

# Performance assessment of static and dynamic routings using 6LoWPAN on small scenarios applied to monitoring of Barranquilla flash flood

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## Research

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# Abstract

The Internet of Things (IoT) is growing rapidly due to the wireless network that provides connectivity to devices at anytime and anywhere. Currently, the wireless sensor network is involved in many research fields like smart health monitoring, smart cities, and smart industries. From all of these, flood monitoring is the most important field in the IoT wireless network to alert about the occurrence of any abnormalities. To monitor the environment wireless sensor network needs a decision-making protocol that sense and route the information timely. The present work includes numerous use of Low Power Wireless Personal Area Networks (6LoWPAN) with IPv6 protocol defined by the Internet Engineering Task Force (IETF) due to its different test conditions, analysing static and dynamic routing and its impact on different performance metrics such as latency and packet losses for their application in monitoring system of the flash floods in any region. In this study, we are using IPv6 6LoWPAN to develop a wireless warning system before a flood event in "The Brigade" in Barranquilla city. The basic purpose for making system is to secure the city from costly damage and life loss. Different types of traffic and different 1-/2-hops scenarios have been considered. In order to implement our system, we use the well-known TelosB platform jointly with TinyOS, BLIP 2.0 and LPL. The experiment result shows that time on 512 ms and 1024 ms with a packet of 120 B obtain good performance on the metrics used for the tests.

## 1. Introduction

The Internet of Things (IoT) is growing due to wireless sensor network that provide smart devices connectivity from anywhere and is evolving many research fields like smart hospitals, smart traffic, smart city, environment monitoring and smart decision making systems. This wireless connectivity also increases the data traffic in IoT [1, 2, 3]. To transmit the data the network needs some new platform, technologies, network architectures and network protocols to route the data [4, 5, 6]. The wireless network has many protocols, one of these protocols is the IPv6 for Low Power Wireless Personal Area Networks (6LoWPAN), defined by the Internet Engineering Task Force (IETF) in the *RFC4944* [7]. It is very vastly in use IPv6 protocol over *IEEE 802.15.4* [8] due to its compatibility with wireless sensor nodes [7–9]. In IoT the research community has developed many environment monitoring applications like Early Warning Systems (EWS) for catastrophic events to improve the life quality and lifesaving [10, 12, 13]. In the case of the EWS, a monitoring system that is the objective of this work for the flash floods that occur in the rainy season in the city of Barranquilla - Colombia. This problem has occurred for many years in this city, therefor this work support by the University of the Coast at a zone known as "The Brigade" for generate alerts when this event is occurred [11, 14]. The existing studies include damages of floods in terms of cost and life. We do not find any study and EWS system for Barranquilla – Colombia to alert from flood. We develop a system and mitigate different kinds of tests with three nodes to send packets, using the 6LoWPAN logical addressing method and two routing protocols. This allow analysing the implementation of 6LoWPAN in the monitoring of flash floods in the area of "The Brigade" as shown in Fig. 1a section of the interest zone where the flash flood occurs.

In this context, the study of the performance of 6LoWPAN considering different routing methods, static and dynamic. In order to compare the performance, the present work is based on the TelosB platform [15], including TinyOS as embedded operative system and the Berkeley Low-Power IP stack (BLIP) [16] as 6LoWPAN network stack. Additional libraries for dynamic IPv6 routing like, IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) [17] and for energy saving purposes like, Low-Power Listening (LPL) [18] have been used. The results are more important in this work therefore the methodologies for the evaluation of 6LoWPAN performance with the established metrics, obtaining impacts important for the select routing type and the channel scan time for the energy saving with the LPL protocol. Furthermore, is possible to analysing the network performance according the select packet length. Criteria is also provided for the selection of TelosB platform and 6LoWPAN applied a monitoring network for flash floods in the "The Brigade" area of the city of Barranquilla. The rest of the paper is organized as follows: Sect. 2 provides an overview of the most relevant work about 6LoWPAN applications and metrics for WSN. Section 3 describes the materials and methods, as well as the test scenarios used. Section 4 presents the results and its analysis. Finally, Sect. 5 describes the most relevant conclusions of this paper.

## **2. 6lowpan: Applications And Metrics For Wsn**

### **2.1 Emerging technologies for Early Warning System**

The natural hazards affect large part of the population, resulting in severe economic and human losses. For mitigate the impact in the population of the natural hazards are implemented Early Warning System (EWS) in vulnerable areas. This System are an important tool to hazard risk management and many applications requires this solutions to face phenomenon such as tornadoes [19, 20], floods [21, 22], landslides [23, 24], flash-floods [25, 26], tsunamis [27], and similar. Therefore, the use of emerging technologies in EWS is relevance and is a challenge for the researchers. This technologies consist of innovations such as IoT, new protocols and low cost platforms, which have been implemented in solutions for monitoring system and IoT. For example, in Surabaya - Indonesia have development an IoT system in EWS to garbage collector robots and be able to monitoring severe and dangerous conditions; this prototype can monitoring the battery level information and operation to the robot; the ESP8266-12 module allows the WIFI communication with an android platform [28]. In Malaysia an IoT system is proposed for a flood EWS; this system consist of a wireless sensor networks, wind sensors and cellphone images that are sent to cloud using Zigbee and 3G for monitoring and warning to the users [29]. In Pakistan, a low cost flood EWS is development using Raspberry Pi platform, video camera, temperature and humidity sensors, energy system (battery and solar panels); this system send GSM data to Web dashboard, showing the level water [30]. In Italy, a WSN (Wireless Sensor Networks) is used to estimate landslide; for this, the RF signal is analyzed in the nodes of the WSN and establish its location in draw a grid map; the change in the locate to the node can indicate that a landslide is present by soil movement [31]. For this work, the flash flood are the principal context, because have caused material and human losses in recent decades in the Barranquilla city, also causing congestion of traffic and dragging

