Introduction to Industry 4.0 and Industrial Internet of Things

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Lecture – 02
Introduction: IOT Connectivity – Part I

In the previous lecture, we have seen the key technologies, which are heart of IoT or IIoT, which is basically sensing and actuation. The sensors can sense some physical changes in the characteristics of the environment in which it is operating. Let us see the temperature sensor. The temperature sensor can sense the changes in the temperature characteristics of the environment where it is operating. The different communication protocols are used for the transmission of the data sensed by the sensor.

So, connectivity is the bottom line. The different available connectivity technologies discussed in the context of IoT, in general, applies to IIoT also.

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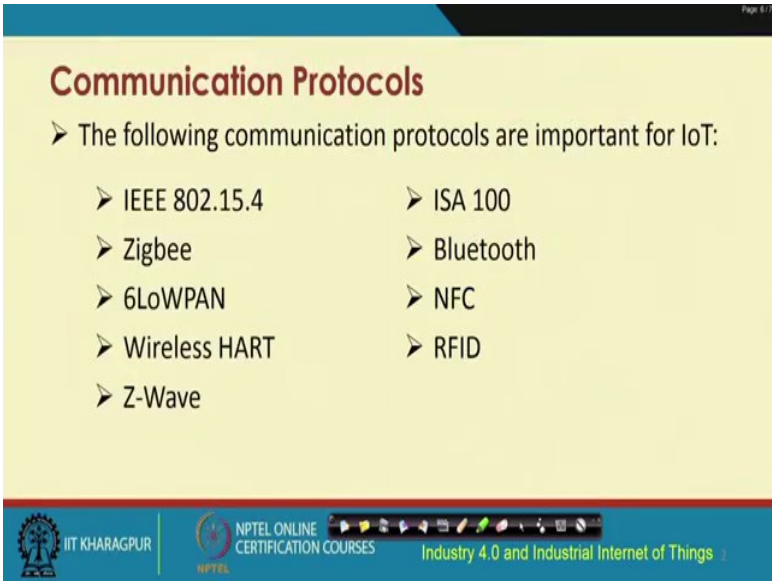

These are some of the communication protocols that are typically used for IoT. The first one is the IEEE 802.15.4 standard. Then you have different other protocols such as the ZigBee, 6LoWPAN, Wireless HART, Z-Wave, ISA 100, Bluetooth, NFC, and RFID.

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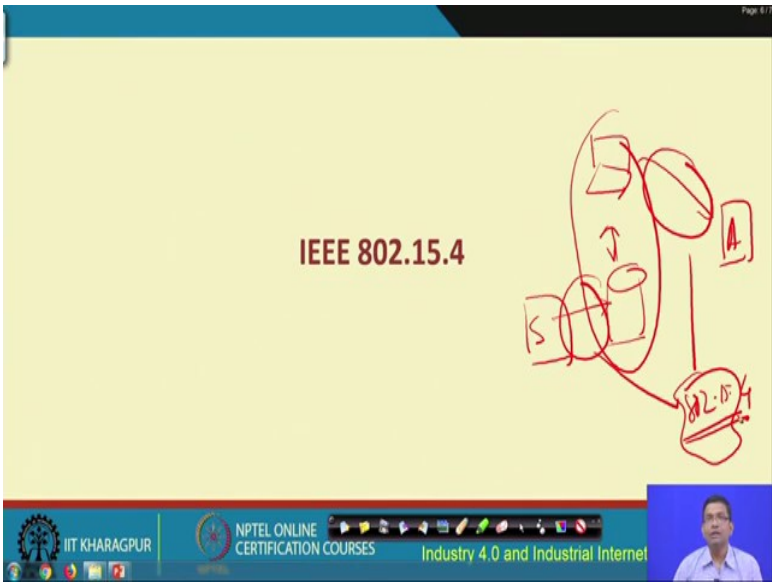

The 802.15.4 IEEE standard is used heavily for connectivity purposes in IoT. The sensed data are to be sent over a network to some remote device, for further processing. And, based on that processing again that signal has to be sent from that processor to some remote actuator, which will do some actuation that will turn on the lights of a room. Let us say, a laptop or something you know a processor or whatever. So, some signal might be required to be sent to the actuator right. We are talking about these different protocols that will be used over here and IEEE 802.15.4 is one such very widely used standards for offering connectivity in IoT.

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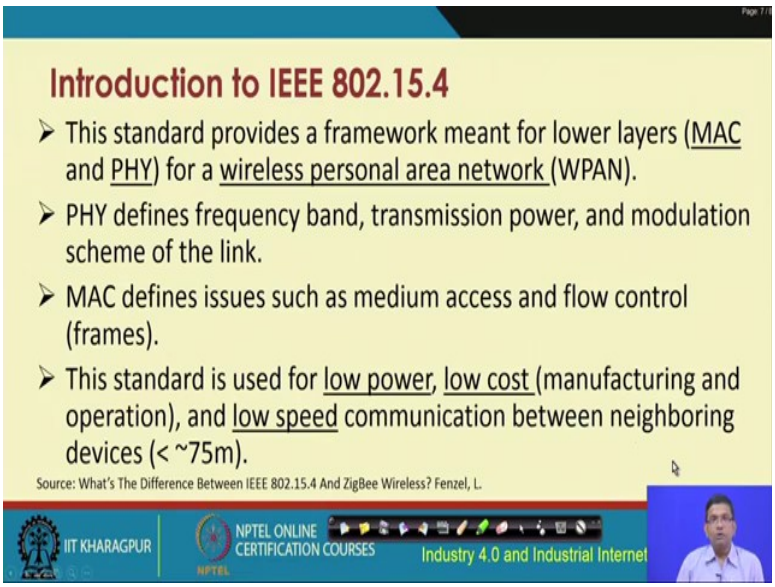

IEEE 802.15.4 basically provides the framework meant to be used particularly for networks such as the wireless personal area networks. Personal area networks means the network which operate in a very small scale and small range. IEEE 802.15.4 basically defines how these physical and the MAC layers are going to be used.

