Monitoring of huge buildings and civil structures using self-powered LoRa Wireless Sensor Networks

Summary

Smart building solutions for structural integrity represents one of the modern challenges in the Internet of Thing (IoT) sector. In particular, Long Range (LoRa) radio frequency technology, which is emerging in recent years, seems to be a suitable protocol for efficiently monitoring a variety of safety indicators for buildings in real-time. LoRa Technology, in fact, offers flexibility and easy deployment into a wide range of infrastructures, both old and new. It is scalable by increasing the number of gateways, low energy and low cost, and brings together sensing and data analytics solutions. All these features fit the requirements for implementing a Structural Health Monitoring (SHM) system that is a useful tool for detecting the evolution of damage and estimating performance deterioration of civil infrastructures. SHM is an area of growing interest and worthy of new and innovative approaches, and the application of LoRa technology to such a purpose is a matter of research. Many aspects, from radio communication to sensors, methods or data reduction and analysis, need in depth investigations.

The thesis work is part of this context with the main aim of studying the potentials of LoRa technology applied to Low Power Wide Area Network (LPWAN) for SHM purposes. The research activities have been carried out in collaboration with the Remote Sensing Group (RSG) of the Department of Electronics and Telecommunications (DET) at Politecnico di Torino and Institutional Partners (CINFAI – Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere, e CIFS – Consorzio Interuniveritario per la Fisica Spaziale), within different research projects. The present work is divided in two main parts: the first one is related to a low-cost sensing network definition for SHM and to the improvement of the functionalities of standard sensors deploying. The second is related to LPWAN, with particular focus on LoRa Wireless Sensor Network (WSN) for indoor and outdoor monitoring (in case of network use in distributed structures, for example bridge). Both the activities are basically devoted to structural monitoring and protection.

Earthquake events are frequent in the Mediterranean area and specially in Italy, which has a medium-high seismic hazard (related to the frequency and intensity of phenomena), a very high vulnerability (related to fragility of building, infrastructural, industrial, productive and service heritage) and a very high exposure (related to population density and presence of historical, artistic and monumental heritage). Italy has therefore a high seismic risk in term of victims, damage of buildings and direct and indirect costs due to earthquakes. In this framework, to efficiently monitor buildings and infrastructure through a distributed sensor network for structural health monitoring should be needed, due to the nature of earthquake events of extended dimensions and the size of the basins of interest, in term of population involved. At this purpose, the Long Range sensor network described in present work is a good and useful solution to improve the protection

of infrastructures, dense (indoor solution) or distributed (outdoor solution). It can also be used as a support for institutional emergency management bodies (say Protezione Civile) that need to know how to operate safely in urban or rural areas .

Chapters form 1 to 3 are all devoted to the study, analysis and test of LoRa technology in order to identify possible applications in a Wireless Sensor Network (WSN) for Structural Health Monitoring and to verify possible use for indoor and outdoor monitoring (with relative obstacles) of buildings, structures and distributed infrastructures. In the same chapters, the behavior of LoRa module employed to realize the prototypal sensing nodes is addressed.

A set of software tools was developed to implement the required LoRa specifications (defined in chapter 1 and 2). The complexity of the system to be implemented allowed to realize a proof of concept of network architecture with the aim to demonstrate its feasibility and having an idea of the potential for SHM of located or distributed structures and infrastructures. (**Chapter 4**).

As mentioned before, in defining and developing a new SHM system, LoRa technology, based on advanced wireless sensors, can offer great potentials for remote and real-time monitoring of building structure and integrity. In **Chapter 5** a sample application of smart devices with LoRa chip-sets is presented to detect and monitor the effect of earthquakes on structures, especially huge infrastructures.

Chapter 6 describes another WSNs developed for multipurpose boards usable with LoRa technologies. In this case, the LoRa application has a completely different purpose than SHM: the timing control board to be used in pulse-jet cleaning of dust collector filter bags or pneumatic conveying systems. The presented prototype is based on microcontroller so it can manage a certain quantity of data arriving from a set of sensors (like differential pressure gauge or triboelectric sensors) or shared on network from other boards. Thus, the board can be used for fully automate the cleaning process, monitoring the condition of the filter and to detect faults in the valves actuation and protect the system from these.

All the activities related to Structural Health Monitoring and Lora Network are part of the main project of the research program, called “Ricerca e sviluppo di tecniche e di sensori innovative per la caratterizzazione ed il monitoraggio del territorio”, which is part of a cooperative program co-founded by CINFAI and CIFS called “STESEM”.

The aim of the program is mainly twofold:

- To offer to the Ph.D student the possibility to work with high-level technologies developed together with external research institutions;
- To attend high-level formation activities offered from both Politecnico di Torino and also from other institutions, thanks to funds provided by research institutions.

CINFAI and CIFS operate in innovative technological solution engineering and scientific and experimental activities in the framework of environmental applications, related to institutional tasks, with particular focus on sensors including performance simulations and develop and prototyping, proposing low-cost solutions and multipurpose electronic tools. Thus, the PhD activities completely fall within the institutional profile.

Contributions

The research activity carried out during the PhD course can be viewed as part of a set of studies aiming to investigate the usefulness of a wireless network based on LoRa technology and low energy IoT sensors for monitoring purposes. The focus of the thesis was on the structural health monitoring of different types of infrastructure, but also other possible applications have been considered.

As will be described in the subsequent chapters, the main results obtained were the subject of publications on international scientific journals. In particular, the activities were devoted to:

(1) The study of indoor and outdoor propagation models for a LoRa network (papers:, Bertoldo S., Paredes M:, Carosso L., Allegretti M:, Savi P. (2019) Empirical indoor propagation models for LoRa radio link in an office environment, 13th European Conference on Antennas and Propagation (EuCAP); Paredes M. Bertoldo S., Carosso L. Lucianaz C., Marchetta E., Savi P. (2019) Propagation measurements for a LoRa Network in an urban environment, Journal of Electromagnetic Waves and Applications, Vol. 33, No. 15, 2022-2036;

(2) The study of SHM system based on advanced wireless sensors (paper: Carosso L., Allegretti M., Bertoldo S. (2017) A new wireless sensor network module for health monitoring of civil structures, EEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 8-11;

(3) The study of other applications than SHM based on LoRa technology (paper: Allegretti, M., Bertoldo, S., Carosso, L., Gaiki, D. (2018). A New Modular Board for Pulse-Jet Cleaning of Dust Collector Filter Bags. Engineering, Technology & Applied Science Research, Vol. 8, No. 2, 2799-2804).