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Construction Machinery Monitoring System Using LoRa WAN

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Abstract
Wireless networks have been widely deployed for many Internet-of-Things (IoT) applications, like smart cities, precision agriculture, etc. Low Power Wide Area Networking (LPWAN) is an emerging IoT networking paradigm to meet three key requirements of IoT applications, i.e., low cost, large scale deployment and high energy efficiency. Among all available LPWAN technologies, LoRa networking has attracted much attention from both academia and industry, since it specifies an open standard and allows us to build autonomous. This paper focuses on leveraging LoRa Technology for Construction Machinery Monitoring and Tracking System to increase productivity and faster execution of construction Projects.

Keywords: IOT, LPWAN, LoRa, BLE, Construction Machinery Monitoring System.

1. Introduction

Construction machinery is a huge investment for any business and it's every owner's concern to keep their construction machinery running at optimal capacity levels. If the construction machinery is left idle or overused, the maintenance cost of the construction machinery increases operational cost. Hence Construction machinery monitoring system is required to monitor the construction machinery performance. Construction machinery Monitoring System is developed to monitor GPS location, fuel levels, Engine on/off time, loading, etc. of various construction machinery as per requirement. The system uses LoRaWAN (Long Range Wide Area Network) technology for data transfer between construction machinery and server.

The main objectives of the construction machinery monitoring system are to

- Track construction machinery with real-time position location
- Deployment vs. planned reports and fleet management
- Construction machinery Condition monitoring data like Service Meter Reading, Loading, fuel levels, operating info, idle time, etc.

The system mainly uses Long Range Wide Area Network (LoRaWAN) technology to transfer the data from field nodes to the application server.

2. LoRa Technology

LoRa is an RF modulation technology for low-power, wide area networks (LPWANs). The name, LoRa, is a reference to the extremely long-range data links that this technology enables. Created by Semtech to standardize LPWANs, LoRa provides for long-range communications: up to three miles (five kilometres) in urban areas, and up to 10 miles (15 kilometres) or more in rural areas (line of sight). A key characteristic of the LoRa-based solutions is ultra-low power requirements, which allows for the creation of battery-operated devices that can last for years.

A network based on the open LoRaWAN protocol is perfect for applications that require long-range or deep in-building communication among a large number of devices that have low power requirements and that collect small amounts of data.

There are various elements to LoRa technology that provide the overall functionality and connectivity for the system

2.1. LoRa PHY / RF interface:

The LoRa physical layer or PHY is key to the operation of the system. It governs the aspects of the RF signal that is transmitted between the nodes or endpoints, i.e. the sensors and the LoRa gateway where signals are received. The physical layer or radio interface governs aspects of the signal including the frequencies, modulation format, power levels, signalling between the transmitting and receiving elements, and other related topics.
The LoRa wireless system makes use of the unlicensed frequencies that are available worldwide. In India it 865-867 MHz, using lower frequencies than those of the 2.4 or 5.8 GHz ISM bands enables much better coverage to be achieved by the LoRa wireless modules and devices, especially when the nodes are within buildings.

2.2. LoRa network architecture (LoRaWAN):

Apart from the RF elements of the LoRa wireless system, there are other elements of the network architecture, including the overall system architecture, backhaul, server and the application computers. The overall architecture is often referred to as LoRaWAN.

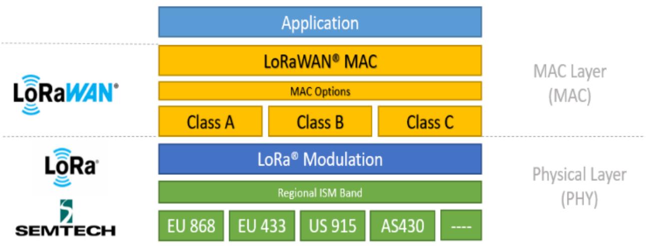

Figure 1 LoRa Layers

To fully understand LoRaWAN networks, we will start with a look at the technology stack. As shown in Figure 1, LoRa is the physical (PHY) layer, i.e., the wireless modulation used to create the long-range communication link. LoRaWAN is an open networking protocol that delivers secure bi-directional communication, mobility, and localization services standardized and maintained by the LoRa Alliance.
Different elements of LoRaWAN Architecture is shown in figure 2.

