Introduction to Internet of Things
Prof. Sudip Misra
Department of Computer Science & Engineering
Indian Institute of Technology, Kharagpur

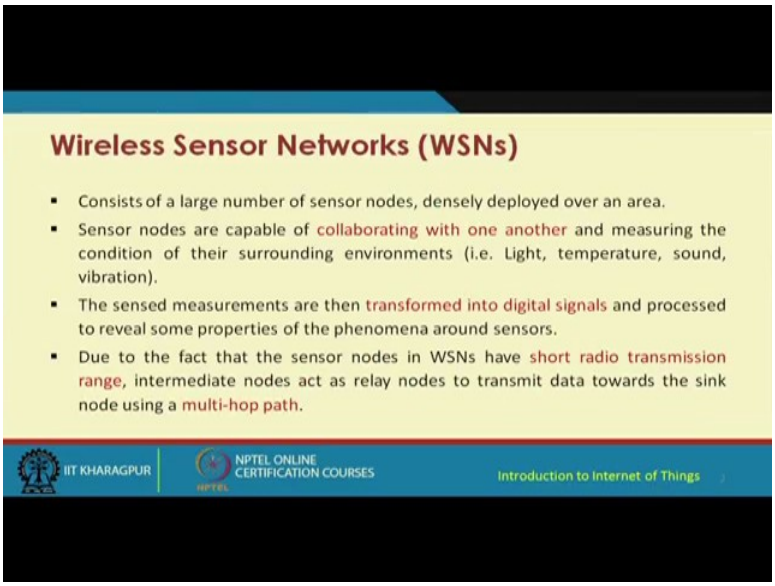
Lecture - 14
Sensor Networks – I

Now a very interesting series of lectures we are going to have, it is on sensor networks. So, the first part is going to be on some of the basic concepts in sensor networks. Sensor network is a very, very important technology that is used for building IoT. Sensors, transducers, actuators these are all very important things for realization of IoT systems. But, when we talk about sensors when we talk about actuators, these are the things that we have already gone through in one of the previous lectures. So, these are stand alone devices that we talk about, but if we can have these sensors connect with one an another we can derive important information continuously, in real time remotely, from a larger terrain. And, this is the benefit of sensor network. And sensor network I would say is one of the most important enablers of IoT.

So, in sensor networks what we have? In sensor networks we have individual sensors, which are embedded in something known as sensor devices or sensor nodes, or sometimes also known as sensor modes. So, these modes or nodes or devices they have one of their components which is the sensor, and they have other components as well. So, these components taken together they comprise that particular node or the device which can help them to communicate. And one device communicates with another device, that device communicates with another device, the third device with a fourth, fourth with the first and so on. And so, we can expand we can expand the sensing we can expand the sensing by having them communicate with one another.

So, what we have are different types of topologies. We can have all sorts of topologies that we have already heard of in networks being implemented in the case of sensor networks as well we can use a star topology. We can use a mesh topology we can have a mesh of we can have a mesh of sensor nodes that are all put together. Right, so we can have star we can have ring we can have you know any kind of topology that you can think of, and mesh is particularly very attractive for obvious reasons that basically includes reliability, security, fault tolerance of the topology itself

(Refer Slide Time: 03:15)



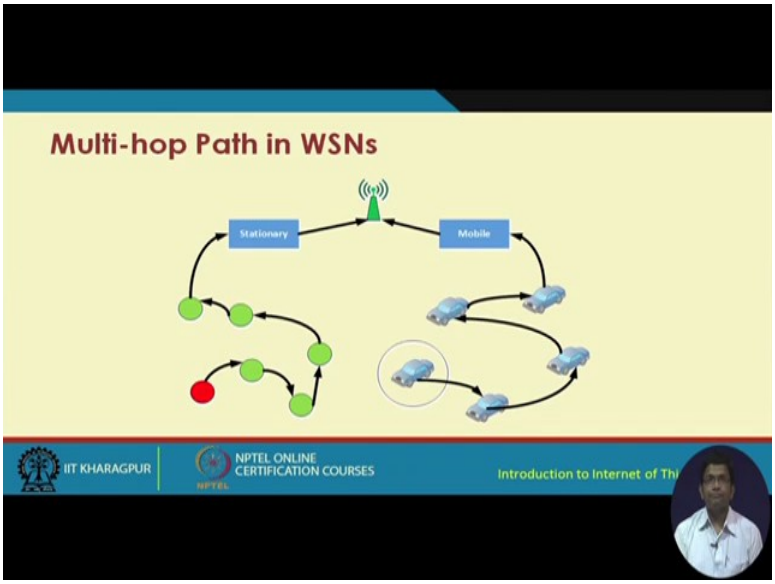
So, let us look at the different basics of sensor networks. So, in a sensor network we have sensor nodes. Every sensor node has a sensing unit. The sensing unit basically senses. Senses what? Senses the particular physical phenomena that it is supposed to sense. A temperature sensor would be sensing the temperature fluctuations. A humidity sensor will be sensing the humidity fluctuations. A camera sensor would be sensing; that means, taking the images of what is around you know what is happening around it.

A vibration sensor will be sensing the vibration. A light sensor will be looking at will be sensing the illumination conditions and so on. But each of them is sensing locally and, every other node that is deployed they are all doing their own tasks separately individually. And now, in a sensor network we all have to we have to put them all together; we have to put them all together how it is possible to put them together? We have to just have some kind of radio connectivity between these different devices. These devices means their sensor nodes and, this is how we build up a sensor network. And what is the main motivation of building a sensor network? To have greater coverage of sensing and, continuously we can monitor in real time we can monitor remotely we can monitor what is going on in a particular terrain, without actually having somebody humanly sitting and monitoring that particular region or space.

