Introduction to Internet of Things

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Lecture – 17
Sensor Networks- IV

In this lecture, we will try to understand a very important concept, which is the coverage the concept of coverage in sensor networks. Coverage is a very important problem because what is required is using sensors or sensor networks. We have to deploy the sensors or more specifically the sensor nodes in a particular terrain in such a way that no point or none of the areas in that particular terrain left unsensed in that region. So, we have to deploy the sensors in such a way that none of the points in the terrain of interest which has to be that means, which has to be sensed which has to be surveilled, it should not happen that there is such a point which is not within the sensing range of if any sensor node.

So, this is basically known as the point coverage like this there are different other types of coverage called area coverage then we have barrier coverage and different other types of coverage which have been researched upon in the literature. So, we will try to understand this concept first.

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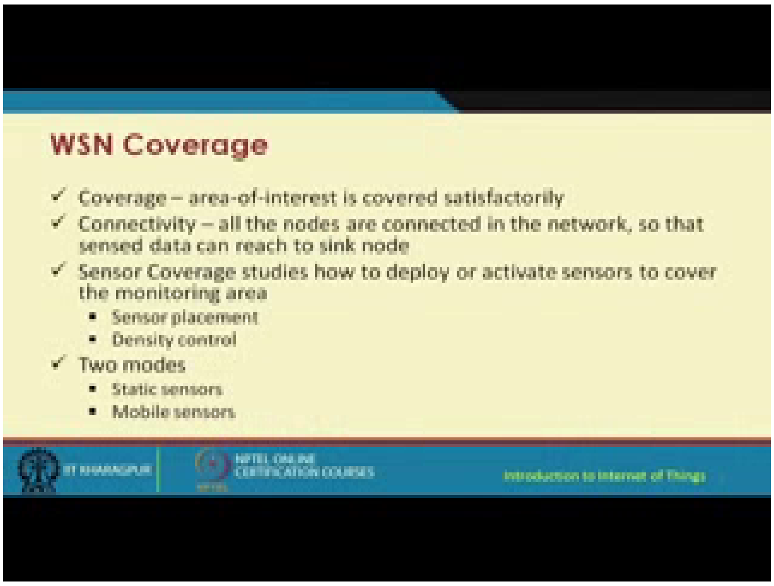

So, we have an area-of-interest and what is required is to ensure that that particular area of interest is fully covered by at least one sensor. So, there has to each and every point in that particular area has to be within the sensing range of at least one sensor. So, there is an elite terminology which is called the connectivity and connectivity of the nodes is basically to ensure that all nodes that means, each and every node in the network from that point to the sink node there is some path that is available to transmit the sensed information. So, we have to ensure in the connectivity problem, we have to ensure that all the nodes are connected in the network. So that the sense data can be reach the sink node.

Sensor coverage basically studies how to deploy or activate sensors to cover the monitoring area. So, there are two variants of this particular problem, one is called the sensor placement problem and the other one is the density control. So, basically we have to ensure that how we are going to deploy the sensor nodes in a particular region of interest, so that the problem of coverage is addressed. So, how do we place the sensor nodes. And the second problem is that minimally how do we place, so that you know appropriate or desirable density is maintained in that particular area.

So, there are two modes of sensors one is the static sensor the other one is mobile sensor. The problem of coverage with static sensors basically is different from the problem of coverage with mobile sensors whereas, in static sensors we are primarily concerned about how to deploy the sensor, so that each and every point in the area is covered. In mobile sensors, we have to ensure that with respect to not only space as in static sensor, but also with respect to time that means spatio temporally that region of interest is covered with respect to space and time and that is in harder problem to solve.

