Introduction to Internet of Things
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Lecture - 19
UAV Networks

So far in the previous lectures we talked about networks, which are going to operate on the ground typically. But it is also possible for networks to be formed out of flying objects. So, we have flying networks. So, these flying objects could be different things like the these could be aero planes, helicopters, you know several helicopters, inter network together or few small, small planes which could be inter network together or nowadays we have these UAVs or drones more popular are the quad copters. These quad copters could be acting as these flying objects. And if we have a several such quad copters flying together we can inter network them we can network them together, So that they can communicate between themselves and they can go about accomplishing some missions.

And this particular, this particularly is very much attractive for different types of applications civilian applications, and particularly for military applications this is very, very important. For example, is form of UAVs, a network of UAVs could be going and accomplishing some task across the border maybe, performing some recognize a survey between 2 countries, border bordering 2 countries right.

So, in the borders the swarm of UAVs can go and it can surveyed. Similarly, if there is some kind of a disaster. Post disaster you know taking stock of the situation a swarm of UAVs can go take stock of the situations maybe through their cameras or whatever and come back. So, they have to interconnect they have to talk to each other and then send that sensed, sensed or you know collected information to the ground station. This is done using something known as the UAV network.

So, in plain and basic terms, UAV network is a network of UAVs. So, quad copters for example, or drones more generally can be internetwork together to form UAV networks. So, there are different features of UAV networks.

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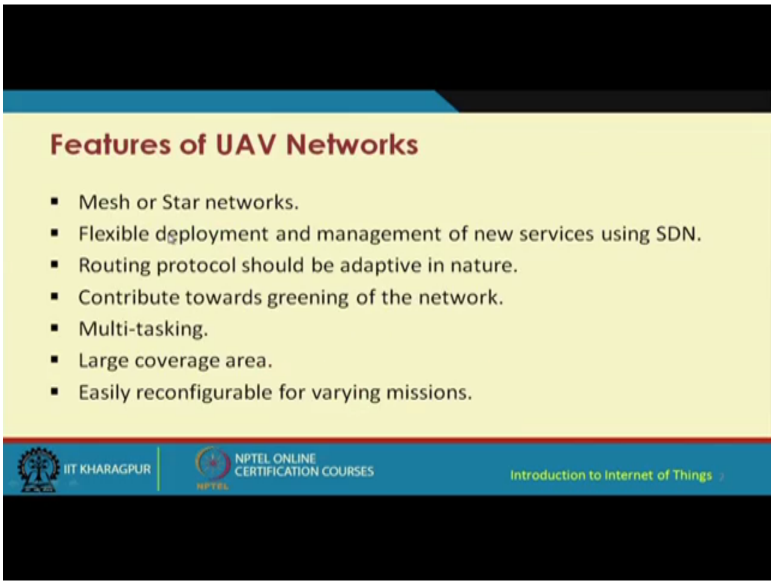

So, first thing is the topology. So, we are talking about a network which is highly dynamic, the topology is fast changing very fast changing, compared to this you know the terrestrial networks, compared to the terrestrial or ground networks. Because these are flying objects and they fly at very high speeds, the topology itself will be changing very fast. And the network itself will be moving together. And consequently the dynamic, dynamism in the topology is going to be very much.

So, there are 2 types of popular topologies that are used to have to model UAV networks. One is known as the star topology. I will show you what is the meaning of star topology. And then we can have a mesh topology which is, attractive in the sense that you know mesh basically mesh kind of topology for any network ensures reliability and fault tolerance. So, mesh networks are very very attractive and, but at the same time star topology is more common and are easily deployable. Then the second feature is the flexible deployment and management of new services using SDN.

So, now a day's people are talking about using SDN to manage UAV networks for deploying flexibly deploying and managing different services. The routing protocols should be adaptive in nature, should contribute towards greening of the network. And, multi tasking, multi tasking is a very important feature. So, these nodes you know, so these flying nodes these quad copters for example, in a UAV network they could be doing different things together, they have to do different things together. And that is a very important feature of UAV network.

Then another very important feature of UAV network is that, you can cover you can offer connectivity over a larger area. So, you can have larger coverage of connectivity or sensing coverage also can be expanded with the help of UAV networks, because these are fast moving flying networks comprising of different flying nodes. So, this could be easily configure reconfigurable for varying missions. So, depending on the mission these networks can be you know programmed or predefined or reconfigured or preconfigured in different ways.

