Introduction to Industry 4.0 and Industrial Internet of Things
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Lecture – 05
Introduction: IoT Networking - Part II

We, now continue our discussions from the previous lecture on IoT Networking and the different issues governing it.

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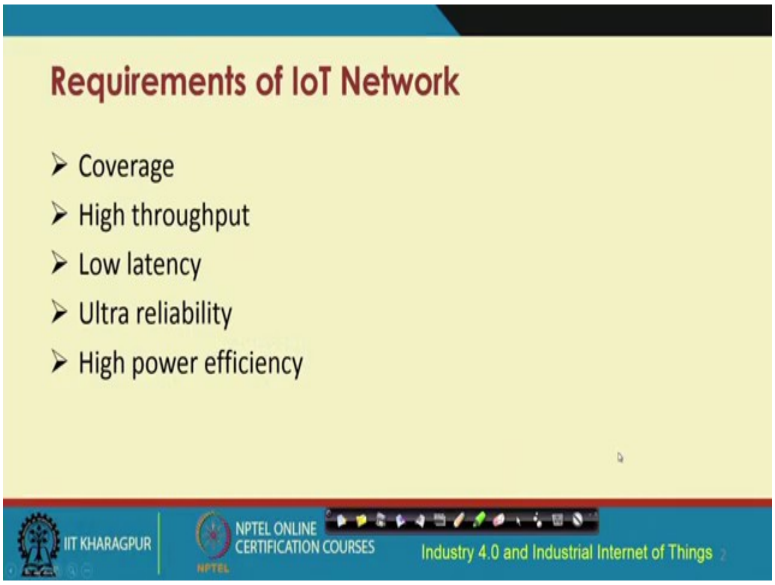

Requirements of IoT Network

- Coverage
- High throughput
- Low latency
- Ultra reliability
- High power efficiency

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The requirements of IoT networks include coverage, high throughput, low latency, ultra-reliability and high power efficiency. We need to ensure that there is adequate coverage, coverage in terms of the deployment of these sensor nodes. And, then ensure that there is sufficient coverage in terms of sensing, communication throughout the territory of interest where the IoT devices are deployed.

The second thing is throughput that the network supports. Throughput essentially talks about the data rates, high data rates ensures that through the network, typically a lossy network; you have higher throughput, higher data rates can be supported. Then, low latency is very important, you need to have an assurance that from the source to the receiver intended receiver the time that is spent is minimum. But, in most cases IoT networks would have to support real time traffic, where the timeliness of the data as we said previously in the previous lecture is very important. These packets if not received on time, then that data is not going to be useful for supporting the adequate quality of service of the network. The next one is reliability ultra-reliability in the face of lossiness, in the face of interference, noise etc. The next one is high power efficiency, we are talking about low powered nodes, low battery power, highly energy constrained environments. So, it is very essential to ensure that whatever solutions we are talking about from a networking point of view, for IoT networks, these have to be highly power-efficient.

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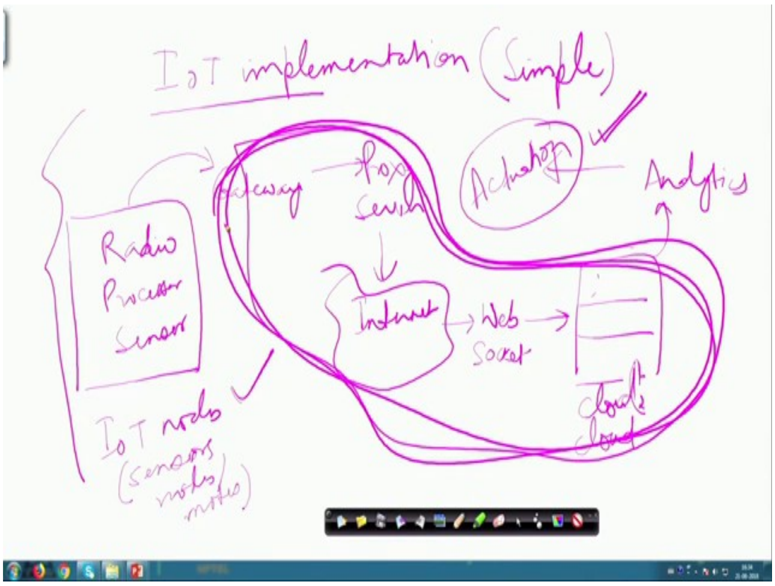

So, before we talk about any further detail, let us again talk about a sample implementation of IoT. So, this is a very simple kind of example that I will give you. Let us say, that these different IoT nodes are like different sensors. These IoT devices will have different components such as the radio interface, the processor, the sensor and few other components. These IoT devices will collect data, which will be sent through the gateway, maybe a proxy server, or through the internet. The cloud will do storage, processing etc and at the cloud there could be different types of analytics; that could be executed. Based on the analytics, there could be some actuation.