sediments by the flow. There are thirty zones where flash floods occur due to the absence of sewerage over the city, and although some canalizations work has been carried out in some cases, it is important to have systems based on emerging technologies that can generate warning for the vulnerable population. This motivated different studies from the “Universidad de la Costa” to generate solutions to this problem in Barranquilla [32, 33, 34].

## 2.2 6LoWPAN and applications

The use of emerging technologies for environment applications is important for evaluate its possible application in EWS. These studies can be complemented by the analysis of IPv6 applications for constrained environments such as the technique 6LoWPAN, in order working on top of the IEEE 802.15.4-standard (see Fig. 2). Between the set of wireless protocols [35], 6LoWPAN shows a major increase of use in several fields like the web or military applications [36, 37] or even as preferred communication method for embedded operative systems such as TinyOS or ContikiOS [38].

As a trend, there are a lot of different studies about its performance like the one about high-precision agriculture [39] or the latency and energy consumption related to networking mobility (NEMO) [40], or even studies about network congestion problems

[41], security in point-to-point networks [42], impact in medical applications within high-mobility environments [43, 44] or deep analysis of the energy consumption among the nodes [45, 46].

In the analysis of the literature different performance metrics was analyzed. Additionally the factors that produced incidence in the metrics were identified. Furthermore, the hardware and software platforms used for 6LoWPAN were analysed. Based on the above, some researches focused on high-precision agriculture have been developed using the *TelosB* platform with different sensors jointly with *TinyOS*, *RPL-6LoWPAN* and *LPL*. In this work different time intervals (512, 1024 and 2048 ms) and their impact in the battery lifetime have been analysed, resulting in an improvement of the lifetime through using a 2048 ms interval [47]. Other relevant work is focused on the carbon-cycle measuring in the Peruvian Amazon jungle, using the same platform [48]. Other applications use the same platform, testing instead of *TinyOS*, *ContikiOS* [49]. This revision is important for select the *TelosB* platform how a tool for the tests analysis in this work. Likewise for the time selection in the tests with the *LPL* protocol.

Different works have analysed the performance of different platforms, covering a wide spectrum among the use of various microcontrollers like *Waspote*, *TelosB*, *Arduino* and radios like *XBee*, *MicaZ* and *iMote2*. These works also analysed different metrics and parameters, such as the delay in the message reception or the throughput using different payloads [50]. Researches in the field of second layer protocols [51] have analysed different metrics such as the duty cycle, latency and throughput, looking for the optimal use conditions in *ContikiOS* [52].

The above analysis is important for the selection of the metrics, such as the latency and the packet loss. Similarly this analysis allows define the platform *TelosB* y the framework *TinyOS* for the use in the traffics tests for the proposed scenario. On the other hand, *RPL*, as a part of *6LoWPAN*, is being widely

studied [53], not only in the field of Wireless Personal Area Networks (WPANs), but also in the field of Body Area Networks (BANs) [54, 55]. Thus the comparative between RPL and static routing is an important factor for the analysis in the tests.

In this study, we are using IPv6 6LoWPAN to develop a wireless warning system before a flood event in “The Brigade” in Barranquilla city. The basic purpose for making system is to secure the city from costly damage and life loss. Different types of traffic and different 1-/2-hops scenarios have been considered. In order to implement our system, we use the well-known TelosB platform jointly with TinyOS, BLIP 2.0 and LPL. The experiment result shows that time on 512 ms and 1024 ms with a packet of 120 B obtain good performance on the metrics used for the tests.

## 3. Mitigation Of System

### 3.1 Materials and methods

This section presents the scenarios and tests carried out. The present work is based on the *TelosB* platform, which is a low-cost and well-known platform in the academic world. This platform also offers support to the *IEEE 802.15.4* and *6LoWPAN* through the use of *TinyOS*, BLIP, RPL and LPL. In order to capture and analyse traffic, like the Internet Control Message Protocol version 6 (*ICMPv6*), *Wireshark* [54, 56] has been used. The traffic for these tests is ICMPv6 (Internet Control Message Protocol for the Internet Protocol Version 6) packet, which has been generated using the tool *PINGv6*. As a result, Round Trip Times (RTT) of the nodes is received on the sink, measuring packet losses and packet delays for the performance analysis. The Fig. 3 show a flowchart for the implementation of 6LoWPAN on the TelosB platform and the basics tests for the initially connectivity.

### 3.2. Scenarios

The scenario presented in this paper is based on three nodes and a host computer. The topology is point-to-point and involves a node working as sink and two as sensor nodes. The Fig. 4 shows the proposed scenario, where the node 1 jointly with the computer acts as sink and the node 2 acts as router.

