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# EXPLORING LORA TECHNOLOGY FOR INTERNET OF THINGS PARADIGM APPLICATION TO CONSTRUCTION SITES

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## Abstract

The technological evolution of the "Internet of Things" (IoT), after its deep innovation in the industrial automation field through the so-called Industry4.0 - the fourth industrial revolution driven by data - is going to deeply innovate also the entire supply chain of the construction sector, including construction sites. This paper aims at analyzing and presenting the communication technologies enabling the IoT paradigm in the construction sector supply chain. In particular, the analysis focuses on field level communication, i.e. solutions for integrating construction site equipment and sensors into the company information system.

## Introduction

The use of solutions coming from the Information and Communication Technology (ICT) field, such as big data analytics (Xiong et al.,2015), cloud computing, sensors and communication (Tagliabue et al., 2020), in the construction management, can easily realize the digitalization of the construction site, becoming in all its aspects intelligent and digital. Intelligent sensors can be installed in the construction site. Some examples are: video data, dust level data, noise data, lift control, crane data, temperature and humidity data, RFID data and data generated by other sensors. Through these data, the site supervisor can make the right decision, in order to ensure safe construction and management of the site (Wang et al., 2016). As far as the site management is concerned, the site monitoring and personnel supervision functions can be easily implemented through a digital construction paradigm. By means of data mining solutions, quality management and safety of the construction site are possible (Deraman et al., 2019), (Park et al., 2017).

A practical example of construction site digitalization benefits is monitoring the progress of the construction site. Many construction projects are delayed due to many factors, including bad weather, material supply problems, but one of the main problems is human error. Operators can lose machining tools or skip some stages of the work. These errors or shortcomings should be detected as soon as possible in order to reduce the delay. But monitoring management and construction work become difficult because construction work can be spread over a very large area and involve several workers (Abd.Majid et al., 2004) (Bayrak et al., 2004). In order to monitor the progress of the works, the construction company sends the project manager to the construction site; the manager recodes any possible change on a paper sheet, tablet or PC and adds photos related to the construction site. Subsequently, the company can view the progress by checking the cards or photographs that have been sent. The most advanced companies monitoring work progress use the Building Information Modelling (BIM), an approach which involves the use of several tools, coordinated in a unique system that allows to view all the information about work progress. However, inserting information about work progress or any errors in construction are still manually carried out and detected (Bohn et al., 2010). Some recent research works (Bouzidi et al., 2012) proposed a semantic web approach to simplify compliance checking in a construction site, but the proposed approach has a limited impact on real construction sites. Remote cameras are essentially used to protect a construction site, but they can also be used to monitor the construction site progress: periodically captured videos visually identify the progress. However, the coverage of cameras is generally limited to small areas; to cover a very large construction site it is necessary to install many cameras, and this is not always possible. To overcome this problem, the use of drones equipped with high-quality video cameras (able of capturing videos of the entire construction site) are being studied. With high-quality videos, the project manager can remotely view the construction site and inspect the construction site progress. However, video images can only capture a large-scale progress. When, however, small changes or changes need to be monitored over a small area, using video footage is not enough. In this case it is necessary to rely on appropriate sensors capable of monitoring the construction site progress and the operations performed by the operators. The digitalization of the construction site allows, therefore, to easily create real-time monitoring systems of the construction site, integrating sensors in the BIM systems. A construction site becomes digital thanks to sensors, that are capable of acquiring data from the physical world and bringing this information into the virtual world. In the industry 4.0 world, the union between a physical device and its electronic / IT counterpart is called Cyber-Physical System (CPS). Its digital counterpart, i.e. the data model associated with it, what information or services that object / system can provide and how to interact with it (on a communication protocol level), is part of the Internet of Things ( IoT) paradigm. One of the main limits of a wide application of IoT technology to the construction site field is the lack of a proper communication infrastructure, able to provide connectivity to smart devices installed in the field. The papers aims at investigating communication technologies, with a specific focus on Low Power – Wide

