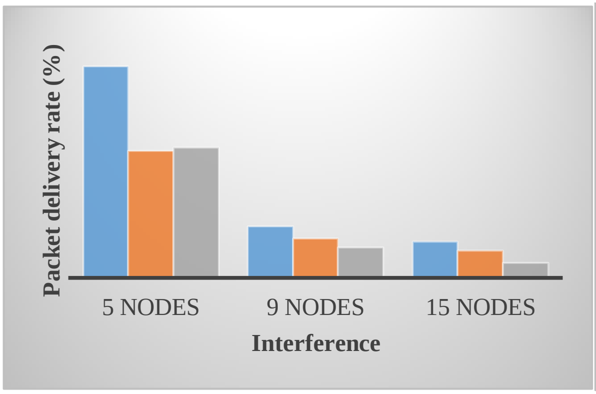


Figure 6. Packet delivery rate for networks of 5, 9 and 15 nodes with circular distribution.

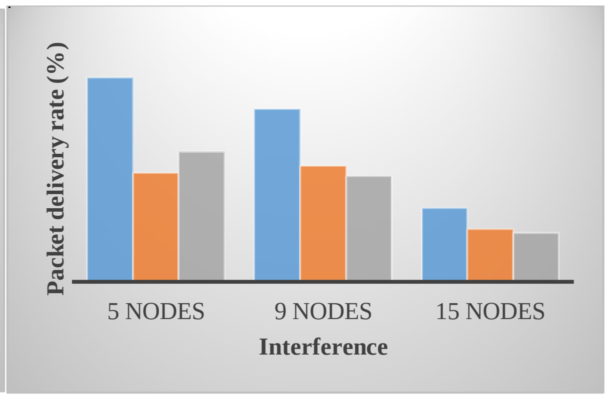


Figure 7. Packet delivery rate for networks with 5, 9 and 15 nodes with uniform distribution

From Figures 6 and 7 we can see how, independent of the distribution of the nodes in the field (circular or uniform), AODV fails when the density of nodes increases; Also, we observe that when we consider the interference models (interference = 1.2), the packet delivery rate experiences an additional reduction compared to when there is no collision but only thermal noise (interference = 0). Consequently, a network with a large number of nodes on the same segment has a larger collision domain and generally more traffic.

On the other hand, for both distributions, the network with five nodes and fifteen nodes shows respectively greater and less variability of the metric in relation to the interference model, however, the uniform distribution seems to offer better results overall than those obtained for the circular distribution.

Average delay results

From figure 8 we can see how the average delay in receiving packets increases when the number of nodes in the network increases. On the other hand, we also see that the sensor network in circular distribution presents the highest delay values with respect to the uniform distribution, consequently, and despite the clearly identified impact of the network density, it could be suggested that the uniform distribution offers greater benefits regardless of the interference pattern.

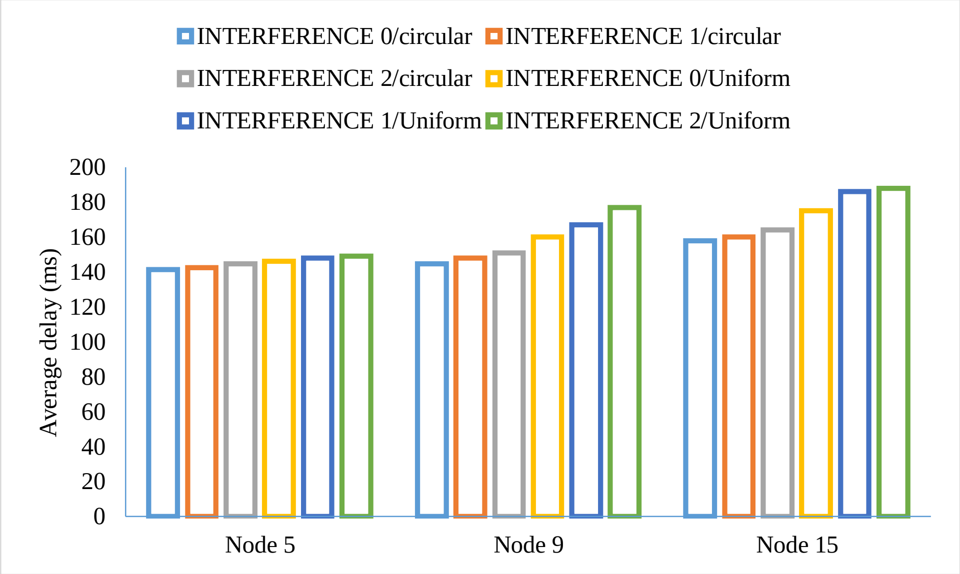


Figure 8. Average delay vs number of nodes for scenarios 1 and 2

Routing overhead results

From the results shown in figure 9 we can make the following observations:

i) The routing overhead value increases as a consequence of the greater number of routing packets sent when the number of nodes increases;

ii) The network of fifteen nodes in circular distribution presents the highest overload levels for all the interference cases considered;

iii) The networks of nine and fifteen nodes in uniform distribution show only a slight increase in the value of the routing overhead with respect to the great variability that they show for the circular distribution.

