On the Application of LoRa LPWAN Technology in Sailing Monitoring System

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***Abstract*—Sailing Monitoring System operating in the sea area has the basic transmission requirement of low power and long range. LoRa Low Power Wide Area Network (LPWAN) technology can be seen as an alternative solution to address this problem. This study focuses on transmission performance of LoRa technology and attempts to apply LoRa technology to Sailing Monitoring System. Experiments of LoRa technology parameters' (e.g spread factor and bandwidth) influences on data transmission time and coverage were set up. Then, the optimal parameters of LoRa technology are used in Sailing Monitoring System, and the evaluation of system's performances is given. The measurements were conducted in Brazil Olympics sailing venue for two cases, and system's performance of coverage and packet loss rate in sea area are analyzed. It shows that the system based on LoRa technology can achieve the intended purpose of system design and meet the basic requirement of system applications. In the concluding section, measurement results are summarized and the future research directions are presented.**

Keywords—LoRa technology; LPWAN; Sailing Monitoring System

I. INTRODUCTION

Sailing is a perfect combination of water, wind, sailboat and human. The environment of sea area is complex and variable, the judgment of the athletes on the external environmental conditions and the manipulation of the sailboat can be directly reflected in the selection of route, adjustments of sailing angle and control of sailing attitude. Those parameters are closely related to the performance of sailing, thus the good or bad competition results. In order to improve the athlete's training level and the results of the competition, it is the most scientific and effective way to establish a scientific and effective sailing training mode by designing a set of scientific instruments to monitor the technical data of sailing training in real time.

Sailing Monitoring System monitors the sea environment and sailboat, including the speed and direction of wind and current, the location and attitude of sailboat. Those parameters are collected by sensor nodes, integrated and transferred to the gathering nodes. Therefore, the selection of transmission way between gathering nodes and base station is very important. It must meet the requirement of at least 2 kilometers range between the nodes and base station. The transmission must be reliable although environment in sea area is tough. Sailing Monitoring System operates in the sea area lacking enough power, which means it should rely on batteries for a long time, so the system must be designed in low power consumption.

The First generation Sailing Monitoring System was designed and used in daily training. The monitoring result can be shown to athletes and coach at the same time and adjustment can be made based on the result. The first generation system used 3G technology as the transmission way, it works well with long range in most cases. However, a few problems still exist as following: The communication become unstable as system is far away from the land, because the coverage of cellar base station has not reached the sea area for a long distance. The result of far away from beach is high packet loss rate and data retransmission, thus increasing power consumption. And 3G technology transmission itself is not in low power. Furthermore, using 3G as the transmission technology greatly relies on local carrier network, which means it have to change SIM card in different countries.

At the same time, emerging Low Power Wide Area Network (LPWAN) technology is gaining momentum in Machine-to-Machine (M2M) communications. LPWAN is featured by wide coverage, low power and large capacity. Compared with short-range multi-hop communication technology such as Wi-Fi, Bluetooth and ZigBee, LPWAN technology realizes wide-coverage and low-cost Internet of Things (IoT). LPWAN technologies fall in between short-range multi-hop technologies and proper broadband cellular systems. Similarly to the cellular networks, LPWAN technologies are characterized by long range links (in the orders of kilometers) and have star network topologies [1]. It usually works in sub-GHz Industrial Scientific Medical (ISM) band. Similar with cellar network, LPWAN typically implement star network topology, where each node communicates with base station directly. Unlike the wireless sensor network's multi-hop mesh or ad-hoc topology, this enables to put all the complexity to the base station, thus keeping the end devices pretty simple and thus low-cost and low energy consuming [2].

Today several competing LPWAN technologies are present, such as SigFox, Weightless, and LoRa. Among them, LoRa technology is taking advantage in the market. LoRa technology is a proprietary spread spectrum method based on chirp spread spectrum (CSS) scheme that uses wideband linear frequency modulated pulses whose frequency increases or decreases based on the encoded information [3]. In addition to low power, this modulation gives tolerance to the frequency deviation, which reduce the cost. It also makes LoRa good resistance against multipath fading and Doppler Effect, and improves the sensitivity of receiver increasing the coverage. All the characteristics of LoRa mentioned above make it a perfect solution to address the problems existing in our system. We designed and deployed Second generation Sailing Monitoring System based on LoRa technology to support the athletes' preparing for 2016 Rio Olympic Games.

This paper is organized as follows. Section II describes the experiments of LoRa module on-the –air transmission time and coverage. System evaluation in Rio sailing venue and measurement results are discussed in Section III. Section IV concludes the paper.

