Quality of Service and Energy Efficient Evaluation of Hierarchical and Flat Routing Protocols for Wireless Sensor Networks

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***Abstract*—Wireless Sensor Network (WSN) is a network with limited power sensing devices with a communications infrastructure for monitoring physical or environmental conditions, such as temperature, sound, pressure, etc. Among the concerns of these networks is prolonging the lifetime by saving nodes energy. There are several protocols specially designed for WSNs based on energy consumption and network lifetime. However, many WSNs applications require QoS (Quality of Service) criteria, such as latency and throughput. In this paper, we will compare three routing protocols for wireless network sensors LEACH (Low Energy Adaptive Clustering Hierarchy), AODV (Ad hoc on demand Distance Vector) and LABILE (Link Quality-Based Lexical Routing) using Castalia simulator in terms of energy consumption, number of nodes alive and stability period, throughput and latency time of packets received by the base station under various conditions. The results prove that LEACH had the longest network stability period, consumes the least energy and had the least latency time, while the LABILE and AODV protocols have the highest throughput.**

Keywords-WSNs; Quality of Service; LEACH; AODV; LABILE.

I. INTRODUCTION

WSNs are a special case of Ad hoc networks [1], widely used in various applications such as, environmental monitoring, military surveillances, intelligent transportation, healthcare, etc. A WSN is a collection of large numbers of sensor nodes deployed in a geographical area to be controlled. Each sensor is limited in terms of processing power, wireless bandwidth, battery and storage capacity. In most WSNs applications, it is difficult even impossible to change or recharge power resources, which makes the energy consumption a major constraint of WSNs lifetime [2]. Since wireless communication requires significantly more power than processing tasks, energy conservation is crucial while designing network protocols for WSNs. Clustering approach is one of the best ways for reducing energy consumption of nodes. In these sensor nodes, rather than sending individually, first, the sensor nodes group themselves into clusters, and then an elected cluster head (CH) sends the aggregated data from all to the sink. Other than the power consumption criterion, real-time applications such as, military applications require QoS criteria like latency.

In typical WSNs applications, throughput is not significant as other parameters, because a sensor node sends small packets. But, the use of acoustic and imaging sensors requires significant throughput, as data must be streamed through the network. Thus, certain WSNs applications require maximizing throughput. In that context, distance-vector routing protocols based on calculating of direction and distance to any link in a network and multi-hop approach can ensure a great throughput.

In this work, we have compared three WSNs routing protocols; AODV and LABILE based on distance-vector and LEACH based on clustering approach. The source codes of these three routing protocols are developed for Omnet++/ Castalia simulator by GERCOM (research Group on Computer Network and Multimedia Communication) [3]. The comparison results show that, LEACH had the longest stability period, consumes least energy, and had the least latency time, while LABILE and AODV protocols have the highest throughput. The rest of the paper is organized as follows. In Section II, we review the related work in this field. Section III will provide an overview of the three routing protocols AODV, LABILE and LEACH. Section IV describes the common simulation settings used in different scenarios. Section V discusses the results and analysis; finally, we conclude the paper in Section VI.

II. RELATED WORK

Various comparative studies have been made between hierarchical and flat routing protocols for WSNs based on the energy saving criteria and network lifetime such as in [4]. In those studies, AODV, LEACH and LEACH-E routing protocols are compared for energy efficiency and network lifetime. The simulation results show that, under different simulation time, LEACH and LEACH-E protocols consume less energy than AODV. Indeed AODV has the least network lifetime. However, many WSNs applications have latency and throughput constraints like real-time application.

The particularity of this work is to compare hierarchical (LEACH) and flat routing protocols (AODV and LABILE) in terms of latency, throughput and energy consumption under different scenarios to determinate which type of routing protocols is more suitable for QoS constraints.

