Introduction to Internet of Things
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Lecture – 43
Sensor Cloud – II

So, this is the second part of the lecture on Sensor cloud.

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In the first part, we have understood what is sensor cloud, the advantages of sensor cloud over regular sensor networks and how sensor cloud can help in real life applications. So, we are now going to look at some of the issues in the building of sensor cloud. So, you know just as a recap of what we discussed before in the first part, when we talk about sensor cloud, it is about integration of 2 technologies. One is sensor networks and cloud trying to take advantage of the inherent capabilities of dissemination of sensor networks. So, sensor networks are very much good in data acquisition and thereafter, dissemination of this information and cloud basically is good in terms of information storage, data storage.

So, trying to harness the advantages of both is what we try to do in sensor cloud. So, how is it done? It is done with the help of the virtualization capabilities. So, in sensor cloud, we are offering sensors as a service through the technology of virtualization by which these different sensors are virtualized and these visualized instances of the sensors are made available to the different users of sensor cloud. In sensor cloud architecture, typically, there are different types of users. One is the end users themselves, the second is the sensor owners and the third is the sensor cloud service provider.

So, like this could be few other you know different types of actors or the stake holders as well, but typically we are talking about these stakeholders. So, what happens is the sensor owner is the one who basically makes these you know who basically procures and makes these sensors available? They own the sensors, they have purchased the sensors and they have made the sensors available for you know for use sensor. Cloud service provider is mostly concerned about the supervision, the management of the sensor services. So, they basically in conjunction with the sensor owners, they deploy the sensor nodes in the region of interest, in the area of interest like in the city or several cities. They will be deploying these different sensors at different points and then, the sensor data are going to be made available to the different users.

So, though the main advantage of sensor cloud is through a virtualized platform, through the technology of visualization, the different owners are able to access these different sensor devices for performing their own sensing tasks. So, what we have is basically sensors as a service or even we can think of as the concept of sensing as a service. So, sensors as a service means that the sensors to whoever require you know who ever requires the sensors, they would be able to get access to the services in the same way as infrastructure is made available through a virtualized platform in cloud to the end users. The similar kind of analogous thing is done over here. Instead of infrastructure, we have the sensors and the sensors are made available to the users.

So, this is the whole idea of sensor cloud and in this particular back drop, we have to understand that if we have to develop this kind of infrastructure of sensor cloud, how can we do it. So, let us look at some of these different issues.

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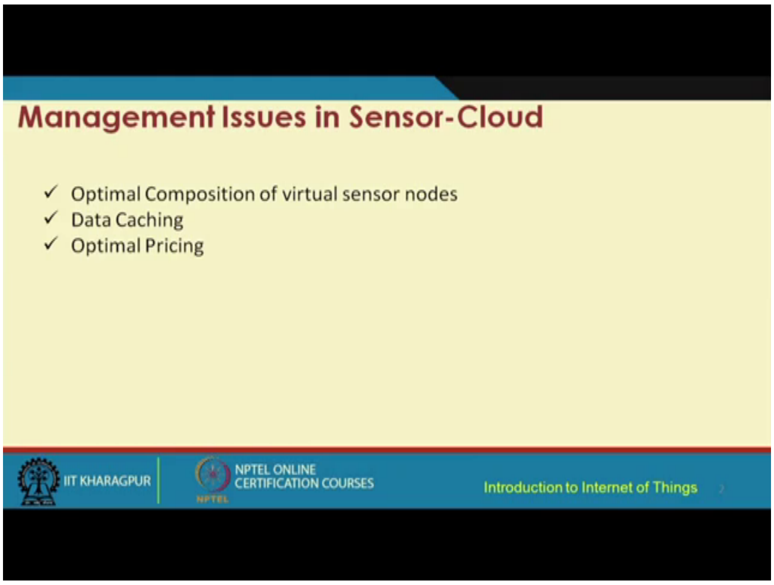

So, first one is the management issue in sensor cloud. So, we have different types of concerns. What is the optimal composition of the virtual sensor nodes and what is the optimal composition of the virtual sensor nodes. So, what it means I will talk about it shortly. The second one is the data caching you know. So, what happens is for certain applications, it is not required to always prime the sensors physically. At the physical level, you know the data do not change too much. So, you know data can be cached and can be made accessible to the end users, to the different users. If the data is not very stale, you know it can be made available to the end users as per the need and then, is the optimal pricing. So, pricing is very much important because it is a service offering sensor. Cloud service provider is offering these different services. So, service offerings are there, so how the price is going to be like, this is the optimal pricing.

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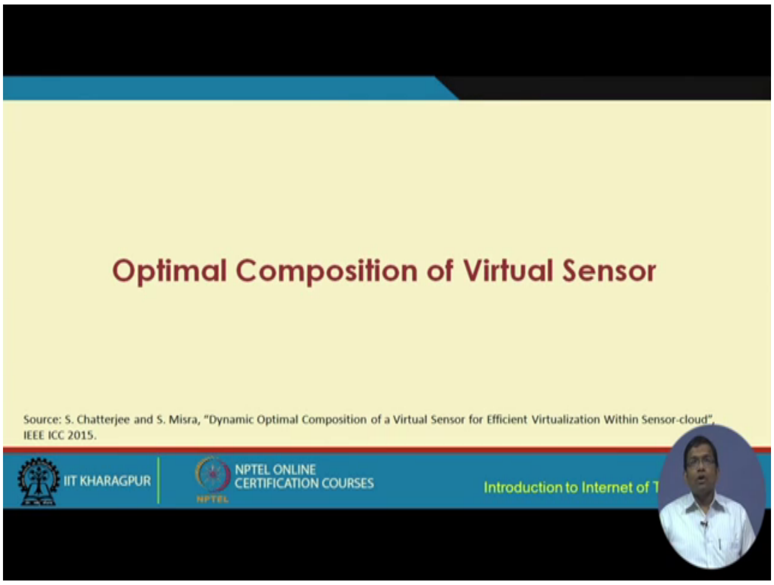

So, first we will talk about the optimal composition of virtual sensors. So, this particular you know; if you are interested to look further into the details of this, this is a paper along with one of my students. We have you know this was published in ICC, International Conference on Communications in 2015. So, optimal composition of sensor virtual sensors.

