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Improved uplink throughput and energy efficiency of LoRaWAN using 2-hop LEACH protocol

Yassine Oukessou[1], Mohamed Baslam[2], Mohamed Oukessou[3]
[1,3]Applied Mathematics and Scientific Computing Laboratory, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco
[2]Information Processing and Decision Support Laboratory, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni-Mellal, Morocco

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ABSTRACT

The low power wide area networks (LPWAN) is the new connectivity technology that is geared towards energy constrained internet of things (IoT) devices, is starting to become one of the drivers of the re-accelerating IoT market and has one goal: ensure the wide range distance while reducing the battery energy consumption. We focus in this paper on the evaluation of the uplink throughput of the long-range wide area networks (LoRaWAN) then we attempt optimize the throughput and power dissipation using low energy adaptive clustering hierarchy (LEACH) protocol. Therefore, we exploit a novel module developed in NS-3 simulator for obtaining the first measurements scenario, then the LEACH algorithm for the second optimization case. As result, the simulation analysis will help us to add a new LoRaWAN routing protocol feature.

Corresponding Author:

Yassine Oukessou
Applied Mathematics and Scientific Computing Laboratory, Faculty of Sciences and Technics
Sultan Moulay Slimane University
Beni Mellal, Morocco
Email: Oukyassine@gmail.com

1. INTRODUCTION

The internet of things (IoT) has lately emerged as a new trend in the growth of wireless networks. In which there will be a billion IoT nodes by the end of this decade [1], [2]. In contrast to typical broadband networks, low power wide area networks (LPWANs) are designed to provide a long-range coverage at a low bit rate to the connected objects powered by batteries in a license-free frequency bands [3]. There are several competitive LPWAN systems on the market today. We concentrate on new Semtech's long-range wide area networks (LoRaWAN), which is operates on LoRa modulation technology [4].

LoRa is a physical layer protocol used for peer-to-peer communications modulation between nodes. Each symbol is modulated by a chirp signal in which their frequency increases up or down and their duration is called spreading factore (SF). The Lora operates from the short SF 7 which has a high bandwidth rate to the long SF 12 which has more resistant to the environment factors like noise, interference and multipath. On the other hand, LoRaWAN is a media access control (MAC) link layer point to multipoint protocol that uses LoRa modulation as physical layer. It provides network routing mechanism, quality of service (QoS), power consumption and security components. The LoRaWAN offers an ecosystem includes hardware module vendors, software service developers, data analyzers, telecommunication operators. Meanwhile, the LEACH protocol [5]-[10] is a multi-hop communication routing technique that improves energy efficiency to minimize the use of energy resources and extend the network lifetime while transferring uplink data from nodes to base stations.

This paper is structured as follows. The second section provides an overview of the LoRaWAN and LEACH protocols. In section 3, we implement the NS-3 [11] simulation of this network; It will be achieved using a number of motes produces a traffic amount and handled by the gateway, then the throughput and packet loss ratio are gathered and measured at the sink. Section 4 will propose a new LEACH design call flow implementation and performance simulation analysis. Finally, section 5 discusses conclusions.

2. OVERVIEW OF LORAWAN AND LEACH PROTOCOLS

2.1. Overview of LoRaWAN

The chirp spread spectrum (CSS) technique is used by the long range (LoRa) modulation, in which uses a wideband linear frequency chirp pulses to modulate the signal information; parameterized by the spreading factor SF, and which can take values from 7 to 12. We note that the higher the SF is, the longer in time the packet and the more reliable its reception will be [12], [13]. As a result, it improves robustness against interference and helps combat multipath fading phenomenon of the indoor environment propagation and urban areas [14], [15].

Typical channel bandwidths are 125 kHz, 250 kHz or 500 kHz; with data rate depends on the used bandwidth. While Semtech's LoRa physical layer is private, the LoRaWAN media access control (MAC) protocol is accessible to developers and detailed in the LoRa Alliance specification [16], [17]. The LoRaWAN network uses star of stars topology, with gateways forming a bi-directional forwarder bridge between end nodes and could servers. The gateways are gathering data via LoRa packets from end devices and converting then aggregating into IP packets towards cloud servers Figure 1.