III. ROUTING PROTOCOLS FOR WSNS : AN OVERVIEW

WSNs routing protocols are classified according to their architecture or their operating principles into flat, location-based and hierarchical/cluster categories [5]. Flat routing protocols represent an appropriate solution for several applications, such as smart-homes, healthcare and environmental monitoring. Many applications employed in these scenarios have low tolerance for packet delay and loss. On the other hand, routing protocols based on clustering are an alternative to improve QoS and energy consumption for many applications [6], such as multimedia traffic [7]. The energy saving, throughput and packets transmission delay represent a great worry for WSNs, and a real compromise between flat and hierarchical routing protocols; so, for these reasons we have chosen to compare AODV and LABILE and LEACH.

A. AODV Routing Protocol

AODV protocol [8] was originally proposed in RFC 3965. In AODV, on-demand routes can be discovered, which decrease the overhead, by using pairs of Route Request (RREQ) and Route Reply (RREP) messages. However, the route selection process is only based on the minimal number of hops, which is not suitable for ensuring energy-efficiency and reliable data transmission. The deficiency of energy-efficiency mechanism results in energy holes and an uneven distribution of scarce network resources. Moreover, AODV only stores one possible route for a given destination node. This means that if a single route fails or is unavailable, a new route must be discovered, which requires more time and increases the delay or failure rate of data delivery.

B. LABILE Routing Protocol

LABILE [9] proposes a routing algorithm based on lexical structures and link quality evaluation. Using LQI, i.e., a metric provided by the physical layer of IEEE 802.15.4 standard, LABILE is able to evaluate the link quality. The LABILE proposal evaluates end-to-end link quality by classifying the possible values of LQI, determines a threshold value for link classification, where the lowest values of LQI (below the threshold) are considered bad, and represents links that are more susceptible to packet loss. During the route discovery process, all the bad links are counted, recorded and reported with the aid of an additional field in RREQ and RREP messages. The purpose of LABILE is to select routes with good link qualities. However, this behaviour implies that these routes have an exhaustive use, and lead to the premature death of these nodes. This is due to a lack of mechanisms for determining when there is a need to use alternative routes.

C. LEACH Routing Protocol

LEACH [10], is the first hierarchical cluster based routing protocol for WSNs, developed by W. R. Heinzelman et al. from MIT. It is based on the concept of rounds where each round consists of two phases: first, clusters set up phase and second a steady state phase.

1) Cluster set-up phase: In this phase, each node decides whether or not to become a CH for the current round r. This decision is made by the node n choosing a number between 0 and 1 randomly. If the number is less than a threshold T(n), the node becomes a CH for the current round [10].

2) Steady set-up phase: In the steady working stage, each member node of the cluster sends data to the corresponding CH during the allocated communication slot. After receiving all the data, the CH aggregates it and sends to the sink. In order to minimize the power consumption, the steady phase duration is kept far greater than the cluster constructing phase duration..

IV. SIMULATION SCENARIOS

In this work, we want to make a comparison between hierarchical and flat WSNs routing protocols in terms of energy consumption, packet latency and throughput. In order to achieve convincing results, we will simulate the chosen protocols several times in various scenarios. For simulation, we will use the OMNET++/Castalia simulator [11]. By using the ”Throughput Test” application implemented in Castalia simulator, we suppose that all nodes have data to sending, have an initial energy of 10 joules and randomly placed in a 100 m x 100 m area.

Table I depicts the common simulation settings for all scenarios, with the last three parameters that contain (*) are specific to LEACH protocol.

TABLE I. GLOBAL SIMULATION PARAMETERS.

Parameters	Values
Routing protocols.	AODV, LABILE, LEACH.
Node deployment (topology)	Random
Number of Simulation Repetition	20
Sink Position (x, y, z)	(50 m, 120 m, 0 m)
Collision Model	Simple collision
Area	100 m x 100 m
Initial energy/node	10 Joules
Sink Initial Energy	100 Joules
TX output power	-5 dBm
Packet rate	1 packet/s
Node Buffer size	1000 bytes
Application name	Throughput Test
Path loss exponent	2.0 (Free Space)
Radio parameter file	CC2420.txt
Round length *	20s (Duration between two rounds)
Slot length *	0.2ms (TDMA slot dedicated to each node)
Routing percentage *	0.05 (Percentage of Cluster Head 5%)

V. RESULTS AND ANALYSIS

In this section, we will present results under different simulation scenarios by varying simulation time, node density and packet size. These results are analysed to demonstrate the performance of these protocols in terms of latency time, throughput and energy consumption.

