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 the sea is complex and variable. The athlete's judgment on the external environment and the manipulation of the sailboat can be directly reflected in the selection of the route, adjustments of the sailing angle and control of sailboat attitude. These parameters are closely related to the performance of sailing, and thus competition results. To improve the athlete's training and the competition results, the most practical way is 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.

Wireless Sensor Networks are utilized in Sailing Monitoring System to monitor the environment of sea and sailboat, including the speed and direction of wind and current, the location and attitude of sailboat. These data are collected by sensor nodes, integrated and transferred to sink nodes. The sink nodes transmit the collected data to a gateway [1]. Therefore, the selection of transmission method between the sink nodes and the base station is very crucial. According to the requirement of application, it needs to cover the distance between the sink nodes and the base station, at least two kilometers. The transmission should also be robust and reliable since the sea environment with waves, currents and sailboats is complex. Besides, Sailing Monitoring System operating at sea faces the challenge of insufficient power supplement [2], which means it will rely on batteries for a long time, so the system should maintain low power consumption.

The first generation Sailing Monitoring System was designed and used in daily training. The results can be shown to athletes and coaches simultaneously, and the adjustments can be made based on the results. Our first generation system uses 3G technology as the transmission mode, which works well in long range transmission in most cases. However, a few problems still exist. Due to the limited coverage of the cellar base station, the communication at sea becomes unstable as the system is far away from the land. Being away from the beach results in high packet loss rate and data retransmission, thus increasing power consumption. And 3G technology transmission itself is not a low power consumption transmission technology. Furthermore, using 3G as the transmission mode largely relies on the local carrier network, which means the SIM card needs to be changed in different countries.

Meanwhile, the emerging Low Power Wide Area Network (LPWAN) technology is gaining momentum in Machine-to-Machine (M2M) communications. LPWAN features wide coverage, low power consumption 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 [3]. It usually works in sub-GHz Industrial Scientific Medical (ISM) band. Similar with cellar network, LPWAN typically implements 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 [4].

Today several competing LPWAN technologies are present, such as SigFox, Weightless, and LoRa. Among them, LoRa technology is developing rapidly 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

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decreases based on the encoded information [5]. In addition to low power consumption, this modulation increases tolerance to the frequency deviation, which reduce the costs. It also makes LoRa good resistance against multipath fading and Doppler Effect, and improves the sensitivity of the receiver increasing the coverage. All the characteristics of LoRa mentioned above make it a perfect solution to the problems existing in our first generation system. We have designed and deployed the second generation Sailing Monitoring System based on LoRa technology to support the athletes' preparation for 2016 Rio Olympic Games.

So far, there are few papers addressing LoRa technology. The coverage of LoRa technology was evaluated in [6] and [7] for outdoor cases. In [4] authors made the first attempt to apply LoRa technology for health and wellness monitoring. In [8] author focused on capacity and scalability of LoRa technology.

The rest of this paper is organized as follows: Section II describes the experiments of LoRa module about 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 used commercial available module YL-800IL and YL-900IL [9] to do the experiment about on-the-air transmission time and coverage. The bandwidth (BW) of the module can take values of 62.5 kHz, 125 kHz, 250 kHz or 500 kHz, and the 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 transmission range.

A. On-the-Air Transmission Time

According to [5], the LoRa packet consists of preamble and payload, and the on-the-air transmission time is the sum of preamble and payload duration. The on-the-air transmission time ToA is given in (1).

$$T_{oA} = T_{preamble} + T_{payload} = T_{sym}\left(L_{preamble} + L_{payload}\right) = \frac{2^{SF}}{BW}\left(\left(n_{preamble} + 4.25\right) + \left(8 + \max\left(ceil\left(\frac{8PL - 4SF + 28 + 16 - 20H}{4\left(SF - 2DE\right)}\right)\left(CR + 4\right), 0\right)\right)\right) \quad (1)$$

Where T_{sym} is the symbol transmission time, determined by SF and BW, $n_{preamble}$ is the programmed preamble length, PL is the number of payload bytes, H=0 means presence of header, H=1 when no header is present, DE=1 when Low Data Rate Optimization is set, DE=0 otherwise, CR ranges from 1 to 4 (corresponding to coding rate from 4/5 to 4/8).