The LoRaWAN defines three device classes as described in Figure 2:

- Class A: At any time, the end node can initiate an uplink transmission signal, then will opens two receive slots windows. The gateway then can respond within the first or second slot, but not both.
- Class B: In addition to class A, the class B will open an extra receive slots for a time-synchronized beacon, allowing the gateway to know exactly when the end node is in listening mode.
- Class C: In addition to class A, a class C device will continuously listen to the gateway.

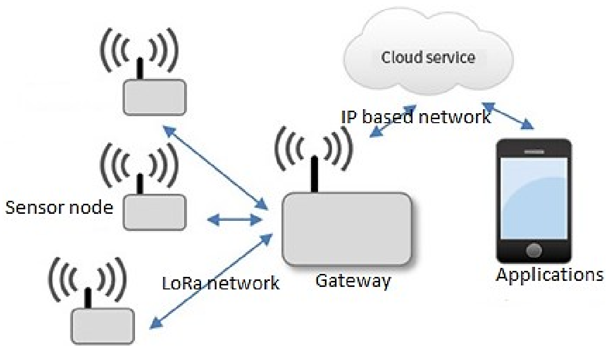

Figure 1. LoRaWAN network architecture topology

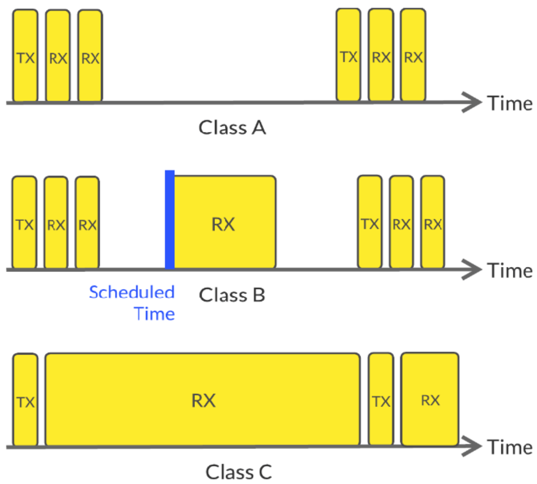

Figure 2. LoRaWAN device classes

2.2. Overview of LEACH protocol

LEACH is a round-based MAC layer low energy hierarchical routing protocol. The round starts by a set-up process where the clusters are arranged, and terminate by a steady-state phase [18], [19], when the gathered packets is transmitted to the sink. Every node decides whether it will be a cluster head (CH) or not during the set-up stage, based on a predetermined threshold T_n and a generated random number $0<i<1$. If $i<T_n$, the node becomes CH and broadcast an advertissment message to the other nodes using the MAC protocol. Otherwise, the nodes will choose the nearest CH that is available. The threshold T_n as following:

$$T_n = \begin{cases} \frac{p}{1-p\left(r \times \mathrm{mod}\left(\frac{1}{p}\right)\right)} & ; n \in K \\ 0 & ; \text{others} \end{cases} \quad (1)$$

where K is the set of devices that not chosen as cluster heads in the previous $\frac{1}{p}$ round; r is the number of the round. After the CH operations have been completed. The steady-state stage begins with the CH allocation time slots to all cluster member devices, followed by the aggregation and processing of the transmitted data, and finally, the packets will transmitted to the gateway, as seen in Figure 3.