A. Energy consumption and network lifetime

In this section, we have evaluated energy consumption and network lifetime for different scenarios described below.

*1) Time variation scenario:*In this scenario, we have simulated the protocols for different simulation times and analysed their performance in terms of energy consumption, network lifetime and network stability period. The parameters of this scenario are illustrated in Table II.

TABLE II. TIME VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	[20, 40, 60..600]
Number of nodes	100
Packet size (byte)	100

Figure 1 shows the variation of total consumed energy according to the simulation time. The graph depicts that LEACH consumes the least, while AODV and LABILE have the highest total energy consumption. It also shows that the nodes that use AODV and LABILE consumes all of their energy at time 150 s, while for LEACH it remains until time 470 s.

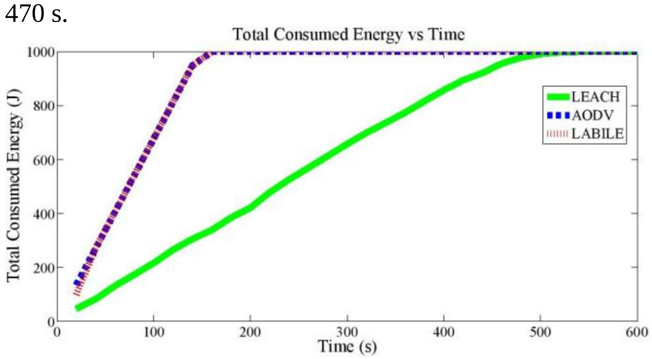

Figure 1. Total Consumed Energy vs Time.

From Figure 2, it is quite clear that by using LEACH the first node dies at time 435 s (stability period = 435 s) and the last at time 470 s. Nevertheless, with AODV and LABILE all nodes are dead between 145 s and 150 s (stability period = 145 s). Therefore, we can conclude that the nodes using LEACH consume less energy and subsequently the network has a long stability period. However, nodes using AODV and LABILE consume more energy and the network has a brief stability period relative to LEACH.

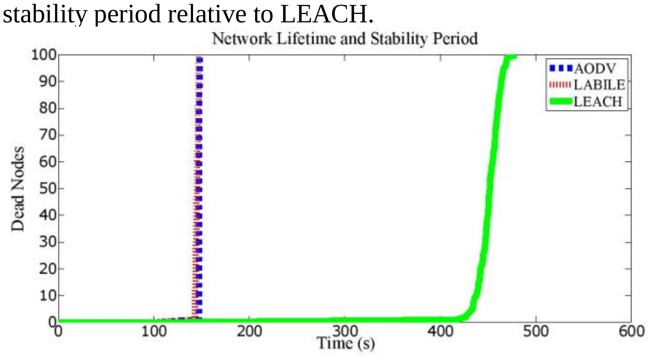

Figure 2. Network lifetime and Stability period.

So, due to the multi-hop routing technique used by flat routing protocols, energy consumption increases proportionally to the number of hops to reach the sink. Therefore, the nodes energy dissipates very quickly and the network stability period becomes short.

However with the hierarchical routing protocol that uses data aggregation; only the CHs nodes (only 5% of nodes) transmit data to the sink. Therefore, it retains the total energy of the network and increases the stability period.

2) Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes (100, 200, 300 and 400) and analysed their performance in terms of energy consumption. The parameters of this scenario are illustrated in Table III.

TABLE III. NODES DENSITY VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100, 200, 300, 400
Packet size (byte)	100

Figure 3 shows the variation of total consumed energy according to the number of nodes. The graph depicts that by increasing the number of nodes deployed, energy consumption also increases for the three routing protocols, but AODV and LABILE consume more energy than LEACH. With flat routing protocols, based on multi-hop routing, if we increase the density of nodes deployed, there will be as many of the nodes involved in the data transmission to the sink, so the energy consumption increases proportionally.

