Wireless Ad-Hoc and Sensor Networks
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Lecture - 18
UAV Networks- Part- I

So, the topic that we have is UAV networks it will be covered in 3 parts. UAV stands for unmanned aerial vehicles. So, the kind of networks that we can form with UAVs they can be either classified as Ad-Hoc networks or it can be a hybrid of Ad-Hoc and infrastructure based networks. So, we are going to look at all of these in in during the course of these lectures

So, the first thing that we are going to cover is the basics of UAV network. So, we also need to understand that how the UAV is the unmanned aerial vehicles fly, but before that I wanted to just impress upon you that UAV is currently are very important and they are very attractive in our society and that is a worldwide phenomenon UAV is also sometimes known as drones. Of course, there is a fine line of difference between the UAVs and drones, but mostly you know you can think of the drones as unmanned aerial vehicle. So, unmanned aerial vehicles in general have found lot of different types of applications ranging from military to civilian ones' applications for digestive management battlefield in assistance in forming networks data mewling and so on and so forth.

So, in large number of different types of applications of UAVs have been witnessed in the last couple of years; different governments worldwide are taking interest in UAVs. So, we are not just talking about use of UAVs, but we are talking about forming a network of UAVs consisting of different you know multiple unmanned aerial vehicles, which can interconnect with one another there by trying to cover a large region for exploration and for support of different applications. So, we are going to look at how these UAV networks can help, but before that we need to understand that how these networks are formed and how the different protocols can help these different nodes the UAV nodes to communicate with one another.

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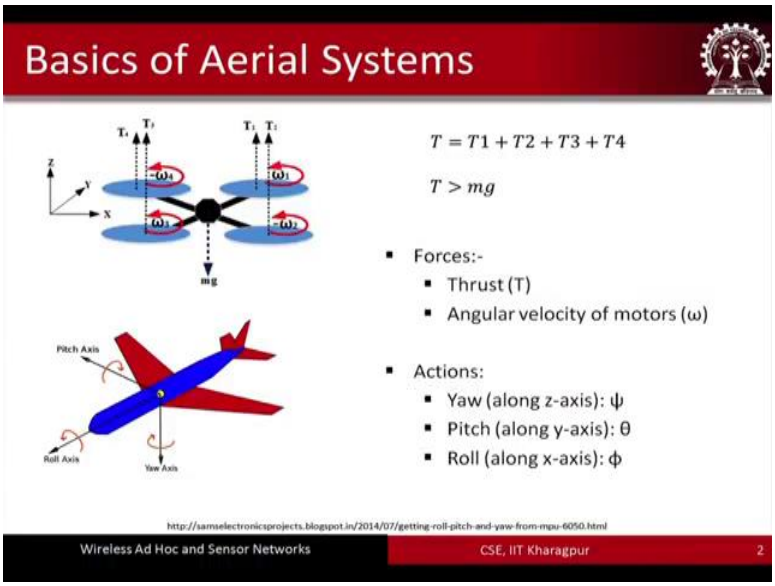

Some of the basics of any aerial system and particularly in the context of UAVs. So UAV is a flying device an unmanned flying device. So, the way a UAV flies is because of a thrust because of the thrust. So, let us say that we have we have an UAV like this. So, this UAV has 4 different propellers and so the different forces that are acting on this UAV are as shown.

So, what we have is the weight of the UAV which is the mg that is shown over. Here which is acting downwards. And so the UAV has to fly from the ground upwards. So, for that what needs to happen is that the 3 propellers that are you know rotating and in fact, they are rotating quite fast at a great speed these propellers they rotate. So, we have 4 propellers that are shown over here. So, 1 2 3 and 4 these rotate. So, fast that there is an upward thrust. So T 1 T 2 T 3 and T 4 because upward thrusts that are created by the 4 rotating propellers together and that upward thrust; that means, the sum of T 1 T 2 T 3 and T 4 should be greater than mg and that is quite obvious by the laws of physics.

So, these are the forces that act on a UAV. So, we have the thrust and the angular velocity of the motors. So, these basically these 2 forces together will help a UAV to climb up to fly and if we look at any aerial device. So, there are different actions any aerial device can perform and definitely a UAV can also perform one is the yaw is. So, if we think of this aeroplane like model to be UAV or aerial system aerial device. So, the u this particular device can either rotate in this manner. So, as shown over here in terms of

the arrow or it can rotate it can roll along this particular axis as shown or it can do. So, do the same along this axis.

So, these axis are the z direction the y direction and the x direction, and the rotations along each of these respectively will give 3 different actions that are performed by the UAVs a UAV can either yaw by rotating in this manner or it can pitch by rotating in this manner as shown in this particular arrow or it can roll in this manner as shown using this particular arrow.

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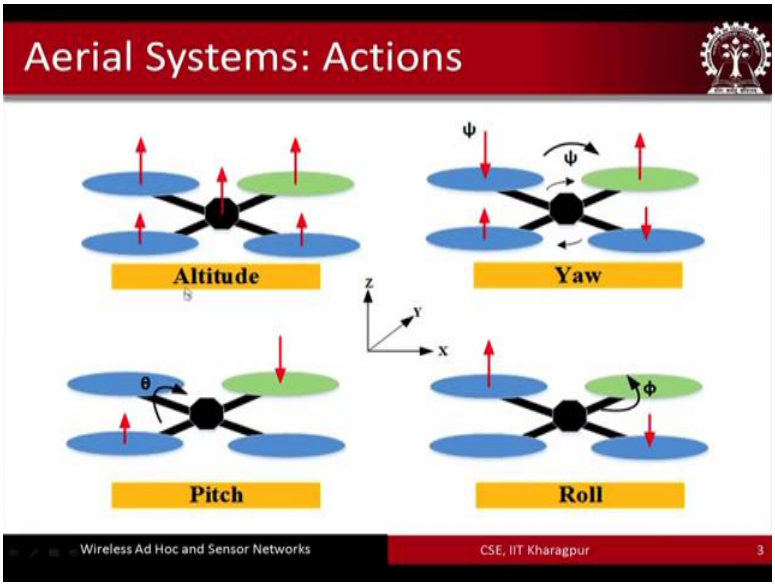

So, these are the basic actions that any UAV can perform any aerial device can perform. So, these are more explained over here vertical altitude climbing or you know climbing up vertically, that is the action which is known as altitude yaw is shown on a UAV like this, and then we have the pitch which is shown like this and the roll is shown like this. So, we have. In fact, in addition to yaw pitch and roll we have the altitude. So, all together all the 4 combined we have 4 different actions that any UAV can perform.

