Introduction to Industry 4.0 and Industrial Internet of Things

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Lecture – 28
Key Enables of IIoT: Connectivity – Part 1

If, we are looking at a IIoT holistically, there are different layers, at a very high level, we can think of an IIoT based system, to be comprised of different layers; layers such as sensing, which is what we have already gone through so far. Then, after the data are sensed from these different industrial equipment's, machinery, and so on, the data will have to be sent through some medium following certain protocols.

So, this is this connectivity part, right. So, after sensing the data will have to be sensed over some kind of connectivity. And, after connectivity, the next layer will be the layer of processing, and based on the results of processing some kind of actuation or control or feeding back the control back to somewhere will have to be done. These are the different layers of layers of an IIoT based system, that we can think of.

Let us go through this connectivity part now. So, we have already understood the sensing part now next comes the connectivity part.

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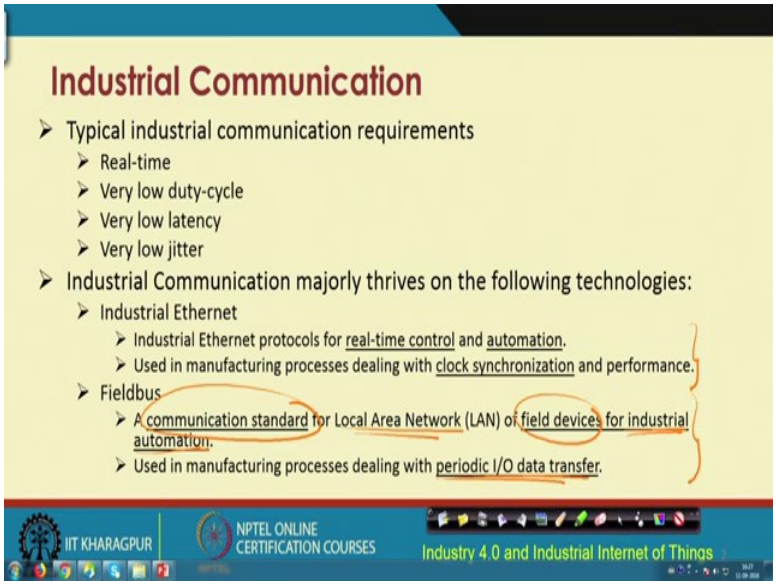

When we talk about industries. Industrial requirements are very specific, industrial communication particularly has certain specific requirements. These requirements are that the communication, the processing, everything will have to be done in real-time, with least delay, whatsoever in all the different respects.

Thereafter, the next important consideration is that there is very low duty cycle; there is very (very) low duty cycle that should be there. So, which basically will ensure that, we need to make our sensors active for only that duration of time, which is sufficient and thereafter put the sensor in the sleep mode; so the duration for the active mode will have to be much less compared to the overall cycle of the operation of the sensor, because of the requirements with the way, the machineries are going to work etcetera. So, there is a very stringent requirement of very low duty cycle.

The third one is that there has to be very low latency. The latency is required to be very low because just consider that you process something and if it does not the processing takes, maybe in the order of few seconds. And, by that time maybe some job will be will which was required to be finished is not finished, and if you do not get that control back to that point where the job is being performed, then that particular job is going to be basically damaged. And, also the latency requirements are very stringent because that can also lead to different types of industrial hazards.

The next one is the requirement of very low jitter. Jitter means the rate of change of delay. There has to be a very low jitter rate, that is required for industrial communication. So, industries so, nowadays, we are talking about IoT. And, consequently, sort of projecting it for industrial requirements we are talking about Industrial IoT, but looking back communication in the industrial sector, let us say, manufacturing plants, and so forth has already been there.

So, there has been different communication requirements, reliable communication for industrial use, those sort of requirements have been there. So, communicating different machines have also been there, but those have been primarily, those have been primarily using the conventional communication mechanisms. And, with the help of guided media wired medium for communication primarily, but gradually the different wellness requirements are also coming into picture. And, also at the same time these sensing enabled, sensor enabled, devices and processing close to the site of sensing and higher

degrees of processing, real time processing, real time analytics. So, those kind of requirements are coming into picture and that is what makes this communication interesting in this current perspective. And, that is where this IIoT is coming into picture, but a IIoT is not something new.

So, the only thing is that we have some stringent requirements with respect to the fulfilment of IoT requirements and that is what makes IIoT much more interesting in the industrial context. So, looking back if you are talking about industrial communication; industrial communication legacy industrial communication was primarily, based on two different technologies; one is the Industrial Ethernet, and the second one is the field bus technology.

So, these are the two major dimensions for industrial communication. So, the Industrial Ethernet protocols for real-time control and automation have been proposed. And, also there are different protocols such as the Modbus based protocols have been proposed to which we are going to go through because this is very important. In the context of Industrial IoT, we cannot basically throw away these legacy communication mechanisms that have been there and that are those are still being used in the industry. So, what has to be done, is whatever newer things we are trying to bring in the context of Industrial IoT, we will have to be built on top of the existing, legacy communication infrastructure that is already in place right. Otherwise, it is going to be complete transformation, it is going to be complete transformation, which may not be desirable. So, rather I think what is better is to have an evolution of the existing, industrial, communication, infrastructure, mechanisms, protocols, etcetera and making it much more transgressional to adopt IoT requirements.

So, Industrial Ethernet and the next one is basically the field bus, in the field bus technology we are talking about, some kind of having some kind of a communication standard, for use with local area networks, having connectivity with the different field devices field instruments in the industrial automation sector.

So, these are time in the field bus technology is primarily used for manufacturing processes dealing with periodic input-output data transfer. So, these are the two main technologies, that are being used in the industrial communication sector, so far.