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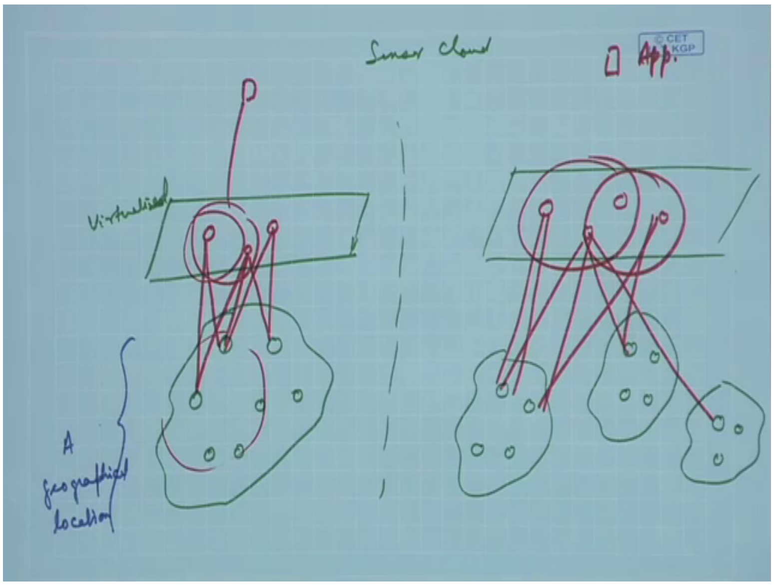

So, let us consider 2 different scenarios like this of sensor cloud. In one scenario, let us say we have these different sensors that are deployed and these sensors finally have to be virtualized, right. So, how many virtual instances are we going to create and what are these instances. It is not going to be like you know one physical sensor to one virtual sensor, it is not like one to one mapping between these physical sensors and virtual sensors. So, we could have these are like few virtual sensors that are created and corresponding to this one. We have this physical sensor, we have this virtual instance, we could even be having something like this or even we could have something like this.

So, this kind of mapping is possible anyway. So, keeping apart that particular issue, you know which sensors, which physical sensors or corresponding to which physical sensors which virtual sensors are going to be or how these virtual sensors are going to be grouped along among themselves for a particular application on top. So, let us say how we are going to group them to serve a particular application on top. So, that is one issue and here we are considering that these sensors are physically located in a particular geographical location.

So, all these sensors are in one geographical location. Now, it might happen that in real scenarios, it might happen that we have different geographical locations and in these different geographical locations, we have first of all different sensors and the same thing has to be done over here in virtualization and the composition of these virtual sensors. So, what is going to happen here, again we are going to have few of these. So, this mapping has to be done and you know this particular sense in a virtual instance might be mapped with 2 different physical sensors in 2 different geographical area or it could even be something like these or these and these and something like that.

So, 2 things have to be taken here of a particular virtual instance corresponds to which physical sensors in a particular geographical location or across different geographical locations, number one and number 2 is how do you group these different virtual sensors together in order to serve a particular application. So, this is the whole problem, a very fundamental problem to do with the deployment of sensor cloud. So, optimal composition of virtual sensors, the detail paper I set is available over here.

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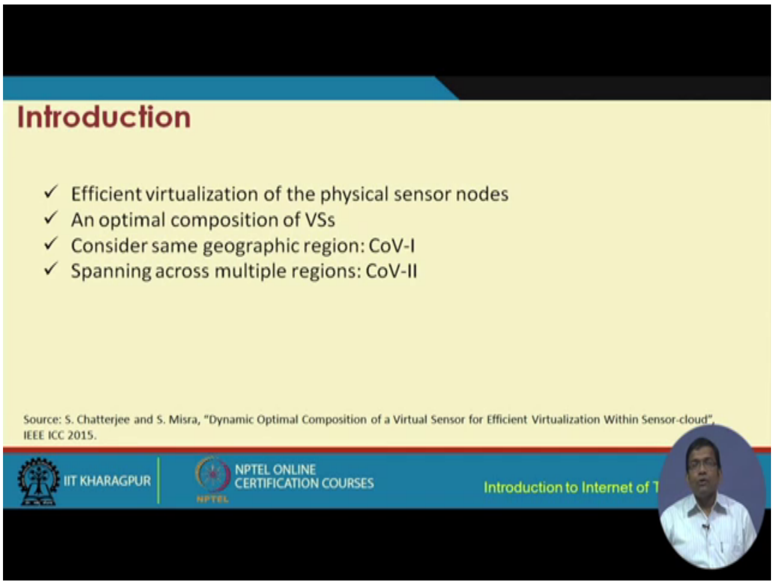

So, efficient virtualization of the physical sensor nodes is one problem. Then, how do you optimally compose these virtual sensors, how do you put them together, how do you group them together. So, for this again if all these sensors are located in the same geographic region, you have one kind of scheme and if it is spanning across multiple regions, you have a different scheme.

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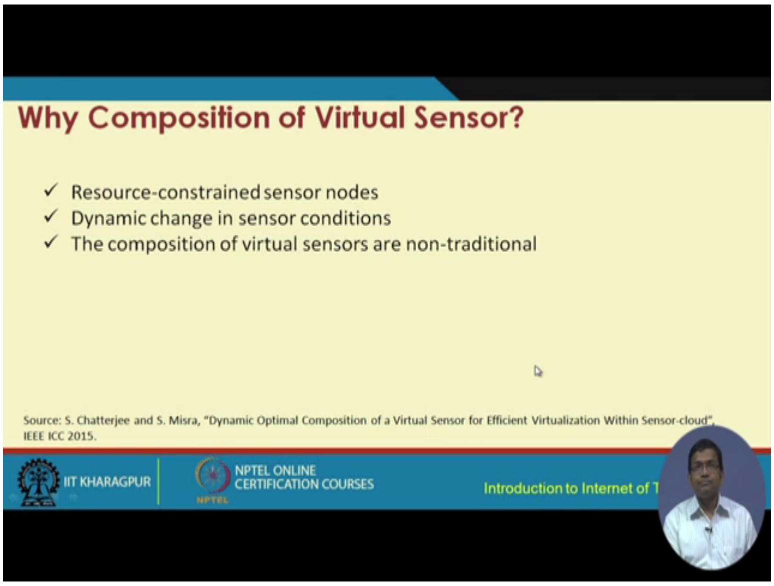

So, why composition of the virtual sensors? It is because the sensors are inherently resource constraint, energy constraint, communication constraint, computation constraint and so on. Dynamic change in sensor conditions also exist to the sensors. We are changing dynamically, not only their duty cycle, the energy resources etcetera. Their status they change dynamically and not only that, but also the physical conditions around them also change. The sensor conditions consequently will also change. Additionally it might so happen that some sensors, they are you know due to some hardware or software failure, they fail operate and that is why they do not you know at one instance of time they are operating, but at the very next instance they may not be operating.