The physical layer defines things like the frequency band in which the communication is going to happen and the transmission power modulation scheme which is going to be used. On the other hand, the MAC layer discuss about different devices, the medium for communication, which protocol is going to be used, how they are going to send, when they are going to send, and what is the discipline that is going to be followed. The frames that are the PDUs in the data link layer, are going to be sent and the flows of the frames are to be maintained.

IEEE 802.15.4 standard is typically meant for use in communication where there is low power, low cost, low speed requirements. The communication between devices which are separated by typically less than 75 meters, 10 to 75 meters. But, you know different operating conditions will result in different ranges.

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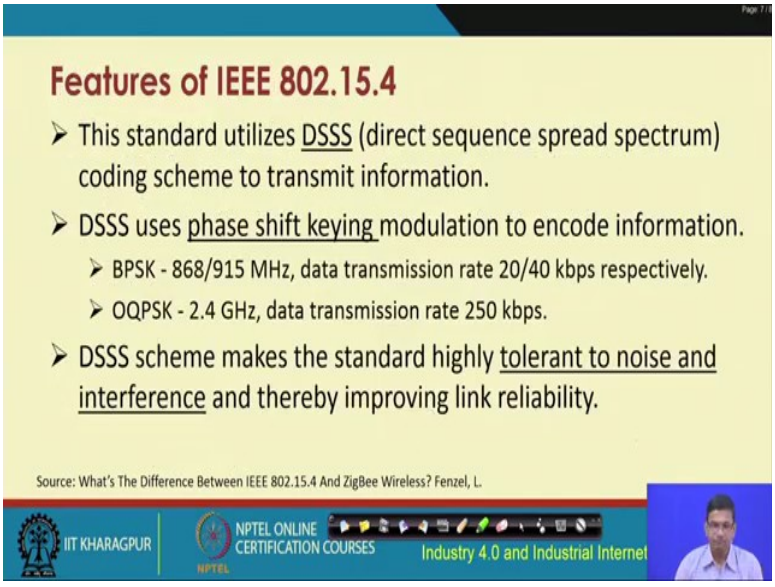

DSSS, the direct sequence spread spectrum coding scheme, is used to transmit information. The coding scheme which will encode the data and it will be sent. The reason DSSS is used is that it offers increased security and reliability. IoT systems typically operate in noisy environments interference where there is a lot of interference. Therefore, DSSS is a kind of

encoding scheme, good for sending information in these kind of channels exhibiting these noisy characteristics. DSSS uses phase shift keying modulation known as the PSK modulation. Phase shift keying modulation encodes the information and the different variants of it.

The first one is the BPSK modulation. Binary phase shift keying and this is typically used for data transmission rate of about 20 to 40 Kbps and in this particular frequency band, 868, 915 megahertz frequency band. There is another one, which is used for the 2.4 gigahertz frequency band, which is the OQPSK. The offset quadrature phase shift keying offers a higher data transmission rate of about 250 kbps. So, this BPSK offers 20 to 40 kbps and OQPSK offers about 250 kbps, a higher data rate, in the 2.4 gigahertz frequency band.

DSSS is a standard that will be highly tolerant to noise and interference. So, ultimately DSSS offers link reliability. Link reliability means that you have to ensure that whatever you are sending reliably and which is the destination.

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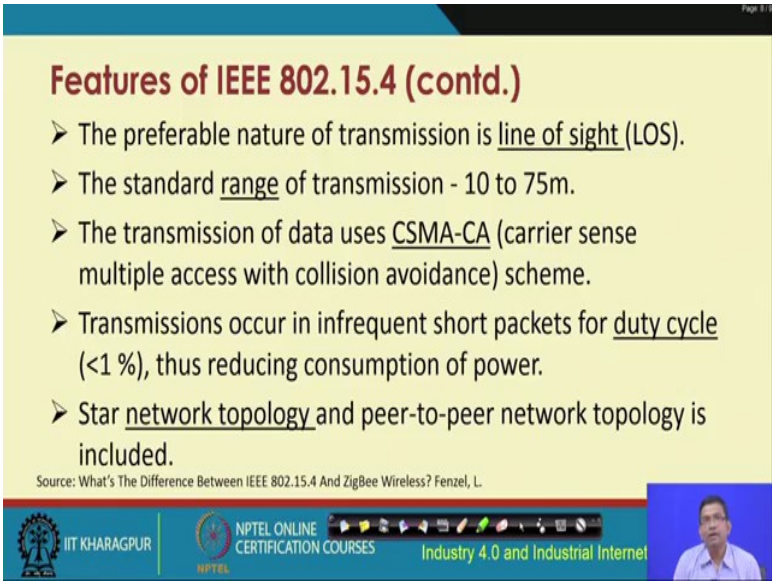

These are some of the features of 802.15.4 that it operates in the line of sight and that is the preferred nature of transmission. The range typically is about 10 to 75. The MAC protocol, that is typically, used if the CSMA-CA protocol carrier sense multiple access with collision avoidance and 802.15.4 has a requirement because it has to work in systems with low power. Therefore, it is used in transmission systems where there is a requirement of producing or using low duty cycle, low duty cycle. Low duty cycle means the sensor will be active for a

short duration of time because that will reduce the power consumption. So, in this kind of environment 802.15.4 is useful. The topologies that are typically used are network topologies such as the peer to peer topology and the star topology.