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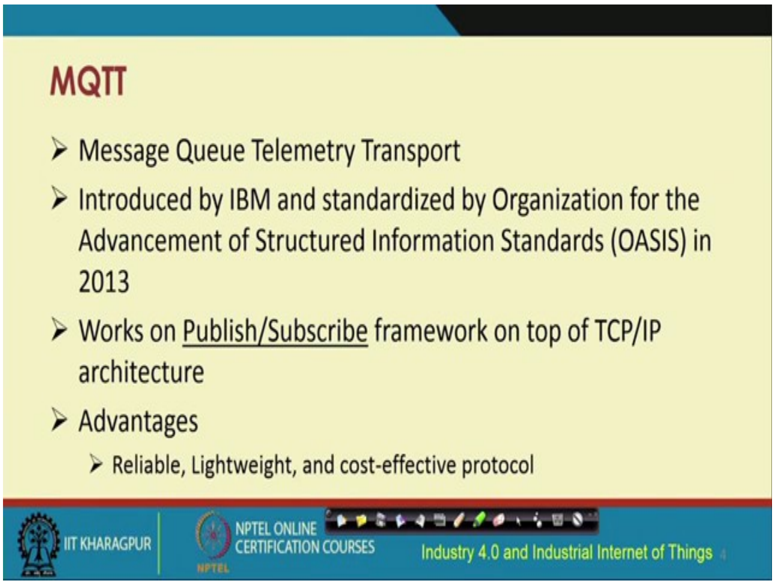

MQTT

- Message Queue Telemetry Transport
- Introduced by IBM and standardized by Organization for the Advancement of Structured Information Standards (OASIS) in 2013
- Works on Publish/Subscribe framework on top of TCP/IP architecture
- Advantages
  - Reliable, Lightweight, and cost-effective protocol

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Let us talk about some of the solutions. One of which is the MQTT protocol. MQTT- the full form is Message Queue Telemetry Transport which was introduced by IBM and standardized by OASIS in 2013. MQTT is based on the concept of Publish/Subscribe. This is the key thing over here in MQTT and this works on top of the existing TCP/IP, the way MQTT has been designed to work right.

So, Publish/Subscribe, but this you know the way MQTT works is basically to work on top of TCP/IP, but you know you could have a different variant of MQTT, where TCP/IP framework may not be used right; you could come up with something else. So, the advantages of MQTT is that a Publish/Subscribe framework has been proposed, which is very suitable for IoT, because IoT devices typically would be publishing data, sensing data, publishing the data. And, you need to take help of the subscribers and the clients, who will try to pull the data out of the published, data that is buffered somewhere in some agent.

So, this kind of architecture is suitable for IoT and it has the advantage of being reliable, lightweight, and cost effective.

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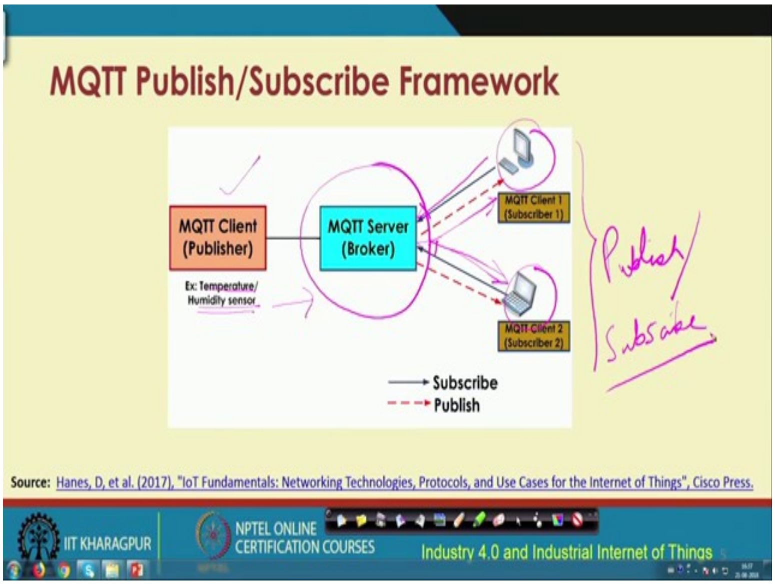

MQTT Publish/Subscribe Framework

MQTT Client (Publisher)
Ex: Temperature/ Humidity sensor
MQTT Server (Broker)
MQTT Client 1 (Subscriber 1)
MQTT Client 2 (Subscriber 2)
Subscribe
Publish
Publish/ Subscribe
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Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

This is an example of how the MQTT publish/subscribe framework works. So, look at this particular picture. We have the MQTT client, which is the publisher on one hand. So, this publisher will publish different sensed data such as temperature, humidity etc. And, this data that will be published in the MQTT broker. MQTT broker, which is a server stores this data.

Now, different clients would subscribe to, depending on their interests, and based on the subscription this MQTT broker, the server is going to respond with the published information. This is based on publish/subscribe model and this is how this MQTT protocol works.