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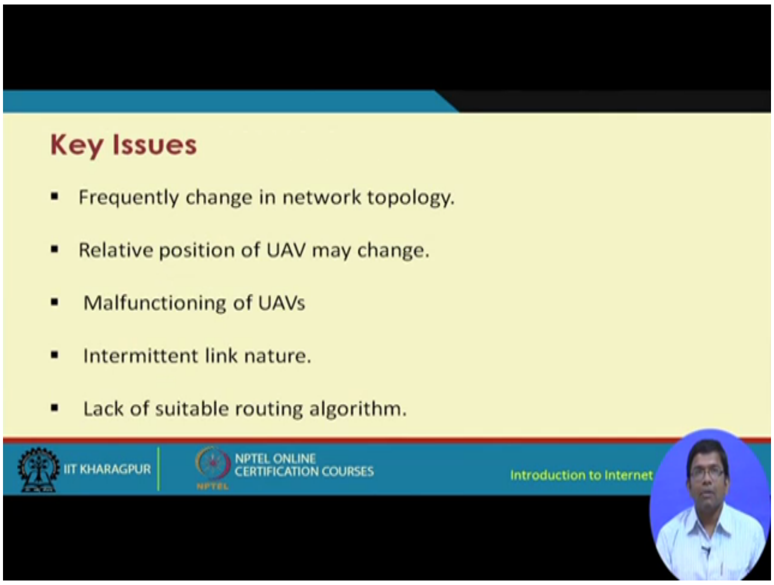

So, the key issues here are that we are dealing with a different type of network, where the topology is going to frequently change, very frequently change. Then the relative position of the UAVs may also change very frequently because within a group these nodes are going to change their positions pretty fast. So, we have a network where not only the network is moving very fast, could be moving very fast, but also these nodes in that particular network they could also be changing their positions pretty fast.

Then the third feature is malfunctioning. If there is some malfunctioning in the network, if there is some malfunctioning in the network maybe a particular node you know the hardware has failed it does not fly any further. Then these networks are developed in such a way that they can still continue to function, they can still continue to function in the presence of malfunctioning. They will reform the network the topology is going to be reformed, the topology is going to be changed and they are going to function. And the next one is intermittent link nature. Which means that because this topology is changing, because the internal node positioning is going to change dynamically over time, the links are going to be also changed you know, so 2 nodes they might be linked up at one instant of time. Then with one of these nodes another link might be set up in another in a instant of time and so on.

So, intermittent link connectivity, intermittent connectivity sometimes these links might be you know these nodes might be able to communicate over a particular link at a few other instance they may not be able to communicate over the links and so on. So, intermittent link connectivity and, lack of suitable routing algorithm is another feature. So, basically you know what happens is because it is a highly dynamic different kind of network that routing algorithms like AODV DSR etcetera, that are available for ground ad hoc networks or ground terrestrial sensor networks are not usable per se in these kind of networks which are highly dynamic, much more highly dynamic than even manets mobile ad hoc networks.

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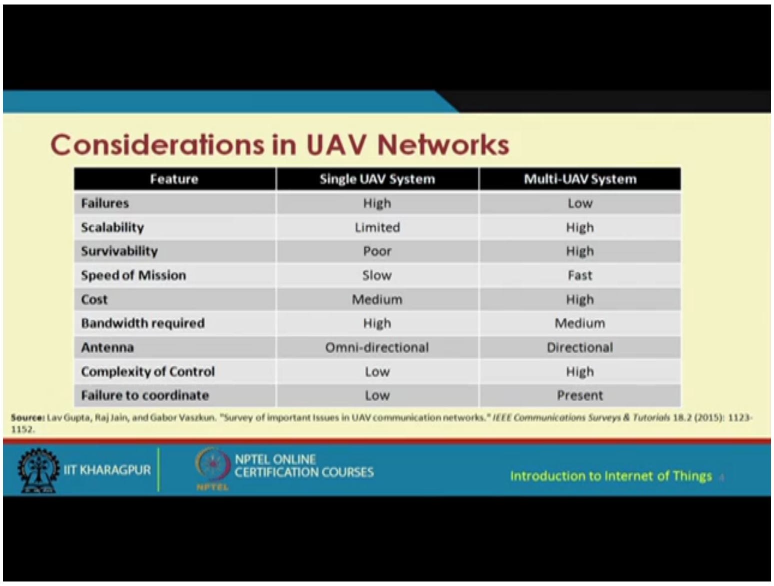

Here are some of the considerations in UAV network. We have a single UAV system and we have a multi UAV system. Failures single UAV system the chances are high. In a multi UAV system the chances of failure are low. Failure of the system as a whole, we are talking about failure of the system as a whole, and this is quite obvious. The scalability is limited in a single UAV system, in a multi UAV system, you know, it is highly scalable. Because, if you, if you increase the few nodes you know the node the basically the network can be expanded further. Then we have the speed of mission. In a single UAV system the speed is slow, but in a multi UAV system the speed of mission is fast.

Survivability is poor in a single UAV system; survivability in a multi UAV system is higher. The cost in a single UAV system the cost is medium cost because, you are dealing with a single UAV and in a multi UAV system the cost is medium because, you are dealing with, sorry the cost is high because you are dealing with a multiple UAVs. In terms of the bandwidth requirement the bandwidth requirement over here is high whereas, when a multi UAV system the bandwidth requirement is medium. In a in the case of antennas, the antennas over here are omni directional whereas, in multi UAV system the antennas are directional. In terms of the complexity of control, it is low in a single UAV system, but high in multi UAV system.

In terms of the failure to coordinate low in a single UAV system and in a multi UAV system it is present.