So, the sensor nodes are capable of collaborating with one another. And measuring the condition of the physical phenomena that are occurring around them with respect to what

into what they are supposed to sense. For example, the lighting condition, temperature, sound, vibration etcetera the sense measurements are then transformed into digital signals and process to reveal, some properties of the phenomena that are occurring around them. So, due to the fact that the sensor nodes in sense WSNs wireless sensor networks have short transmission range. Immediate nodes act as intermediate relays and, they transmit the data that they receive from these other frame nodes the other neighboring nodes in a multi hop manner, until the data is received at the sink node.

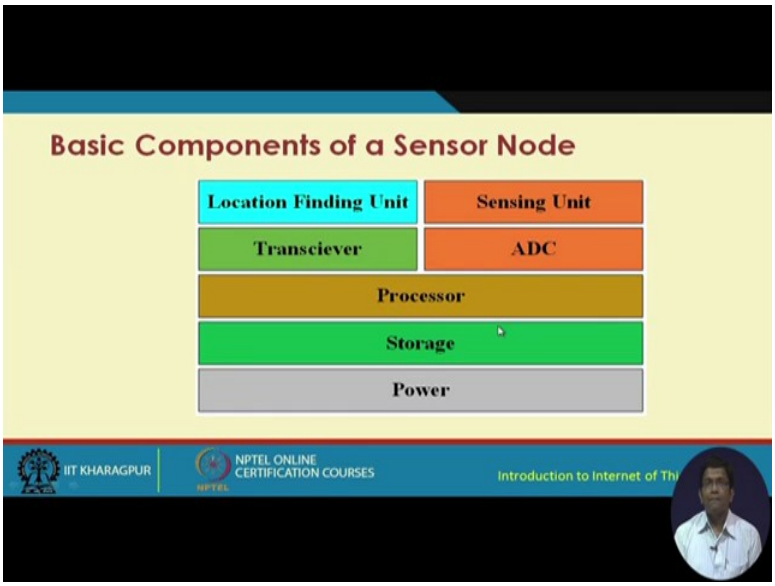
(Refer Slide Time: 05:55)



So this is how the entire sensor network concept functions. So, what we have is multi hop communication. So, let us consider a stationary sensor network. Stationary means what? Stationary means that, the node all these nodes, when they are deployed they will maintain the position at subsequent instants of time after deployment. So, they will all maintain their own respective positions. And they will not move they are all stationary the nodes are all stationary. So, this is an example of a stationary sensor network. Mobile sensor network on the contrary, have the sensors and the sensor nodes that move around like this.

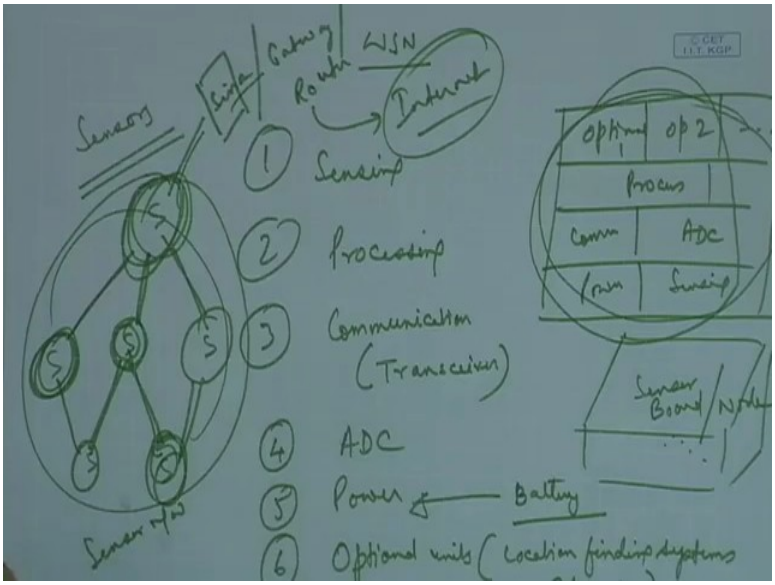
So for example, the sensors that are fitted to a car, to an airplane, to a truck to, a bus and so on. These become mobile sensors mobile sensor nodes because, they are fitted to devices which move with time. So, they become you know together when you connect them in this manner, what you get is a mobile sensor network.

(Refer Slide Time: 07:16)



So, if we look at in a sensor network, what we have? In a sensor network we have different units. So, WSN we have different units.

(Refer Slide Time: 07:28)



So, the first thing that is required is to have some kind of sensing unit. Then we have some kind of a processing unit. Third is we need some kind of communication to take place between these different nodes. So, we have a communication unit, you with the help of transceiver devices. Then we have different other units such as, the analog digital converter, we have the power unit, we have, power unit will do what? Are in it includes

things such as battery and so on, which is going to power these devices. So, these are the different units. And then we have other optional units optional units such as the location finding systems for example, GPS etcetera.

