Wireless Ad Hoc and Sensor Networks
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Lecture – 15
Opportunistic Mobile Networks-Part-I

Opportunistic mobile networks; so in the first part we are going to cover some of the basics of opportunistic mobile networks. And we are going to look at some of the characteristics of these networks. The different types of protocols that are used that had been proposed for use in these networks and so on. And thereafter will I will take up the second part of this topic and where we will get into the more advanced concepts.

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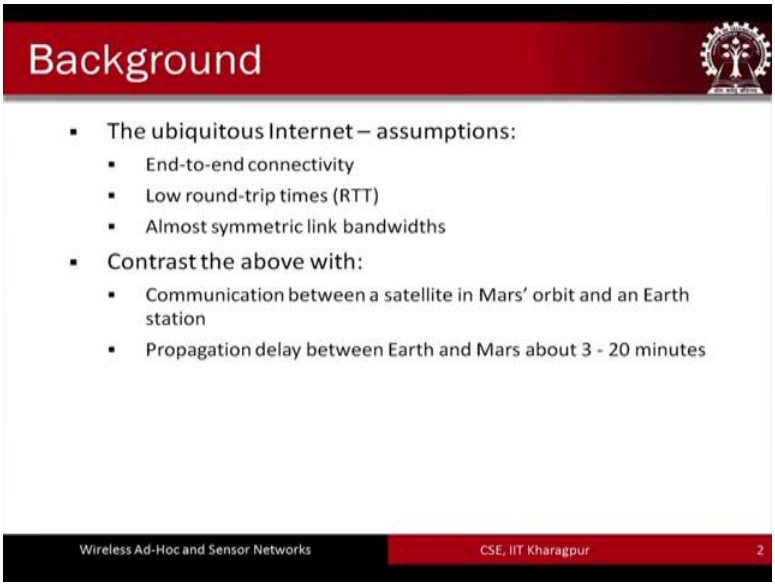

So, if we think about the ubiquitous internet, the internet that we are using currently. The internet has certain assumptions with which it works. So, first of all the very fundamental assumption is there is an existence of internet end to end connectivity in the internet. The second thing is that there is low round trip times. And third is that the link bandwidths are symmetric both ways. So, up and down both uplink and the downlink the bandwidths are symmetric. Now these are the some of the fundamental assumptions with which the internet works. Now in contrast if we think of sending some signals from the surface of the earth to other planets like mars, there is a huge delay this is something that is very important for people who are working on interplanetary network. Interplanetary

networks talk about how to send how to communicate between 2 different planets. How to send signal from one planet to another? So, for instance in this particular example. So, we are talking about sending a signal from mars from earth to mars and back.

So basically for sending a signal from earth to mars the propagation delay is in the order of 3 to 20 minutes. So, you see that the propagation delay and consequently the RTT the round trip time is much more compared to that experienced in the internet. So, this is one of the reasons why the protocols that are proposed all the not only the protocols the different solutions the architectures over all that are proposed for use in the internet are unusable in this particular context; that means, interplanetary networks.

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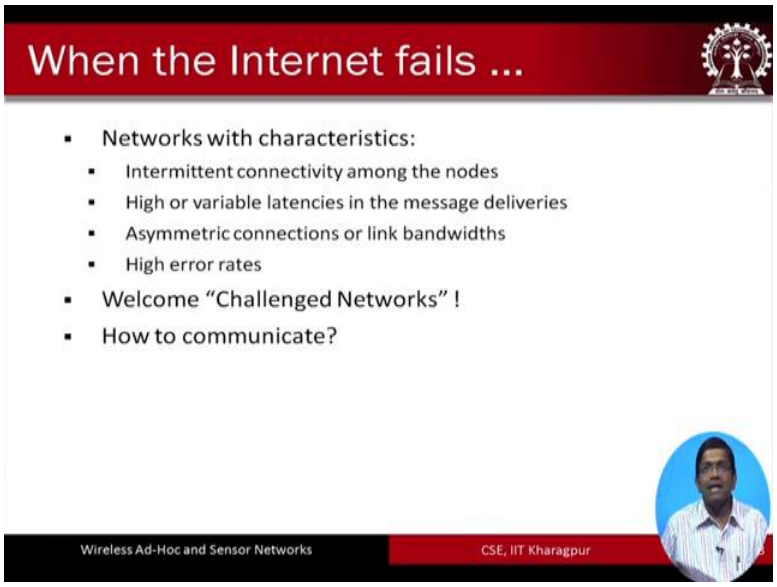

So, when does the internet fail? When these assumptions are no longer valid the assumptions that I just mentioned. So, networks certain types of networks more specifically exhibit properties of intermittent connectivity between the different nodes. So; that means, that there is no end to end connectivity guarantees at different instants of time. So, at certain instants of time the nodes are connected 2 different nodes are connected at another instant of time these nodes may not may not be connected at all. And for them to get connected at later instant of time it may not be a short duration.

So, it may be a long duration of time that elapses before those 2 nodes get connected again. So, this is one of the issues. Now look at another issue. So, there are some networks where there is high or very variable nature of latencies in the message

deliveries high latencies. So, the interplanetary network is an example that I mentioned like this there are other types of similar kinds of networks where the latency in message delivery latency in packet transmission is not only high, but they are also variable so; that means, that one cannot really always predict how much time is it is going to take for a signal to go from the source to the sender and get an acknowledgment back. The third issue is that asymmetry as asymmetric nature of connections.

So basically the link bandwidths in the uplink and the downlink may not be the same. And these networks these new types of networks that that I am telling you the networks which do not behave the way the internet behaves. These networks I am going to tell you what type of networks do they say this particular way behave this particular way. So, these networks are also very much highly error prone. So, highly error prone environments. So, the networks which exhibit these kind of characteristics.

So, for instance in terms there is intermittent connectivity between the different nodes there is high or variable latencies in the message deliveries. There is asymmetricity in connection and the link bandwidths uplink and downlink are not the same or similar and where there is high error rates these networks are often termed as the challenge to networks. Because these networks unlike the internet which operate in a very ideal kind of environment much I much more idle than these kind of environments. So, these networks basically deviate from there because they exhibit this kind of properties and that is why these networks are termed as the challenged networks.