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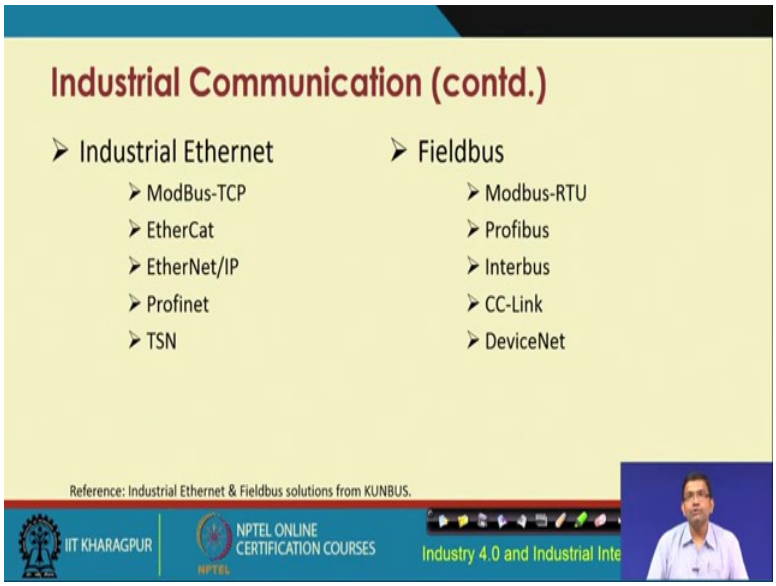

So, for the industrial Ethernet there are different protocols that are there, number one is the Modbus TCP.

Modbus TCP is a very popular industrial Ethernet protocol. Second one is the ether EtherCat, third is Ethernet/IP, next is Profinet, and TSN, Time Sensitive Networks. These are some of the Industrial Ethernet protocols that are used in practice in for industrial communication. Particularly in the manufacturing, industries manufacturing plants and so on.

The other one is the field bus technology, where different protocols such as the Modbus-RTU version, not the TCP version Modbus-RTU. Profibus inter bus CC-link, Device Net; these are some of the different protocols that are used in the field bus in the field bus category.

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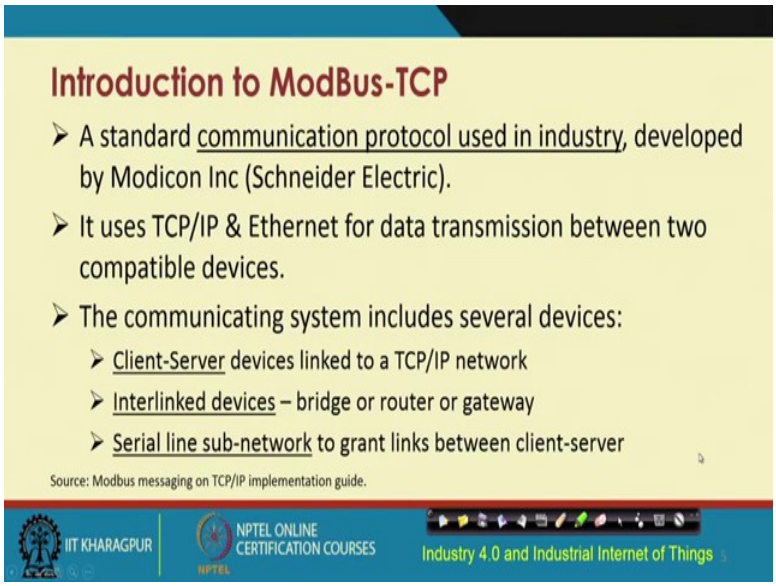

So, we will start with the ModBus-TCP. As this name suggests, ModBus-TCP is built on top of TCP/IP suite of protocols. So, it uses the TCP/IP and the Ethernet for data transmission between different compatible devices. Compatible means, that they have to talk the same language, they will have to talk the same language, both will have to use the same protocol then only the communication can happen.

TCP/IP suite of protocols is used and on top of that the Modbus is used. So, you have TCP/IP Ethernet and Modbus TCP built on top of the existing TCP IP Ethernet protocols. So, incidentally Modbus TCP has been proposed by present day Schneider electric, which was earlier known as the Modicon Inc. And, this particular protocol was proposed to cater to certain industry specific requirements that Schneider Electric or Modicon had you know in their plans. And, to in order to cater to those requirements particularly requirements such as reliable communication, low latency communication. This kind of protocol was required, because the existing TCP IP protocol in its in the TCP IP form was not very suitable.

So, it has to be modified in order to be used for the industrial communication requirements in manufacturing plants. Schneider electric came up with their own protocol, which later became sort of like an industry standard communication protocol for being used. And, what was TCP is a popularly used protocol present. So, ModBus TCP has different types of communication, in the different devices that they have.

So, first of all they use the client-server based mechanism for communication, which is quite well known what is the client-server mechanism? Client-server communication is used and for that a TCP/IP conventional one is used for the communication with between the client and the server.

The next one is the devices such as the bridges, routers, gateways etcetera, which interlink different parts of the network, right. So, that is these inter-linked devices part. And, the third one is basically the serial line sub network that basically grants the links between the client and the server. So, these are the three parts of the communication system, that are used in the Modbus TCP protocol.

