Rendimiento de Evaluación de Análisis de Redes Inalámbricas de Protocolos del Sensor en Redes Inteligentes

Performace Evaluation Analysis of Wireless Sensor Networks Routing Protocols in Smart Grids

Carlos Deyvinson Reges Bessa[1], Rodrigo Soares Semente[1], Xiankleber Cavalcante Benjamim[1], Talison Augusto Correia de Melo[1], Felipe Denis Mendonça de Oliveira[1], Daniel Holanda Noronha[1], Antônio Eduardo de Morais Silva[1], André Laurindo Maitelli[1], Andrés Ortiz Salazar

[1] Laboratório de Automação em Petróleo, Universidade Federal do Rio Grande do Norte, UFRN Natal, Brasil

RESUMEN

Este trabajo tiene como objetivo estudiar el protocolo de enrutamiento de la red de sensores inalámbricos es más adecuado para aplicaciones de redes inteligentes, a través de la simulación de protocolos AODV, AOMDV, DSDV y HTR en el entorno de simulación NS2. Se simuló una red basada en una zona residencial con 47 residencias, con un nodo para cada residencia y una estación base, situada a unos 25 metros de los otros nodos. Muchos parámetros, tales como la pérdida de paquetes, rendimiento, retardo, jitter y el consumo de energía se probaron. La red se incrementó a 78 y 93 nodos con el fin de evaluar el comportamiento de los protocolos de redes más grandes. Las pruebas demostraron que el HTR es el protocolo de enrutamiento que tiene los mejores resultados en el rendimiento y el segundo mejor en el consumo de energía. El DSDV tuvo el peor desempeño de acuerdo a las pruebas.

Palabras Clave.- redes inteligentes, análisis de calidad de servicio, redes de sensores inalámbricas, protocolos de enrutamiento.

ABSTRACT

This work aims to study which wireless sensor network routing protocol is more suitable for Smart Grids applications, through simulation of AODV protocols, AOMDV, DSDV and HTR in the NS2 simulation environment. Was simulated a network based on a residential area with 47 residences, with one node for each residence and one base station, located about 25m from the other nodes. Many parameters, such as packet loss, throughput, delay, jitter and energy consumption were tested. The network was increased to 78 and 93 nodes in order to evaluate the behavior of the protocols in larger networks. The tests proved that the HTR is the routing protocol that has the best results in performance and second best in energy consumption. The DSDV had the worst performance according to the tests.

Key words.- Smart grid, QoS analysis, Wireless sensor networks, Routing protocols.

1. INTRODUCCIÓN

The increase of the amount of electronics worldwide has caused an increase in the global energy consumption. Studies have reported that this increase tends to continue, causing harmful effects, especially to the environment [1]. Nowadays homes and businesses power consumption is much higher than before. On the other hand, due to the advancement of new technologies and tools of the electric power systems (EPS) there are new technologies such as Smart Grid that helps minimizing energy costs [2].

The construction of a wired communication system in order to monitor the power grid costs time and money, because configuring additional equipment and cables is needed. The technological advances of low cost wireless sensors enabled the automation and real-time monitoring of the network [3].

The WSNs (Wireless sensor networks) are widely used in self-organizing systems. Although they encompass a significant amount of devices that work at a low operating cost per minute, these devices have limitations, such as processing, memory, communications and energy resources [4]. Due to these limitations, some optimization techniques such as the hibernation technique are used. Hibernation seeks to reduce energy expenditures by putting the

* Corresponding author:
E-Mail: carlos.deyvinson@hotmail.com

nodes in a sleep state while the data is collected [5]. Ensuring the data delivery between sensors and the base station is also an important prerequisite to any network. A reliable protocol is usually implemented in the network, in order to ensure the transfer of data reliably between the source and the destination so a low packet loss ratio is achieved [5].

Technologies such as Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS) and other residential and industrial networks work with the IEEE 802.15.04 standard. These technologies replace wired connections and can be used in Smart Grids [6].

This article aims to conduct a performance analysis of routing protocols in a WSN, searching for the protocol that best fits a Smart Grid Network in a residential condominium. Several routing protocols were presented at section 2, and some plain and hierarchical routing protocols were chosen to verify its efficiency to this application.