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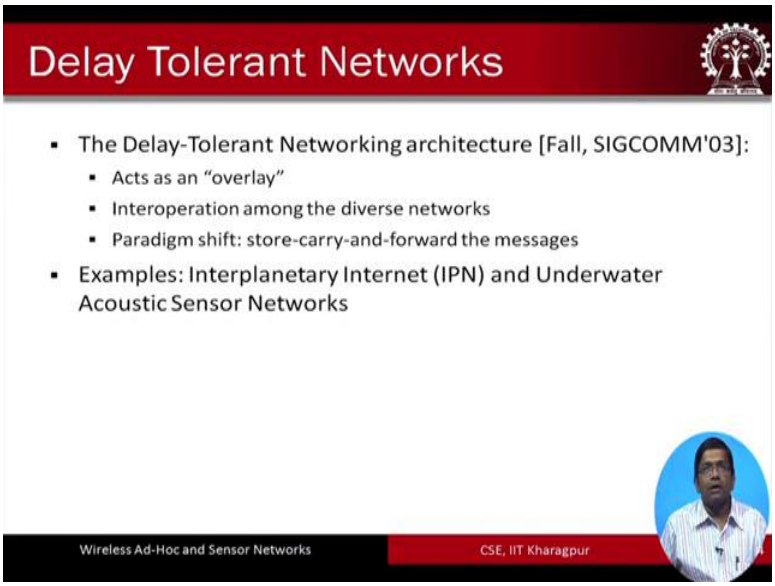

So the whole issue is that how to establish communication in these challenged networks. So, delay tolerant network is a type of challenged network. In short details detail delay tolerant networks are known as the DTNs. So, DTNs basically follow a certain type of architecture, which often is of the nature of an overlay architecture meaning that it is sort of like a blanket over the existing networks. So, this blanket architecture. So, blanket is something that operates on top of the existing underlying networks, which basically are similar in nature to the regular networks. So, these act as the details basically the architecture act as overlays overlay architecture is typically exhibited by these networks there is inter operation among the diverse networks. And these networks basically forward messages bit differently from the way the messages are delivered in the case of internet in delay tolerant networks, these networks basically are delay prone. So, delay prone means that a signal might take lot of time there is lot of latency exhibited for a message to be delivered from the source to the destination. And that order of time delivery time of delivery is much higher compared to the internet networks.

So in these networks basically the way it is done in the internet that one when one when a particular node gets a message it buffers it for some time and then forwards it. So, that kind of paradigm of message forwarding is not suitable. So, in these networks what might happen a node might be in contact with a particular node at certain instant of time then it loses contact and it does not get any connectivity at all with any other suitable node for forwarding the message.

So, what these nodes would have to do is they have after on receiving a message they would have to not only store the message they would not only have to buffer the message, but they would have to buffer it carry it carry the message for certain duration of time, and then forward the message to another node which has a likelihood of delivery to the intended destination. And that forwarding time might occur at much more time than then when the message was received. So, examples of these DTNs are interplanetary networks underwater acoustic sensor networks.

Underwater acoustic sensor networks will talk about underwater acoustics a sensor networks in the little part of this course, but just to give you an idea the whole thing is about having different sensors communicate with one another under the surface of water. And under the surface of water there is basically these kind of properties that are exhibited there is lot of end to end latencies much higher than what is exhibited by the similar kind of networks on the surface of the earth; that means, terrestrial networks and there is not only end to end connectivity, there is lot of error these networks are very much error prone and so on. So, there are like this there are actually lot of different challenges and in these networks again that store carry forward and the mechanism is more suitable.

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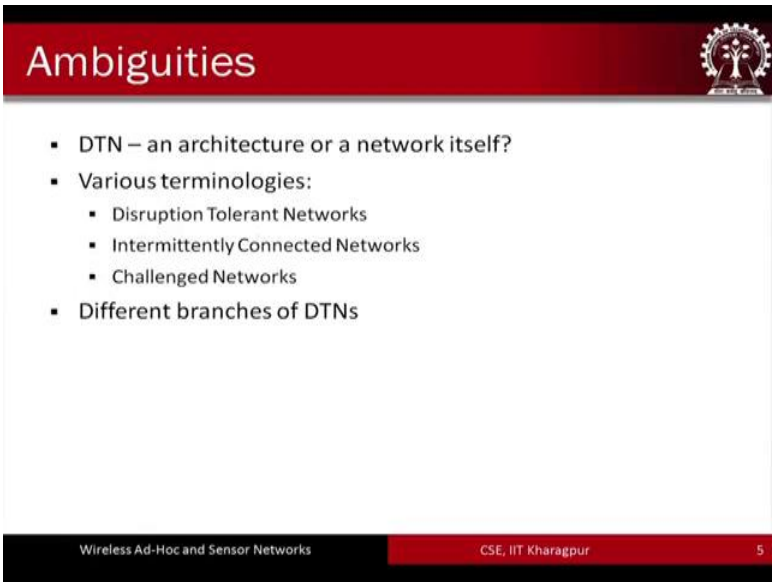

So as I was telling you that DTN it will basically are confused about it is ambiguous to have to classify these networks the DTNs as a separate type of network; that means,

having a separate identity of these networks by themselves or to have them as a separate kind of architecture which is going to work as an overlay on top of the existing networks. So, these networks the DTNs there are different terminologies that are used to denote to refer to these networks. Some people prefer to call them as DTNs delay tolerant networks, some people prefer to call them as a disruption tolerant networks because these networks basically the links are very much disruption prone.

So, as they so that is why people often prefer to call them as the disruption tolerant networks and some people even prefer to call them as delay slash disruption tolerant networks DTNs. Some people even prefer to call them as intermittently connected networks and challenged networks. So, these are the different there are different branches of DTNs there are different branches of DTNs, DTNs is an overall concept it is an overall idea about how to you know communicate in under certain types of constraints in a challenge environment, but there are lots of different you know different types of specific types of networks which can be classified under the DTNs.

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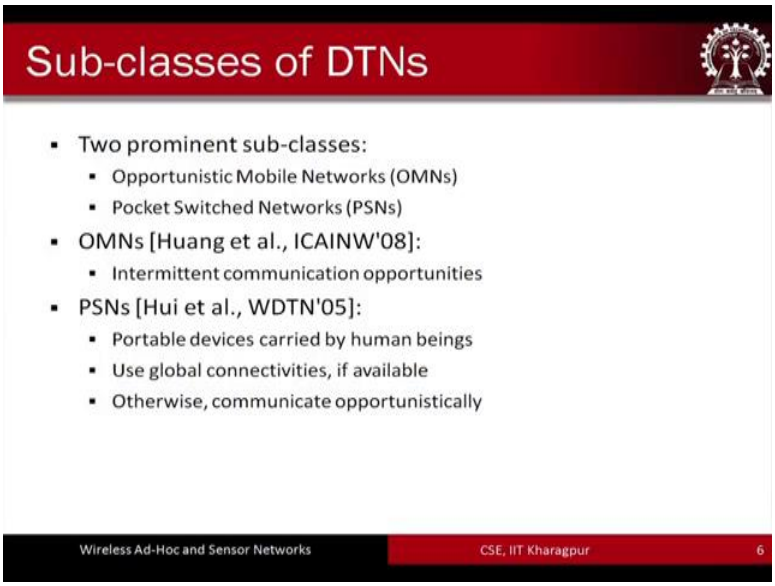

So these are some of the different classes subclasses of DTNs, to popular very popular subclasses these are not the only subclasses, but 2 very popular subclasses are the OMNs opportunistic mobile networks. And the other one is the pocket switch networks. So, we are going to go through each of them a little later. So, the OMNs basically one of the first works was done was published on OMNs opportunistic mobile networks by Huang et al

and the reference is given over here it was published in 2008. So, in opportunistic mobile networks the nodes basically communicate with one another opportunistically; because the communication is an intermittent between the different nodes.