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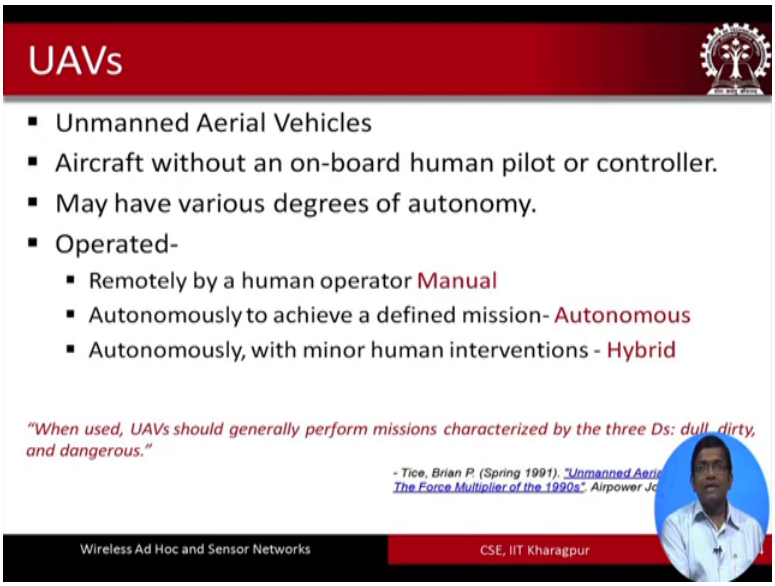

So, we said earlier that UAV stands for unmanned aerial vehicles and these are basically aircrafts or small devices which can fly and there is no human pilot or any human operator that basically sit is in these devices to control them. So there are different degrees of autonomy of these devices and these devices the UAVs can either operate manually; that means, remotely a human operator might be operating it may be using some kind of a remote device. So, remote with a using the help of a remote a human operator might be operating it manually.

Second thing is that there is a well defined mission and the UAV might perform everything autonomously without any human intervention, in order to achieve that particular mission. And that is the autonomous operations and third is the hybrid operation. So, which is basically like the second, but with minor human interventions as and when required.

So, there are you know there are different things that UAV can do UAV can perform different actions, they can operate under different circumstances to achieve the mission objectives that are there to serve the particular mission or the application for which they have been deployed.

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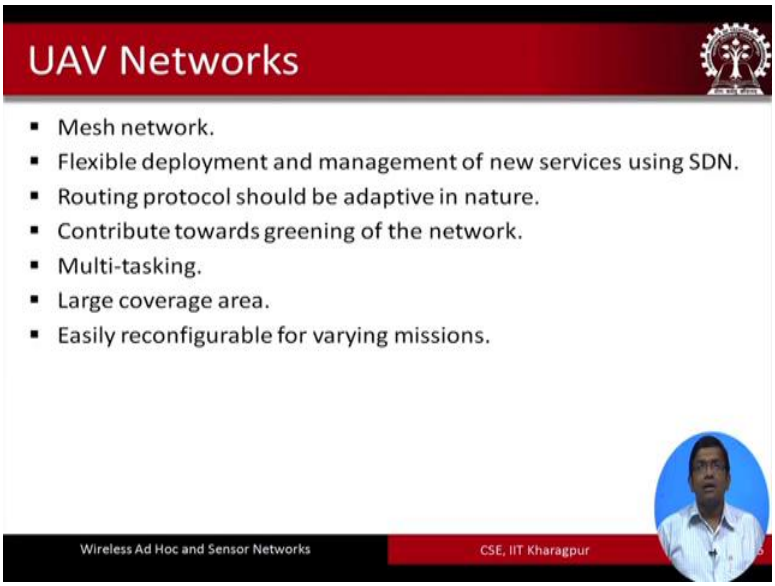

UAV networks are basically not about single UAVs, but multiple UAVs which can communicate with one another. And all of which are going to fly higher up and they are going to fly together either in synchrony or maybe asynchronously and together when they fly they are going to achieve the mission objectives with which these UAVs are deployed. So, the main thing in UAV network is to have these individual UAVs talk to one another in order to accomplish them overall mission objectives.

So, the typical there are different topologies of the UAVs there are different structures of UAV networks. So, the UAV networks can either be deployed using it star like topology or these networks can also be deployed using a mesh like topology. So, these different topologies and the advantages and disadvantages of these we are going to talk about later on in this particular lecture.

So, the main thing that we also need to understand is not only that it is desirable to have communication between these different UAVs, but also there has to be flexibility in terms of deployment of these UAVs they are flying together and the communication between them. So, everything has to be flexible autonomous and so on and so forth and that is the overall idea of having a fully functional autonomous UAV system UAV network system.

So, when we have any network and definitely in the context of UAV networks as well the first very important thing that is required is to have some kind of routing protocol a

very fundamental problem; that means, having some kind of a routing protocol which is adaptive in nature and that is able to help a particular node a UAV node to be able to send message to another UAV node.

So, these nodes they can do different types of multitasking they can perform together, they can perform different tasks performing different tasks together, and together they can cover a large area, that is the advantage of a multi UAV system a network of UAVs over a single UAV system and these UAV networks should be easily reconfigurable for you know for addressing the requirements of different missions. So, different missions have varying objectives and with the variations in the objectives the UAV networks that are deployed they would be able to reconfigure themselves, it should be able to these UAV networks should be able to perform, this would be able to configure reconfigure themselves in order to perform the different specific mission objectives with which they are deployed.

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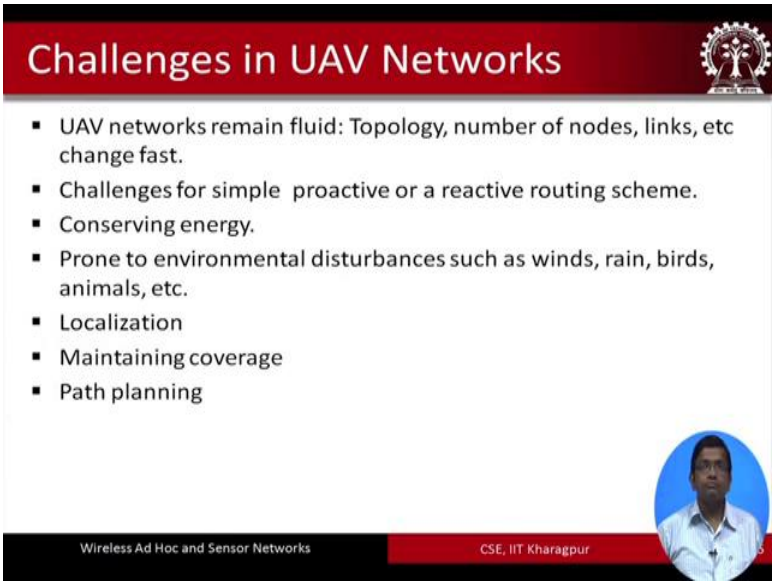

There are different challenges in implementing UAV networks. And the first thing that is very important is that UAV networks and the nodes the UAVs themselves that help form a network they are very fast moving they move extremely, fast in different directions they yaw very fast they pitch very fast, and they can roll very fast not only that, they can gain altitude very fast they can traverse different in different directions very fast and

these propellers in them they move. So, fast that the UAVs can get enough thrust to climb up to move forward or backward or in different directions and so on.