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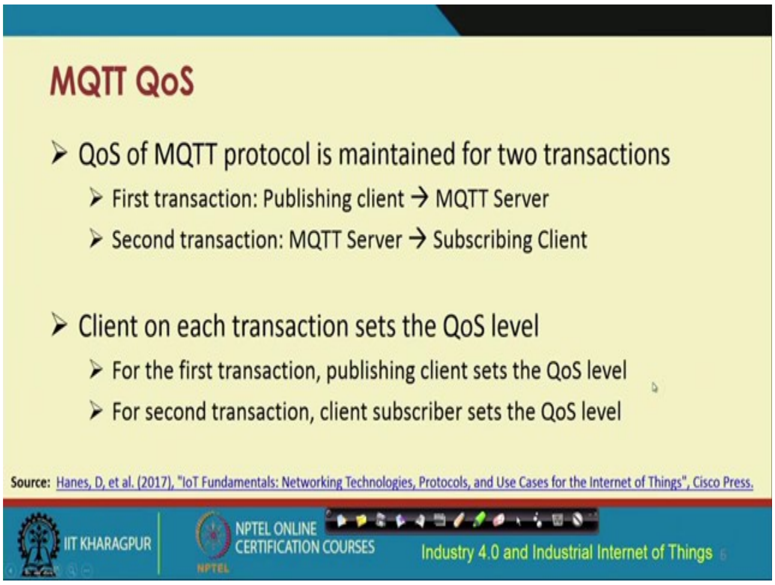

MQTT QoS

- QoS of MQTT protocol is maintained for two transactions
  - First transaction: Publishing client → MQTT Server
  - Second transaction: MQTT Server → Subscribing Client
- Client on each transaction sets the QoS level
  - For the first transaction, publishing client sets the QoS level
  - For second transaction, client subscriber sets the QoS level

Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

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Now, let us look at few more concepts before we talk about few other things. In MQTT we are talking about different components.

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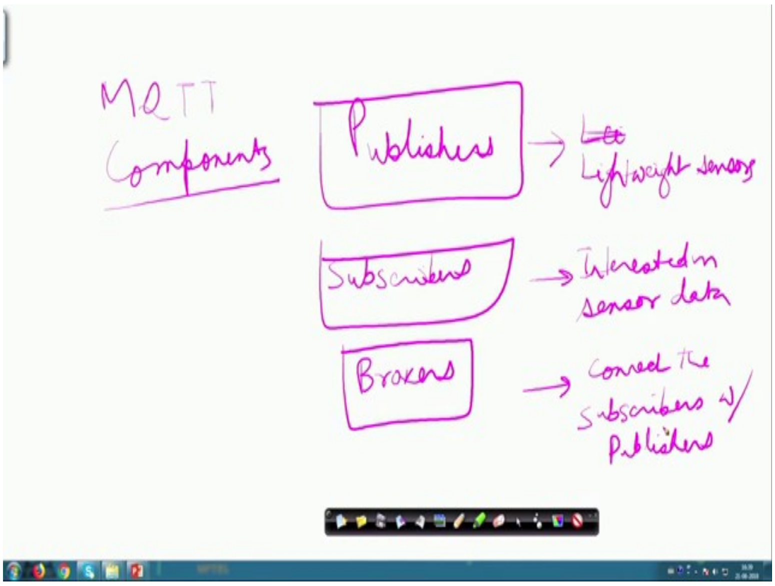
MQTT Components
Publishers → ~~Le~~ Lightweight sensors
Subscribers → Interested in sensor data
Brokers → Connect the subscribers w/ Publishers

MQTT components: what are these components? We are talking about publishers, subscribers, and brokers. These publishers are lightweight sensors.

The subscribers are the applications, which are interested in sensor data. These brokers would help to connect the subscribers with the publishers. So, this is how it is going to work. Now, let us look at in this kind of backdrop what are the different models for this connectivity.

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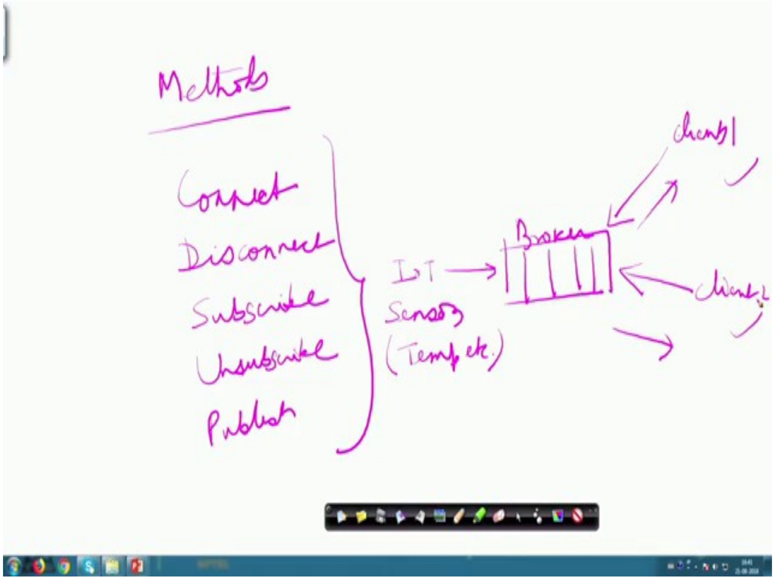

MQTT provides different methods that are used to connect, disconnect, subscribe, unsubscribe, and publish.