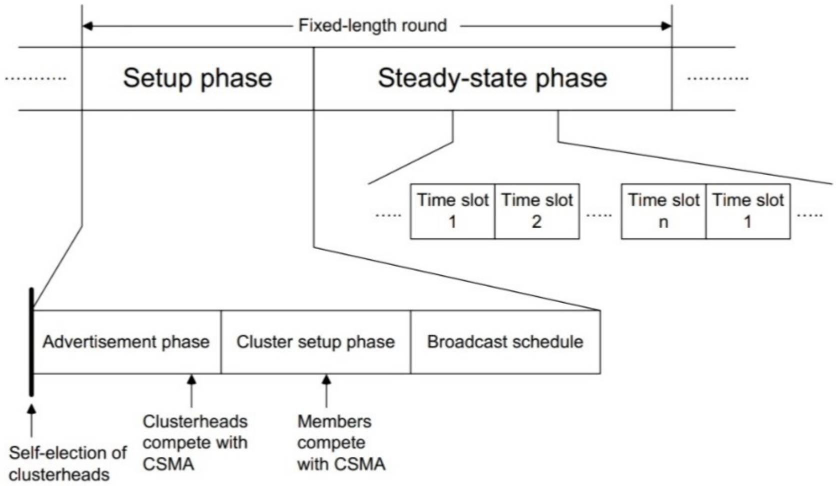

Figure 3. Time line steps of LEACH

3. LORAWAN THROUGHPUT EVALUATION

We created the simulation by analyzing the throughput of the LoRaWAN network described by a number of motes arranged around a single sink in a specified area circle (no obstacles are in sight) using the NS-3 network simulator [11] and the repository [20]. Only node-generated uplink data traffic (each of which produces 1 packet per 10 minutes) is allowed in the simulation test, and that each node uses a specific spreading factor SF randomly. The gateway then enables 8 window receivers that are all active at the same time (1% duty cycle shared across all subchannels). For 1000 nodes, we get about 100 packets per minute, according to Figure 4. We also observe a minor fluctuation in throughput reported with a minor interference occurred, and there were no longer any subchannel receivers available (if a packet comes on a certain LoRa subchannel and there are no window receivers available, the packet will fail [21], [22], [23]) as defined in Figure 5.

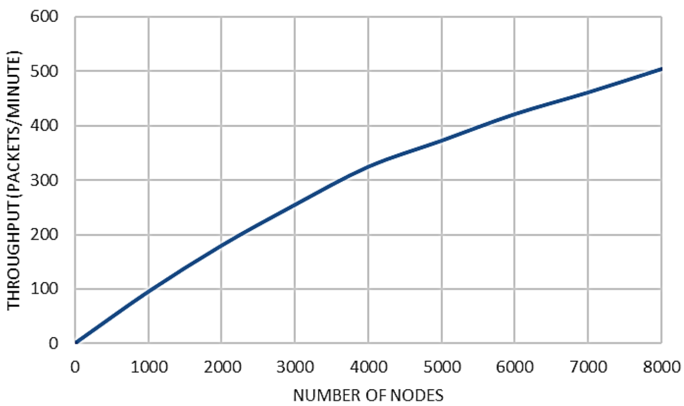

Figure 4. Throughput per number of nodes

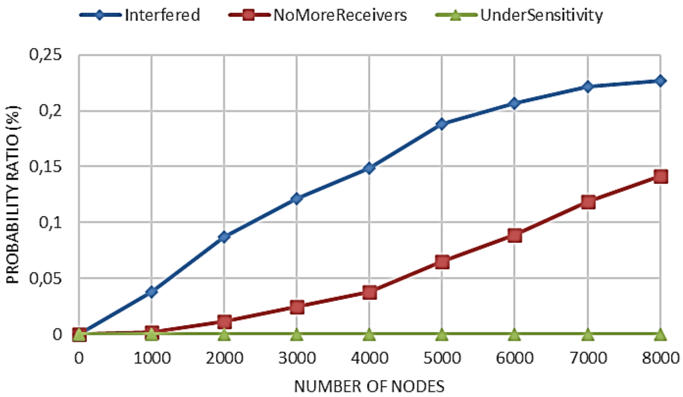

Figure 5. Probability ratio loss per number of nodes

4. LORAWAN LEACH PROTOCOL

In difference to the LoRaBlink protocol [24], [25], [26] in which enables the multi-hop communications based on the flooding mechanism, by distributing the time slotted channel synchronization from the gateway to the nodes, then the motes uses the flooding approach for the uplink data transfers. Also authors in [27] propose the Destination Sequenced Distance Vector DSDV routing protocol implemented to cover the leaf nodes which are not covered by the gateway and based on the storing routing table of each node. However, the energy efficiency is not considered at all for both solutions, the only duty cycle is enabling by default for conserving the battery power energy.

We propose here a new 2-hop implementation LoRaWAN LEACH protocol (LLP) using LEACH algorithm, in which still the best energy effiency routing protocol. Therefore, we assume in this section that all the LoRaWAN nodes are in class B mode. Therefore, it is energivorous because of the listening mode radioactivity; by the way, the LEACH protocol will surely reduce the power consumption. At first, we provide a sample explanation of the new proposed design, then a simulation comparison using NS-3 tool.

