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RF Technologies for Connecting Various Constrained Devices in IoT System

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Abstract

In IoT systems various sensors, actuators and smart objects are used for different purposes, some smart objects require high bandwidth, some may need very low bandwidth. Some objects need to communicate over a long range, some objects need to consume very low power, so that its battery life should be long. To cater to these IoT system's requirements there is a lot of research on communication technologies by IEEE, resulting in the development of various Radio Frequency (RF) standards for the different types of smart objects and sensors. IEEE 802.15.4 standards are mostly used for the constrained devices with low power consumption and low data rate, at the same time 4G/5G are being used in sensors like cameras with edge nodes at high data rate to process high volume of images and videos with various image processing algorithms. In this paper we are classifying the different RF technologies and its features best suited for the specific sensor in an IoT system as well as classification of RF modules (like Zigbee, 6LoWPAN, and LoRa) for connecting different types of constrained devices for different IoT projects. At the same time 4G/5G sim-based Wi-Fi modules will be used for integrating cameras like sensors which run on AC/DC power, to process high volume of data using various image processing algorithms at the edge node which further transfer the processed information to the cloud for further analysis and future use. Main objective of this paper is to classify and analyse the best suited RF standards for various constrained devices on low data rate, as well as for power full smart objects at high data rate in IoT systems.

1. Introduction:

An IoT system is a collection of various sensors, actuators, computing devices with communication technologies, for continuously taking input from various sensors through some radio frequency (RF) module into the computing devices for processing and analysis as well as to get an actionable insight based on the data. These sensors can be a severely constrained node like a push button to a full-fledged sensor like a web camera to run with a high bandwidth data communication network. Constrained nodes mostly powered in the IoT system with battery and required to operate on very low data transmission rate so that it can be working for a long time without changing the battery, at the same time other sensor like camera needs to operate on high data rate so that it can give a better-quality video. So, during the implementation of these sensors in an Internet of Things (IoT) system we need to classify and use the

best suited RF technologies for the specific sensors.

IEEE 802 working groups have invented the arrays of wireless technologies for connecting the IoT sensors with IoT nodes with different frequencies and data rate. Most widely used IEEE 802 standards are for Wireless LAN, Wireless PAN, Wireless MAN, Wireless Coexistence, Media Independent Handover Services, and Wireless RAN with a dedicated Working Group providing focus for each area. IEEE 802 also coordinates with other national and international standard bodies, including ISO which has published certain IEEE 802 standards as international standards. For selecting a suitable standard for a specific sensor or a smart node, it is important to classify the existing standard and its features as well as the power consumption of the node and the requirement of the data rate for the nodes. (Bartleson)

2. Internet of Things (IoT)

IoT is the combination of OT and IT where OT is Operational Technology and IT is Information Technology. OT refers to the hardware which may include various sensors, actuators, routers etc. and as usual IT which includes internet, operating system and different applications, Cloud, having these features an IoT project connects physical devices and everyday objects like (light, fan, refrigerators, fan, smart speaker, biometric, cameras, TV, etc.) to internet and applications to monitor and control the devices and to make them automated.

Common examples of IoT implementations are smart roadways, smart parking, smart cameras, smart home, smart traffic system, smart street etc. most of these IoT implementations are prefix with smart, the main reason is that these IoT systems work on its own and take decisions based on the sensors data and the logic written for triggering the actuators to work as per the requirement. (Khan and Jayanthi)

3. RF Technologies

Radio Frequency (RF) is any frequency within the electromagnetic spectrum, associated with radio wave propagation. When an RF current is supplied to an antenna, and then an electromagnetic field is created, then it can propagate through space. Many wireless technologies are based on RF field propagation. RF Technologies lies at the core of the IoT and enables the long range to short range with low power connectivity for IoT nodes. There are a variety of technologies built on Radio Frequency. RF technologies refers in the context of IoT the use of RF signals to enable wireless data transmission between IoT nodes, this feature of RF helps connect electronic devices wirelessly through the internet and makes Internet of Things. Thus, making a decision on choosing a suitable RF technology for a specific IoT node is important. Common examples of RF technologies are Bluetooth, Wi-Fi, Zigbee, LoRaWAN, 5G etc.