This work considers the Line-Of-Sight (LOS) between nodes as a reference in order to deploy the nodes. Thus, the network has been designed avoiding the LOS between node 1 and 3 in order to generate a directed routing scheme (i.e. the 2-hops route used in the tests). For this network, both static and dynamic routing methods have been considered. Table 1 shows the static routing configuration, for the dynamic routing, RPL is the protocol used.

Table 1  
IPv6 addressing for 6LoWPAN Network

Node	IPv6 Address	Location
1	FEC0::1	10°59'41.10"N ; 74°47'27.82"O University of the Coast
2	FEC0::7	10°59'42.94"N; 74°47'29.11"O
3	FEC0::8	10°59'40.61"N; 74°47'31.41"O
Computer / Edge Router	FEC0::100	10°59'41.10"N ; 74°47'27.82"O University of the Coast

### 3.3. Test Description

The tests carried out have been based on the sending of *PINGv6* messages, first, to test the connectivity among nodes, afterwards, generating traffic during 5 minutes that can be captured and analysed with *Wireshark*. The performance of the network is based on the packet size and the distance between nodes. Table 2 shows all the different tests carried out.

Table 2  
Performance tests for 1- and 2-hops 6LoWPAN networks

Distance to sink (m)	Hops	Nodes	Packet size (Bytes)	Time Sleep Interval (ms)	Routing type
10	1	Node 1 – Node 2	120, 1133	0, 1024	Static
20	1	Node 1 – Node 2	120, 1133	0, 1024	Static
30	1	Node 1 – Node 2	120, 1133	0, 1024	Static
40	1	Node 1 – Node 2	120, 1133	0, 1024	Static
65	1	Node 1 – Node 2	120, 1133	0, 512, 1024	Static, RPL
165	2	Node 1 – Node 3	120, 1133	0, 512, 1024	Static, RPL

The metrics analysed in the present work are shown below and are based on previous works [56, 57, 60], considering those, which generate delays in the network and changes in the packet delivery rate.

- Packet losses
- RTT Average time
- RTT Average delay

- Sending packet delay
- Average Jitter

### **3.3.1. Packet Losses**

The packet losses have been measured firstly between the sink and the node 2, with only one hop, varying the payload, the time interval configuration of LPL and the distance between both nodes. After this test, a second analysis has been carried using all the nodes in the network and analysing the performance with two hops, varying also the time configuration of LPL and the routing type. The traffic monitoring has been focused on nodes 2 and 3.

### **3.3.2. RTT average time**

To calculate this metric, the time between packet sending and packet response arrival has been measured. A previous theoretic analysis shows that the packets could suffer of delays, due to the processing time, which is associated to routing tasks among the network. It can be affected also by delays derived of the application of LPL. The RTT average time is measured as the sum of the RTT average time for a 5 minutes test, using the same tests and conditions than in the packet losses analysis.

### **3.3.3. RTT sending average delay**

The RTT sending delay is measured as the elapsed time between sending two packets with acknowledging receive, consecutively. This metric is calculated because in some cases the packets sent from the sink do not produce any reply from the nodes. Then, the RTT sending average delay is the average time elapsed between sending two packets with acknowledging receive consecutively, using the same factors and conditions as in the packet losses analysis.

The RTT delay is measured in the sink by the information received in the Wireshark tool [58, 59].

### **3.3.4. Sending packet average delay**

The packet sending response has been analysed, regardless of the successful acknowledge message reception, as the elapsed time between the sending of a packet from the sink node to the node 2. The tests carried out have been similar to the previous ones.

### **3.3.5. Average Jitter**

The average jitter has been measured based on the time obtained from the subtraction of the delay to two consecutive packet sending time. The average of these results is calculated giving the final average jitter measurement.

## **4. Results And Discussion**

Figures 5 and 6 and Tables 3 and 4 presents the results corresponding to the tests previously explained.

Table 3  
Average results of 6LoWPAN performance in one hop test

PERFORMANCE OF METRICS	DISTANCE (m)			
Packet Loss (%)	10	20	30	40
LPL = 0 ms (No LPL)	0,66	1,32	11,7	4,95
LPL = 1024 ms; Packet 120 B	16,55	22,92	23,66	27,9
LPL = 1024 ms; Packet 1133 B	66,45	56,91	73,26	75,39
RTT Length Time (s)	10	20	30	40
LPL = 0 ms (No LPL)	0,67	0,66	0,82	0,79
LPL = 1024 ms; Packet 120 B	0,52	0,52	0,52	0,52
LPL = 1024 ms; Packet 1133 B	1,14	1,12	1,14	1,1
RTT Send Average Delay (s)	10	20	30	40
LPL = 0 ms (No LPL)	1,01	1,01	1,13	1,05
LPL = 1024 ms; Packet 120 B	1,2	1,3	1,31	1,38
LPL = 1024 ms; Packet 1133 B	2,21	2,3	3,8	4,06
Packet Send Average Delay (s)	10	20	30	40
LPL = 0 ms (No LPL)	1	1	1	1
LPL = 1024 ms; Packet 120 B	1	1	1	1
LPL = 1024 ms; Packet 1133 B	1,01	1	1,01	1,01
Jitter Packet Send (s)	10	20	30	40
LPL = 0 ms (No LPL)	0	0,001	0,001	0,001
LPL = 1024 ms; Packet 120 B	0,001	0,002	0,001	0,002
LPL = 1024 ms; Packet 1133 B	0,005	0,005	0,005	0,005