We have some kind of this publisher, which are like different IoT sensors like temperature sensor. These will send the data to the broker which has this queue, where the data will be queued at the broker. And, then based on the subscription from clients, the data are going to be sent.

These could be laptops, PDAs, mobile phones etc. We need to talk about QoS, because without QoS we cannot think of IoT. Quality of service (QoS) is very important. So, for QoS of MQTT protocol, there are different transactions that will have to be taken into consideration. The first transaction is basically between the publishing client and the MQTT server. The second transaction is between the MQTT server and the subscribing client.

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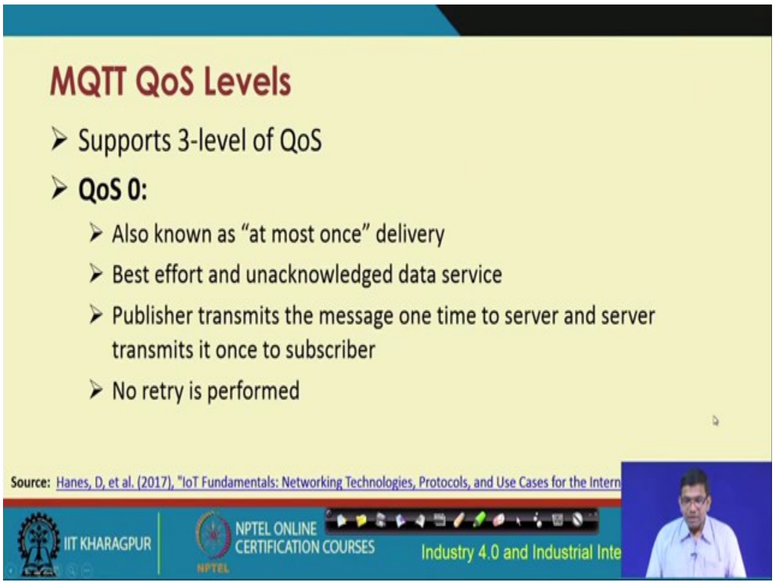

MQTT QoS Levels

- Supports 3-level of QoS
- **QoS 0:**
  - Also known as "at most once" delivery
  - Best effort and unacknowledged data service
  - Publisher transmits the message one time to server and server transmits it once to subscriber
  - No retry is performed

Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Intern

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There are different levels of QoS; the first one is the QoS 0 which is about ensuring at most once delivery. So, this is kind of a best effort and unacknowledged data service. And, here the publisher transmits the message one time to the server and the server transmits it one time to the subscriber. There is basically no scope for retry.

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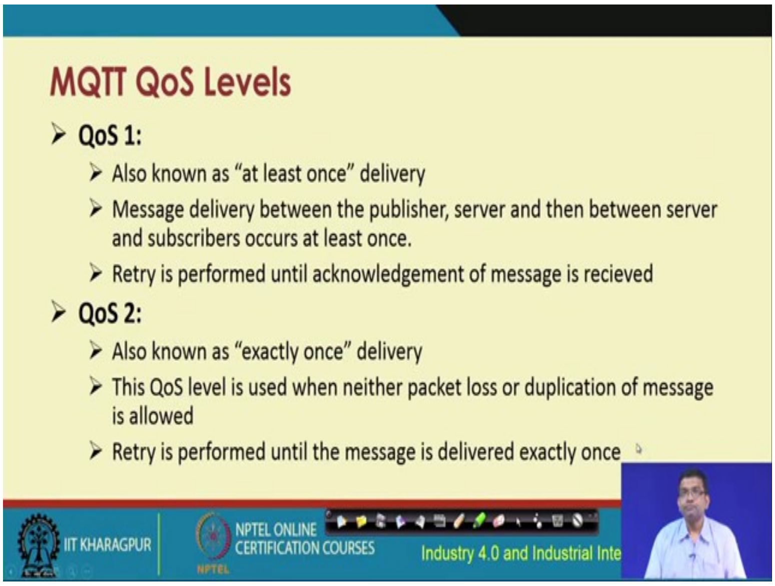

MQTT QoS Levels

- **QoS 1:**
  - Also known as "at least once" delivery
  - Message delivery between the publisher, server and then between server and subscribers occurs at least once.
  - Retry is performed until acknowledgement of message is recieved
- **QoS 2:**
  - Also known as "exactly once" delivery
  - This QoS level is used when neither packet loss or duplication of message is allowed
  - Retry is performed until the message is delivered exactly once

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QoS 1: on the other hand, talks about at least once delivery, where retry is performed until the acknowledgement of the message is received. QoS 2 is further different; it is about exactly once delivery and ensuring that the retry is performed until the message is delivered exactly once. So, this is how this MQTT protocol works.

Let us now look at the CoAP protocol. CoAP is kind of an application layered protocol. It is kind of session protocol. CoAP is a protocol, which helps ensure running different APIs, different applications in IoT.

