A review of wireless sensor networks for structural health monitoring: offshore wind turbines deployment

I Lestari¹ and M Arafat²

¹School of Electrical Engineering, Telkom University, Bandung 40257, Indonesia
²School of Industrial Engineering, Telkom University, Bandung 40257, Indonesia

Abstract. Offshore wind turbine is being the trend because the consistency wind resource on open seas. But the harsh environmental condition could lead to damage, corrosion, and erosion. With these challenges, structural health monitoring (SHM) plays an important role to ensure the functionality of offshore turbines, and wireless sensor networks (WSNs) help to reduce costs compared to the wire-based ones. This paper presents a literature review for two of main parameters to deploy WSNs for SHM; data rate and bandwidth which indicate the efficiency of communication for each nodes.

1. Introduction

As public awareness of global energy issues has increased, renewable energy is seen to be alternative for any limited resource fuels. Wind energy, one of the most widely available natural resources, is becoming popular with the fact that it is cost effective, environmentally friendly, and socially popular amongst a majority of the populace [1]. According to Global Wind Energy Council, the wind energy global installation has been increasing since 2000s, with 486.749 MW in 2016. The interest of deploying wind turbines for distributing power has grown. These turbines represent a significant capital investment for the owner and the turbine must operate for up to 25-30 years [2,3]. Once their lifetime has been full-filled, the turbines need to be decommissioned.

Offshore wind turbine installations are arising due to better, more consistent wind resource available on open seas [1]. But harsh environmental condition and un-predictable weather are some of the main challenges. Profitability, reliability, and availability are considered to install wind turbines. Within these determination, structural health monitoring (SHM) has been seen essential to deploy [2]. SHM must be designated with long-term structural integrity and the operational aspect of wind turbines, with respect to damages and deteriorations. And the monitoring of structural components on the other hand is vital with challenges due to specific problems related [4].

The main drawback of traditional wire-based SHM systems is the high cost, mainly because of sensors and cables. Wireless sensor networks (WSNs) has been getting advanced recent years, with increasing interest of deployment for SHM. Compared with the traditional wire-based SHM systems, wireless communication eradicates the need for wires and there-fore represents a significant cost reduction and convenience in deployment. A WSN-based SHM system can achieve finer grain of monitoring, which potentially increases the accuracy and reliability of the system⁶. To do so, right type and numbers of sensors for either wire-based or wireless sensor networks for SHM are needed to be considered.

This paper reviewed wireless network system for structural health monitoring, focusing on offshore wind turbines. The main parameters being studied are data rate and connection bandwidth which indicate the efficiency of communication for each node.
2. Literature review

2.1. Sensor networks types in SHM

The usage of sensors to monitor the health of structures is crucial and serious issues may occur in SHM due to their detriment. Low cost and power, durable sensors are required to distinguish any abnormal behavior from normal one. Different types of sensors are chosen depending on the application. Military and environmental monitoring, for example, mostly used IEEE 802.15.4 compliant radio nodes hardware platform operating in the 2.4 GHz range. Similar products provide a few hundred-meter communication range, 50 mW power consumption, and 250 kbps raw data rate.

Wireless sensor networks (WSNs) for structural health monitoring are adopted as they promise lower installation costs compared to wired-one. This is achieved by replacing the cables between the sensors and the data logger with wireless links. A WSN is basically a computer network consisting of many small, intercommunicating computers equipped with one or several sensors.

2.2. Number of sensors

Deciding the proper number of sensors in SHM is important to be implemented in wind turbine. There are massive number of sensing systems for SHM and the usage depends on the specific SHM activity to collect data continuously[5]. Later, data is filtered and converted into information by Decision Support System[6].

Sensors configuration is a critical factor to not only increase accuracy, but also minimize the number of sensors placed [7]. This has to be done without interfering much too any construction used by contractors. The importance of sensors placement is to describe continuous functions, using discrete sensor information [8]. Steven Lovejoy [9] explains eight key elements of a success SHM system which reduce the number of sensors when compared to structural monitoring approach[10]. These are applied to highway bridges, but also extensible to wind turbine. Four of which are:

1. Understand the parameters and how to measure them;
2. The right number of sensors used;
3. Choose high quality components with environmental consideration;
4. Provide inspection periodically, to monitor any faulty or degrading sensor components.

2.3. Data rate

High data rate that is required for wireless sensor networks based SHM in offshore wind turbine, is limited with the available wireless bandwidth[11]. There are some conditions that refer to the usage of the filter pattern in WSNs. The filter pattern should be used when:

- The amount of data sensed is comparatively higher than available bandwidth;
- The actual reading of sensors is rarely needed and not always required;
- The cost of processing data on the node is lower compared to data transmission.

Data rate may vary from low to high in different kind of sensors. However, in most cases, data rate gets lower as distance increased. Data rate might range from 10 Kbps to 1.6 Mbps in different conditions[12]. To accomplish the objective of WSNs in SHM, the system should have the capability of high data rate communication between each sensors.

2.4. Bandwidth

The success of SHM system is challenged with some constraints, in particularly bandwidth in wireless communication[13]. In the definition of sensor properties, common issues concern with itself should be done before the system established. Sensor bandwidth, number of sensors, reliability, and cost are the most common challenges. Higher bandwidth provides greater accuracy in the system. However, even though processing data from many sensors results better performance, but it costs more[5].
With the development of wireless sensor networks, the concern of bandwidth is arising due to its limitation. In offshore wind turbine context for health monitoring, a large number of sensors are placed in the different parts of the turbine. At the same time those sensors generate a large amount of data. Researchers showed that the transmission of wireless data rate vary with different types of sensors[14]. Most WSNs could reach the peak communication to its maximum 250 kbps[15], while in order to transfer the data for processing, system requires wireless bandwidth with high capacity.