So, these UAV networks and the UAVs in them basically help the nodes to move ahead to move we have lot of mobility and the network as a whole, gets lot of mobility and consequently the topology also changes quite fast in a fluid like manner the topology changes. So, we have UAV networks which are very fast changing in terms of topology and they have a topology which has characteristics of how the fluids flow.

So, and the routing protocols that are designed for these networks they can be classified like in the case of a regular MANET they can be classified into 3 categories or primarily 2 categories. So, one is the proactive routing protocols and the other one is the reactive routing protocols. This is a very important challenge to design any kind of routing protocol for UAV networks, because these networks have very fast changing topologies much faster than in the case of a MANET, and that is the reason why designing of any routing protocol is highly challenging in these networks.

So, this is number 2 the number 3 is that it is you know, So, whatever protocols you design routing protocols or anything that you design like in the case of a regular Ad-Hoc network and most. So, in this particular case these networks should be highly energy conserving. So, this should not consume too much of power. So, they have to perform lot of mechanical tasks; that means, propulsion etcetera, last there is a lot of communication that has to take place sensing also additionally has to take place in many of the UAV systems and that is the reason there is lot of requirement of energy and at the same time once for a particular mission once these batteries in the UAVs are charged, they are assumed to survive for long durations of time. Substantial durations of time. And so whatever solutions are proposed hardware software protocols algorithms and so on they have to be energy conserving.

So, this is the third challenge the fourth one is there are lots of environmental disturbances, when you are talking about any flying system there are lots of environmental disturbances due to wind, the you know wind currents and rain bird's different types of animals there are different birds which are flying. So, these are the physical obstructions that can come on the way of a UAV system or any flying system.

Localization is very important, the UAVs they move individually or together and what is very important is to have these UAVs their locations you know you know. So, it is required to get the locations of these different UAVs and together as a whole at different instances of time. And so localization is a very important issue and it has to be a fast localization algorithm. So continuously every second or even faster than that one needs to have an algorithm that will give the locations of the different nodes and holistically the network in the space.

The next challenge is maintaining coverage is a very challenging issue. So, we have these couple of UAVs that are working together to cover a particular area; that means, that every point every area in a particular region has to be covered by at least a single UAV coverage is also a very challenging task achieving coverage optimal coverage rather is a very challenging task in the context of UAV networks.

Path planning is another. So, it is very important to plan the path of the single UAVs or the group of UAVs or the swarm of UAVs together. So, that as to understand so as to infer how these UAVs singly or in a group are going to move in different trajectories. So, path planning is very important. So, one has to be able to predict that given the previous history, how this UAV or the set of UAVs or the swarm of UAVs are going to move forward, and where they are going to go at a future instant of time. So, this is another very important a very difficult challenge you know to achieve in the context of UAVs single UAVs and; obviously, in the context of multi UAV systems or network of UAVs.

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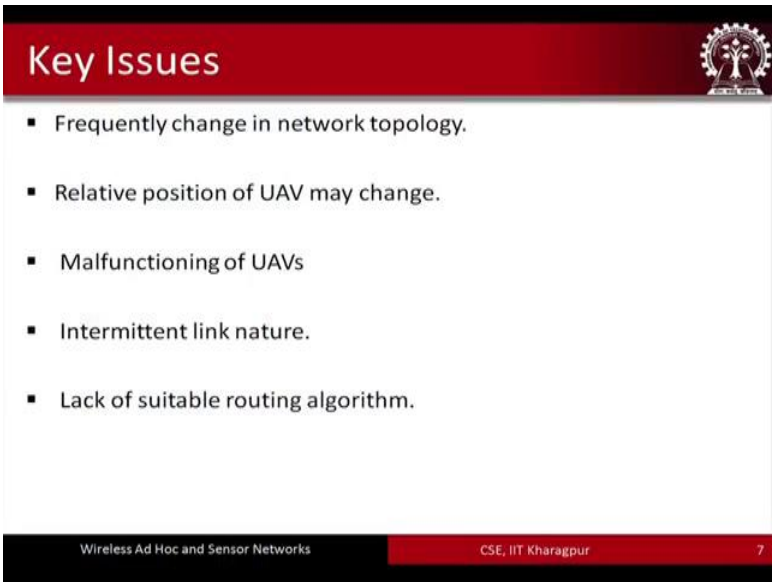

So, different key issues I think I have already mentioned about many of these challenges and I hope you have a good understanding about how the UAVs functions what are the basic physics behind the flight of a single UAV, and how these UAVs can form a network within themselves and so on. And what are the key issues with this, So, these are the things that we are going to understand the key issues are the ones that we are going to understand now.

So, the frequent one very important issue. In fact, it is a very challenging task is that we have a frequently changing network topology. Much more frequently changing than in the case of MANETs or even VANETs. And the relative position of the UAV is in a UAV network may also change. They might change due to the nature of this UAV network, or they might change due to other external forces like winds etcetera, which are which are acting differentially on the different UAVs which are part of the same network and malfunctioning of UAVs is another thing. So, it is quite often that actually these UAVs are vulnerable to different types of faults occurring faults particularly in terms of the hardware you know mechanical faults can occur electronic system might also become faulty or even communication. So, how malfunctions of different kind can occur in these UAVs. And how these UAVs are going to survive in the presence of different types of malfunctions is something that is very important to consider while designing a UAV network system.

Additionally, this networks are prone to the networks the nodes and the links connecting them are prone to different types of failures. So, it is quite often there due to the mobility of the different nodes. The links between these different nodes, they are they might become unavailable they are prone to different types of breakages. So, there might be intermittent you know connectivity failure between the different nodes in these networks. And the existing algorithms the existing routing algorithms more specifically that are proposed that were once running in such a condition they may not be usable as such at a later instant of time.

So, whatever routing algorithm is proposed they have to keep in mind that these networks the UAV networks are fault prone. In fact, these are much more fault prone than in the case of other types of Ad-Hoc networks MANETs VANETs and so on. And the existing routing protocols existing solutions of all kinds that are proposed for MANETs and VANETs are as such not usable in the context of these networks. So, that is why where you know in the case of UAV networks we need a new class of solutions for making these networks functional.