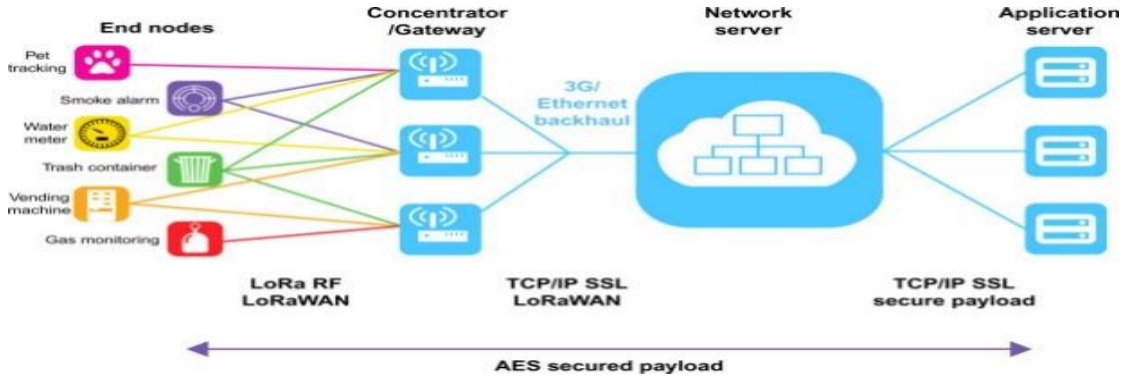

Figure 2 LoRaWAN Architecture

2.2.1. End Devices:

A LoRaWAN-enabled end device (Figure 3) is a sensor or an actuator which is wirelessly connected to a LoRaWAN network through radio gateways using LoRa radio frequency (RF) Modulation.

In the majority of applications, an end device is an autonomous, often battery-operated sensor that digitizes physical conditions and environmental events. Typical use cases for an actuator include: street lighting, wireless locks, water valve shut off, leak prevention, among others.

When they are being manufactured, LoRa-based devices are assigned several unique identifiers. These identifiers are used to securely activate and administer the device, to ensure the safe transport of packets over a private or public network and to deliver encrypted data to the server.

Android Application is used to configure AppKey, Carrier Band Frequency, ADR, Device commissioning method, Unconfirmed/Confirmed, etc.

In the present case, one end device equipped with Bluetooth, GPS, and supports both Class A and Class C with Low Power Mode, to meet the present application requirement.

Figure 3 Field LoRa Nodes

2.2.2. Gateway:

A LoRaWAN gateway as shown in figure 4, receives LoRa modulated RF messages from any end device in hearing distance and forwards these data messages to the LoRaWAN network server (LNS), which is connected through an IP backbone. There is no fixed association between an end device and a specific gateway. Instead, the same sensor can be served by multiple gateways in the area. With LoRaWAN, each uplink packet sent by the end-device will be received by all gateways within reach. This arrangement significantly reduces packet error rate (since the chances that at least one gateway will receive the message are very high), significantly reduces battery overhead for mobile/nomadic sensors, and allows for low-cost geo location.

The IP traffic from a gateway to the network server can be backhauled via Wi-Fi, hardwired Ethernet or via a Cellular connection. LoRaWAN gateways operate entirely at the physical layer and, in essence, are nothing but LoRa radio message forwarders. They only check the data integrity of each incoming LoRa RF message. If the integrity is not intact, that is, if the Cyclic Redundancy Check (CRC) is incorrect, the message will be dropped. If correct the gateway will forward it to the LNS, together with some metadata that includes the Received signal strength indicator (RSSI) level of the message as well as an optional timestamp. For LoRaWAN downlinks, a gateway executes transmission requests coming from the LNS without any interpretation of the payload. Since multiple gateways can receive the same LoRa RF message from a single end device, the LNS performs data de-duplication and deletes all copies. Based on the RSSI levels of the identical messages, the network server typically selects the gateway that received the message with the best RSSI when transmitting a downlink message because that gateway is the one closest to the end device in question.