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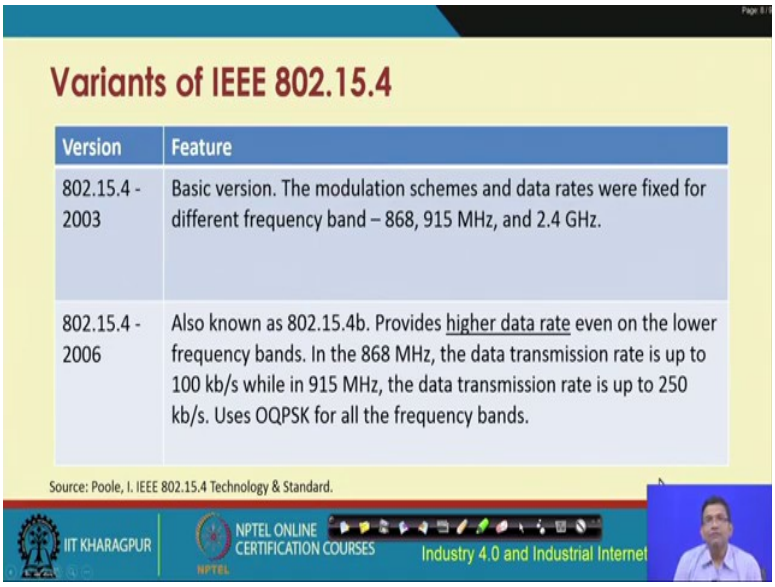

The basic version of IEEE 802.15.4 is the 2003 version, where the modulation scheme and data rates were fixed for different frequency bands as 868, 915 megahertz and 2.4 gigahertz. In 2006, the next variant came, which is popularly known as the 802.15.4b, which offer higher data rates compared to the previous version.

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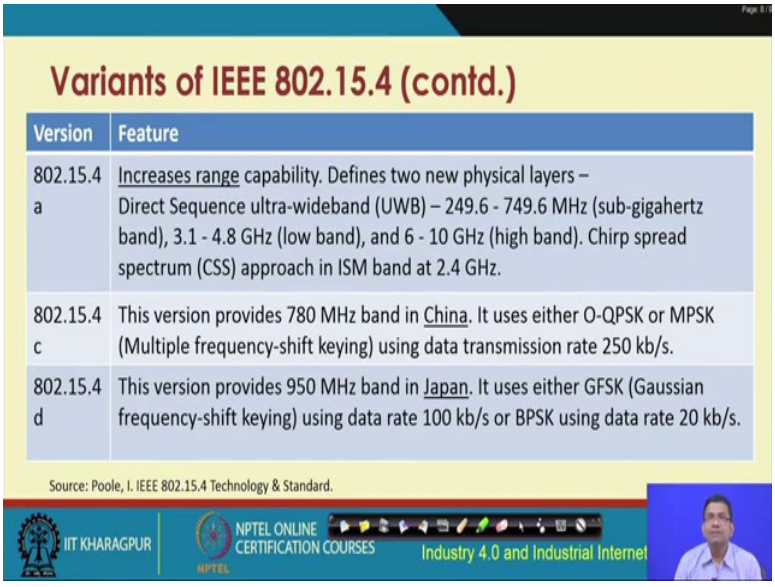

We have the next one, 802.15.4a, which talks about increasing the range capability. Then came the 802.15.4c which talks about using the 780 megahertz band in china for offering connectivity and communication. So, this basically uses O-QPSK or MPSK multiple phase frequency shift keying mechanisms for data transmission with data rate 250 kbps.

The IEEE 802.15.4d provides 980 megahertz band communication in Japan and it uses the GFSK and BPSK with different data rates.

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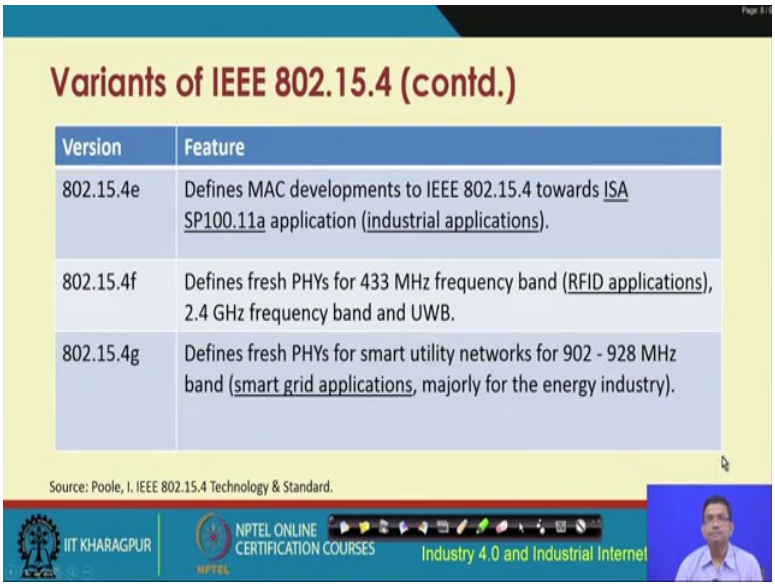

The e-variant (802.15.4e) is particularly meant for serving MAC applications for industrial environments, f-variant (802.15.4f) is for particular use in RFID applications, g-variant (802.15.4g) for smart energy smart grid etc. So, these are the different variants of 802.15.4.

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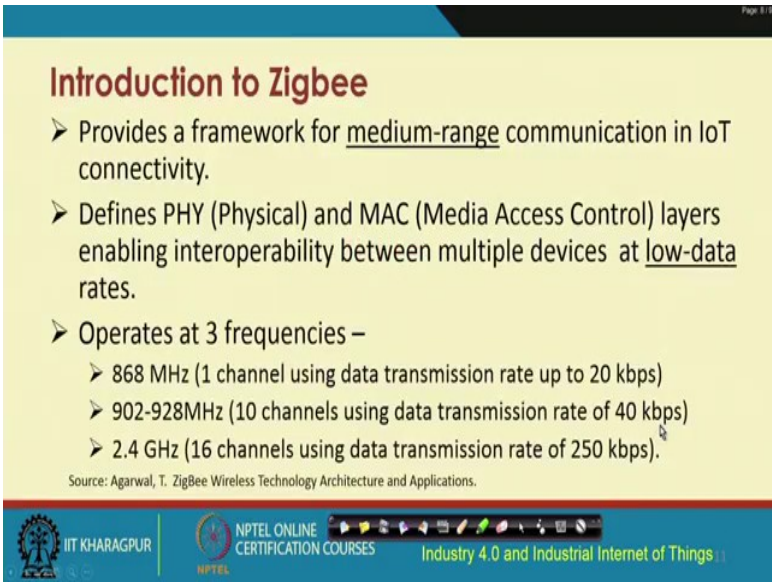

There are different protocols like the ZigBee protocol which is primarily based on 802.15.4. The ZigBee protocol provides a framework for medium range communication to offer IoT connectivity, it defines the physical layer, and MAC layer characteristics enabling interoperability between multiple devices at low data rates. ZigBee operates in three frequencies: 868 megahertz, 902 to 928 megahertz and 2.4 gigahertz.