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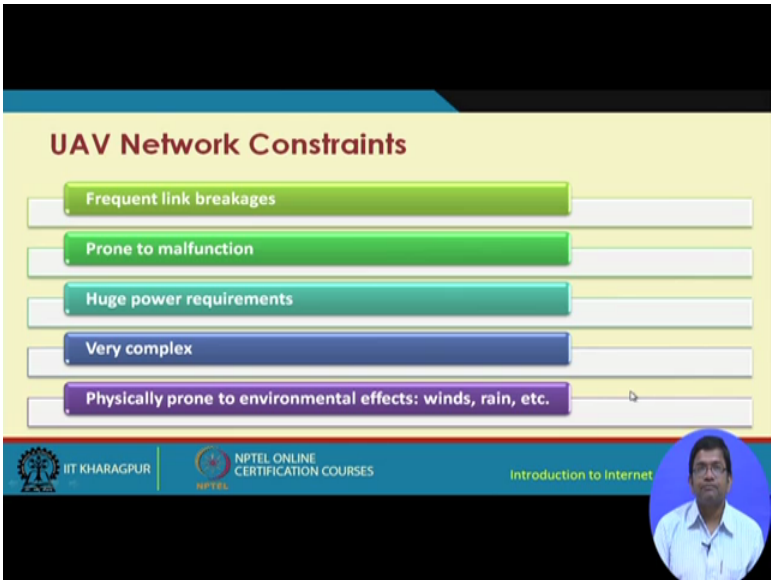

So, there are different constraints on these UAV networks we have frequent link breakages due to the high degrees of dynamism that I just mentioned. These networks are prone to malfunctioning due to one or more nodes failing, and this is quite possible in these flying networks. Then we have huge power requirements because you know these nodes are like you know high powered you know these nodes they have to fly and they have to again carry some payload, and then they have to communicate.

So, all these basically increase the power requirements per node. These networks that are formed are quite complex very complex networks because of these all these dynamisms and the complexity of changing topology, mode position, link breakages and makages and so on. Then physically these nodes are physically prone to environmental effects with respect to wins, rain etcetera. Because they operate in such kind of environment, where they are they are they are susceptible to environmental effects.

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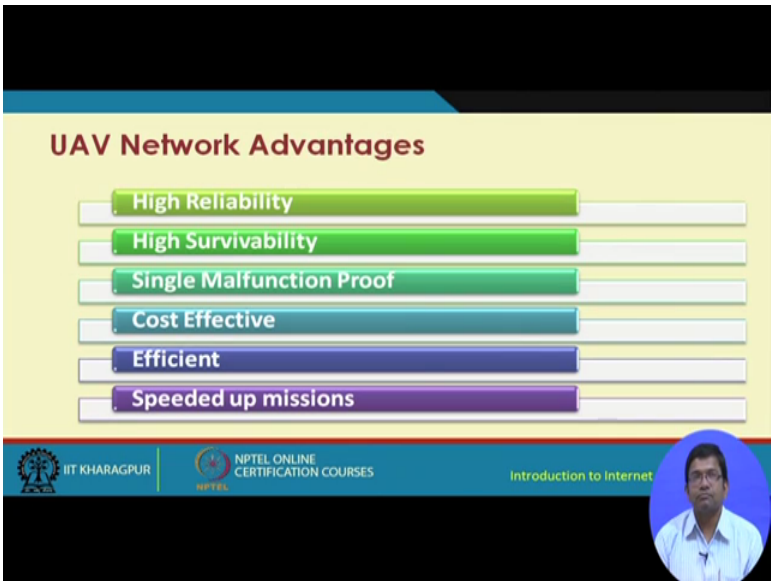

The advantages of UAV networks include high reliability. Because you know, instead of a single UAV if we are talking about several UAVs that improve in that improves the reliability of the system, high survivability is another important feature. Single mal function proof you know, if single node malfunctions you know UAV network are not going to get affected where is the single UAV systems are going to get affected. Cost effectiveness you know, In fact, you know unlike what would normally be believed you know, these networks UAV networks are cost effective. Cost effective because you know, so what happens essentially is I mean although initially you we are going to buy couple of these UAVs not one, but they can you know accomplish a mission much more efficiently compared to a single UAVs.

So, that way basically the cost is you know the efficiency with respect to cost is improved in a UAV network. Efficiency overall of the network improves in a UAV network system, and the missions can be speeded up you know. So, the time that it takes for accomplishing a particular mission that gets speeded up in UAV networks.