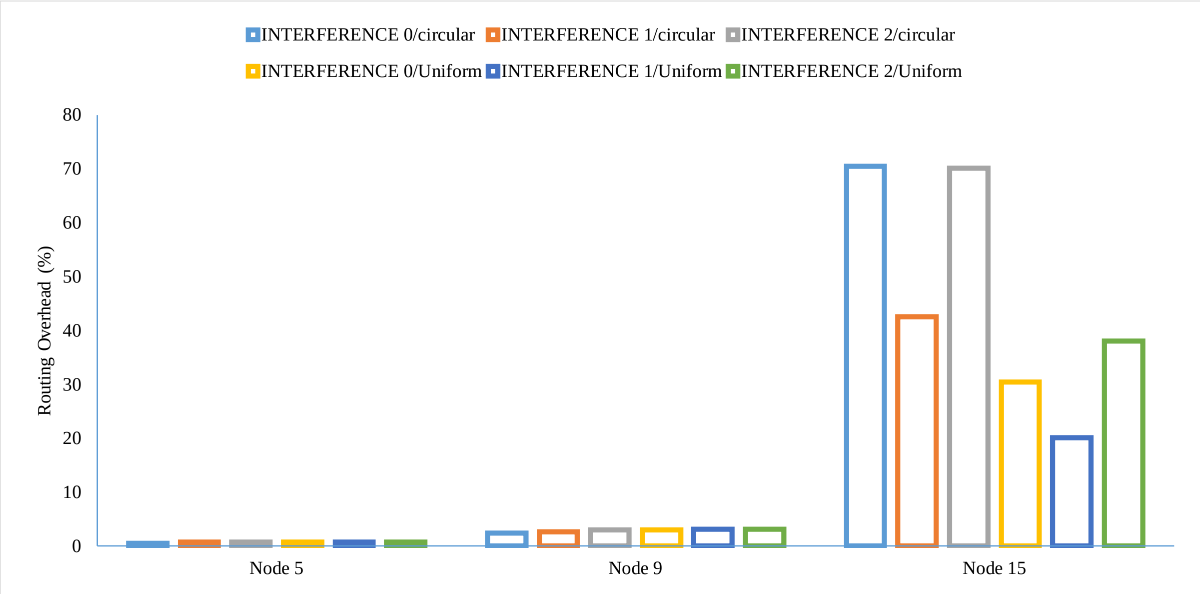
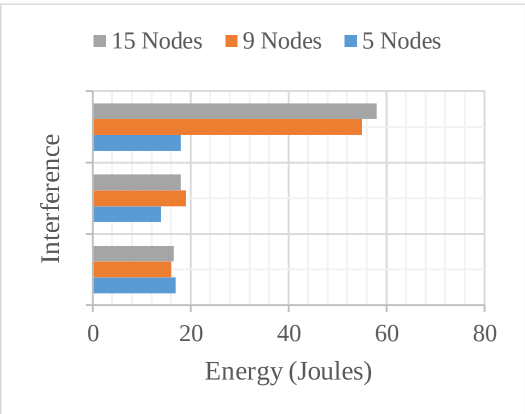


Figure 9. Routing overhead vs number of nodes for scenarios 1 and 2.

Power consumption results

From the results shown in Figures 10 and 11, it is concluded that, regardless of the distribution of the nodes in the field and the interference model, energy consumption increases as the number of nodes in the network grows. Thus, the network with fifteen sensor nodes presents the highest levels of energy consumption. However, it is very notable that for the uniform distribution (figure 8) consumption levels are observed almost double those obtained for the circular distribution. On the other hand, you can also see the additional effect on consumption introduced by the interference model. For all cases, the coordinating node presents the same level of consumption (6.79 joules), for the network with circular distribution, the average consumption of the nodes is approximately 2.5 joules and for the network with uniform distribution it is approximately 5.5 joules.



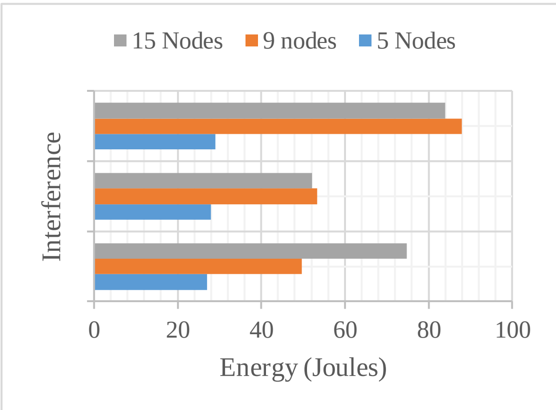


Figure 10. Energy consumption of the entire network with circular distribution.

Figure 11. Energy consumption of the entire network with uniform distribution.

Conclusions

The appropriate selection of the routing protocol shows a strong dependence on the type of application for which you want to implement the network. The density and distribution of network nodes can add to the complexity of problems in wireless sensor networks. This means that for some applications one type of routing protocol will be better or another, reaching the extreme that some algorithms are not valid according to the applications. In this work, the performance of the AODV protocol was evaluated under four metrics (packet delivery rate, average delay, power consumption, and routing overhead), the evaluation was carried out for a network in star topology, considering different densities (5, 9 and 15 nodes), different spatial distributions of the nodes (circular and uniform) and different interference models (no collision, simple collision, additive collision). Based on the simulation results obtained, it can be concluded that: 1) independent of the distribution, the AODV protocol is suggested to be used only in small networks (number of nodes <9 nodes), since all the metrics get worse as the number of nodes increases, this is because the flow of messages grows considerably, so the probability of collisions between packets is higher; 2) regardless of the density and the interference model, AODV for the network in uniform distribution shows the best results although with a high energy cost and, consequently, with a reduced estimated life time of the network; 3) In general, we consider that the performance variations were mainly due to the spatial distribution of the network nodes rather than the protocol mechanisms. As future work it is intended to carry out new simulations considering other distributions and other routing protocols.

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