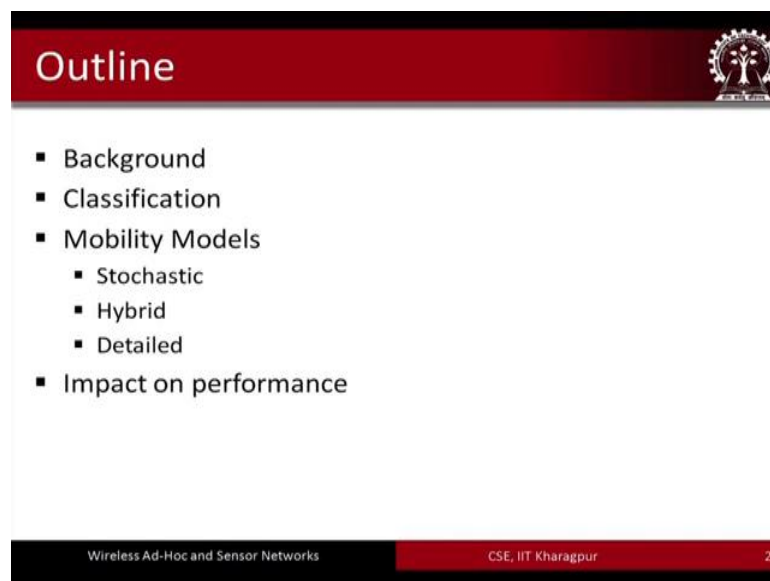


Wireless Ad-Hoc and Sensor Networks
Prof. Sudip Misra
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture - 12
Mobility Models for MANETs

So the lecture that we are going to cover now is on the topic of mobility models for mobile Ad-Hoc networks.

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The slide is titled "Outline" and features a list of topics. The list is as follows:

- Background
- Classification
- Mobility Models
 - Stochastic
 - Hybrid
 - Detailed
- Impact on performance

The slide also includes a logo in the top right corner and footer text at the bottom: "Wireless Ad-Hoc and Sensor Networks", "CSE, IIT Kharagpur", and "2".

So, brief outline of how I am going to what I am going to cover now. So, we will start with the background some of the background information it is required to understand the topic. Here after the classification of the mobility models which mobility models can be classified into stochastic hybrid and detailed and some of the performance issues using each of these mobility models.

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The slide is titled "Background" and features a red header bar with a logo on the right. The main content area is white and contains a bulleted list of testing methods for ad hoc networks. To the right of the list, there are two vertical red arrows: one pointing up labeled "Accuracy" and one pointing down labeled "Convenience", indicating a tradeoff. At the bottom right, there is a circular inset photo of a man. The footer consists of a black bar with the text "Wireless Ad-Hoc and Sensor Networks" on the left and "CSE, IIT Kharagpur" on the right.

- Testing the performance of ad hoc networks:
 - Test-bed
 - Simulation
 - Analytical

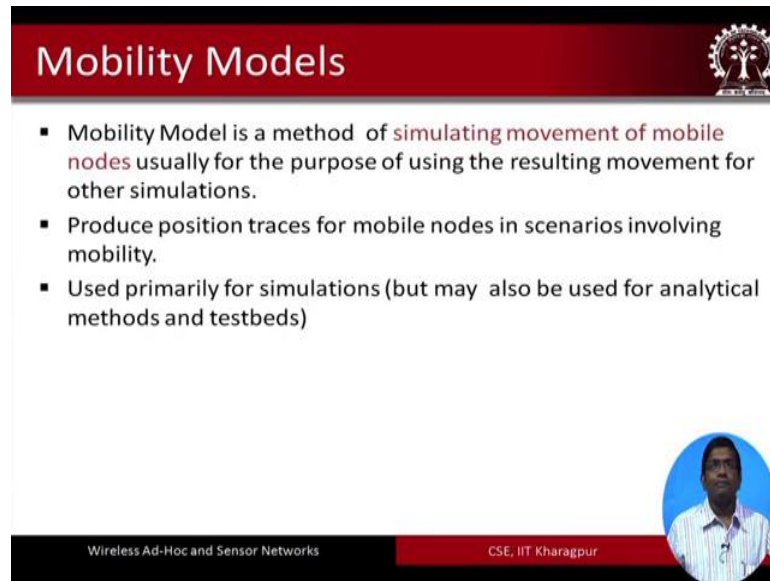
Accuracy ↑
Convenience ↓

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In terms of assessing the performance of an Ad-Hoc network, the Ad-Hoc network can be performance an Ad-Hoc network can be analyzed in 3 different ways, using test beds using simulations or analytical methods. So, there is a tradeoff between which method is used and with respect to accuracy and convenience there is tradeoff between the each of the use of each of these different methods whereas, the test bed based methods are the least convenient, and the analytical methods are the most convenient. In terms of accuracy on the other hand the test bed based methods would lead to the most accurate results of the performance of Ad-Hoc networks, compared to the simulation based means or the analytical based means.