Figure 4 LoRa Gateway

2.3. LoRaWAN Network Server (LNS):

The LoRaWAN network server (LNS) manages the entire network, dynamically controls the network parameters to adapt the system to ever-changing conditions, and establishes secure 128-bit AES connections for the transport of both the end to end data (from LoRaWAN end device to the end users Application in the Cloud) as well as for the control of traffic that flows from the LoRaWAN end device to the LNS (and back). The network server ensures the authenticity of every sensor on the network and the integrity of every message. At the same time, the network server cannot see or access the application data.

In general, all LoRaWAN network servers share the following features:

- Device address checking
- Frame authentication and frame counter management
- Acknowledgements of received messages
- Adapting data rates using the ADR protocol
- Responding to all MAC layer requests coming from the device,
- Forwarding uplink application payloads to the appropriate application servers
- Queuing of downlink payloads coming from any Application Server to any device connected to the network
- Forwarding Join-request and Join-accept messages between the devices and the join server

2.4. Application Servers:

Application servers are responsible for securely handling, managing and interpreting sensor application data. They also generate all the application-layer downlink payloads to the connected end devices.

LoRaWAN Security

There are two key elements to the security of a LoRaWAN network: the join procedure and message authentication. The join procedure establishes mutual authentication between an end device and the LoRaWAN network to which it is connected. Only authorized devices are allowed to join the network. LoRaWAN MAC and application messages are origin-authenticated, integrity-protected and encrypted end-to-end (i.e., from end device to the application server and vice versa). These security features ensure that:

- Network traffic has not been altered
- Only legitimate devices are connected to the LoRaWAN network
- Network traffic cannot be listened to (no eavesdropping)
- Network traffic cannot be captured and replayed

3. System Architecture

The system is designed and developed to monitor various critical parameters of the heavy equipment/machinery deployed at any construction site, based on which the health and suitability of the equipment can be determined. The basic architecture of the system as shown in Figure 5, contains the following parts:

a. Sensors
b. Field node
c. LoRa gateway & Application server
d. Database
e. User Application

The sensors like GPS, pressure, temperature, load, height, accelerometer, Gyroscope, wind velocity, etc. are fixed in the equipment at appropriate places. These sensors measure the various parameter and send the data to the field node. The Sensor data from various Machines is collected in the field and transferred to field Nodes through 0-12V/ 4-20mA / UART /I2C / SPI / RS485 protocols. The field node consists of a microcontroller that can perform basic data processing and basic mathematical computation at the edge layer. The processed data is transferred to the LoRa module connected with the microcontroller through the UART communication protocol. The LoRa module then transfers the data packet to the LoRa gateway using LoRaWAN in encoded format. The LoRa gateway can transfer the data to an on-premise/ cloud server as per requirement. At the server end, the data is decoded and processed, and saved in a dataset. The user application uses this data to visually represent the various parameters and other details of the equipment on the user screen through a web application.

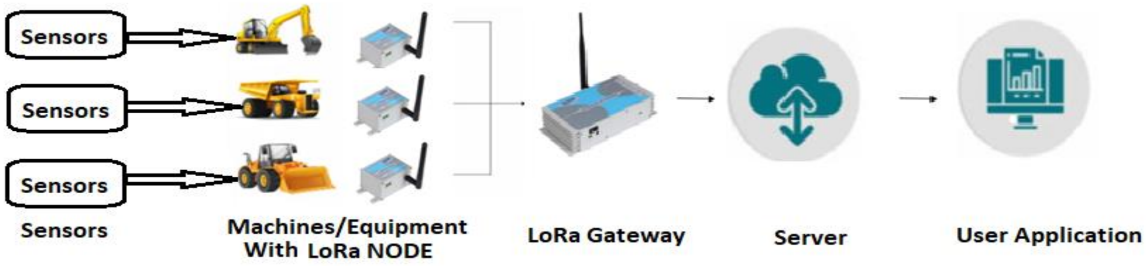

Figure 5 System Architecture

3.1. Sensors

The system is designed for mainly Heavy equipment with various sensing parameters as shown in fig. However, any other equipment with any required parameter can be added to the system. Table 1 Various equipment and their parameters.