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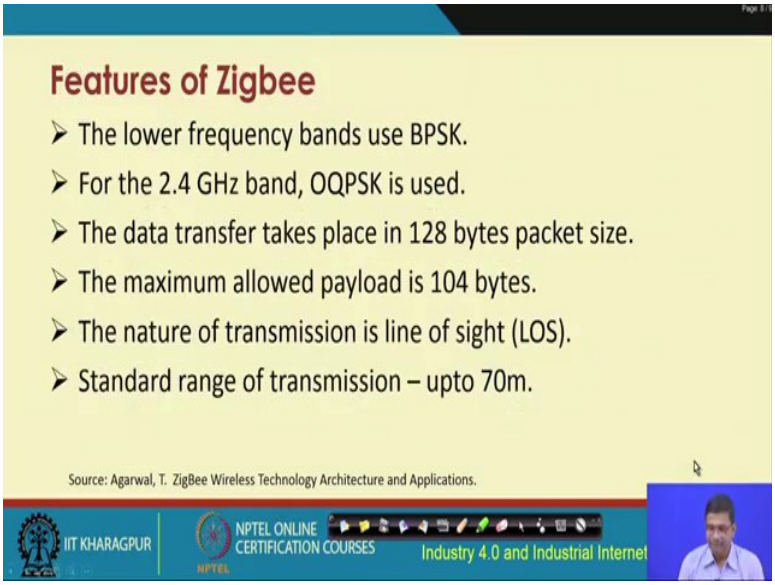

The lower frequency bands in ZigBee use BPSK, the 2.4 gigahertz band uses OQPSK, the offset QPSK, and then the data transfer takes place in 128 bytes packet size. So, each of these

packet size in ZigBee is typically 128 bytes and the maximum allowed payload is 104 bytes. The nature of transmission is not necessarily to be line of sight (LoS). ZigBee works with reduced data rate to some extent for long distance. The standard range of transmission is about 10 to 70 meters in ZigBee.

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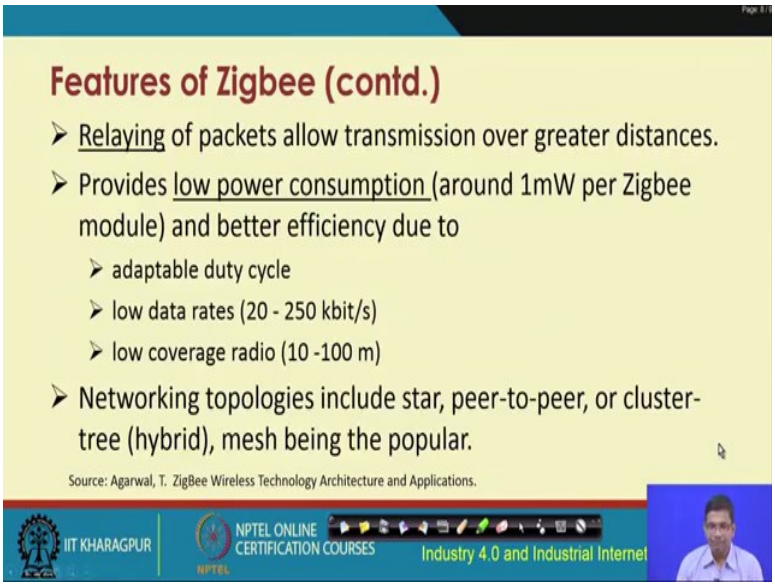

ZigBee basically helps in packet transmission over greater distances with the help of the concept of relaying. A ZigBee device, which receives a packet, sends the data packet to one of its neighbors and through multi-hub process communication from the source will be received at the destination node. ZigBee supports the relaying concept, virtually communication range can be increased. ZigBee provides low power communication around 1 megawatt per ZigBee module and it has different features such as offering adaptable duty cycle, low data rates of about 20 to 250 Kbps, low coverage ratio of 10 to 100 meter and so on. ZigBee supports different network topologies such as the star topology, P2P cluster tree topology and mesh topology and the mesh.

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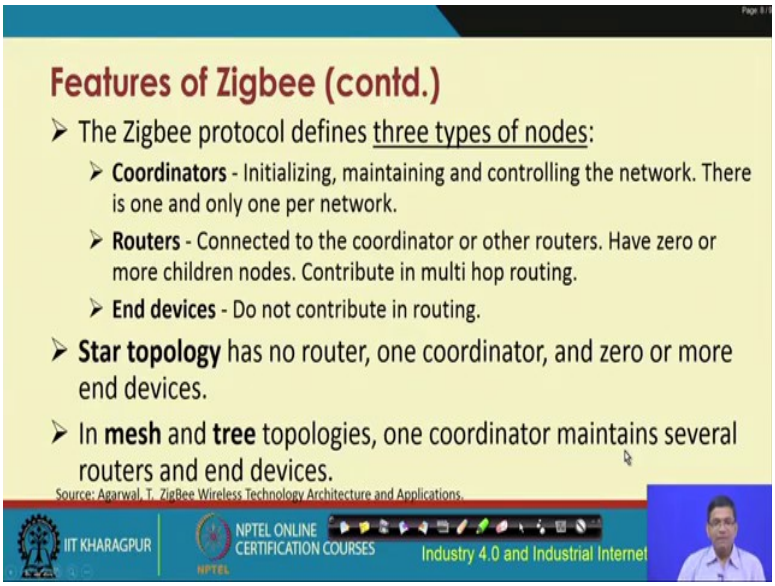

ZigBee protocol defines three types of nodes: the coordinator node, the router node and the end devices. The coordinator takes care of issues of initialization, maintaining, and controlling of the network. There is normally one controller per network. There are routers, which are typically used for multi-hop routing, to transmit the data packets received. The end devices are the recipients of the data which do not contribute to further routing.