So, we have all these different types of changes that are possible in these kind of networks. The composition of the virtual sensors are non-traditional you know. So, you know if we talk about traditionally, what is going to happen let us say we have this infrastructure as a service software as a service you know each of these. So, let us see infrastructure as a service or like software as a service. So, what they are dealing with is just one kind of virtualization, virtualization of only one type whether if the virtualization of software virtualization of infrastructure and so on, but over here we have a different scenario. Here we are talking about virtualization of different things. Different types has to be virtualized, so it is a bit different over here.

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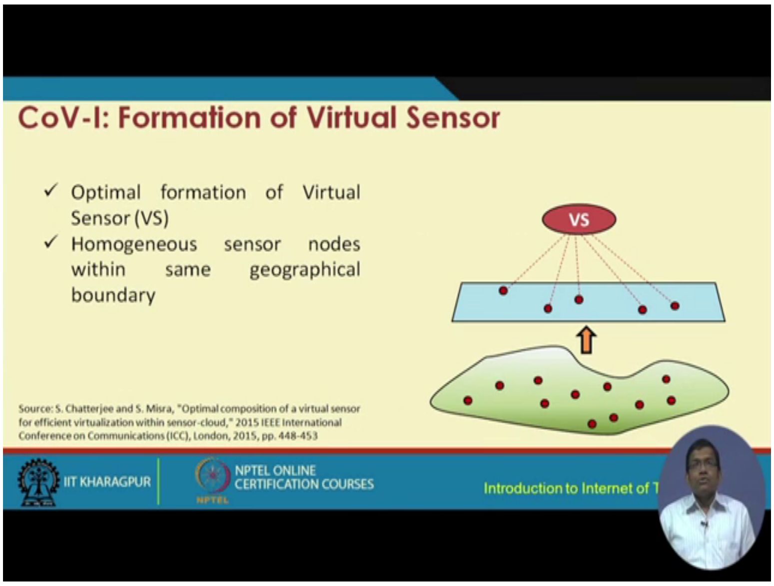

So, the formation of virtual sensors as I tell you before, if all these different sensors are located or collocated, not only collocated, but also may be in the same geographic location, they could be virtualized and these virtual composition, virtual sensor could be formed out of a subset of the physical sensors in this particular manner and in this particular scenario, it is considered that for optimal composition. We at the physical level, we are homogenous sensor nodes. The sensor nodes, they all have their own you know different specifications. Not different specifications, but the same specification. They all have their own same specification and you know you group them together in order to form the virtual sensor node.

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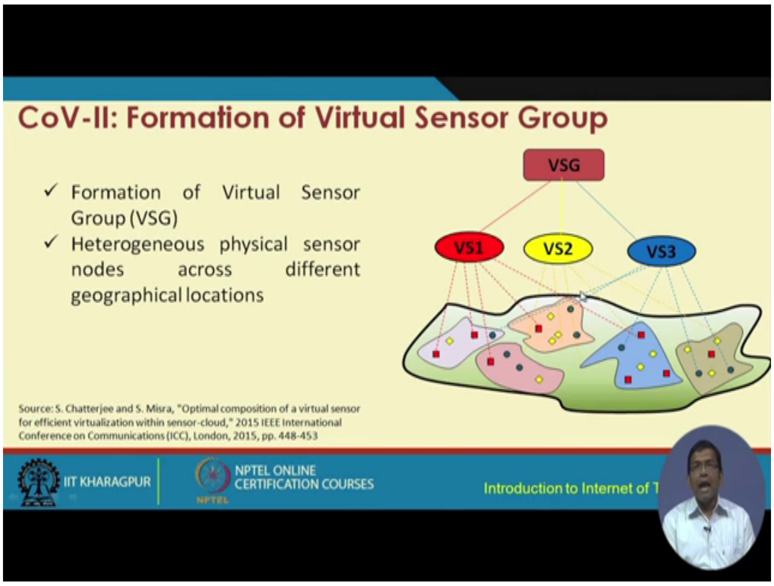

In this particular scenario, we have the virtual sensor groups, different locations, geographical locations having different sensors and as you can see over here through these different labels, they have not labels, but you know we have these different colored sensors denoting different types of sensors in specification in types. Types means; you know temperature sensor, humidity sensor, these are different types.

So, you know temperature sensor, you know pressure sensor, camera sensor, these are different types of sensors. So, you know in this particular formulation, they have considered, we have considered that not only that the sensors are geographically distributed, they are geographical separated from each other, but you know they can be composed, they are heterogeneous and they can be composed in this particular fashion. So, you can have a virtual sensor which is comprised of or it is mapped to the physical sensors in one geographical location and some other physical sensors in another geographical location, some other physical sensor in a third geographical location, some other physical sensor in a fourth geographical location.

So, these all will be taken together. They may not necessary be one and the same. They may not be the same that is they may not all be of the temperature sensor, but they could be you know temperature sensor along with pressure sensor. You know temperature sensor in one location; pressure sensor in one location. So, they all can be put together and club together, abstract it together as a virtual sensor. So, we have likewise different other virtual sensors formed together and these virtual sensors add another higher level can be put together and grouped together to form virtual sensor groups. So, for example, VS1 and VS2 can be grouped together to form a virtual sensor group or VS2 and VS3 could be you know grouped together to form virtual sensor group. In this particular example, we see that a particular virtual sensor group is formed out of these three VS; VS1 VS2 and VS3.