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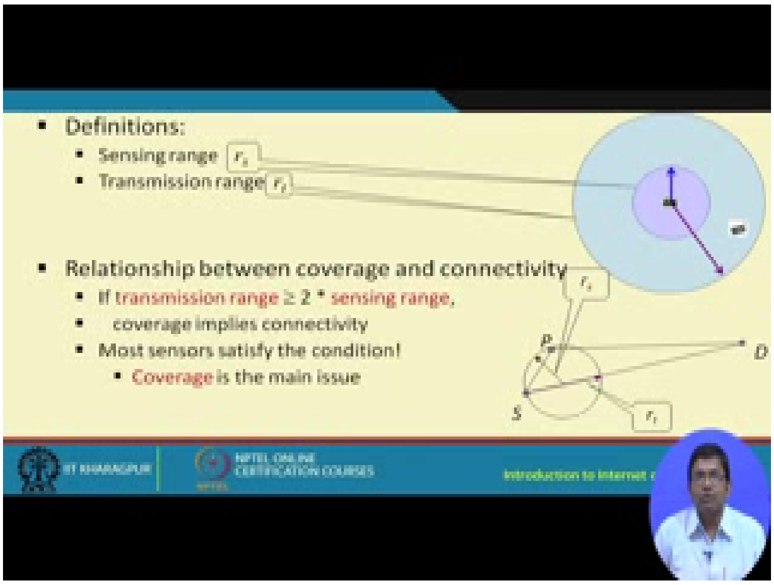

Now, let us try to understand few concepts. The first is the concept of sensing range and transmission range. So, when we have a node like this, it can sense up to a certain radius around it. So, it is typically like few meters or so. So, for a particular sensor node the sensing radius is the sphere around it, till which this particular node can sense. So, this is the sphere we are talking about or into D it is a circle. Now, there is this elite concept of transmission range, which is bit different. So, this transmission range or the communication range is concerned about how far this particular node can communicate. So, these are concentric circles and typically the sensing range is lesser than the communication range as shown in this particular figure.

But in literature on coverage, you will often find that the sensing range and the communication range are equated, they are considered to be equal. So, there is a relationship between the coverage and connectivity. If the transmission range is greater than or equal to twice the sensing range, it has been shown by researchers that the problem of coverage implies the problem of connectivity. In other words, we simply have to take care of coverage, and if we have ensured that coverage has been taken care of in a particular area then automatically connectivity is also taken care of.

So, for ensuring coverage as well as connectivity, we have to ensure that for the particular sensor node, that we are considering. The transmission range is at least twice the sensing range. And typically for most of the available sensor nodes in the market most of the you know so this particular condition is taken care of. So, typically the the the transmission range or the communication range is quite much bigger than the sensing range and that is why coverage becomes the main issue to be addressed.

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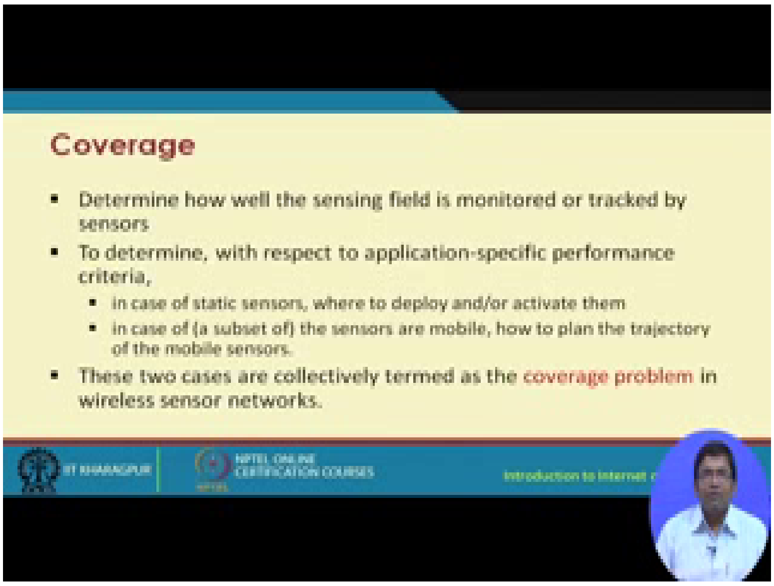