The topology used are star topology and there is one coordinator, zero or more end devices. If the mesh and tree topologies are used, there is one coordinator that maintains several routers and end devices.

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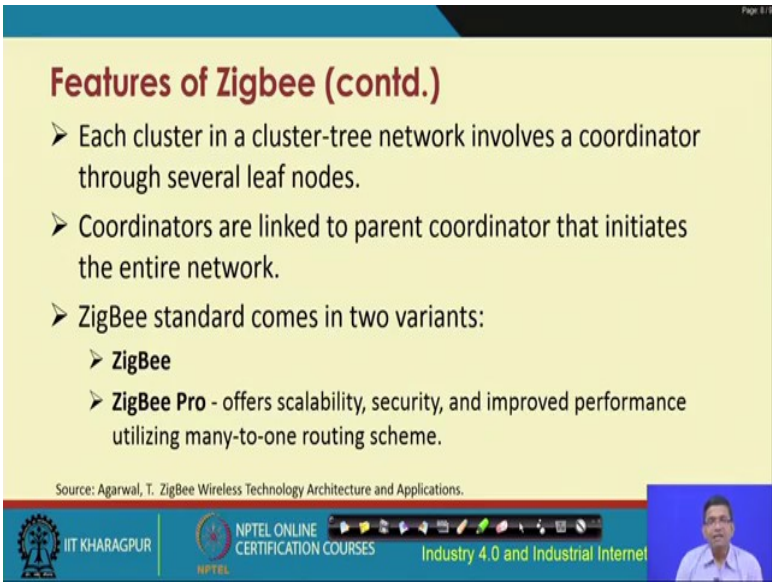

Each cluster in a cluster tree network topology is used involves a coordinator through several leaf nodes. So, there is some cluster and there is a tree kind of structure. The coordinators are linked to the parent coordinator that initiates the entire network.

ZigBee standard comes in two variants: the regular ZigBee and the pro variant. Pro is attractive, because it offers you know issues of scalability. ZigBee pro offers better security; improved performance utilizes many routing scheme.

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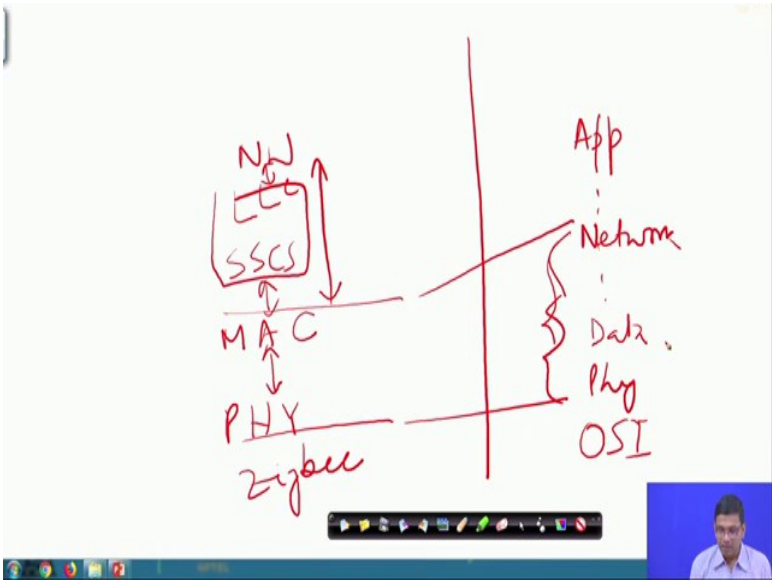

In ZigBee, the physical, then the MAC, have different layers such as the SSCS, the LLC, and the network layer. Traditional OSI is used for the internet. The physical layer has the data link layer all the way up to application.

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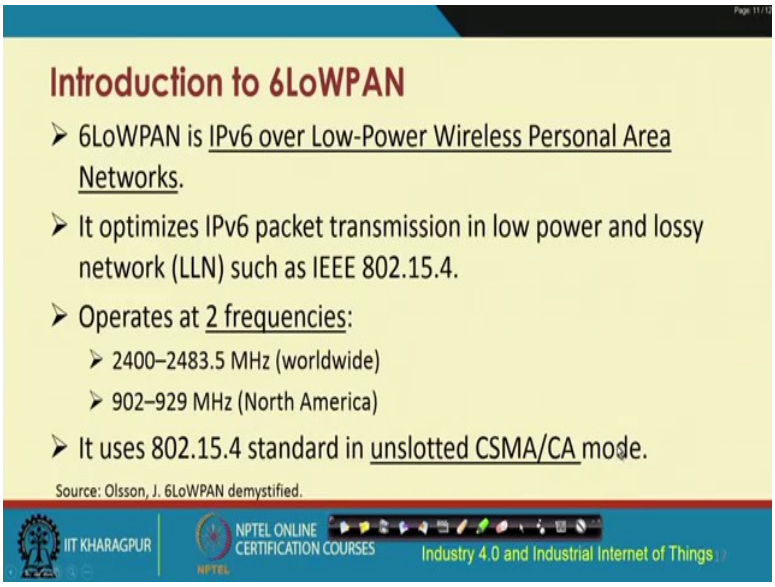

6LoWPAN, you must be wondering, that what is this 6, with a numerical value the name of a protocol starting with the numeric value. 6 stands for the letter 6 in IPv6. 6LoWPAN is about use of IPv6 over wireless personal area networks. The personal area network, the wireless one and there is low power. This optimizes 6LoWPAN optimizes IPv6 packet transmission in low power lossy networks. 6LoWPAN operates at two frequencies: one is the 240, sorry, 2400 to 2483.5 megahertz frequency band which is used worldwide and the other one is in North America which is the 902 to 929 megahertz band. IEEE 802.15.4 standard in the unslotted CSMA/CA MAC protocol mode.