However, with hierarchical routing protocol, if we increase the node density the energy consumption increases obviously well, but with a lower slope than AODV and LABILE. These results are explained by the made where the number of nodes increases only the number of CHs increases (which are responsible for the data transmission to the sink).

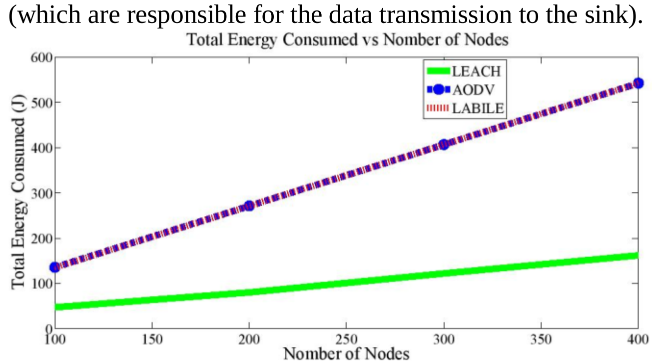

Figure 3. Total Consumed Energy vs Number of nodes.

3) Packet size variation scenario: In this scenario, we have simulated the protocols for different packet size (100, 200, 400, 600 and 800 bytes) and analysed their performance in terms of energy consumption. The parameters of this scenario are illustrated in Table IV.

TABLE IV. NODES DENSITY VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100
Packet size (byte)	100, 200, 400, 600, 800

Figure 4 shows the variation of total consumed energy according to the different packet size. The graph depicts that by increasing packet size energy consumption also increases for the three protocols but AODV and LABILE consume more energy than LEACH. For AODV and LABILE, by using multi-hop routing technique, by increasing packet size, nodes consume more energy to forward the packets from node to other until arriving to the sink. LABILE consumes less energy than AODV because it uses roads based on good link qualities selection technique. For LEACH, with the use of data aggregation, the CH eliminates data redundancy, which reduces the size of the transmitted packets to the sink. Therefore, the energy consumption increases proportionally with packet size, until it reaches the maximum data buffer size.

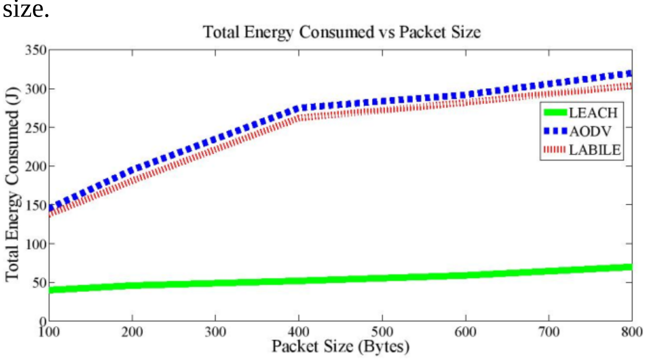

Figure 4. Total Consumed Energy vs Packet size.

B. Throughput

In this section, we have evaluated throughput (Total Data received by sink) for different scenarios described below.

*1) Time variation scenario:*In this scenario, we have simulated the protocols for different simulation times and analysed their performance in terms of total data received by the sink. The parameters of this scenario are illustrated in Table V.

TABLE V. TIME VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	[20, 40, 60..600]
Number of nodes	100
Packet size (byte)	100

Figure 5 shows the variation of total data received by the sink according to the simulation time variation. The graph depicts that by increasing the simulation time AODV and LABILE transmit more data to the sink than LEACH until it consumes all of her energy.

For these simulation results, we will compare the protocols, only during their stability period. LEACH has a low rate compared to other protocols because only CH sends data to the sink (5% of the total number of nodes). LABILE has a less rate than AODV because it sends the data only through the good quality links, so less traffic in the network and fewer packets transmitted to the sink.