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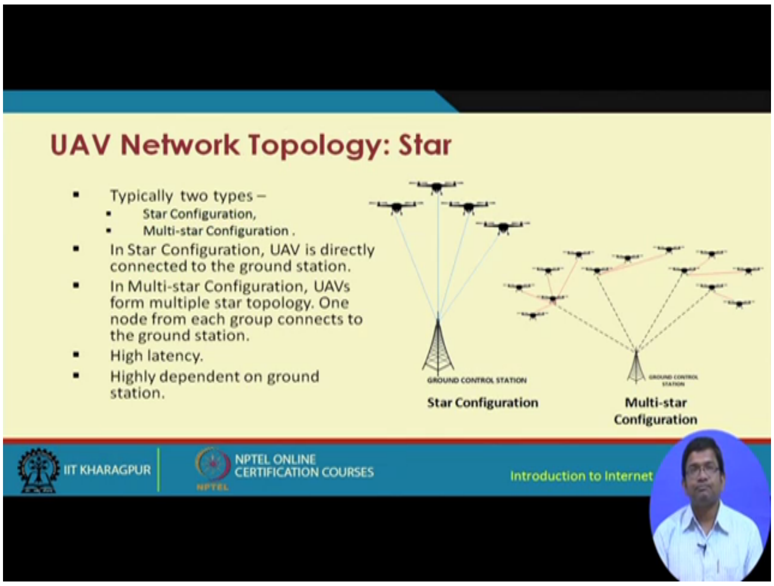

So, if you recall that initially we were discussing about the different topologies of UAV networks. So, we will start with the star topology. So, there are 2 types of topologies in star one is the basic star, and where we have this ground station. And these different UAVs basically connected directly to this ground station to form a star topology.

Then we have the multi star topology where, basically you know this particular unit is repeated and, so we have 1 star 2 stars 3 stars and 4 star 4 star topology you know 4 stars all connected to you know 4, 4 of these starts call connected to the ground station.

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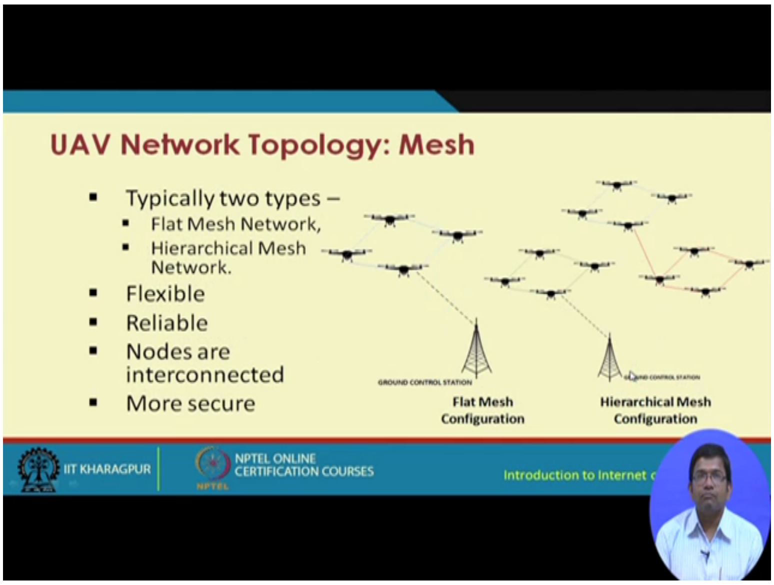

In a mesh topology, a mesh kind of topology is formed. And one of these nodes in this mesh is going to connect to the ground station like this. So, we have this unit of the mesh and this is repeated and this kind of architecture this kind of topology is; obviously, quite scalable.

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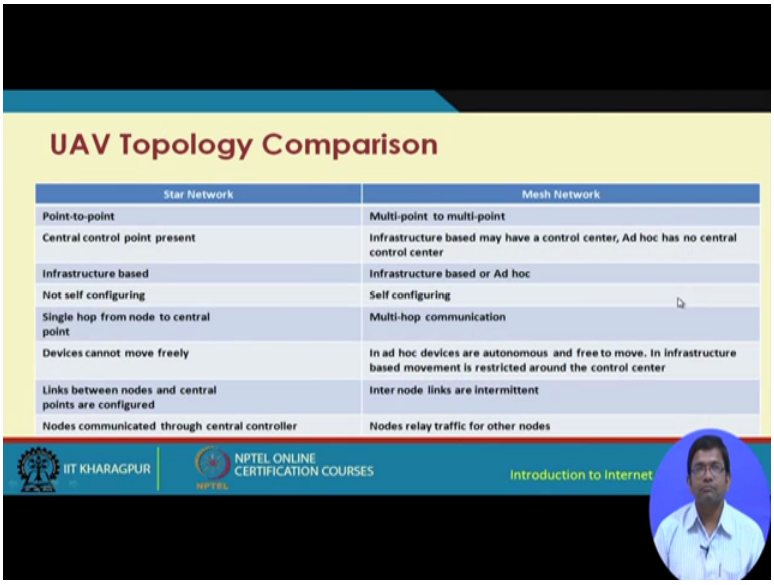

Star Network	Mesh Network
Point-to-point	Multi-point to multi-point
Central control point present	Infrastructure based may have a control center, Ad hoc has no central control center
Infrastructure based	Infrastructure based or Ad hoc
Not self configuring	Self configuring
Single hop from node to central point	Multi-hop communication
Devices cannot move freely	In ad hoc devices are autonomous and free to move. In infrastructure based movement is restricted around the control center
Links between nodes and central points are configured	Inter node links are intermittent
Nodes communicated through central controller	Nodes relay traffic for other nodes

So, when we compare the star topology and the mesh topology star topology is point to point communication, in the mesh topology we have multi point to multi point communication. Then we have the central control point present in a star topology whereas, it is infrastructure based may have a control center and ad hoc has no central control center. So, basically you know if it is infrastructure based it may have a control center whereas, if it is a adopt based then there is no control center in the mesh network.