So, in terms of accuracy test bed based methods are the most accurate. Most accurate in the sense that because they are capturing the real scenario. So, this results would lead to real more accurate results. And the results that are obtained using the test bed based performance evaluations they are going to lead to more accurate results compared to the simulation and analytical means. And on the other hand as I said before that in terms of convenience analytical models are the most convenient. Because you know we are talking about designing mathematical models mathematical equations which are easiest easier to perform compared to simulations running simulations or the most difficult ones are to design the test beds. These are the most difficult wants to achieve and, but if one is able to design the test beds that on the results that are obtained using the test beds are the most accurate.

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The slide features a red header with the title "Mobility Models" and a small logo on the right. Below the header, there is a bulleted list of three points. At the bottom right of the slide, there is a circular portrait of a man. The footer contains two red boxes with white text: "Wireless Ad-Hoc and Sensor Networks" on the left and "CSE, IIT Kharagpur" on the right.

Mobility Models

- Mobility Model is a method of **simulating movement of mobile nodes** usually for the purpose of using the resulting movement for other simulations.
- Produce position traces for mobile nodes in scenarios involving mobility.
- Used primarily for simulations (but may also be used for analytical methods and testbeds)

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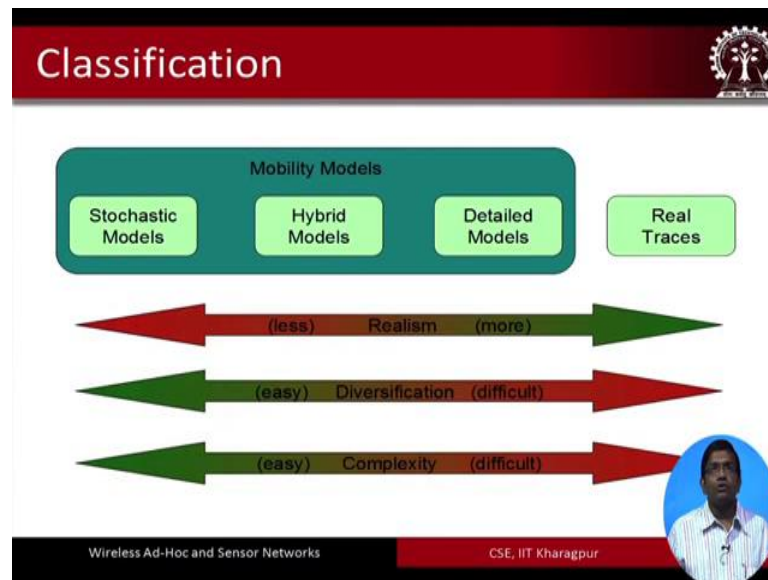
A mobility model is a method of simulating the movement of mobile nodes usually for the purpose of using the resulting movement for other simulations.

So, what happens is the nodes that are going to because we are talking about Ad-Hoc networks. Mobile Ad-Hoc networks in a mobile Ad-Hoc network the nodes move. So, what is required is to understand. So, when we want to simulate we want to understand that how these nodes are going to move. So, in reality the movement might be very different. Different in the sense that it is often not very much possible to predict how the nodes are going to move in reality; however, there are different ways there are different models which can be adopted to predict the mobility of the different nodes.

So, this is what the mobility models do. So, the mobility models will help in simulating the movement of the mobile nodes. They produce position traces for the mobile nodes in scenarios involving mobility, which means that position traces means that when the node moves in a particular terrain, the traces are going to capture the different positions at different instants of time of the nodes. And those stresses can help in understanding the capturing of the stresses can understanding can help in understanding the performance of the different protocols that are that are designed for these networks.

So, these are used primarily for simulations in mobility models are used primarily for simulations; however, they can also be used for other methods like you know displaced based methods or analytical methods.

