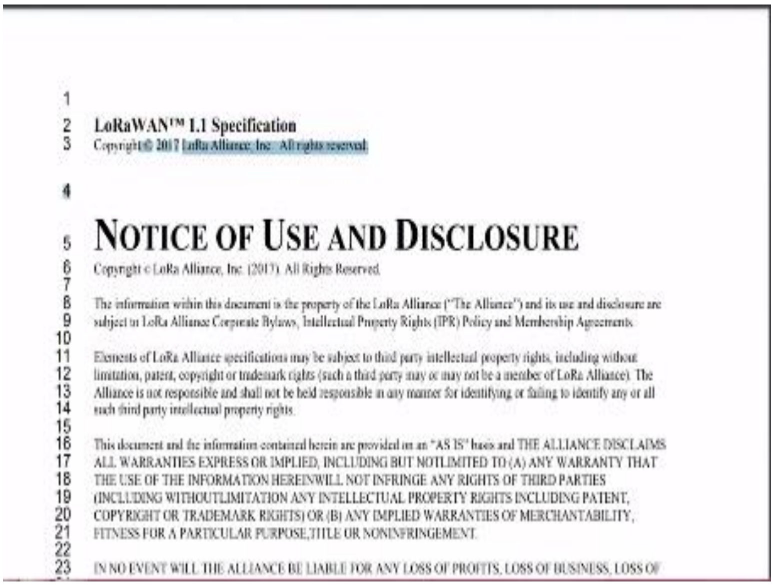
Design for Internet of Things
Prof. T V Prabhakar
Department of Electronic Systems Engineering
Indian Institute of Science-Bengaluru

Lecture - 49
LoRa – 02

Welcome. Let us go back and look at this exciting protocol called LoRa. We will spend some 10 minutes understanding this protocol. But if you want to know a lot about that protocol, the best possible, you know a place where you can look that up is this specification itself. So let me show you the specification once.

(Refer Slide Time: 00:47)


LoRaWAN™ 1.1 Specification
Copyright© 2017 LoRa Alliance, Inc. All rights reserved.

NOTICE OF USE AND DISCLOSURE

Copyright © LoRa Alliance, Inc. (2017). All Rights Reserved.

The information within this document is the property of the LoRa Alliance ("The Alliance") and its use and disclosure are subject to LoRa Alliance Corporate Bylaws, Intellectual Property Rights (IPR) Policy and Membership Agreements.

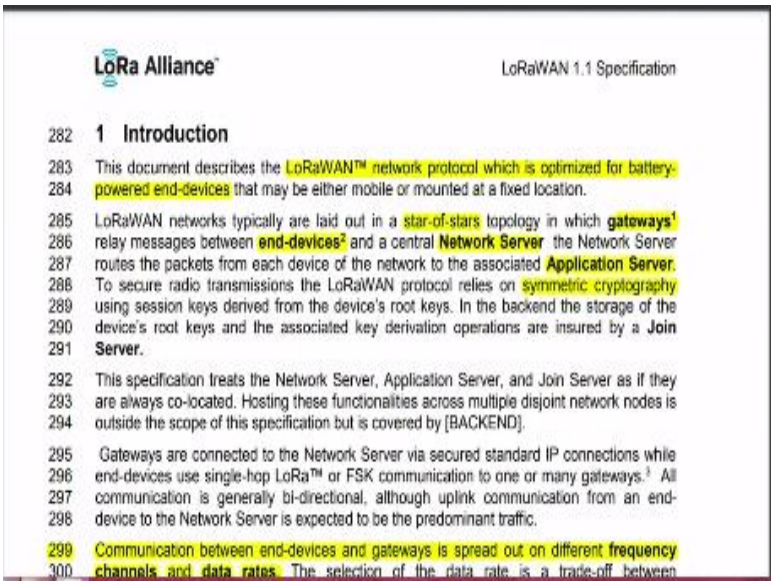
Elements of LoRa Alliance specifications may be subject to third party intellectual property rights, including without limitation, patent, copyright or trademark rights (such a third party may or may not be a member of LoRa Alliance). The Alliance is not responsible and shall not be held responsible in any manner for identifying or failing to identify any or all such third party intellectual property rights.

This document and the information contained herein are provided on an "AS IS" basis and THE ALLIANCE DISCLAIMS ALL WARRANTIES EXPRESS OR IMPLIED, INCLUDING BUT NOTLIMITED TO (A) ANY WARRANTY THAT THE USE OF THE INFORMATION HEREINWILL NOT INFRINGE ANY RIGHTS OF THIRD PARTIES (INCLUDING WITHOUTLIMITATION ANY INTELLECTUAL PROPERTY RIGHTS INCLUDING PATENT, COPYRIGHT OR TRADEMARK RIGHTS) OR (B) ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE,TITLE OR NONINFRINGEMENT.

IN NO EVENT WILL THE ALLIANCE BE LIABLE FOR ANY LOSS OF PROFITS, LOSS OF BUSINESS, LOSS OF

This is essentially the 1.1 specification of LoRa, you can see here, it is written here 1.1 specification. It was released in 2017. Everything you want to know about LoRa, and the LoRa Alliance can be read from this major document okay, it was released here. Everything you want to know is here, okay. And it will take us quite some time for you to grind this document and understand it thoroughly.

(Refer Slide Time: 01:15)



LoRa Alliance

LoRaWAN 1.1 Specification

1 Introduction

This document describes the LoRaWAN™ network protocol which is optimized for battery-powered end-devices that may be either mobile or mounted at a fixed location.

LoRaWAN networks typically are laid out in a star-of-stars topology in which **gateways**[1] relay messages between **end-devices**[2] and a central **Network Server** the Network Server routes the packets from each device of the network to the associated **Application Server**. To secure radio transmissions the LoRaWAN protocol relies on symmetric cryptography using session keys derived from the device's root keys. In the backend the storage of the device's root keys and the associated key derivation operations are insured by a **Join Server.**

This specification treats the Network Server, Application Server, and Join Server as if they are always co-located. Hosting these functionalities across multiple disjoint network nodes is outside the scope of this specification but is covered by [BACKEND].