So, remember one thing that unlike the previous formulation, here we had considered homogenous sensors at the physical level and here we have considered heterogeneous sensors on top of the fact that they could be geographically dispersed. They may not all be in the same geographic location. Different sensors from different geographic locations can be mapped together to form virtual sensors at the higher level of abstraction and these different virtual sensors again can be clubbed together to form virtual sensor groups.

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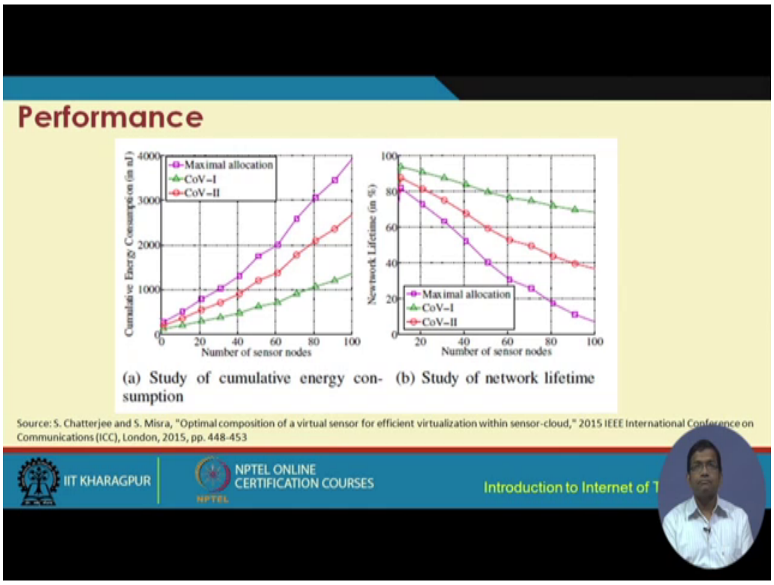

So, in terms of the performance, you know when we talked about CoV I and CoV II corresponding to the composition of the virtual sensors in the homogenous and the heterogeneous geographically distributed manners as we spoke about in the previous 2 slides. So, we have you know if we look at the comparison of performance with respect to the energy consumption, because this is cumulative energy consumption for PC over here is CoV I. This is the plot for CoV I and this is the plot for CoV II. So, as we can see over here that the energy consumption basically steadily increases in each of these and quite understandably that CoV II basically in curse greater energy consumption compared to CoV I and in terms of the life time, this is a comparison of the lifetime for each of these 2 scenarios. As we can see over here that the red colored one is for CoV II and the green colored labels are for CoV I.

So, life time on the other hand increases not other hand, but lifetime basically increases if we have the homogenous sensor scenario, where the sensors are from one geographic location and they all have the same specification. So, we have these 2 different scenarios of cumulative energy consumption and network life time and the comparisons between CoV I and CoV II and as I said before if you are interested to look further into these, you may refer to this particular paper. The optimal composition of a virtual sensor node, for efficient virtualization within sensor cloud, this is a paper that you know was published by us in ICC conference that was in 2015 in London.

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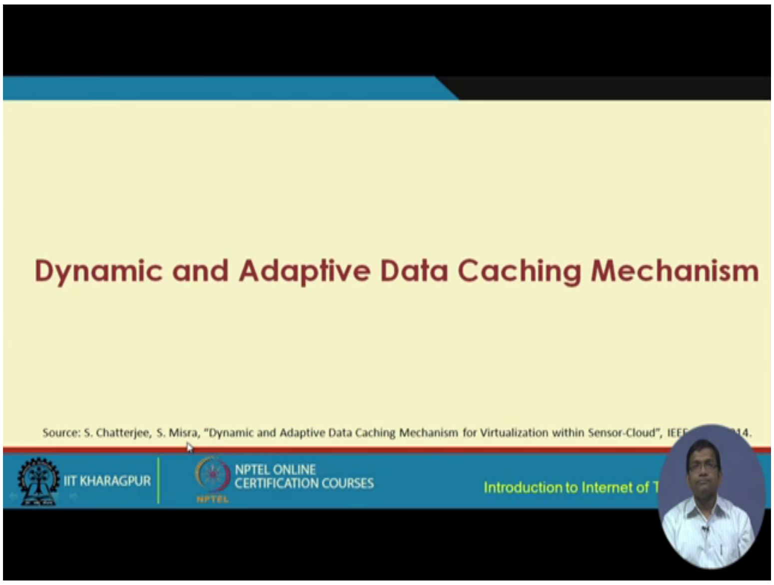

Then, we come to the second problem which is the dynamic and adaptive data caching mechanism. So, before I go to the details of it, I would like to give you a few examples. Let us say we are talking about environment monitoring with the help of different types of sensors including temperature sensor.

Now, in a particular area, the temperature does not change too frequently. So, it is unnecessary to always collect data from the different sensors at very frequent intervance. It is unnecessary and similarly, it is also unnecessary to make the corresponding virtual sensors available to the end users to different end users. So, it is sufficient if the temperature values are connected and are cached and are stored and we made available to the different users whenever they need access to that information. It is not required to create a virtual instance and then, have that virtual through that virtual instance collect or prime that particular sensor to collect the data to make that sensor in a sense and collect the data at you know consecutive instances of time at subsequent intervals of time by different users.

So, it is required to cache. So, there are likewise different scenarios, different applications where this is required to cache.

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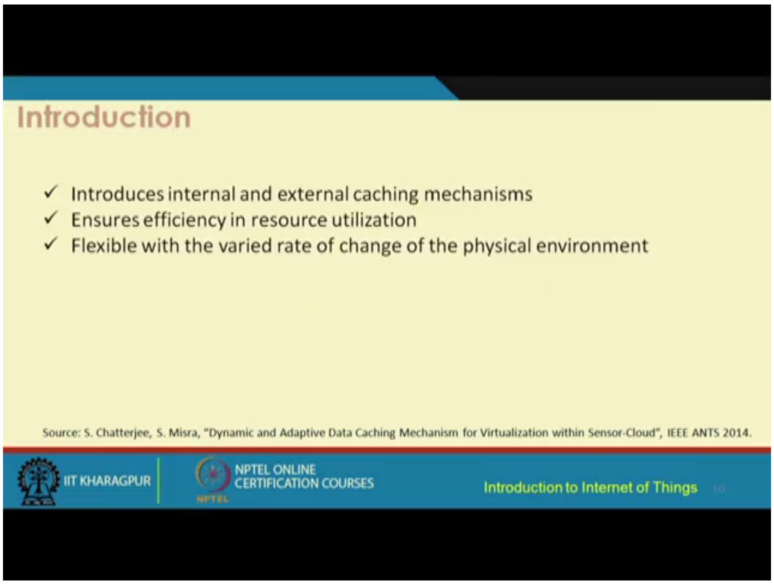

So, we will look at the different ways to cache. So, basically this caching introduces 2 different types of cache. One is the internal cache; the other one is the external cache. So, this example that I was giving you was about that external cache. We will look at the internal cache shortly. So, this caching mechanism basically ensures efficiency in resource utilization. So, caching basically is flexible with the varied rate of change of the physical environment.