It is infrastructure based in the star network whereas; it is infrastructure based or ad hoc in the mesh network. Likewise actually there are other properties that differentiate the star topology with the mesh topology. I am not going to go through them further, but it is given to you in this particular table for you to go through.

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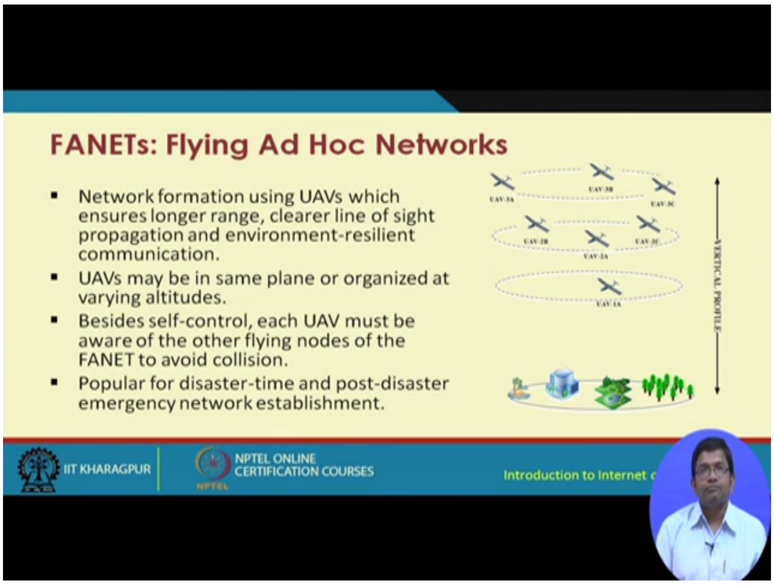

So, essentially what we are talking about is something like a flying network. So, ad hoc networks on the ground we have already we know how they work. So, there is no centralized coordinator, there is no network manager, the nodes they come together they self organize self configure and then they start working. Now imagine that that ground ad hoc network is brought up to, to fly.

So, then what we have is a flying ad hoc network. And this flying ad hoc network is known in short as fanets on the contrary, the ground based ad hoc networks are known as mobile ad hoc networks. So, we have this network formation done using UAVs which ensure longer range, clearer line of sight propagation and environment resilient communication. And these UAVs maybe in some plane or are organized at different altitudes like shown over here.

So, like these 3 UAVs are in the same plane, these 3 UAVs are in another plane and these this UAV is another plane. So, as we can see that they are they are in 3 different planes with 3 different altitudes, but these UAVs in a single plane they are they are in that same plane. So, besides self control each UAV must be aware of the other flying nodes of the flying ad hoc network to avoid collision because if that information is not known then it might. So, happen that you know there might be chances of physical collision between the different nodes of the same network.

So, this sort of network topology flying ad hoc networks is popular for applications such as disaster monitoring, post disaster monitoring, emergency network establishment and so on.

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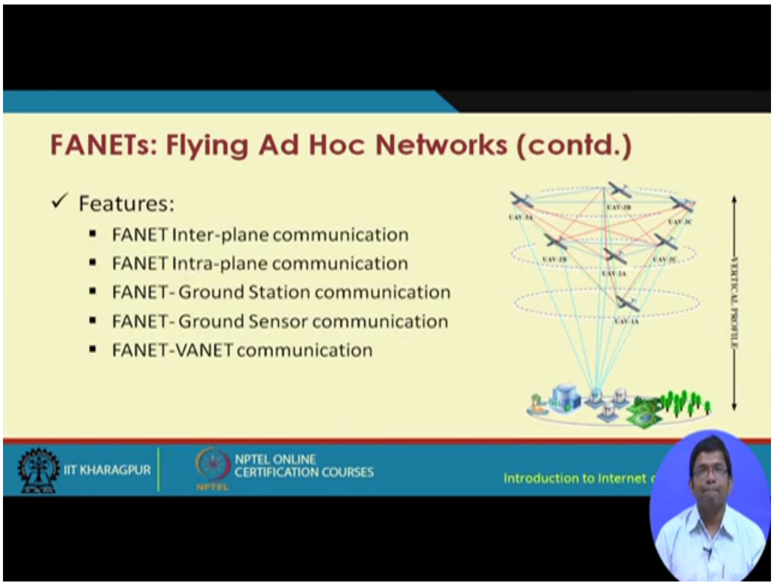

Flying ad hoc networks basically the communication takes place in different planes. One is inter plane communication. So, inter plane communication means that, so as we can see in this particular figure, we have one plane, we have second plane, we have a third plane. Inter plane communication basically takes clear you know, takes into account how the UAV of one plane communicates with UAV of another plane.