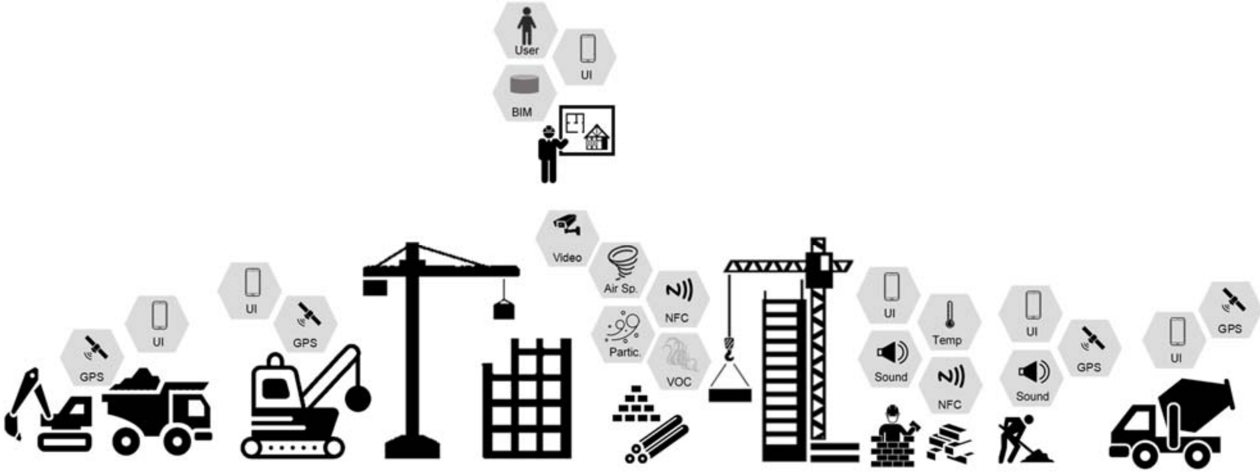


*Figure 1: An example of the application of IoT for the virtualization of construction sites.*

Area Network (LP-WAN) technologies, such as LoRa, able to provide a low-cost solution to cover a wide range.

## Construction site digitalization: which are the enabling technologies

In the following section, two of the technologies behind the success of industry 4.0 will be briefly introduced: cyber-physical systems (CPS) and Internet of Things (IoT). After a brief introduction, we'll discuss the application of these technologies to construction sites (Figure 1).

### Cyber Physical Systems

Cyber-Physical Systems (CPSs) are characterized as collaborative computational element systems that control physical entities (Griffor et al., 2017). A processing and communication core monitors, coordinates, controls, and integrates the operations of CPS, which are physical and engineering systems. By mixing processing and communication with physical processes, these systems enable physical systems to gain computational capabilities. The relationships between computational elements and physical elements are shown in Figure 2. CPS are widely used in different domains, such as the automation of electrical networks (Rinaldi et al., 2015) and industrial automation systems.

CPS are intended to conduct time-sensitive functions that interact with their surroundings. As a result, they incorporate all the necessary components, including processing power, communication, sensing and actuation. The architecture of a CPS is designed to take into consideration CPS timing requirements: Software and hardware of a CPS are both aware of time. Timing requirements are known as Time Interval (TI) constraints in CPSs and they apply to any pair of critical system events. These TI limitations can be classified into three groups:

1. "Fixed TI": events requested from CPS, whose temporal behavior must be satisfied;
2. "Deterministic TI": events requested from CPS with repeatable and precise times in relation to the time of the entire system;
3. "Accurate TI": used to coordinate events in CPS distributed over a large area.

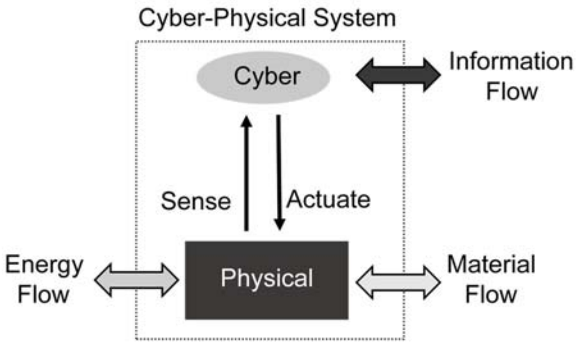


*Figure 2: The structure of a Cyber Physical System.*

CPS places a high value on temporal interactions with physical processes. This is especially true for CPS systems that have strict real-time requirements. In that case, an advanced programming model, like the one suggested by (Derler et al, 2013), capable of explicitly accounting for temporal dynamics in its model, is required for this class of CPS devices.