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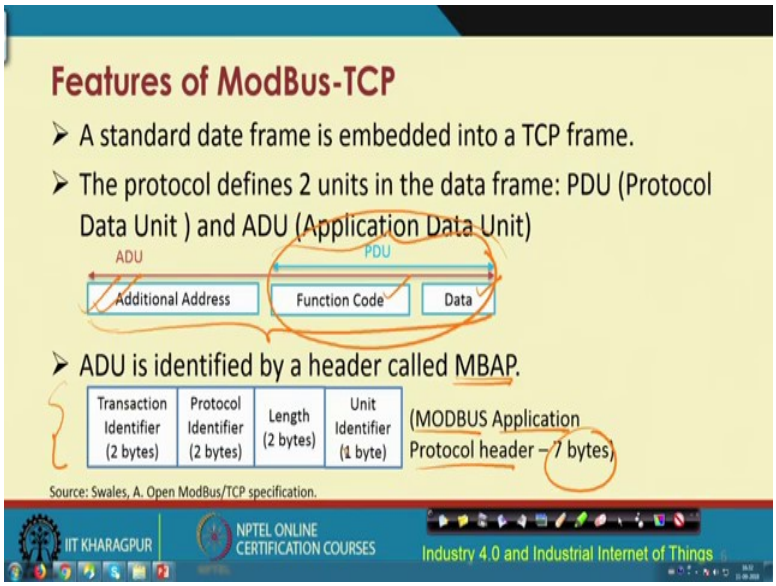

So, these are some of the features there are many many different features I will talk about some of the salient ones. So, here are some of the salient features of the Modbus-TCP protocol. So, the standard data frame is basically embedded in Modbus-TCP into a TCP frame into a TCP frame a standard data frame, which carries the information is embedded into it into the TCP frame. So, the protocol basically defines two units in the data frame; one is known as the application data unit, the other one is the protocol data unit. So, as you can see over here this entire thing is the application data unit and this part is the protocol data unit. So, basically the protocol data unit has the functional code, function code and the actual data. And, the application data unit includes the PDU plus

the additional address. So, this ADU application data address, data unit has some header, which is known as the MBAP.

An MBAP stands for Modbus application protocol header, which is of length 7 bytes and this header structure is over here. So, 2 bytes of transaction identifier, 2 bytes of protocol identifier, 2 bytes of actual length, and 1 byte of unit identifier. This is the Modbus application protocol header, the MBAP structure, right.

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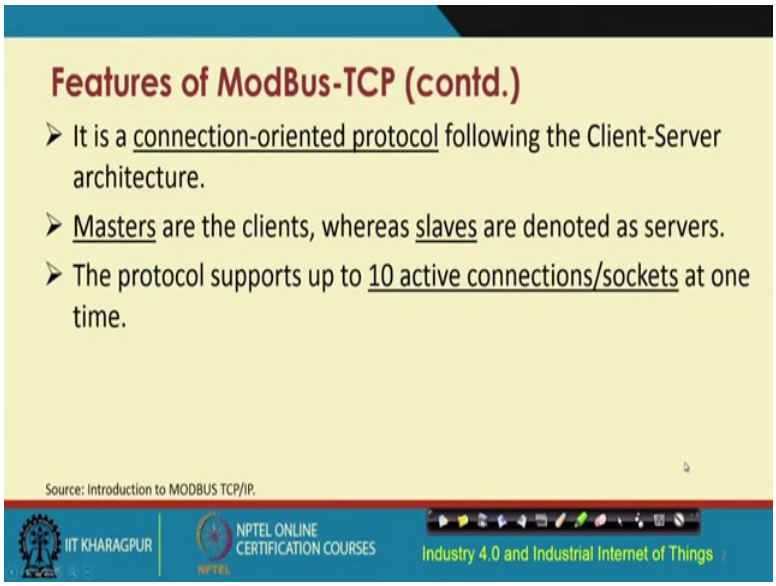

So, we go next and look at the other features. Modbus TCP is a connection-oriented protocol and as I said before, which uses client-server architecture for the client to communicate with the server. And for the server to respond back to the client done on using the TCP protocol of the TCP/IP suite. Now, in Modbus TCP the clients are basically the masters and the servers are the slaves.

So, master slave kind of communication takes place between the client and the server. So, in the same way as the master asks the slaves to, I am not quite impressed with these terms, but this is what is used the term slave or, the master this is not a very comfortable term for use for me, but let us continue, to use the terms that are used in the literature. So, masters basically in the same way as masters ask the slaves to do certain work. Here, also the clients ask the servers to do certain work and the servers respond back. In the same way, as the slaves who do the work and respond back to the masters, here also the servers respond back.

So, Modbus TCP basically supports up to 10 active connections or sockets at one time.

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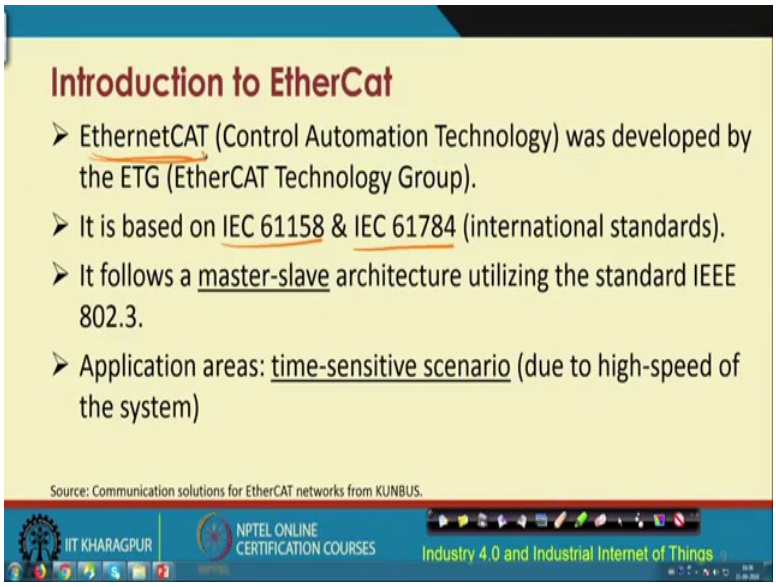

Next, protocol is the EtherCAT protocol and the full form of CAT is Control Automation Technology. And, this was developed this particular protocol, EtherCAT was developed by the technology group EtherCat, EtherCAT technology group, ETG, this developed this Ethernet CAT protocol.

So, this particular protocol is based on two different industrial standards; one is the IEC 61158 and the other one is 61784. These are two industrial international standards and based on which the ether Ethernet CAT protocol was proposed. So, this particular protocol follows a master slave architecture utilizing the standard IEEE 802.3; that means, the Ethernet, the standard Ethernet is used and the master slave communication basically follows this particular standard 802.3 Ethernet.