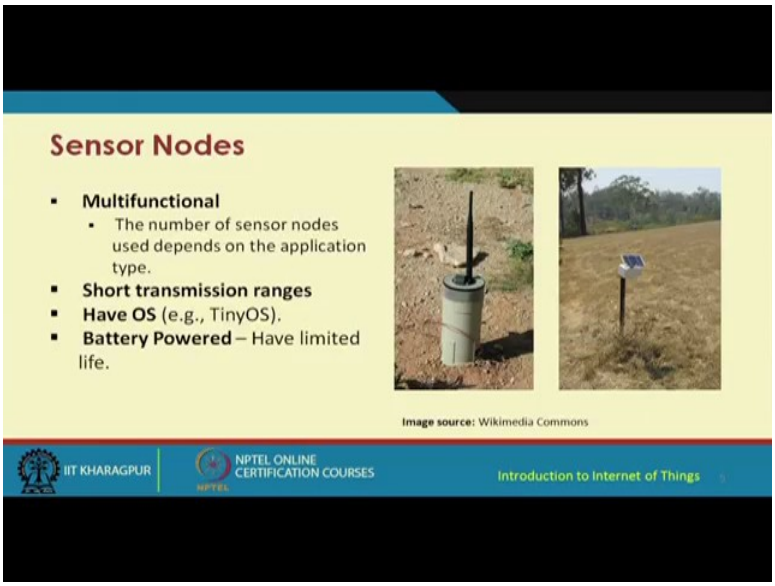
So, this is how a sensor node looks like. So, we have you know in all these optional units optional unit 1 optional unit 2 etcetera. We have a processor, we have a communication unit, we have analog digital converter, we have a power unit, we have what did I miss out a sensing unit, a processing unit, it is already given and so on and so forth. This is how a sensor node looks like. So, if you recall in one of the previous lectures when we talked about sensors, we also talked about the different types of sensors. So, what happens is you know we have to develop something like a sensor board. So, this becomes a sensor board or a sensor node or a sensor device.

So, this sensor board the hardware of it has different components. All these different components that I just mentioned, all these different components are basically built into this hardware device. So, you need to have a particular circuit design for building these sensor nodes with these different components. So, essentially what are we trying to do, we are trying to have, so let us say the this is one such sensor node communicating with another sensor node, with another sensor node, with another sensor node sorry, with another sensor node and right.

So, we are going to form a sensor network. So, what I these are all sensors, these are all sensors, sensor nodes. So, mind you that in every sensor node we have a sensing unit. And sensing unit has the sensor that we are. So, temperature sensor is basically built into that sensing unit of that sensor board.

So, then what happens? So, through a multi hop path all these sensed information are sent to the sink node or the gateway or this router for further dissemination to the internet. So, then what happens is finally, all this sensed information they will all go through the sink to the internet for further use. This is the whole purpose of this sensor node.

(Refer Slide Time: 11:48)



So, this is these are some of the pictures of sensor nodes as you can see in this particular figure. So, this is one such figure. One such sensor node here is another sensor node. I will show you a sensor node that we have basically deployed for different purposes. One of one such purpose is for agriculture. In our agricultural field we have sensor nodes that are deployed and these are all solar powered.

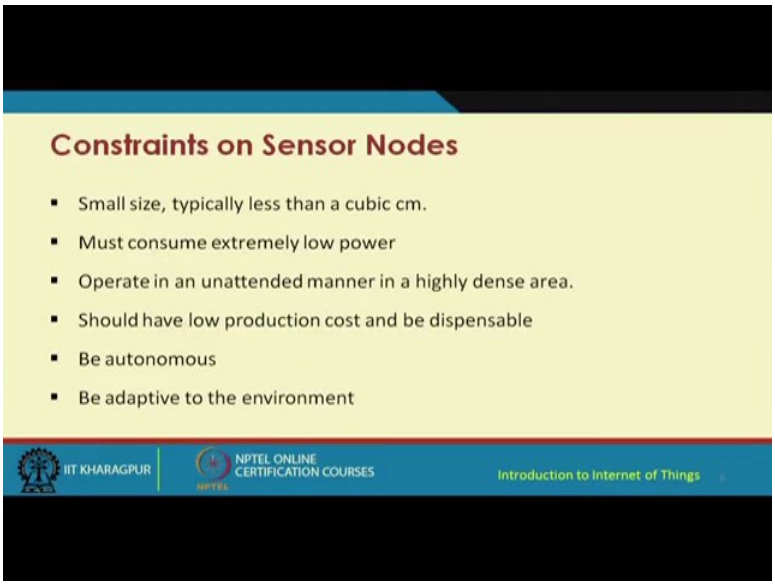
So these are solar powered you know sensor nodes. So, the power unit basically has a battery which basically hardnesses. Not battery but, you know it basically hardnesses the solar energy through the solar panel and powers the rest of the components of the node. The sensor nodes are multifunctional. So, they can be used for different purposes. In fact, the sensor board you know you can change different sensors and you can use the sensor board the different components of it, put together, you can remove the sensor, you can put another sensor and typically you know it will work for serving different types of applications.

So, the number of sensor nodes that are used depends on the application type. The sensor nodes they have short communication range, may be powered by zigbee. A zigbee has very short communication range. So, this short communication range means that the sensed information by a particular node can be sent only up to couple of meters or tens of meters. And after that what? Finally, it has to be sent to the sink node. So, after that what? After that within that communication range of let us say thirty meters if it is

zigbee up to above thirty meters then we need to have another node which again has to relay that information that has been received from this particular node.

This is how we have this multi hop communication taking place between these different nodes in the network. Multi hop, multi hop means what? A particular node has to send something to a remote destination, but it is not within the direct communication range of it. So, what it will do is, it will send to some of it is neighbors. These neighbors will relay the information or the data the sense data that has been received. And send forward and this is this process is going to continue until the data is received at the intended destination nodes or the sink node. So, this is multi hop not single hop. So, source node to the sink node sink node not within the right communication range of the source node. There has to be intermediate nodes acting as relays and this is the whole idea of multi hop communication in sensor networks.