Table 4  
Average results of 6LoWPAN performance in two hops test

TEST	STATIC ROUTING		RPL ROUTING	
Packets Loss Rate (%)	Node 2	Node 3	Node 2	Node 3
LPL = 0 ms (No LPL)	0	48,36	0,36	49,41
LPL = 512 ms	51,47	78,47	49,28	81,54
LPL = 1024 ms	60	79,66	56,76	82,77
RTT Length Time (s)	Node 2	Node 3	Node 2	Node 3
LPL = 0 ms (No LPL)	0,66	1,07	0,66	1,07
LPL = 512 ms	0,87	1,56	0,9	1,41
LPL = 1024 ms	1,13	2,12	1,12	2,07
RTT Send Average Delay (s)	Node 2	Node 3	Node 2	Node 3
LPL = 0 ms (No LPL)	1	1,93	1	1,98
LPL = 512 ms	2,07	4,81	1,98	5,33
LPL = 1024 ms	2,52	4,96	2,33	5,53
Packet Send Average Delay (s)	Node 2	Node 3	Node 2	Node 3
LPL = 0 ms (No LPL)	1	1,002	1	1,003
LPL = 512 ms	1,003	1,005	1,003	1,006
LPL = 1024 ms	1,004	1,005	1,004	1,006
Jitter Packet Send (s)	Node 2	Node 3	Node 2	Node 3
LPL = 0 ms (No LPL)	0	0,002	0	0,003
LPL = 512 ms	0,004	0,005	0,003	0,006
LPL = 1024 ms	0,004	0,005	0,004	0,005

## 4.1. Packet Losses

Figure 5A shows the results for the packet losses considering the distance differences, packet size and LPL use. These results show that without LPL, the loss rate is lower than with LPL, ranging from 1–10%. Using LPL with a 1024ms sleep interval and 1133 Bytes packet size, the loss rate ranges from 68–72%. The distances chosen do not exceed 40m. These experiment results show that the packet size has an impact on the loss rate, even being twice as much as the rate for 1133B packet size. It results interesting that increasing the distance does not show any impact in the results for this scenario and configuration.

Figure 6A shows the packet losses for nodes 2 and 3, using static and dynamic routing. LPL with a configuration of 0, 512 and 1024ms has been applied, resulting the 1024ms configuration, the best in terms of energy consumption. The Fig. 6A shows that the routing type does not affect the performance. Another interesting fact is that the node 2 does not lose any packet for the 0ms LPL-configuration, otherwise, the node 3 loses up to 50% more packets than the node 2 for the same scenario and configuration.

In the test with LPL the packet loss rate increases for the node 2 and 3, but the difference between different LPL-configurations is not significant, even in the node 3, where the differences are higher than in node 2.

## 4.2. RTT Latency

Tables 3 and 4 show the average RTT latencies. Figure 5B shows similar results for the different distances tested in the 1-hop scenario. The RTT with a lower packet size shows a shortest duration, due to the shortest processing time among the route. There is no significant difference for the RTT duration sending 120B between 0 and 1024 ms LPL-configuration. On the other hand, the RTT duration increases up to 50% for 1133B sending with 1024 ms LPL-configuration. Finally, the best results are shown in the test sending 120B with 1024 ms LPL-configuration, showing also that the distances are not significant for the performance analysis. Figure 6B presents the RTT duration results for a 2-hops scenario, showing no significant difference in the results derived from the routing type. With 0 ms LPL-configuration the overall performance in terms of RTT duration is shorter than with the other configurations. The Fig. 6B also shows differences of 0.3 s for node 2 and 0.5 s for node 3 with a 512 ms LPL-configuration, however the RTT duration is even higher for a 1024 ms LPL-configuration. These test results show that node 3 has a higher RTT, almost being twice as much as the duration than node 2 shows, in all the 2-hop tests carried out, considering all the different configurations.

The application of a 0 ms LPL-configuration results in an increment in terms of energy consumption but it also results in an improvement of the RTT duration time. Thus, between a 512 ms and a 1024 ms LPL-configuration, the RTT duration time differences are not significant, so it would be better to use a 1024 ms LPL-configuration in order to improve the energy consumption. Figure 5C presents the results in terms of RTT send average delay for 1-hop, showing a shorter delay for the 0 ms LPL-configuration configuration. Delay lightly increases with the distance as show the difference of 0.2s between 10 and 40 m scenarios. This small difference does not affect the development of the tests. Figure 6C shows the results of RTT send average delay for 2-hops scenario, showing no significant differences between routing types. For a 0 ms LPL-configuration the RTT delay is generally shorter than for other LPL-configurations. In this scenario, the difference between nodes is significant, reaching 2–3 seconds. For 512 and 1024 ms LPL-configurations there is no significant difference. Like in other scenarios, a 1024 ms LPL-configuration results in better energy consumption.

## 4.3. Jitter

Tables 3 and 4 show the packet sending delay and the jitter results for the 1- and 2-hops scenarios under different configurations. Figure 5D presents the packet sending delay for 1-hop scenarios, showing 1 s delay for all the distances considered, regardless the packet size. The delays detected have been very short 3–4 ms, which have been associated to the processing time among the route. There are no significant differences between 0 and 1024 ms LPL-configuration for 120B sending. Moreover, the distances do not present any significant influence in the jitter results.