Gateways are connected to the Network Server via secured standard IP connections while end-devices use single-hop LoRa™ or FSK communication to one or many gateways.[3] All communication is generally bi-directional, although uplink communication from an end-device to the Network Server is expected to be the predominant traffic.

Communication between end-devices and gateways is spread out on different **frequency channels** and **data rates**. The selection of the data rate is a trade-off between

What I will do is I will entice you into understanding this LoRa, so that further reading will help you to pick up on your own, because we cannot obviously cover in a limited amount of time, everything. My suggestion is read this document thoroughly to get a grasp on what actually is happening with LoRa. Fine. So essentially, LoRa is something that can be applied into in several areas, okay.

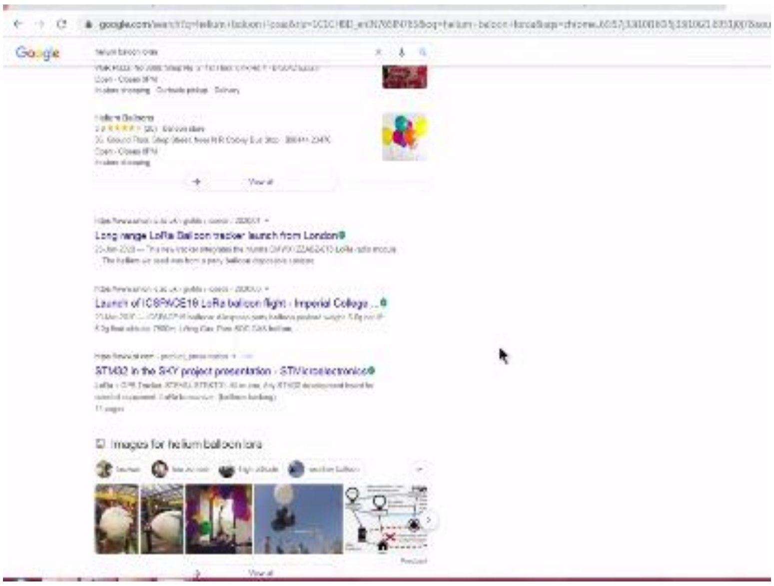
One of the very strong points for LoRa is the fact that it is ultra low power okay, it is ultra low power. It is a long range. It can work deep indoor environments. It can penetrate deep indoor places. It is license free, very important. It is something that you can mix and match private deployments and public deployments. And you get end-to-end security services, okay.

You get end-to-end security services because end-to-end is completely data is confidential, okay. And it is an amazing thing. And finally, and last but not the least I would say is that if you deploy a device, a LoRa device in the outdoor, you can program it over the air, okay. So that is a very special thing that is firmware upgrade over the air as they call. So all these are very good features.

And their application areas are innumerable. You can talk of smart agriculture, you can talk of protecting plants, you can talk of protecting wildlife. You can be talking about smart cities. You can be talking about logistics and asset tracking. And you can be talking about smart metering where water, gas, electricity all of them can be applied.

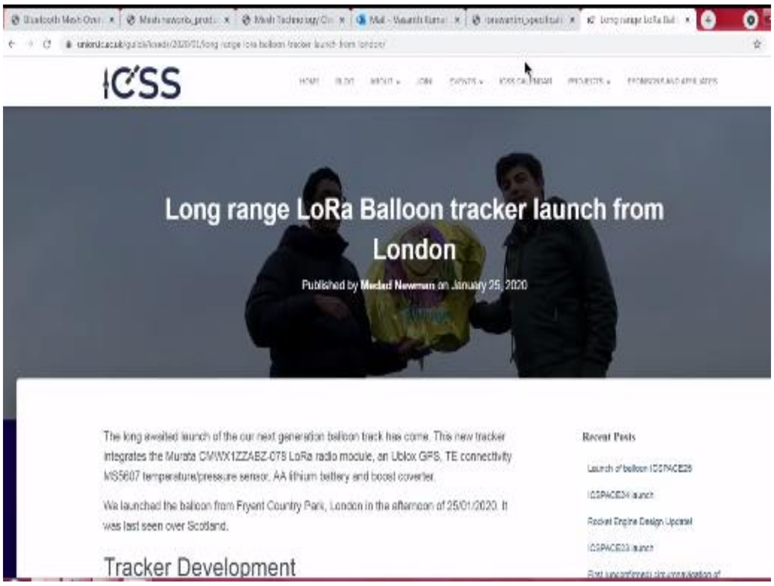
Why all these examples is because of the fact that LoRa is not great in terms of its offering you high data rates okay, it does not. But it has this fantastic ability of giving you extremely long range, extremely long range. And when I mean extremely, theoretically you can reach up to 850 kilometers, okay.

(Refer Slide Time: 03:30)



And there was a recent experiment which I can also point you to. Launch of ICSpace LoRa 19 balloon flight, okay. You can see there is lot of information out there here and the distance that it traveled, the distance between the source and the destination between two LoRa devices is was indeed about 800 kilometers or so. So you can see this is LoRa tracker. Please read up.