So, inter plane communication, then we have intra plane communication like, within the same plane these UAVs communicating with each other is inter plane communication. Ground station communication from a UAV in one of these planes to the ground station, is ground station communication. Ground sensor communication likewise in sensor communication with the ground and then we have fanet vanet communication, so fanet is this one that we are discussing about. Now these could be connected to vehicular ad hoc networks on the ground the vanets on the ground.

So, flying ad hoc networks vehicular ad hoc networks can be connected together to be able to communicate.

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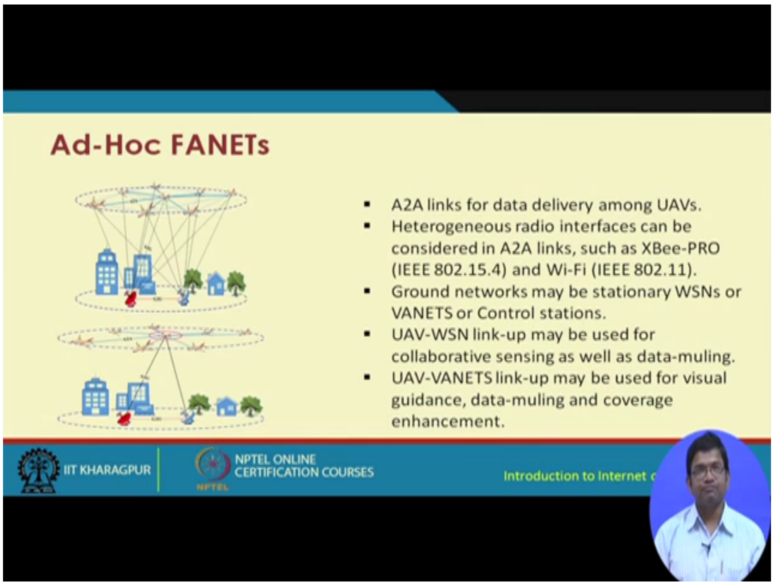

So, we have different types of links, we have the air to air links for data delivery among the UAVs. Then we have heterogeneous radio interfaces in the a to a links, using zigbee pro following 802.15.4 standard or using Wi-Fi 802.11 standard. The ground networks may be stationary sensor networks or vanets or contour stations, and the UAV-WSN link up may be used for collaborative sensing as well as data muling.

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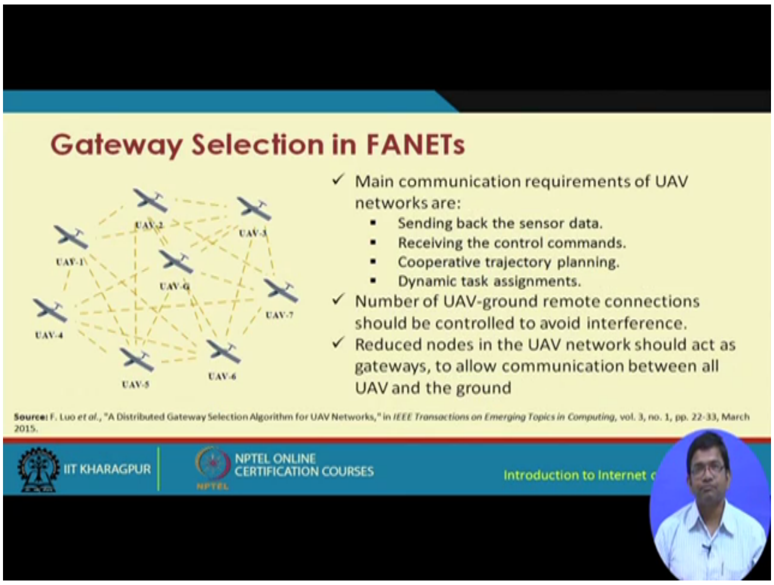

The main communication requirement of UAV networks are sending back of the sensor data, deceiving the control commands, cooperative trajection trajectory planning and dynamic a task assignments.

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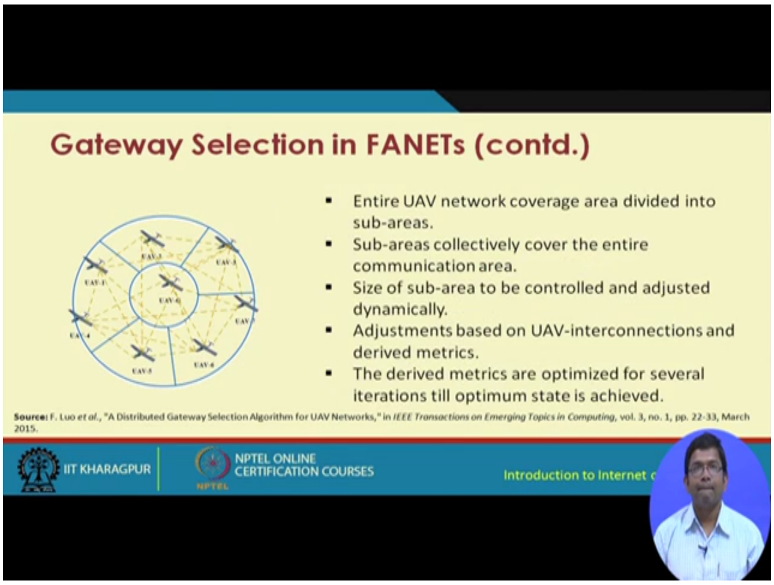