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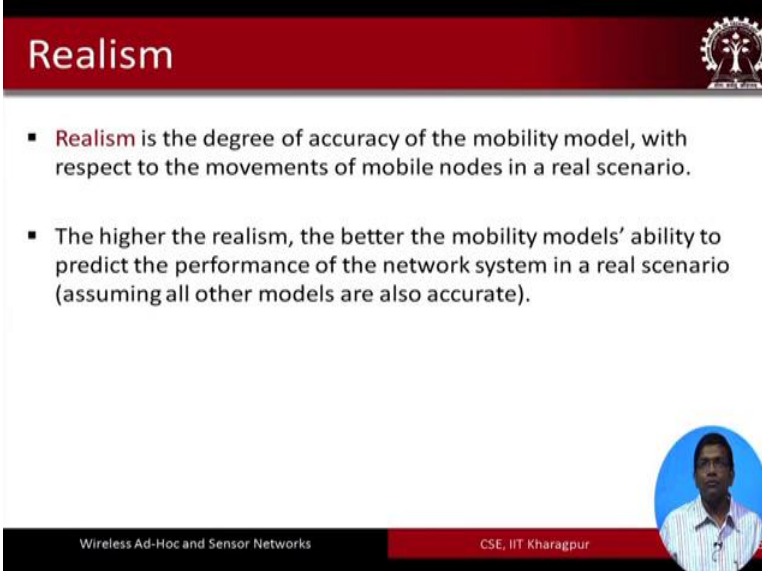
So, mobility models can be classified into 3 different types. Stochastic models hybrid models and detailed models. Additionally, as I mentioned just a while back that there could be traces that could be captured from a real life mobile scenario. So, these real traces can also help in understanding the how a particular protocol a particular algorithm or a scheme that is designed for these networks they perform. So, if we think if we look at these 3 classes of mobility models the stochastic models hybrid models and the detailed models. In terms of really realism the stochastic models are the re least realistic. On the other hand, the detailed models are the most realistic

So, stochastic models are the least realistic. Whereas, the detailed models are the most realistic. And on the other extremity the real traces; obviously, are more realistic because they. In fact, have been captured from the real movement of nodes in an actual setting. In terms of diversification, the stochastic models are the easiest to be diversified. And then comes the hybrid models and among all the mobility models the most difficult wants to diversify are the detailed models; obviously, real traces are the most difficult to diversify. They are even more difficult to diversify than a detailed mobility model.

In terms of the complexity the complexity is the list in the stochastic models, whereas, they are the most in the case of the detailed models or even more in the case of real traces. So, in case of real traces and detailed models detailed mobility models the

complexity is much more is a maximum compared to the hybrid models and the stochastic models.

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The slide features a red header with the word "Realism" in white. In the top right corner of the header is a circular logo with a tree and the text "IIT KHARAGPUR". The main content area is white and contains two bullet points. In the bottom right corner of the slide is a circular portrait of a man with a beard, wearing a light blue shirt. The footer consists of a black bar on the left with the text "Wireless Ad-Hoc and Sensor Networks" and a red bar on the right with the text "CSE, IIT Kharagpur".

Realism

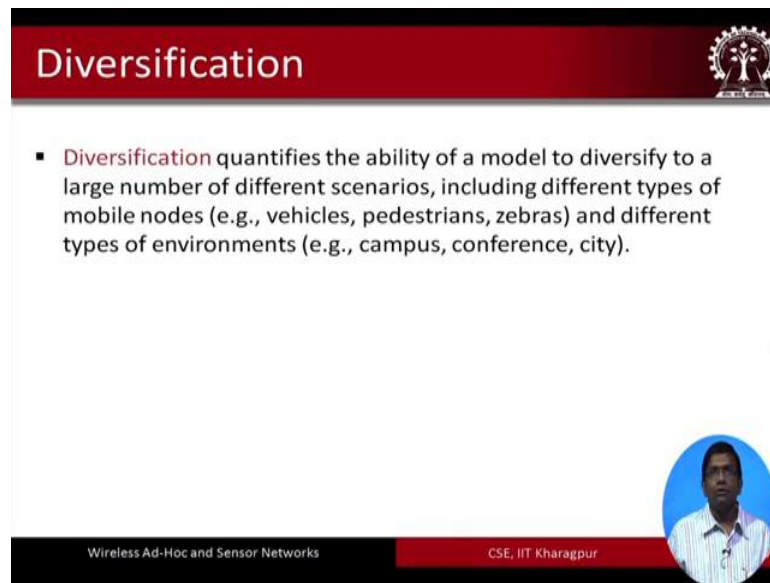
- **Realism** is the degree of accuracy of the mobility model, with respect to the movements of mobile nodes in a real scenario.
- The higher the realism, the better the mobility models' ability to predict the performance of the network system in a real scenario (assuming all other models are also accurate).

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So, let us now go through exactly what is meant by these terms realism, diversification and complexity. Realism is the degree of accuracy of the mobility model with respect to the movement of the mobile nodes. In a real scenario in reality what is going to happen and trying to capture the degree of accuracy of the mobility model with respect to what is going to happen in a real scenario. So, basically the higher the realism the better is the mobility models ability to predict the performance of the network system in a real scenario. And that is quite obvious I do not think that I need to elaborate further on this.


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Diversification

- **Diversification** quantifies the ability of a model to diversify to a large number of different scenarios, including different types of mobile nodes (e.g., vehicles, pedestrians, zebras) and different types of environments (e.g., campus, conference, city).