So, consequently the communication type the mechanism of communication is opportunistic in nature. So, that is the reason why these networks are often referred to as opportunistic mobile networks or OMNs in short. The other type of DTN is the pocket switch networks. So, these basically pocket refers to carrying the portable devices by the human beings in their pocket. So, that is where this term pocket. So, in their pockets in their garments in their pockets they are going to put the mobile phones the portable devices. So, the way we do currently. So, these are the smart phones that are carried by these human beings and because the mobile phones are carried in the pockets of the human beings, these are referred to these networks which are formed by connecting these nodes these device mobile devices in the pockets of the you know different human beings in a particular locality these are referred to as pockets switched networks.

So in these pockets switch networks global connectivity are used if this connectivity is available. Otherwise these nodes they would communicate opportunistically. So, basically it is not that PSNs have a very distinct identity and not that they have very sharp differences from OMNs. Many of the properties of PSNs have been borrowed from OMNs. So, there is there are lots of overlapping properties of these networks OMNs and PSNs. So, in terms of OMNs and PSNs.

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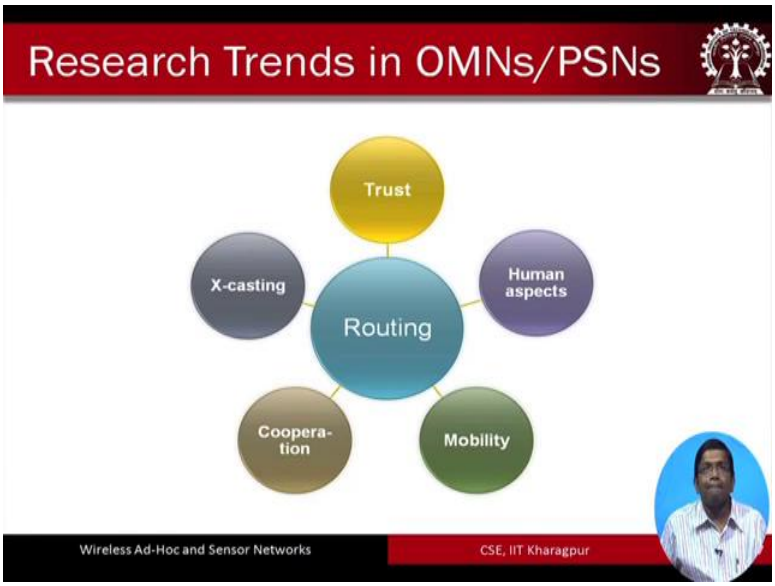

There are lots of research works that are going on. So, most of the research works on OMNs focus on routing; there are other issues cooperation there is a certain volume of literature on cooperation different types of casting multi casting broadcasting any casting geo casting and so on. Similarly, there is there are there is lot of research works which have been undertaken on the issue of trust in OMNs. On the issue of mobility how the nodes are going to move whether there is going to be testing mobility active mobility how the nodes are going to be encouraged to move in a certain way and so on and so forth. There are large number of different issues with respect to mobility of nodes in OMNs which have also drawn interest in the research community. And finally, there is another stream of work with respect to human aspects.

So, basically getting the humans in the loop in the network humans are active participant active participants in the network. So, this is what that basically has been has been adopted and they have been used in certain types of OMNs human aspects and in fact, in our research group the swine research group at IIT Kharagpur we have done lot of works with respect to you know considering humans in the loop and human aspects of opportunistic mobile networks. And some our works are quite unique worldwide and the results that we have obtained are quite important in the field.

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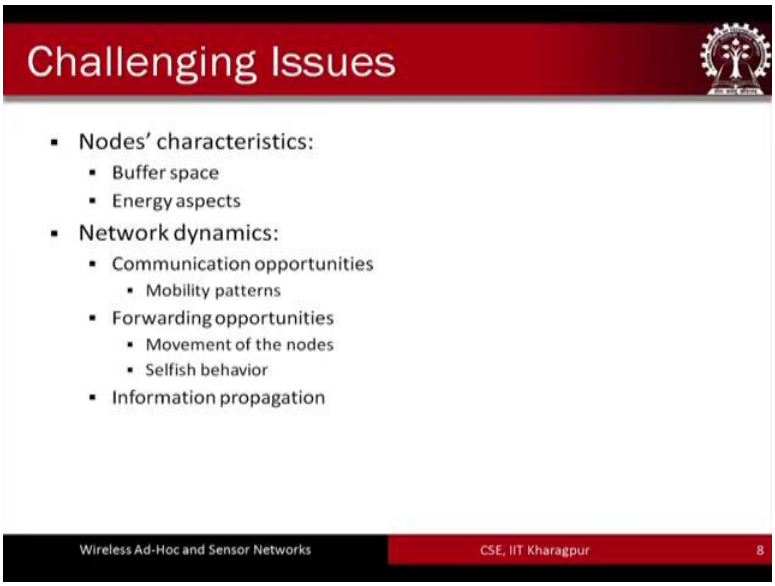

So there are different challenging issues with respect to the behavior of the nodes the behavior of the networks and so on. So, if you look at the nodes in the OMNs they have certain characteristics. So, characteristics with respect to the buffer space, you see that these nodes not only have to buffer the messages, but they will have to buffer for long durations of time. So, consequently the nodes should in OMNs should have lot of a buffer space energy. Energy is very important because energy is consumed not only in computation, but also in communication getting the message forwarding the message, but not only that energy is also consumed for storing the basic message carrying the message for certain duration of time, until it is delivered to another node and so on.

So, energy is very crucial energy aspects are very crucial for consideration in these networks. In terms of the network dynamics are there are different issues with respect to the mobility. So, mobility is very important because as I told you before that the nodes in these networks they come in contact with one another, but when they are going to come in contact with one another and how long is going to be the inter contact time and the intra contact time; that means, the nodes when they come in contact with one another how long they are going to stay connected. So, these are different issues these are very different very important issues forwarding opportunities. So, the nodes might behave a selfish node. So, they may or may not be willing to forward the messages that they receive. So, selfishness cooperation become very important in these networks.

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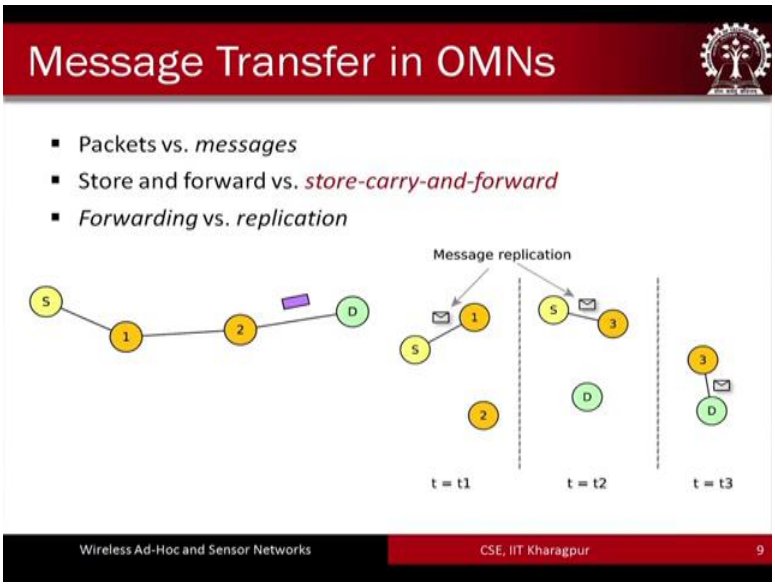

Let us now look at a very important a very fundamental concept the concept of message transferred in these networks. So, mind you that before we get into this I would tell you I should remind you that in the context of OMNs. Unlike the other wireless and word counterparts in the case of OMNs now the very important very fundamental and a very challenging issue is the issue of routing. Not although issues such as medium access transport and so on. And the different functionalities in these layers are definitely important in these networks or rather in any other similar kind of network, but the most important issue is routing this the fact is that in these networks, it is more or less a big achievement if somehow the nodes are able to send the packet to a particular disc they to the intended destination.