So, the problem of coverage once again ensures that how well the sensing field is monitored or tracked by the different sensors. And to determine that with respect to certain application specific performance criteria in the case of static sensors where to deploy and or activate them; and in case of mobile sensors how to plan the trajectory of the sensors. So, these two cases are collectively termed as the coverage problem in wireless sensor networks. So, we have the coverage problem for static sensor networks concerned mostly about how to place the sensors or if they are already placed how to activate them, when and how to activate them, so this is the problem of coverage for static sensors the problem of coverage. For mobile sensors is basically, how to plan the trajectory of these mobile sensors, so that the region of interest is covered spatiotemporaly.

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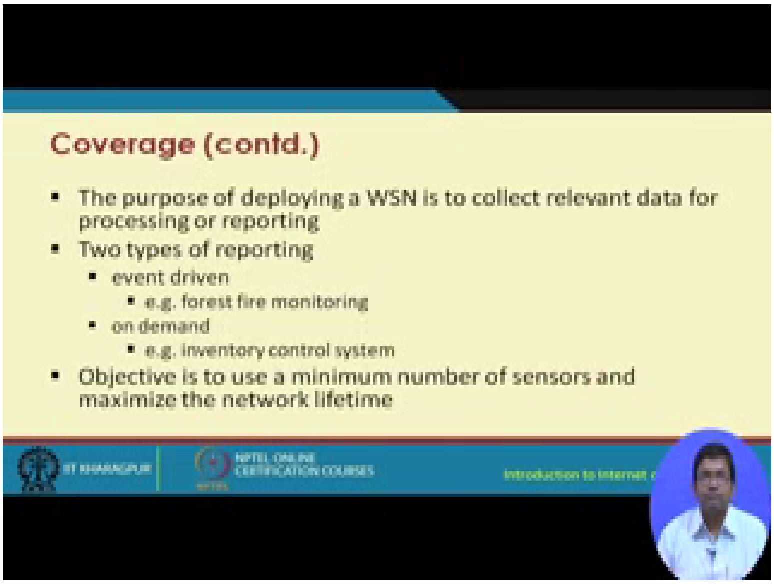

So, the purpose of deploying a sensor network is to collect relevant data for processing or reporting. And there are two types of reporting one is event driven, the other one is on demand. Event driven applications include like forest fire monitoring building fire monitoring and so on. So, whenever there is some kind of event. So, event means like fire taking place that is an event so then that particular event is reported. And on demand is basically that for example, if there is some information that is required then that you know some query is going to be sent for example, in inventory control systems. So, query is sent whenever there is some information that is required. So, the objective is to use a minimum number of sensors and maximize the network lifetime. And network lifetime is basically in plane and simple terms, it is about how long the network is going to survive how long the network is going to survive.

So, actually in the literature there are different definitions of network lifetime. So, one definition basically says that the time until which the first sensor node in the network dies. There is another definition which says, that the time until which the last sensor node in the network dies that means, it would runs out of battery power or it you know it stops functioning. And there are different other definitions as well, which are somewhere in between. So, the time until which let us say P percentage of sensors die in a particular network is the network lifetime.