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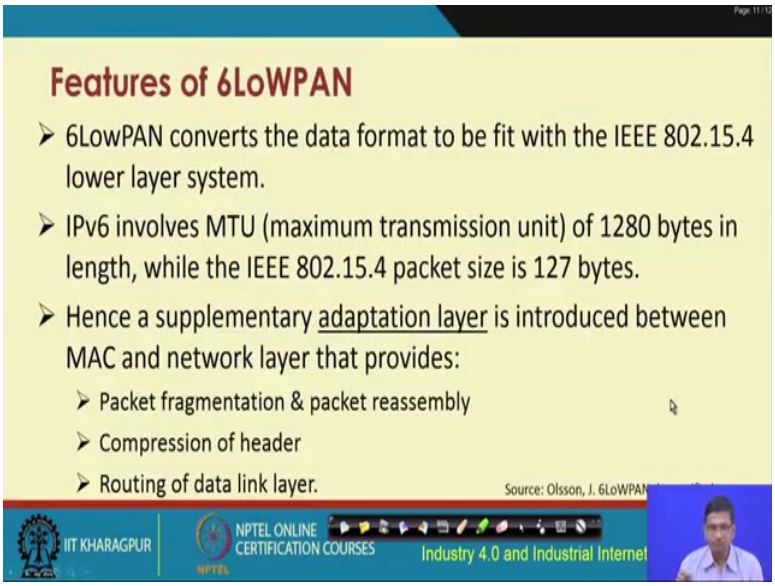

6LoWPAN converts the data format to be fit within 802.15.4 lower layer system. IPv6 basically involves MTU of 1280 bytes in length, while 802.15.4 permit a packet size of upto 127 bytes. Therefore, there is a big mismatch, 1280 is permitted by IPv6 and 802.15.4 allowing 127 bytes only. This can be achieved with the help of a layer which is known as the adaptation layer, which is introduced in between the MAC and the network layer. This helps in packet fragmentation. Fragmentation has to be done because, 1280 and 127, there is a mismatch in the sizes. This adaptation layer will help in few other things such as the compression of header, routing of data link layer. So, routing help with the routing on top of the data link layer, with the help of this particular adaptation layer.

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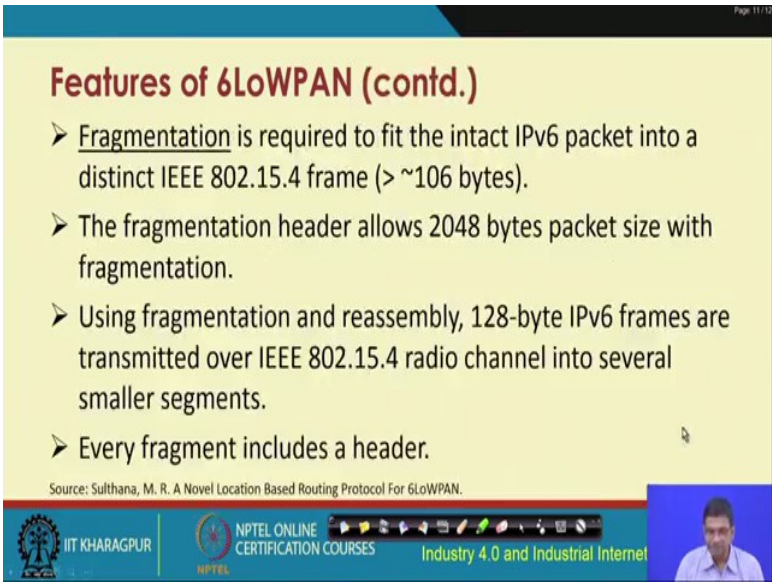

So, fragmentation is required to be able to fit the intact IPv6 packet into the IEEE 802.15.4 frame. So, this fragmentation header allows 2048 bytes packet size. Using fragmentation and reassembly 128 bytes, IPv6 frames are transmitted over 802.15.4 radio channel into several smaller fragments. IPv6 will take care of the 6LoWPAN protocol, the adaptation layer will basically take care of both the fragmentation as well as the reassembly.

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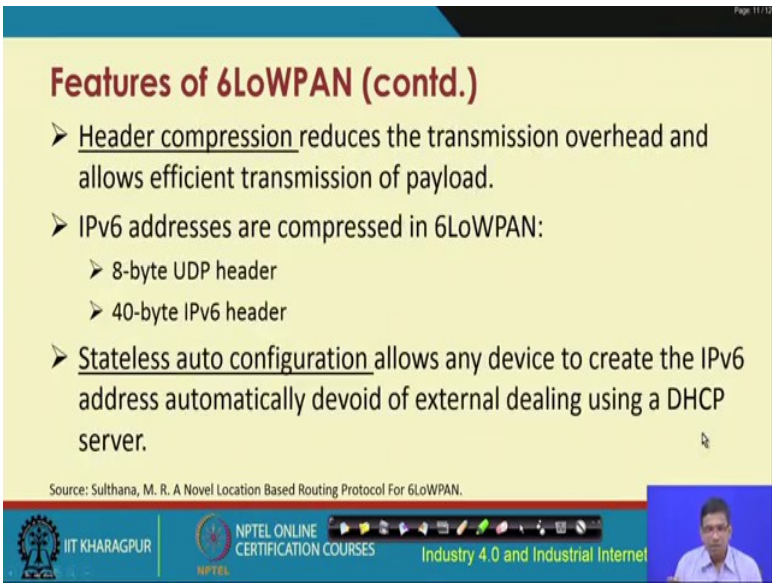

The header compression reduces the transmission overhead and allows efficient transmission of payload. So, IPv6 addresses are compressed in 6LoWPAN into two types: 8-byte UDP header and 40-byte IPv6 header. DHCP is not used in 6LoWPAN.