Some main network parameters such as percentage of packet loss, throughput, end-to-end delay, jitter and energy consumption were analyzed. From the results, it is possible to determine which is the best performing protocol for this application. The performance evaluation of WSNs has been carried out in the NS2 (Network Simulator 2). The main contribution of this work is to show a more detailed set of tests for WSNs, in an environment that reproduces a scenario that is closer to the reality. Previous works in this area tend to only use small and symmetric environments [7] or not to take the energy consumption into consideration, when using larger networks [8].

2. ROUTING PROTOCOLS OVERVIEW

A SMART system of residential energy monitoring is responsible for measuring the voltage and frequency provided by the network as well as the current and power consumption of the residence and the destructive harmonics generated by the network and the residence. The connection with the SMART GRID generally is made through wired protocols that use the electric infra-structure (use of combined electric cables and information cables), or with other information networks available (telephone, cable TV ...) [9]. The combined cables are usually not available to the customer, especially in residential condominiums. is also important to notice that the use of previously existing information networks generate additional monthly costs for the system, making the investment recovery time of the system longer [9]. In this context, the use of wireless sensor networks, especially those working with the IEEE 802.15.4 standard, becomes a good alternative due to its characteristic of low cost, low power consumption, reliability, easy installation and reconfiguration [3].

When using a WSN with a large number of sensor nodes distributed in a SMART GRID system installed in a residential condominium, the use of routing protocol is necessary to ensure QoS (Quality of Service) for satisfactory monitoring of SMART GRID. Network protocols can be classified as flat (reactive and proactive), hierarchical, location-based, and hybrid [10].

Reactive routing protocols, such as DSR [11], AODV (Ad hoc On Demand Distance Vector) [12], AOMDV (Ad Hoc On-Demand Multipath Distance Vector Routing) [13], R3E (Reliable Reactive Routing Enhancement for Wireless Sensor Networks) [14] and the HEER (hybrid energy efficient reactive protocol for wireless sensor networks) [15], the processing route only happens when there is information to be transmitted. This creates adaptable routes that fit the environment and may be constantly changing in a WSN (like inserting and removing nodes). It is important to notice that since each node updates its route table individually, the network topology changes and new routes are created. This implies constant processing during data transmission, increasing latency and power consumption [10]. Proactive routing protocols, such as OLSR (Optimized Link State Routing Protocol) [16], DSDV (Destination-Sequenced Distance-Vector) [17] and the DEEC-LCH (Distributed Energy Efficient Clustering with Linear Cluster Handling) [18] constantly update routing information from each node to all other nodes of the network. This creates an overhead in the transmission of this information over the network, consuming part of the network bandwidth in order to maintain the routing table of network nodes up to date [19].

The plain protocols usually increase the amount of routing and processing information when the network size increases. Hierarchical routing protocols, such as HTR (Heterogeneous Routing Protocol) [20], CGSR (Clusterhead Gateway Swtching Routing) [21], LEACH (Low Energy Adaptive Clustering Hierarchy) [22], HRTS (Hierarchical reactive time synchronization protocol for wireless sensor networks) [23] and the (LEACH)2 [24] seek to solve this problem by creating clusters, which are groups of nodes that work as sub-networks, limiting the size of the routing table and the size of the update packages within the group. Clusters

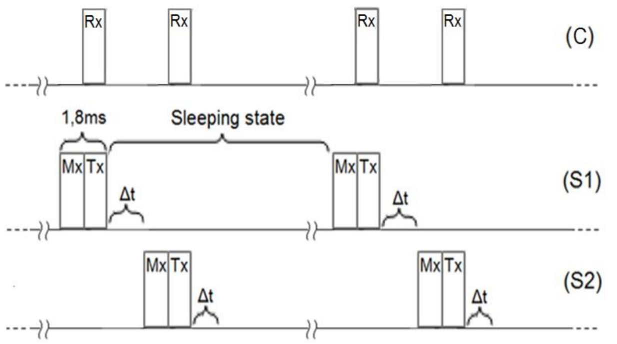

Figure 1. Example of communication sequence.

are typically grouped according to geographical closeness of the nodes.

