Wireless Ad Hoc and Sensor Networks
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Lecture - 26
Mobile Wireless Sensor Networks

The topic that we are going to cover now is mobile wireless sensor networks. So far whatever we have covered in sensor networks we have been assuming that all the nodes are stationary; that means, the nodes are, nodes do not move in the terrain where they have been deployed so, but what happens is in many practical scenarios of sensor network deployment mobility is something that should be considered, mobile sensor networks consequently are very important. So, let us look at some of the fundamental aspects of mobile sensor networks.

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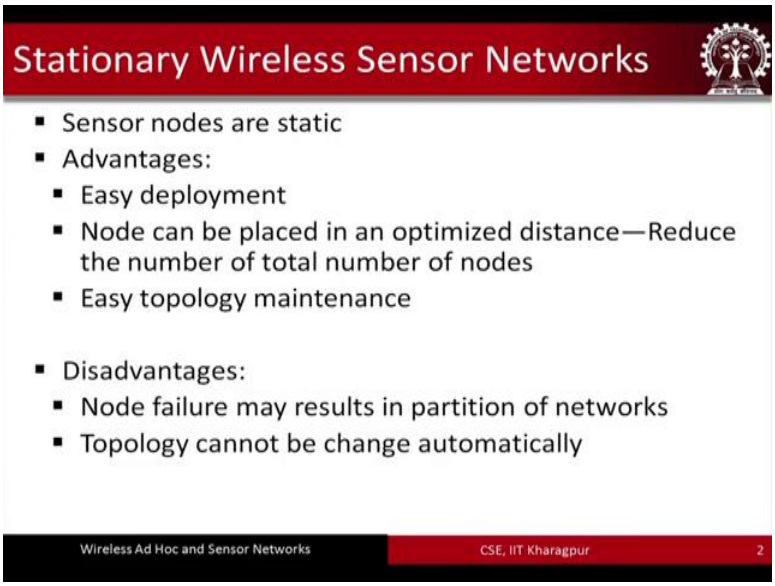

So, when we have covered the different aspects of sensor networks we have been talking about stationary wireless sensor networks where the sensor nodes are stationary or static the main advantage of assuming stationarity in the sensor network deployment is that first of all it is very easy to deploy these sensor nodes when we want to make a sensor network it is very easy to deploy the sensor nodes we just have to plan that where these sensor nodes have to be deployed. And thereafter once the network start starts these nodes this they start sensing and they maintain their own specific positions fixed

positions consequently the overall physical topology of the network does not change and that makes it very easier for the network management tasks or network operations to be performed.

So, easier deployment is one thing second thing is that nodes can be placed in an optimized distance from one another when we are considering a stationary sensor network and that will help in properly planning and optimizing the total number of nodes that would be required in the region. And as I said few minutes back that the overall topology the physical topology of such as network does not change over time and consequently these networks the stationary sensor networks are easier to maintain. So, there are many more advantages of having stationary sensor networks which more or less attribute to the fact that it makes it easier simpler for these networks to deploy and maintain.

However as I said before that mobility is something that should be considered in many practical scenarios, mobile sensor networks is what results from the deployment of the sensor nodes and that is something that has to be considered and this is what we are going to cover in the next little while.

So, but before that let us look at what we were discussing that we have seen that there are lots of different advantages, but there are disadvantages also of these stationary sensor networks. So, there let us say that when in a stationary sensor network when one or more sensor nodes fail over time that can result in the network to be partitioned and once the network is partitioned because of that reason there is no other way, but to replace the node the node which has failed and is causing the partitioning in the network there is no other way, but to replace those nodes. So, this is very crucial because you know partition networks will not be good because you know the data will be lost in between from the source node, it will not be able to that the data that is sensed the information that is sensed will not be able to be delivered to the intended destination node or the sink node.

So, another disadvantage is that the topology cannot change automatically in these networks right. So, the topology is the physical topology there is another concept when we were talking about topology management we have seen that there is another concept of topology where we are concerned about you know topologies due to the fact that the nodes they have certain sleep cycle you know and the management of the sleep cycle

results in a dynamic topology similarly clustering leads to dynamic topology and so on. So, we are not talking about that we are talking about the physical topology. So, once the nodes are deployed in the in the region of interest the physical topology does not change. So, that makes it very simpler, but that is a disadvantage as well. So, that is the disadvantage. So, let us look ahead further.

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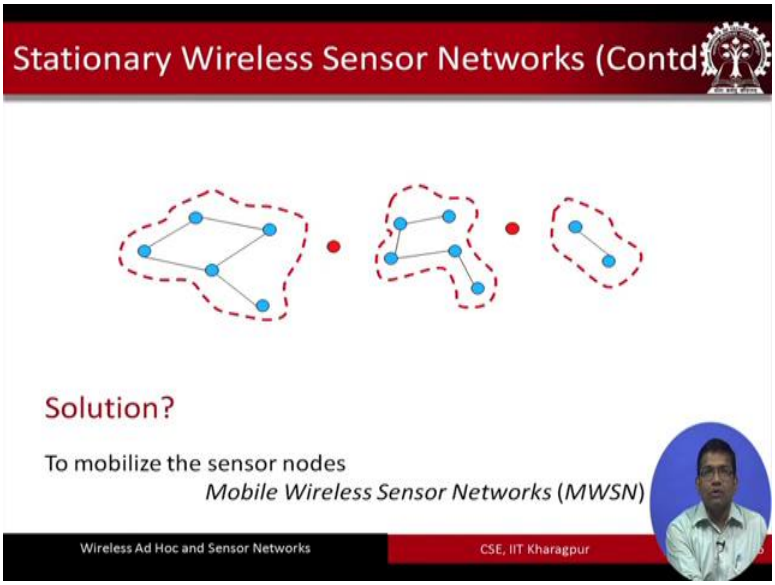

So, let us now consider a stationary deployment of sensor nodes as shown. So, here we have a fully connected network of nodes, but what happens is the red coloured nodes basically they depict scenarios of failure. So, this node is a point of failure could be a point of failure and this node would be a point of failure and if that happens. So, if these nodes fail for one reason or another maybe battery is depleted in these nodes because of which they cannot function in further or maybe some hardware software component has failed because of which these nodes are not able to operate any further.