II. EXPERIMENT

We use commercial available module YL-800IL and YL-900IL [4] to do the experiment about on-the-air transmission time and coverage. The bandwidth (BW) of module can take values of 62.5 kHz, 125 kHz, 250 kHz or 500 kHz, spreading factor (SF) can be changed between 7 and 12. Therefore, users can find an optimal trade-off between link budget, interference immunity, spectral occupancy, data rate, and range.

A. On-the-Air Transmission Time

Spectrum analyzer RSA306 [5] was used to measure the on-the-air transmission time of module. We used module YL-800IL with transmit power 100 mW and payload length 1 byte. The measurement result with different BW and SF is shown in Fig. 1 and Fig. 2.

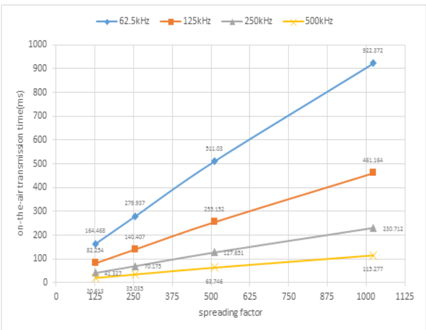

Fig. 1. *On-the-air transmission time with different bandwidth*

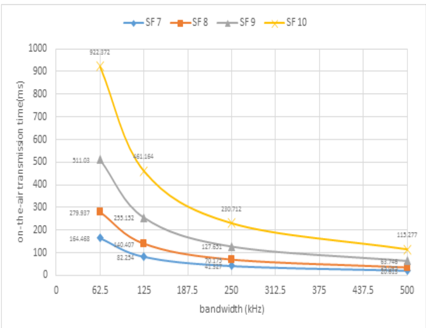

Fig. 2. *On-the-air transmission time with different spreading factor*

The result shows that with the same BW, on-the-air transmission time increases as SF increases. With the same SF, on-the-air transmission time increases as BW decreases.

B. Coverage

The testing was conducted on a lake in the city of Shanghai, China. The measurements were executed for case when a module located on a boat reporting data periodically (every one second) to a module act as base station. The antenna of module on a boat is one meter high above water, and the base station module with 4 meters height of antenna was located in the center of lake without any blockings. The measurement result are shown in Table Ⅰ.

It shows that the increase of range depends on the decrease of BW or increase of SF, which also decreases the date rate and increases the transmission delay. In addition to the parameters of LoRa technology, a high-gain antenna and higher transmit power (under regulation) are also helpful.

In addition to long range and low power, date rate and transmission delay must be taken into account when design the sailing monitoring system. For the reason, SF=7, BW=125 kHz are used in make the optimal trade-off in our system.

III. TESTING OF SYSTEM

Sailing Monitoring System deploys star topology which consists of one gateway and several gathering nodes, as shown in Fig. 3. The gateway are installed on the coach's boat and gathering nodes are on the athletes' sailboat, as shown in Fig. 4 and Fig. 5. The monitoring parameters such as speed, direction of wind and sailboat, GPS location, collected by sensor nodes, combing in gathering nodes, transferred to gateway by LoRa technology. The system using module YL-900IL operates in 433MHz band with SF 7 and 125 kHz BW. The data rate can reach 5 kbps. The nodes and gateway are all powered by 3.7 V batteries. Gathering nodes send data with payload length 96 bytes to gateway every 2 seconds. The data packet contains time, GPS locations, which can be used to estimate the packet loss rate and the position of the gathering nodes respectively. We have tested two cases in the Rio sailing venue.

A. Test Case 1

Both gateway and gathering nodes were operating on the moving boat on the sea area. The antenna of node was 1 meters high above sea level and the antenna of gateway was 4 meters high. The gathering nodes were keeping a distance of 400 m away from gateway to guarantee the absolute reliability of transmission. The results are shown in Table Ⅱ.

It shows that the packet loss rate is only 0.34% within the range of 400 meters. The average speed of sailboat was 20 km/h, and it could even reach 37 km/h. The results show that the system can work well with good mobility. Furthermore, the coverage was much smaller than that of experiment on the lake. One reason may be the tough environment on the sea, e.g. the great waves. The only 1 meter high antenna also accounted for the short range.

TABLE I. COVERAGE MEASUREMENT RESULT

Module	Gain of Antenna(dB)	Frequency (MHz)	SF	BW (kHz)	Range (km)
YL-800IL	6	433	9	250	1.8
				500	1.5
		380		250	1
YL-900IL	5	433	9	250	1.4
	6			250	2.3

TABLE II. RESULT OF CASE 1

Range (m)	Number of Packet Loss	Number of Total Packet	Packet Loss Rate	Average Speed of Sailboat (km/h)	Max. Speed of Sailboat (km/h)
< 400	13	3819	0.34%	20	37

TABLE III. PACKET LOSS RATE IN DIFFERENT ZONES

Zone	Average Distance to Gateway (m)	Number of Packet Loss	Number of Total Packet	Packet Loss Rate
A	3284	712	1177	60.49%
B	2309	7	116	6.03%
C	2111	1	276	0.36%
D	2157	0	88	0
E	2953	105	302	34.77%

B. Test Case 2

Gateway was fixed on the roof of 20 meters high building which was 1 km away from the beach. The gathering node was located on the moving sailboat along training route, and the antenna was 4 meters above sea level. The testing environment and the route of athlete's sailboat are presented in Fig. 6.