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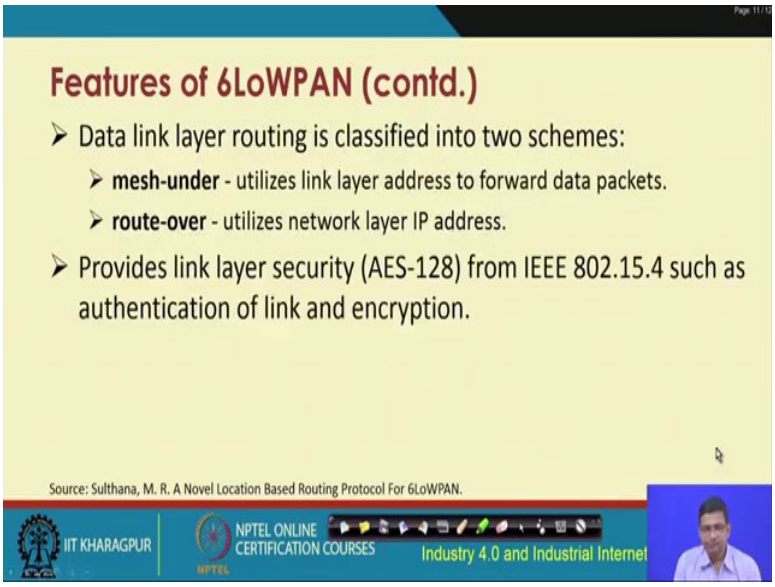

The data link layer routing is classified into two schemes: one is the mesh under which utilizes the link layer addresses to provide to forward data packets and the other one is the route over. So, route over utilizes network layer IP address.

Let us look at one more thing is that this AES-128 link layer security is used.

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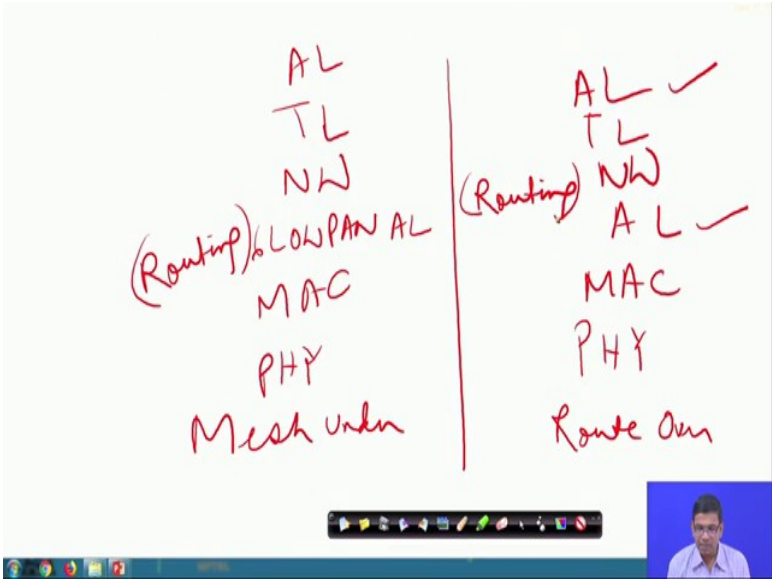

The physical layer, then the MAC layer, the adaptation layer which is the 6LoWPAN, the network layer, the transport layer, and the application layer are placed.

The difference in case of mesh under this routing is done in the adaptation layer.

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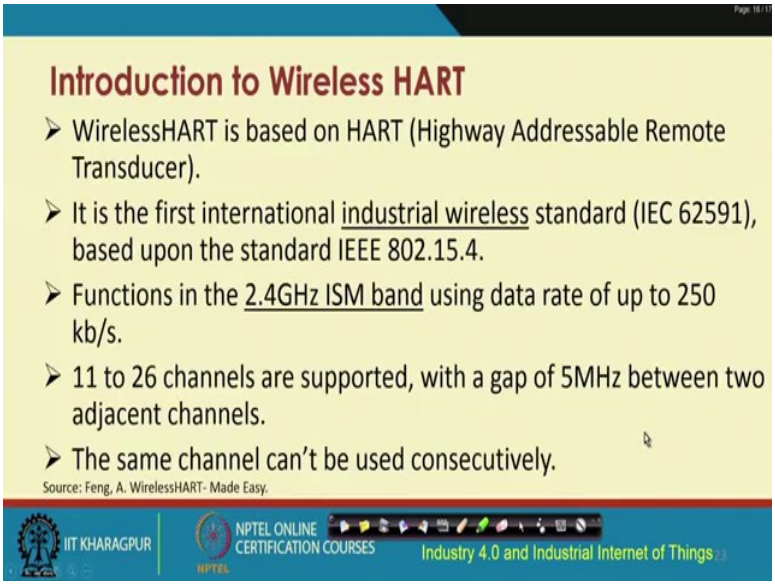

Another protocol, which is the wireless HART protocols, are used particularly for industrial applications. The full form of HART is Highway Addressable Remote Transducer and is based on IEEE 802.15.4 standard.

It functions in the 2.4 gigahertz ISM band using data rates upto about 250 kbps and there are 11 to 26 channels with a spacing of about 5 megahertz between two adjacent channels. HART wireless protocol makes it mandatory that the same channel cannot be used consecutively.

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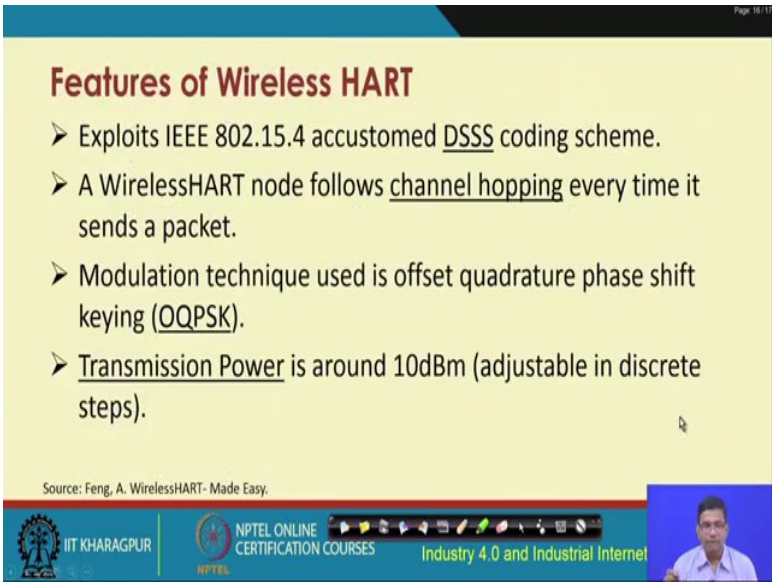

These features of wireless HART is it uses DSSS based on IEEE 802.15.4. Wireless HART protocol follows the channel hopping every time it sends a packet. And, the modulation scheme is used is the OQPSK offset quadrature phase shift keying and the transmission power is around 10 dBm.