RF technologies are very suitable for IoT project implementation and very commonly used because of some valuable characteristics, which are: a) Low Power Consumption, b) Fine operating range, c) Data transmission rate and d) Able to penetrate walls or does not require a line of sight. (Tan)

4. Constrained Devices

Constrained devices are the edge nodes with sensors or actuators which are generally used for a specific application purpose in an IoT project. It is generally integrated with wireless nodes with low power and lossy network and can be sending the data to the server or the cloud platform. The Reason behind connecting the constrained devices with low power and low data rate, RF signal, is to give a long life to the device and its battery, as well as its data rate requirement for communication. Constrained devices are generally powered with batteries and generate and process very low data rates from below 10KiB to 50KiB approximately. Since it is battery power and with low RAM and processing capacity, it is integrated with low power RF technologies like Bluetooth, IEEE 802.15.4 (6LoWPAN, Zigbee, Wireless HART, Thread etc), IEEE 802.11ah (Wi-Fi HaLow), etc. (Nagasai)

According to Internet Engineering Task Force (IETF) described in the document Request for Comments (RFC) 7228, Constrained devices are classified into 3 groups: Class 0: called severely constrained device, with less than 10 KB of memory and less than 100 KB of Flash processing and storage capability and do not have the resources required to directly implement an IP stack and associated security mechanisms. Example of a Class 0 device is a push button. Class 1: nodes are still lower than expected for a complete IP stack implementation. They cannot easily communicate with nodes

employing a full IP stack. However, these nodes can implement an optimized stack specifically designed for constrained nodes, such as Constrained Application Protocol (CoAP). This allows Class 1 nodes to engage in meaningful conversations with the network without the help of a gateway and provides support for the necessary security functions as well. Examples of class 1 devices are the environment sensors. Class 2: devices are characterized by running full implementation of an IP on the embedded devices. They contain more than 50 KB of memory and 250 KB of Flash. Example of a class 2 device is a smart power meter. (Barton et al.)

5. IEEE 802 Standards

IEEE 802 LAN/MAN Standard Committee (LMSC) has developed and maintains networking standards and has recommended practices of WLAN, WPAN, WMAN and other networks (Bartleson) Common IEEE 802 working groups and study groups are listed below:

- 802.1 : Higher Layer LAN Protocols Working Group
- 802.3 : Ethernet Working Group
- 802.11: Wireless LAN Working Group
- 802.15: Wireless Specialty Network (WSN) Working Group
- 802.18: Radio Regulatory TAG
- 802.19: Wireless Coexistence Working Group
- 802.24: Vertical Applications TAG

5.1. 802.15.4

It is a low-rate wireless network standard from 802.15 group, is most common and base for low rate WSN modules like Zigbee, smart utility network (SUN) and HART etc. these modules are mostly used in smart home and smart city-based devices. Like the 802.15.4 many standards are available from 802.15 for different purposes like unlicensed frequency bands and communication are discussed in (Rajan and Abirami).

5.2. Zigbee

Zigbee is one of the popular network technologies for low data rate from the IEEE 802.15.4 standard. Zigbee is used in different sectors such as industrial sectors (Rajan and Abirami), home automation (Yuneela and Sharma), and medical and healthcare sectors (Islam et al.) as a popular low data rate IoT technology because of its multiple advantages like- low latency, low power consumption, low cost, large scaling capability, flexible topologies; but mainly, Zigbee has been popular for its indoor applications on date rate up to 250 kbit/s with 10 to 100 meters range (Lavric) which is well suitable for indoor smart objects to communicate with others.

5.3. 6LoWPAN

It is an IPv6 based networking standard for IoT which is designed to connect multiple smart devices with IPv6. It is an IPv6 over low Power Wireless personal area network. IETF 6LoWPAN working group define the adaptation layer that explain the transportation of IPv6 packets over 802.15.4 layers (Barton et al.) , because of unique security mechanism of IPv6 and capability to generate huge combination of the required demands IP addresses for future IoT implementation. 6LoWPAN is compatible with other wireless 802.15.4 devices as well as with the devices on other IP networks like Wi-fi or Ethernet with the help of a simple bridge device. Bridging between the Zigbee and non-ZigBee requires a complex application layer gateway.

5.4. LoRaWAN

Is a scalable technology designed for longer distances with low power requirements in the unlicensed spectrum, it can cover the range up to 5km (Barton et al.) generally it is one of the best standards for the IoT implementation in farming and industrial sectors. (Lavric)

5.5. 5G

Is the 5th generation technology standard for broadband cellular network. It has been deployed worldwide from 2019 and it is promised to avail fast internet connection up to 10 Gbits/s. 5G is based on millimetre wave and microwave technology (Wikipedia).

