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Compromises Between Quality of Service Metrics and Energy Consumption of Hierarchical and Flat Routing Protocols for Wireless Sensors Network

[1] Abdelbari BEN YAGOUTA and [2] Bechir BEN GOUISSEM

[1, 2] Communication System Laboratory Sys'Com, National Engineering School of Tunis
University Tunis El Manar, BP 37, 1002 Tunis Le Belvedere, Tunisia
[1] Tel.: (+216)52910006, fax: (+216) 71 872 729
[1] E-mail: Abdelbari.benyagouta@gmail.com

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Abstract: Wireless Sensor Network (WSN) is wireless network composed of spatially distributed and tiny autonomous nodes, which cooperatively monitor physical or environmental conditions. 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 conservation. However, many WSNs applications require QoS (Quality of Service) criteria, such as latency, reliability and throughput. In this paper, we will compare three routing protocols for wireless sensors network 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, throughput, reliability and latency time of packets received by sink under different conditions to determinate the best configurations that offers the most suitable compromises between energy conservation and all QoS metrics for each routing protocols. The results show that, the best configurations that offer the suitable compromises between energy conservation and all QoS metrics is a large number of deployed nodes with low packet rate for LEACH (300 nodes and 1 packet/s), a medium number of deployed nodes with low packet rate For AODV (100 nodes and 1 packet/s) and a very low nodes density with low packet rate for LABILE (50 nodes and 1 packet/s).

Keywords: WSN, Routing protocols, Latency time, Reliability, Throughput, Energy consumption.

1. 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. In this context clustering approach is one of the best ways for saving energy and prolonging network lifetime. In this approach, the sensor nodes group themselves into clusters, and then an elected cluster head (CH) sends the aggregated data from each cluster of nodes to the sink. Other than the power consumption criterion, some WSN applications such as, real-time applications require QoS criteria like latency.

On the other hand, there are other types of WSN applications like acoustic and imaging applications that requires significant throughput, as data must be streamed through the network and requires high reliability so that the captured information does not lose its relevance.

In this context, distance-vector routing protocols based on calculating of direction and distance to any link in a network and multi-hop routing can ensure a great throughput and high reliability.

There have been some works already done to compare the performances of energy conservation and quality of service between hierarchical routing protocols based in clustering approach and flat routing protocols based in distance vector as that in [3], who find that hierarchical routing protocols better conserves energy and provides low packets latency time and the flat routing protocols are more efficient in terms of throughput.

In this work, we have compared the same three WSNs routing protocols compared in [3]; AODV and LABILE based on distance-vector and LEACH based on clustering approach to determinate the best configurations that offers the most suitable compromises between energy conservation and QoS metrics for each routing protocols.

The source codes of these three routing protocols are developed for Omnet++/ Castalia simulator by GERCOM (research Group on Computer Network and Multimedia Communication) [4].

The results show that, the best configurations that offer the suitable compromises between energy conservation and all QoS metrics is a large number of deployed nodes with low packet rate for LEACH (300 nodes and 1 packet/s), medium number of deployed nodes with low packet rate For AODV (100 nodes and 1 packet/s) and very low nodes density with low packet rate for LABILE (50 nodes and 1 packet/s).

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.

2. 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 [5]. 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.

Other works like in [3], LEACH, LABILE and AODV routing protocols are compared for energy consumption, network lifetime, latency time and throughput. 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.

However, many WSNs applications require c compromise between energy conservation and some QoS criteria like imaging applications.

The particularity of this work is to compare hierarchical (LEACH) and flat routing protocols (AODV and LABILE) in terms of energy consumption, reliability, latency time and throughput under different scenarios to determinate the best configurations that offers the most suitable compromises between energy conservation and all QoS metrics for each routing protocols.

3. Routing Protocols for WSN: an Overview

WSNs routing protocols are classified according to their architecture or their operating principles into flat, location-based and hierarchical/cluster categories [6]. 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 [7], such as multimedia traffic [8].