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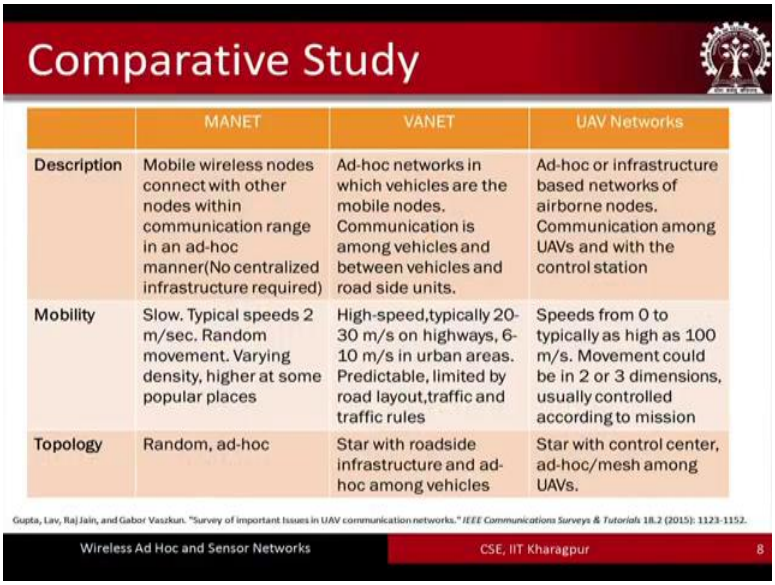

Now, here is the comparative I already mentioned about the different types of networks. UAV networks are kind of Ad-Hoc networks in general of; obviously, there are some features of infrastructure based networks which are also borrowed, but UAV networks are a class of Ad-Hoc networks in general and how they compare with respect to

different attributes, or different criteria how they compare with MANETs and VANETs. VANETs means vehicular Ad-Hoc networks. So, VANETs are again a class of MANETs where the nodes are different vehicles in general. MANETs we already know VANETs are basically Ad-Hoc networks where the mobile nodes are basically the vehicles and communication between the different vehicles and between the vehicles on the roads and the roadside unit is which are basically some kind of communication equipment, which are installed which are fixed on the roadside the this is these are the 2 different important components of communications in a VANET.

Whereas in the case of UAV networks as I said earlier also primarily it is Ad-Hoc nature of these networks, but there can be infrastructure based communication that can also make a UAV network survive. And communication among the UAVs and with the control station are the 2 different modes of communications are the 2 important features of communications that have to be considered. So, the this is this is the primary difference between UAV network and the MANETs and VANETs. In terms of mobility MANETs are very slow they have a typical speed of 2 meters per second whereas, the VANETs are having higher speed the nodes in the VANETs have higher speed typically 20 to 20 to 30 meters per second, on highways and 6 to 10 meters per second in urban areas. And in the case of UAV networks the speed is typically much higher in terms of about in order of about hundreds of meters per second.

So, and in this particular case in the case of UAVs unlike the MANETs and the VANETs the movement could be in 2 dimensions or 3 dimensions, which are usually controlled according to the specific mission for which they are deployed. The number third 3 attribute the third attribute for comparison is topology whereas, in the case of MANETs we have random topology and Ad-Hoc deployment of nodes in the case of VANETs we have a star like topology, with roadside infrastructure and Ad-Hoc, you know Ad-Hoc connectivity between the different vehicles. And in the case of UAV networks it can be either is to star topology or a mesh topology that can be used to form that that these part these networks the UAV networks.

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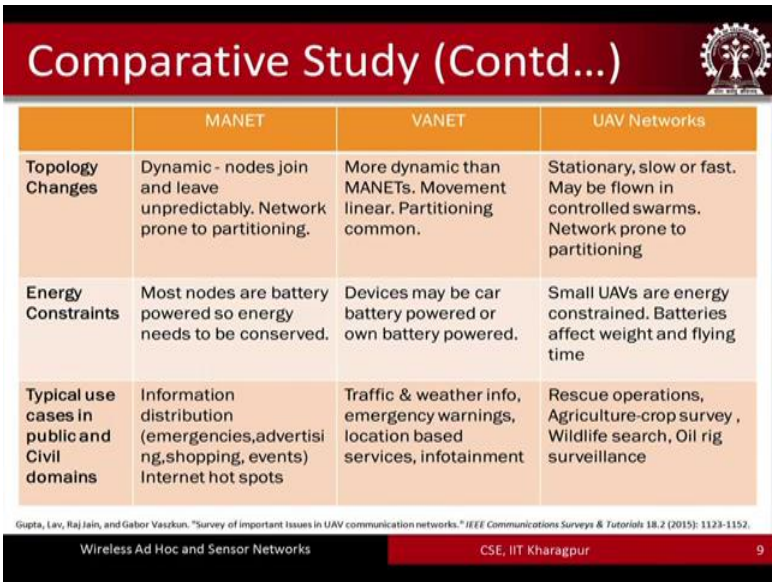

The next criterion for comparison is topology change. So, MANETs basically are quite dynamic VANETs are even more dynamic in terms of the movement of the nodes and the movement of the network. And the you know the movement of the different nodes in the in the network, and in the case of UAV networks you know these UAV networks the topologies can change they may not change the overall topology may not change because you know what might. So, happen is that when these networks when these UAVs in the network are flying in a formation, you know where the inter UAV spacing is maintained So, these UAVs can be made to fly in such a way that either they are stationary; that means, the relative position of these nodes they do not change over time in this networks or even if they change the relative position changes, they might be changing quite slowly or even that relative position of the different nodes in this networks, they might even change much faster.

In terms of energy constraints most nodes are battery powered. So, energy needs to be conserved in the case of MANETs in the case of VANETs, devices maybe car battery powered or own battery powered because it is a vehicle. So, it can take help of the battery that is resident in the car and in the case of UAV networks, what we have a small UAVs typically and they have very small batteries consequently, with lot of energy constraints and; obviously, batteries affect the weight and the flying time as well. So, it is also not a very good idea to have heavy you know batteries, you know heavy and energy efficient batteries to be deployed in this UAV networks.

So, in typical terms of application in the civilian domains semantics are typically used for information distribution. VANETs for traffic and weather information or for emergency warnings and so on. Whereas, in the case of UAV networks typically for rescue operations agriculture crop crops survey and oil monitoring and so on.