So, in such a scenario what would happen is we would get something like this where the entire network is partitioned into three. So, we have three partitioned networks like this. So, this is one partition this is the second partition and this is the third partition and this is not very desirable.

So, what is the solution the solution is that this is happening because none of these nodes were mobile? So, these nodes were stationary. So, once we have failed they have failed and there is no other way, but to go and replace these nodes in failed nodes and re

establish connectivity; however, if we had a mobile sensor network meaning that one or more of the nodes in the network is mobile; that means, they can move from one point to another. So, in such a case what could what could have been done is some nodes could have gone and you know they have they could have taken the position of the failed nodes and would have in turn helped these disconnected partitions to reconnect back again.

So, mobility has lot of advantages this is one advantage that overall the there could be dynamism in the topology of the network that would be established and because of which because of the dynamism in the topology the because of the by virtue of the movement of the different nodes one would be able to maintain connectivity between the different nodes in the network into an connectivity between the different nodes in the network resulting in improved partition sorry improved performance and reduced downtime of the network.

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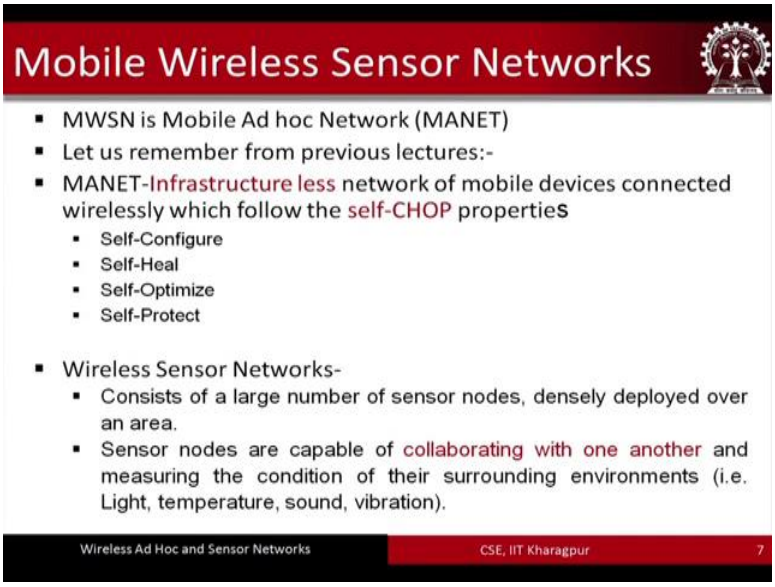

So, when we talk about mobile sensor network what we are talking about is trying to fuse the concepts of mobile ad hoc networks that we have learned before along with the sensor networks the stationary sensor networks the concepts the first part of this course in the first part we had talked about mobile ad hoc networks. So, there the nodes were all mobile. So, let us say that you know if we are talking about our cell phones or you know laptop, PDAs, etcetera, etcetera forming an ad hoc network. So, then the nodes are inherently mobile. So, we basically take the ideas from these mobile ad hoc networks

and also we take the ideas from the stationary wireless sensor networks and we fuse them together in order to form the mobile sensor networks.

So, and by doing that what we are doing is we are also inheriting the properties of both MANETs and sensor networks stationary sensor networks properties like infrastructure less ness that we had seen of MANETs properties like the self chop properties like self healing self configuring self optimizing self protecting and so on. So, these self behaviours we inherit in the mobile sensor networks plus we also inherit the properties of stationary sensor networks where accept the stationarity part. So, where basically you know we are talking about having large number of different sensor nodes which are individually physic physically sensing the phenomena that are occurring around them individually and collaborating with one another to send the sensed information from the source from the source point of source of sensing to the intended destination or typically the sink node of the base station.

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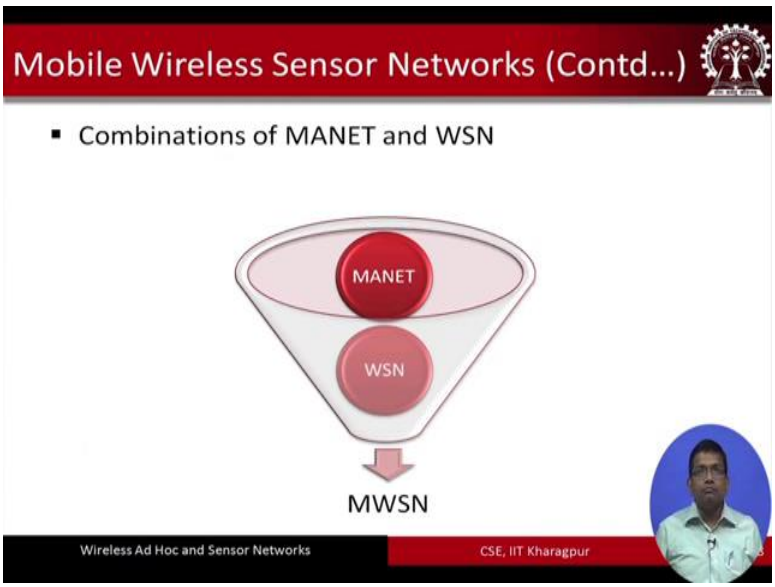

So, we basically fuse these 2 concepts. So, this is what is pictorially depicted over here. So, we have the properties of MANETs plus wireless sensor networks the stationary ones to give us the properties of the mobile wireless sensor networks. So, when we talk about mobile wireless sensor networks.