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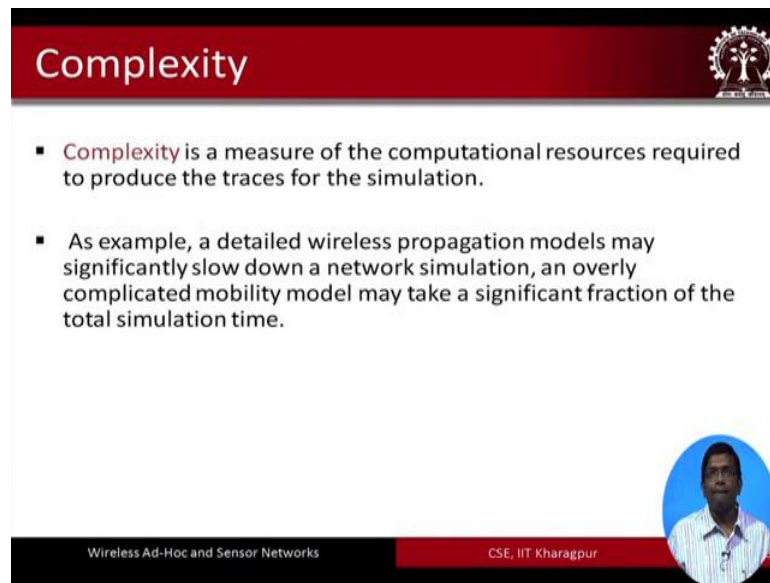


In terms of diversification this is an attribute that quantifies the ability of a model to diversify to a large number of different scenarios.

So, for example, mobile nodes in vehicles pedestrians' zebras are all different. So, basically if somebody is capturing an environment involving vehicles pedestrians and zebras, those cannot probably or more likely be applied in environments such as a campus of a university a conference or a city environment.

So, this is basically that the you know if the mobility model captures if the mobility model captures a particular type of scenario whether it can be diversified and be applied and be used in other types of scenarios.


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Complexity

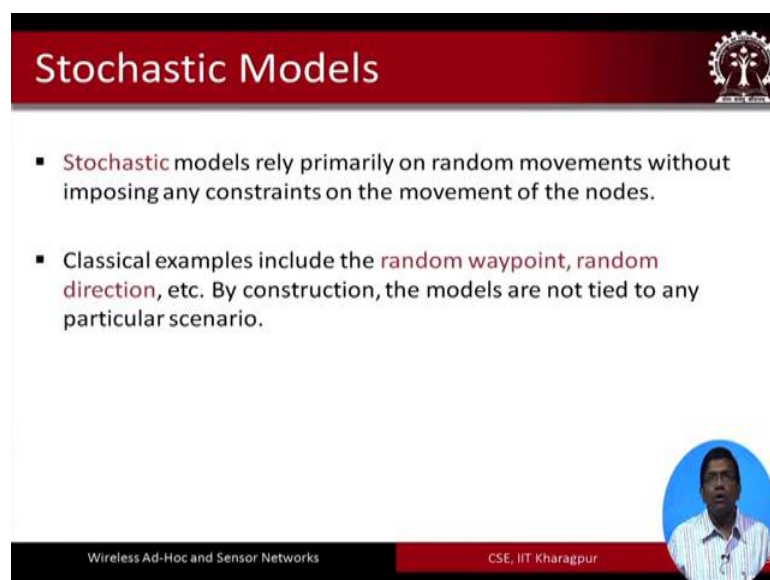
- **Complexity** is a measure of the computational resources required to produce the traces for the simulation.
- As example, a detailed wireless propagation models may significantly slow down a network simulation, an overly complicated mobility model may take a significant fraction of the total simulation time.

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Complexity is basically the measure of the computational resources that are required to produce the traces of simulation. So, for example, a detailed wireless propagation model, may significantly slow down a network simulation and overly complicated mobility model may take a significant fraction of the total simulation time. So, complexity basically increases in such cases.


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Stochastic Models

- **Stochastic** models rely primarily on random movements without imposing any constraints on the movement of the nodes.
- Classical examples include the **random waypoint**, **random direction**, etc. By construction, the models are not tied to any particular scenario.

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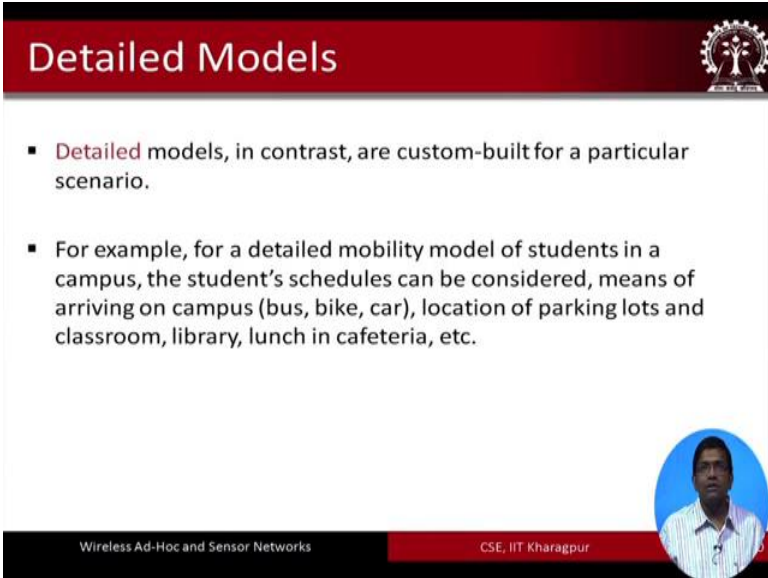


Stochastic models basically rely on the random movement of the nodes, and they do not impose too many constraints on the movement of the nodes. So, some of the examples of

stochastic models include the random way point model, the random direction model and so on.