According to (1), on-the-air transmission time is inversely proportional to BW, and increases with increase of SF.

Experiment was done to verify the relationship between on-the-air transmission time, SF and BW. Spectrum analyzer RSA306 [10] was used to measure the on-the-air transmission time of the module. We used module YL-800IL with transmission power 100 mW and payload length 1 byte. The

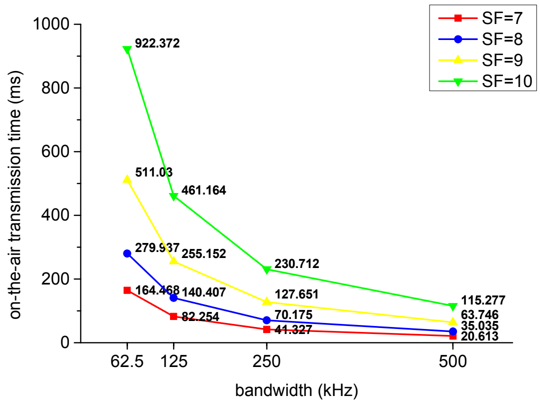

Fig. 1. *On-the-air transmission time with different bandwidth*

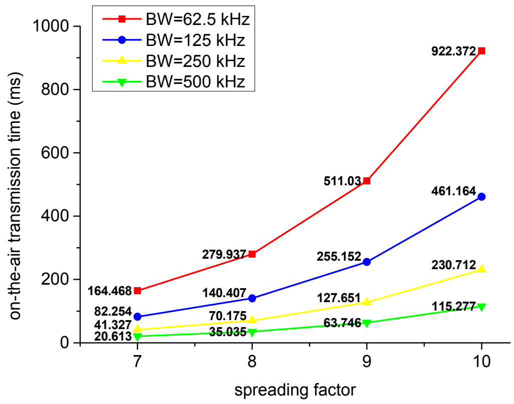

Fig. 2. *On-the-air transmission time with different spreading factor*

measurement results with different BW and SF are shown in Fig. 1 and Fig. 2.

The result in Fig.1 shows how increasing BW can decrease on-the-air transmission time under the same SF. Fig.2 illustrates that with the same BW, on-the-air transmission time increases as SF increases, which is consistent with (1).

B. Coverage

The test was conducted on a lake in Shanghai, China. The measurements were executed for the case when a module YL-900IL located on a boat reported data periodically (every two seconds) to a module acting as the base station. The antenna of the module on a moving boat was 1.5 m above the water, and the base station module with 4 m above water antenna was fixed at the center of lake without any blockings. The modules operated in 433 MHz frequency band with 100 mW transmission power and 6 dBi antenna gain.

The measurement results are shown in Table I. The results are the farthest distance under 10% packet loss with different SF and BW. It shows that the increase of range depends on the decrease of BW or increase of SF, because smaller BW and greater SF can significantly improve the sensitivity. However,

TABLE I. COVERAGE MEASUREMENT RESULT

SF	BW (kHz)	Range under 10% packet loss (m)
7	250	2910-3110
9	250	3140-3340
	500	2130-2330
11	500	4810-5010

they also decreases the date rate and increases the transmission delay.

Apart from wide coverage and low power consumption, date rate and transmission delay must be taken into account when design the sailing monitoring system. For this reason, SF of 7 and BW of 125 kHz are used in our system to make the optimal trade-off.

III. Testing of System

Sailing Monitoring System deploys star topology which consists of one gateway and several sink nodes, as shown in Fig. 3. The gateway and the sink nodes are respectively installed on the coach's boat and athletes' sailboat, as shown in Fig. 4 and Fig. 5. The monitoring parameters such as speed, direction of wind and sailboat, GPS location, etc., are collected by sensor nodes, combined at sink nodes and transferred to the gateway by LoRa technology. The system using module YL-900IL operates in 433 MHz band with SF of 7 and BW of 125 kHz. The data rate can reach 5.47 kbps. The nodes and gateway are all powered by 3.7 V batteries and the transmission power is 500 mW. The sink nodes send data with payload length 96 bytes to the gateway every two seconds. The data packet contains time, GPS locations, which can be used to estimate the packet loss rate and the position of the sink nodes respectively. Two cases were tested in the Rio sailing venue.