(Refer Slide Time: 14:35)

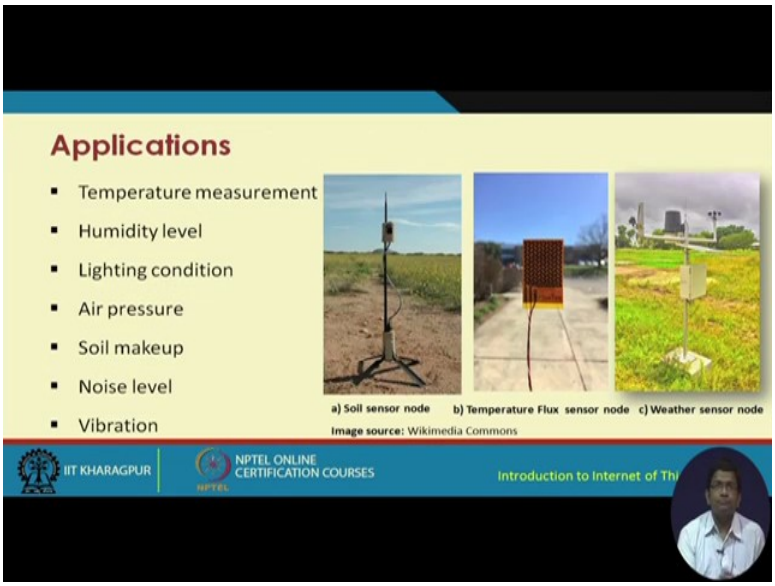


These sensor nodes I should also mention, that these sensor nodes are all not only battery powered. But, they act as mini computing devices. So, they have their own processors and we have already seen that. Processors microcontrollers and so on. They have their own they have their own power unit. They have their own communication unit plus they have their own operating system. One such very popular operating system that is used for sensor nodes is known as the tiny operating system tiny OS.

So, these are the different features and, now let us look at the different constants on the sensor node. So, the sensor nodes are typically small in size, low powered, resource constraint in all different ways, although they are acting as small size computational devices, but they are heavily resource constrained in all different ways that you can think of. So, due to their small size typically in the order of few cubic centimeters or even they can be little bigger also if it is not a mains based sensor.

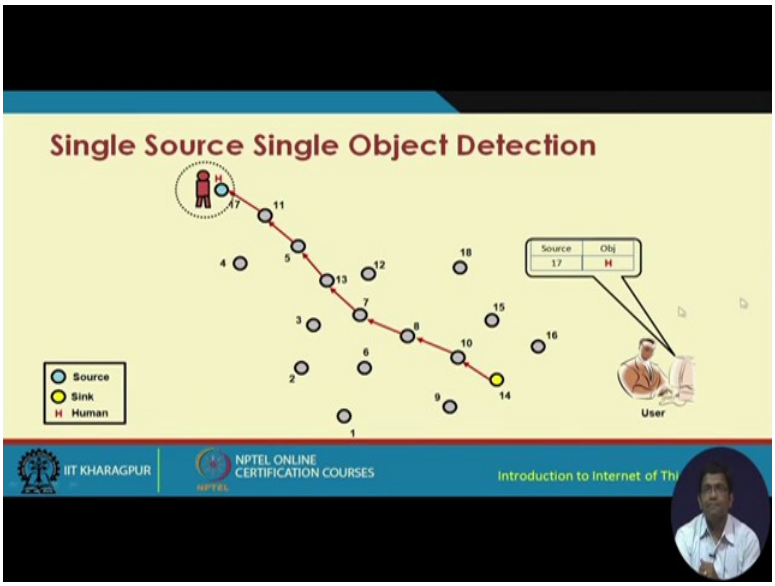
So, because of the small size they must consume extremely low power. They must operate in an unattended manner in a highly dense area, should they should be produced using low cost at low cost, production costs should be less, and they should be easily dispensable. They should be like couple of dollars few hundred rupees and so on. This would be autonomous they should be able to operate on their own and be adaptive to the environment in which they are operating. So, if there is some change in the environment this should be able to you know automatically this would be able to adapt to those changes

(Refer Slide Time: 16:18)



Here a few examples of sensor nodes soil sensor node temperature sensor node weather sensor node and so on, all deployed in real life. And for serving different applications such as temperature measurement, humidity level condition measurement, lighting condition, air pressure, soil makeup, noise level, vibrations and so on.

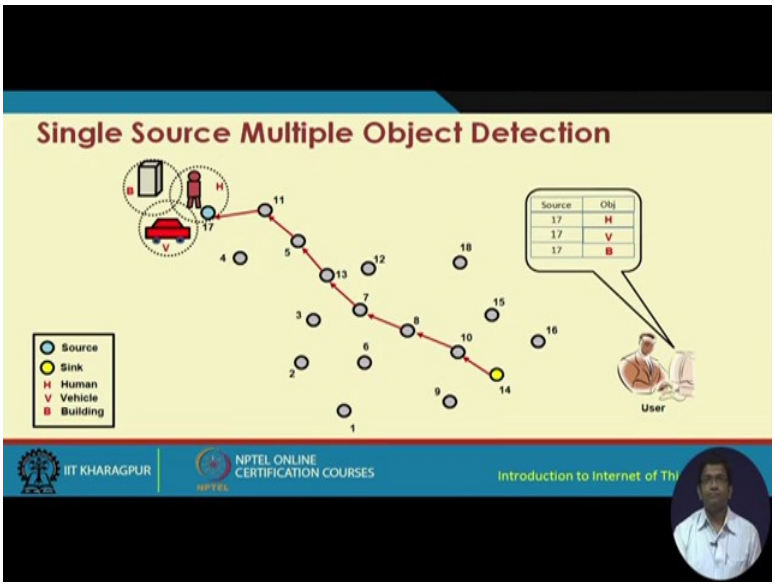
(Refer Slide Time: 16:40)



Now, let us look at few important concepts in sensor network. So, we have seen that in sensor networks we have different sensor nodes that a deployed in a particular region. The sensor nodes they have to communicate via multi hop communication. So, let us say that we have a surveillance kind of application, and where it is required to detect objects. So, as we can see in this particular figure, that the sensor node 17 detects a human object. And that information through this multi hop path is sent to the sink node 14 and there is a monitor a user who is continuously monitoring that, where it can see you know close to which sensor it can see any object, any human object or whatever object it is programmed to sense.