### Table 1. Wireless sensor networks specifications used in SHM applications. [16]

|                        | A/D (Resolution) | Radio            | Frequency Band | Data rate |
|------------------------|------------------|------------------|----------------|-----------|
| Bennett and Hayes-Gill (1999) | 16-bit           | Radiometrix      | 418 MHz        | 40 kbps   |
| Lynch et al. (2002)     | 16-bit           | Proxim RangeLan2 | 2.4 GHz        | 1.6 Mbps  |
| Mitchell et al. (2002)  | 16-bit           | Ericsson Bluetooth | 2.4 GHz      |           |
| Lynch et al. (2003a, b, c, d, 2004a, b[12] | 16-bit           | Proxim RangeLan2 | 2.4 GHz        | 1.6 Mbps  |
| Aoki et al. (2003)      | 16-bit           | RealtekRTL-8019AS | –              | –         |
| Casciati et al. (2004)[12] | 12-bit           | Aurel XTR-915    | 914.5 MHz      | 100 kbps  |
| Wang et al. (2004)      | 12-bit           | Linx Technologies | 916 MHZ       | 33.6 kbps |
| Mastroleon et al. (2004) | 16-bit           | BlueChip RFB915B | 900 MHz       | 19.2 kbps |
| Ou et al. (2004)        | 8-bit/10-bit     | Chipcon CC1000   | 433 MHz        | 76.8 kbps |
| Sazonov et al. (2004)   | 12-bit           | Chipcon CC2420   | 2.4 GHz        | 250 kbps  |
| Farrar et al. (2005) and Allen (2004) | 16-bit           | MotorolaneuRFon | 2.4 GHz        | 230 kbps  |
| Polastre et al. (2005)[17] | 12-bit           | Chipcon CC2420   | 2.4 GHz        | 250 Kbps  |
| Musiani et al. (2007)   | 12-bit           | Chipcon CC1100   | 1 MHz          | 0.6-250 kbps programmable |
| Wang et al. (2007)[18]  | 16-bit           | 9XCite           | 902-928 MHz    | 38.4 kbps |
| Bocca et al. (2009)     | 12-bit           | ChipconCC2420    | 2.4 GHz        | 20 kbps   |
| Zhou et al. (2009a)     | 12-bit           | ChipconCC2500    | 2.4 GHz        | 250 kbps  |
| Paoli et al. (2014)[19] | 8-bit            | Atmega128RFA1    | 16 MHz         | 128 kbps  |
| Kilic et al. (2015)[20] | 32-bit           | Atmel AT91RM92   | 2.4 GHz        | -         |
| Taylor et al. (2016)[21] | 14-bit           | LTC2351          | 70 KHz         | 250 kbps  |
| Maicon et al. (2017)[22] | 8-bit            | CC2420           | 2.4 GHz        | 250 kbps  |

### Table 2. Difference between Wireless and Wired Sensor Networks for SHM.

|                                      | Development Cost | Scalability | Deployment | Lifespan | Design level | Sensibility to environmental effects |
|--------------------------------------|------------------|-------------|------------|----------|--------------|--------------------------------------|
| Wireless sensor networks for SHM     | Low cost[23] ($100-$500) for each node | Easy        | Rapid      | Short    | Difficult    | Yes                                  |
| Wired sensor networks for SHM        | Very high[23] ($1,000-$25,000) | Difficult   | Several days[24] | Long    | Fair         | No                                   |

2.5. **SHM in offshore wind turbine**

Wind turbines is estimated to last damage up to five times a year[25]. During bad weather, it is difficult to inspect any kind of nondestructive experiment of offshore wind turbines. Which means, these turbines are keep servicing without any monitoring process. As a result, most of long period turbines can lead a great financial inefficiencies. It has seen from past, that SHM and condition monitoring using different types of method, specialized instruments improve the reliability of the offshore wind turbines.
Research has introduced Integral SHM-System for offshore wind turbine (figure 1), that combines three independent computational modules. That provide three level damage detections namely existence, location, and severity[25].

**Figure 1.** Overview of the Integral SHM-System for offshore wind turbines. [25]

Offshore wind turbine structures monitoring has gained more attraction than onshore structure monitoring. One of the reason is that offshore wind turbines are remotely located while these maintains under challenging conditions[26]. However, many questions considering SHM of offshore wind turbine has come surroundings due to the challenges, complexity of monitoring and maintenance.

3. **Conclusions**

Complex configuration is a standard of wireless sensor networks (WSNs) for SHM. Compared to traditional wire-based SHM, WSNs are relatively lower cost with reducing the needs of cables. Proper number of sensors in WSN is important to ensure the continuity of communication for each network nodes, although it varies, depending on the structure type and activity. The main focus in this paper is to acknowledge the requirements to reach expected data rate and bandwidth. Bandwidth will be equal to accuracy, which means, the higher bandwidth, the better accuracy resulted. Offshore wind turbines, with some challenging conditions, require comprehensive design, including for the monitoring system. Drawbacks of installing offshore wind turbines, such as corrosion and erosion, then being one of main reasons of why implementing structural health monitoring is important.

4. **References**

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