Batching Plant	Loader	Concrete Pump	Tower Crane	Diesel Generator	Pick & Carry Crane
Load start	Idle Time	No of Strokes	Load	Current	Payload
Load end time	Payload	Hydraulic Oil Pressure, Temperature	X,Y Inclination	Voltage	Hydraulic Oil Pressure, Temperature
No. of alarms	Hydraulic Oil Pressure, Temperature	Engine Oil Pressure, Temperature	Trolley position	Power Generated	Engine Oil Pressure, Temperature
Present Location	Boom Angle	Fuel Level	Height under hook	Power Factor	Fuel Level
Fuel Level	Present Location & Path info	Present Location	Present Location & Path info	Present Location	
	Coolant Temperature	Fuel Level	Fuel Level	Fuel Level	
	Fuel Level				

Table 1 various equipment and their parameters

Based on the required parameters suitable sensor is selected and used in the system. These sensors are fixed to the heavy machinery/equipment at suitable places. These sensors can transfer the data to the field nodes through any of the following protocols:

i. Digital I/O- e.g. Load, RPM, etc.
ii. 0-12V/4-20mA analog- e.g. Temperature, Pressure, wind velocity, etc.
iii. UART- GPS, Bluetooth, etc.
iv. I2C- Height, Accelerometer, etc.
v. SPI - Height, Accelerometer, etc.
vi. RS485 - Energy meter etc.

3.2. Field Node

There are two different types of field nodes developed.

3.2.3. Field Node-1

This Node is developed via using Developmental Board (Arduino MKRWAN 1300) which has Cortex M0 SAMD21 microcontroller and Murata Based LoRa Module, Along, with GPS Module, Bluetooth Module and MAX485 Module are being used. This Field Node is developed to Monitor Diesel Generator. An External RS485 Communication-based Energy Meter is used to get data of 3 Phase Supply. To measure

Current, 3 Rish 105/50SC Current Transformer is being used to measure 3 Phase current. Block Diagram of the Field Node is shown below in Figure 6.

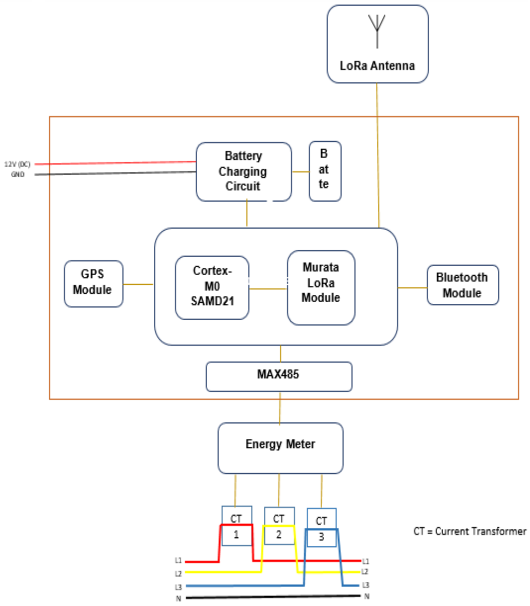

Figure 6 Block Diagram of Field Node – I

3.2.4. Field Node-2

General Block Diagram is being shown in Figure 7.