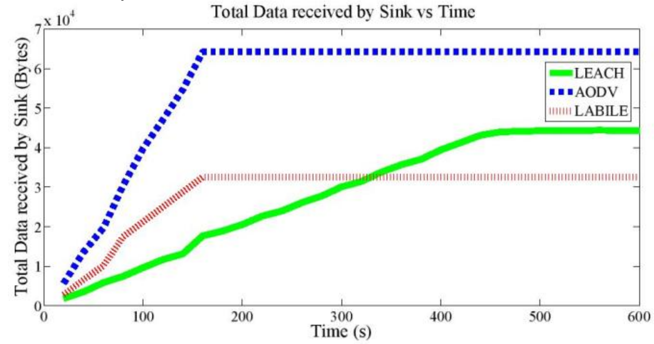

Figure 5. Total data received by the sink vs Time.

2) Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes (100, 200, 300 and 400) and analysed their performance in terms of throughput. The parameters of this scenario are illustrated in Table VI.

TABLE VI. NODES DENSITY VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100, 200, 300, 400
Packet size (byte)	100

Figure 6 shows the variation of total data received by sink according to the number of deployed nodes. The graph depicts that by increasing the number of deployed nodes AODV and LEACH are able to transmit more data to the base station unlike LABILE that transmits less. In this scenario, LABILE possesses a lower throughput than AODV and even as LEACH, because if we increase the number of nodes, the route selection algorithm takes a long time in the processing and in links quality selection phase. Therefore, fewer packets transmitted to the sink. LEACH throughput increases proportionately by increasing the numbers of nodes because the number of CH increases.

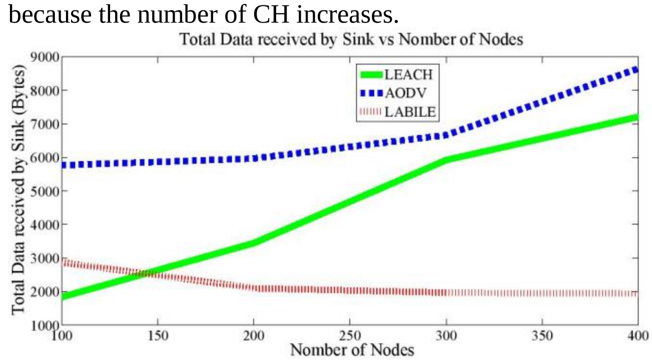

Figure 6. Total data received by the sink vs Number of nodes.

3) Packet size variation scenario: In this scenario, we have simulated the protocols for different packet size (100, 200, 400, 600 and 800 bytes) and analysed their performance in terms of total data received by the sink. The parameters of this scenario are illustrated in Table VII.

TABLE VII. PACKET SIZE VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100
Packet size (byte)	100, 200, 400, 600, 800

Figure 7 shows the variation of total data received by the sink according to the packet size. The graph depicts that by increasing the packets size, AODV and LABILE transmit data to the base station more than LEACH. AODV and LABILE provide better throughput for a packet size of 400 bytes. If the packet size exceeds 400 bytes, the buffer becomes overloaded and throughput decreases. For LEACH, throughput increases proportionately with the packet size until the size of 600 bytes because the CHs remove data redundancy in the packets. If the packet size exceeds 600 bytes, the buffer saturates.

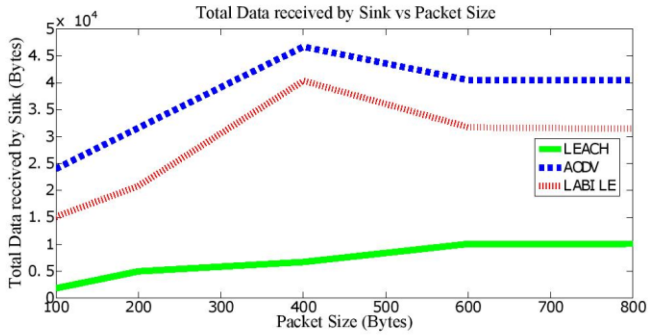

Figure 7. Total data received by the sink vs Packet size.