### Internet of Things: definition

If CPSs represent the physical integration of electronics, IoT represents the cyber counterpart. The "Internet of Things" term has been exploited or misused in several sectors in the latest years. This term refers to a wide range of solutions that are in some way connected to the worlds of intercommunication and intelligent gadgets. Some of these solutions, such as (Carbone et al., 2013) (Depari et al., 2013), should more properly be referred to as "INTRAnet of Things", rather than the "INTERnet of

Things" because they represent vertical domains with minimal or no interoperability. The Internet of Things Architecture (IoT-A) project (Bauer et al., 2012) aimed to promote greater interoperability across multiple platforms deployed in the same environment, both in terms of communication, service, and even knowledge. IoT-A project is composed by two mains parts: a Reference Model (RM) and a Reference Architecture (RA). The former provides for concepts and definitions required to build IoT architectures. The latter represents a reference for the design of compliant IoT architectures for specific applications. In the rest of the section, the Domain Model (DM) and the Functional Model (FM) of the RM will be briefly presented.

**Domain model**

DM defines the characteristics of an objects, such as name and identifier, in a generic IoT application, as well as their connections, a common language and taxonomy, in order to enable an easy data exchange between domains. A generic user must engage with an entity (perhaps distant) from the real world in a wide IoT scenario. A user can be a human or a digital artifact (such a software agent) that interacts with a Physical Entity (PE). A Virtual Entity (VE) is a synchronized representation of a collection of PE attributes that is used to represent PEs in the digital world.

As a result, the devices are technical artifacts that connect PE's physical world to the Internet's digital realm. Monitoring, sensing, actuation, calculation, storage, and processing were all used to build this bridge. PE requires resources, which are software components that give data or allow PE to function.

A VE can also be connected to resources that allow users to interact with the PE it represents. A service is a standardized, well-defined interface that has all of the functionality needed to connect with PE and its associated processes. The network and its associated protocols are used to communicate with the service. Thanks to these abstraction and modeling skills, IoT systems find wide application in different fields, such as industrial automation systems (Ferrari et al., 2018) and building automation systems (Rinaldi et al., 2019), all sectors where interoperability of systems is a key point.

**Functional model**

FM is an abstract approach to understand the primary functional groupings and their relationships in the IoT-A environment. FM is made up of distinct functional groups (FG) that are based on DM principles. The IoT Business Process Management adds capability to various IoT components, such as sensor data reliability and accountability, which delivers VE information. IoT services allow to access to the resources of sensors and actuators: this services can be discovered through physical world features of the VE level. To facilitate interactions between visual events, the relationship between IoT services and visual events must be characterized by associations. The FG Communication protocol allows data to be addressed and routed, bypassing limitations of hop-to-hop communication and permitting connections between various networks. Connection problems, traffic congestion and other forms of unexpected events are addressed by the FG Management. FG Security is in charge of ensuring that worldwide systems are safe and private.

## Available IoT transmission technologies for construction sites

The concept of the Internet of Things (IoT) has the potential to change how we live and work (Sisinni et al., 2018). Intelligent devices will be able to study their surroundings thanks to omnipresent connectivity, and vast data volumes will be uploaded to the cloud to feed deep learning algorithms. Each of these systems has different communication requirements, but some of them are common to all: low-power wireless access to the field devices and separation of data from their users. When it comes to communication systems, a first distinction must be made between transmission technologies, or the physical systems used to transmit information (e.g., Wi-Fi, Bluetooth, 4G / 5G), and communication protocols (e.g., HTTP, SNMP, MQTT and many more) that use these transmission media to transmit information. The same communication protocol can be indistinctly used regardless of the physical system used for the transmission. For example, a (HTTP protocol) web page can be accessed through a smartphone, using Wi-Fi connection or 4G connectivity. The end user does not have (and must not) have a perception of which physical level is being used. The same happens for IoT objects. Each object will have its own type of connection which can depend on several factors, but the protocol for communicating to this object remains the same.