Figure 6D presents the packet sending delay for 2-hops scenarios, confirming that routing type does not have any impact in the sending delay. For both routing types, 0 ms LPL-configuration shows a shorter delay than a 1024 ms LPL-configuration, but as collateral drawback shows higher energy consumption and 4 ms delay. Regarding to the jitter, Fig. 5E shows a higher jitter for 1-hop scenarios than for 2-hops scenarios. Configuration also plays a major role, showing a higher jitter sending 1133B and using 1024ms LPL-configuration. Changes in distances do not show any significant impact in jitter results. Figure 6E presents the jitter results for 2-hops scenarios, and it shows lightly differences, around 6 ms for all the cases analysed. For these tests, the shortest jitter is shown with a 0 ms LPL-configuration, whereas the other LPL-configurations do not present any significant difference. The difference between a 0 and 1024 ms LPL-configuration remains under 4 ms, resulting much more suitable the 1024 ms LPL-configuration in order to reduce the energy consumption. Again, the routing type does not impact the overall performance in terms of jitter.

## Conclusion

Based on the 1-hop tests carried out, it seems to be better the use of 1024 ms as channel scanning time configuration (LPL-configuration) because the network performance does not drop and the energy consumption is reduced. It has been observed that the packet size is significant for this scenario, resulting the use of 1133B payload in longer delays and higher packet losses. Packet losses increase for 2-hops scenarios, reaching its maximum for node 3. The impact of the LPL-configuration is lightly significant in terms of packet losses, but more significant in terms of energy consumption. A 1024 ms LPL-configuration results in a good compromise between losses and energy consumption. Routing types do not present any significant difference for the different metrics analysed in the present paper. Packet sending delays are not significant between 1- and 2-hops scenarios, remaining under 5 ms, thus, there is no significant impact in the network performance. Distances between nodes do not seem to be significant for the performance of network, at least, not for the considered scenarios and configurations. It is highly recommended to use 1024 ms LPL-configuration, not only for 1-hop scenarios, but also for 2-hops scenarios in order to obtain an overall improvement in terms of energy consumption.

Finally, the TelosB platform is a system that allows its use for evaluation of data transmission. Although it is not a robust system, its use for monitoring flash floods is possible by implementing sensors such as rain gauges, given its easy integration. Currently the literature does not evidence works that apply the TelosB platform and the 6LoWPAN method for flash flood monitoring systems.

# List Of Abbreviations

**6LowPAN:** IPV6 Low Power Wireless Personal Area Networks

**BAN:** Body Area Networks

**BLIP:** Berkeley Low-Power IP stack

**EWS:** Early Warning System

**ICMPV6:** Internet Control Message Protocol for the Internet Protocol Version 6

**IETF:** Internet Engineering Task Force

**IoT:** Internet of Things

**LPL:** Low Power Listening

**NEMO:** Networking mobility

**RPL:** Routing Protocol for Low-Power and Lossy Networks

**RTT:** Round Trip Times

**WPAN:** Wireless Personal Area Networks

**WSN:** Wireless Sensor Networks

## Declarations

**Availability of data and materials:** The authors declare that all the data and materials in this manuscript are available.

**Competing Interest:** There is no competing interest.

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# Figures



**Figure 1**

A-B. Flash foods Barranquilla City. B-C. Flash food in “The Brigade” zone.