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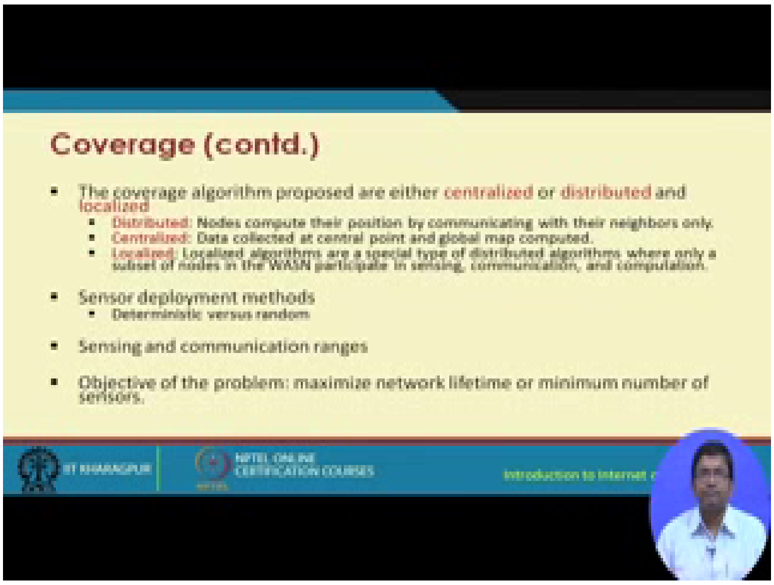

So, basically the objective is to use a minimum number of sensors and maximize the network lifetime. So, this coverage problem is such that it can be addressed either using centralized algorithms or using distributed algorithms or using localized algorithms. In distributed version of the problem the nodes basically compute their position by communicating with their neighbors only. Every node basically computes their position by communicating only with their neighbors. In the decentralized version the data are collected at the central point and global map is computed and in the localized version here. Basically, it is sort of like a distributed algorithm where only a subset of the nodes in the sensor network participate in sensing communication and computation. So, it says sort of like a variant of the distributed algorithm localized algorithm.

So, the different ways in which the sensors can be deployed for the purpose is basically either using deterministic means like you know, you preplan everything in a particular area. You know that xyz coordinates where each of these individual sensor nodes are going to be deployed and that is PD determined P calculated and the other one is basically random where using some random means like airborne means or whatever the sensors are thrown into that particular area.

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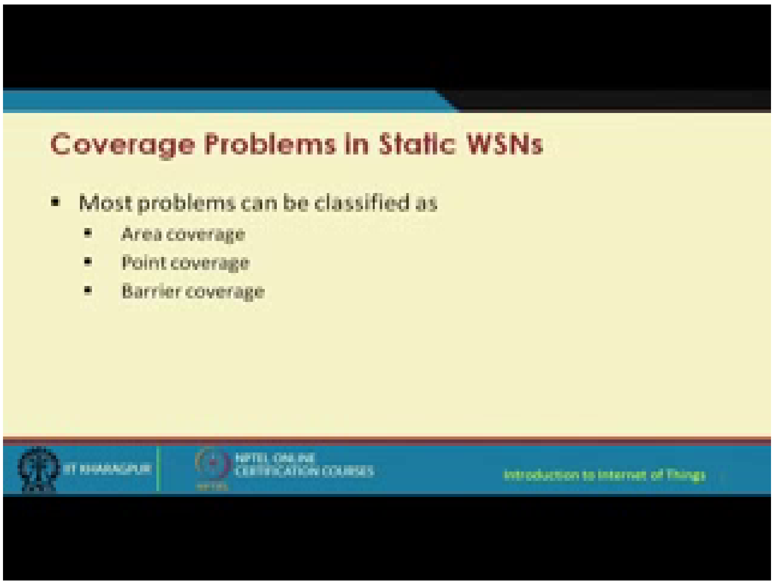

So, there are two types of ranges one is the sensing range and the other one is the communication range and the objective of the problem is to maximize the network lifetime or minimize the number of sensors. There are basically mostly three types of coverage that are quite common one is the area coverage the second is the point coverage and the third is the barrier coverage.