So, that is a big achievement by itself because of the lack of connectivity between the different nodes at different instants of time and the point how much time it is going to take for the nodes to get reconnected back again. Because that is a very long duration of time and it is an unknown parameter often. So, that is the reason why routing; that means, just sending the message from one point to another that is a big achievement. And because of the fact that not too many nodes often in this type of networks are very closely spaced and these networks are often very sparsely located it is these networks in these networks issues of medium access or even issues of transport the issues the transport are not.

So, important or I mean rather the issues of medium access and transport are not so important because of these reasons. So, issues of transport because end to end connectivity for sending for doing file transfer for instance which is an application layer protocol application running on top of transport layer etcetera. So those sort of things are not so important in these sort of network environments.

So let us look at our slide the picture that we have. So, what we have is in these networks as I said the very fundamental thing the most important thing rather is to deliver the message. So, people do not talk about different types of PDUs like packets segments frames and so on. So, there is only the concept of messages. So, messages holistically are sent from the sender node with an idea of getting this you know delivered to the destination node. In the same way as one would send the packets from a source node to a destination node in the regular internet.

So, in these networks it is sufficient it suffices to simply focus on forwarding or routing, but there is a difference in which by which the packets are forwarded in or the messages are forwarded in these networks. So, if we look at the left hand side what we see is a packet being sent from the source to the destination and the packet traverses through the path is 1 2 and 3. So, this is what is would happen for routing uni cast routing more specifically in the case of internet.

On the contrary if we look at the right hand side figure what we see is the nodes are not only forwarded, but they are replicated before forwarding. So basically you know what we see on the right hand side is at a time instant t equal to t 1, t equal to t 1 what we see is node 1 sends a message to, sorry, the sender the sender node sends a message to node 1. At time instant a related later time instant t equal to t 2, the sender node s sends a message to node 3 and at another time instant t equal t 3 the node 3 moves from it is current location and sends and transfers the packet the message to node d, because it has moved and it has come in contact in proximity of node d, and because of which they are connected with each other and the node 3 is able to deliver the message to d. So, what we have noted over here, we have noted that source node s at time instant t 1 and at time instant t 2 have replicated the message and have once sent it to node 1 and at the later time instant sent the message same message the replicated message to node 3.

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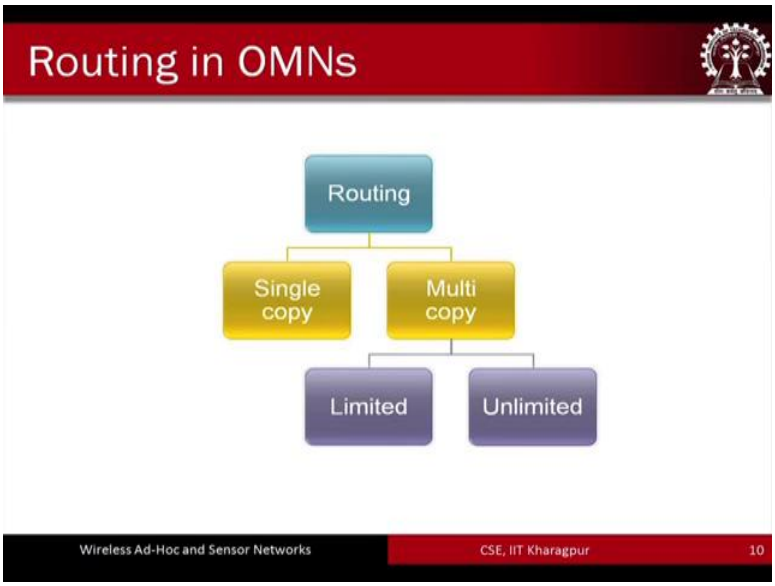

So I told you already that routing is one of the most important aspects issues of concern in OMNs. So, routing can broadly be classified as single copy routing and multi copy routing. Single copy means that only it is basically the same way the traditional way; that means, that one copy of the message is sent. Only a single copy of the message is sent multi copy. So, multiple replicas of the message are made and these replicas are sent through different paths; that means, once to a particular node the same copy of the message will be sent to another node and so on.

So, multiple copies of the message are sent. So, I think this is by very much clear by now why one would go for multi copy replication multi copy forwarding in the case of OMNs. The reason is that in this particular case there you know to what is very fundamental is to ensure that at least a single copy of the message gets delivered to the intended destination node. So, network overhead and all the other things which would arise issues of network overhead and all these other things which would arise because of doing multiple copies that becomes a that becomes unimportant right. So, that becomes you know the overhead due to those becomes unimportant. So, reliability of message delivery becomes most important and if we look back. So, what we have under multi copy we have limited we have protocols which basically talk about forwarding limited number of copies of the same message and there are some other protocols routing protocols we talk about sending unlimited number of copies of the same message.

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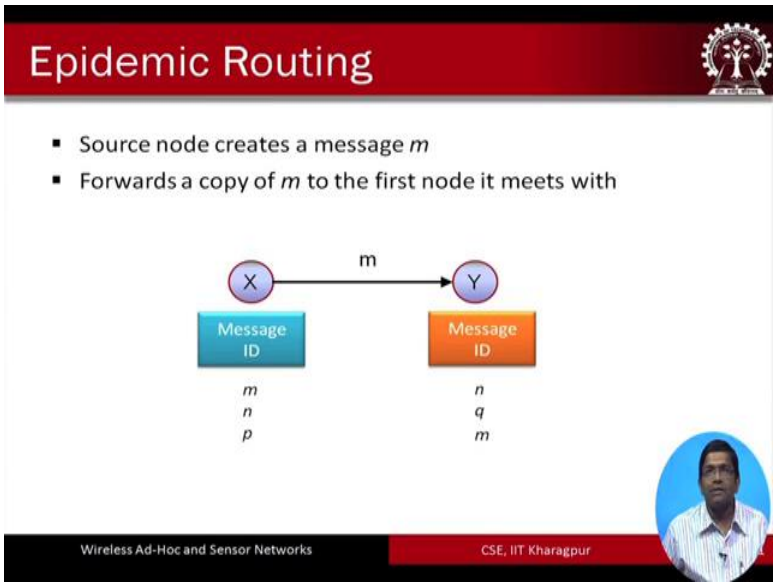

Now let us look at epidemic routing. This is a very fundamental form of routing in OMNs. So, as we can see in the figure in front of us, we have 2 nodes X and Y the source node X has to forward the message to node Y. So, this is what is going to happen the source node creates first of all would create the message m. It forwards a copy of the message to the first node it mates with like this, it creates copy of them and it forwards to the first node Y that it meets. So, that is why we have seen that over here we have m buffered along with the messages n and q in node Y.