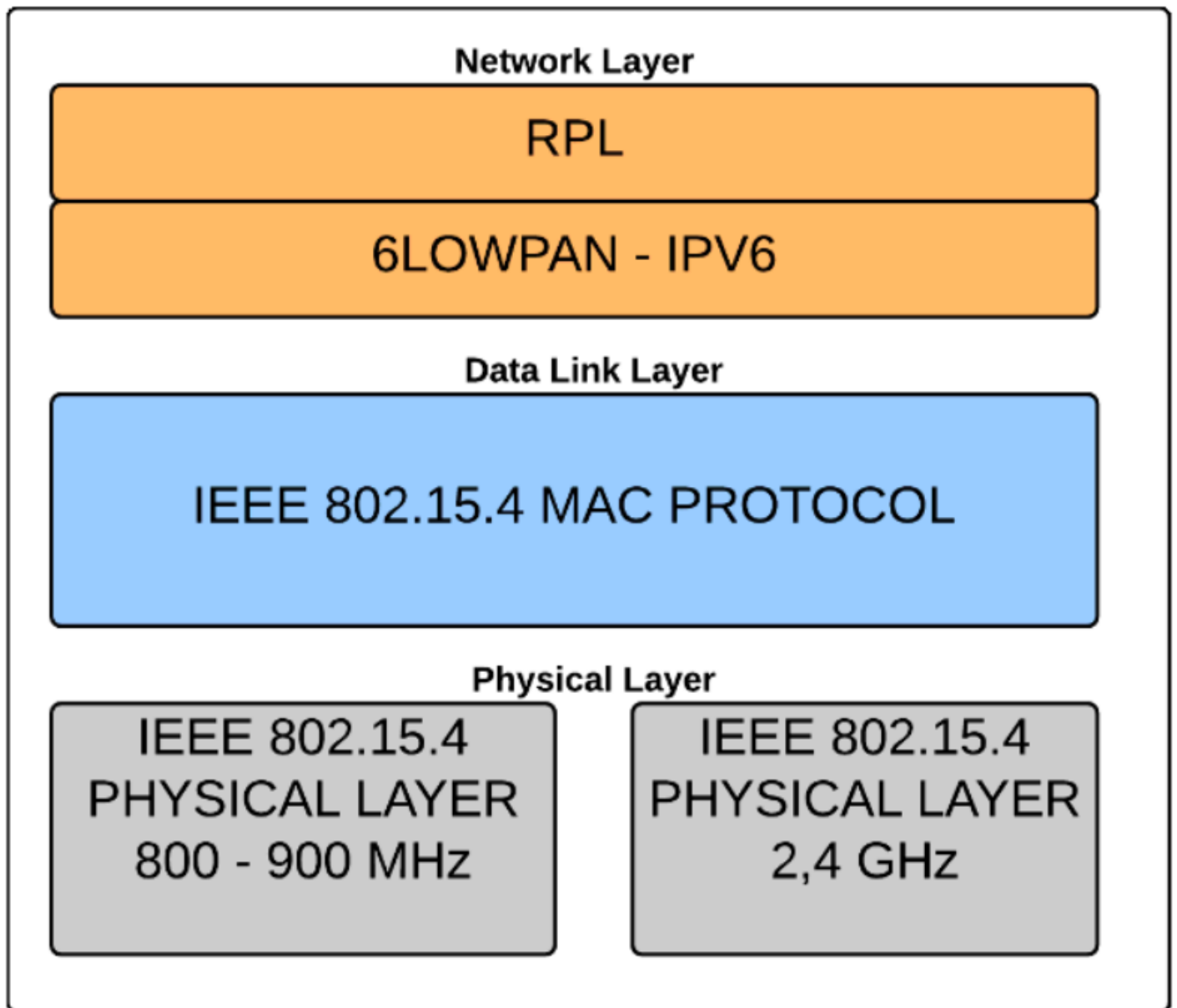


Figure 2

RPL-6LoWPAN network stack

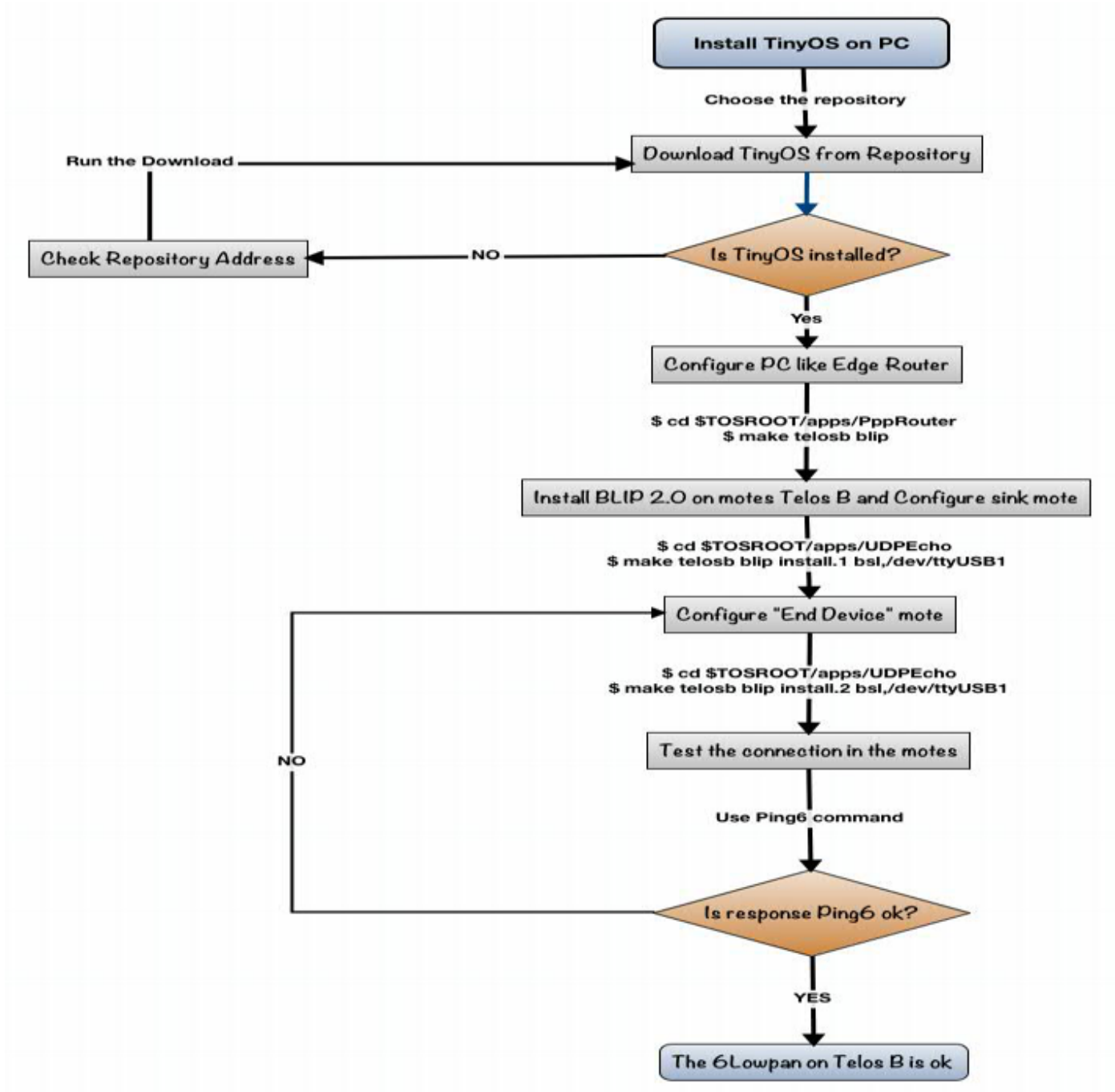
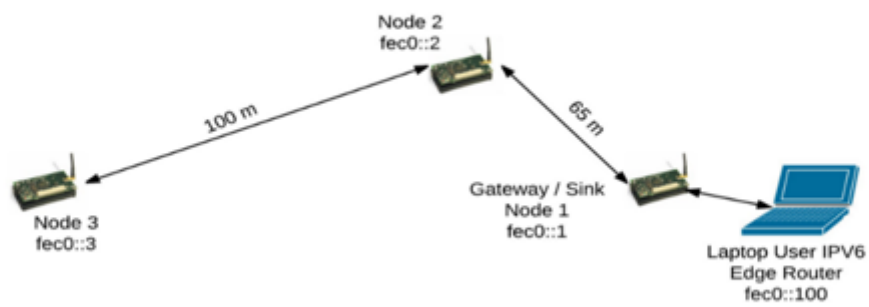