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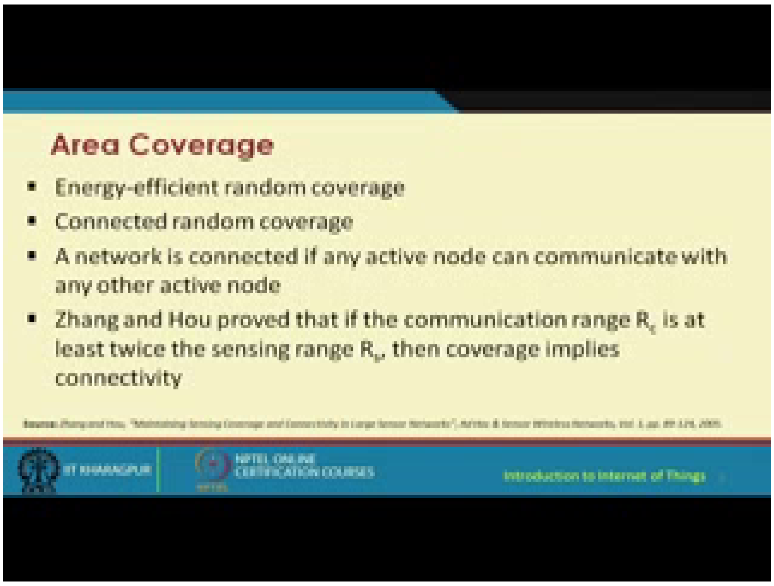

So, area coverage out of these three is the most common form of coverage in area coverage what has to be done is, we have to ensure that each and every point in a particular area is within the sensing range of at least one sensor node and that is that area covered. So, likewise actually that entire area is it consists of infinite number of points. So, we have to ensure that those infinite number of points each and every point in a particular area is within the sensing range of at least one sensor node. And on area coverage lot of work has been done by Zhang and Hou, who proved that, if the communication range is R c and the sensing range is R s then if the condition R c greater than equal to twice of R s holds then coverage implies connectivity. And this is something that I told at the outset as well of this lecture.

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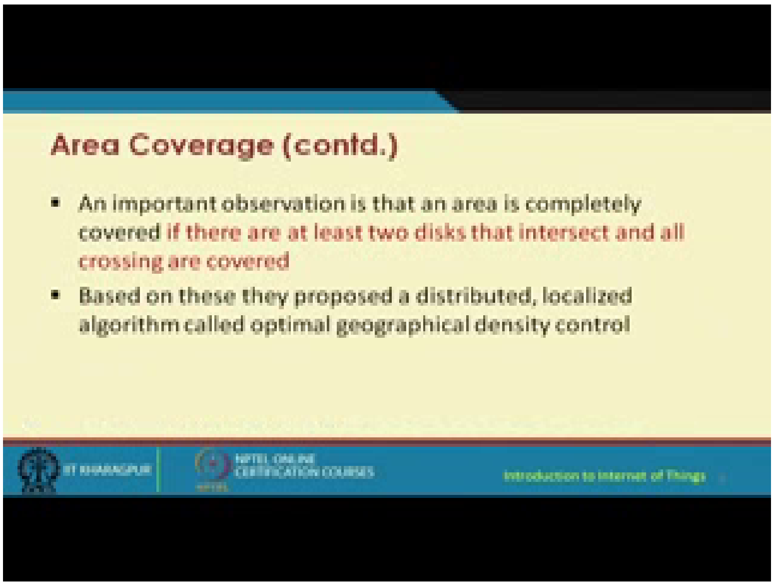

So, this is what has to be done. So, what basically has to be done is we have to ensure that two disks intersecting at crossings will be determent. And then, we have to ensure that likewise there are you know all these crossings that are formed out of the intersection of the different circles are covered. And this is what the algorithm one of the algorithms that was proposed by Zhang and Hou the OGDC algorithm that, we going to talk about shortly basically does and you know so without going into the details of it me also explain the concept of point coverage.