So, as we can see in this particular figure that, node number 17 has seen has sensed a particular object the human object. Now it is going to send the data in this particular direction as we have already seen. But then, why is this arrow shown in the other direction? These arrows are shown in the other direction to signify that, from this sink a query can be sent to all the nodes the query can be sent to all the nodes to see that whether any of them has observed any object around them. So, this is the direction in the other way that is shown that is the whole purpose of showing it in that particular other direction. So, the previous example was for a single source detecting a single object.

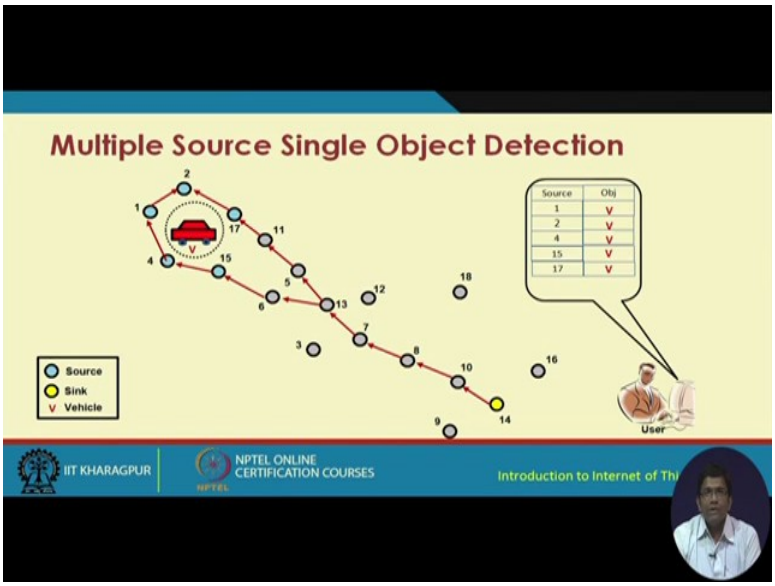
(Refer Slide Time: 18:28)



Now, let us make our life little bit more complicated. So, we have single source detecting multiple objects. So like this. So, earlier there was only human object now we have two more objects. So, we have a vehicle and we also have some other building or something like that. So, we have 3 different objects a human, a vehicle and a building. So now, you as we can see over here, it becomes very difficult for this particular node to recognize that what are the different objects. So, because there are there is not a single object, but three different types of objects and what object. So, object recognition is also very important. So, here in addition to object recognition the complexity is that whether node number 17 will think that, it can see only a single object or 3 different objects. This is something that has to be decided upon. So, you see that by adding few objects only within the periphery of within the vicinity of a single node the life has become So complex.

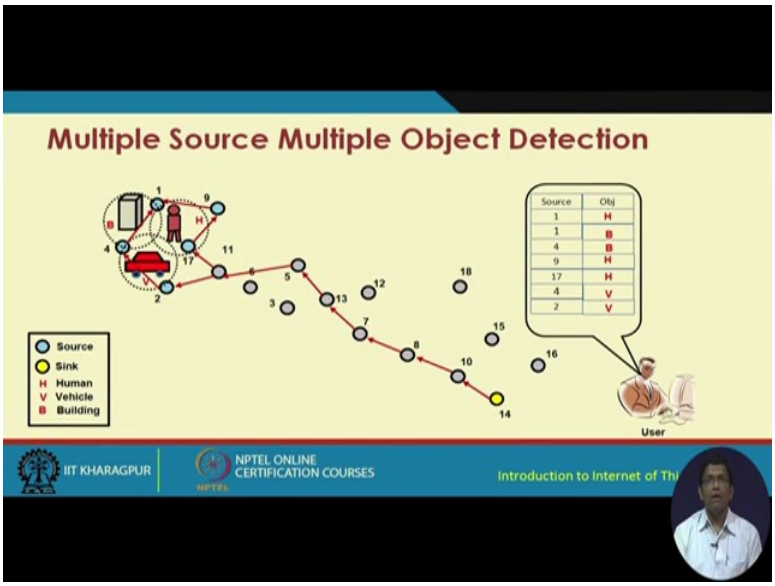
So, so this is the whole idea behind the use of sensor networks for this thing. But we have seen that, by adding few complexities the entire complexity of the entire network increases manifold.

(Refer Slide Time: 19:56)



Now, we see another scenario of multiple source detecting a single object. So, here the single object is a vehicle and, all these blue colored nodes they all act as sources and they sent that sends information to the sink node. Now the sink node and the user that is connected to the sink, the complexity now is that, it will try to understand that whether all these 5 nodes have seen a single object; that means, a car a vehicle or 5 different objects. How will it know? It is not possible. It is difficult to basically a discriminate between these sense data that are received from 5 different nodes, and that is the reason why it is not possible to know that what is the difference. I mean whether it is the same object that is this you know that is all seen by the although all the 5 nodes or 5 different objects.

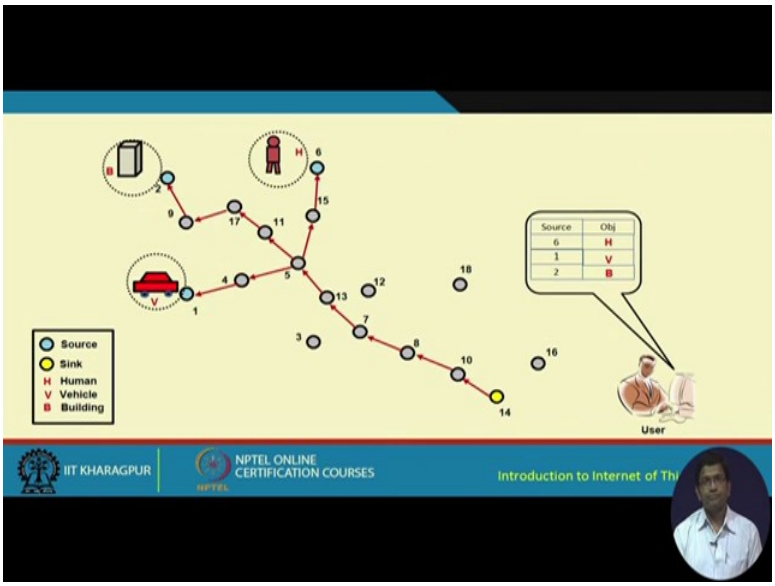
(Refer Slide Time: 21:00)



Another example of multiple sources detecting multiple objects like in this particular figure. And here again you see that complexity is quite increased.