So, this is a scenario and it is a copy of the message. So, that is the reason why you see that over here we have not deleted. We have not deleted m. So, a copy of only a copy of m has been sent to Y. And then whether you are going to delete or not at the source that depends on getting the confidence about Y about whether the message has indeed been delivered to Y or not getting some kind of a confirmation and then then only you know. So, the message can be removed from the buffer of X. So, that is actually not what one would think about in the pure epidemic routing. So, in the pure epidemic routing only a copy of the message is forwarded and that is basically stored in the buffer of node Y.

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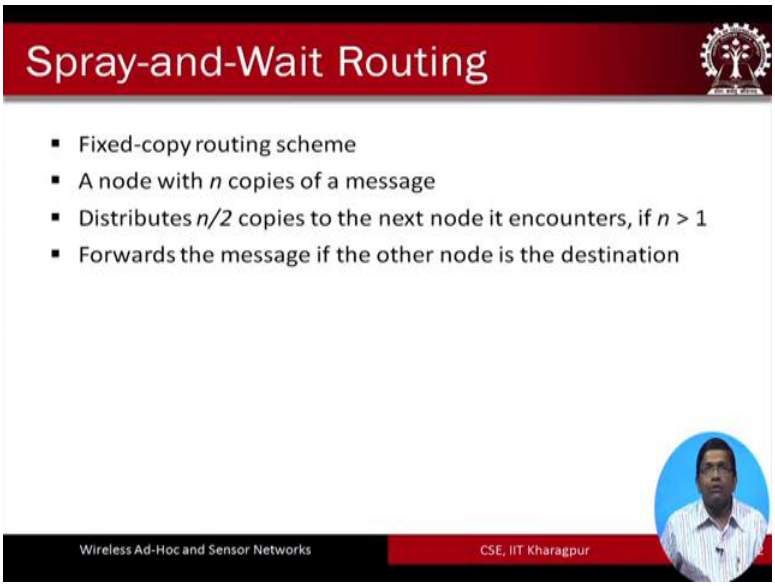

So after epidemic routing we have another kind of routing which is known as spray and wait routing in short it is often referred to as SNW routing and in SNW routing the features are like this it is a fixed copy routing scheme. So, fixed copy means that only a fixed number of copies of the message are routed. So, in spray wait routing what happens is a node, with n copies of a message would distribute half of those copies to the next node it encounters. And; obviously, n has to be greater than one; that means it has to be 2 and up. So, at least 2 messages right to copy.

So, a node with n copies of the message would distribute n by 2 copies to the next node, it encounters and forwards the message if the other node is the destination. So, half of it. So, that is how basically the send a you know forwarding of all the messages is restricted and half of the copies of the message that are received are only forwarded for forward. So, this is some of the this is these are some of the characteristics of the spray and wait routing.

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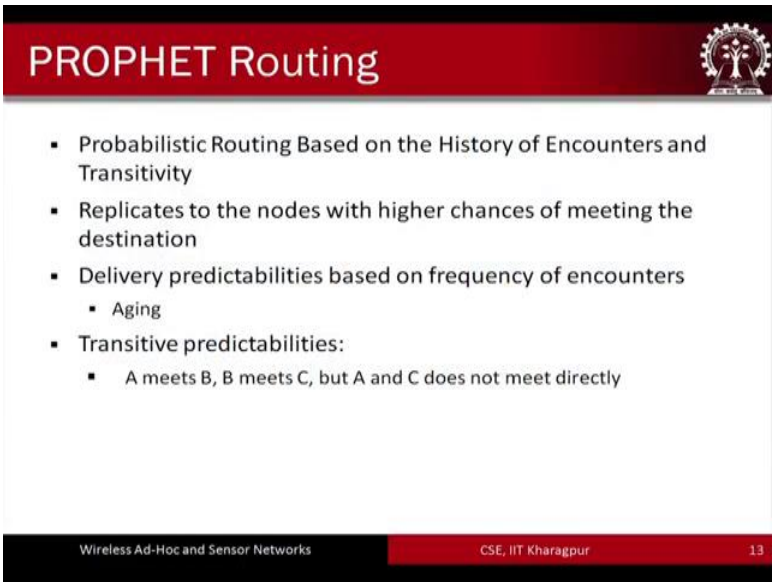

Next comes the prophet routing. So, prophet the full form is probabilistic routing based on history of encounters and transitivity though. So, this basically this name the full form basically speaks all about what prophet does. So, in prophet the message is replicated to the nodes with higher terms of to those nodes, which have higher chance of meeting the destination and there are delivery predictabilities, predictabilities mean probability the delivery predictabilities are calculated and based on those probabilities. So basically the on the basis of the frequency, so let me just rephrase this. So, on the basis of the frequency of encounters the delivery predictabilities or the probability of delivery are calculated and these probabilities or this predictability have been shown in this particular work in this protocol to have some kind of aging phenomena.

So the basically the age with time this so; that means, that the predictabilities are going to change over time right. So, this is what happens in the case of prophet. And this the other property of these predictabilities or the probabilities are that they are transitive in nature. So, what is meant by being transitive in nature is that if node A meets with B and then B meets with C, but A and C do not directly meet, but still the predictability would be transitive in nature. So, basically, So, although A and C are not meeting directly one can transitively predict the delivery of the message from A to C.

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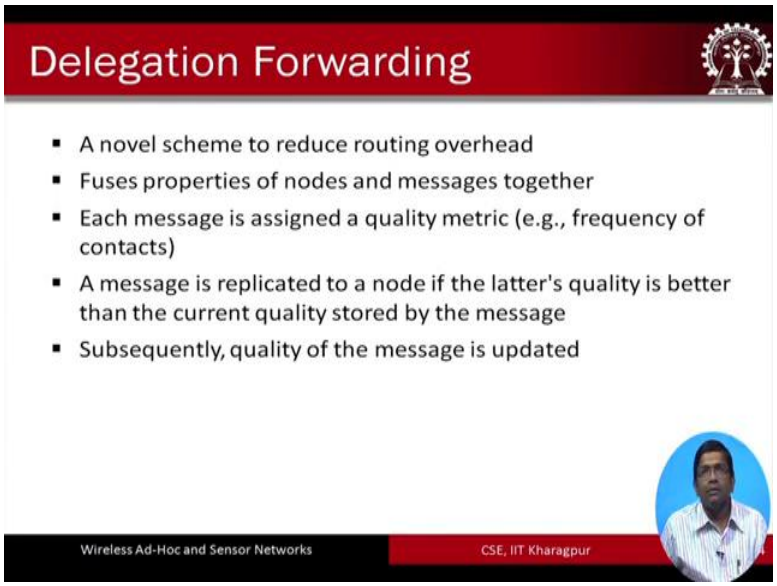

Delegation forwarding is another scheme; it is a novel scheme to reduce the routing overhead. So, it basically fuses the properties of the nodes and the messages together. So, here each message is assigned some kind of a quality metric, based on the frequency of contact. So based on this if the node has more frequency of contact then with another node, so the quality metric increases; so a message is replicated to a node if the letters; that means, the node to with which it is coming in contact ah. So, if the latter's quality is better than the current quality stored by the message. So, then it is replicated to that node subsequently the quality of the message is updated.