The construction site is a very specific case of environment in which IoT systems operates, both because of the mobile nature of the construction site and the requirements that these systems must guarantee.

Considering the typical services required by the construction site, as described in the previous section, the communication layer should be able to offer the following features, each of them with a different degree which depend on the specific application:

- Reliability
- Localization Service
- Time synchronization
- Security

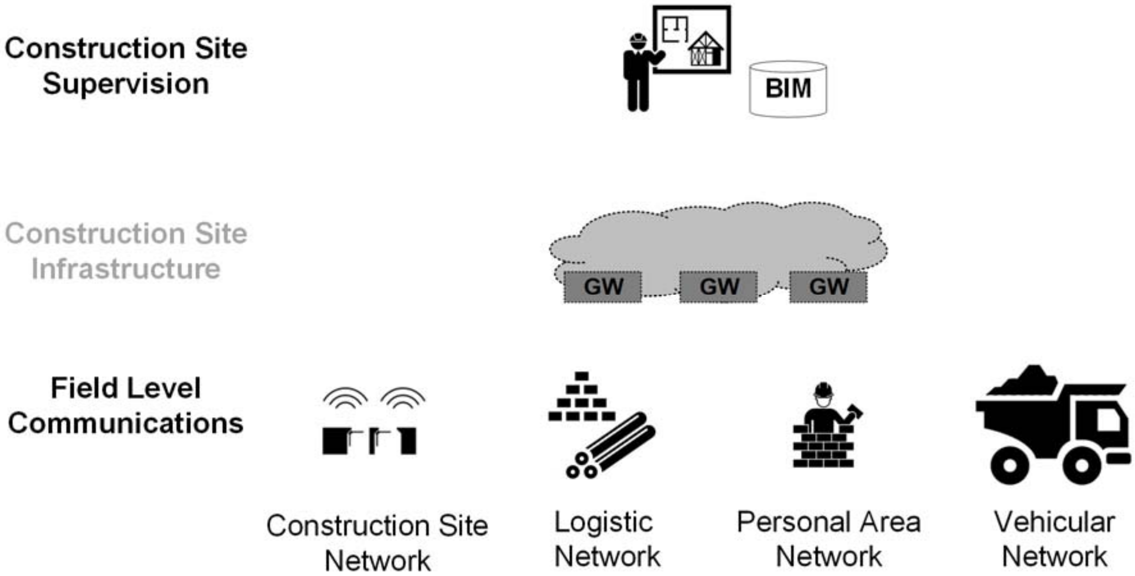


*Figure 3: An example of the application of IoT for the virtualization of construction sites.*

Thus, the selection between different available solutions depends on the specific application requirements. Figure 3 schematically represents the communication systems within a construction site. As can be seen from the figure, there are several systems that must interact with each other in order to ensure a correct functioning of the construction site and IoT services. Each of these subsystems has its own specific requirements and needs. Thus, different transmission technologies could coexist on the same site, offering connection to different physical objects. On a field level, each of the sub-system has its own communication technology, able to satisfy application requirements. Construction vehicles are usually equipped with cabled fieldbus used to monitor the state of vehicle itself. The operators could be equipped with sensors to monitor their health, or to monitor their position in the construction sites. The construction material can be equipped with RFID tag for an automatic supply chain management.

To simplify, we identify three different communication levels: field communication (which include the communication systems on board the operating machines, and the Personal Area Networks of the operators), area communication systems (which include the backbones communications located in the areas of the construction site) and supervisory communication systems (i.e., communications to remote cloud systems).

Several communication technologies can be used to satisfy the requirements of digital services in construction sites. Figure 4 classifies some of them considering two of the most important parameters: data rate and communication coverage. Three communication families can be identified, each of them grouping similar technological solutions: Mobile, Short Range and Long Range. The former is characterized by high throughput, but, at the same time, the transmission is power hungry. The Short-Range technologies are designed for limiting the consumption required by the communication. These solutions are characterized by limited data rate (if compared to the previous ones) and limited range coverage (generally tens of meters). Example of these communication solutions are Bluetooth, NFC or RFID.