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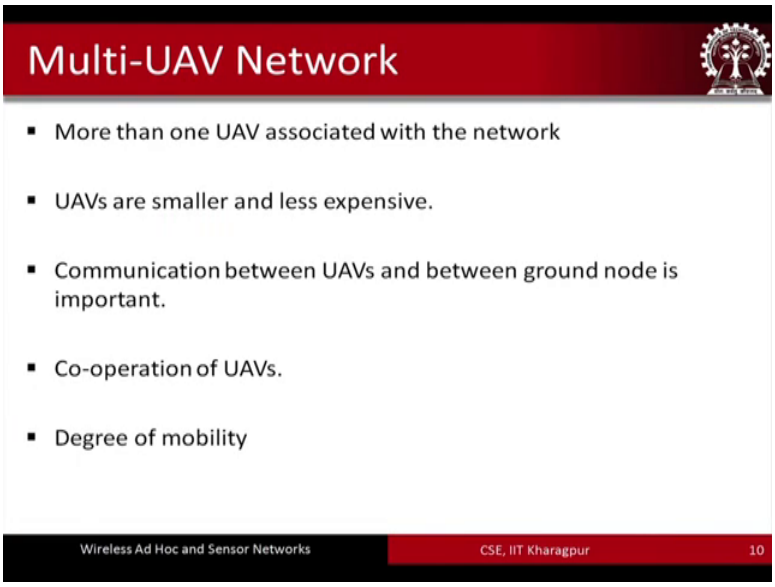

There are large number of different applications of these UAV networks. So, when we talk about UAV network we are talking about multiple UAVs. So, more than one UAV that we associated with the network and these UAVs are smaller and are less expensive and communication between the UAVs and between the ground node is also very important. So, these UAVs they fly they communicate with one another in the air, but at the same time from the UAV network there is a node a gateway node which has to communicate with the ground station.

So, the cooperation of UAVs is also very important like in the case of any other type of Ad-Hoc network UAVs also. The different UAVs which are part of the network they also need to cooperate with one another for relaying their information and for performing different tasks together. So, cooperation between the UAVs is important the degree of mobility is very important, all these nodes if they move with the same kind of pattern, if they have a similar mobility pattern then what we are going to have is a swarm of UAVs which are going to which do not have too much of inter UAV, you know rewrote a change of relative position or relative velocity, but if we are talking about UAVs which

move you know without considering, the mobility of the others then what is going to happen is the topology is going to change quite fast, and what is also going to happen is that there are going to be frequent links changes a link disruptions and so on. And the network can be partitioned quite often due to the mobility of the different nodes in in these networks.

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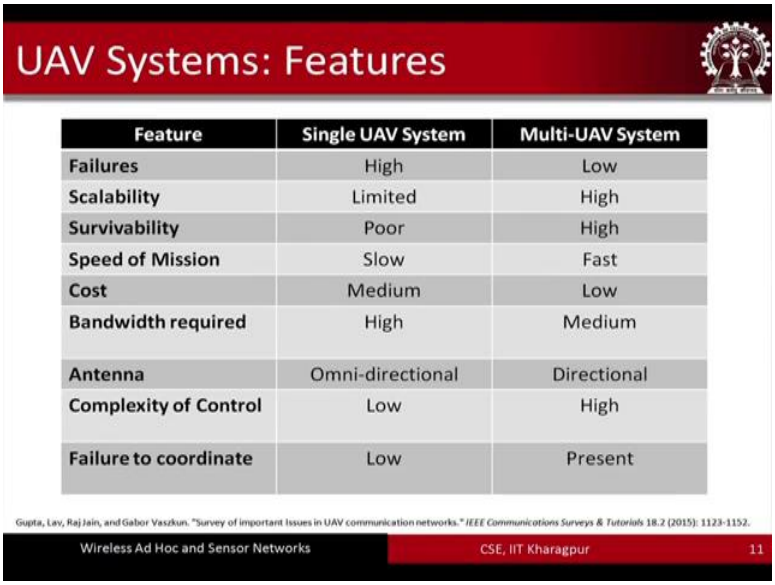

So, there are different features of these UAV systems. When we compare a single UAV system with a multi UAV system. So, we have a multi UAV system which have generally low less number of failures compared to a single UAV system.

In terms of scalability the single UAV systems has a very limited scalability. And in the case of multi UAV system the scalability is higher. I do not need to explain these thing, but I hope that all of you can understand why it is so. In terms of survivability single UAV systems have poor survivability in the case of failures whereas, multi UAV systems have higher rate of survivability in the case of failures. Speed of mission it is slow here and in the case of multi UAV system it is fast. In terms of cost single UAV systems are medium have medium costs whereas, multi UAV system have lower costs and there is a particular rationale for it and I hope I am not elaborating it why this is counter intuitive. So, there is a particular rationale to it and I hope that the audience can understand why it is so.

Bandwidth required in the case of single UAV systems is high whereas, in the case of multi UAV systems it is medium. In terms of m antenna that is used typically in a single UAV system one uses the omni directional antenna and typically in a multi UAV system one uses different directional antennas complexity of control is low in the case of single UAV system whereas, it is high in the case of multi UAV system. Failure to coordinate is low in the case of single UAV system, and in the case of multi UAV system it is simply present.

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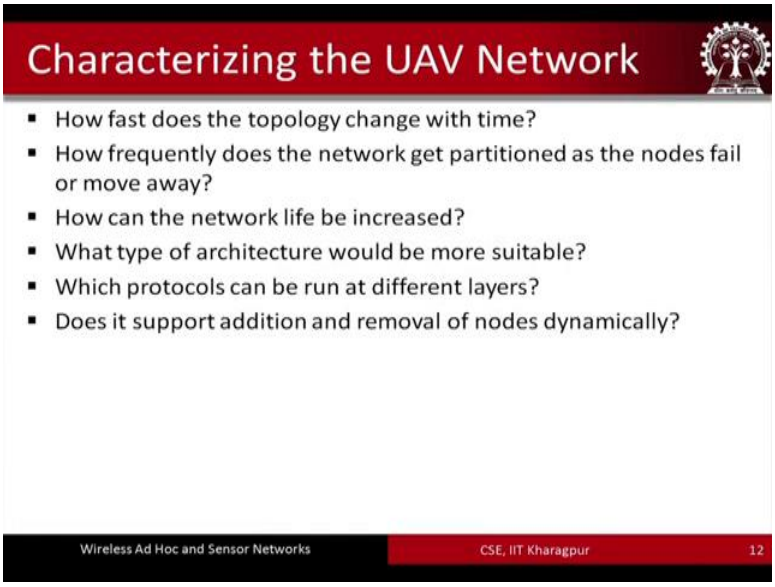

So these are the different features of and the differences between a single UAV system and the multi UAV system. There are different characteristics of these UAV networks. So, which are very important while designing such a network. And so different considerations like how fast the network changes with time, how frequently the network gets part partitions partitioned as the node fail or removed away from each other, or how can the network life be increased or what type of architecture would be more suitable or which protocols can be run at different layers or does it support the do these networks support additional and removal of nodes dynamically.