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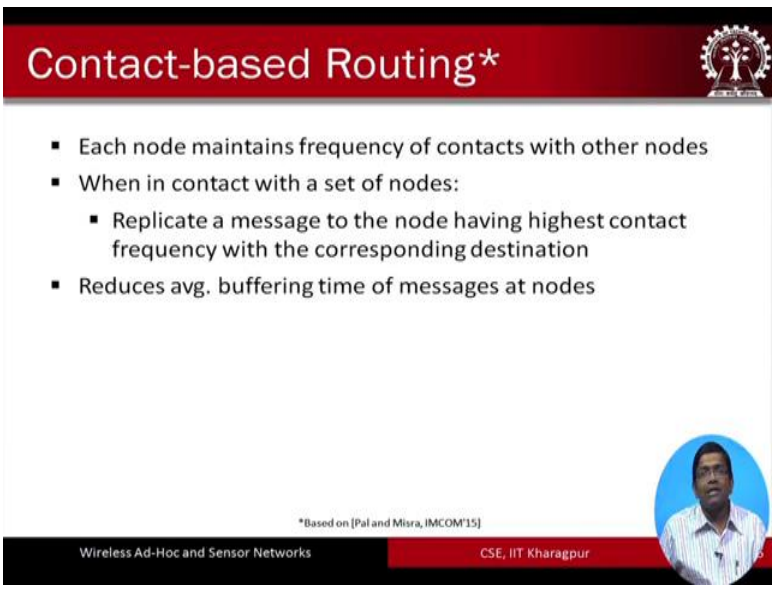

Contact based routing. So, here each node maintains the frequency of contacts with other nodes. So, when in contact with a set of nodes it replicates the message to the node having the highest contact frequency with the corresponding destination and it reduces the average buffer time of messages at the different nodes.

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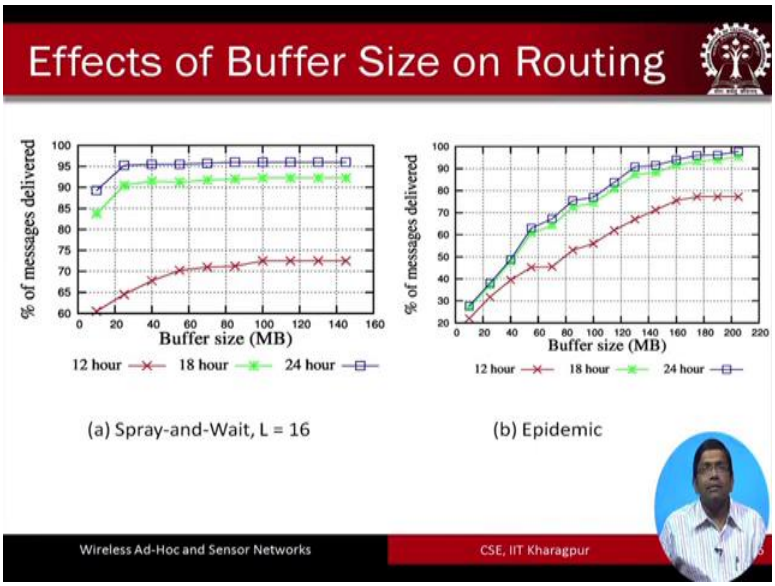

So this is a comparison of the performance of spray and wait and epidemic. As we can see by looking at these figures, that in the case of spray and wait. So, this is the effect of buffer size. So, if it is effect the buffer size on the percentage of messages delivered. So, if we compare these 2 protocol spray and wait and epidemic, we find that the percentage of usages delivered basically is more in compared to a more in a spray and wait compared to that in epidemic. So, there is a general train that we see over here of course, there are some specific instances where we cannot really have this kind of observation, but in general. So, basically spray and wait basically performs better than epidemic in terms of the number of messages delivered.

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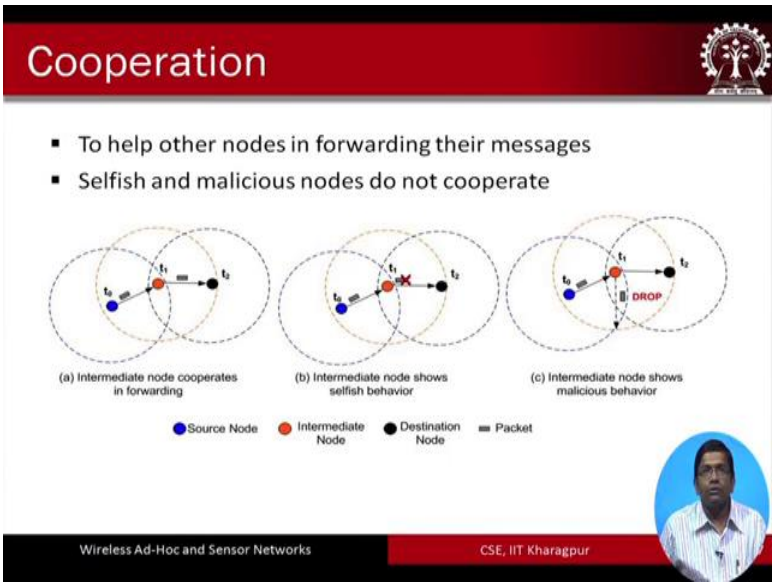

Cooperation is another very important issue as I said that the messages are basically given to a particular node handed over 2 particular nodes the node would have to buffer carry the message forward of another node. So, message basically belongs to that other node, but it still has to store and carry it forward and move and then deliver to another node until it basically finds that particular node which is suitable. So, in this particular case it is quite obvious that cooperation becomes a very important issue. So, to help other nodes in forwarding their messages the coop and issue of cooperation comes into picture so on the left hand side. So, we see 3 figures we on the left hand side we see the scenario where an intermediate node this one basically cooperates with the sender in forwarding the message that it has sent to the intended destination node. So, this is a case of cooperation proper cooperation.

In this particular case we see that the message is not forward. It this is this node basically behaves in a selfish node. So, although it receives the message it will not forward it further and in this particular case we find that not only that the message. So, it is this particular node basically behaves as a malicious node. So, because it is a malicious node intentionally what it is going to do and with the malicious intent what it is going to do is on receiving the message, it is going to drop the message without forwarding it further.