Each cluster has a leader (cluster head) that communicates with the other nodes of the cluster and with other cluster heads of the network [10]. Routing protocols based on geographic location, such as GEAR (Geographical and Energy Aware Routing) [25], GPSR – TPC (Greedy Perimeter Stateless Routing in Wireless Networks) [26] and the LDDP (A location-based directed diffusion routing protocol for smart home sensor network) [27], use the GPS to determine the position of the nodes and the best possible route. These protocols can organize the network in simple or hierarchical topologies, depending on the availability of the geolocation devices. The uses of these protocols increase the cost of hardware and the additional energy consumption [10]. Due to these factors, these protocols will not be tested in the simulations of this work.

Hybrid routing protocols such as DDR [28], ZigBee Routing Algorithm (ZBR) [29], ZRP (Zone routing Protocol in Wireless Sensor Network) [30] and the FTE-LEACH (Fault-tolerant and Energy-efficient LEACH) [31] have characteristics of plain and hierarchical protocols and may or may not use geolocation techniques. These protocols create groups of nodes that perform routing near each other, thus reducing overhead of the network due to routing computation. Usually a proactive approach is performed within the groups. When two distant nodes are involved, the route is calculated through route discovery techniques [10]. The ZBR is one of the most used protocols in the industry, and it adapts itself to the size the network. In very small networks the peer-to-peer connection is used, and in larger networks with mesh topology AODV is used. In hierarchical topologies HTR is used [29].

As the SmartGrids networks are usually composed of multiple nodes, it is important to find the routing protocol that is best suited to this application, ensuring better performance and guaranteeing QoS. The protocols used in the NS2 simulation for this paper were AODV, AOMDV, DSDV and HTR. These protocols are extensively tested for various applications, such as use in MANETs [13] and WSNs applied in wind farms [8]. The ZBR will be analyzed indirectly by comparing the AODV with the HTR, since ZBR is a hybrid protocol

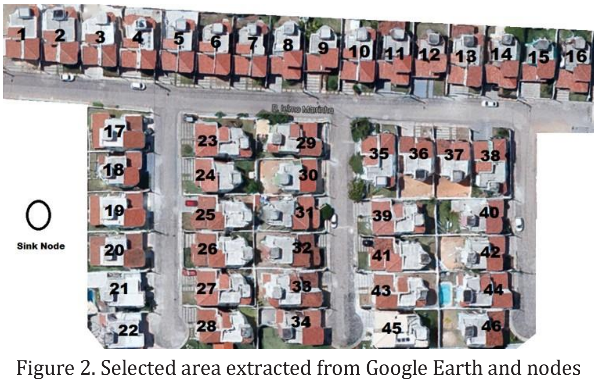

Figure 2. Selected area extracted from Google Earth and nodes used in the NS2 simulator.

based on these two other protocols.

It is important to notice that there are two ways of communication between the nodes and the sink: The always-on mode, with no hibernation of the transceivers, and the sleep mode, with transmission of periodic data with the hibernation sensor nodes between a transmission, but with the sink node always awake. In the communication mode with hibernation, a scheme for ensuring the time of sending the data between node and sink is required. This is important for providing efficiency and minimizing the energy consumption of the nodes. A temporary communication scheme based on [32] was implemented as described as follows. The implemented scheme is shown in Figure 1, which shows the communication between two sensors and the sink. Initially, the (S1) sensor measures a physical variable (Ms) and transmits the data (Tx) to the sink (C). Soon after the Sink receives the data correctly (R) it sends a message to the sensor 1, which starts sleeping. Then, the sensor (S2) that was still asleep wakes up after a time Ts, set by the microcontroller. After waking up the sensor (S2) performs the same procedure of sensor (S1).