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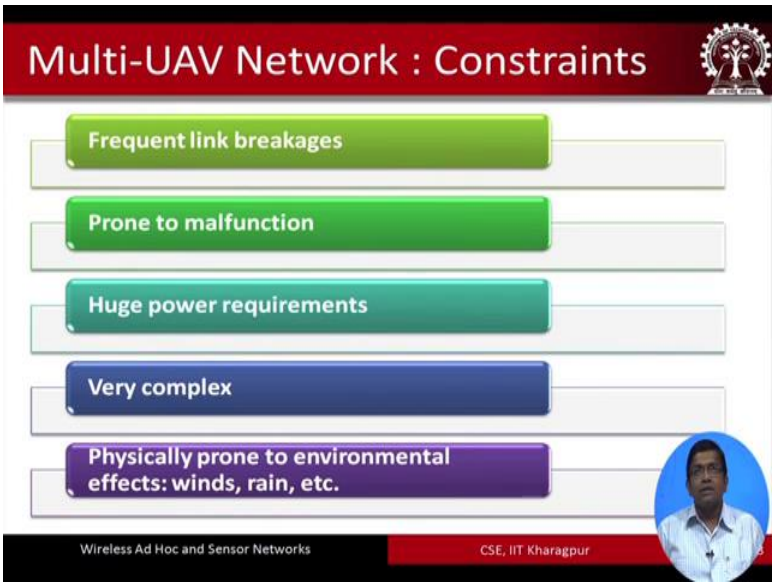

So, these are the different questions that have to be answered for characterizing a UAV network. For multi UAV systems multi UAV networks there are different constraints I am not going to elaborate them, but I am just going to read out. So, the first thing is the frequent link break breakages are very important. These networks are prone to different types of malfunctions. They consume much higher energy as such they are very complex to form and to deploy and they are physically prone to different types of environmental effects of winds rain and snow and so on and so forth.

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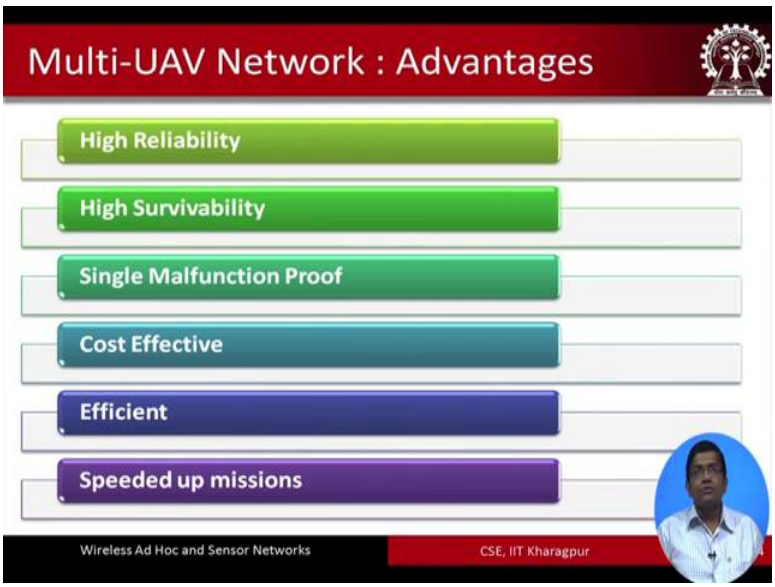

Multi UAV networks have different advantages, they offer higher reliability higher survivability in the case of in the case of failures. Single malfunction proof So, if a single UAV network malfunctions, as well there are other nodes which are going to take over. So, take up take over and together the network as a whole will be malfunction proof. Cost effectiveness is again an advantage of these networks. Efficiency is another efficiency in all respects is what is achieved through formation of a multi UAV networks. And these multi UAV networks basically cover help cover these different nodes in these multi UAV networks they help cover you know larger areas and the missions can be accomplished in a faster manner compared to doing the same with the help of a single UAV system.

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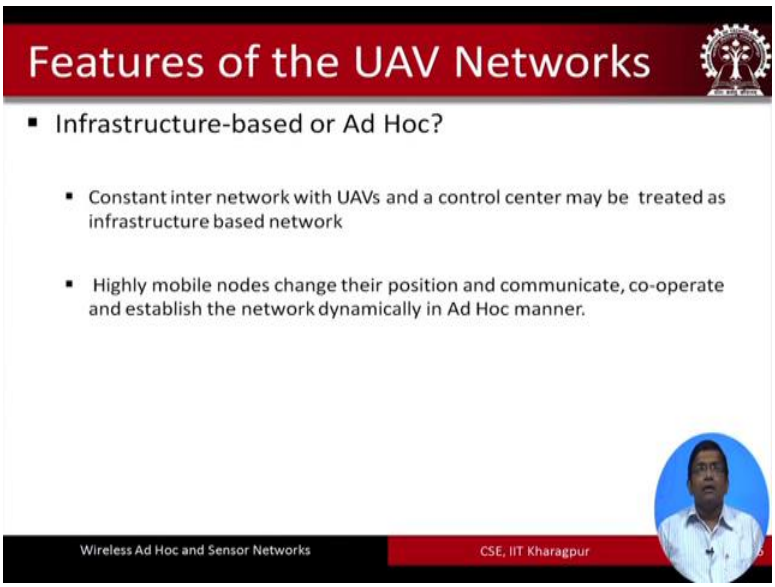

So, there are different features of this UAV networks, are these UAV networks infrastructure based or are they infrastructure less; that means, Ad-Hoc. So both basically and sometimes they can behave as Ad-Hoc particularly for communication, between the different nodes in these in these networks for communication bit from the network from the nodes in the network to the ground. That particular communication is mostly infrastructure based. So, typically we have both a combination of infrastructure less or Ad-Hoc mode of communication plus infrastructure based communications together basically helps these networks to survive.

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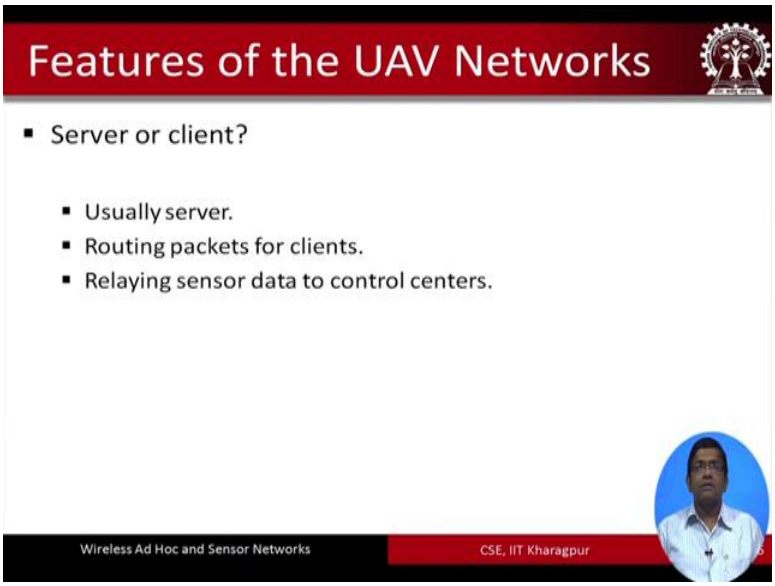

So, there are other features are these networks usually you know are particularly you know when we are talking about a single UAV in a UAV network is it going to serve as a server or a client. So, I mean. So, essentially both, usually it is a server any UAV is a server, but also in terms of routing of packets they can serve as clients as well. And these networks they can help in relaying the sensor data to the control centre. So, since the sensor data are basically coming from the different sensors that are deployed in these different UAVs UAV nodes.