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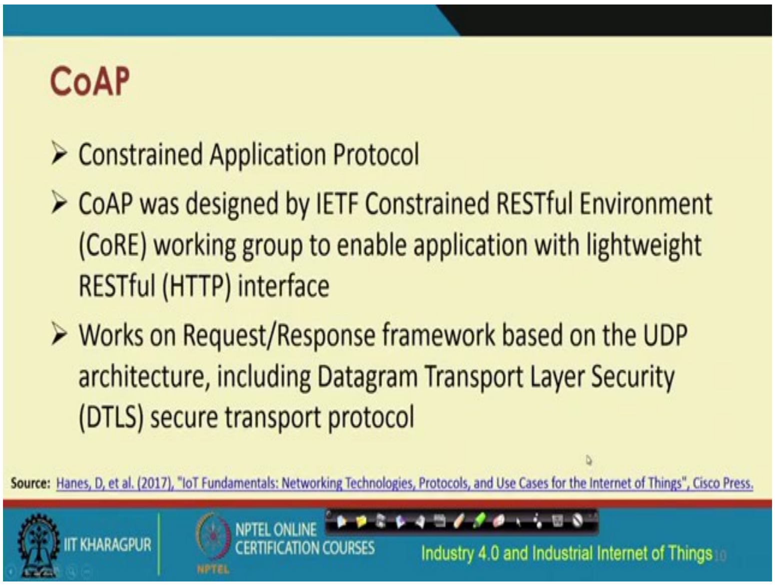

CoAP

- Constrained Application Protocol
- CoAP was designed by IETF Constrained RESTful Environment (CoRE) working group to enable application with lightweight RESTful (HTTP) interface
- Works on Request/Response framework based on the UDP architecture, including Datagram Transport Layer Security (DTLS) secure transport protocol

Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

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The full form of CoAP is Constrained Application Protocol, which was designed by IETF. The full form of core is Constrained RESTful Environment. So, this particular working group has come up with this core to enable applications with lightweight interface to run in place of HTTP.

It is a restful service, which is equivalent of the HTTP. So, instead of HTTP, you run CORE. Core basically works on top of UDP, in the transport layer. This is a protocol, which is called the Datagram Transport Layer Security Protocol; for securing the transport layer.

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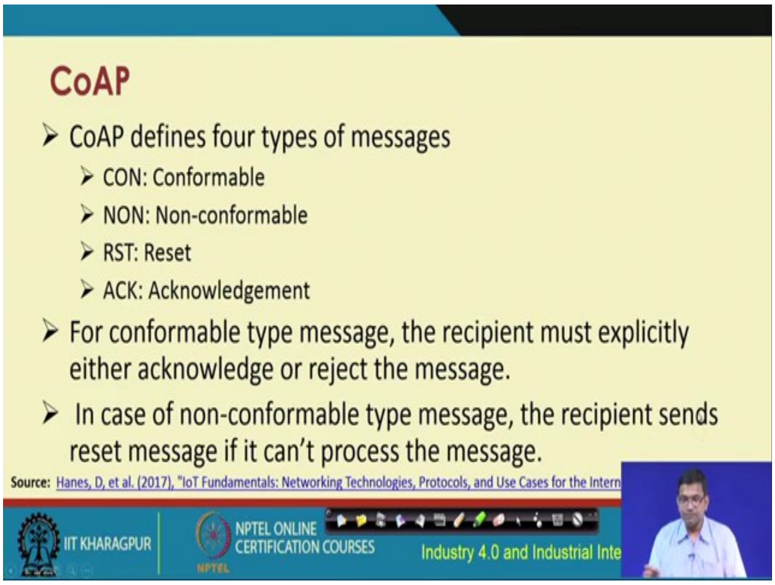

CoAP

- CoAP defines four types of messages
  - CON: Conformable
  - NON: Non-conformable
  - RST: Reset
  - ACK: Acknowledgement
- For conformable type message, the recipient must explicitly either acknowledge or reject the message.
- In case of non-conformable type message, the recipient sends reset message if it can't process the message.

Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Intern

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CoAP defines four types of messages: conformable message, non-conformable message, RST is the reset message, acknowledgement. For confirmable type message, the recipient must exactly explicitly either acknowledge or reject the message. So, some confirmation has to be received. And, in case of non-confirmable type message, the recipient sends the reset message, if it cannot process the message.

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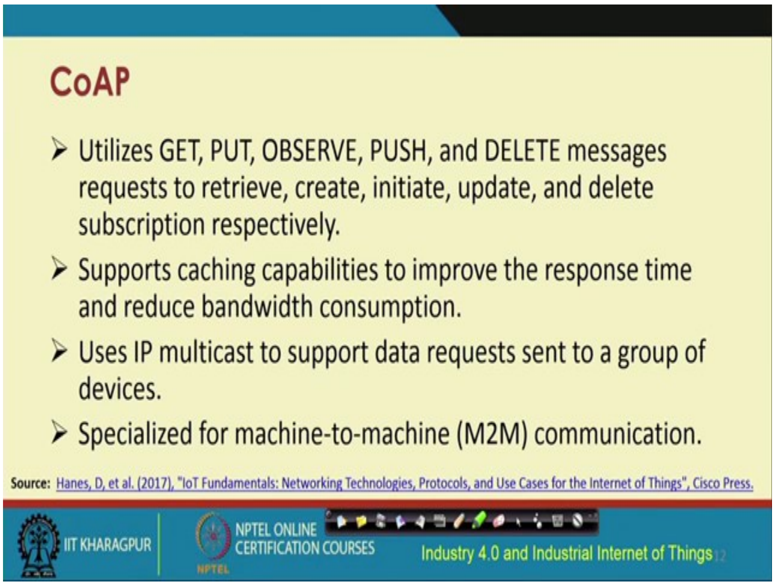