And, the application areas of for use of EtherCAT are basically systems, where there is a requirement of time sensitivity, where there are time-sensitive scenarios, and basically these scenarios will have to cater to specific times by when the jobs will have to be completed, or certain process will have to be completed. And, this is typically used in systems which are of high speed and industrial machinery typically operate in very high speed, right.

So, there is lot of batch processing and high speed processing by these different industrial machinery takes place. So, that is the reason as you can see, industry specific requirements will have to be taken into account in order to come up with these protocols and EtherCAT is one such protocol, which cater to this particular need.

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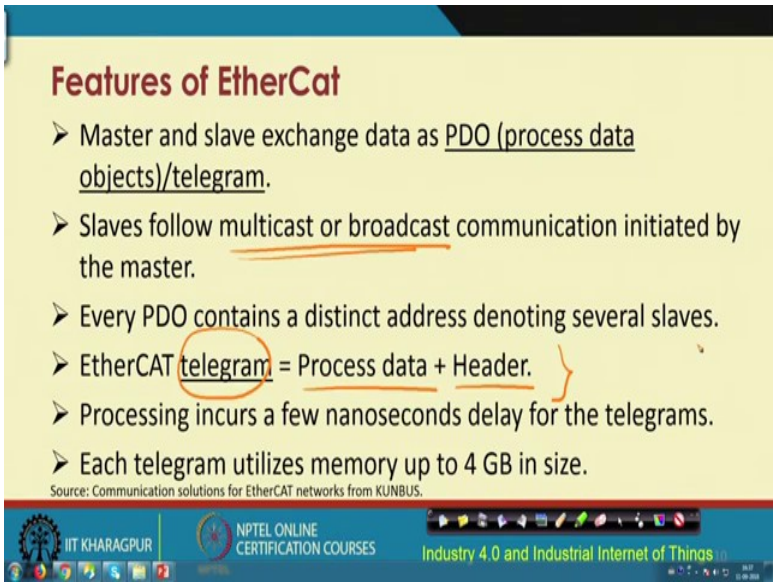

So, here are some of the features of EtherCat, here also it uses the master slave protocol for detects exchange between the client and the server. And, this is done in the form of something known as the PDO, which is the Process Data Object, it is also known as the telegram. Now, in EtherCAT this telegram is defined in this manner, telegram is the processed data plus the header, together it forms the telegram or the PDO in EtherCAT. So, going back the slaves so, I said that it is master slave communication. So, the slaves basically will follow multicast or, broadcast communication and every PDO contains a distinct address denoting the several slaves.

So, every telegram basically utilizes the memory up to 4 gigabytes in size in EtherCat.

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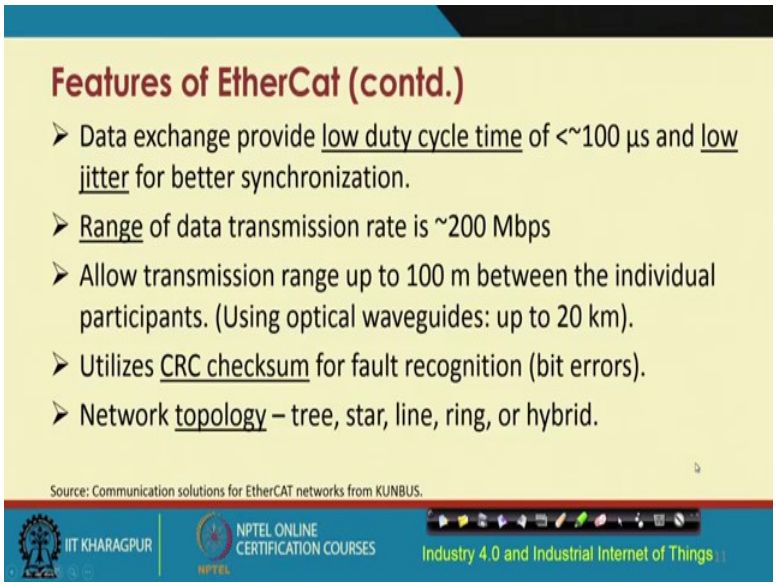

Other features low duty cycle requirement. So, fulfilling to low duty cycles less than less than about 100 microseconds, low jitter, better synchronization so, all of these are requirements for data exchange with EtherCat. And, the range of data transmission in EtherCat is typically in the rate of about 200 Mbps, 200 Mbps in that kind of quarter.

And, in terms of security not only security, but also error correction, error detection, error detection and control etcetera. The CRC checks take some based error detection or fault recognition, mechanisms are used where the, but errors are found out with the help of this kind of CRC based checksum mechanism.

The network topology that is used are the tree topology, the star topology, line topology, ring topology, hybrid topology, different types of network topologies are supported by EtherCAT.

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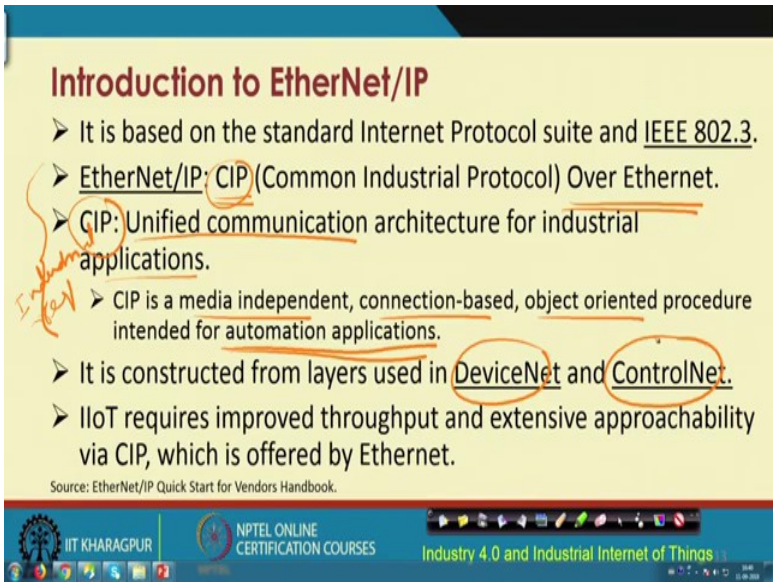

Next comes a protocol Ethernet/IP. So, this Ethernet/IP is based on the standard IP suite of protocols plus the Ethernet, which is IEEE 82.3 compliant. So, this Ethernet IP protocol follows the common industrial protocol, Common Industrial Protocol CIP, common industrial protocol and Ethernet IP basically happens to be like, CIP over Ethernet, CIP over Ethernet.