The energy saving, throughput, reliability 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.

3.1. AODV Routing Protocol

AODV protocol [9] 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.

3.2. LABILE Routing Protocol

LABILE [10] 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.

3.3. LEACH Routing Protocol

LEACH [11], 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.

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 [11].

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...

4. Simulation Scenarios

In this work, we want to make compromises between energy consumption, packet latency time, reliability and throughput by comparing hierarchical and flat WSNs routing protocols. 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 [12].

By using the ”Throughput Test” application implemented in Castalia simulator, we suppose that all nodes have data to sending, have an initial energy of 100 joules and randomly placed in a 100 m x 100 m area, and the base station is placed in the field centre (x=50 m, y=50 m and z= 0 m).

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

Table 1. Global simulation parameters.

Parameters	Values
Routing protocols.	AODV, LABILE, LEACH.
Node deployment	Random (topology)
Number of Simulation Repetition	20
Sink Position (x, y, z)	(50 m, 50 m, 0 m)
Collision Model	Simple collision
Area	100 m ×100 m
Initial energy/node	100 Joules
Sink Initial Energy	1000 Joules
TX output power	-5 dBm
Packet size	100 bytes
Node Radio Buffer Size	100 bytes
Node Mac Buffer Size	100 bytes
Node Net. Buffer Size	2048 bytes
Sink Net. Buffer Size	10240000 bytes
Application name	Throughput Test
Path loss exponent	2.0 (Free Space)
Radio parameter file	CC2420.txt
Round length *	20 s (Duration between two rounds)
Slot length *	0.2 ms (TDMA slot dedicated to each node)
Routing percentage *	0.05 (Percentage of Cluster Head 5 %)

5. Results and Analysis

In this section, we will present results under different simulation scenarios by varying simulation time, node density and packets rate. These results are analysed to study the compromise between latency time, reliability, throughput, and energy consumption of these protocols.

5.1. Throughput and Energy Consumption

In this section, we have evaluated energy consumption and throughput (packets received by sink) for different scenarios described below.

Time variation scenario: In this scenario, we have simulated the protocols for different simulation times (20, 100, 200, 300) and analysed their performance in terms of energy consumption and throughput. The parameters of this scenario are illustrated in Table 2.

Table 2. Time variation simulation parameters.

Parameters	Values
Simulation time (s)	20, 100, 200, 300
Number of nodes	100
Packet rate (packet/s)	1

Throughput is defined as the number of packets received by the base station.

E/T ratio is defined by the ratio energy over Throughput expressed in [J / packet].

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Fig. 1 shows the variation of total packets received by sink and the total energy consumed according to the simulation time.

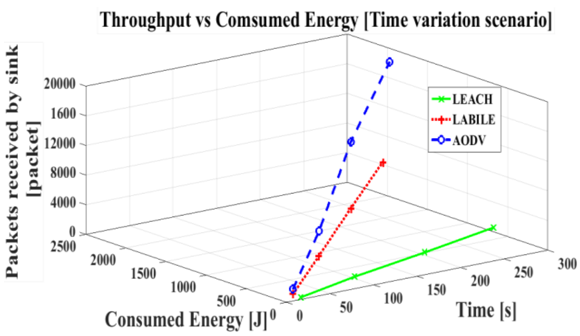

Fig. 1. Throughput and Consumed Energy vs Time.

The graph depicts that by increasing simulation time, throughput and energy increases also for the three routing protocols but with different slopes in the following way:

For LEACH, if we increase simulation time from 20 s to 300 s, throughput increase also from 25 packets to 576 packets and energy increase also from 42j to 676j, supposedly with a ratio E/T = 1.18 j/packets.

For LABILE, if we increase simulation time from 20s to 300s, throughput increase also from 102 packets to 4362 packets and energy increase also from 137j to 2057j, supposedly with a ratio E/T=0.48 j/packets.