So, we are going to go through some of them by construction these models are not tied to any particular scenario. So, basically they can be they are so much generic in nature that they can be applied and we adopted in different types of environments. So in fact, let me put it more clearly that one can apply one can use the random waypoint model or the random direction model in campus environments, in hospital environments, in the case of you know tracing of pedestrians in a public place in the case of zebras the mobility of zebras and so on. So, all of them are assumed to be having some similar characteristics in terms of mobility and a similar kind of movement pattern is adopted in all of them.

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The slide features a red header with the title "Detailed Models" and a small logo on the right. Below the header, there are two bullet points. In the bottom right corner, there is a circular inset photo of a man. The footer contains the text "Wireless Ad-Hoc and Sensor Networks" and "CSE, IIT Kharagpur".

- **Detailed** models, in contrast, are custom-built for a particular scenario.
- For example, for a detailed mobility model of students in a campus, the student's schedules can be considered, means of arriving on campus (bus, bike, car), location of parking lots and classroom, library, lunch in cafeteria, etc.


So, they are not very much scenario specific. Detailed models on the other hand are very much custom designed they are built for a particular scenario keeping a particular scenario in mind.

So, for example, a detailed mobility model of students in a campus the student schedules can be considered means of arriving on the campus, whether in a bus using a car or any other means a bike and so on. The location of the parking lots and classroom library lunch in cafeteria. So, all of these different you know. So, different entities all of these can be considered and how the students are going to move around these different entities in a particular scenario are all captured in details in these classes of mobility models.

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Hybrid Models

- **Hybrid** Models aim to balance the realism of detailed models with the diversification convenience of stochastic models. Depending on the particular target, the model can lean more on one side or the other of the two extremes. Hybrid models are divided into group, obstacle, and trace-based mobility models.



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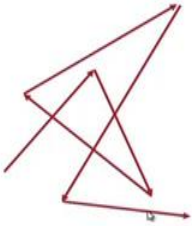
The detailed mobility models; Hybrid model and as this name suggests they basically are designed to balance the realism of detailed models with the diversification convenience of the stochastic models.

So, depending on the particular target the model can lean more on one side or the other of the 2 extremes. Hybrid models are divided into group based models obstacle based models and trace based mobility models some of which we are going to elaborate further today.

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Random Waypoint (RWP)

- Each node moves independently
- Chooses a random destination
- Chooses a random speed
- When it arrives at the destination it chooses a random pause time
- Repeats the same process



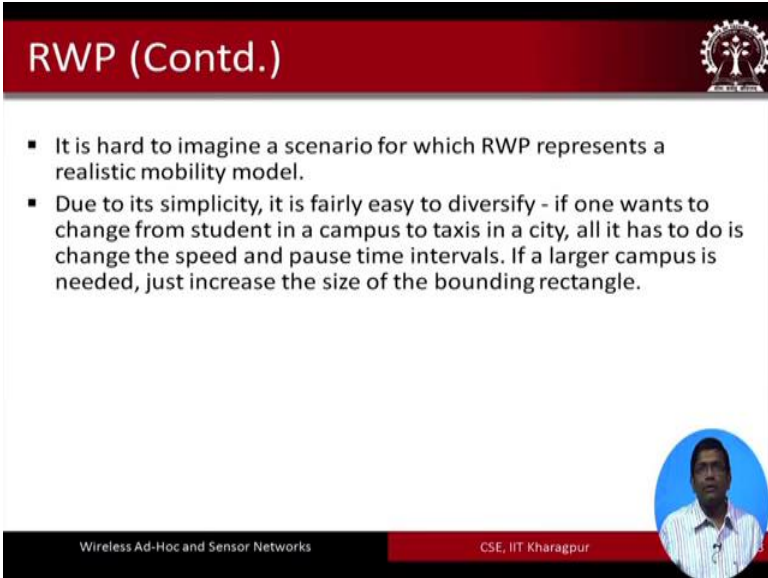
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The random waypoint model is a stochastic model and these are easily diversified the easiest to diversify and are easier to implement as well. So, here in the RWP mobility models each node basically moves independently of the others.