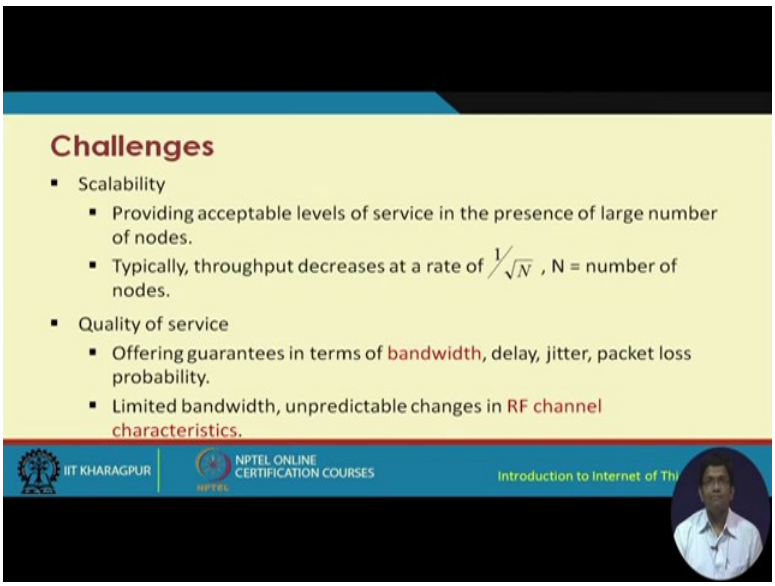
So, these 5 sources whether they have detected 5 different objects or the same object and not only that, but also whether these objects are all different. So, these are the different complexities that are involved in implementing sensor networks. But these are only some of the primitive complexities that we are talking about. There are So many different other sorts of complexities that also have to be worked upon that also have to be implemented when we are talking about using sensor networks to build internet of things.

(Refer Slide Time: 21:48)



This is another scenario and I do not need to explain this further. And as we have seen that this basically you know these scenarios of surveillance basically complicates our life, it is not very simple. And here mind you that in all these 4 5 scenarios that I have just shown you, here we have considered that the nodes are all static and with respect to time. But in reality it is not going to happen, the nodes are going to move around.

(Refer Slide Time: 22:18)

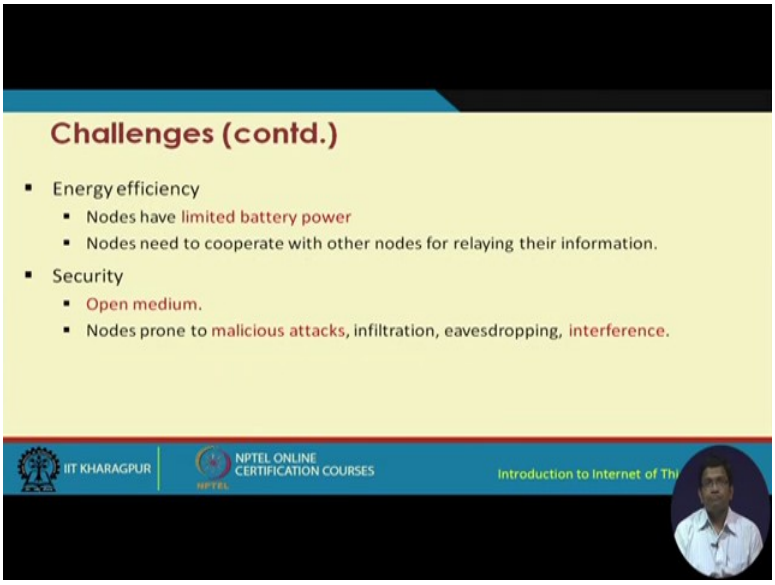


So, what is going to happen? The complexity is going to be even increased further. So, there are different challenges in implementing sensor networks. Scalability is one.

Scalability means that if you are increasing the number of nodes in the network, then how is the throughput going to behave? So, theoretically in the past it has been shown that, if n denotes the number of nodes in the network then the throughput basically decreases at the rate of one over square root of n. And this is as we can understand that from 2 nodes to 4 nodes if we increase the throughput basically goes down drastically. Now from 4 to 8, 8 to 16 and so on and so forth. The throughput decreases quite fast. So, how you are going to handle the issue of scalability in sensor networks? Because, in sensor networks we are inherently talking about networks with large number of nodes. And So, how do we handle the throughput decrease in this particular manner?

Second issue is quality of service. Quality of service guarantees is required for any network. Sensor networks, IoT using sensor networks, also you know need to have seen you know quality of service guarantees. Quality of service guarantees talks about offering guarantees in terms of the bandwidth, delay, jitter, packet loss probability and so on and so forth. And in a sensor network we are talking about, very limited bandwidth heavily constraint network with heavily constant resources, unpredictable changes in RF channel characteristics and so on.