The latter solution is characterized by an extremely low data rate (on the order of few kilobytes), but a range coverage of several kilometers. These communication technologies are perfect for low power IoT devices transmitting only a limited amount of data per day, such as environmental sensors.

The 5G mobile communications promises to meet all (or at least a substantial portion) of the requirements, but off-the-shelf field devices are not yet ready and widespread deployment is still underway (Shafi et al., 2017).

## LPWAN paradigm as Wireless IoT transmission technology in construction sites

Low-Power Wide Area Networks (LPWANs) have emerged as a feasible alternative for interconnecting IoT devices with limited resources (Raza et al., 2017). The

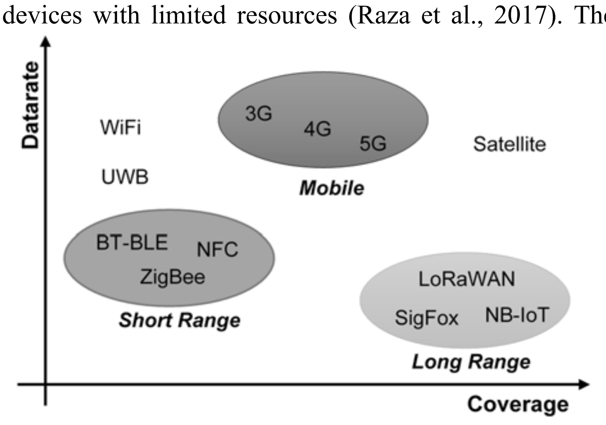


*Figure 4: A comparison between several transmission technologies for IoT.*

term "low-power wide-area network" (LPWAN) refers to a group of wireless communication solutions whose purpose is to reduce consumption while increasing coverage. Reduced throughput and a rather slow update rate are the price to pay, but they are still acceptable for most IoT applications. To reduce total costs, LPWANs mimic the mobile communication technique by building a network of stars that uses a small number of base stations joined by a simple infrastructure (Centenaro et al., 2016). To limit the processing capabilities required by IoT nodes, the protocol stack is also basic.

In general, wide coverage is achieved by reducing the available bandwidth (thus boosting the receiver radio's sensitivity and filtering out most of the noise) and operating in the sub-GHz range of the spectrum. There are a number of commercial LPWANs, each with its own set of benefits and drawbacks, but the Long-Range Wide Area Network (LoRaWAN) is the most widely used. On the wireless frontend, LoRaWAN uses CSS modulation, while the backend is made up of internet-connected Network, Application and Join Servers (NS, AS, and JS, respectively) (Antelado et al., 2017).

Sensor information recovery time is differently constrained in systems with strict time limitations. In other words, the data's value is contingent on all end nodes connected to the infrastructure being "simultaneously" available. For the uplink and downlink communication channels, analytical methods for measuring. The performance , in term of latency, collision rate and throughput of a LoRaWAN network have been investigated in (Delobel et al., 2017). However, up until now, only few scientific research, such as (Potsch et al., 2019), focused on the overall system performance, including the servers required for LoRaWAN communication.

In recent years, LPWAN networks have emerged as a viable and cost-effective solution for meeting the communication needs of conventional IoT applications. LPWAN networks may be a viable alternative for providing cloud access to field devices in construction sites with restricted real-time performance needs, based on some of their characteristics. All wireless communications must strike a balance between energy consumption, costs and bandwidth; LPWANs were created for applications that require sporadic transmissions and instead require attention to energy consumption and cost reduction, even if it means accepting a significant bandwidth limitation (which translates into good receiver sensitivity and coverage of the area). Furthermore, because they operate in non-licensed frequencies, they are limited in their broadcast time. The interconnection servers that actually perform the offer of services and allow the integration of end users are often based on a wireless frontend and a wired backend for LPWANs. Complex actions are downloaded to the backend, where massive computer resources are accessible, lowering the overall cost. Because LPWAN are frequently connectionless and mainly based on uplink transmissions, network capacity per base station is exclusively defined by the quantity of generated messages rather than the actual number of field devices. These qualities are appropriate for use on construction sites because sensors and equipment in the field typically only need to send a small amount of data to the back-end.