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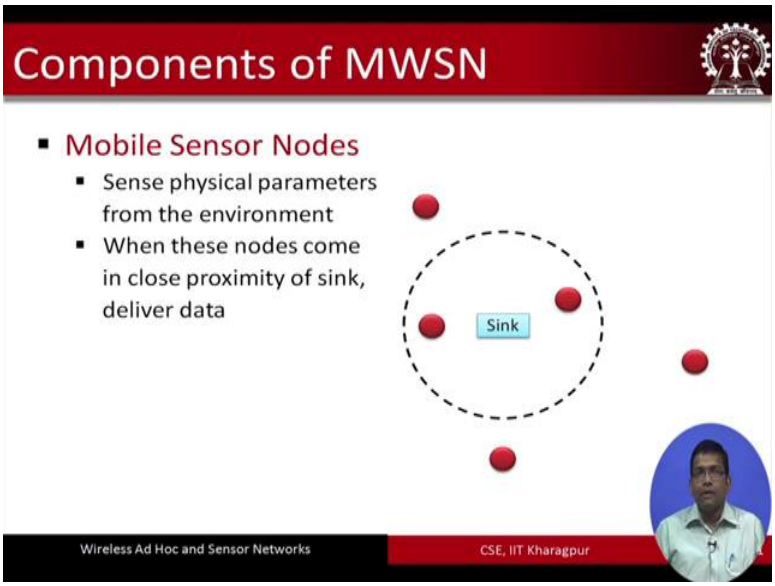

So, there are different sorts of mobilities that can happen. So, in if this you know in any wireless sensor network we have broadly 2 types of nodes one is the regular sensor nodes and the other one is the sink node additionally in a mobile sensor network we could have another node which is called the data mule. So, the task of the data mule is basically to physically collect the data from a particular node and go and give it or deliver it to another node from one node to another physically transferring the data that is done by the data mules.

So, data mule could be a some a some sort of a robotic device for instance which will come in close proximity of a node which is stationary and collect the data and then it will move itself and go to the intended node where it has to dump the data to and then the data will be transferred to that intended node.

So, let us take one by one. So, we what we have we have three classes of nodes now in mobile sensor networks one is the regular sensor nodes which basically sends the environment which are tasked to sense the environment around them or the physical phenomena that are occurring around them. So, we have this is the first class the second class is the intended destination node which we refer to as a sink node and a third in mobile sensor networks specifically is the data mules. So, let us look at the components of mobility and the different scenarios that arise due to the mobility of each of these classes of nodes. So, let us consider that we have these red coloured sensor nodes and a

sink node as shown over here. So, let us say that these nodes they are sensing the physical phenomena of the environment physical parameters of the environment around them.

So, these nodes when they come in the close proximity of the sink they can deliver the data earlier what we have seen is the these nodes these 2 nodes that just came into the region of the sink node they were outside the transmission or the communication range of these of the sink node. So, because of which they were not able to communicate with each other, but they can physically move into the radius of the sink node and by virtue of doing that they would be able to send their data deliver their data that they have collected from the earlier location the sense data that they had collected and they would be able to deliver to the sink node.

So, what have you seen we have seen that even if we do not have hundred percent coverage let us say you know hundred percent area coverage to be you know to be more clear let us say that we are considering area coverage and with fewer number of nodes we may not be able to cover a big area. And in such a case the spatial coverage due to the reduced spatial coverage by these few sensor nodes it might be possible to have lot of places which are like coverage holes which do not get sensed and also the same thing can be extrapolated for the communication as well. Let us say that with fewer nodes the nodes which are sense the information they will not be able to communicate to the intended destination node as such if there is no other intermediate nodes which can relay their packets.

So, basically by introducing the mobility of these sensor nodes what happens is with fewer number of nodes in a particular area the data the data communication can takes take place; that means, the sense data by these different individual nodes they can be sent to the intended sink node even with lesser number of nodes in the region. So, both with respect to sensing as well as with respect to communication with fewer number of nodes by adding mobility to these nodes you can have a spatiotemporal cover coverage not just spatial coverage spatial coverage is difficult with fewer number of nodes, but with respect to time these the trajectories of these nodes can be planned in such a way that spatiotemporally you can get better coverage.

So, this is the whole idea of adding mobility to the different sensor nodes let us now go back and look at another scenario. So, this is what I just told you that these nodes they come in close proximity with each other and not each other, but with the sink and they deliver the data to the sink node.

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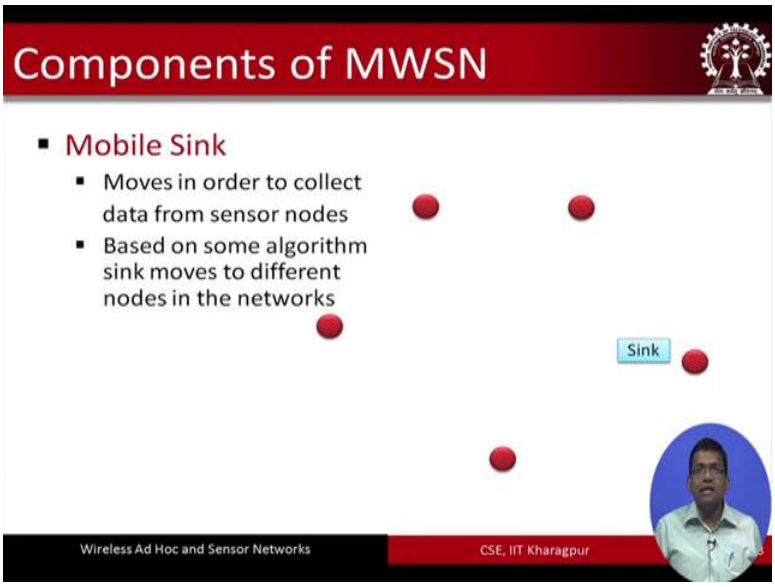

Let us now consider the different scenario where the sink is mobile; sink is mobile. So, the sink node basically what it does is it moves and collects data from the sensor nodes in the earlier case we had seen that the sink was state stationary the sensor nodes were mobile. So, once they have sensed they would come in close proximity of the sink node if that was not already the case and then they would transfer the data that they had sensed now in this particular case, what we see is we have the sink node which will be mobile and the other nodes are stationary.