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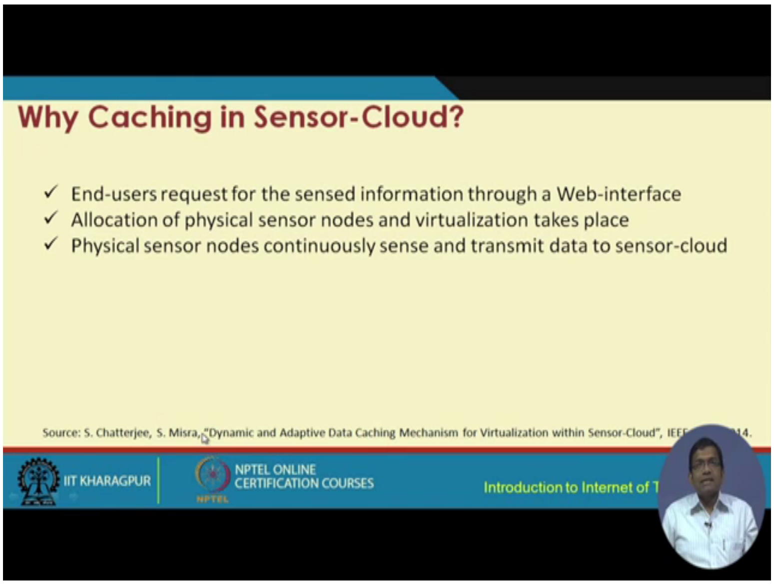

So, why caching is required in sensor cloud because end users request for the sensed information through a web interface and the allocation of the physical sensor nodes and virtualization takes place and the physical sensor nodes continuously sends and transmit the data to the sensor cloud, and that is the reason why you know it is not always required to you know prime and probe the sensors to sense and continuously send the sensed data through the web interface to different end users.

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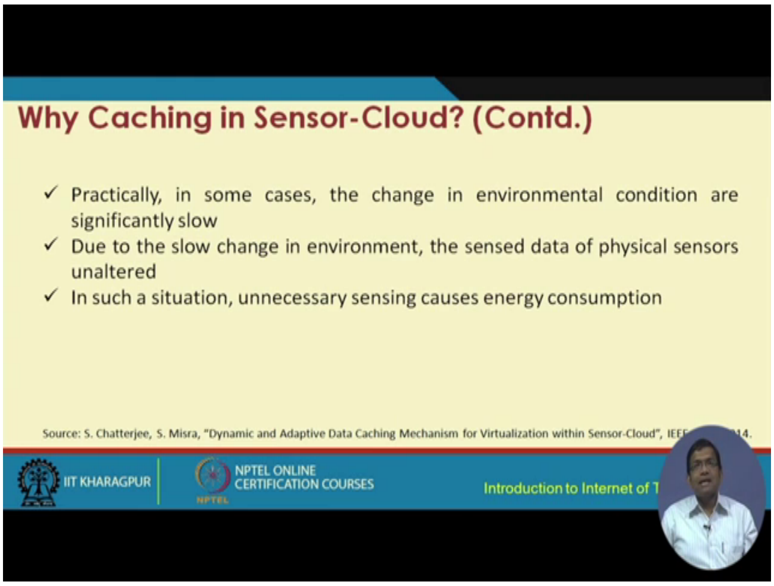

So, practical in some cases, the change in environmental conditions are significantly slow like in the case of temperature change or humidity change and so on. So, they are not very fast. So, it is not required to always sense through the physical sensors. So, even if you sense, it will give you merely the same value. The physical sensors are not going to give vastly different values. So, they remain physically unaltered. Due to the slow change in the environment, the readings are going to be unaltered.

So, in such a situation, it is unnecessary to sense because sensing would again unnecessarily consume energy which is undesirable.

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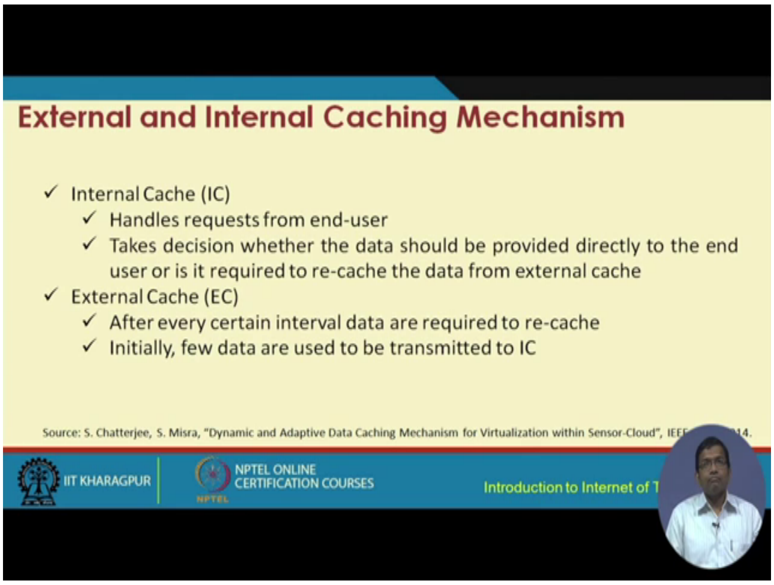

We introduce the concept of internal cache and external cache. I am going to talk about these 2, but before I proceed further, I would like to give you the reference for this particular paper while published by us. If you need more details about this internal and external cache and how this caching mechanism operates, you can go through this particular paper, the reference of which is given over here at the very bottom of this slide and this was published in the IEE conference in 2014. So, let us now go back and try to understand; what is the difference between the internal cache and the external cache.