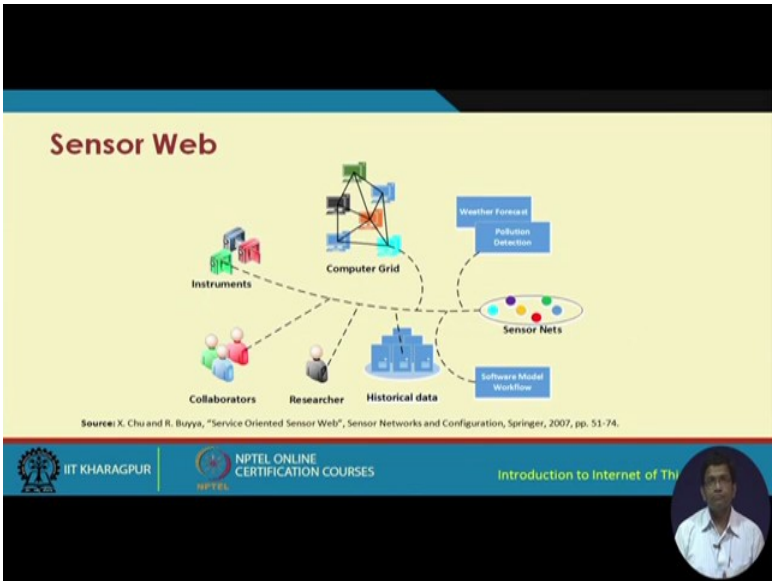
(Refer Slide Time: 23:51)



So, in such kind of chaotic environment, how we are going to offer deliver quality of service guarantees? Other challenges include energy efficiency. We are talking about very limited battery power small size batteries, low electrochemical efficiency, limited

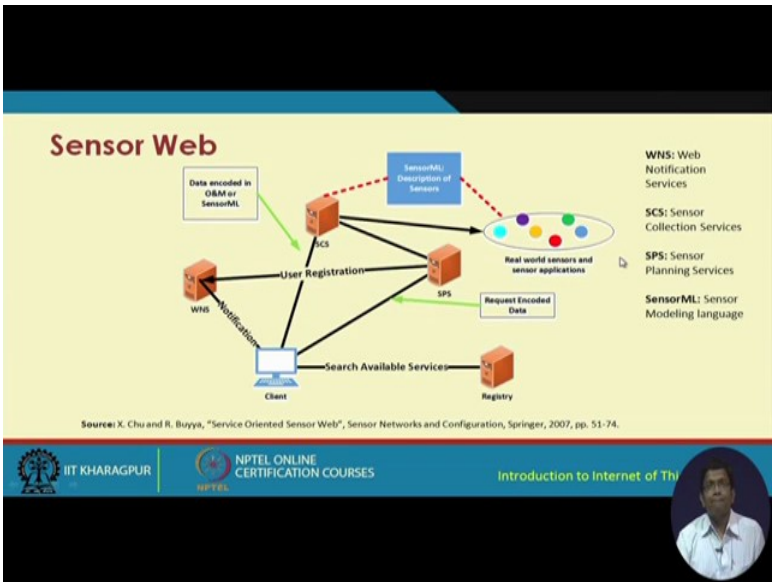
battery power, how we are going to have these nodes not only function their own things, but also cooperated cooperate with the other nodes the neighbors to relay their information and so on and so forth. Security is also very important. We are talking about an open medium where the nodes are prone to different types of attacks, malicious attacks, infiltration eavesdropping interference and so on.

(Refer Slide Time: 24:25)



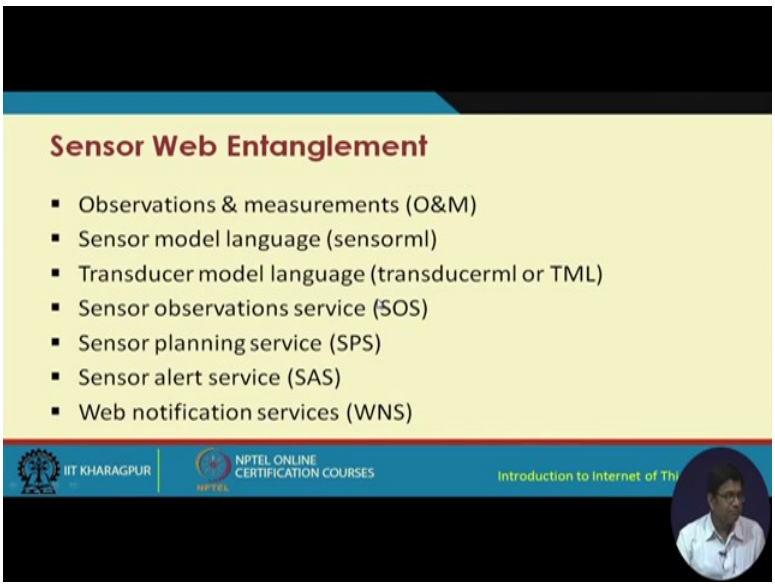
Now let us look at little bit more you know glittering kind of technological concept in sensor network, which is known as the sensor web. In sensor web what we are talking about is not just the sensor networks, but also sensor networks connected to sensor networks. So, what we have are different types of sensor networks like this which are connected 2 different things like computer grid 2 different instruments such as microscope telescope and so on. Scientific instruments; different collaborators through mobile phones etcetera, researchers, different historical data legacy data, which a store in data servers are you know server forms, cloud etcetera. And taking care of issues such as weather forecasts, pollution detection, software model workflow and so on.

(Refer Slide Time: 25:26)



So all these together form what is known as the sensor web. So, in sensor web we have to deal with different types of servers which will take care of web notification services, sensor collection services, planning services, modeling language and so on. Where is the modeling language? We have the sensor modeling language like right here and so on. So, all these WNS sensor collection service running service SensorML.