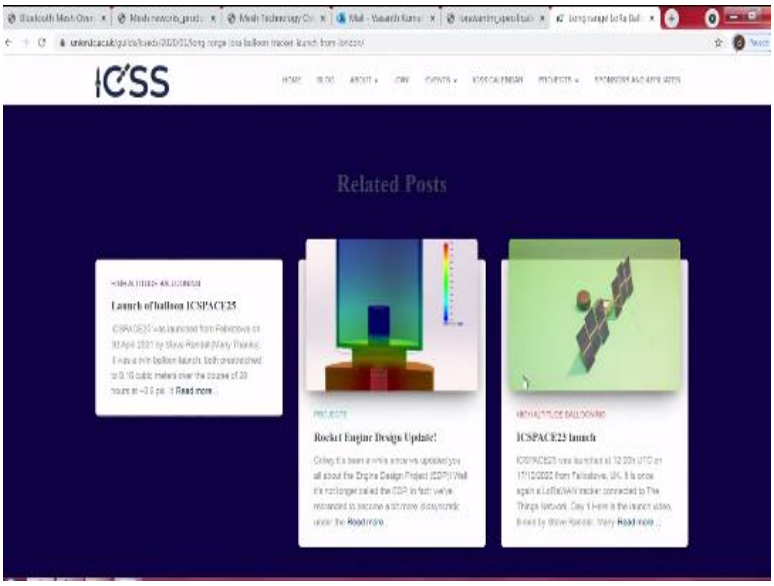
(Refer Slide Time: 03:57)



There is so much of information about the range, of long range LoRa balloon tracker launched from London. This was a recent article, you can see it was in 2020 and so on. So if you read up the Google for LoRa helium balloon experiment, you actually find that the balloon was launched. In several papers you would see that the balloon was launched at something close to about 36 kilometers.

And it gave a range of roughly 850 kilometers or so. So you can see balloon technology photos from the launch and a lot of exciting work was done.

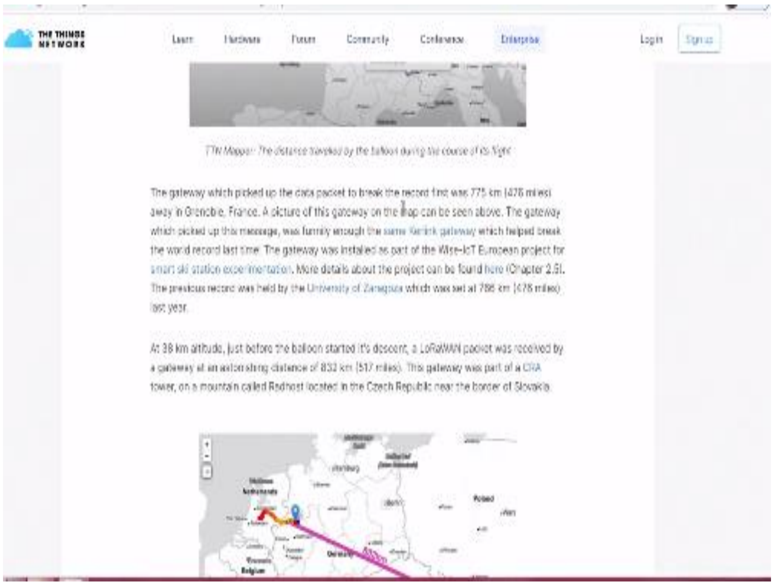
(Refer Slide Time: 04:35)



And so here you could go and look up not just one article, I just mentioned about one article but there are enough number of articles to talk to you to give you. Yeah you can look up this. LoRa world record broken. 832 kilometers 517 miles using 25 milliwatts, okay. So this is the experiment I was actually going through.

I was trying to tell you. You can see that the kind of range that LoRaWAN was trying to provide is quite significant the number. And you can do lot of interesting things. Yeah. So this is a post which comes, who made the world record attempt. You can see that balloon just taking off and starting its ascent.

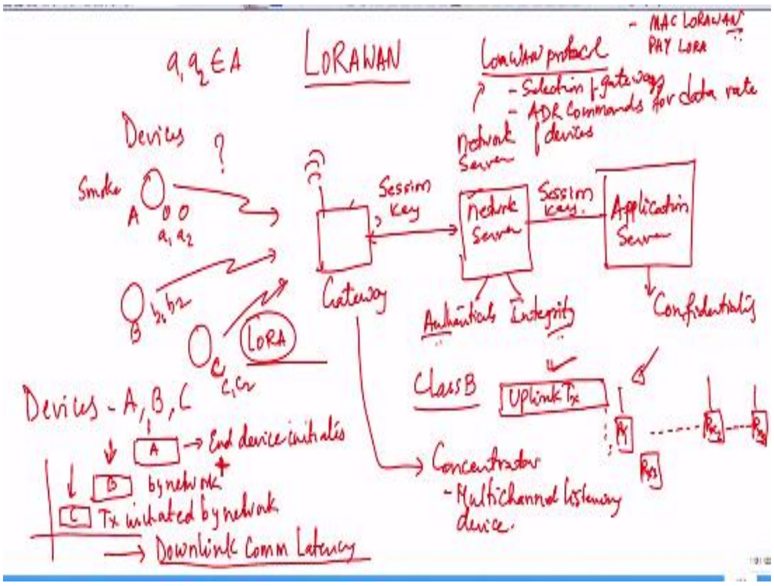
(Refer Slide Time: 05:20)



And you can see that if you read this article, it is talking about the gateway, which picked up the data packet to break the record first was 775 kilometers away in Grenoble, France, and you can see that it actually triggered. And what is the kind of power you are talking of? Hardly anything, right? It is just about 25 milliwatts of power that you are pushing through this system.

So why this is so inspiring is because LoRa gives you that kind of huge range. It is not about data rate, it is not about the amount of payload that it can carry. But the fact that the radio signal can reach this long distance with very small payloads will allow you to build very nice compelling applications. Great. So let me go back and tell you a little more about, this is fine, but then you need to know a little more about the LoRa itself, okay.

(Refer Slide Time: 06:12)



So now you see on the left side, I have put devices, okay. This is typical of what Vasanth showed in the demonstration, right? We had LoRa transmitter and a receiver. And we showed you that little small video clip and there you could see that there were two devices and even we shared the datasheet of that particular LoRa device that we had with us. Alright. So those are essentially this.