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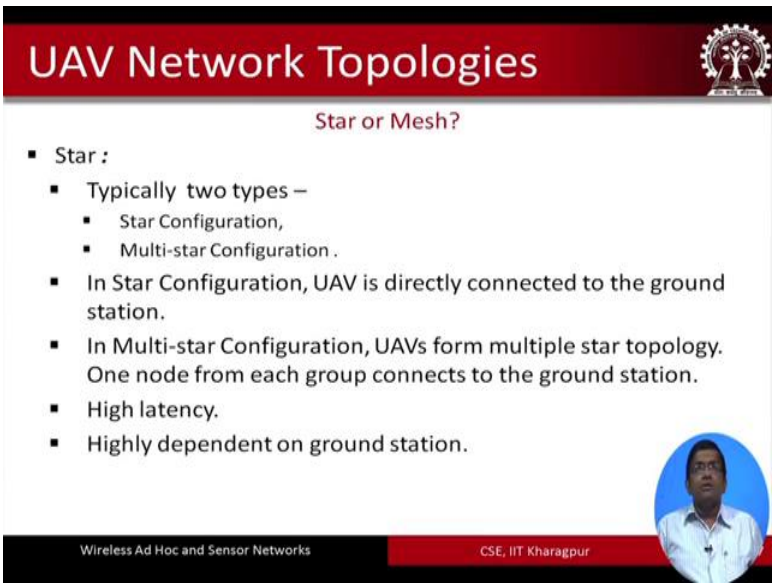

So, that a particular type of topology that is used it can be typically either is star like of like topologies, typically used for forming UAV networks or even a mesh like topology. So, either we can have a star configuration or a multi star configuration. In a star configuration, so, when we are talking about you know star configuration either it can be a single star configuration or a multi star configuration in single star configuration UAV is directed directly connected to the ground station. In the case of multi star configuration the UAVs form multiple start topologies one loop from each group basically connects to the ground station. So, I am going to show you a picture in a short while and then you will be able to understand that what is the primary difference between the star configuration and the single star configuration and the multi star configuration in any UAV network.

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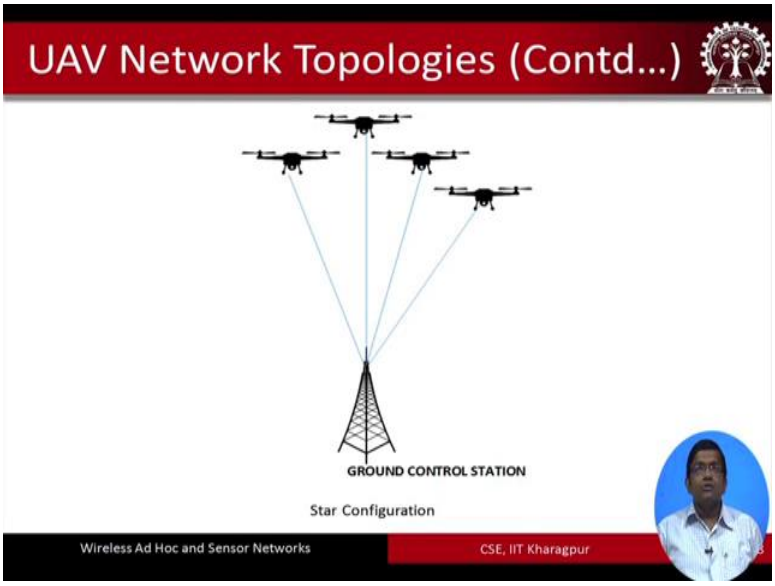

So, this is the star configuration as we can see that this is the star topology. So, these are the UAVs the 4 UAVs they connect with the ground control station. And this is how the star topology looks like here.

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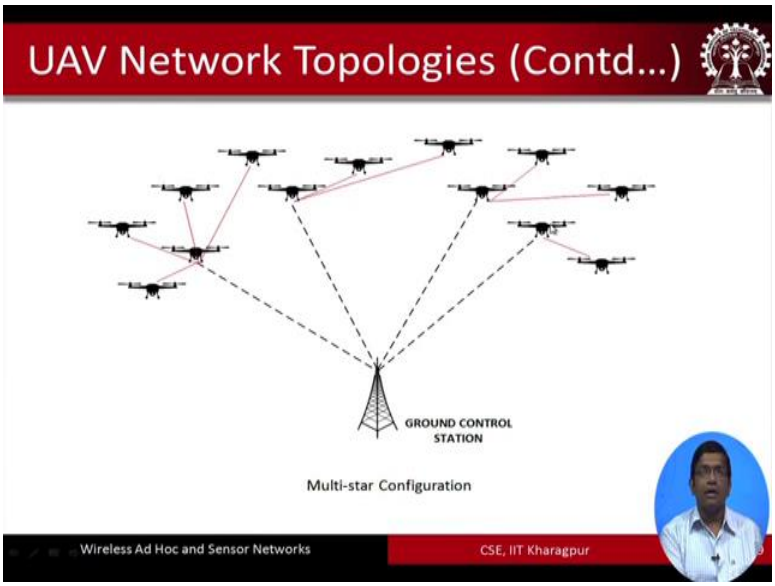

Here in the case of multi star configuration what we have is multiple instances of what we have seen in the case of a single star configuration. So, we have one star configuration another star configuration a third and a fourth and so on. So, these are the different star configurations and from the centralized coordinator or any UAV node these the data that are received from the different other UAVs can be sent to the ground stations and all the other UAVs are also going to do the do the same for each of these different clusters or each of these different network formations.