So, the internal cache basically handles the request from the end users, takes decision whether the data should be provided directly to the end user or is it required to re-cache the data from the external cache. What is this external cache? So, it is a separate piece of server or hardware which at every certain interval of time, it collects the data and stores inside it. So, initially few data are used to transmit to the internal cache.

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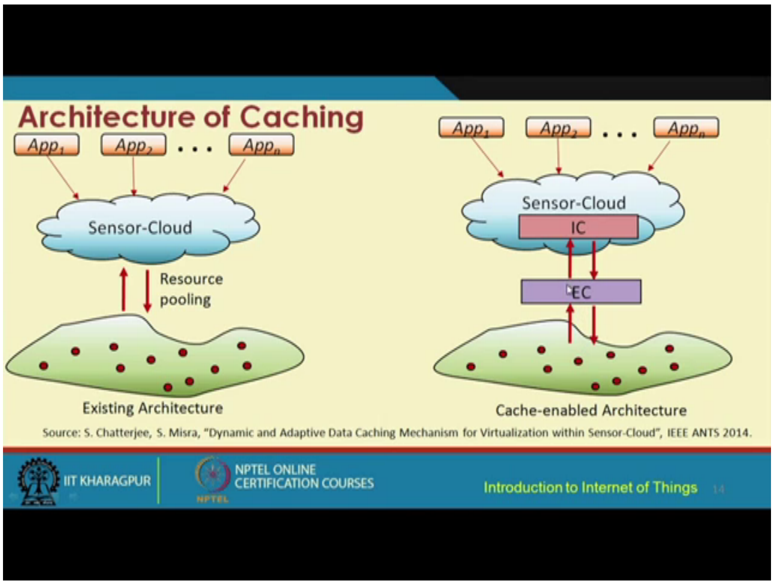

So, this is the architecture of caching. So, this is the existing architecture and this is the case cache enabled architecture. On the left, we have this existing architecture where we had these different physical sensors and this is that sensor cloud and these apps are getting accessed to the sensors through the sensor cloud, through resource pooling mechanisms.

Now, in the cache enabled architecture, we have this internal cache and the external cache. External cache could be conceptualize something like a separate server which is outside the cloud, where the data that are made available to the end users through these apps are also cached at the same time in this server in this external cache. So, you know it might happen that periodically at different instances of time, it is not required to prove that physical level sensor again. So, you know the data if it is not very much stale, it could be fetched from this particular external cache and if it could be done even better, it might happen that these different virtual instances that are in the sensor cloud here, the data might be also available. May be one user is already using it and that data could be made available because if you have to fetch it outside the cloud, that is going to increase the time for fetching. So, you want to keep something over here as well.

So, this is internal cache and this is how it differs from the external cache. So, external cache is an external server kind of thing, however internal cache is resident inside the cloud, inside the sensor cloud and this is how it differs from the external cache.

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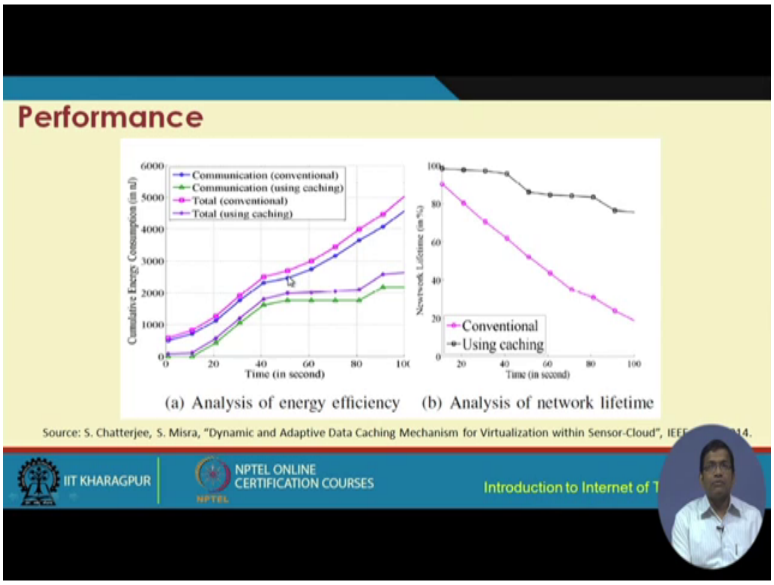

Here is the comparison of performance between the caching mechanism you know using internal and external caching mechanisms and in the conventional mechanism like as I showed, the conventional means this is existing conventional mechanism and caching based mechanism means this particular mechanism is what we see is the performance comparison between the 2.

So, in terms of let us say the total you know cost total energy consumption, so total energy consumption in the case of the conventional mechanism means, without using the caching mechanism is shown over here, in this particular pink colored plot. Whereas, the total energy consumption using caching is shown in this particular purple color plot. So, as you can see over here that the total energy consumption decreases quite significantly if we are using the caching mechanism as shown in this particular figure. How it compares with this pink colored plot in terms of the network life time here is the conventional scenario and here is the scenario of using caching. So, as you can see over here, conventionally the network lifetime is much more reduced and if we are using caching, the lifetime basically improves a lot.

So, it is quite significant in terms of the difference between using caching and without caching mechanism. So, caching basically improves overall network life time.