CoAP

- Utilizes GET, PUT, OBSERVE, PUSH, and DELETE messages requests to retrieve, create, initiate, update, and delete subscription respectively.
- Supports caching capabilities to improve the response time and reduce bandwidth consumption.
- Uses IP multicast to support data requests sent to a group of devices.
- Specialized for machine-to-machine (M2M) communication.

Source: Hanes, D, et al. (2017), "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", Cisco Press.

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So, it utilizes different message messages, such as GET, PUT, OBSERVE, PUSH, DELETE etc like the MQTT. Similarly, all these different message types like GET, PUT, OBSERVE, PUSH and DELETE, together are used in order to perform different-different things such as IP multicast, in M2M communication for IoT.

There are lot of things available, if you have further interest to dig into this particular protocol. But, from an expository point of view I think this kind of information whatever I have provided to you is sufficient.

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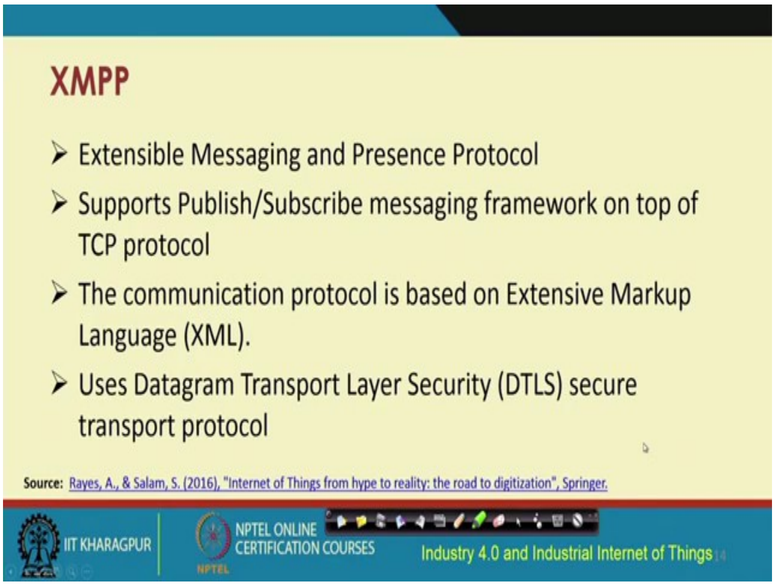

XMPP

- Extensible Messaging and Presence Protocol
- Supports Publish/Subscribe messaging framework on top of TCP protocol
- The communication protocol is based on Extensive Markup Language (XML).
- Uses Datagram Transport Layer Security (DTLS) secure transport protocol

Source: Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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From another point of view, there is another protocol which is called the XMPP protocol. The full form of which is Extensible Messaging and Presence Protocol, which is again based on publish, subscribe, model that we talked about in the context MQTT. The communication protocol, XMPP is based on XML, and it uses DTLS secure transport layer at the bottom in the transport layer for transport layer security.

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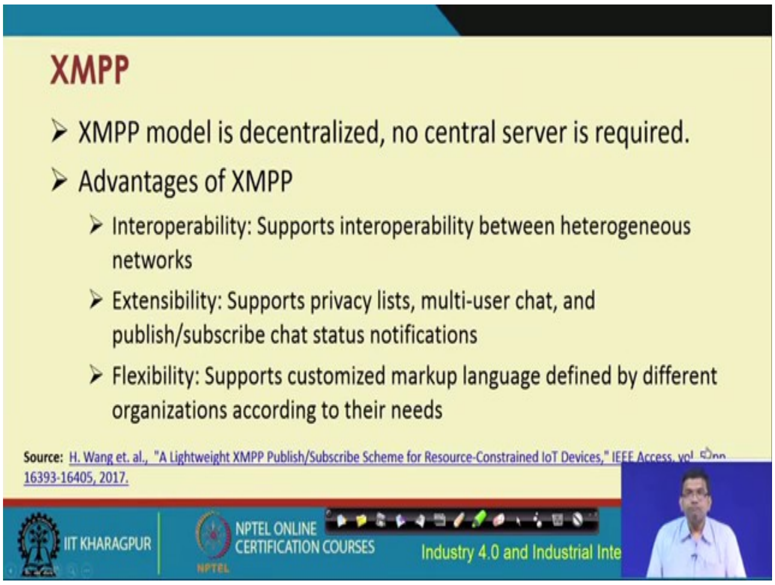

XMPP

- XMPP model is decentralized, no central server is required.
- Advantages of XMPP
  - Interoperability: Supports interoperability between heterogeneous networks
  - Extensibility: Supports privacy lists, multi-user chat, and publish/subscribe chat status notifications
  - Flexibility: Supports customized markup language defined by different organizations according to their needs

Source: H. Wang et. al., "A Lightweight XMPP Publish/Subscribe Scheme for Resource-Constrained IoT Devices," IEEE Access, vol. 5, pp. 16393-16405, 2017.