So, a particular node or rather each and every node we choose a random direction and a random speed and when the node arrives at the destination it to this a random pause time. So, a random destination is chosen from a particular point and a random speed is chosen the node starts from a particular point in the terrain using the random speed that is chosen and the direction that is chosen the node is going to come to the new position.

When it comes to the new position it waits is there it pauses there for a certain duration of time which is technically known as pause time in the literature, and the process repeats like this. So, this is how the random mobility model looks like. So, as we saw in the animation. So, the node started from here took a specific direction, alpha and a random velocity, we came to this random destination then it applied the same thing came to this random destination along using a particular speed and it continues to do the same for the rest of the journey.

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The slide features a red header with the text "RWP (Contd.)" and a small circular logo on the right. The main content area is white with two bullet points. In the bottom right corner, there is a circular inset photo of a man in a light-colored shirt. The footer consists of a black bar on the left with the text "Wireless Ad-Hoc and Sensor Networks" and a red bar on the right with the text "CSE, IIT Kharagpur".

RWP (Contd.)

- It is hard to imagine a scenario for which RWP represents a realistic mobility model.
- Due to its simplicity, it is fairly easy to diversify - if one wants to change from student in a campus to taxis in a city, all it has to do is change the speed and pause time intervals. If a larger campus is needed, just increase the size of the bounding rectangle.

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So, it is hard to imagine a scenario for which RWP represents a realistic mobility model. I mean this kind of. So, what is meant basically is that this kind of mobility model are not so realistic. So, seldom you will be able to find real scenarios where RWP would be exactly applicable, but due to the simplicity of this model. It is easier to implement them

it is easier to diversify this model. So, diversification in this particular case once again means that.

So, let us say that you have a scenario of an of the students moving in the campus, and then you apply the RWP model get the performance results how the protocol that we have designed performs using this particular mode mobility model and then you shift it and apply the same thing for the same protocol in an environment like a city where the taxis are moving for incidence. So, what is meant by this diversification easier to diversify is that these models can be easily the results that are obtained by applying this RWP model in a school scenario. They can be translated and be used when you change the scenario to the city environment and the mobility of the taxis in such environment.

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The slide is titled "Random Walk" and features a red header bar with the IIT Kharagpur logo on the right. The main content area is white and contains a bulleted list of characteristics for the Random Walk model. To the right of the text are three red line diagrams illustrating random paths. At the bottom right of the slide is a circular inset photo of a man. The footer consists of a black bar with the text "Wireless Ad-Hoc and Sensor Networks" on the left and "CSE, IIT Kharagpur" on the right.


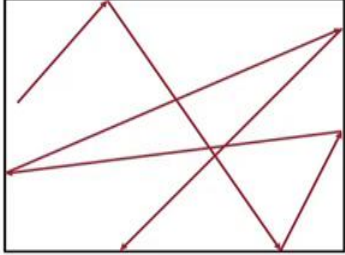
- Each node moves independently
- Choose random direction and random speed
- It moves for a time period (or over a fixed distance) with this speed, then it repeats its choice.
- Unlike RWP, it does not choose any destination.

Next comes the random walk mobility model here each node moves independently. So, if every node to just a random direction and a random speed. The node moves for a time period or over a fixed distance with the speed then it repeats it is choice the only difference I mean these 2 are quite similar in functionality; however, unlike the random waypoint model the random walk model does not choose any destination. So, earlier if you recall the RWP model basically assumes that the destination is chosen randomly. So, that is basically not adopted in the case of such a strategy is not adopted in the case of the random walk mobility model.

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Random Direction

- Choose a random direction and a random speed
- Move until it encounters an edge
- Repeat
- Results in a uniform distribution in the scenario area



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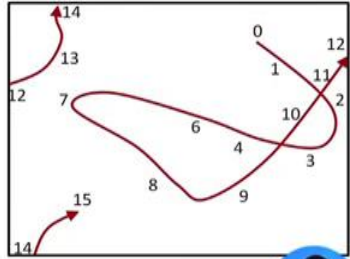
Now, we see in front of us how the random direction mobility model works. So, in the random direction model as the name suggests again the node basically chooses a random direction and a random speed and it moves until it encounters an edge. So, this is what we just saw. So, random direction α random speed v . So, the node keeps on traveling. So, the random destination is not chosen here. So, their destination is basically when this node hit is the boundary. So, it hit is the boundary and then it continues to repeat the same.

So, this sort of mobility model results in a uniform distribution in the scenario area.

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Smooth Mobility Model

- Each node changes speed and direction smoothly
- The world is a torus, resulting in smooth trajectories
- Each node is characterized by a motion vector (v, q) , where v is the speed of the node and q is the direction. The position (x, y) of a node and its motion vector are updated periodically.



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The smooth mobility model looks like what is shown in the figure in front of you. Where each node changes the speed and direction smoothly. Earlier if you recall in all the mobility models the nodes were going through in a straight line. So, it either it would go and hit the node would start for a particular position, choose a random alpha the direction with a random speed it would go and it would either hit the boundary of the region and then it is going to get reflected from there, or what it is going to do is it is going to choose a random destination and change its position from there.