You can have devices which are A, B and C type of devices or class of devices. So what is the difference? Essentially I put down a picture on the extreme left here. And this picture tells you all about why these there are different device classes. If you take A, A is shown to the extreme right. The x axis is the downlink communication latency and y axis is simply the number of devices that are here, the type of devices that are there.

A gives you the highest communication latency because it is A which decides to transmit data to the network server. Now I will not be talking about gateway because gateway is just a pass through device. It is a pass through device. Simply you can think of something like this, okay. Without making much noise about the gateway we should be talking about A connecting directly to network server.

This is absolutely important. Because the fact that authenticity of data, of the device, and integrity of the data message is actually done by the network server. It is the network server which maintains network key right, it maintains a session key between the gateway and the network server and therefore gives you, gives the device authenticity and provides integrity of the data okay, that is sent by these devices either A, B or C.

Similarly for confidentiality of the data, the key, the application server actually holds, that is where the end data is to be consumed. Source is A, B or C any one of these devices. I mean when I say A, B or C I am talking of class of devices, okay. In class of devices you can have let us say I can put two small classes a1 and a2 are two, a1 and a2 are part of belong to a class of device called capital A okay, these.

And why they are called small a1. Why are they called Class A devices because they can take the decision on their own of when to transmit, okay. When to transmit is in their hand. So they can sleep as long as they like and then they can wake up and then do a transmission, okay. And that allows them to essentially you know save a lot of battery life. Look at the picture that I have drawn here, okay.

Here I say about Class A. Here you do an uplink transmission. When we say uplink we talk about device to gateway is called uplink, gateway to device is called downlink. When you talk about Class A device, you talk about uplink transmission. Soon after uplink transmission, there will be a small delay over which the device shifts to reception mode and wait for a data.

If there is any data from the network server, then the data can be pushed only when, here this is important, only when A has, actually the Class A kind of device has transmitted. That is only after an uplink transmission, the network server can push data back to the end node. Which means bidirectional communication is initiated by the Class A device. This is important, okay.

And if there is more data, it can wait for one more slot and then receive it on Rx2 and so on. Do not worry about that. Now Class B device is interesting. Class B device does everything that Class A does, except for the difference that you can also have network initiated waking up, okay. So network can also initiate. That means network server can give a nudge at periodic intervals and say, hey, wake up, I have data for you, okay.

So that is something that Class B devices are expected to honor. Therefore, what happens in terms of communication latency, it reduces compared to that of A. That is what I have shown here, okay. And now Class C is even lower latency because the device has no control, it is the network that holds control and therefore C gives you even smaller latency.

And because it is initiated by the, by the network. So therefore, this is interesting. But while I say this is interesting, there is even more interesting thing that I have drawn here. What I have drawn here is I have mixed Class A with Class B and Class C. Look at the power. You can have all of them contacting a single gateway or multiple gateways.

Which gateway to choose, the devices a1, a2, let us put me here; b1, b2, c1, c2, okay. c1, c2, b1, b2 and a1, a2 are actual devices. They are Class A, Class B, and Class C devices respectively. These six devices, which gateway they should contact is decided by the network server. This is important. So what are the functionalities of the network server?

Selection of the gateway device is decided by the network server, the LoRaWAN protocol. See what I put here is only LoRa protocol. I did not put LoRaWAN. LoRa is actually a wireless 5 layer technology. LoRaWAN is a MAC layer protocol. This is important. Please differentiate between the MAC and the 5 layer protocols. This is simply LoRa and this is LoRaWAN.

The fact that LoRaWAN exists, means multiple vendors can work together. Whoever implements LoRaWAN perfectly, vendor A and vendor B, they can mix match and work together. That is the advantage of using LoRaWAN system, which is at the MAC layer, okay. And the network server does something even more interesting. It does what is known as adaptive data rate commands okay, for data rate of devices.

At what rate should c1 communicate to gateway, b1 to the gateway, a1 to the gateway can also be decided by the network server, okay. I will come to that in a moment. But I just wanted to show you that different classes of devices essentially will have a picture like this. For example, what I showed you here is Class A. And if you have to redraw this picture for Class B, it is quite simple.

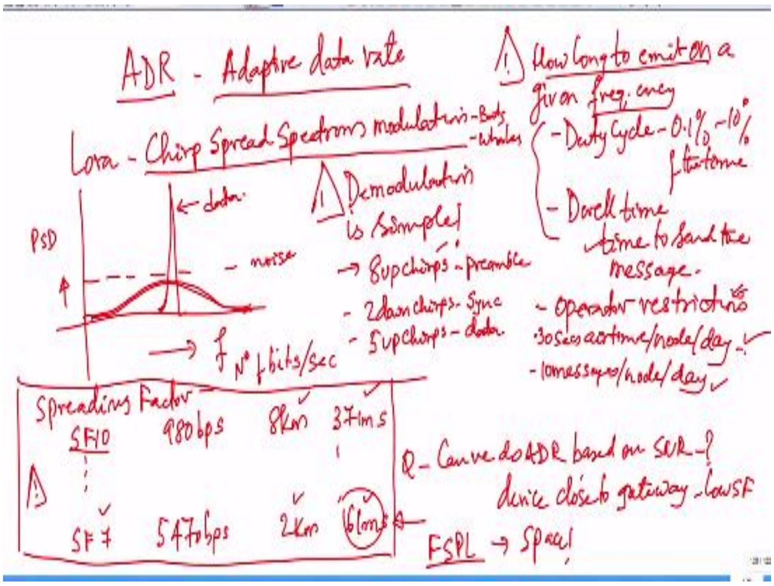
I will replace this. For me it is very simple. I will replace this with Class B device. And what I will do is I will put back Rx1, actually the same one, then I will put Rx2 and what I will do, I will give a certain delay, and network has to initiate again. Therefore because it is plus here, do not forget this. Class B is end device initiates plus network. Therefore, this Rx2 comes back here.