And, the CIP provides unified communication architecture for industrial applications. So, CIP basically is the Common Industrial Protocol, which is media independent, connection-based, object oriented, and primarily targeted towards automation-based applications. So, as you can now understand, why it is industry oriented. So, Ethernet IP protocol is overall catering to the different industrial requirements.

So, this particular protocol is constructed from layers used in the device net protocol and the control net protocol. We will look at these in more detail, later on, but just for your information device knit and control net together, basically controls the different layers of Ethernet IP.

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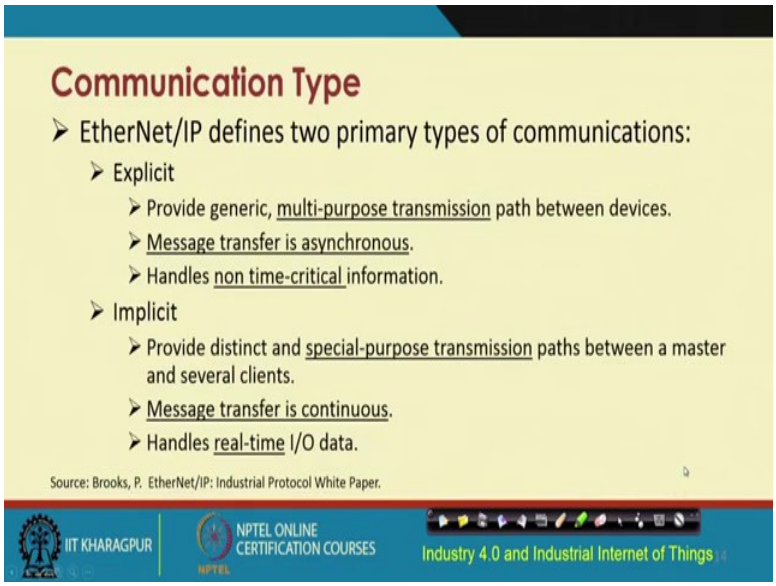

So, in EtherNet/IP there are two types of communications; explicit and implicit communication. Explicit communication provides generic multipurpose transmission between different devices. And, typically the message transfer is asynchronous in this explicit type of communication.

Explicit handles non time critical information. On the contrary, implicit handles real time input output data requirements. Here, unlike in the case of the explicit, where the message transfer was a synchronous, here the message transfer is continuous. And implicit type of communication provides distinct and special purpose transmission between the master and clients.

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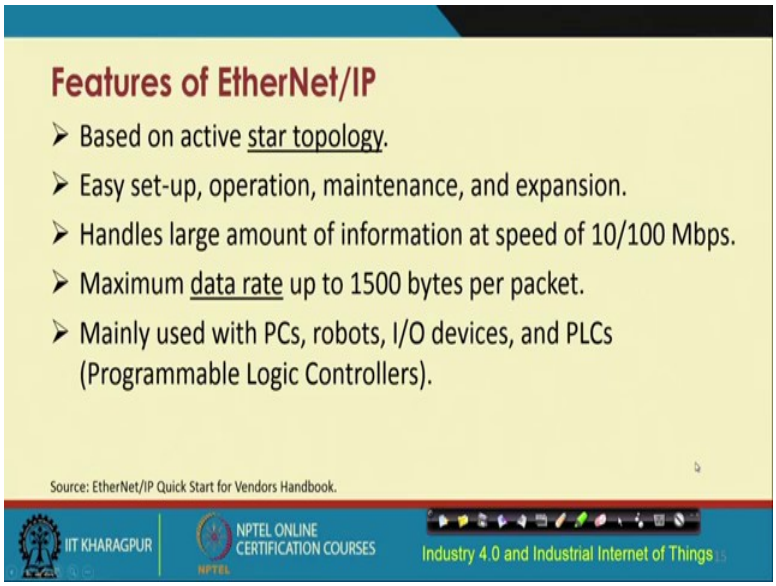

Ethernet IP uses the star topology and (Refer Time: 21:17) it supports data rate of up to about 1500 bytes per second. And, this is mainly used Ethernet IP protocol is mainly used with PCs, robots, input output devices, PLCs and so on and connectivity between them.

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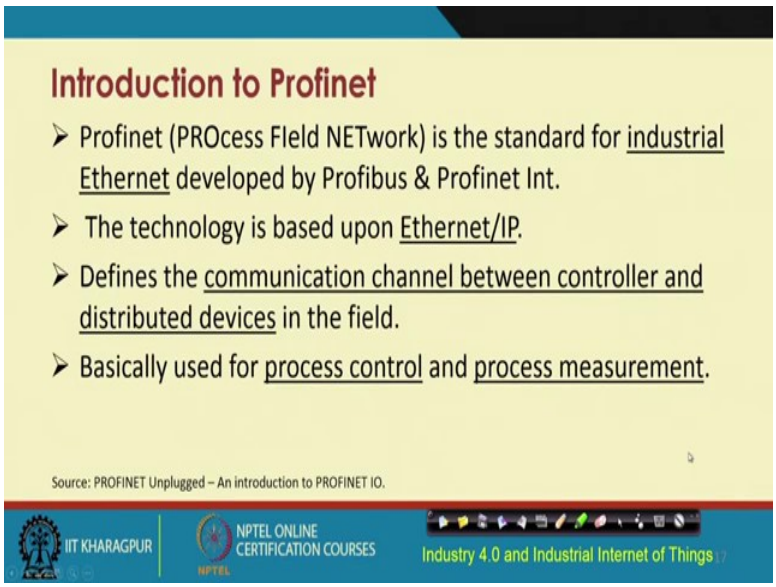

Next, comes the Profinet protocol. So, profinet is a standard for Industrial Ethernet, it was developed by the Profibus and Profinet Int organizations. It is based upon the Ethernet IP protocol, which we have discussed before. This Profinet defines the

communication channel between the controller device, and the distributed devices in the field for example, the different sensors and the controller, and so on.