3. PERFORMANCE EVALUATION

This section presents information to the evaluation of the AODV, AOMDV, DSDV and HTR routing protocols under 802.15.4 MAC protocol in a scenario that aims to represent a residential condominium. The 802.15.4 MAC protocol was adopted because of some of its particular characteristics, such as low transmission rate and low energy consumption when compared with 802.11. These characteristics make it suitable for smart grids applications. Using the Google Maps website, an image of a condominium in the city of Natal / RN, Brazil was captured. The purpose of this image is to locate the network nodes based on a real case. The above mentioned picture can be viewed in Figure 2.
Based on that image, a script using MatLab[a] was developed. This script is responsible for loading the image in the background and choosing the location of the nodes based on a simple mouse click. Using the image scale, the script is able to automatically generate a vector of points converted into the metric system that is used in the simulation.

The simulation base scenario consists of 46 sensor nodes, one for each house, and one sink node (represented in the Figure. 2 by the black circle).

There are some popular network simulation environments, such as NS-2, NS-3, OPNET, OMNet++ and QualNet.

These simulators differ in terms of scope, features and license. Since the early versions of the NS-2, many researchers have used it to evaluate scenarios that are usually difficult to implement in real life. Hence, NS-2 has gained considerable popularity among the researchers and has been extensively used in researches on data communication in Smart Grid networks. Therefore, all simulations were performed on version 2.35 of NS-2.

NS-2 is an open source and discrete event simulator developed by the VINT project research group at the University of California at Berkeley.

***Table 1**. Parameters used in the simulation.*

MAC Protocol	**802.15.4**
Antenna	Omni directional
Simulation Time	3600 s
Simulation Area	170m x 100m
Radio Propagation Model	Two Ray Ground
Routing Protocols	AODV, AOMDV, DSV, HTR
Number of Nodes	47, 48 and 93
Transmission Rate	5 packets/s
Packet Size	70 bytes
Transport Protocol	UDP
Traffic Type	CBR

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In the simulation, the routing protocols have been tested with 47, 78, 93 normal nodes and one a single sink node.

The simulation time is 3600 seconds, transport protocol is UDP and traffic generator source is CBR. Simulation area is 170 x 100 meters and two-ray ground is used as propagation model. The message size of each package is assumed to be 70 bytes. Table 1 summarizes the parameters used in the simulation.

It is important to determine if the communication occurs in always-on mode (no hibernation of sensor nodes transceivers) or in sleep mode (periodic data transmission, interspersed with hibernation of sensor nodes' transceivers, except the sink, which remains permanently awake).

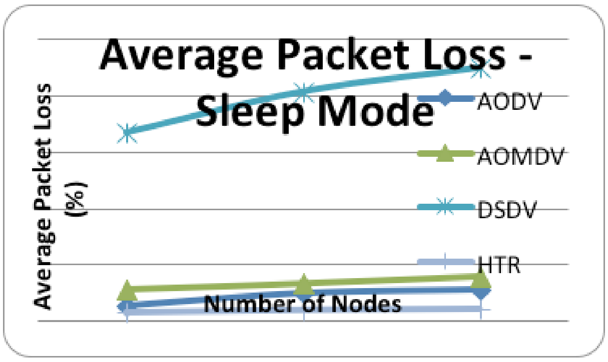

Figure 3 Average packet loss in sleep communication scheme.

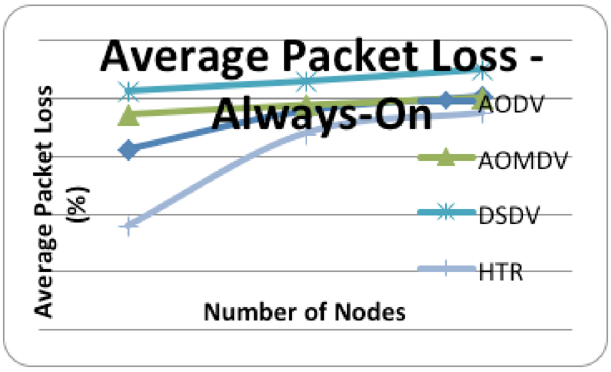

Figure 4. Average packet loss in always-on communication scheme.

This article evaluated both of those cases. Transmission starts at 40s and, in sleep mode communications, sleep time is assumed to be 5 s. In order to improve the accuracy of the tests, 10 rounds of 1 hour each (3600s) were performed.