For AODV, if we increase simulation time from 20 s to 300 s, throughput increase also from 795 packets to 18178 packets and energy increase also from 136j to 1972j, supposedly with a ratio E/T= =0.117 j/packets.

Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes (50, 100, 150, 200, 250, 300) and analysed their performance in terms of energy consumption and throughput. The parameters of this scenario are illustrated in Table 3.

The density D is defined by the number of nodes deployed in an area of 100 m × 100 m.

Table 3. Nodes density variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	50, 100, 150, 200, 250, 300
Packet rate (packet/s)	1

Fig. 2 below shows the variation of total packets received by sink and the total energy consumed according to the number of nodes. The graph depicts that by increasing the density of nodes:

For LEACH, if we increase the number of nodes from 50 nodes to 300 s, throughput increase also from 104 packets to 538 packets and energy increase also from 159j to 614j, and the E/T ratio decreases from 1.52 J/packet to 1.14 J/packet.

For LABILE, if we increase the number of nodes from 50 nodes to 300s, the total energy consumption increase also from 346j to 2016j and throughput increase also from 1322 packets for 50 nodes to 1826 packets for 200 nodes then decreases to 986 packets for 300 nodes so, the E/T ratio increases proportionally to the number of nodes from 0.26 j/packet to 2.05 j/packet.

For AODV, if we increase the number of nodes from 50 nodes to 300 s, the total energy consumption increase also from 332j to 2054j and throughput increase also from 2820 packets for 50 nodes to 4782 packets for 100 nodes then decreases to 3842 packets for 300 nodes so, the E/T ratio increases proportionally to the number of nodes from 0.117 j/packet to 0.53 j/packet.

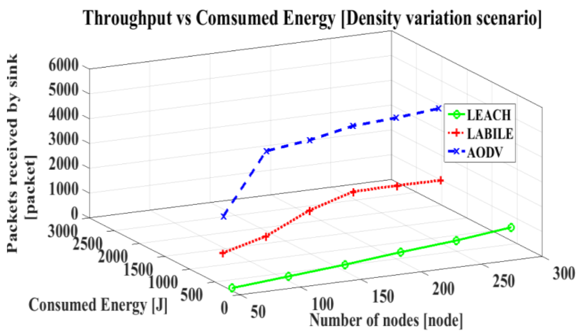

Fig. 2. Throughput and Consumed Energy vs Density.

So we can conclude that the best compromise between throughput and energy consumption is achieved with the following density:

D=100 nodes for AODV, with 4782 packets received by the sink and 680j total energy consumed, supposedly with a E/T ratio of 0.14 J/packet.

D=50 nodes for LABILE, with1322 packets received by sink and 346J energy consumed, supposedly with a ratio of 0.26 J/packet.

For LEACH, since throughput and energy consumption increases with very similar slopes so no compromise occurs between throughput and energy consumption for the configurations shown in Table 1 and Table 3.

Packet rate variation scenario: In this scenario, we have simulated the protocols for different packet rate (1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28) and analysed their performance in terms of energy consumption and throughput. The parameters of this scenario are illustrated in Table 4.

The Packet rate PR is defined by the number of packets sent per second by each node.

Table 4. Packets rate variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	100
Packet rate (packet/s)	1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28
Node Radio Buffer Size	10000 bytes
Node Mac Buffer Size	10000 bytes
Node Net. Buffer Size	10000 bytes

Fig. 3 shows the variation of total packets received by sink and the total energy consumed according to the packet rate.

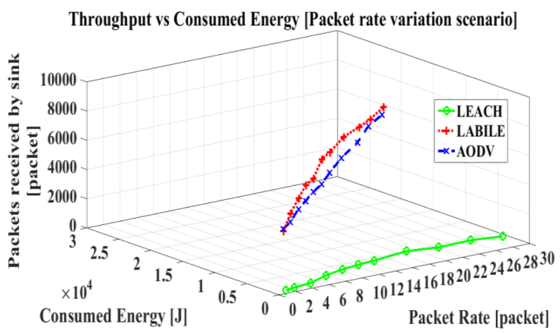

Fig. 3. Throughput and Consumed Energy vs Packet Rate.