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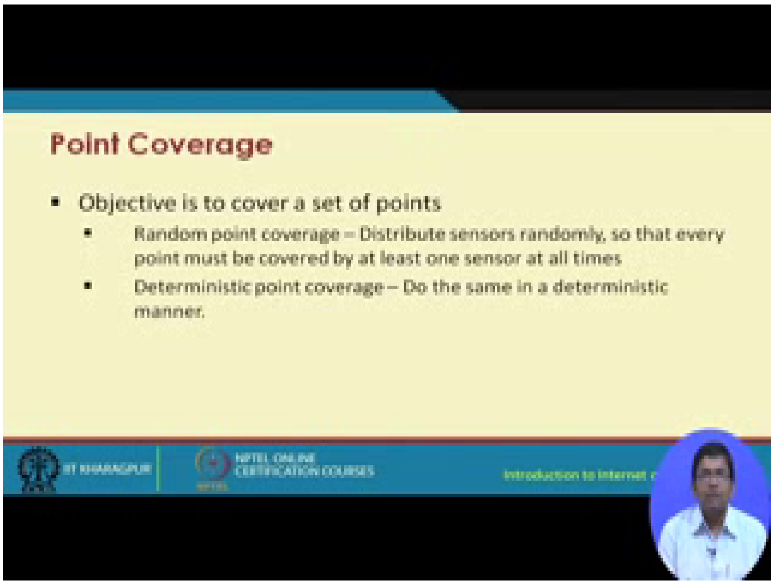

So, in point coverage, what we are doing is we are ensuring that if there is a set of points in a particular area to ensure that, those set of points are covered. Those set of points are covered in that particular area with minimal number of sensor nodes. So, it comes in two flavors one is the random point coverage and the other one is the deterministic point coverage in random point coverage it is required to distribute the sensors randomly. So, that every point must be covered by at least one sensor at all times and in deterministic point coverage we have to do essentially the same thing in a deterministic manner.

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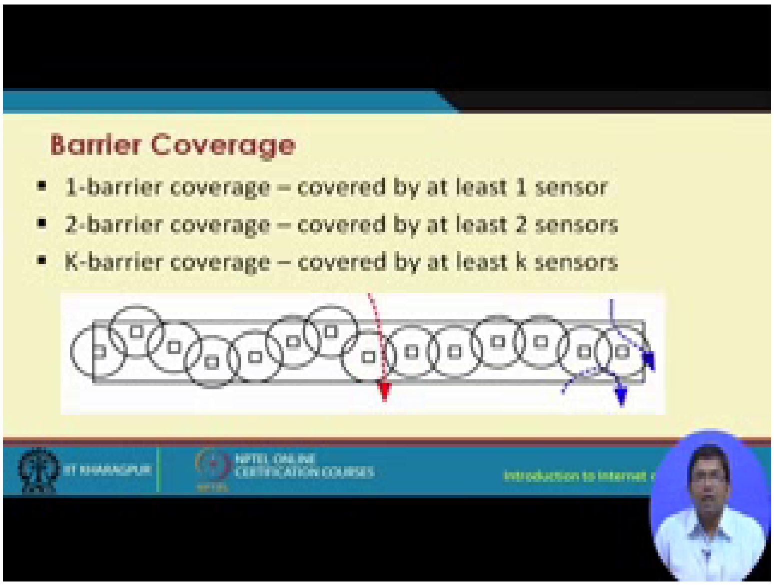

Then we have the barrier coverage in barrier coverage we have three variants one is the one barrier coverage the second is the two barrier coverage and the third is the K barrier coverage. So, here we have to ensure that a particular barrier is covered. So, let me just explain to you this particular concept.