C. Throughput

In this section, we have evaluated packets latency time for different scenarios described below.

1) Time variation scenario: In this scenario, we have simulated the protocols for different simulation times and analysed their performance in terms of packets latency time. The parameters of this scenario are illustrated in Table VIII.

TABLE VIII. TIME VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20, 40, 60, 80, 100
Number of nodes	100
Packet size (byte)	100

Figure 8 shows the variation of latency intervals of received packets according to the simulation time. The graph depicts that by increasing the simulation time LEACH sent 90% of data in the range of (0-20 ms) while AODV sent the majority of data with time greater than 200 ms and LABILE with uniform distribution between 0 and 200ms. Conversely, LEACH sends 90% of the data with a latency less than 20 ms, because the nodes send their data to the CH and the CH forward this data directly to the sink. AODV and LABILE send their packets with a larger latency because the packets are moving from node to node until they reach the sink.

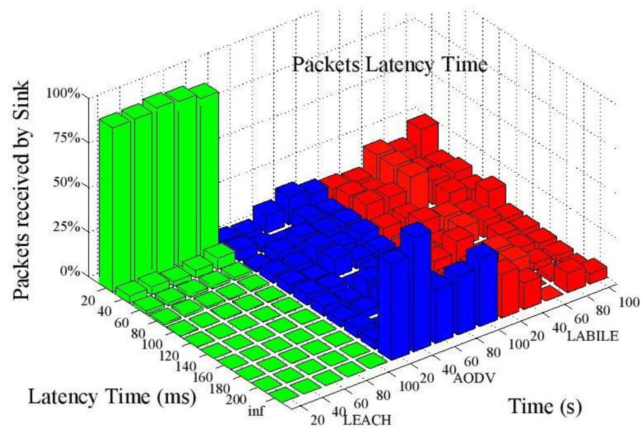

Figure 8. Packets latency time vs Time.

2) Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes and analysed their performance in terms of packets latency. The parameters of this scenario are illustrated in Table IX.

TABLE IX. NODES DENSITY VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100, 200, 300, 400
Packet size (byte)	100

Figure 9 shows the variation of latency intervals of received packets according to the number of deployed nodes.

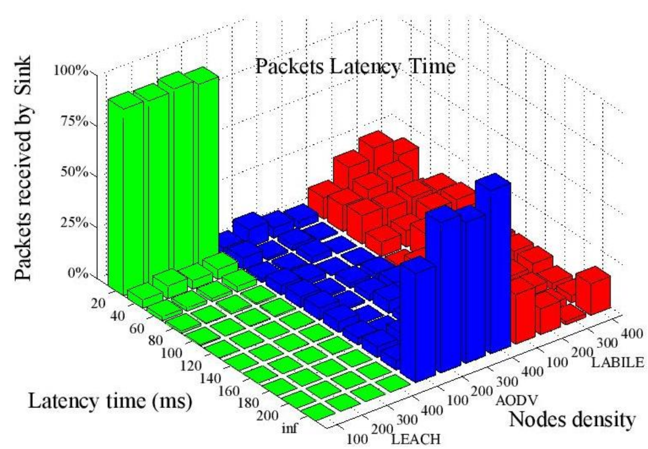

Figure 9. Packets latency time vs Number of nodes.

The graph depicts that by increasing the number of deployed nodes LEACH sent 90% of data in the range of (0-20 ms) while AODV sent 50% of data with time greater than 200 ms and LABILE with uniform distribution between 0 and 200 ms. For LEACH, if we increase the number of nodes, 90% of the packets always arrive at the sink with a latency less than 20 ms.

For flat routing protocols, if the number of nodes increases, the number of packets hops increases and the delay accumulates. With LABILE packets have less delay than AODV, due the mechanism of good links selection, which reduces the number of hops to the sink.

3) Packet size variation scenario: In this scenario, we have simulated the protocols for different packet size (100, 200, 400, 600 and 800 bytes) and analysed their performance in terms of packets latency time. The parameters of this scenario are illustrated in Table X.