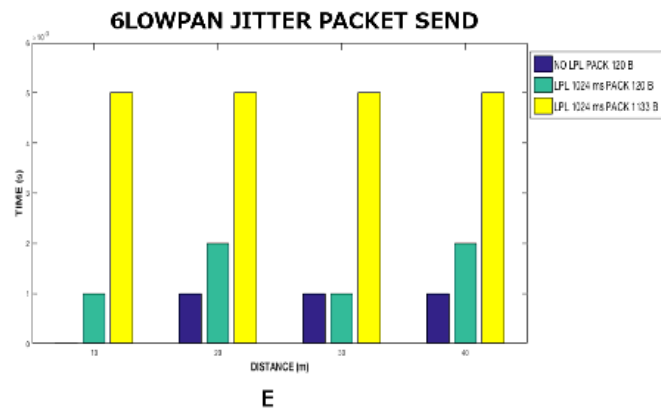
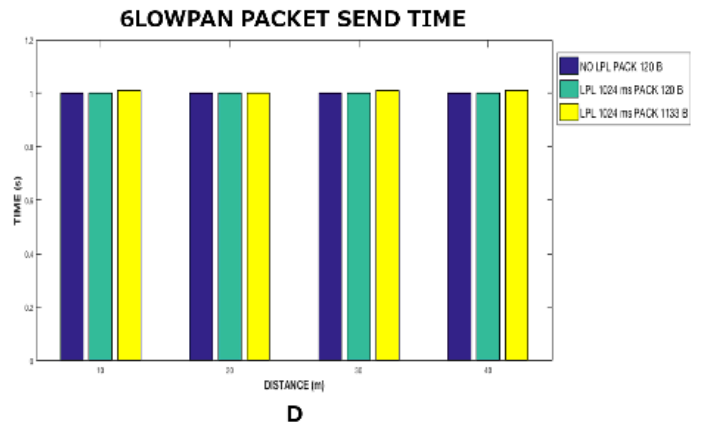
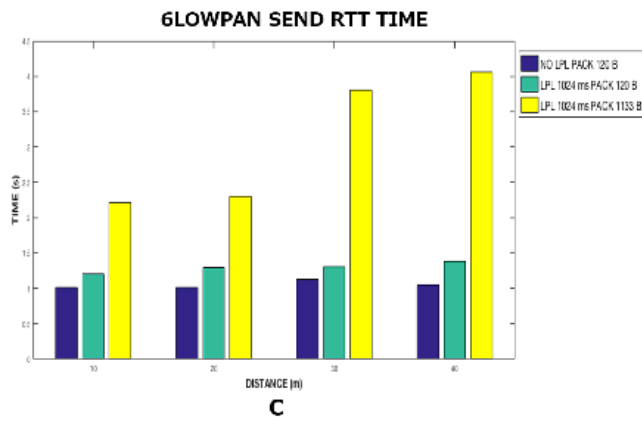
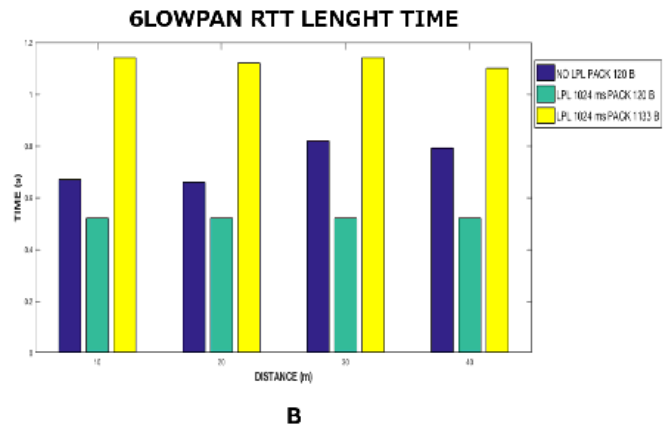
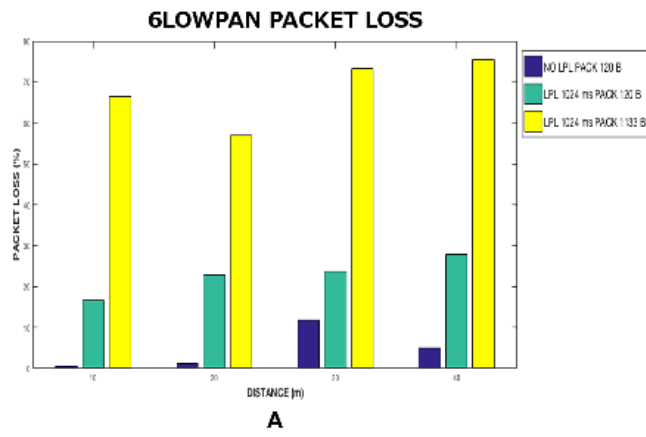
Figure 3