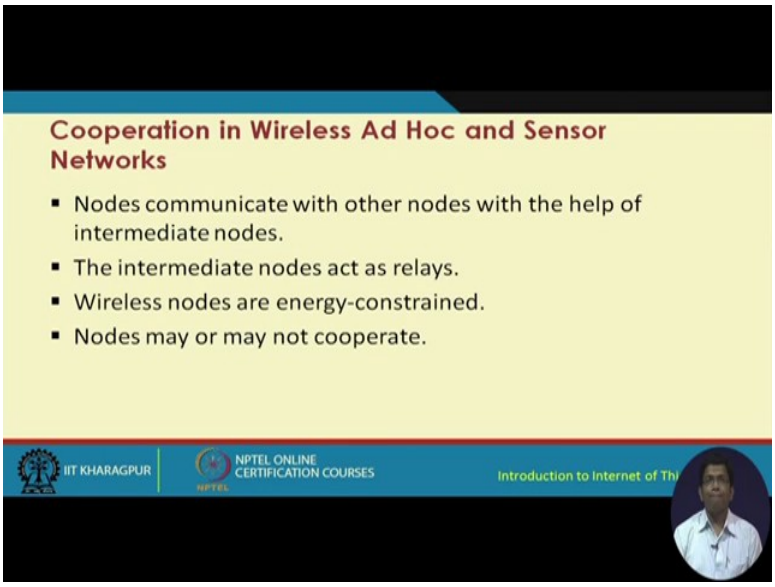
(Refer Slide Time: 26:59)



And so many different types of concepts and components that have to be used.

So in sensor web we have concepts of observations and measurements SensorML, which is sort of like an XML extended XML, a very similar in lines with let us say UML, you know some kind of a modeling language that supports sensor modeling. Then we have the transducer modeling language, transducerml sensor observation service sensor planning service sensor alert service web notifications services. All these put together basically a constitutes the sensor web.

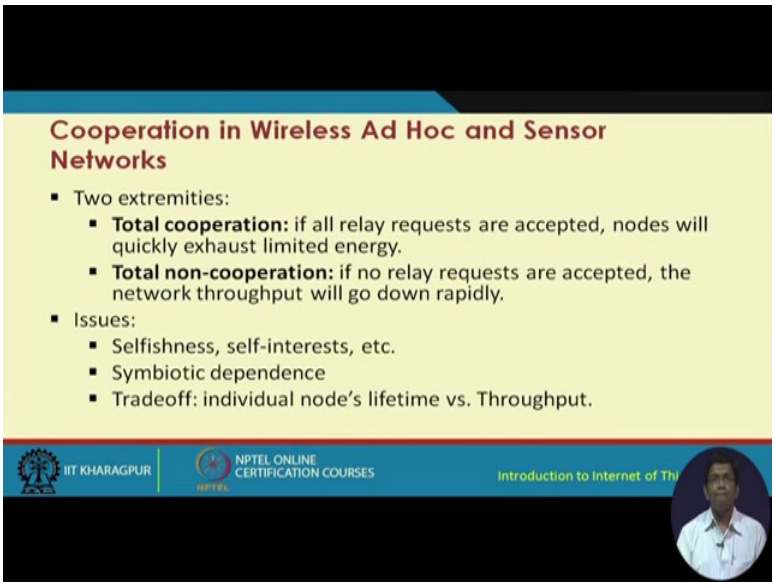
(Refer Slide Time: 26:33)



Now, few other concepts have to be taken care of. One is the concept of cooperation. Cooperation is paramount we are talking about you know a multi hop network, where there are relay nodes in between. So, what happens if these intermediate relay nodes instead of forwarding the packet further, they drop the packet because they will tend to be selfish. They will tend to be selfish because, to forward the packet to relay the packet forward they would have to expend their own little energy. So, why would they do that?

So these nodes are supposed to be cooperative, but, but they may not be as much cooperative because of all these selfish interests you know, resource limitations and all these different other types of considerations. The intermediate nodes act as relays. The wireless nodes are energy constraints the notes may or may not cooperate consequently. Because of all these different constraints, the nodes may not be willing to cooperate with the other nodes for collectively accomplishing the tasks that are supposed to be required to be accomplished in such a social network, socially connected network.

(Refer Slide Time: 27:48)



So taking care of the issue of cooperation, there are 2 extremities that have to be thought about. One is the total case of total is total cooperation. And the other one is the case of total non cooperation. Case of total cooperation where all the relay requests that are received are accepted by the nodes and the nodes will quickly exhaust the limited energy. And the case of total non cooperation if no relay requests are accepted the network throughput will go down rapidly. So, these are the 2 different extremities and, they are corresponding limitations are mentioned over here. So, if none of the relay requests are by are accepted, then what is going to happen? The network throughput will go down rapidly.

So there are issues of selfishness, self interests, symbiotic dependence between these different agents, there have to be worked out. That have to be increased in order to symbiotic dependence has to be increased, not selfishness of course selfishness is a problem self interest selfishness are problems that have to be handled. And symbiotic dependence how it can be promoted? And that also has to be thought of, and corresponding mathematical models have to be developed. And the trade off is between the nodes lifetime versus the throughput.

(Refer Slide Time: 29:03)

There are security I challenges in cooperation. So, first of all we have to get back to our old concept; that means, multi hop network. In a multi hop network sensor node, the intermediate node is cooperating with other nodes.

Now that cooperating node is a good guy. So, that good guy by looking at it there are so many you know there could there could malicious nodes, which might want to intentionally hurt the successful functioning of it and the other similar kinds of nodes. So, what it can do is it can initiate a denial of service attack kind of thing. So, what it will do is it will start you know pumping in lot of false routing information, that and thereby paralyzing the whole network. So, this is basically one of the security challenges in cooperation.

So, with this we come to an end of the first lecture on sensor networks for developing internet of things. And in subsequent lectures we are going to go through the different other concepts in sensor networks we have already seen that there are so many different types of constraints and challenges that have to be overcome in a sensor network, and that is where the sensor networks have to work on to, you know to come up with different solutions that have to be implemented in them to make them work efficiently.

Thank you.