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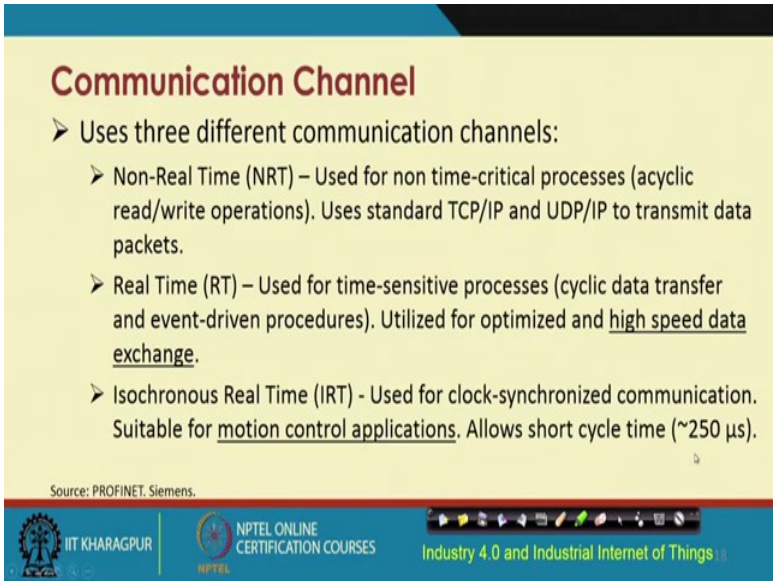

So, profinet will help in this kind of communication between the controller and the field devices. So, basically it is used for process control, process measurement and so on. So, the communication channel supports three types of communication, non-real-time communication, which is used for non-time critical processes. Second is real-time communication as the name suggests used for time sensitive processes, such as cyclic data transfer even different procedures, where basically high speed data exchange is very much required, between different, maybe different processes, different machinery use high speed data exchange requirements are there in those machinery.

So, high speed means like the machine is operating in such a high speed, that the communication will have to happen in real-time. For this real time communication channel will help in it.

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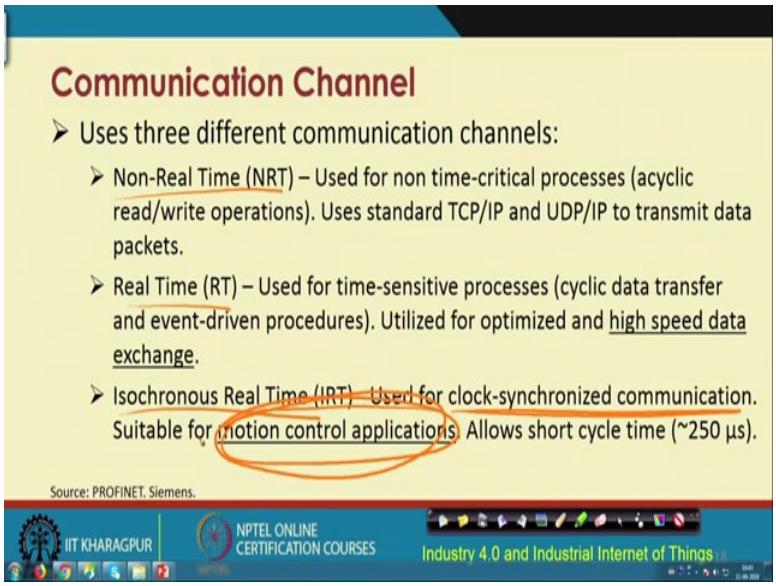

And, then we have so, we have the non-real time real-time, and then we have the isochronous real time requirements. So, this is this isochronous one are used for clocks synchronized communication scenarios, clocks synchronized communication scenarios, and are suitable for motion control applications.

So, as you can understand that clock synchronization is very important in motion control applications. And, that is why this IRT or the; I soaked isochronous real time communication requirements or these channels are important and required.

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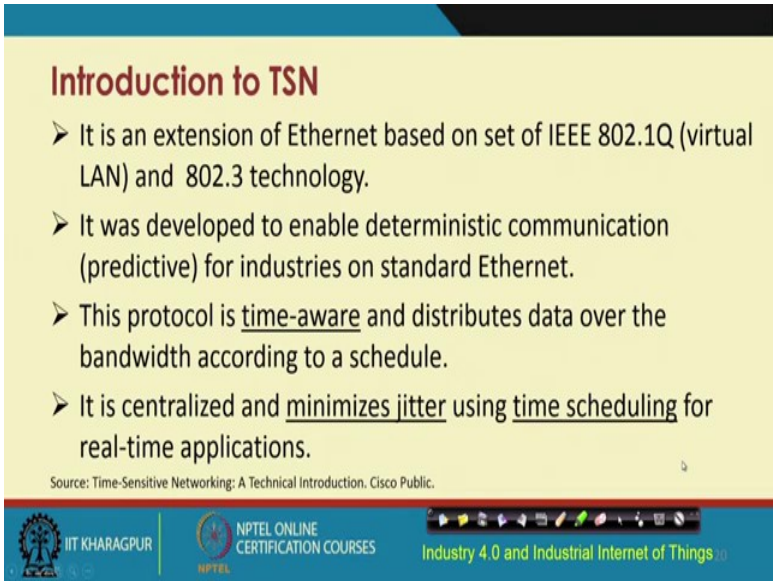

Next, we come to the TSN, which is the Time Sensitive Networking. So, here this particular protocol is based on the Ethernet protocol; rather it is an extension of the Ethernet. And, it uses it is built on top of I EEE 2.1Q 1Q, which is the standard for the virtual LANs and the 802.3, which is the standard used by Ethernet.