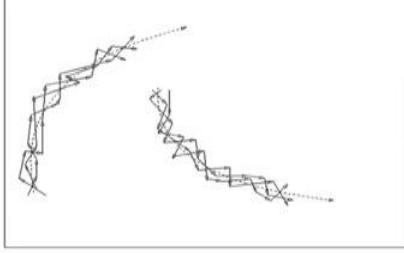
So, these in the previous models the ones that I just mentioned all of them result in straight line vectors; however, if we look at the figure in front of us for the smooth mobility model for each of the nodes which moves we find that the trajectory is basically a smooth trajectory smooth trajectory not a straight line or anything like that. So, here each node is characterized by a motion vector v, q where v is the speed of the node and q is the direction the position x, y of a node and its motion vector are updated regularly or periodically rather.

So, a certain interval of time both the positions x and y and the motion vector; that means, v, q . So, these are basically updated. So, v, q means like the velocity of the node and the direction in which it is moving. So, so all of these they basically change over time due to which we get a pattern like this we do not have straight trajectories like the previous models, but we have the curved mobility patterns in the region.

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Group Mobility Models

- Each group moves randomly (i.e., uses RWP mobility model)
- Each node in the group moves randomly around the group center
- First step toward realism models



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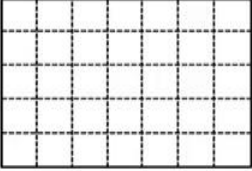
Now, what we see is the group mobility model. So, here each group moves randomly. So, the previous models that we have seen. So, far here basically we considered the mobility of a single entity the mobility of a single node; however, in practice in real life, we encounter scenarios where groups of people may walk in a particular pattern, where there are flux off birds that fly in a particular pattern and so on.

So, basically what is also required is apart from the single mobility model single node mobility models, it is required to have mobility models for the groups as well. So, here each group moves randomly that is using the RWP mobility model, each node in the group moves randomly around the group center. So, if you look at this particular case we have a group like this. So, around the group center all the nodes in the group they move around and finally, the group moves as a whole and what we see over here is the group mobility model. So, this is the first model towards realism. So, this is the first step that has been taken towards develop designing realistic models, group based mobility models, because these are the models that exist in reality in real life scenarios.

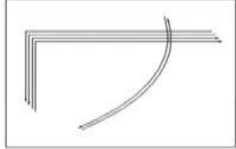
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Obstacle Models

- Restrict the degrees of freedom for movements
- In *Manhattan mobility model*, nodes can only move on a grid (of roads)
- In *Freeway mobility model*, nodes follow the rules on Freeways (with multiple lanes and two directions).



Manhattan mobility model



Freeway mobility model

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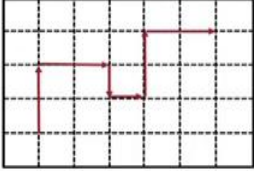
Then we have the obstacle models which basically as the name suggests again, which basically and assume that the degree of freedom of the movement of the nodes are restricted from obstacles from obstacles. So, these are 2 examples that are shown in the figure in front of you. So, one the first one on the top is the Manhattan mobility model. And this looks like moving on a grid of roads. So, as this name suggests Manhattan in US have a pattern of roads like what is what is shown in the figure.

So, what we have is north south east west 2 sets of lines or roads cutting each other. So, giving a grid like pattern of roads and that is why these nodes these mobility models that follow this kind of pattern in the movement of the nodes are known as the Manhattan mobility models. The bottom figure shows the freeway mobility model, where the nodes follow the rules on freeways with multiple lanes and 2 directions and that is also quite visible from here. If you see here if you look at here carefully, we have these freeways running in 2 completely different opposite directions and the mobility of the nodes basically are carried on using this kind of mobility model.

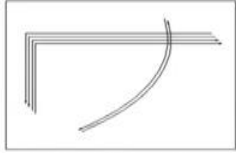
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Obstacle Models

- Restrict the degrees of freedom for movements
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- In *Freeway mobility model*, nodes follow the rules on Freeways (with multiple lanes and two directions).



Manhattan mobility model



Freeway mobility model

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So, in both the directions the nodes can move.

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Detailed Mobility Models

- Detailed mobility models are the extreme in realism for mobility models
- Captures very detailed behavior (e.g., lane changes, stop signs, etc.)
- More realistic than previous mobility models
- Unfortunately they are very difficult to diversify (e.g., cannot use a vehicular mobility model to simulate movement of zebras)

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Detailed mobility models are basically the extreme in terms of realism these are the most among all the mobility models these are the most realistic ones they capture the very detailed behavior in terms of things like lane changes stop signs etcetera. They are more realistic than the previous mobility models; however, unfortunately they are very difficult to diversify. Example one cannot use a vehicular mobility model to simulate movement of zebras in a forest trace.