The graph depicts that by increasing Packet Rate the energy consumption increases for the three protocols but the throughput reaches a maximum and then decreases when the buffers become saturated for the three protocols but with different slopes in the following way:

For LEACH, if we increase the packet rate, throughput increases also from 175 packets for PR = 1 packet/s until 973 packets for PR = 16 packet/s then decreases to 485 packets for PR = 28 packet/s and the energy consumption increases from 225J for PR=1 packet/s to 1630J for PR =28 packet/s.

For LABILE, if we increase the packet rate, throughput increases also from 4169 packets for PR = 1 packet/s until 7283 packets for PR = 16 packet/s then decreases to 6504 packets for PR = 28 packet/s and the energy consumption increases from 612j for PR=1 packet/s to 20190J for PR =28 packet/s.

For AODV, if we increase the packet rate, throughput increases also from 4277 packets for PR = 1 packet/s to 6080 packets for PR = 26 packet/s then decreases to 5893 packets for PR = 28 packet/s and the energy consumption increases from 680j for PR=1 packet/s to 20509J for PR =28 packet/s.

So we can conclude that the best compromise between throughput and energy consumption is achieved with the following packet rate:

PR=8 packets/s for LEACH with 714 packets received by sink and 586j, supposedly with a ratio of 0.82 J/packet.

PR=1 packet/s for LABILE with of 4169 packets received by sink and 612j, supposedly with a ratio of 0.14 J/packet.

PR=1packet/s for AODV with 4277 packets received by sink and 680j, supposedly with a ratio of 0.16 J/packet.

5.2. Throughput and Reliability

In this section, we have evaluated throughput and reliability for different scenarios described below.

Time variation scenario: In this scenario, we have simulated the protocols for different simulation times (20, 100, 200, 300) and analysed their performance in terms of throughput and reliability. The parameters of this scenario are illustrated in Table 5.

Table 5. Time variation simulation parameters.

Parameters	Values
Simulation time (s)	20, 100, 200, 300
Number of nodes	100
Packet rate (packet/s)	1

Fig. 4 shows the variation of total packets received by sink and reliability according to the simulation time. The graph depicts that by increasing the simulation time, throughput and reliability increases for all protocols but with different slopes in the following way:

For LEACH, if we increase simulation time from 20 s to 300 s, throughput increase also from 25 packets to 576 packets and reliability increase from 1.4 % to 2.2 %.

For LABILE, if we increase simulation time from 20 s to 300 s, throughput increases also from 102 packets to 4362 packets and reliability increases from 5.5 % to 15.6 %.

For AODV, if we increase simulation time from 20 s to 300 s, throughput increases also from 795 packets to 18178 packets and reliability increases from 42 % to 61 %.

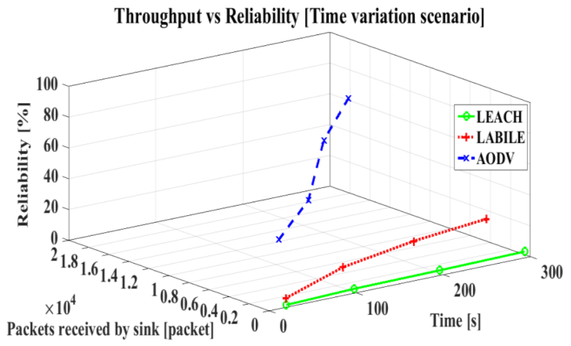

Fig. 4. Throughput and Reliability vs Time.

Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes (50, 100, 150, 200, 250, 300) and analysed their performance in terms of throughput and reliability. The parameters of this scenario are illustrated in Table 6.

Table 6. Nodes density variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	50, 100, 150, 200, 250, 300
Packet rate (packet/s)	1

Fig. 5 shows the variation of total packets received by sink and reliability according to the number of nodes.