6. High data rate network and Low data rate network for IoT

Parallel research is happening to reduce the data rate for certain devices and at the same time to increase the data rate for general purpose use as per the requirement. LoRa, Zigbee and the 6LowPAN are the end results of such research to reduce the data rate and used especially for battery powered constrained devices in IoT (Farahani). And 5G is the

best example of the research to boost the data rate, where 3G used to give 14mbps, 4G up to 100mbps and 5G promises up to 10gbps (Deepender et al.) presented in the figure1. We needed both networking standards in IoT implementation. Zigbee, LoRa and 6LoWPAN are used in smart home, smart farming because the devices here are mostly powered on battery and need a very limited data rate to operate. Whereas 5G can be used in smart cities, especially for smart cameras related IoT system implementation for processing high resolution images and videos in real time.

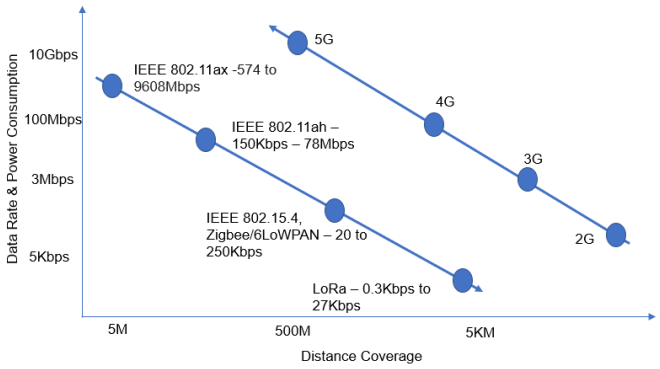

FIGURE 1. Networking technologies with high & Low Data rate

6.1. IEEE standard based RF modules for IoT:

There are many modules are manufactured and available in the market from IEEE standards and are used in the IoT project implementation, some of the best modules are Zigbee, 6LoWPAN from IEEE 802.15.4, LoRa from IEEE 1451 for long range, ESP8266 from IEEE 802.11b/g/n, and RFID from IEEE 802.15.

6.2. ZigBee Module

This is a wireless network module which is mostly used in domestic and indoor smart objects like light, fan, speaker etc. This is one of the best modules to power with Wi-Fi feature to a sensor to create WSN in unlicensed local area network for constrained devices.

Microcontroller module like Arduino does not have its own networking module, thus it requires an external module like Zigbee to give wi-fi capability to transfer the sensor data to the internet.

6.3. Zigbee with Arduino Uno

Zigbee can be integrated with Arduino as demonstrated in the figure 2. We can integrate the TX, RX

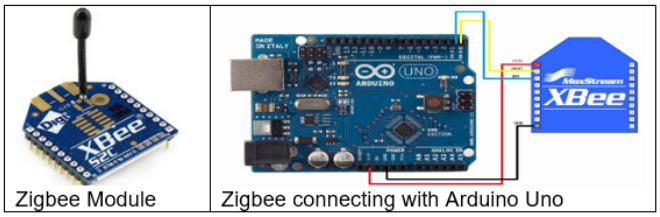

FIGURE 2. Zigbee with Arduino Uno Integration

pins of Zigbee with TX, RX pins with Arduino and 3.3v VCC to Arduino to VCC of Zigbee and similarly GND of Arduino to GND of Zigbee (Hanafi et al.). Sensors can be integrated with Arduino to take the data and do computation on the board to make a decision to trigger actuators or to alert the owner of the system.

6.4. 6LoWPAN Module

This is very similar to Zigbee and it is also from the 802.15.4 standard with major advantage of 6LoWPAN is that it operates on IPv6 which make it the future network node to communicate with 128 bit IP addresses for all module of the IoT system. It is like Zigbee with a low power and mesh network module.

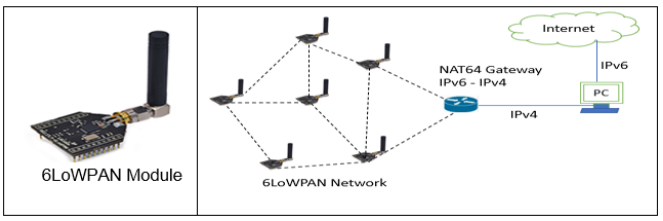

FIGURE 3. 6LoWPAN with Mesh network and NAT64 IPv6 to IPV4 converter

Because of the exponential growth in the IoT devices, and the demand of IP addresses, IPV4 can not meet the demand that is way the IPv6 is invented to full fill the demand exponential number of IP addresses, 6LoWPAN is the module here which helps us to integrate our sensors and IoT nodes with IPv6 as presented in the figure 3.