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Trace-based Mobility Models

- Aim to replicate/emulate the type of movements in a sample trace
- Given a sample trace from a target scenario, many “similar” traces can be produced.

The flowchart illustrates the process of trace-based mobility models. It starts with 'Real Traces Or Detailed Simulator Traces' (enclosed in a dashed box) which go through 'Trace Processing' to create a 'Parameter Set'. This 'Parameter Set' is fed into a 'Mobility Model'. The 'Mobility Model' also receives 'User Parameters' and a 'Seed'. The 'Mobility Model' then produces 'Generated Traces', which are used by a 'Network Simulator'. A small circular inset image of a man is visible in the bottom right corner of the slide.

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Based mobility models as I told you before, they talk about extracting or generating the traces from the movement of nodes in real life. So, the aim to replicate or emulate the type of movements in a sample trace given a sample trace from a single from a target scenario many similar target traces can be produced. So, this is an observation. So, you have a repository of traces of real traces.

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Trace-based Models: Performance Criteria

- A target protocol can be used for validation of the generated traces against the real traces.
- Protocol-dependent performance measures:
 - Throughput
 - Delay
 - Packet loss
 - Overhead

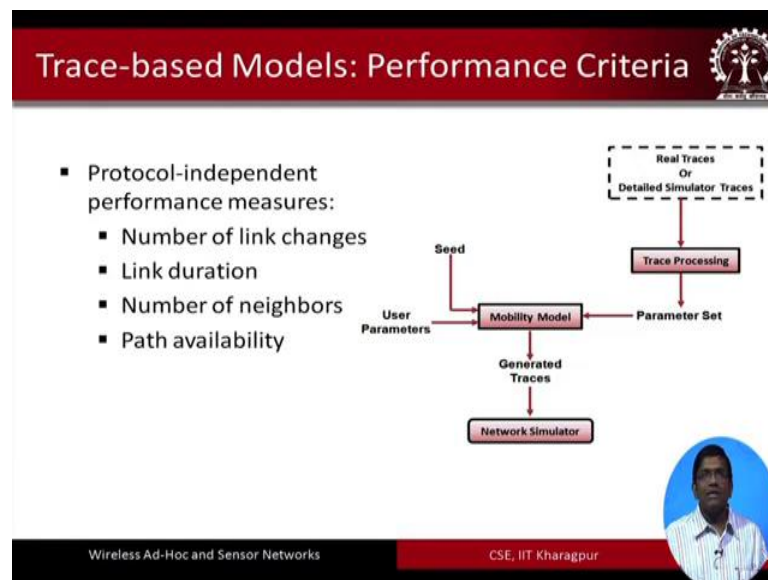
The flowchart illustrates the process of trace-based models for performance criteria. It starts with 'Real Traces Or Detailed Simulator Traces' (enclosed in a dashed box) which go through 'Trace Processing' to create a 'Parameter Set'. This 'Parameter Set' is fed into a 'Mobility Model'. The 'Mobility Model' also receives 'User Parameters' and a 'Seed'. The 'Mobility Model' then produces 'Generated Traces', which are used by a 'Network Simulator'. A small circular inset image of a man is visible in the bottom right corner of the slide.

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So, when we talk about these mobility models, the performance of these models have to be compared. They can be compared with the help of the performance evaluation of the

target protocol that could be run using them. So, different measures such as throughput delay packet loss overhead etcetera they all can be considered as the different performance measures that can be used to understand the performance of the mobility models the ones that we just went through.

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There are some performance measures which are protocol independent for example, the number of link changes the link duration number of neighbors' path availability and so on. So, these are the different other mobility different other independent protocol independent performance measures that can also be used.

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Conclusion

- The choice of a mobility models matters a lot for meaningful performance evaluation
- Stochastic mobility models are very easy to implement, but highly unrealistic
- Trace-based Models can be very realistic and flexible, but difficult to implement

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So, basically one cannot say that a particular type of mobility model is the best or is better than another. It all depends the choice of a mobility model which is very important and is very important for performance evaluation of a particular protocol.

So, this is important for evaluating the performance of a particular protocol that is designed and it basically the mobility model that is used basically influences the overall performance of the network or the protocol, it is designed to run on the network stochastic mobility models are very easy to implement, but are highly unrealistic trace based models can be very realistic and flexible, but are difficult to implement.

So, with this we again come to the end of this lecture. So, with this we will complete mobility models. So, mobility models as we have seen are very important. They are very important to understand how a particular node is going to move in reality and these movement models these mobility models the mobility traces from a real life scenario, these can be used these can be. So, in the case of traces one can build mobility traces or mobility repository trace repositories, and from these trace repositories using these mobility models or mobility traces, one can basically assess the performance of the different protocols that are going to run using the MANETs. So, we come to an end of this.

Thank you.