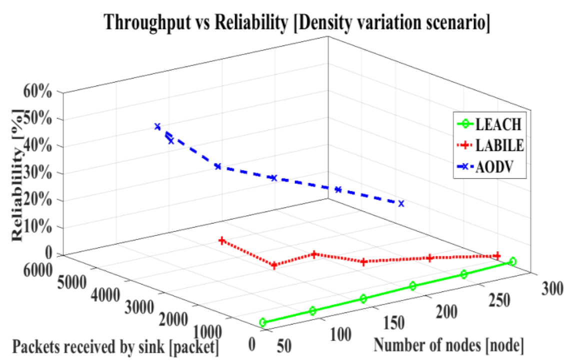

Fig. 5. Throughput and Reliability vs Density.

The graph depicts that by increasing nodes density, throughput evolves as cited in above scenarios of nodes density variation and the reliability decreases with different slopes as follows:

For LEACH, the reliability decreases from 2.1 % for 50 nodes to 1.6 % for 300 nodes.

For LABILE, the reliability decreases from 27 % for 50 nodes to 1.7 % for 300 nodes.

For AODV, the reliability decreases from 60 % for 50 nodes to 8 % for 300 nodes.

So we can conclude that the best compromise between throughput and energy consumption is achieved with the following density:

D=300 nodes for LEACH, with a throughput of 538 packets received by sink and 1.6 % of reliability.

D=50 nodes for LABILE, with a throughput of 1322 packets received by sink and 27 % of reliability.

D=100 nodes for AODV, with a throughput of 4782 packets received by sink and 50 % of reliability.

Packet rate variation scenario: In this scenario, we have simulated the protocols for different packet rate (1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28) and analysed their performance in terms throughput and reliability. The parameters of this scenario are illustrated in Table 7.

Table 7. Packets rate variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	100
Packet rate (packet/s)	1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28
Node Radio Buffer Size	10000 bytes
Node Mac Buffer Size	10000 bytes
Node Net. Buffer Size	10000 bytes

Fig. 6 shows the variation of total packets received by sink and reliability according to the packet rates.

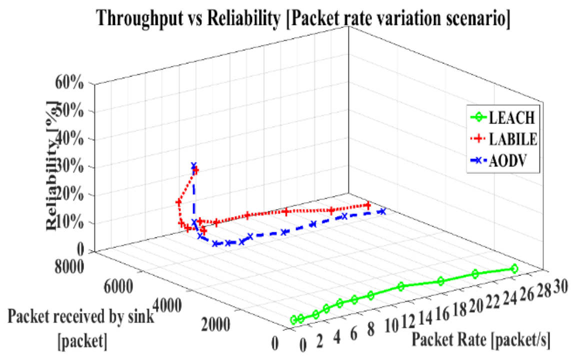

Fig. 6. Throughput and Reliability vs Packet Rate.

The graph depicts that by increasing the packet rate PR, throughput evolves as cited in above scenarios of packet rate variation and the reliability decreases for the three protocols but with different slopes as follows:

For LEACH, the reliability decreases from 1.7 % for 1 packet/s to 0.17 % for 28 packets/s

For LABILE, the reliability decreases from 42 % for 1 packet/s to 4 % for 28 packets/s

For AODV, the reliability decreases from 43 % for 1 packet/s to 2.1 % for 28 packets/s.

So we can conclude that the best compromise between throughput and energy consumption is achieved with the following packet rates:

PR=12 packets/s for LEACH, with 827 packets received by sink and 0.7 % of reliability.

PR=1 packets/s for LABILE with 4168 packets received by sink and 43 % of reliability.

PR=1 packets/s for AODV with 4277 packets received by sink and 42 % of reliability.

5.3. Throughput and Latency Time

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

Time variation scenario: In this scenario, we have simulated the protocols for different simulation times (20, 100, 200, 300) and analysed their performance in terms of throughput and latency time. The parameters of this scenario are illustrated in Table 8.