So, it was developed to enable deterministic communication, where the communication is going to be deterministic, predictive. So, where beforehand how much time will be required. So, superlative communications and how the process the processes are predictive; so predictive communication scenarios it is used.

So, it is sort of a protocol that is time ever, it is a time-aware protocol, time-sensitive predictive nature of communication is supported in this particular protocol. It is centralized and minimizes jitter, using time scheduling for real time application support.

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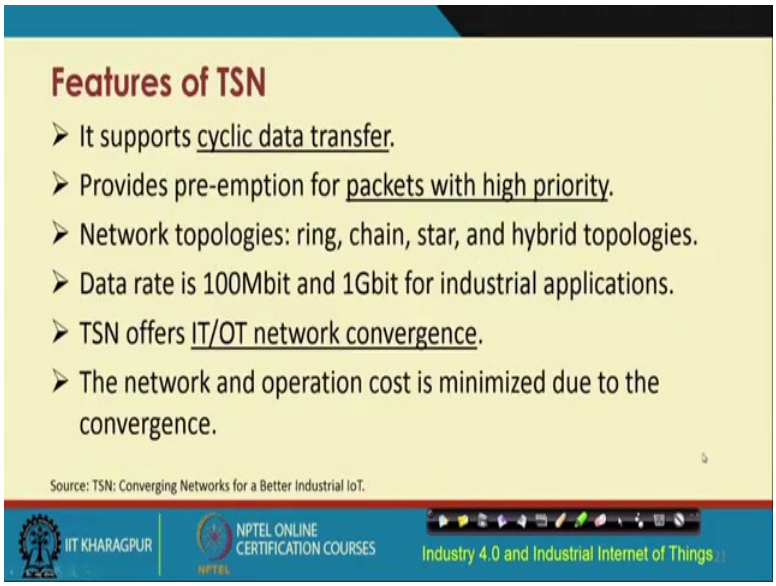

It supports cyclic data transfer provides PM cell for packets with high priority, different network topologies that are supported our ring topology, chain topology, star topology, hybrid topologies.

It supports network convergence of IT; that means the Information Technology. And, the Operational Technology IT, OT, convergence is supported by TSN.

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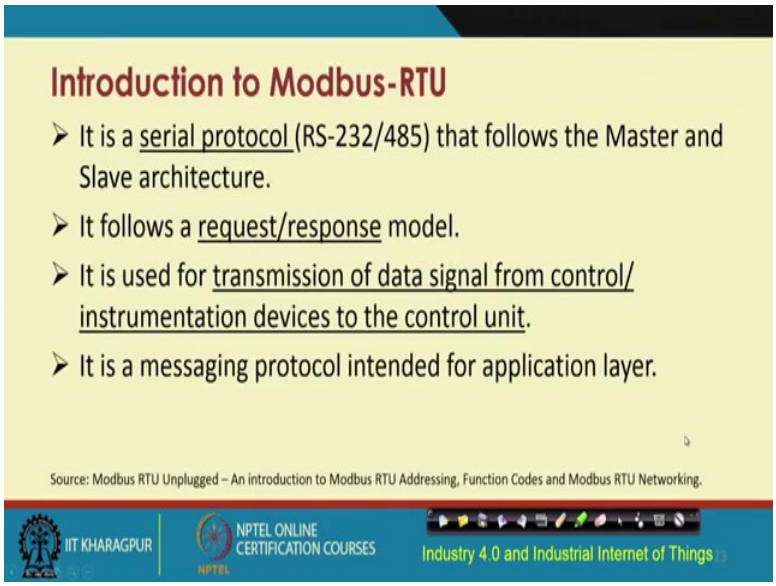

Then, comes the field bus protocol which is the Modbus RTU. This Modbus RTU protocol is a serial protocol following RS 232 and RS 484 standards. So, it provides the serial communication between the master/slave and follows a request/response model.

So, it is used for transmission of data signal from the control or instrumentation devices to the control unit.

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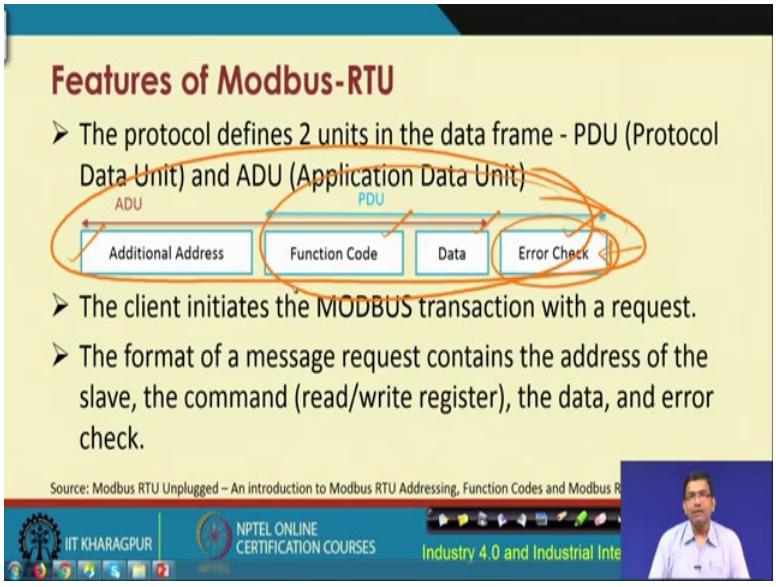

So, here is basically the overall structure of the Modbus RTU protocol data frame. So, as you can see over here, this is this PDU, this PDU consists of the function code data, and

the error checking mechanism, and this if you recall earlier in Modbus TCP this error check field was not there. So, here it is in the Modbus RTU and, this is the whole ADU the application data unit, which has the PDU plus the additional address.