So, in this particular figure as we can see over here. We have a bunch of different UAVs, maybe working in a plane, functioning in a plane. And then we have one of these nodes which is designated as the gateway which acts as a coordinator, with all the other nodes in the same plane. So, inter UAV network coverage area will be divided into sub areas as shown over here. So, this particular coverage area is divided into sub areas like this, this, this, this and this. And the sub areas collectively covered the entire communication area. The size of a sub area to be controlled and adjust is to be controlled and adjusted dynamically. And these adjustments are based on UAV interconnections and derived matrix. The derived matrix are optimized for several iterations till optimal and the till the optimal state is achieved.

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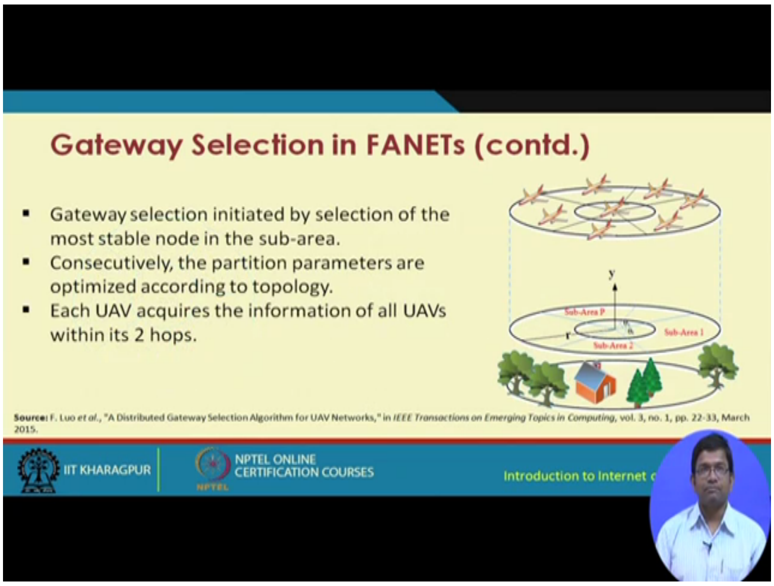

So, how do you select the gateway the gateway selection is initiated by the selection of the most stable node in a particular sub area? So, in a particular sub area the most stable node is considered. That must consecutively the partition parameters are optimized according to the topology where, each UAV acquires the information of all UAVs within it is 2 hops. So, flying ad hoc networks and vehicular ad hoc networks as you can see over here, there is a link up.

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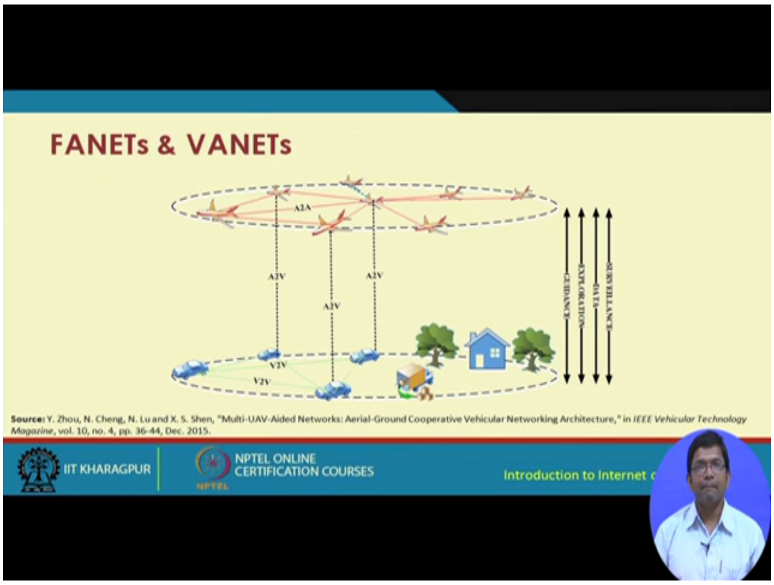

So, this is the flying ad hoc networks with a to a link etcetera, and then we have this v to v link over here in the vehicular network. And then here this connectivity shows the a to v link where, it is basically air to vehicle link.