TABLE X. PACKET SIZE VARIATION SCENARIO PARAMETERS.

Parameters	Values
Simulation time (s)	20
Number of nodes	100
Packet size (byte)	100, 200, 400, 600, 800

Figure 10 shows the variation of latency intervals of received packets according to the packet size. The graph depicts that by increasing the packet size, LEACH sent the majority of data in the range of (0-20 ms) while AODV sent 80% of data with time greater than 200 ms and LABILE sent 50% of data with uniform distribution between 0 and 200 ms. For flat routing protocols, if the packets size increases, the processing time and the packet forwarding delay increases and subsequently the packets arrives at the sink with over delay. For LEACH, if the packet size exceeds 600 bytes, the CHs take longer for data fusion and elimination of redundancy. By result, only 50% of data arrives with a latency of less than 20 ms.

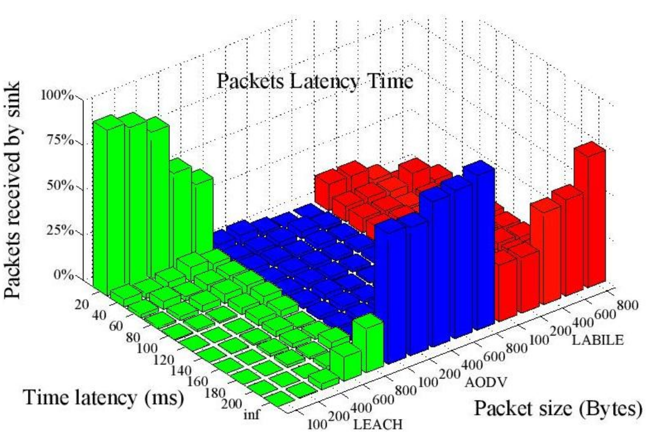

Figure 10. Packets latency time vs Packet size.

General Synthesis: For LEACH, with a 100 bytes packet size, 90% of the packets always arrive at the sink with a latency less than 20 ms, even with a density of 400 nodes / 100 m x 100 m. Even with a packet size of 400 bytes 75% of data arrives to the sink with a latency time less than 20 ms. So, we can conclude that LEACH protocol has the least delay to send data due to the data aggregation technique. Nevertheless, the LABILE and AODV protocols have the highest delay to send packets due the using of the multi-hop routing technique.

VI. CONCLUSION

In WSNs, a significant consideration has been given to the prolongation of node lifetime. Efficient utilization of energy is crucial for enhancing the node lifetime. Although wireless network sensors routing protocols like ad hoc on demand distance vector can be used, they usually do not focus on energy conservation, network lifetime prolongation of sensor nodes and delay to send data.

In this paper, we have evaluated three routing protocols for WSNs namely AODV, LABILE and LEACH using Castalia Simulator for energy consumption, network lifetime, throughput and latency time with reference to simulation time, number of deployed nodes and size of transmitted packets. Simulation results show that, under different conditions, LEACH protocol has least energy consumption and highest network lifetime compared to the LABILE and AODV protocols. The AODV and LABILE protocols have the least network lifetime because of high-energy consumption per node. This makes AODV and LABILE unsuitable for WSNs, where lifetime is a primary metric for evaluating the performance and LEACH protocol has become better for network lifetime.

Under different simulation conditions, the results show that LEACH protocol has the least throughput because of the use of data aggregation technique. Nevertheless, the LABILE and AODV protocols have the highest throughput and that from the multi-hop technique used by both routing protocols. This makes LEACH unsuitable for WSNs applications, where throughput is a primary metric for evaluating the performance likewise, AODV and LABILE become better for this type of applications. Under different scenarios, the results show that LEACH protocol has the least delay to send data due to the data fusion technique. Nevertheless, the LABILE and AODV protocols have the highest delay to send packets due to the using of multi-hop technique. This makes AODV and LABILE unsuitable for real-time WSNs applications, where latency time is a primary metric for evaluating the performance and LEACH become better for this type of applications.

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