Today, two technologies - SigFox and LoRaWAN - have emerged as standard solutions for LPWAN. Both methods are based on proprietary patented radio interfaces and are open standards. SigFox employs a technique known as ultra-narrow band modulation (UNB). The Chirp Spread Spectrum (CSS) modulation is used by LoRaWAN. The commercial model of SigFox is similar to that of mobile communication, in which only a few accredited operators can deploy and manage the backend infrastructure; actually, each dispersed node requires a subscription. LoRaWAN, on the other hand, supports both a public and a private backend (controlled by the operator). As a result, LoRaWAN is viewed as an alternative mobile network that does not require the identification of the used, and thus, the payment to access to the services made available from the provider network.

**LoRaWAN**

LoRaWAN appears to be the most popular LPWAN technology right now, with a lot of academic interest and a number of pilot installations, mostly from multi-utility organizations all over the world. Several vendors offer comprehensive ready-to-use modules that make setting up a real-world experimental network much easier. When compared to the SigFox solution, LoRaWAN can handle more data and messages per node, allowing it to offer applications beyond environmental monitoring and remote meter reading. One of the benefits of this technology is the possibility to design a completely private backend infrastructure.

**Protocol stack**

The LoRaWAN defines a Data Link (DL) layer on the top of the physical layer (PHY), based on the LoRa radio patented by Semtech. The PHY level employs a complex CSS modulation mechanism. The so-called Spread Factor (SF) is encoded using a linearly frequency modulated signal (chirp). Due to the low cross-correlation between chirps of varying lengths and their near-orthogonal nature, channels may be easily generated by altering the SF value. As a result, virtual channels and ambient noise robustness are impacted by SF and adaptive data rate.

Because the regulatory framework for unlicensed bands varies from country to country, the bandwidth, B, and duration of the chirp (i.e. the permissible SF) are rigorously determined by the country from which the activities originate. B is [125.250] kHz in Europe, while SF is [7..12]. As a result, data transfer rate ranges from 300 bps to 11 kbps. The maximum payload at DL level is 250 bytes (at SF7) and can change from a region of the

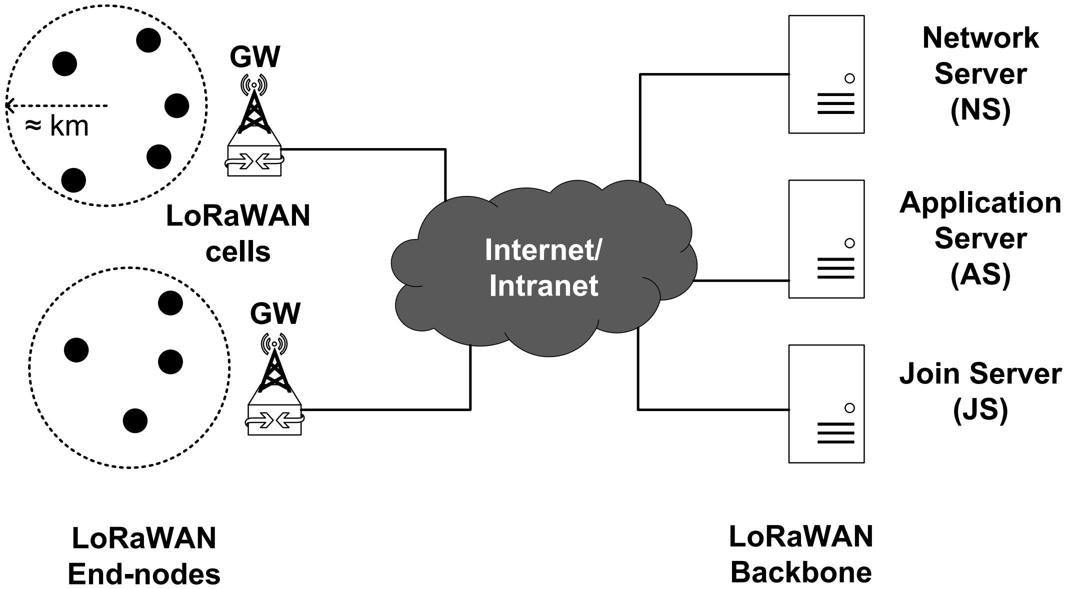


*Figure 5: The architecture of a LoRaWAN network.*

globe to limit the maximum duration of the message, and thus reduce collisions.