The gateway is marked with a yellow dot on the map, note that the path between gateway and gathering node includes lands and sea. There are tall building, trees, and hills on the land area and the waves are large on sea area. The measurement area can be divided into five fan-shaped zones depending on the topography and obstacles. Zone A has a lots of tall building with average height of 100 meters. Zone B, C, D have differences in geographical location, but the buildings are not tall and the landforms are mainly flat. A hill and a lot of tall buildings with average height of 80 meters exist in zone E.

Table III shows the average distance between gateway and gathering nodes and the packet loss rate of five zones respectively. The number of some zones are not sufficient due to the variable speed of sailboat along the real training route. Nonetheless, the results can also be useful to provide an insight into the performance of LoRa technology in our system.

The results in Table III show that packet loss rate in zone B, C, D are under 6%. The reason is that there are few obstacles in the transmission path in these zones. It also reveals that packet loss rate increases as the distance between gathering node and gateway increases, but not significantly (within 2300 m range). In zone A and E, 60.49% and 34.77% packets were lost. The high rate of packet loss may be caused by blocking of the tall buildings in zone A and hills in zone E.

The presented results show that Sailing Monitoring System based on LoRa technology works well in long range of over 2 km, low power consumption, transmission reliability and good mobility.

Meanwhile, the performance of LoRa technology inevitably are impacted by surrounding environment, including the buildings, trees and hills. Therefore, these factors should be taken into account when implementing LPWAN LoRa networks.

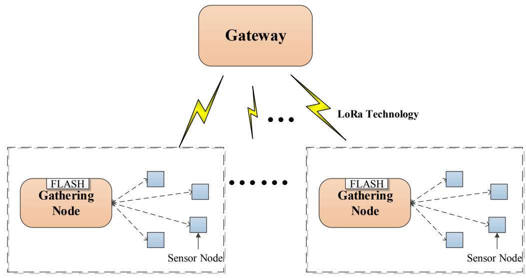

Fig. 3. Architecture of Sailing Monitoring System

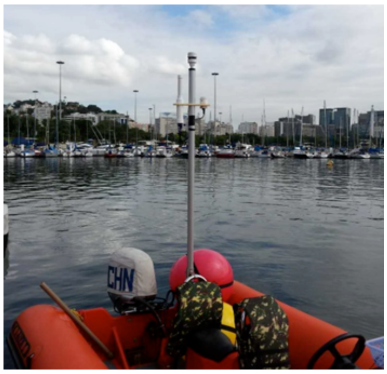

Fig. 4. Gateway installed on the coach's boat

Fig. 5. Gathering node installed on the sailboat

Fig. 6. Testing environment and sailboat's route

IV. Conclusion

Limited coverage and power consumption are the main shortcomings of the first generation Sailing Monitoring System with 3G technology. In order to address these problem, we apply LoRa technology to the system. The experiments about on-the-air transmission time and coverage of LoRa modules were done to analyze the performance of LoRa technology. The experiments verify that the transmission time on-air increases with the BW decreases or SF increases. The result about coverage shows that the smaller SF or greater BW can increase the range at the expense of an increase of delay and decrease of data rate. SF 7 and 125 kHz BW are used in our Sailing Monitoring System to meet the trade-off of data rate, coverage and link budget. The evaluation of our system was conducted in Rio sailing venue for two cases. The case 1 when gathering nodes and gateway were all on the water shows that LoRa technology in our system can have a good performance in mobility with 20 km/h average speed. The case 2 when gateway was fixed on the land and gathering nodes were on the water reveals that system with LoRa technology has a good performance in low power consumption, wide coverage and reliable transmission. The system has a low packet loss rate under 6% and long range of over 2 km in the flat zones. Meanwhile, LoRa technology is influenced by obstacles such as high buildings and trees, which lead to the high packet loss rate of over 34% in those zones with a lot of obstacles. Therefore, these factors should be taken into account when LPWAN LoRa network are implemented.

In the future, we will focus on designing LoRa adaptive network to get the optimal performance. For example, the parameters of LoRa technology such as SF and BW can be changed automatically to improve the sensitivity, interference immunity and coverage when a lot of obstacles exist in the transmission path.

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