4.1. LoRaWAN LEACH design

In our design each gateway synchronization beacon will start a LEACH round challenge. A set-up stage and a steady-state phase then will be performed. The following is the call flow explanation of the new algorithm and the illustration on Figure 6.

Algorithm: LoRaWAN LEACH protocol
The Gateway initiate the LEACH round by sending the synchronization beacon to all the nodes
for each node N selects a random number $0 < i < 1$
if $T_n < i$
then N becomes a CH and advertise their identifications IDs, and the allocated TDMA timeslots to the neighbor nodes.
else N becomes a normal node and receives the advertisements from CHs.
N transmit a unicast data to the closest CH based on the RSSI of their advertisements message.
CH receives data from the client nodes, then it will compress it and transmitted to the gateway.
end

4.2. LoRaWAN LEACH protocol simulation

We ran the first simulation using the modified repository [28], and checking the average energy consumed by all the nodes over a given time period. We keep as the previous NS-3 simulation each device generate one packet every round (set-up and stady-in-stage duration phases) exactly each 10 minutes. The second simulation is the lifespan of the power consumption nodes. Finally, we examined the overall throughput created by all nodes and transferred to the gateway. We will presume then that the gateway is plugged into a power source. We also configured a certain network setting as shown in Table 1.

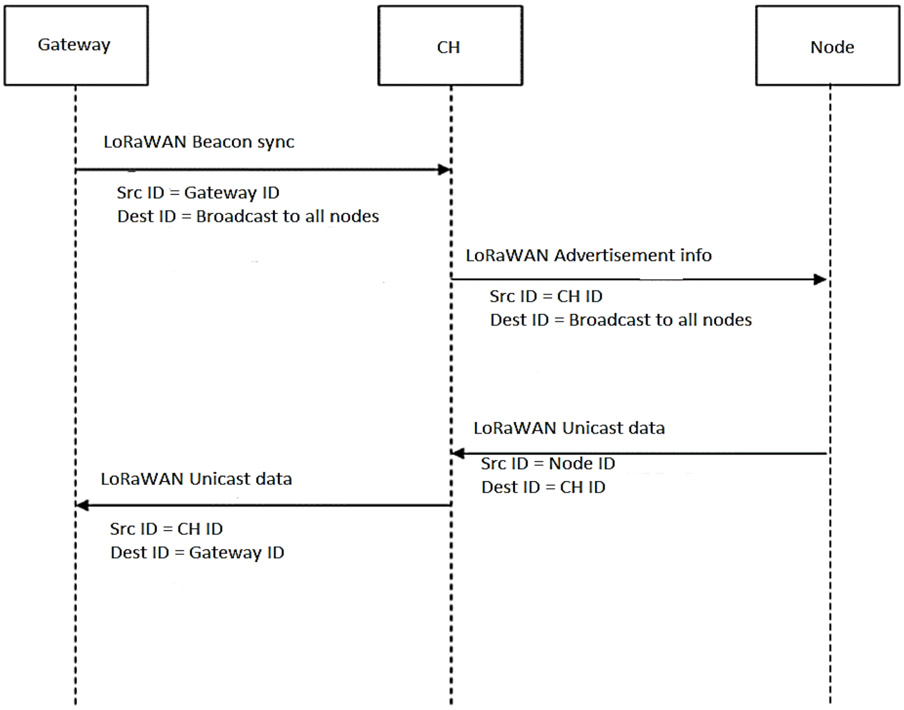

Figure 6. LoRaWAN LEACH network call flow

Table 1. Network simulation parameters

Parameter	Value
Total number of nodes	1000
Area size	10000×10000 m
Initial energy of node	30 mj
Simulation period	1000s
Percentage of CHs	0.1
Packet lenght for CH	2040 bits
Packet lenght for node	64bits

Figure 7 shows the results of the first simulation. We obtain a minor average dissipation as performance result in comparison to the LoRaWAN and a uniform distribution of the energy utilization of each node. As a result, more nodes may kept alive by maintaining their lifespans falling evenly throughout time as showed in Figure 8. The last simulation test Figure 9 depicts a constant uniform total throughput. Consequently, we get a better gap difference in comparison to LoRaWAN.