The access strategy is defined by LoRaWAN, as previously stated. The ALOHA approach is utilized to keep the strategy as basic as feasible (thus minimizing expenses and energy consumption). In environments with many nodes, clear channel assessment techniques can be utilized to limit collisions.

Furthermore, because of the regulations that govern unlicensed bands, data transmission periodicity may be limited: the three obligatory channels in Europe (868.1 MHz, 868.3 MHz and 868.3 MHz) allow a maximum duty cycle of d = 1%.

**Architecture**

The LoRaWAN network structure is built on a cluster of stars. The center of the star is called base station, also known with the name of gateway. Because communication is generally started by the end device, uplink transactions from the field are preferred. The gateway is always one hop away from the final node, as in the case of mobile communications. The gateway directs the received packets to the backhaul network, allowing LoRaWAN messages to be tunneled there and vice versa (see Figure 5). The gateway works at the PHY level and it is not able to user data, that are encrypted for security reasons.

Each LoRaWAN network must have a Network Server (NS) at the backend, responsible for identifying and authenticating incoming messages by validating the Message Integrity Code (MIC) attached to the message. A network-level key shared by both NS and end device is used to calculate the MIC. It should be noted that many gateways can listen to the same message sent by a end node. The "forwarding NS" function, which propagates the message to the end destination, helps allow roaming.

The Application server (AS) is part of the backend and it allows the integration of end-user applications. Although the requirements do not specify how these servers should be implemented, the most prevalent solutions use ordinary TCP/IP or telemetry middleware (such as MQTT) to access application data. A AS that it is used for message encryption and decryption. In that case, the node and the AS must have the same encryption key.

## Conclusions

IoT technologies are revolutionizing several industries. In particular, the construction sites field will benefit from all services enabled by the huge amount of data generated by IoT paradigm, including predictive maintenance, integrated supply chain management, which have revolutionized the industrial world in recent years. The word "digital construction site" refers to the use of solutions provided by the world of Information and Communication Technology (ICT) for an accurate design, planning and construction of buildings. The "digital construction paradigm" aims at easing supervision and management of works and making the construction phase more efficient, to decrease the impact of these activities on the environment and create increasingly energy efficient buildings with the lowest possible ecological impact. One of the main obstacles to a larger diffusion of IoT paradigm in construction sites is the lack of a pervasive communication solution, able to offer a low-cost communication channel to sensors and systems installed in construction sites. The paper analyzed the typical communication requirements of systems installed in construction sites. The LP-WAN communication technologies, and LoRa in particular, are a promising solution to provide a viable infrastructure to IoT devices installed in construction sites, thanks to their wide area coverage and low-cost and low-power transmission.

## References


Xiong Gang, Dong Xisong, Zhu Fenghua, Ji Tongkai, "Big Data Technologies and Intelligent Application System for Urban Transportation," Big Data Research, Vol. 1, 2015, pp. 2:1-16.

Tagliabue, L.C.; Re Cecconi, F.; Moretti, N.; Rinaldi, S.; Bellagente, P.; Ciribini, A.L.C. Security Assessment of Urban Areas through a GIS-Based Analysis of Lighting Data Generated by IoT sensors (2020) Applied Sciences (Switzerland), 10 (6), art. no. 2174.

Wang Xiaobing. Agricultural informatization and big data. Big Data Research, 2016, 2(1), pp.34.

Deraman, R.; Wang, C.; Yap, J.B.H.; Li, H.; Mohd-Rahim, F.A. Developing Internet Online Procurement Frameworks for Construction Firms. Future Internet 2019, 11, 136.

Park, K.; Lee, S.; Ahn, Y. Construction Management Risk System (CMRS) for Construction Management (CM) Firms. Future Internet 2017, 9, 5.