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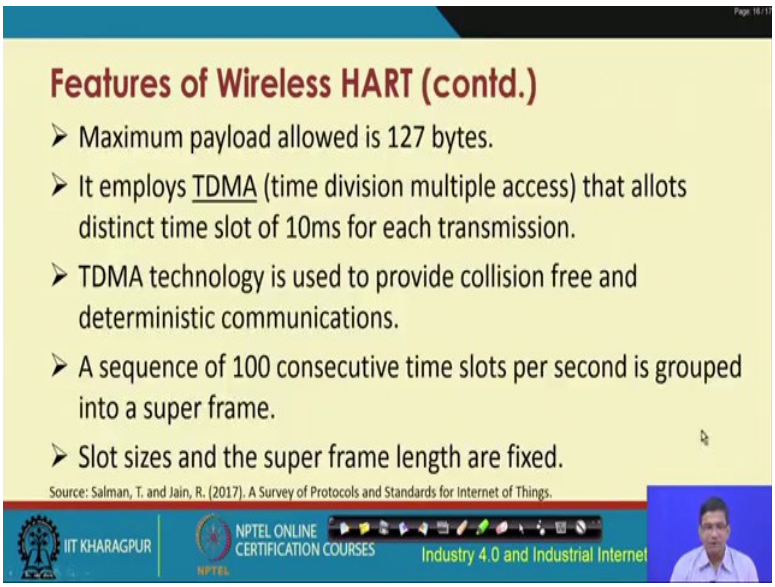

There are other features such as the payload size that is allowed is 127 bytes. The MAC protocol used is TDMA. This TDMA technology is used to provide collision free and deterministic communication. There are different time slots in which the communication

takes place, so, there is no collision. A sequence of 100 consecutive time slots per second is grouped into something known as the super frame. This super frame concept is very important.

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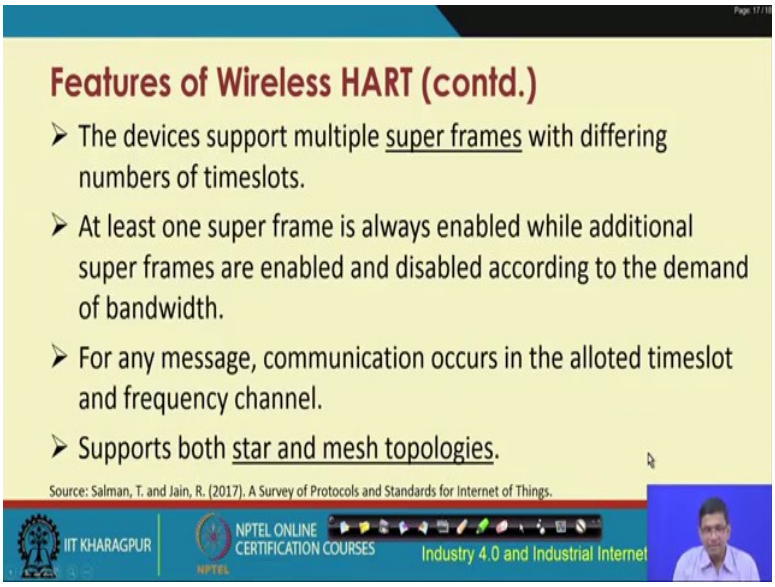

The devices support multiple super frames which will have differing number of time slots. At least once per frame is always enabled while additional super frames are enabled and disabled according to the demand of the bandwidth. For any message the communication occurs in the allotted time slot. So, wireless HART basically supports both star and mesh topologies.

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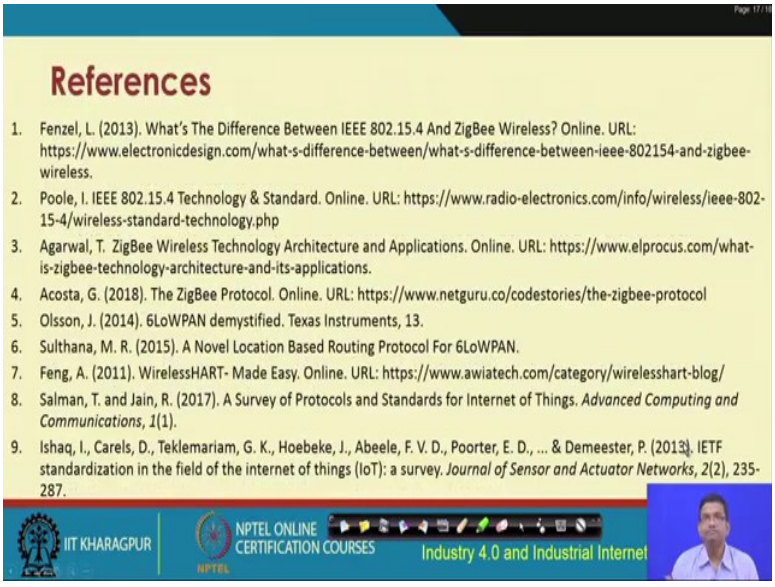

These are the some of these features of the wireless HART and as we have seen industrial applications are the ones where wireless HART is very attractive for use. It is based on IEEE 802.15.4 standard. And, it is a very attractive protocol for industrial applications. If you want to know further about wireless HART and the other protocols and the standard 802.15.4 in more detail, these are some of the references.

This lecture introduces you to only these protocols, but if you need to know this kind of understanding will be sufficient for you to go ahead with the further lectures. But, in case you need to go ahead these are some of these references that are listed which you can go through in further detail and gain even more in depth, an understanding if you require to.

Thank you.