So, what this sink node is going to do is it is going to physically come closer in the close proximity of each of these stationary red coloured sensor nodes and then it would collect the data that has been sensed by each of these nodes. So, let us look at this figure in order to understand this concept better you see how the sink node changed its position original position came in the close proximity of one of these sensor nodes the red coloured sensor node and then it would get the data like this the same thing is going to repeat. Now the sink node goes to another node sensor node gets the data from that sensor node it moves again and so on it continues with the same operation.

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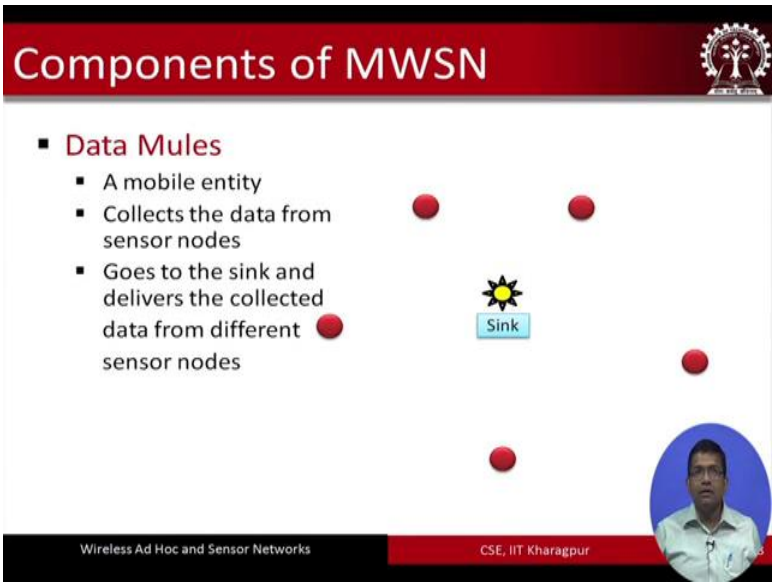

So, it will go; I mean whoever are the intended sink intended sensor nodes it is going to come in close proximity with those sensor nodes and the sink is going to get all the data now the third category of mobile nodes in mobile sensor networks is the data mule which I spoke about earlier.

So, here basically a mobile data mule is just a mobile entity and as the name says that this entity basically collects the data from the sensor nodes and goes to the sink and delivers the collected data from these different sensor nodes. So, like this. So, this let us say that this is the data mule. So, you see how it goes to the different sensor nodes and then it will go to the sink node and deliver the data that has been collected from each of these red coloured regular sensor nodes in the network.

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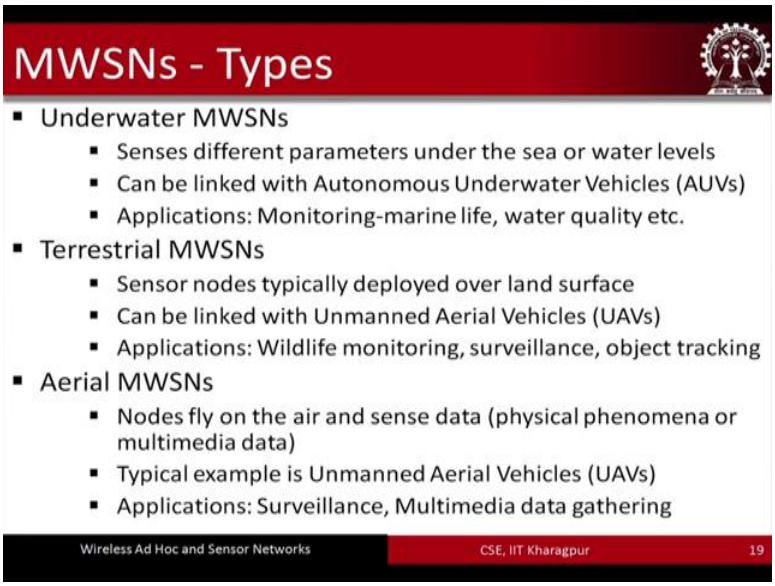

So, this is what we have seen that; what are the different entities in a mobile sensor network and how they can move in order to increase the performance of the network? Now these mobile sensor networks they can be of different types mobile sensor networks could be deployed in the terrestrial environment. So, far actually we were assuming that we have a terrestrial environment, but the concepts that we have co covered. So, far could also be applied to other environments like underwater environments or aerial environments. So, essentially we could have terrestrial mobile sensor networks we could have underwater mobile sensor networks and we could have aerial sensor networks mobile sensor networks.

So, as these names suggest terrestrial mobile sensor networks are deployed over a land surface or in terrestrial environments and again you know. So, it could so happen that essentially what would happen is you have some robotic devices like this which would be move moving in the terrain and they would be collecting data or they would be transferring data depending on their roles and by virtue of doing all these different things they would be that the overall communication is going to sustain.

Now, the applications of terrestrial mobile sensor networks could be for wildlife monitoring surveillance object tracking and so on and as I said that the similar concepts could also be applied to underwater environments where the sensor nodes which are deployed in this environments they would be having their own mobility. So, if you recall

what we discussed for underwater environments earlier that underwater sensor network underwater mobile sensor networks the nodes in these networks they can get mobility which is active; that means, they actively want to move from one place to another maybe they have a propeller or something like that attached to each of these nodes and the other one is the passive mobility passive mobility arises due to the fact that once these nodes they are floating. So, there could be different ocean waves or currents which could hit them and these nodes are going to be displaced from their original positions.

So, that is both passive mobility. So, one is active mobility where the nodes intentionally want to move from one point to another and the other one is the passive mobility. So, you can you have an additional type of mobility in underwater sensor networks. So, this active mobility can be had with the help of a type of device called autonomous underwater vehicles AUVs, UAV is basically can also act like sensor nodes in these environments along with there could be other floating sensor nodes like our like the you know like our regular sensor node that terrestrial wants you know you have some kind of you know you attach them to some kind of a boy or something like some other rotational device and because of which these nodes they are going to float. So, these floating nodes they could be transferring the data to the autonomous underwater vehicles UAVs or even the UAVs could also be sending data that the different sensors in these UAVs have sensed and together you can have a mobile underwater sensor network.