Abd.Majid M.Z., Memon Z. A., and Mustaffar M., "Conceptual digital monitoring model for evaluating the progress of work.", Proceedings of 4th conference of construction applications of virtual reality, 13-15 September 2004, pp.161.-166

Bayrak T, and A. Kaka, "Evaluation of digital photogrammetry and 3D CAD modelling applications in construction mangement", 20th Annual ARCOM conference

Bohn J, and Teizer J, "Benefits and barriers of constuction project monitoring using high resolution automated cameras", Journal of Construction Engineering Management, 136(6), pp.632-640.

Bouzidi, K.R.; Fies, B.; Faron-Zucker, C.; Zarli, A.; Thanh, N.L. Semantic Web Approach to Ease Regulation Compliance Checking in Construction Industry. Future Internet 2012, 4, 830-851.

"Framework for Cyber-Physical Systems", Cyber Physical Systems Public Working Group, draft 0.7 , 3/3/2015.

S. Rinaldi, P. Ferrari, A. Flammini, "Analysis of IEEE 1588-based Cyber Physical System for micro grid automation", 2015 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control, and Communication (ISPCS), Beijing, China, October 15-16, 2015.

P. Derler, et al. "Using Ptides and synchronized clocks to design distributed systems with deterministic system wide timing", in Proc. of ISPCS 2013 pp.41,46, Sept. 2013.

P. Carbone, A. Cazzorla, P. Ferrari, A. Flammini, A. Moschitta, S. Rinaldi, T. Sauter, E. Sisinni, "Low Complexity UWB Radios for Precise Wireless Sensor Network Synchronization", IEEE Trans. Instrumentation and Measurement, September, 2013, Vol. 62, N. 9, pp. 2538-2548.

A. Depari, A. Flammini, S. Rinaldi, A. Vezzoli, "Multi-sensor system with Bluetooth connectivity for non-invasive measurements of human body physical parameters", Sensors and Actuators A: Physical, November, 2013, Vol. 202, pp. 147-154.

M. Bauer, et al., "Internet of Things Architecture IoT-A. Deliverable D1.4 –Converged architectural reference model for the IoT v2.0" 2012.

P. Ferrari, A. Flammini, S. Rinaldi, E. Sisinni, D. Maffei, M. Malara, "Impact of Quality of Service on Cloud Based Industrial IoT Applications with OPC UA", Electronics, July, 2018, Vol. 7, N. 7, pp. 109.

S. Rinaldi, A. Flammini, L. C. Tagliabue, A. L. C. Ciribini, "An IoT framework for the assessment of indoor conditions and estimation of occupancy rates: results from a real case study", ACTA IMEKO, June, 2019, Vol. 8, N. 2, pp. 70-79.

E. Sisinni, A. Saifullah, S. Han, U. Jennehag and M. Gidlund, "Industrial Internet of Things: Challenges, Opportunities, and Directions," in IEEE Transactions on Industrial Informatics, vol. 14, no. 11, pp. 4724-4734, Nov. 2018.

M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, F. Tufvesson, A. Benjebbour, G. Wunder, "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 6, pp. 1201- 1221, June 2017.

U. Raza, P. Kulkarni and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview" in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 855-873, Secondquarter 2017.

M. Centenaro, L. Vangelista, A. Zanella and M. Zorzi, "Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios," in IEEE Wireless Communications, vol. 23, no. 5, pp. 60- 67, October 2016.

F. Adelantado, et al.,"Understanding the Limits of LoRaWAN," in IEEE Communications Magazine, vol. 55, no. 9, pp. 34-40, Sept. 2017.

F. Delobel, N. El Rachkidy and A. Guitton, "Analysis of the Delay of Confirmed Downlink Frames in Class B of LoRaWAN," IEEE Vehicular Technology Conference (VTC Spring), Sydney, 2017, pp. 1-6.

A. Potsch, F. Hammer, "Towards End-to-End Latency of LoRaWAN: Experimental Analysis and IIoT Applicability", 2019 15th IEEE World Conference on Factory Communication Systems (WFCS), Sweden, 2019, pp 1-4.