A. *Test Case 1*

Both gateway and sink nodes were operating on the moving boat on the sea area. The antenna of node was 1 m high above sea level and the antenna of gateway was 4 m high. The sink 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 m. The average speed of sailboat was 20 km/h, and sometimes could even reach 37 km/h. The results show that the system can work well with good mobility.

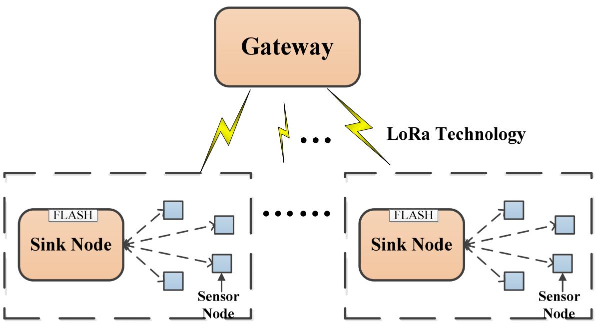

Fig. 3. Architecture of Sailing Monitoring System

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

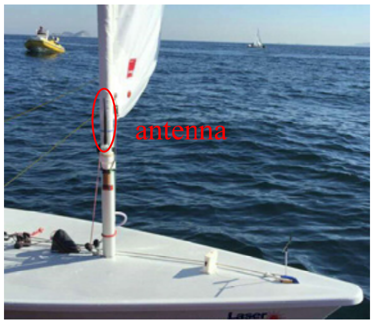

Fig. 5. Sink node installed on the sailboat

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

B. *Test Case 2*

The Gateway was fixed on the roof of 20 m high building which was 1 km away from the beach. The sink node was located on the moving sailboat along training route while the antenna was 4 m 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 Fig.6, noting that the path between gateway and sink node includes lands and sea. There are tall building, trees, and hills on the land area and the waves are large in the sea. The measurement area can be divided into four fan-shaped zones depending on the topography and obstacles. Zone A has many tall buildings with average height of 100 m. In zone B and zone C, the distances between sink nodes and gateway are similar, but zone B has a few buildings and zone C's landforms are mainly flat. A hill and a lot of tall buildings with average height of 80 m exist in zone D.

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

Fig. 6. Testing environment and sailboat's route

The results in Table III show that packet loss rate in zone C is only 0.26%, the reason is that there are relatively fewer obstacles in the transmission path in zone C. The 5.00% packet loss rate in zone B is larger than that in zone C, although the distance in zone B is even shorter than that in zone C. It reveals that the influence of obstacle may be much greater than distance. In zone A and D, 63.26% and 20.34% 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, hills and waves. Therefore, these factors should be taken into account when implementing LPWAN LoRa networks.

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 problems, 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 on-the-air transmission time increases as 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 of 7 and BW of 125 kHz are used in Sailing Monitoring System to meet the trade-off of data rate, coverage and link budget. The testing of our system was conducted in Rio sailing venue for two cases. Case 1 where sink nodes and gateway were all on the water shows that LoRa technology in our system has a good performance in mobility with 20 km/h average speed. Case 2 when gateway was fixed on the land and sink 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 5% 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 20% in those zones. Therefore, these factors should be taken into consideration when LPWAN LoRa network are implemented.

In the future, we will focus on designing LoRa adaptive network to get the optimal performance. When the environment changes, whether better or worse, the parameters of LoRa technology such as SF and BW can be changed automatically to improve the sensitivity, interference immunity and coverage.

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	3467	756	1195	63.26%
B	2207	7	140	5.00%
C	2500	1	379	0.26%
D	3707	24	118	20.34%

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