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This model is decentralized; that means, there is no requirement for having a centralized server. And, it has manifold advantages such as it supports interoperability between heterogeneous networks, heterogeneous devices, and heterogeneous agents. It supports extensibility; that means, supporting privacy lists, multi-user chat, publish/subscribe chat, status notifications etc.

And, it also talks about the advantage of having flexibility of supporting customized markup language defined by different organizations according to their needs, because it is based on XML. Some of these are very high level. Another one at a very high level is the AMQP protocol.

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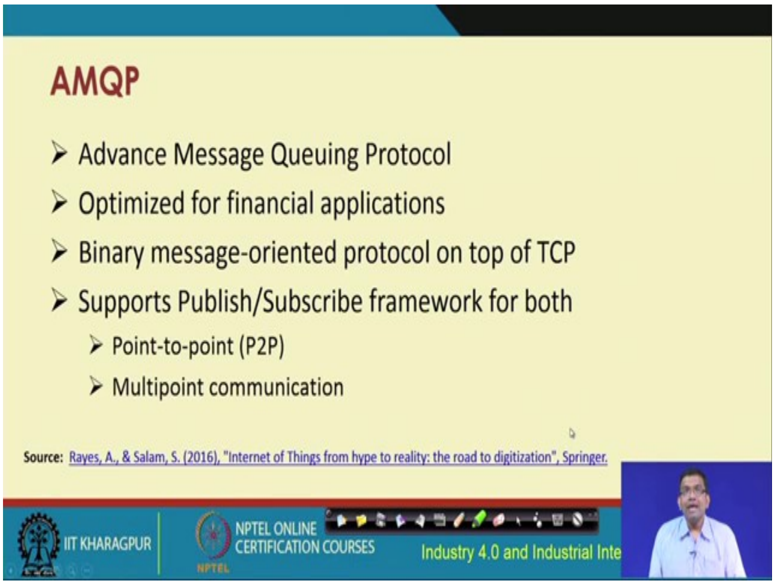

AMQP

- Advance Message Queuing Protocol
- Optimized for financial applications
- Binary message-oriented protocol on top of TCP
- Supports Publish/Subscribe framework for both
  - Point-to-point (P2P)
  - Multipoint communication

Source: Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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AMQP-full form is Advanced Message Queuing Protocol. This is also based on the publish/subscribe model like MQTT and XMPP. And, it supports two types of framework: one is the point to point communication and the other one is multi-point communication and is typically used for application such as financial applications, and digital finance. It uses token based mechanism for flow control, which ensures that there is no buffer overflow at the receiving end. So, flow control is all about use of a token-based mechanism.

The details of which you know I am not going through, at a very high level this is the kind of feature that is there with AMQP to ensure that there is minimal buffer overflow at the receiving end and the flow control is preserved. The message delivery guarantees are of different types using AMQP: one is at least once; that means, offering guarantees in terms of message delivery. But, these guarantees may do so, multiple times at most once which is about each ensuring that each message is delivered once or never. And, exactly once which talks about ensuring no message gets dropped and is delivered only once.

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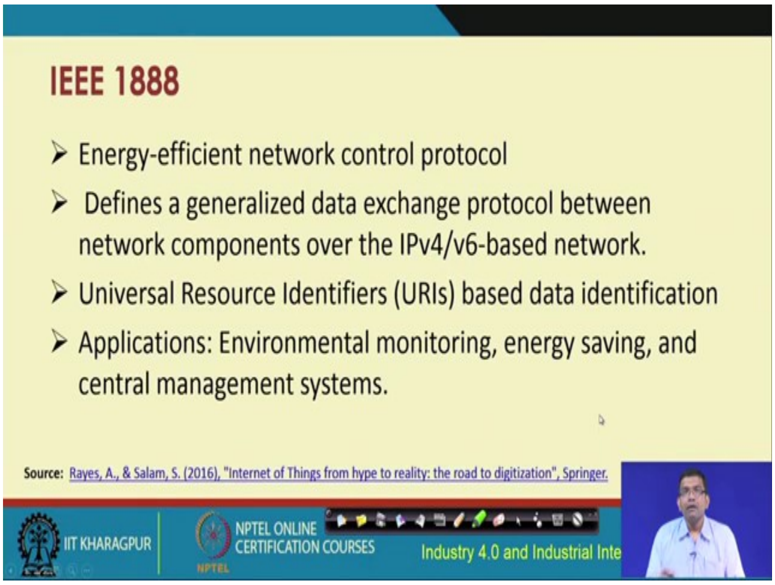

IEEE 1888

- Energy-efficient network control protocol
- Defines a generalized data exchange protocol between network components over the IPv4/v6-based network.
- Universal Resource Identifiers (URIs) based data identification
- Applications: Environmental monitoring, energy saving, and central management systems.