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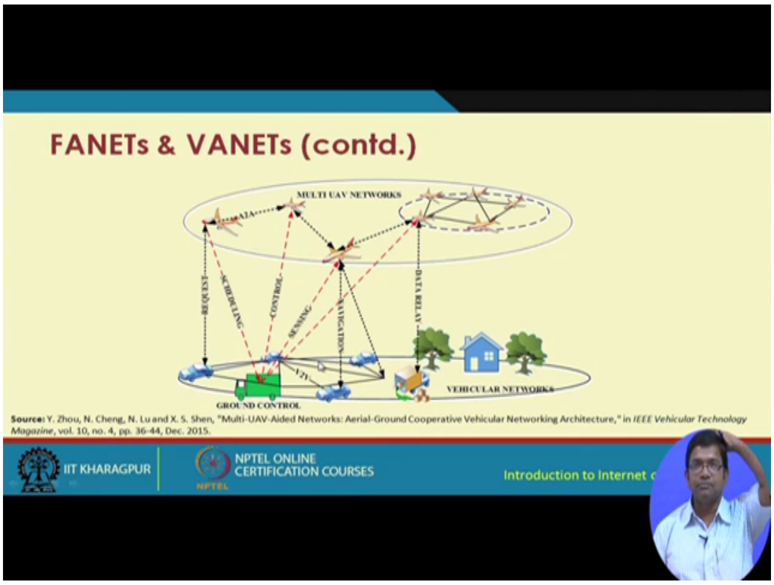

So, meshed kind of network can be formed in a particular particular plane. And then there can be different links between the UAV network and the ground vehicle between the ground vehicle and another flying node, and so on and so forth. So, like this actually the different types of communication are going to take place. So, the trajectory control for increasing the throughput how the trajectory is going to be controlled in order to improve the overall throughput.

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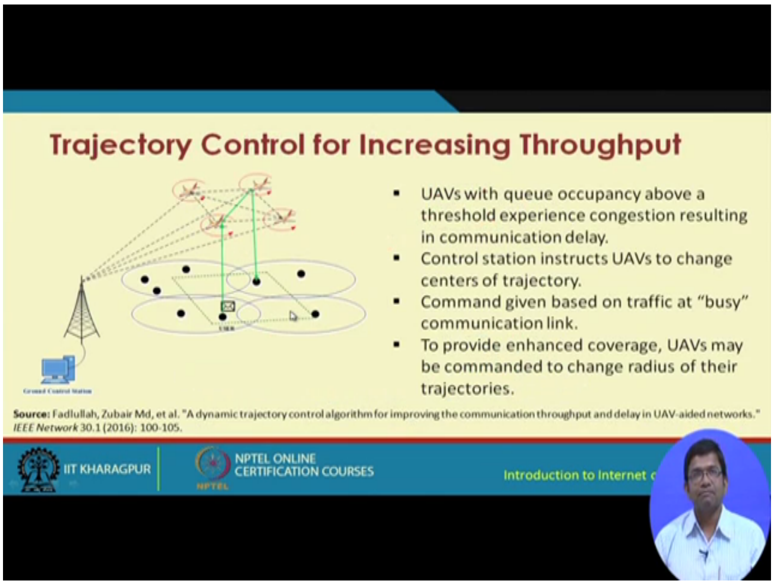

So, typically what happens is UAVs with queue occupancy above a threshold experience condition resulting in communication delay. The control station instructs the UAVs to change the centers of trajectory, and the command is given based on the traffic at the busy communication link.

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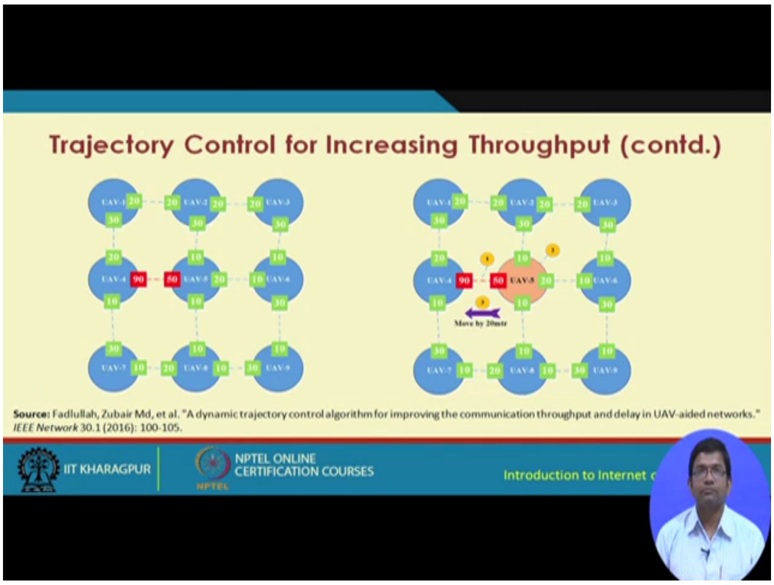

So, as we can see over here, in this figure we see that this is a grid like deployment of the UAVs. And the buffer occupancy or the queue occupancy are also shown in this green and red colored nodes. Great not nodes, but these grid colors green colored and red colored symbols.

And then on the other hand we see that if, a particular node like this node will do it is dynamism it has moved 20 meters for example, then we see that these things have to be handled, this has to be handled. This buffer occupancy of 90 and 50 has to be has to be handled.

So, with this we come to an end of the lectures on UAV networks. And I will tell you that UAV networks are very important, they have lot of attractive applications. Military particularly, all over the world, they are they their potential customers of UAVs and UAV networks. And these UAV networks are quite popular and are bit difficult to implement as well and so we have understood the basic concepts for developing, developing these UAV networks. And there is lot of research that is going on UAV networks on different other aspects.

Thank you.