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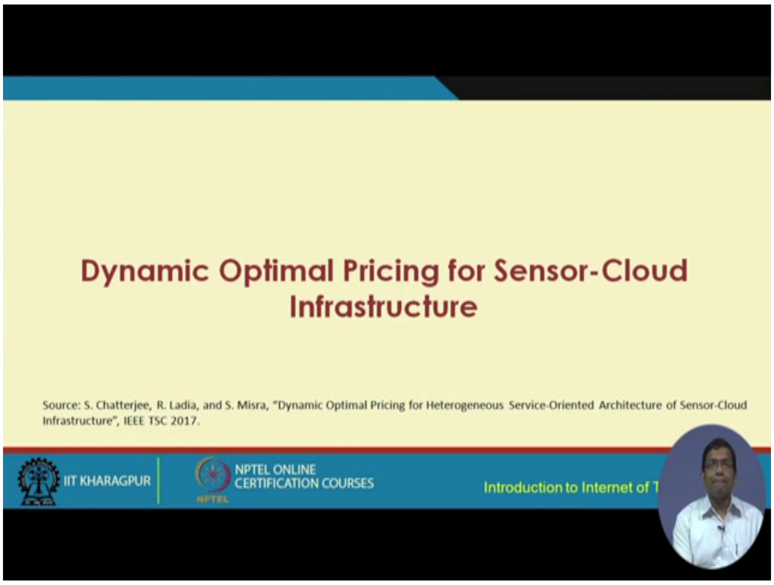

Finally, I would like to talk about another issue of sensor cloud. Again this is taken from a paper that we have published in IEE transactions on services computing in 2017 and here we have ticked into the issue of pricing in sensor cloud and how we can come up with an optimal pricing mechanism in a sensor cloud scenario, where that pricing mechanism itself is not only optimal, but dynamic in nature. So, the pricing itself is dynamic.

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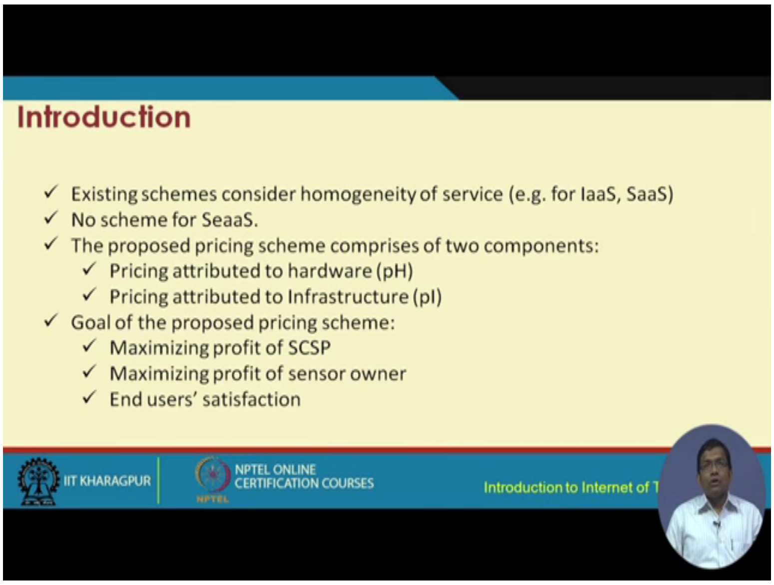

So, how does it happen? So, we will talk about that.

So, if we look at the existing cloud where IaaS, SaaS, PaaS models are used, there you are talking about homogeneity of services. So, existing pricing schemes in the cloud, the regular cloud are talking about homogenous services whether it is a SaaS service, the PaaS service or IaaS service and there is no scheme for pricing for sensors as a service. That means, this particular sensor cloud scenario sensors as a service c as scenario. So, we have proposed a pricing mechanism that comprises of 2 components. One is the pricing that is attributed to the hardware which means the sensor and the pricing that is attributed to the infrastructure. That means, the other infrastructure that are that are in place the operating system, the other hardware infrastructure the switches the servers and so on.

So, pricing attributed to the hardware which is for hardware like sensors and the pricing attributed to infrastructure, so p H and p I. So, the goal of the proposed pricing scheme is to maximize the profit of the sensor cloud service provider, maximize the profit of the sensor owner and to maximize the satisfaction of the end users.

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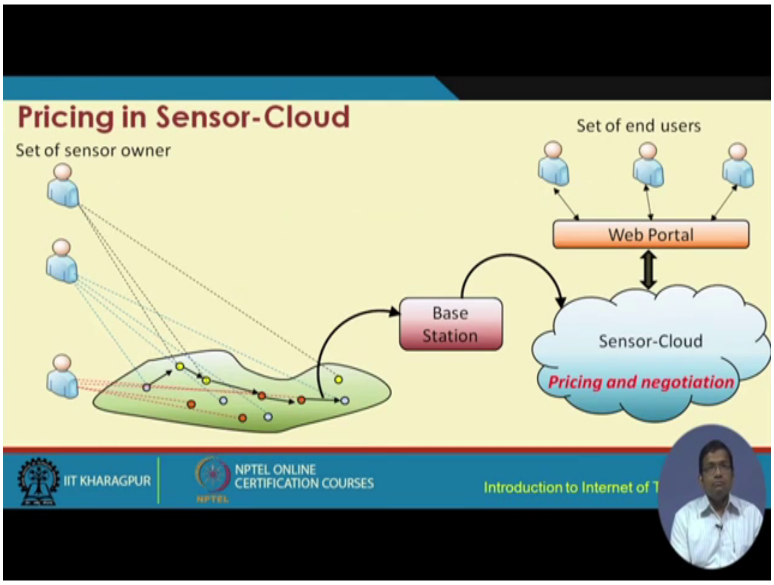

So, if we look at this scenario, we have this different end users. Now, you see that what might happen if the sensing has started from particular point. So, to sink when it travels in sensor networks; the sensor data from the source to the sink, it travels via different intermediate hops and these hops could be belonging to different sensor owners in this particular manner.

So, when you talk about a pricing mechanism, we have to take into consideration the pricing due to the hardware cost belonging to different sensor owners in addition to the sensor cost of the specific owner from where the sensor sensing has taken place of the sensor from the sensor. So, this sensor data is made available through the base station to the sensor cloud and is made accessible to the end users. So, end users will not only have to pay for the hardware cost of these sensor, that means the source sensor, but also the hardware cost of these sensors plus also hardware cost. Not hardware cost, but the infrastructure cost or other types of infrastructure that are in place like the base station, the servers, the switches and so on.

So, all these also have to contribute towards the price. So, how do we come up with a pricing mechanism, negotiation is the scenario where the prices can also be negotiated. So, this may not happen in all different cases, but in some cases it might happen that the end users would be able to bargain and be able to negotiate the price with the sensor owners or with the sensor cloud service provider. So, there would be some kind of a bargaining mechanism in place. It will be a market place kind of scenario, an oligopolistic market place scenario, where this kind of bargaining can take place.