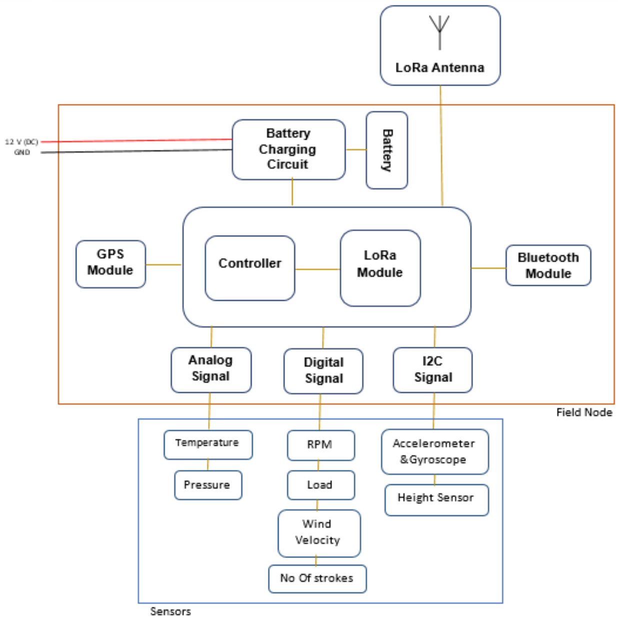

Figure 7 Block Diagram of Field Node – II

4. Server Application & Web Application

The server application was developed using PHP Scripting language. Which takes the raw data from the application server either by subscribing to required LoRa Nodes via Message Queuing Telemetry Transport (MQTT) protocols or by the LoRa network server sending the data to the application server through HTTP protocol. After that, it converts the raw data into required relevant information and stores the same in the database along with its time stamps. A web-based application was developed to configure and see the real-time status of all the heavy machinery/equipment deployed at the construction site. The web application is developed using the following programming languages and software:

Front End: HTML5, CSS, bootstrap
Back End: PHP-7, JS
Web Server: Apache
Dashboard is shown in Figure 8

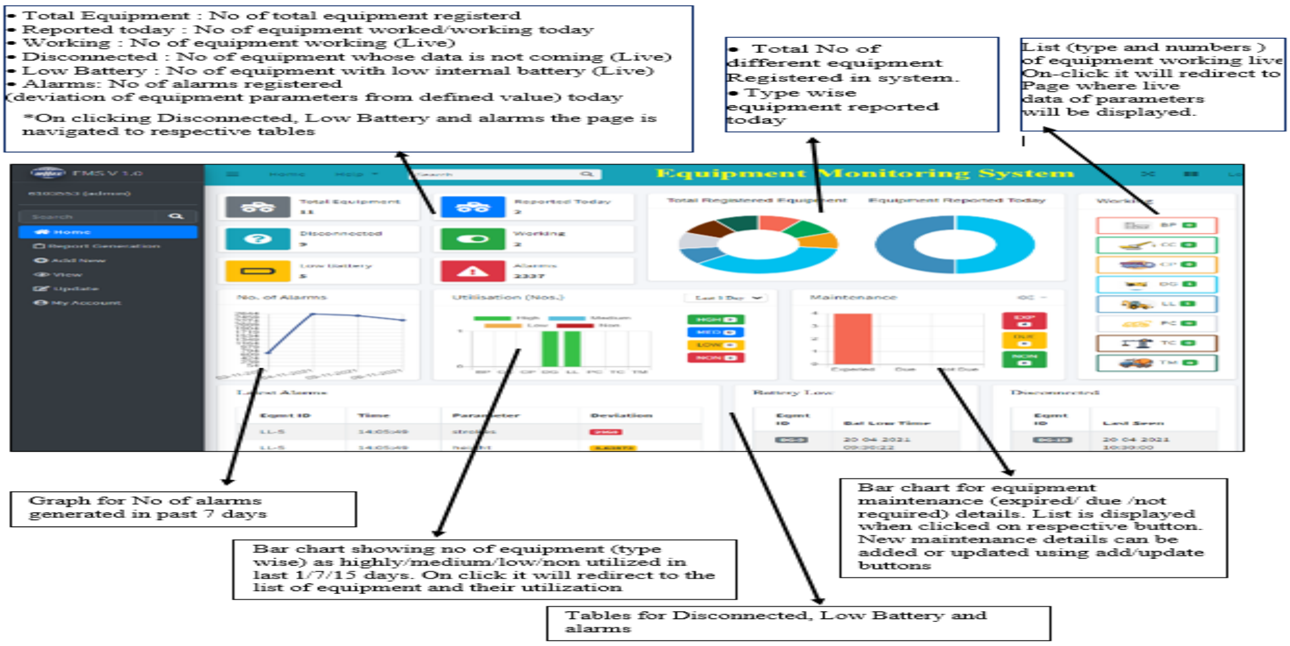

Figure 8 Dashboard

5. Conclusion

The Developed Equipment monitoring system is presently installed at the workshop department of BHEL Corporate R&D and it is under monitoring and testing. All the required software for the Server and web interface is developed in-house. The system is developed using open source applications. The design and development of field nodes are also in-house. This system is cost effective as compare to 3G/4G cellular system. A typical 660 MW power plant may consists of 100-150 heavy equipment. For 3G/ 4G data transfer system each node will require a dedicated SIM card which will have recurring charges, while if LoRa is sued for data transfer only one LoRa gateway is enough.

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