And after that there will be an Rx3 also. So periodically, the network can initiate communication back to Class B devices. And therefore latency is lower compared to that of Class A devices. So you can redraw pictures like this for other type of the Class C devices as well. Great. So we covered that, we covered the gateway, we covered the network server, and we covered the application server. Folks, everything about LoRa is in this picture.

You deploy end devices, you connect to a gateway, from the gateway, you connect to the network server and from the network server you connect to the application server. Authenticity, integrity, support for all the devices at the network server because of the session key, network server session key. The confidentiality essentially encryption decryption of data sent by these devices handled by the application server.

Because the end consuming application is sitting out there. So therefore authenticity, integrity and confidentiality are guaranteed in LoRa system and therefore extremely powerful again, and extremely feature rich when we talk about LoRa, okay.

(Refer Slide Time: 15:12)



A little more about the data rates. I mentioned to you that LoRa offers you network server allows you also takes care of ensuring that devices communicate, end devices communicate at a particular data rate. And how is that done? Before we go into that, first of all, let us understand how LoRa modulation works. LoRa modulation is based on chirp spread spectrum modulation.

Essentially this modulation is supported by bats as well as whales. These are also those which actually use chirp spread spectrum modulation, right? And here is what the whole picture is. If you consider x axis as ‘f’ the frequency and the y axis for power spectral density, you can see that the spread of energy is like this. And there is a small hump here which essentially contains the data.

And this is where the signal is peaking above the noise. And that is you know is indeed the point where the data is available, okay. The whole bandwidth is 125 kilo hertz. That is f2 – f1 is 125 kilo hertz and the bandwidth is either 125 kilo hertz or 250 kilohertz, both bandwidths can be set. Please note, I am differentiating the bandwidth of LoRa with respect to the operating center frequency of LoRa.

Center frequencies can lie in the 433, in the 868, 915 megahertz systems. In any frequency band you can take, but the bandwidth is limited to 125 or 250 kilo hertz ranges. So folks, the demonstration we showed you was even more interesting because the demodulation of LoRa is very simple. So what is the gateway doing there you may ask. Gateway is not doing any magic folks.

The Gateway has the ability to listen to multiple channels from LoRa and decode the system. So the difference between end device demodulating and a gateway demodulating is just that the gateway has multiple receivers, multiple channel receivers. So if you cascade let us say, four or five end devices and put them in reception mode to different frequencies, it becomes a gateway.

So you can build gateways even from end devices. So essentially, I am saying that there is no magic about gateway or anything. In fact, even end device can because the demodulation is damn simple. It is very simple. In fact, how do you start sending out a preamble? 8 up chirps, chirp spread spectrum means you will have an up chirp and a down chirp, okay.

I would not go into the detail, but just you can think about up and down chirps. 8 up chirps means it is a preamble. 2 down chirps means it is synchronization. And 5 up chirps means the data is coming, right? So already you know that. You are going to pack data with this signal, right? So essentially, this is what any receiver will have to decode on. Now the data rate itself holds the key to the range. Very important.

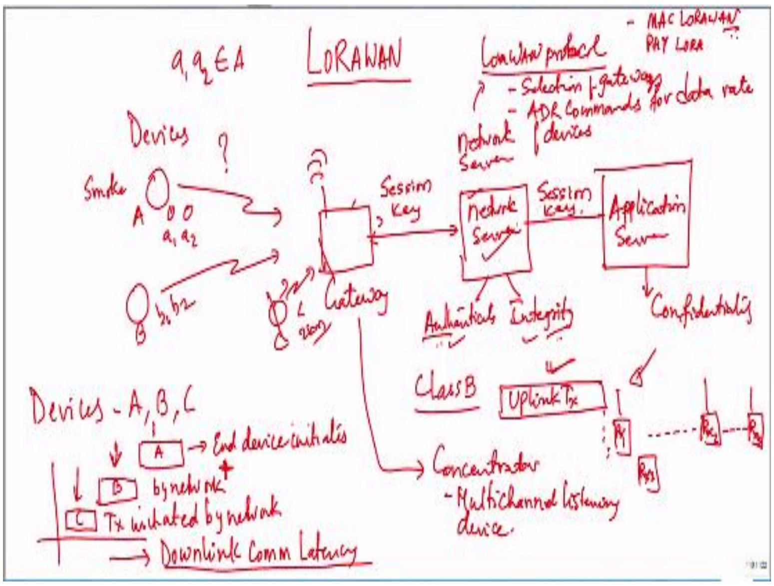
Absolutely critical as far as data rates and range is concerned in LoRa, because we spoke even about the experiment done by the Things network, right? The helium experiment, balloon experiment and all that with just 25 milliwatts and all that I mentioned. So how is all that possible? Because you have a very important part in LoRa is about the spreading factors.

And I want to put this picture right in front of you and ask you to remember this quite well. The spreading factor, essentially spreading factor is you call it with there is a name for it, okay. So we will, without going into the detail, I will simply say it is the number of bits per second. You can think about it like that, okay. You can have spreading factor supported from 10 to 7. So you have 9, 8 and all that.

So if you have spreading factor of 10, you will get 980 bits per second, but you will get a range of 8 kilometers, and the transmitter will be on for 371 milliseconds. If you go down to SF7, you will get 5.4 kilobits per second or 5470 bits per second, but your range will come down to 2 kilometers. And the air time, the time over which the transmitter is on will be about 61 milliseconds.

So you can trade the distance to that of the time over which the transmission happens. See obviously this has a merit. Because the transmitter is on for a very short amount of time what will happen to the battery life? It will improve, okay. That is a great news, right? Now you can do the following, right? Now we can go back and modify this picture.