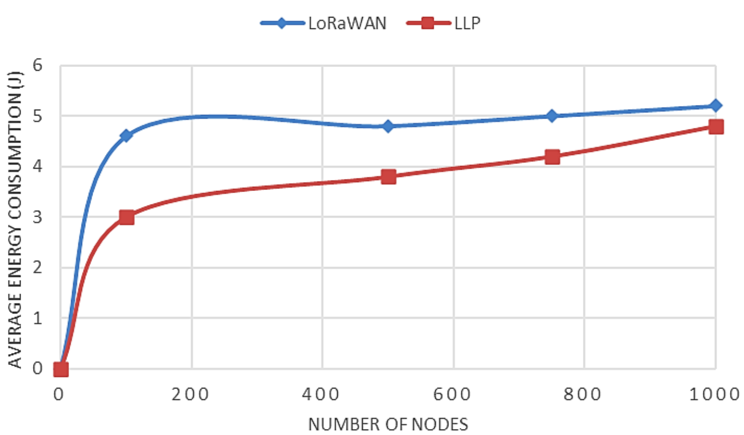

Figure 7. Average energy dissipation per number of nodes

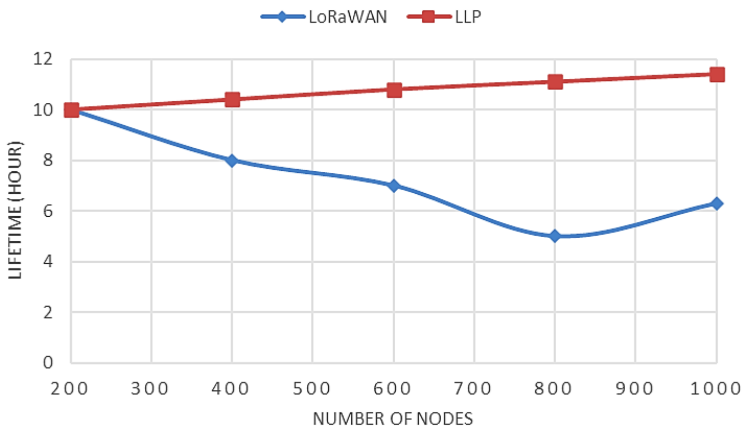

Figure 8. Lifespan per number of nodes

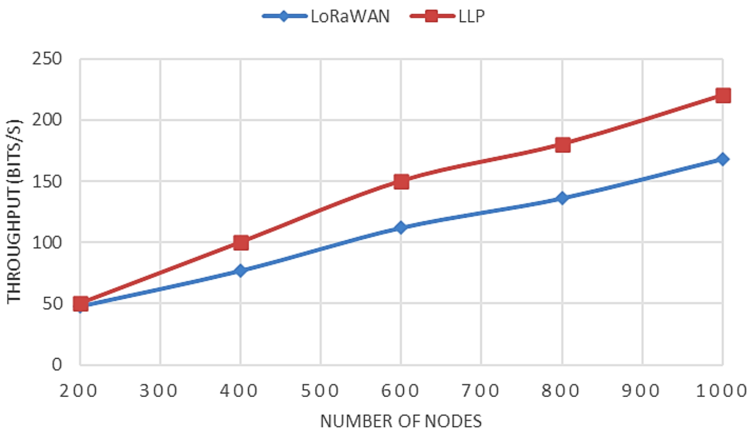

Figure 9. Throughput per number of nodes

5. CONCLUSION

In this paper, we have made a real network simulation of the LoRaWAN using NS-3 simulator for evaluating the uplink throughput. Then we have proposed and simulated a new architecture design for enhancing the uplink throughput and improving the energy efficiency using LEACH protocol. The simulation analysis reveals that the LLP performs well on throughput and energy consumption. Consequently, these model considerations have to be followed in order to build a new generation of class B LoRaWAN network gathering speed and energy efficiency.

In our future work, we plan to propose a new network health access control NHAC model. It will be based on a new fog server health policy that implement and provide a security control mechanism layer to a wireless sensor network. Therefore, the data sharing protection over the network will be ensured.

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