Steps by configuration the TelosB platform.



**Figure 4**

Snapshot of the scenario tested



**Figure 5**

Results obtained in the 1-hop tests

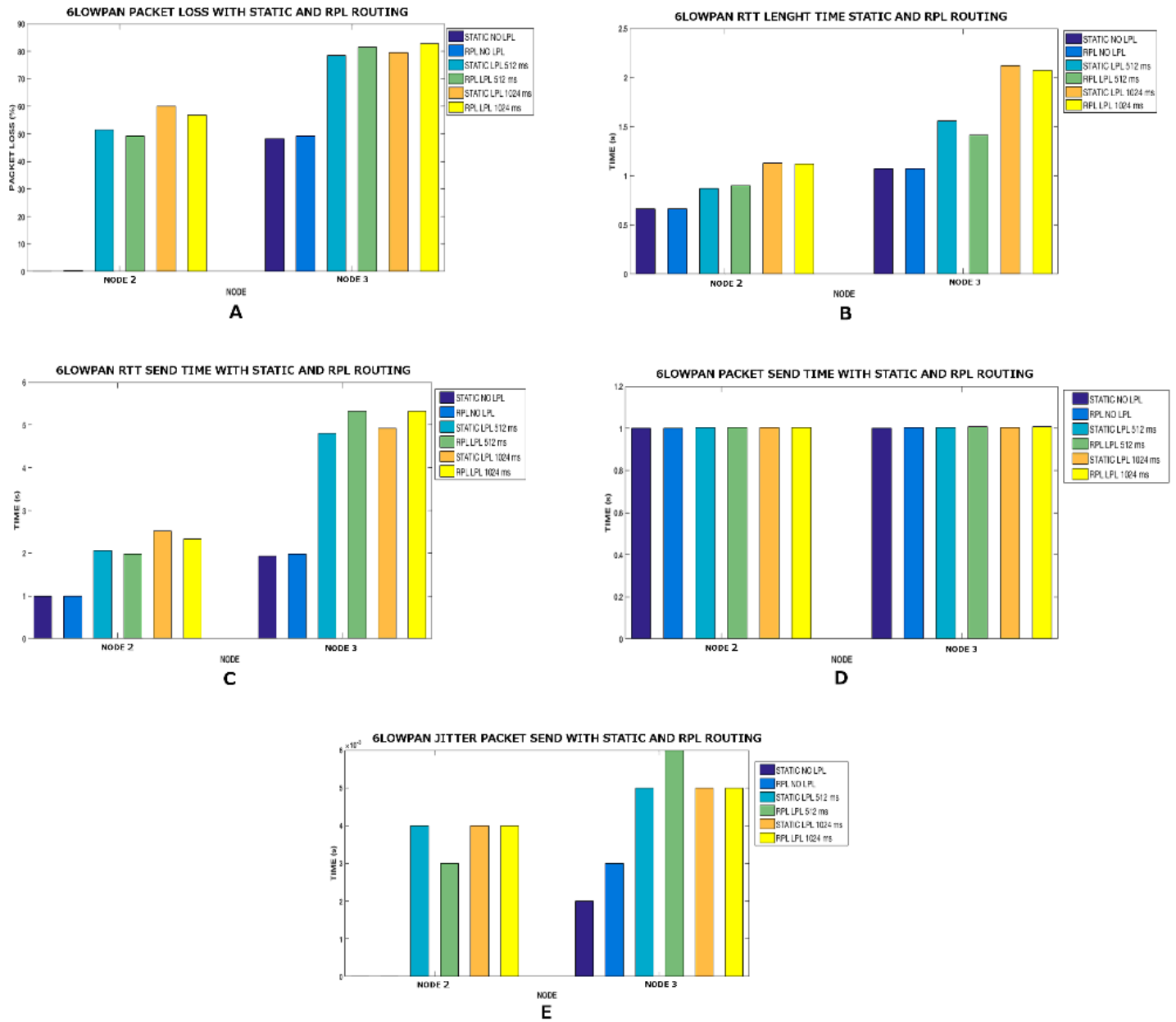


Figure 6

Results obtained in the 2-hops tests