So, typically these mobile underwater sensor networks are have different applications covering monitoring the marine life then you know tracking the water quality of a particular part of the ocean where it has been deployed or there are different other surveillance also surveillance is another aspect of another interesting application of mobile wireless sensor network.

Then we have the aerial mobile sensor networks where you use something called UAVs unmanned aerial vehicles these unmanned aerial vehicles are going to be fitted with different sensors and these nodes are going to fly in the sky and because of which. So, you have la large number of different nodes which are going to aerially cover a particular region and they are going to sense continuously and they are also going to change the positions from one point to another they are going to move as a whole individually within the swarm as well they are going to move and they are going to not only move, but they are going to communicate with each other they are going to communicate with

each other. So, essentially they would communicate with each other they would sense they would communicate with each other in a multi hoc fashion and then send the sensed information aerially from these unmanned aerial vehicles to the ground station and this is how you know for certain aerial applications these UAVs could be used to sense the different parameters in the sky.

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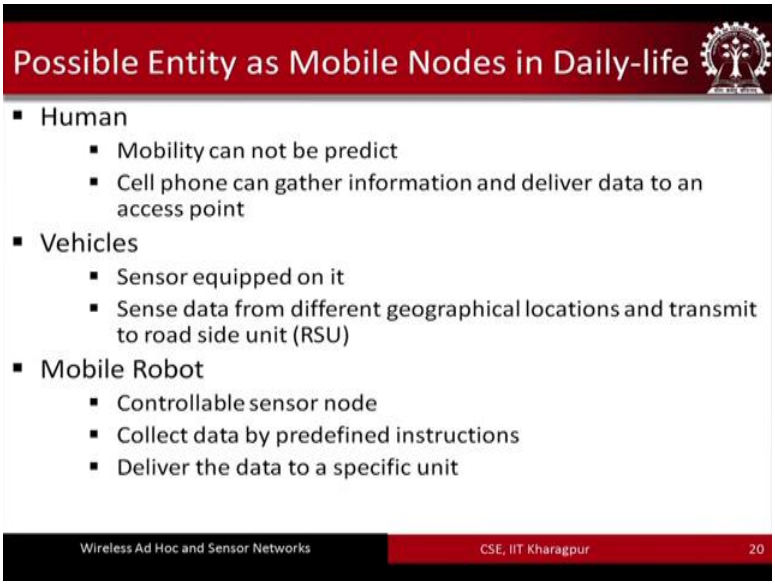

So, there could be you know. So far actually when I mentioned about the mobile sensor nodes I have been telling you that we could use mobile robots now mobile robots is one type of you know mobile device that could be used these sensor nodes these mobile sensor nodes could also be like human beings human beings are also sensing different data human beings first of all human beings themselves have different sensors right we humans we have different sensors in us biosensors basically. So, not only that additionally we carry mobile phones with us because of which these mobile phones are fitted with different sensors and these sensors would in turn become mobile by virtue of our mobility and that that makes us a one of the entities that could be used for mobility in mobility of nodes in these networks.

And third is the vehicles the vehicles could also be mobile. So, if you have sensors fitted to these vehicles these vehicles because by virtue of their motion the sensors would also be mobile the sensors which are fitted to these are also going to be mobile. So, and these mobile sensors in these vehicles they are going to sense the different data for which they

have been deployed and then the data are going to be sent to the roadside units something called the roadside units in vehicular communication this terminology is used roadside units are basically like sort of like base stations along the road.

So, if we have a stretch of road where the vehicle moves. So, along the stretch of road you have some posts which are called roadside units which are like you know multiple base stations where the data that are sensed by these vehicles are going to be sent directly to and these are along the roadsides. So, that is why they are called as the roadside units or the RSUs.

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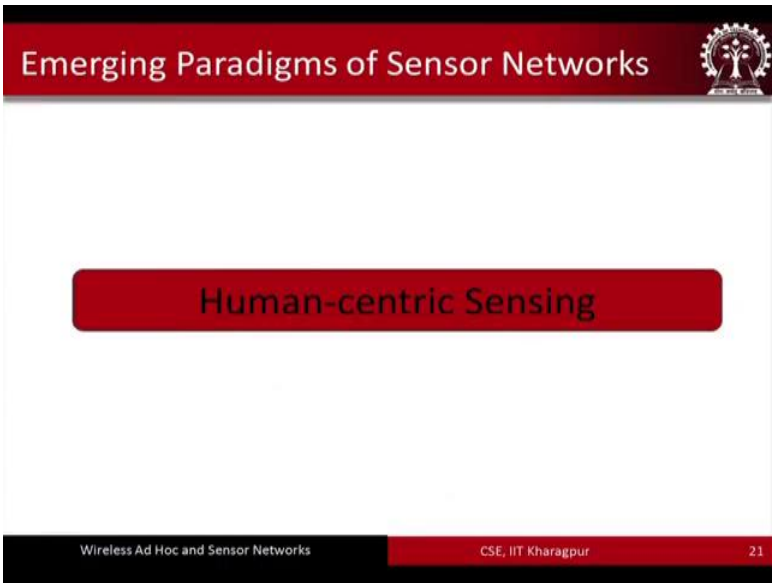

Now, the other forms of mobility because of vehicles or because of mobile robots is something that can be imagined quite easily that could be understood quite easily there is an interesting type of mobility due to human cities. So, the humans as I said earlier could also sense the humans could sense themselves humans could be using mobile phones which have their sensors individual sensors. So, because of the mobility of the humans what would be happening is you would be having a mobile sensor node which is a human being basically mobile sensor node which is a human being. So, this is called human centric sensing these mobile human beings which are acting like the sensor nodes they are going to sense and they are also going to moves you have human centric sensing due to this particular phenomena.