(Refer Slide Time: 20:11)



I can do the following. I will take the C okay and I will place it very close to the gateway. Now here you are not worried about range, okay. Let us say this is under 2 kilometer. If it is under 2 kilometer what will you do? You will set it to SF7. And therefore, if you set it SF7, who will set it, that is the question. Who will set it? The command to set it will be given by the network server.

That is the most important thing, okay. So you set it to SF7. That is the function that typically the network server can do. And then you can go up, you can go up to 980 bits per second, but you will get 8 kilometers. The theoretical limit of whatever LoRa is supposed to give you is in hundreds of kilometers, we even said that. And that is because we are assuming free space path loss, okay.

That is important, free space path loss. And free space path loss you can think of only happening in space and not in on ground or not on Earth, because you will have trees, you will have buildings, you will have so many obstacles, you will never get free space on anywhere near the ground. So if you go higher and higher, you will definitely get free space and it will support you extremely high data rates okay, that is one part.

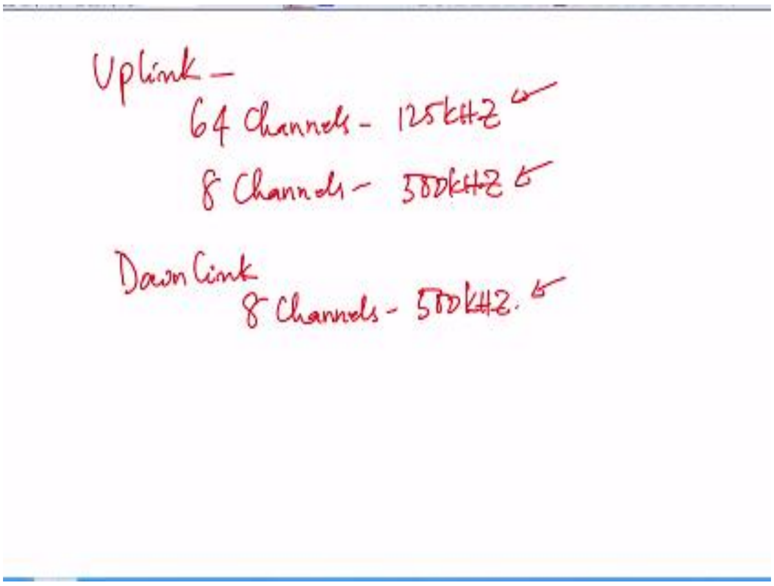
So the ADR is nothing but adaptive data rate is a command issued by the network server to inform end devices to adjust the spreading factor such that the time over which they transmit can be reduced or increased and can be reduced actually.

If it is SF7 it will be reduced and also ensure that you get higher data rates and ensure that the whole system is actually adapting based on where these devices are placed and their physical distances from the gateway device. So that is a important thing. Now another important point about the about LoRa is about the how long can a signal be emitted on a given frequency. Two terms come to our mind.

One term is called the duty cycle. It is usually expressed in terms of 0.1% to about 10% of time. And there is another term which is called dwell time. Dwell time is the time to send the message, okay. So you can think about this 61 milliseconds as typically of what the dwell time is. And how much time, overall time that the system can emit is actually the nothing but the duty cycle, okay. So these are two important terms.

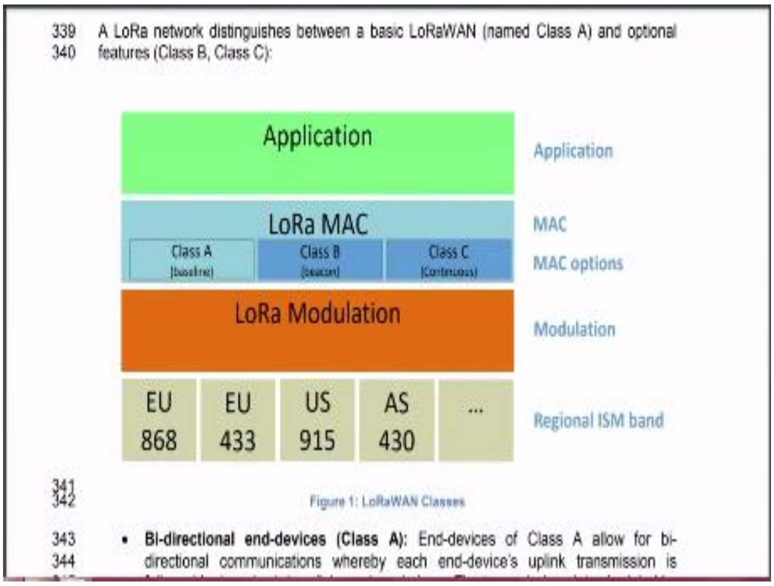
Apart from that operator also may bring in a lot of restrictions. For example operator may say 30 seconds of airtime per node per day. This is what I will support. And he may say as far as downlink is concerned, I will allow you only 10 messages per node per day. That is also possible. So all of this is an important aspect in LoRa communication.

(Refer Slide Time: 23:27)



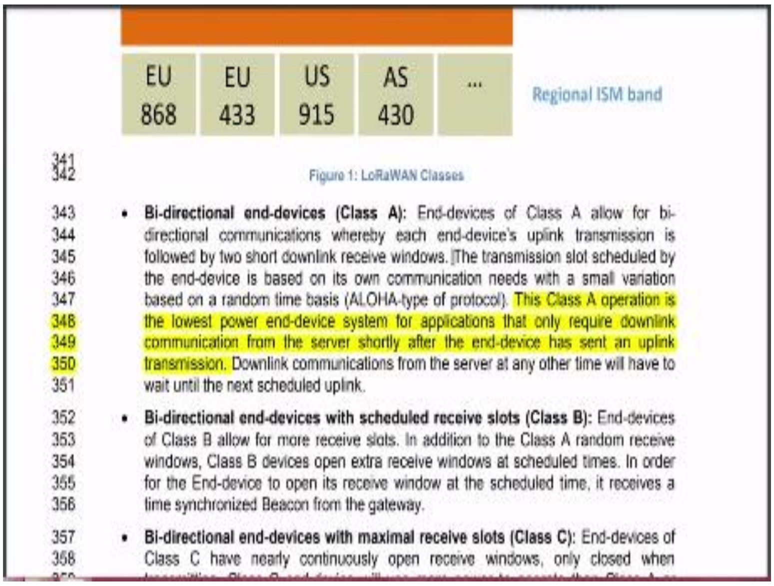
And yeah, I think this is a good wind up of what LoRa offers you. Uplink you will get 64 channels of 125 kilo hertz or 8 channels of 500 kilohertz. Downlink is 8 channels of 500 kilohertz usually. All this information which I put here is actually you can easily read up, understand from the centerpiece document which is out here as you can see. If you go through this document, you will see the whole lot here.