So, basically in this kind of communication the client initiates the Modbus transaction with a particular request. And, the format of a message request contains the address of the slave, the read write register the data and the error check.

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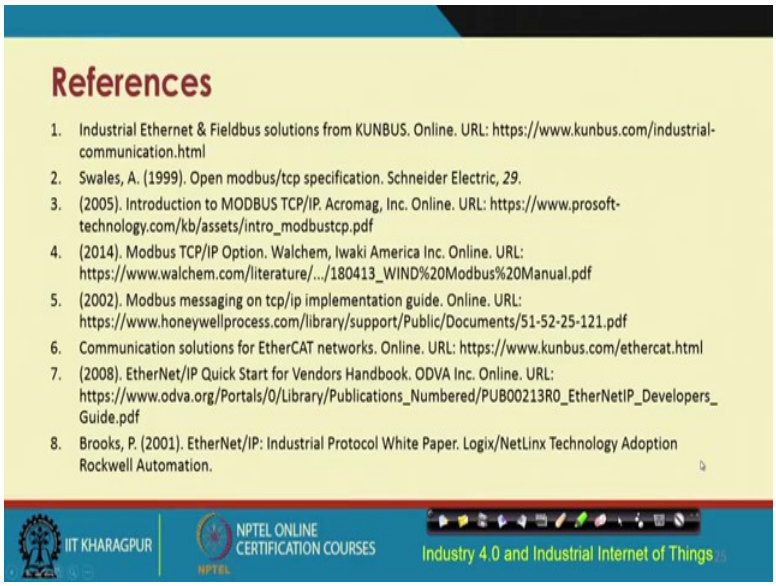

So, before we end I wanted to show you something very interesting. So, we have gone through different protocols. So, let me now give you a holistic picture of connectivity in the industrial context.

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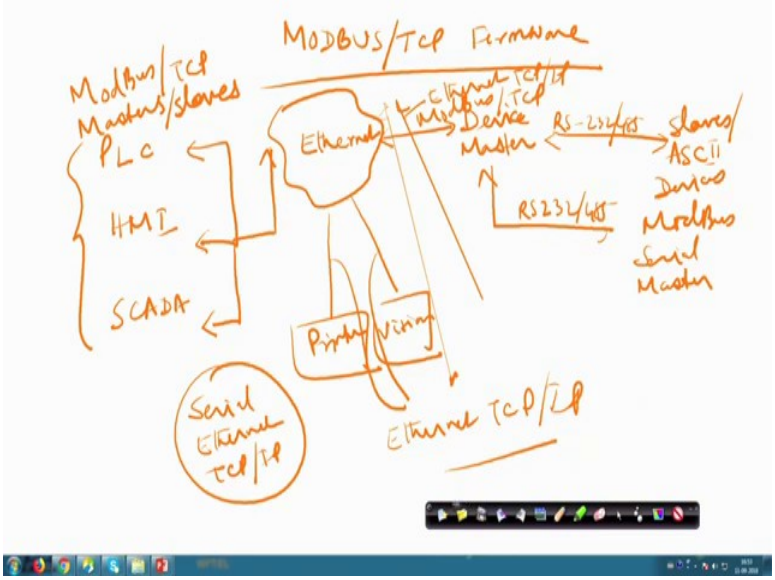

So, I am going to show you, how this Modbus; Modbus TCP firmware works. So, we have different requirements, we have the PLC devices, we have HMI, the HMI devices and SCADA. These are some of the different types of devices that are used in the industrial contexts, right, PLC, SCADA, HMI.

So, these basically would be the Modbus TCP masters or they can even act as the slaves. So, these devices are operating and they collect these different information, and this information is sent through, let us say, this particular cloud we call it as the Ethernet. It is sent through the Ethernet and then this is sent further to it can be two-way communication to the device master, to the device master. And, this is this device master if you recall this is what I was talking about earlier. And, so, we have this device master and this communication will be taking place, with the help of this Ethernet TCP/IP, and Modbus TCP.

Then on the other side this figure looks little ugly, but I am afraid that I am not able to delete these 3 lines. And, so, but this part we can use the serial communication, and we have these different devices such as the ASC II devices or, the slave devices, Modbus slave devices. And, this could be even like, Modbus serial master.

So, these two can use the RS 232/485 standard, right and this is also two-way serial communication. So, this is the overall how these different communications can happen. So, we can have different types I mean this can be extended even further you can have

these different printer devices for example, printer devices we can have vision systems connected over here vision systems, and so on.

So, anyway so, holistically we will have in a single industrial scenario industrial communication scenario, we will have serial communication, Ethernet net communication, and TCP/IP, or rather Ethernet TCP/IP connections. So, we can have different links for supporting different communication.

So, and as I said that you can extend this even further and you can have a much more comprehensive kind of communication support. And, as we can see over here this part we have all these PLCS, HMIS, SCADA. You know communicating as either masters or they can be slave typically masters, but they could be slave as well.

Here you would be having this part you could be having all these different master and this part you could be having all these different slave devices and master-slave communication, different parts, different protocols. You know so, different like this part would be Modbus TCP protocol, which will be used this part would be the RS 232 484 could be used between the device master and the slave.

So, like this you could even extend it even further and you could have different other communication, mechanisms in place. And, this part also even could be this one and this one could be Ethernet TCP, IP. So, this is how it is going to work holistically.

So, next we come to the references which you can use for getting a comprehensive overview of the different protocols and getting an in-depth understanding of these different protocols that we have discussed so far, with this we come to an end.

Thank you.