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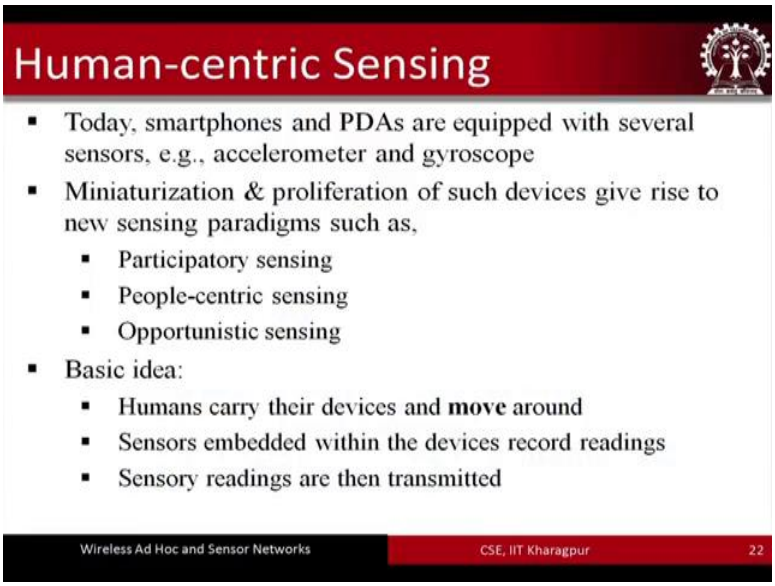

So, this is something that I have already mentioned these current days smart phones p d as etcetera are equipped with lot of different sensors accelerometers gyroscopes etcetera. So, and also due to the miniaturization and proliferation of these devices the smart phones etcetera currently almost everybody has a smart phone nowadays. So, that basically gives rise to these phenomena of human centric sensing which can be further classified into different categories called participatory sensing people centric sensing and opportunistic sensing.

So, basically as the human beings carrying these devices are moving around the sensors that are embedded in them they are going to record their readings that they are supposed to you know that they are supposed to read and then we sense sensed readings are then going to be transmitted further. So, this is what happens in human centric sensing.

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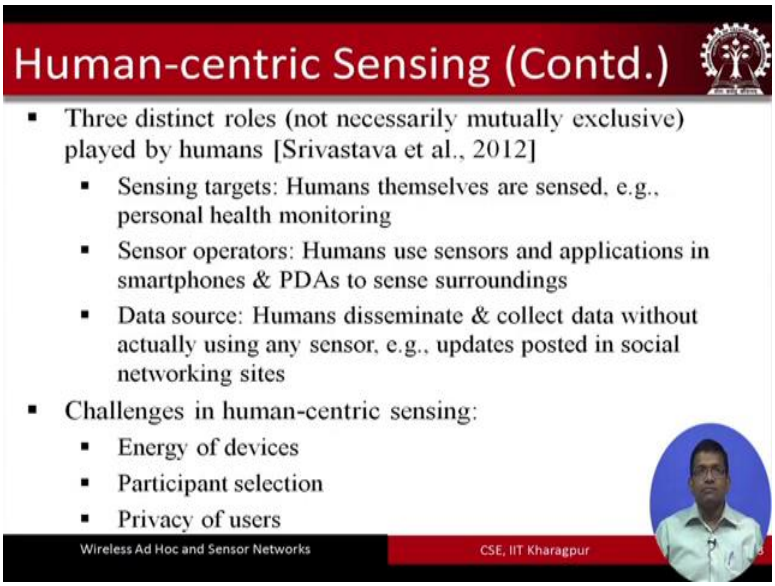

There are three distinct roles in human centric sensing one is the sensing of the targets. So, human humans themselves are sensed. So, for example, you know when we have different physiological sensors that are fitted on the human body. So, our physiological parameters are going to be sensed. So, human is a physiological parameters personal health conditions are going to be sensed this is number one sensing of the targets.

Secondly, sensing of the operator sensor operators; so humans use sensors and applications in smart phones and PDAs to sense the surroundings and the third is the data source the humans disseminate and collect data without actually using any sensor without actually using in the sensor example updates posted in the social networking sites. So, this is the third role that is played by the humans in human centric sensing and the challenges in human centric sensing are that first of all the energy comes back once again.

So, the energy of the devices are very limited and you know participants which participants are going to be selected for forming the network that is a very important challenge. So, who are going to participate in the network that is a very important challenge additionally as you can understand that when we are talking about humans as nodes sensor nodes in these networks privacy becomes a very important issue privacy of the users. So, let us say that the sensed information from one human being is going to the intended destination like the sink node through intermediate nodes which are also

humans and that basically as we can understand or imagine that invites lot of privacy issues. So, these are the different important challenges in human centric sensing.

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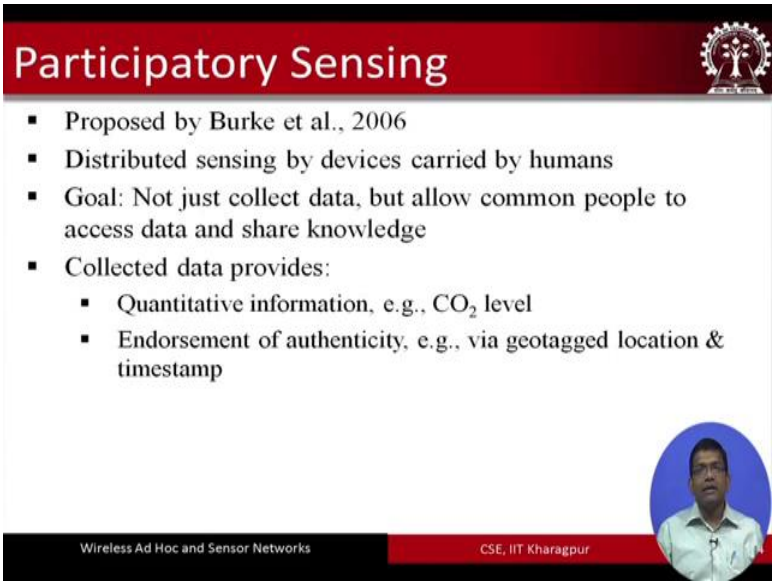

So, first participatory sensing it was proposed by Burke et al in 2006 which basically constant distributed sensing by devices that are carried by the humans the goal is not just to collect data, but allow the common people to access the data and share the knowledge. So, quantitative information with respect to let us say carbon dioxide level or you know so, different poisonous gases, etcetera, etcetera for air quality monitoring kind of inform application. So, that that data can be collected by these different nodes as they move around this is one thing the second thing is the endorsement of authenticity.