4. PERFORMANCE METRICS

The parameters used for assessing the performance of the routing protocols by this article were:

Packet loss

Packet loss occurs when one or more packets of data travelling across a network fail to reach their destination. It is measured as a percentage of packets lost with respect to packets sent.

Throughput

Throughput is measured in terms of successful delivery of data packet within the threshold time. It is measured using number of bits of packet received per unit time [33].

End-to-end delay

End-to-End delay is a parameter used to measure the performance with time taken by a package to travel across a network from a source node to the destination node. It evaluates latency between data send by sensor nodes and received by destination

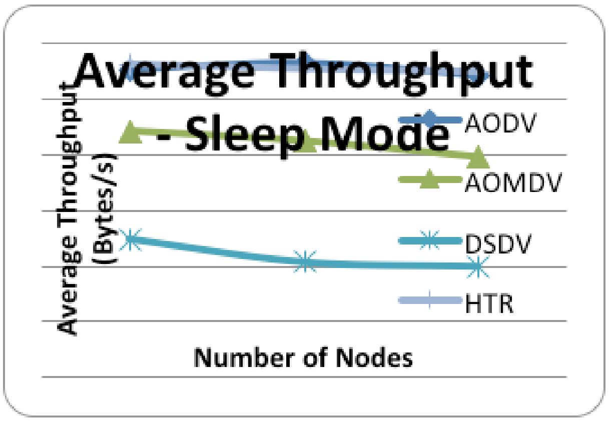

Figure 5. Average throughput in sleep communication scheme.

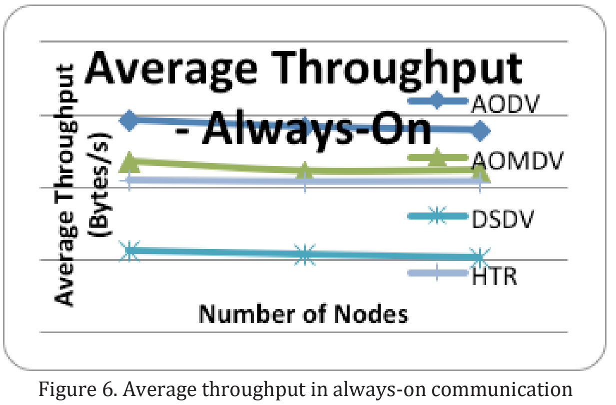

Figure 6. Average throughput in always-on communication scheme.

node. An end-to-end delay includes all possible delay caused during route discovery, retransmission delay, queuing delay and relay time [33].

Jitter

Jitter is a performance characteristics used to measure deviation from true periodicity eventually of inactivity in packet across a specific network [33].

Residual energy

Residual energy is the remaining energy of the network after the simulation.

5. THE SIMULATION RESULTS

Each graphic presented below was build using the average value of 10 simulations for each scenario and each protocol.

Packet loss

Figure 3 and 4 show the average packet loss in sleep and always-on communication scheme, respectively. In always-on mode, all routing protocols tested presented a high number of package losses. The large amount of packet losses can be justified by the dispute of communication for permission to communicate with the sink. In sleep mode, the average packet loss decreased when compared with always-on mode. In all cases, average packet loss increases with addition of nodes.

In the sleep and always-on communication scheme, the average packet loss of the DSDV protocol is too high because it is a proactive protocol and needs to maintain your routing tables always updated. Hence, DSDV waits for a certain period to update its routing tables. If some node wants to send packets during this interval, these packets are put in the queue and when the queue is full, packets will be dropped.

Only HTR maintained an acceptable percentage of loss, which is below the margin of 5% desirable for this application.

Throughput

The average throughput shown in the Figure. 5 and 6 demonstrates that all protocols expressed a higher throughput in always-on mode. In sleep mode, the HTR routing protocol presented the better throughput results but very close to AODV. DSDV had the worst throughput in both modes. In general, the performance was stable with increase of node density for all routing protocols.