(Refer Slide Time: 23:55)



You see here LoRa modulation 868, 433, US 915 and AS 430. LoRa modulation comes in here. LoRa MAC, Class A Class B Class C we know this very well now. There are applications which you build on top, right. So it is easy now for you to pick up from here.

(Refer Slide Time: 24:16)



EU 868	EU 433	US 915	AS 430	...

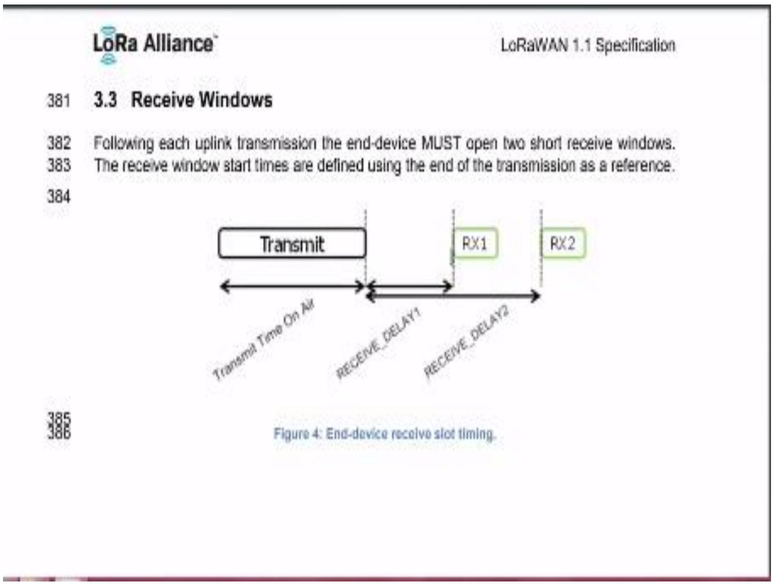
Regional ISM band

Figure 1: LoRaWAN Classes

- **Bi-directional end-devices (Class A):** End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.
- **Bi-directional end-devices with scheduled receive slots (Class B):** End-devices of Class B allow for more receive slots. In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. In order for the End-device to open its receive window at the scheduled time, it receives a time synchronized Beacon from the gateway.
- **Bi-directional end-devices with maximal receive slots (Class C):** End-devices of Class C have nearly continuously open receive windows, only closed when

Bi-directional. What happens in Class A? Bi-directional in Class B, Class C and so on, okay. Now physical message formats, how should the uplink message look like, that is given here. How should a downlink message look like is also mentioned here, okay.

(Refer Slide Time: 24:32)



LoRa Alliance LoRaWAN 1.1 Specification

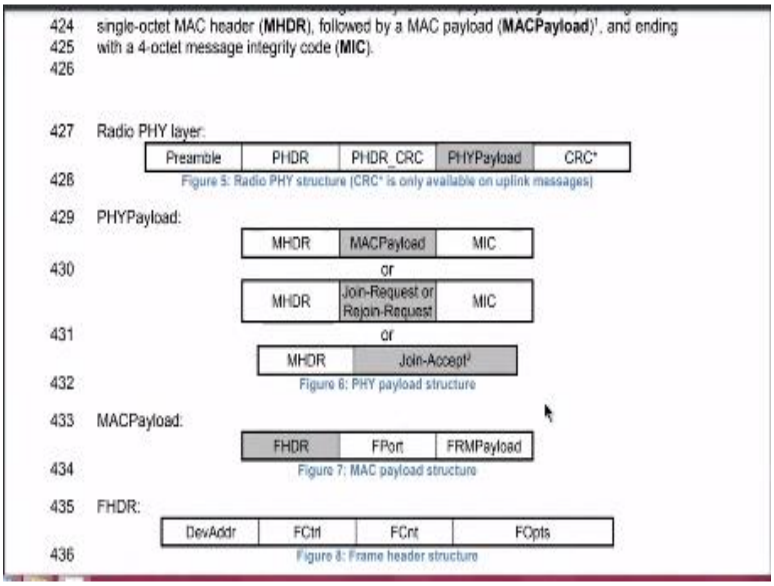
3.3 Receive Windows

Following each uplink transmission the end-device MUST open two short receive windows. The receive window start times are defined using the end of the transmission as a reference.

Figure 4: End-device receive slot timing.