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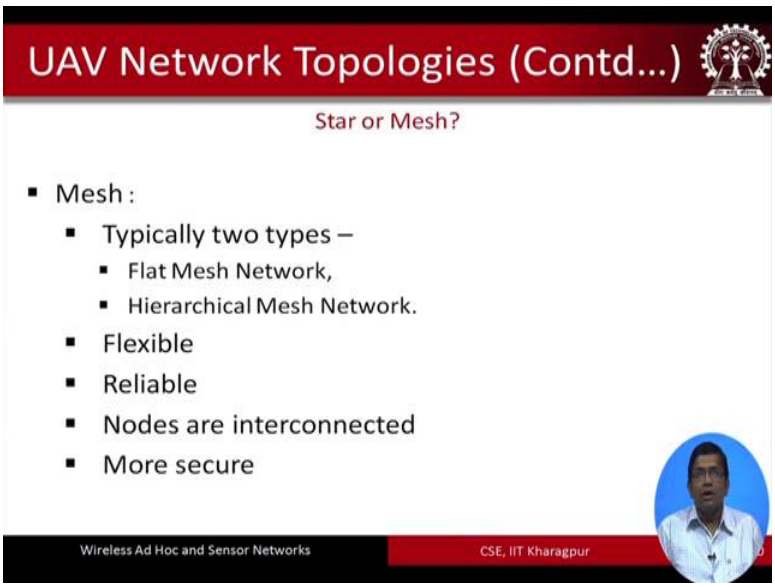

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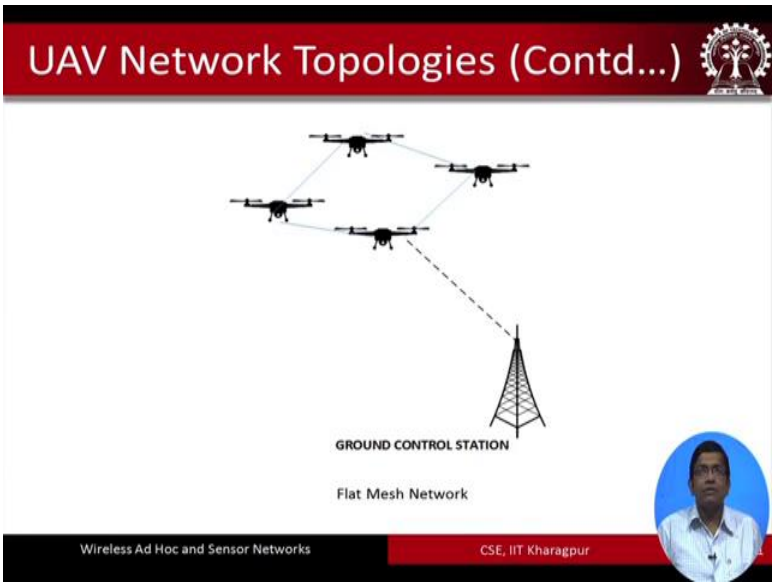

They can also be de deployed using a mesh like pattern. Either it can be a flat mesh network or a hierarchical mesh network. So, these are the different ways in which these mesh networks can be this is the example of a flat mesh network. So, mesh network means, that there is multiple connectivity from one node to the other nodes in the network. So, mesh kind of configuration is useful in the case of these UAV networks because these UAV networks are very much fault prone faults of different types links and nodes and so on. So, if there is a particular link from one UAV node that breaks then there is quite likely that there are other links which can take effect.

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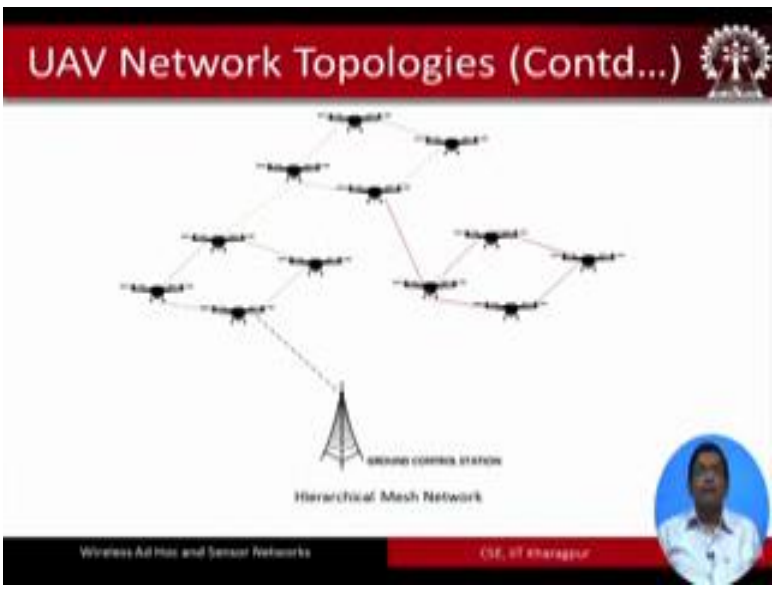

So, this is how a flat mesh network looks like. So, here what we have is a hierarchical mesh network and this is quite obvious. So, not only that we have a flat mesh like configuration, but from here again there it basically connects with another mesh and from this mesh again there is connectivity to another mesh. So, this is how different hierarchies are formed. And we have a hierarchical mesh network and from this mesh network there is connectivity to the ground control station

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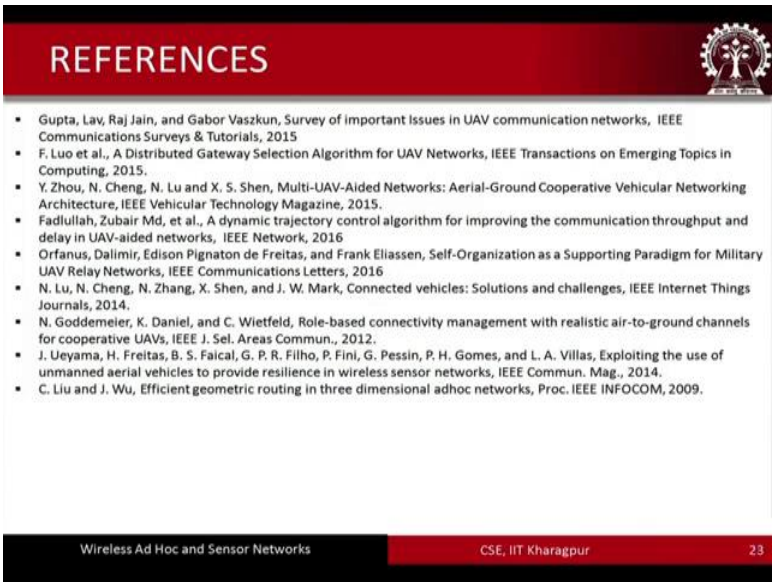

So, with this we come to the end of the first part of UAV networks. These are very important references for you and the first paper is a survey on the important issues of UAV networks. A very important paper to read and this will give you general good idea about how to form UAV networks and the different issues surrounding it, and the rest of the papers are also very useful and these can also give you different insights of insights on UAV networks.

Thank you.