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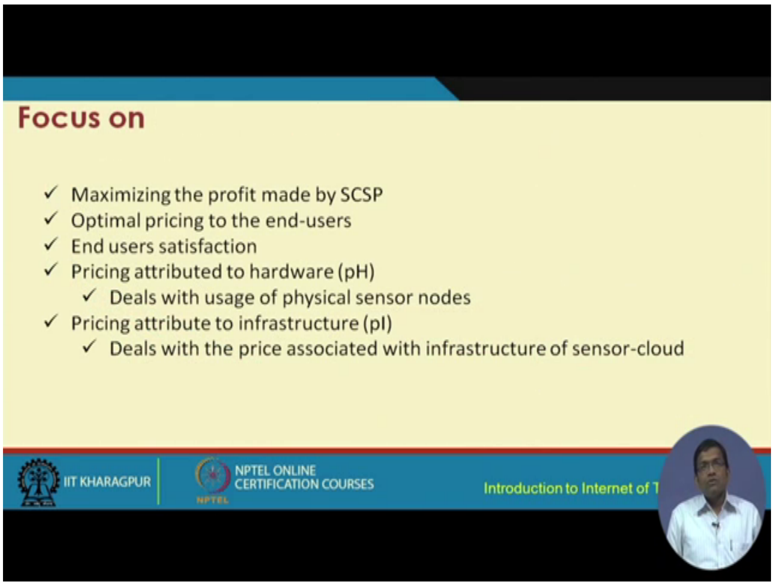

So, the focus is on maximizing the profit that is made by the sensor cloud service provider, optimal pricing to the end users, increasing the satisfaction of the end users by considering different factors. All the above three by considering different factors, such as the pricing that is attributed to the hardware while dealing with the usage of the physical sensor nodes, pricing attributed to the infrastructure by dealing with the prices associated with the infrastructure of the sensor cloud.

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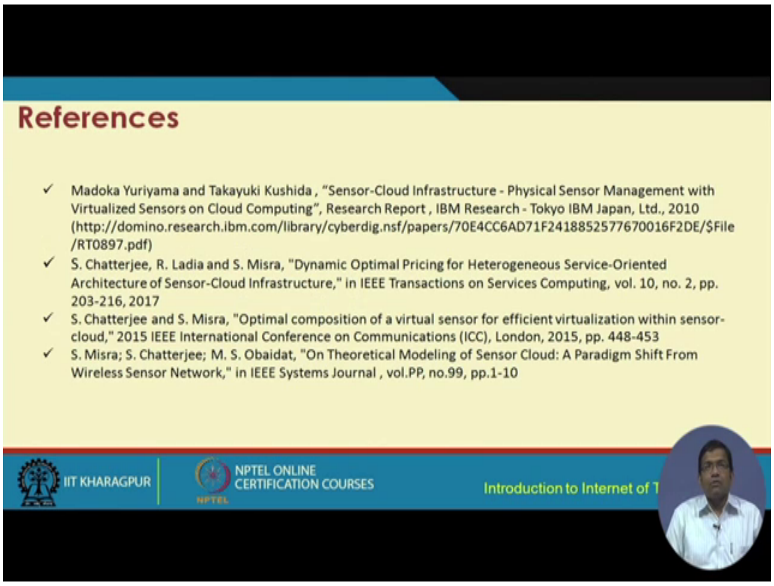

So, these are some of the different issues and the least of different references. If you are interested to know further about sensor cloud, the different works on sensor cloud, here are few references for you. As you see over here in our group in the Swan lab, we have done a bit of a digging into the depth of sensor cloud, sensor as a service, virtualization of sensors, composition of sensors, caching of different sensors and so on. So, these are different things that we have done in one of the papers. I will tell you that this particular paper also talks about a comparison between a side by side comparison, a quantitative comparison between sensor cloud and the traditional sensor networks.

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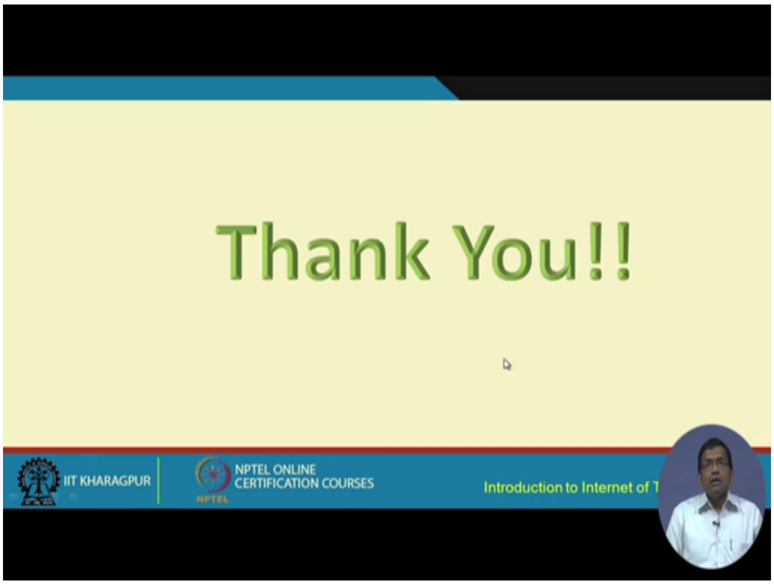

So, with this we come to an end of sensor cloud. Sensor cloud is a very important technology at present for enabling sensor networks; sorry for enabling internet of things and internet of things basically you know if you think little bit deep can be made efficient. The implementation of internet of things can be made efficient if we are talking about sensor cloud and sensor cloud has some similarities with in concept with the fog computing and cloud computing.

That also has been covered in the different literature and this is for you to try to understand that; what is the difference between sensor cloud, fog computing and regular cloud computing. This is all to do with efficiency; you know access to different services. You know these are with respect to these things. Basically they differ a lot and we know it is not like if sensor cloud is there. We do not need cloud. It is not like that and also, it is not like that if sensor cloud is there, we do not need fog. So, we need all these three things at different times. You know they are useful for different scenarios. So, we need all of them together. So, all of these technologies are required to build Internet of Things.

Thank you.