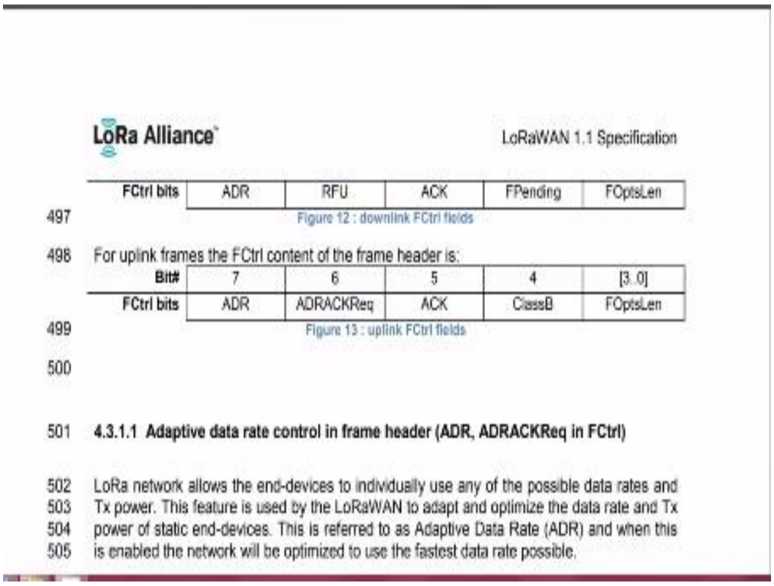
Then you have receive windows. I mentioned to you after an uplink transmission, there is a certain amount of delay after which the receive delay 1, you apply receive delay 1. You allow the system to transmit so that the device Class A, Class B, and Class C device is one of them. Depending on the mode, depending on the class they are, can receive data in Rx1. And therefore, the end device receives a slot timing is mentioned here clearly.

(Refer Slide Time: 25:07)



And yeah, so then MAC message formats are there. There is MAC header, there is MAC payload and then there is the Mac footer, MAC trailer as well. Yeah. So MAC header field, data messages. Yeah. So you I would strongly encourage you to look at.

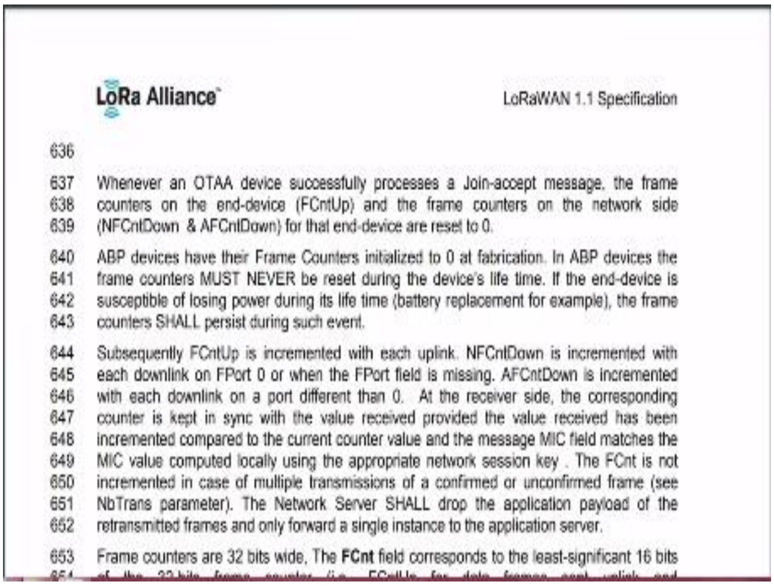
(Refer Slide Time: 25:26)



So there you are. This is about ADR, all about ADR. How does the network server give a ADR command back to the end device? That will be a question for you. You can see it is written here. ADR is mentioned here. And you could go through that in detail. You will understand about the adaptive data rate control in the frame header, okay.

Then there are other important fields, which you may also want to pick up. Please do read the document, and you will definitely be able to understand several parts of what this document is, after you have listened to this particular discussion I had with you.

(Refer Slide Time: 26:07)


LoRa Alliance

LoRaWAN 1.1 Specification

Whenever an OTAA device successfully processes a Join-accept message, the frame counters on the end-device (FCntUp) and the frame counters on the network side (NFCntDown & AFCntDown) for that end-device are reset to 0.

ABP devices have their Frame Counters initialized to 0 at fabrication. In ABP devices the frame counters MUST NEVER be reset during the device's life time. If the end-device is susceptible of losing power during its life time (battery replacement for example), the frame counters SHALL persist during such event.

Subsequently FCntUp is incremented with each uplink. NFCntDown is incremented with each downlink on FPort 0 or when the FPort field is missing. AFCntDown is incremented with each downlink on a port different than 0. At the receiver side, the corresponding counter is kept in sync with the value received provided the value received has been incremented compared to the current counter value and the message MIC field matches the MIC value computed locally using the appropriate network session key . The FCnt is not incremented in case of multiple transmissions of a confirmed or unconfirmed frame (see NbTrans parameter). The Network Server SHALL drop the application payload of the retransmitted frames and only forward a single instance to the application server.

Frame counters are 32 bits wide. The **FCnt** field corresponds to the least-significant 16 bits

I also mentioned to you about over the air updates, which are possible, and how a node can join the network by someone goes and deploys a node, and you want to join it into the network. That is quite simple in LoRa, where because it supports over the air joining. And there are frame options for that, and so on.

So folks, this is a windup on LoRa, and do look up the story, the Google links that I showed you, and read this document in thorough detail, you will understand LoRa. It is very promising. I would say you must seriously consider LoRa as an option in several applications. LoRa does not stop there. I will put one important picture. It will connect to your other story of other protocols that we discussed.

You see, what happens is if you look at the application server, you can run broker here. You remember the broker? We also called it the server. You can have MQTT clients. MQTT clients running here, folks. So you see you can mix match different protocols. MQTT can happily run off from the application server.

So if you are talking about a LoRa device, Class A device and an MQTT system, which is either publishing or subscribing to data, maybe subscribing data from let us say one of the LoRa devices, then it is the application server which can nicely interface to the broker and the broker or server, we should call it server. And the server can use the MQTT protocol to publish the data to the end system which has asked for data.

So a lot of interesting possibilities exist. And so mix matching these protocols becomes absolutely critical. I hope you got a overview of LoRa and LoRaWAN protocol. I think it would be sufficient in detail for you to read further and experiment all by yourself in this very exciting protocol. Thank you very much.