End-to-end Delay

Figure 7 and 8 show a comparison between the average end-to-end delay of the routing protocols in sleep and always-on communication scheme, respectively. DSDV immediately drops the packets in the case of a link failure, due to its proactive behavior. Therefore, it usually has low delay. But, DSDV is not suitable for large networks and this compromised its performance. Hence, DSDV routing protocol

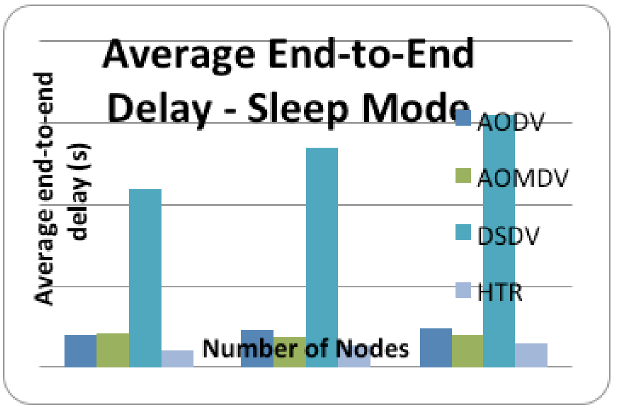

Figure 7. Average end-to-end delay in sleep communication scheme.

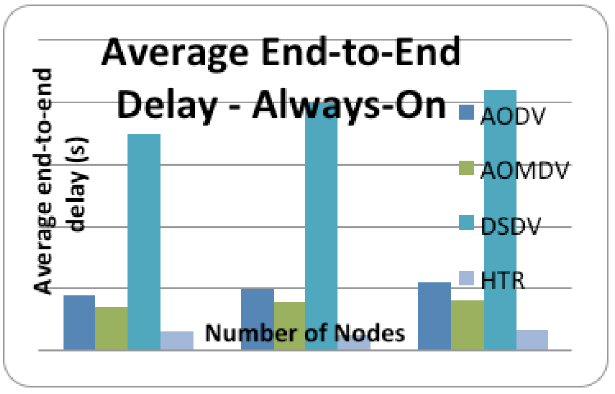

Figure 8. Average end-to-end delay in always-on communication scheme.

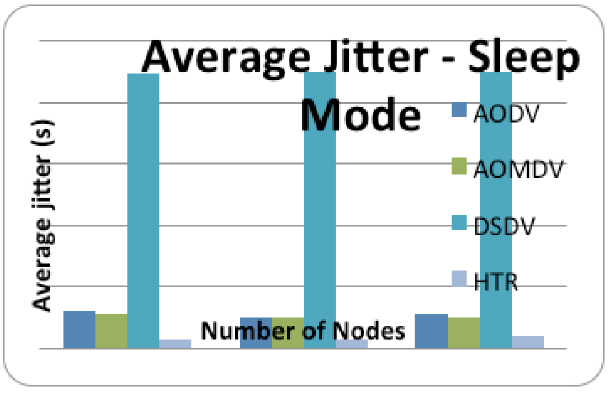

Figure 9. Average jitter in sleep communication scheme.

did not have satisfying results for average delay in these applications. All other routing protocols tested presented acceptable average delay values. AODV, AOMDV and HTR did not have big variations in their performance with increase of node density. The HTR hierarchical routing protocol got the best results for delay.

Jitter

The average jitter shown in Figure 9 and 10 demonstrates that, considering the results obtained by DSDV protocol, this protocol had the worst result due the high node density of the network that compromised its performance.

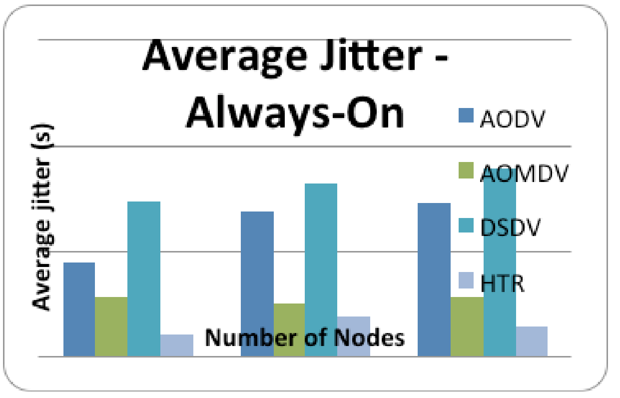

Figure 10. Average jitter in always-on communication scheme.