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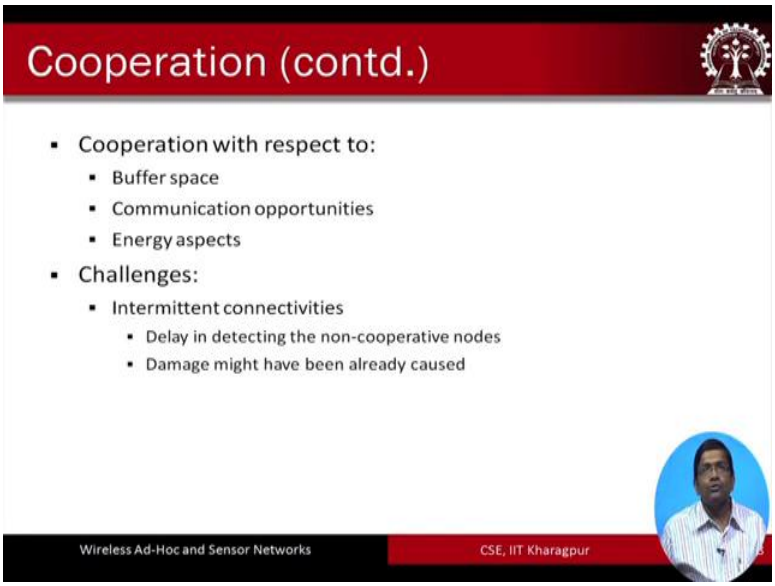

So, cooperation issues are important issues when we talk about cooperation specific issues. For example, the buffer space communication opportunities energy aspects these are quite intuitively important. So, consequently I am not going to elaborate on each of these issues further. So, there are different challenges that are encountered, so encountered of enforcing cooperation in these networks issues of interconnectivity which are the pine concerns in OMNs. So, because of intermittent connectivity there is delay in detecting the non cooperative nodes. And by that time the nodes are detected due to the delay in detecting the non cooperative nodes some damage might have already been caused by the malicious node by the non cooperative node to the network.

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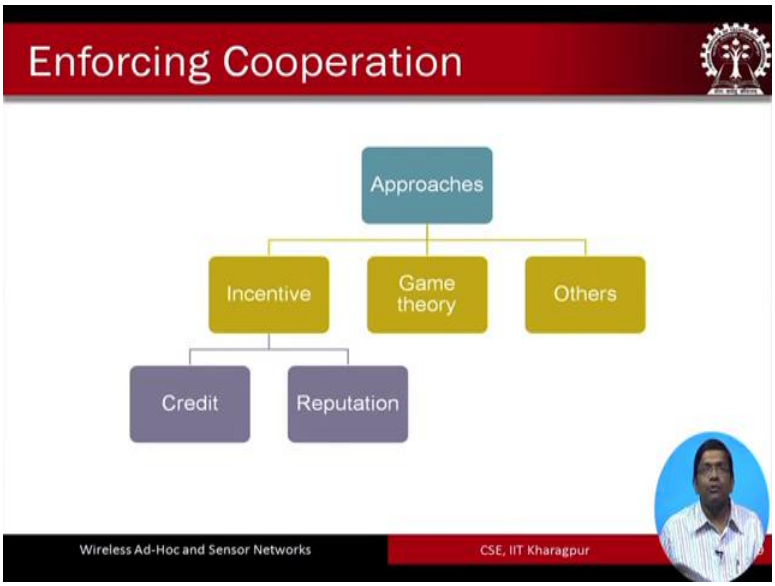

So for enforcing cooperation different approaches have been proposed incentive based approaches game theory based approaches, and there are different other approaches which do not belong to either the incentives incentive based approach or the game theory based approach.

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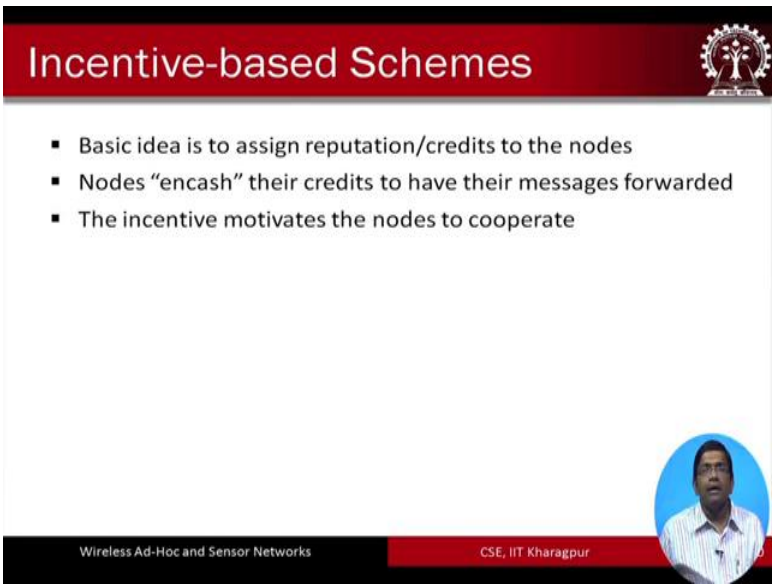

Under the incentive based approach credit based approach and reputation based approaches. So, let us now first look at incentive based approaches. So, as the name suggests the basic idea is to assign reputation or credit is to the nodes here the nodes are

going to earn the credit is and they are going to encash their credit is in order to have their messages forwarded. So, the incentive over here is in terms of earning the credit is because ultimately if a node later on has to forward it is own message then if it does not have enough credit is it will not be able to forward the message. So, basically there is an incentive for cooperation in terms of earning the credit is earning the cash. So, that it can encash it at later point of time encash the credit is that it has earned at later point of time to forwards it is message.

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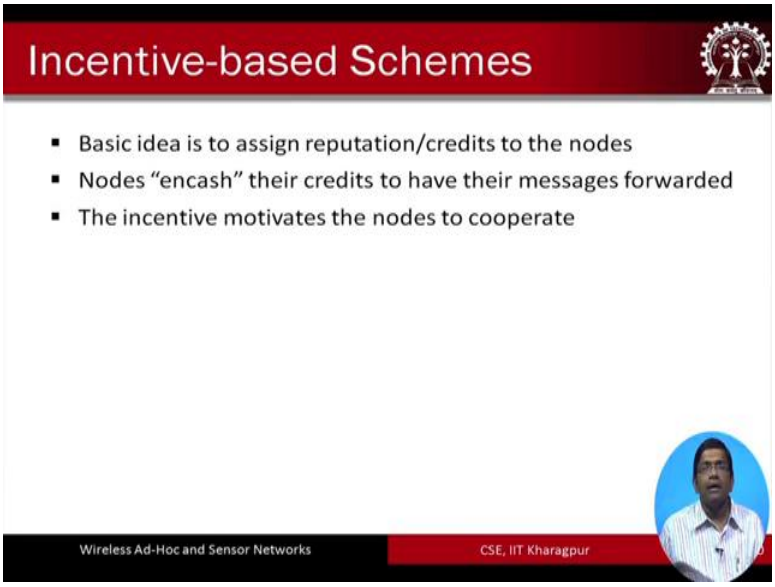

Credit based schemes again the name says it all. So, here basically you know that is I mean one of the examples of credit based scheme is the tit for tat incentive mechanism. So, here basically what happens is that tit for tat means that it is a very simple kind of mechanism. So, here basically what happens is 2 nodes A and B let us consider if A does not forward the message it has received from B. So, later on B is also going to do the same the tit for tat normally that we follow in the regular society in our society right.