The percentage L_{20} is defined by the percentage of packets that arrive at the Base Station with a latency time less than 20 ms.

Table 8. Time variation simulation parameters.

Parameters	Values
Simulation time (s)	20, 100, 200, 300
Number of nodes	100
Packet rate (packet/s)	1

Fig. 7 shows the variation of total packets received by sink and the percentage of packets that arrive at the sink with a latency time less than 20 ms according to the simulation time.

The graph depicts that by increasing simulation time, throughput increases for the three protocols as cited above in the time variation scenario but the L_{20} percentage remains almost constant for the three protocols as follows: 91 % for LEACH, 21 % for LABILE and 6 % for AODV.

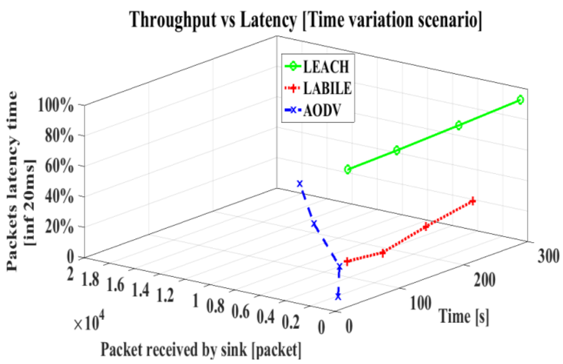

Fig. 7. Throughput and Latency vs. Time.

Nodes density variation scenario: In this scenario, we have simulated the protocols for different numbers of nodes (50, 100, 150, 200, 250, 300) and analysed their performance in terms of throughput and latency time. The parameters of this scenario are illustrated in Table 9.

Table 9. Nodes density variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	50, 100, 150, 200, 250, 300
Packet rate (packet/s)	1

Fig. 8 below shows the variation of total packets received by sink and the percentage of packets that arrive at the sink with a latency time less than 20 ms according to the number of nodes.

The graph depicts that by increasing nodes density D, throughput evolves as cited in above scenarios of nodes density variation and the latency time represented by L_{20} decreases for the three routing protocols with different slopes as follows:

For LEACH, the percentage L_{20} decreases proportionally from 94 % for 50 nodes to 86 % for 300 nodes.

For LABILE, the percentage L_{20} decreases proportionally from 28 % for 50 nodes to 6 % for 300 nodes.

For AODV, the percentage L_{20} decreases proportionally from 11 % for 50 nodes to 0.1 % for 300 nodes.

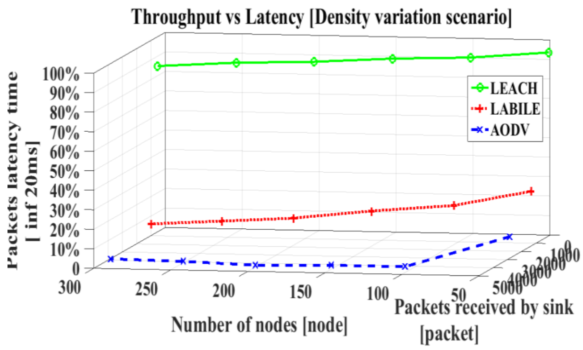

Fig. 8. Throughput and Latency vs. Density.

So we can conclude that the best compromise between throughput and latency time is achieved with the following density:

D=300 nodes for LEACH, with 540 packets received by sink that 85 % of them arriving at the sink with a latency time less than 20 ms.

D=50 nodes for LABILE, with 1322 packets received by sink that 27 % of them arriving at the sink with a latency time less than 20 ms.

D=100 nodes for AODV with 4782 packets received by sink that 6 % of them arriving at the sink with a latency time less than 20 ms.

Packet rate variation scenario: In this scenario, we have simulated the protocols for different packet rates and analysed their performance in terms throughput and latency time. The parameters of this scenario are illustrated in Table 10.

Table 10. Packets rate variation simulation parameters.