So, these different nodes they have to be geotagged and geotagged information has to be retrieved because you know there is no point in getting CO2 level information if we do not know the exact geological geographical location from where it is coming right. So, geotagged location and timestamp this is another; this is very important issue. So, what we have is how do we know, how do we know that it is coming data is coming from an authentic authentic source not only authentic source, but the geotagged information; that means, the exact geographical location that is coming is the correct one how do we know that. So, these are the different challenges with respect to the collected data.

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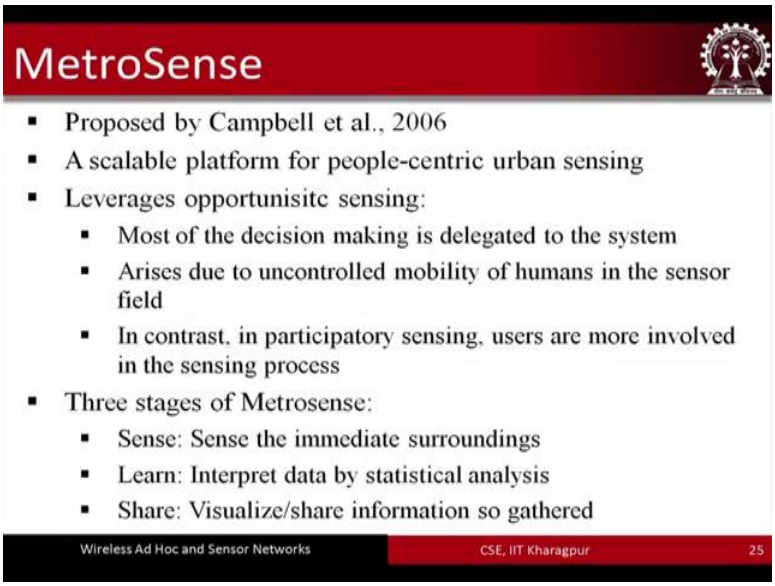

There are 2 projects one is the Metrosense project which was proposed by Campbell et al on this human centric sensing in urban environments and which basically leverages opportunistic sensing. So, where most of the decision making is dedicated to the system and it arises due to uncontrolled mobility of humans in the sensor field.

So, you see we can have 2 types of mobility due to humans one is the uncontrolled mobility; that means, that human beings they can be moving all around you know you do not know it is unpredictable that how this move human being is going to move right. So, that is not only human beings, but uncontrolled mobility can scenarios like this can happen with other animals as well as the animals move we do not know that where the animal is going to move at the next instant of time.

So, this is uncontrolled mobility the other one is control mobility con in case of control mobility if we are talking about control mobility in the case of humans the humans basically know exactly how the human is going to human being is going to travel in the particular region, but control mobility happens move in the case of mobile robots where the mobile robots are pre programmed to basically follow a particular trajectory over time.

So, that is control mobility and uncontrolled mobility is more common in the case of human beings other animals and so on, but as I also said that control mobility is also possible with humans and humans particularly human beings you know if they know

exactly and if they declare the trajectory that they are going to take and that can be controlled let us say that somebody you know verbally informs that this is the next direction that you have to take. So, that becomes the control mobility even with humans.

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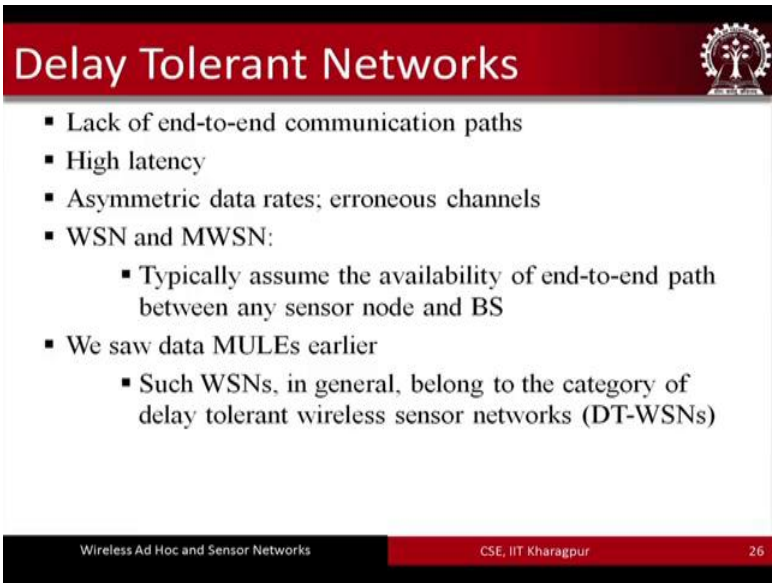

So, the last thing that we are going to cover is the delay tolerant networks where in these networks that is lack of end to end communication paths, there is high latency and the channel has asymmetry data rates and the channel is typically very much error prone. So, wireless sensor networks are mobiles wireless sensor networks, they typically assume the availability of end to end paths between sensor nodes and the base station, but we have seen earlier that data mules can be used and as such in sensor networks belonging to this category in general you know delay tolerant kind of environments is going to arise.

Delay tolerant wireless sensor networks are going to arise because there may not be end to end connectivity between the different nodes in such a network. The data mules; they are going to come in the close proximity of the different nodes and then the data that has been buffered in each of these nodes the that data is going to be dumped into the data mule the data mule is going to move to the next node keep on collecting moving and so on until it comes into a close proximity of the sink node to deliver the information.

So, as we have seen that these kinds of scenarios are basically you know delay tolerant kind of scenarios. So, delay tolerant means that there is as such know end to end connectivity between the sensor nodes and the sink node, but these you know these

nodes we are not going to drop the packets immediately, but they are going to buffer the information; the sensed information that they have for certain duration of time until there is some node which comes in close called proximity with them and they can deliver that sensitive data that they have their buffer.