So if A does not forward the message of the B is also not going to do the same. So, there are different constraints under which the tit for tat may be made to operate issue of generous generosity and contrition. So, generosity means that in certain cases not that a will not forward any message of B if B is not doing the same, but maybe n number of messages will be generously forwarded even if, B does not forward any of the messages of A. So, generous t f t is one of these schemes the other is contrition. So, contrition

basically prevents selfishness. So, contrition is some kind of a remorse. So, remorse kind of you know. So that kind of feeling not feeling, but that is emulated in the different nodes. So, contrition the feeling of contrition is all your calling a feeling of remorse is emulated in the different nodes through different algorithms in order to prevent selfishness in these networks.

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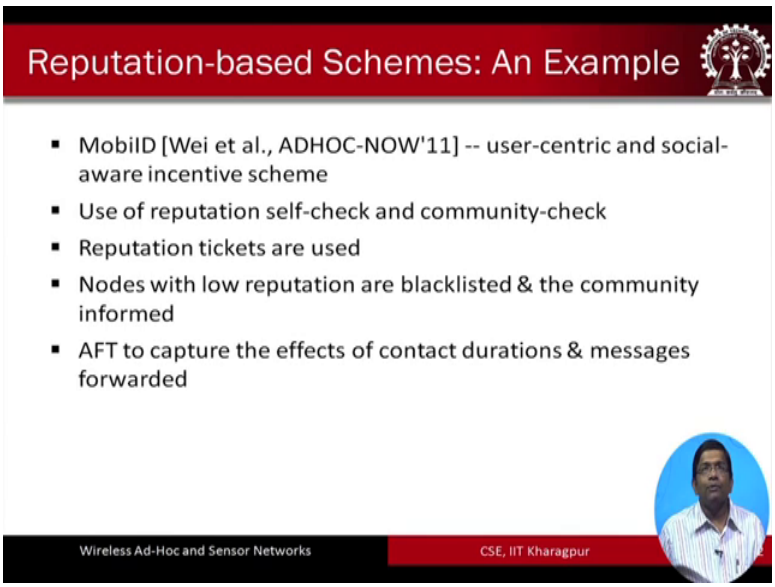

Reputation based mechanisms again you know reputations values of reputations are maintained at the different nodes use of the reputation is made by self checking and community checking. So, the node directly is going to observe the behavior of the different other nodes, it is vicinity or it is going to check in the entire community by contacting the other peers that it is in connectivity with similar thing is going to happen to those peers as well, and consequently the entire community is going to be checked and the reputation values are going to be updated. So, reputation tickets are issued or used the concept of reputation ticket. So, basically in any ticket based mechanism what happens is, So, 2 parties will have to sign 2 parties will have to sign. So basically you know 2 parties will have to agree. So, if I say that you know a particular node is reputed. So, that basically has to be also endorsed by other nodes. So, and at least one more node has to endorse it. So, that is how the reputation tickets are signed. So, that is the signing mechanism of the reputation tickets and so on. So, nodes with no reputation are blacklisted eventually and the community is informed.

So AFT, AFT stands for average forwarding time the concept of calculation of AFT average forwarding time is used to capture the effects of contact durations and the messages forwarded.

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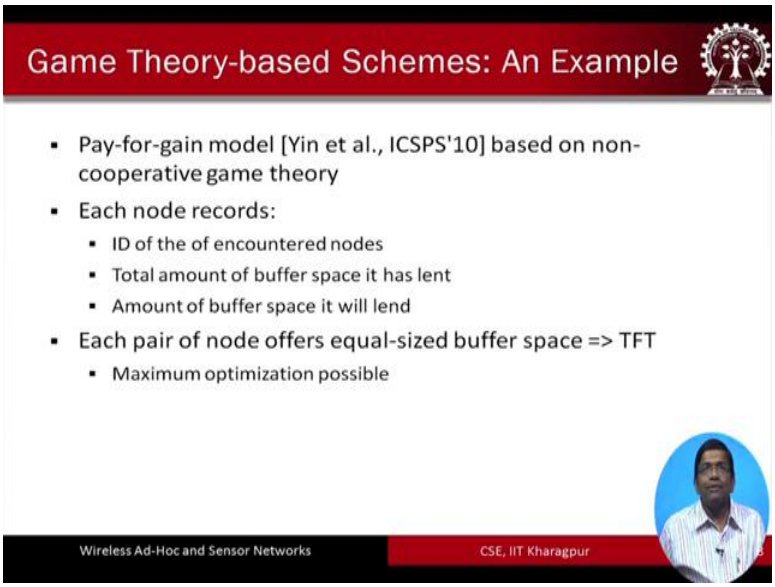

In the game theory based approaches there are different types of game theory based approaches one is basically cooperative based approach, based on cooperating game theory the other one is non cooperative game theory in non. So in a game basically what happens is there are 2 or more players. So, 2 or more nodes let us say. So, and some kind of a game is emulated some kind of a game is formed game like scenario. So, the nodes basically the or the actors are performing different strategies they have different strategies. And the based on the strategies the payoffs are updated; so basically in a non cooperative game. So, basically it is non cooperative and you know. So, 2 parties they try to earn their own credit is by following their individual strategies and in a cooperative game the strategies are performed collectively and collectively a joint solution is try to achieve.

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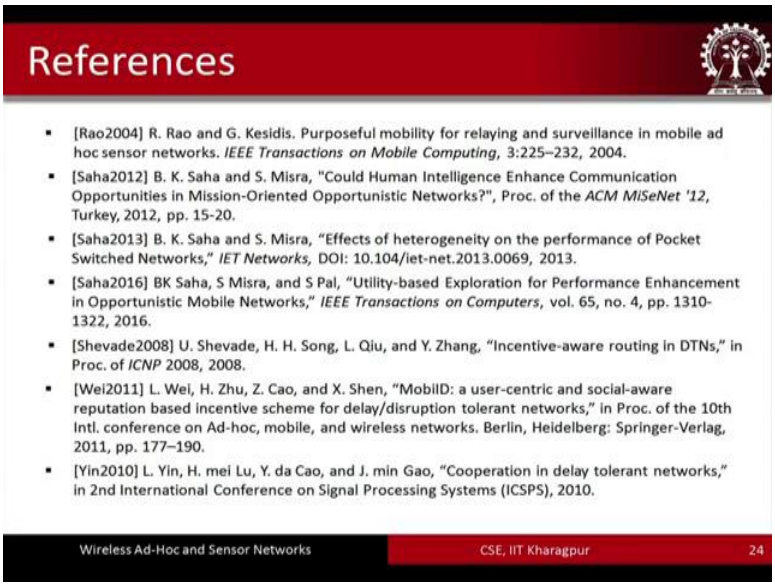

So, these are the differences and some of these things that, I already spoke about are available in these references.

Thank you.