Source: Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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IEEE 1888-this one is an energy-efficient network control protocol, which defines a generalized data exchange protocol between the network components over IPv4 or IPv6. It talks about the use of resource universal resource identifiers and supports different applications for environmental monitoring, energy saving, central management systems, and so on.

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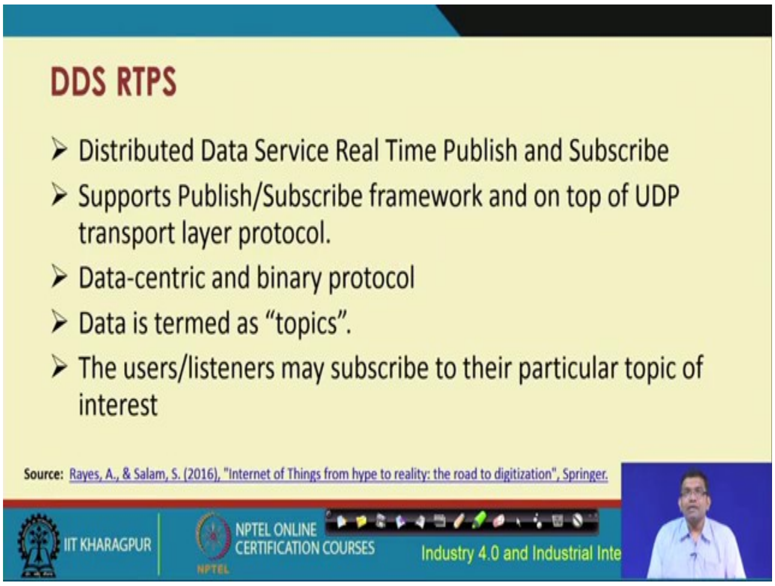

DDS RTPS

- Distributed Data Service Real Time Publish and Subscribe
- Supports Publish/Subscribe framework and on top of UDP transport layer protocol.
- Data-centric and binary protocol
- Data is termed as "topics".
- The users/listeners may subscribe to their particular topic of interest

Source: Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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The full form of this thing is Distributed Data Service Real Time Publish and Subscribe; again we are talking about publish/subscribe. Because of its inherent characteristics, it is very much attractive for use in IoT networks, this support Publish/Subscribe framework on top of UDP transport layer protocol. So, it is a data centric binary protocol and this data in this context are termed as “topics”. There are topics means like there are users, which subscribe to a particular topic of interest and the listeners listen to these.

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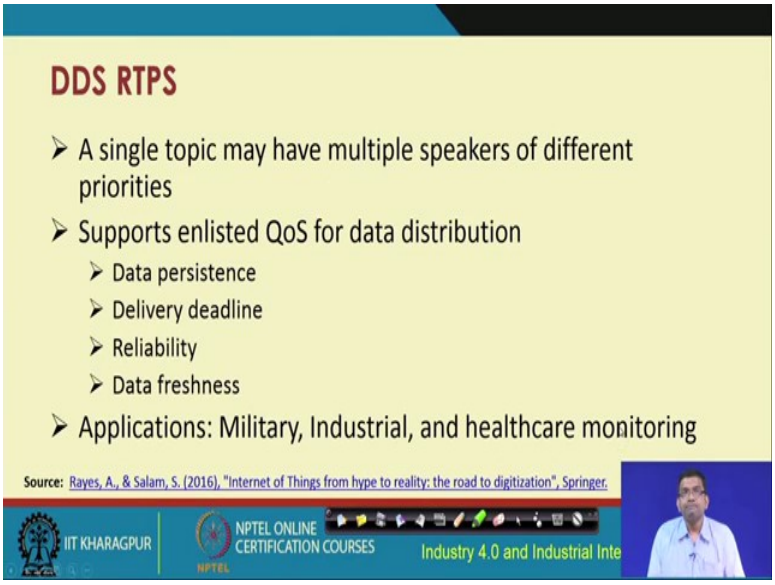

DDS RTPS

- A single topic may have multiple speakers of different priorities
- Supports enlisted QoS for data distribution
  - Data persistence
  - Delivery deadline
  - Reliability
  - Data freshness
- Applications: Military, Industrial, and healthcare monitoring

Source: Rayes, A., & Salam, S. (2016), "Internet of Things from hype to reality: the road to digitization", Springer.

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There is a single topic that may have multiple speakers of different priorities and this supports enlisted QoS for data distribution in terms of data persistence, maintaining, ensuring, delivery deadline, reliability, freshness of data and in a different protocol, earlier in the context of IoT networks. The application such as military, industrial and healthcare monitoring are the ones that find this particular protocol to be of use.

With this we come to an end of both the lectures on IoT networks. All these protocols that we have talked about are very much attractive for use with any kind of IoT applications and IoT and industry 4.0 applications these protocols are very attractive.

One of the very key requirements is connected behavior. And for this, all these protocols these publish, subscribe based protocols that we have talked about in this lecture and the previous one these will help you to build this kind of connected system, connected network, and the behaviors content within it.

With this we come to an end of this lecture.

Thank you.