Parameters	Values
Simulation time (s)	100
Number of nodes	100
Packet rate (packet/s)	1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28
Node Radio Buffer Size	10000 bytes
Node Mac Buffer Size	10000 bytes
Node Net. Buffer Size	10000 bytes

Fig. 9 below shows the variation of total packets received by sink and the percentage of packets that arrive at the sink with a latency time less than 20 ms according to the packets rate. The graph depicts that by increasing Packet rate PR, throughput evolves as cited in above scenario of packet rate variation and the latency time represented by L20 decreases for the three routing protocols with different slopes as follows:

For LEACH, the percentage L_{20} decreases proportionally from 91 % for PR=1packet/s to 0 % for PR=24 packets/s.

For LABILE, the percentage L_{20} decreases proportionally from 2.5 % for PR=1packet/s to 0 % for PR=4 packets/s.

For LABILE, the percentage L_{20} decreases proportionally from 1.2 % for PR=1packet/s to 0 % for PR=2 packets/s.

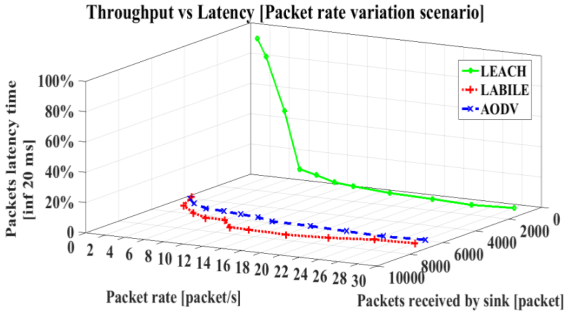

Fig. 9. Throughput and Latency vs Packet Rate.

So we can conclude that the best compromise between throughput and latency time is achieved with the following packet rate:

PR=2 packets/s for LEACH, with 540 packets received by sink that 80 % of them arriving at the sink with a latency time less than 20 ms.

PR=2 packets/s for LABILE, with 5240 packets received by sink that 1 % of them arriving at the sink with a latency time less than 20 ms.

PR=1 packets/s for AODV with 4280 packets that 1 % of them arriving at the sink with a latency time less than 20 ms.

6. Conclusions

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, throughput, reliability and latency time with reference to simulation time, number of deployed nodes and rate of transmitted packets to determinate the best configurations that offers the most suitable compromises between energy conservation and QoS metrics for each routing protocols.

For LEACH, under different scenarios, as shown above in Table 1, 2, 3 and 4, the results show that with a density of 300 nodes/100 × 100m² and a packet rate of 1 packet/s, we obtain the best compromise between energy consumption and all QoS metrics with total consumed energy of 614j, 1.6 % of reliability and 538 packets received by sink that 85 % of them arriving at the sink with a latency time less than 20 ms.

For LABILE, under different scenarios, as shown above in Tables 1, 2, 3 and 4, the results show that with a density of 50 nodes/100 × 100 m² and a packet rate of 1 packet/s, we obtain the best compromise between energy consumption and all QoS metrics with total consumed energy of 346 j, 27 % of reliability and 1322 packets received by sink that 28 % of them arriving at the sink with a latency time less than 20 ms.

For AODV, under different scenarios, as shown above in Tables 1, 2, 3 and 4, the results show that with a density of 100 nodes/100 × 100 m² and a packet rate of 1 packet/s, we obtain the best compromise between energy consumption and all QoS metrics with total consumed energy of 332 j, 57 % of reliability and 2820 packets received by sink that 11 % of them arriving at the sink with a latency time less than 20 ms.

So we can conclude that, LEACH protocol is suitable for WSN applications, with large number of deployed nodes but with a low packet rate (300 nodes and 1 packet/s), AODV is suitable for WSN applications with medium number of deployed nodes and with a low rate (100 nodes and 1 packet/s) and LABILE is suitable for WSN applications that requires very low nodes density with a low packet rate (50 nodes and 1 packet/s).

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