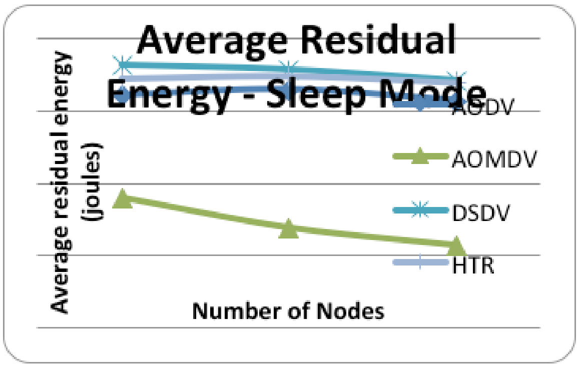

Figure 11. Average residual energy in sleep communication scheme.

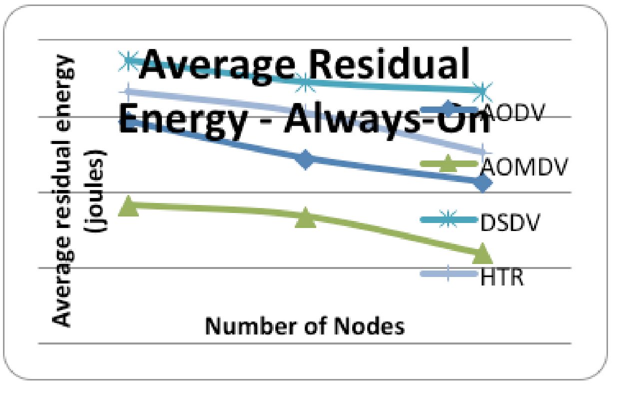

Figure 12. Average residual energy in always-on communication scheme.

Based on the results it is possible to notice that in all protocols, except DSDV, the average jitter remained within acceptable levels. HTR had the best performance for the jitter parameter.

Average residual energy

The mathematical energy model of NS-2 was used to evaluate the average residual energy. The energy model in a node has an initial value which is the level of energy the node has at the beginning of the simulation, called initialEnergy_. It also has a given energy usage for every packet it transmits and receives, called txPower_ and rxPower_, respectively. The simulation time of 620 seconds was used for evaluating this parameter. The other parameters were the same as summarized in the Table 1 and 2, summarizes the parameters used in the energy model.

Table 2. Parameters used in the energy model.

initialEnergy_	**50 Joules**
rxPower_	0,39 Watts
txPower_	0,66 Watts
Simulation Time	620 s

Figure 11 and 12 show a comparison between the average residual energy of the routing protocols in sleep and always-on communication scheme, respectively. The average residual energy in the always-on mode is lower than sleep mode because node's transceivers do not hibernate. Therefore, always-on mode has higher energy consumption.

AOMDV is the routing protocol that consumes more energy because this protocol tries to find multiple paths, using more resources and obviously consuming more energy. Hence, its average residual energy is low. DSDV consumes low energy considering that it fills its routing tables without using techniques such as broadcast used by AODV.

6. CONCLUSIONS

This paper presented an analysis on the performance evaluation of four WSN's routing protocols (AODV, AOMDV, DSDV and HTR), based on IEEE 802.15.4 standard applied in smart grid applications for residential condominiums. The simulation was based on a real area extracted from Google Maps. Performance parameters, such as packet losses, throughput, end-to-end delay, jitter and residual energy were tested.

The results presented shows that HTR routing protocol used by ZIGBEE expressed, in general, better performance when compared with flat protocols (AODV, AOMDV and DSDV) for this application, even with the growing size of network.

DSDV routing protocol has the best energy efficiency but worst result in the other metrics, therefore, considering the result obtained in this metric and the application to be deployed, DSDV cannot be viable to be used.

As a future work, we plan to study other performance metrics in larger residential areas and to implement some techniques to improve energy consumption.

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