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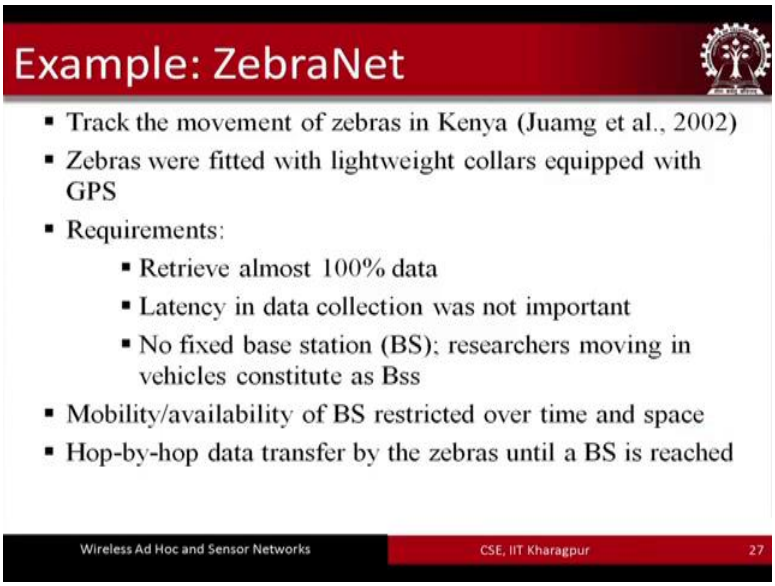

Finally the zebranet; so, as this name suggests again this was a project that was performed in executed in Kenya to track the mobility of the zebras and the zebras in this particular project in their colors they were fitted with GPS and the requirement was to retrieve data from these zebras as these zebras were moving around and how they move basically to understand their mobility etcetera, etcetera.

So, in this particular project, latency was latency data collection was not very important and there was no fixed base station. So, the researchers moving in the vehicles constituted as the base stations which; that means, that there was no single base station, but this base station where mobile again and the mobility or the availability of the base station restricted over time and space. So, this is what was typical of this zebra net and the data was transferred from the zebras to the base station in the hop by hop manner.

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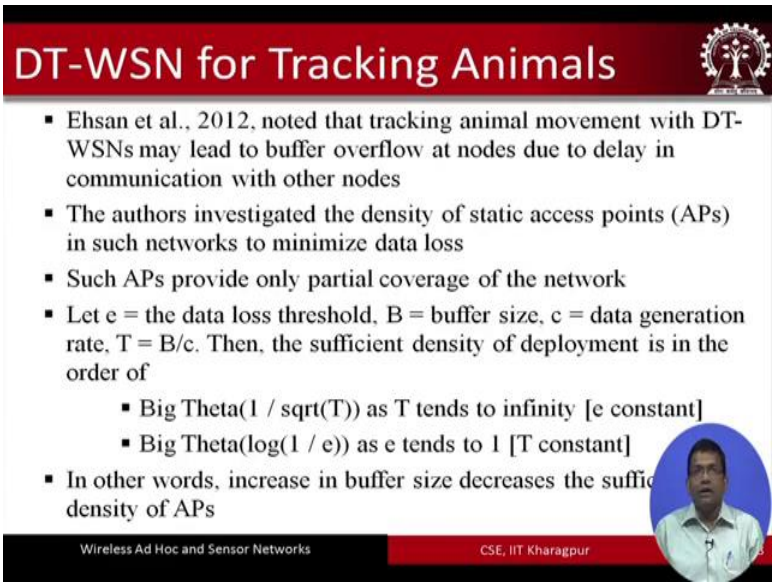

So, this was the example of the zebra net project which was a mobile sensor network project which was used for tracking the animals the zebras and similarly there was another one that was performed by a very similar kind of project that was executed by Ehsan et al in 2012 for tracking the mobility of the animals these animals again. We are fitted with different sensor nodes as these nodes as these animals moved the sensor nodes also got their mobility etcetera and that is how is animal that that is how the sensor mobile sensor network was obtained.

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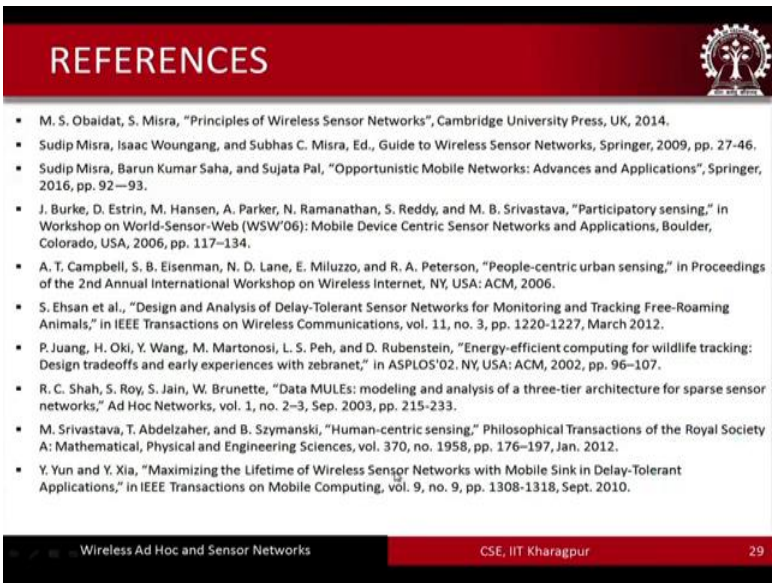

So, here are some of the references on mobile sensor network some of these are very interesting the last one particularly is very important maximizing lifetime of wireless sensor network with mobile sink and so this is very important because you know when we have a mobile kind of environment where the sink node or any other node is moving the lifetime becomes very important because you know you are using these constant resources in each of these sensor nodes much more than you would be using in the case of in the case of a stationary sensor node. So, it is very important to maximize the lifetime understand the lifetime how it can be maximized and so on in these mobile environments.

Thank you.