6.5. LoRa Module

This is especially designed to communicate in a long distance with very low power consumption and best suited with microcontroller boards like Arduino, STM32 and ESP8266. Because of the long coverage and low power consumption features it is used with constrained devices in farming and industrial

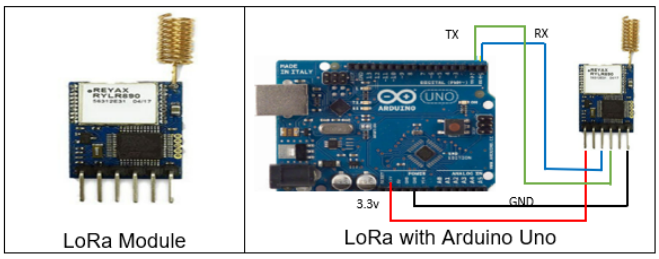

FIGURE 4. LoRa module with Arduino Uno Integration

IoT projects. Integration of LoRa with Arduino Uno is presented in figure 4.

Circuit diagrams explain the integration of the Arduino Uno with LoRa module with GND to GND between the modules, 3.3v VCC of Arduino to VCC of LoRa and TX, RX to the respective TX, RX of the module. It can be changed as per the requirement of the system.

6.6. NodeMCU ESP8266

This is a popular module mainly because of its low price and both computing as well as the communication capability. So, it's not only the wi-fi module like Zigbee and LoRa but also has a microcontroller on board for coding for the IoT data. It can be also integrated with Arduino to power the board with internet connectivity as well as it can be used as a standalone module with sensors to push the sensor's data to the gateway (Mesquita et al.), it is demonstrated with the help of figure 5.

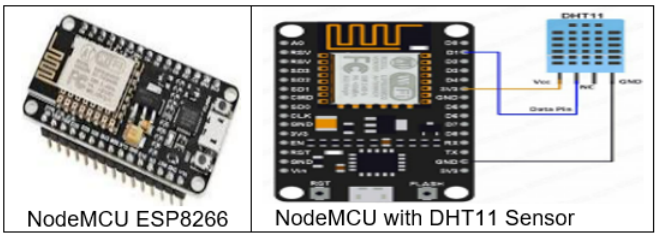

FIGURE 5. NodeMCU integrated with DHT11 temperature sensor.

6.7. RFID

Radio frequency identification is an old technology but used in IoT with new applications and in innovative ways. It is like barcodes where data digitally encoded in RFID tags which can be read by a reader with the help of an RF module (Chechi, Kundu, and Kaur). Best use of RFID is in the fast tag for toll plaza, fast Tag is an RFID tag which is read by the system using an RF module and automatic cash is deducted to open a toll plaza gate. Like the barcode or QR code it does not require to be in line with the reader device, this feature makes it best suited for reading tags from any types of object/vehicles.

7. Comparison between the different IEEE standards

IoT system implementation required to include various types of sensors, actuators, MCU nodes and networking devices with IT applications and cloud services. Different sensors and MCU nodes required a different types of networking technologies as highlighted above constrained nodes like temperature sensors, moisture sensors, light sensors generate few bytes of data and mostly implemented with battery powered nodes so these nodes are classified under the constrained devices which required to be integrated with constrained network devices like Zigbee/6LoWPAN/LoRa or NodeMCU. Sensors which run on AC/DC power and require a good amount of bandwidth for huge volumes of data processing, like cameras and local servers need to be integrated with IEEE 802.11wi-fi or 4G/5G cellular network module or using broadband.

8. Conclusion

In this paper we have classified and analysed the different RF technologies and modules based on data rate, power consumption and distance coverage by the different RF technologies. Different IEEE standards are being used to integrate constrained devices with low data rate, low power consumption but without compromising the distance coverage for example LoRa. Zigbee, 6LoWPAN and LoRa are being used as network modules of constrained devices at the same time licensed network 4G LTE and 5G cellular technologies are used for integrating full-fledged devices in IoT like cameras, edge devices or the server for in time data processing and analytics.

9. Authors' Note:

We declare that there is no conflict of interest regarding the publication of this article. We confirmed that the paper is free of plagiarism (similarity index of the paper is just 2%).

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