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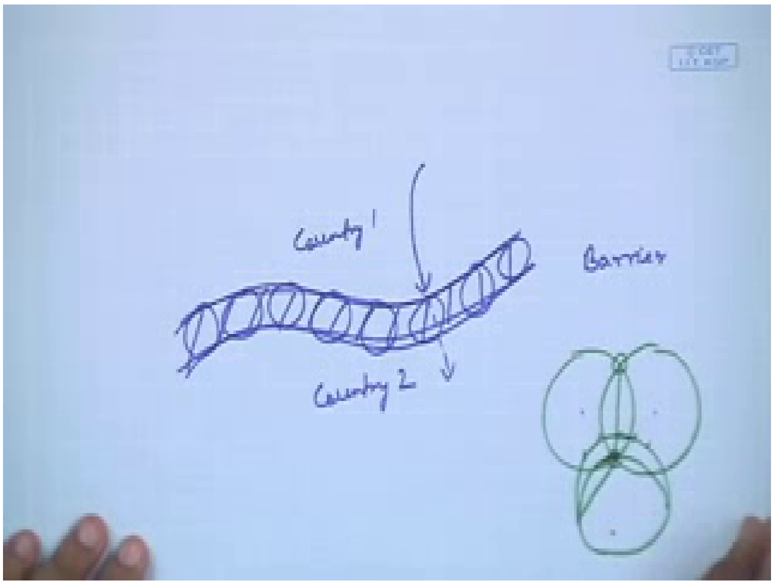

Let us say that we have two countries. Let us say that, we have two countries. And we have this is country 1 and this is country 2. So, this let us assume is the border between these two countries. So, the barrier coverage problem says that how we are going to place the sensor nodes and at what interval we are going to place them so that this particular barrier is covered. Covered means what that let us say that if there is some intruder that gets into from country 1, it tries to get into country 2, then it will get detected by at least one sensor node. So, this is the barrier coverage problem.

So, one barrier coverage ensures that at least one sensor node detects the intruder in what I just explained before. Two-barrier coverage ensures that, you know at least 2 sensors detect such an intrusion and k-barrier coverage ensures that at least k number of sensors k can be anything greater than 2, k number of sensors basically detect this particular intrusion.

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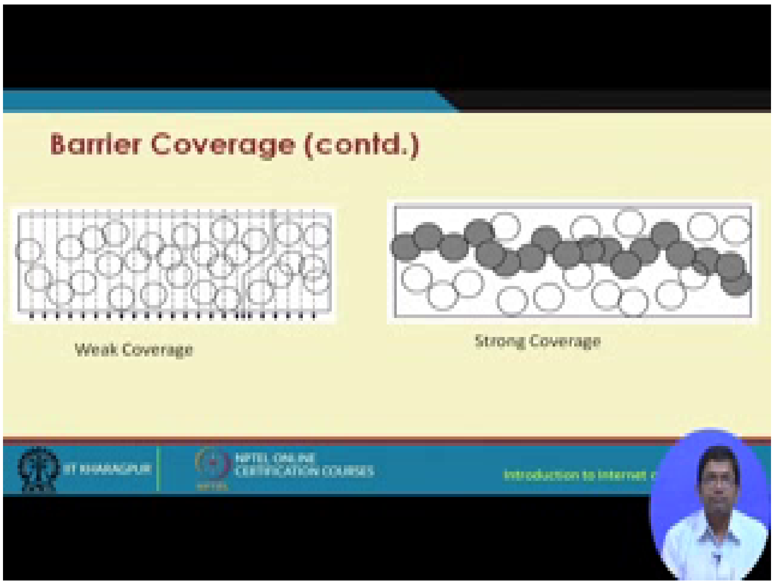

So, we have different types of barrier coverage the left hand figure shows thus case of weak coverage and the right hand side figure shows the case of strong coverage. So, as you can see over here in this scenario we have weak coverage because, you know one can find paths by which one can you know avoid getting sensed avoid getting sensed. On the other hand, if you look at over here, there is no such paths that can be found without getting detected without the intruder getting detected by one of these sensor nodes.

So, in this particular figure, what we see is that these empty circles basically denoting the nodes which are there, but and not active and these shaded circles denoting the nodes which are active. So, I hope that this point is clear over here. So, we have weak coverage and we have strong coverage. So, as you can see over here. So, a path like this by an intruder can avoid getting detected by add at least one sensor node; however, no such path can found out over here. So, this is the case of strong coverage and this is the case of weak coverage.

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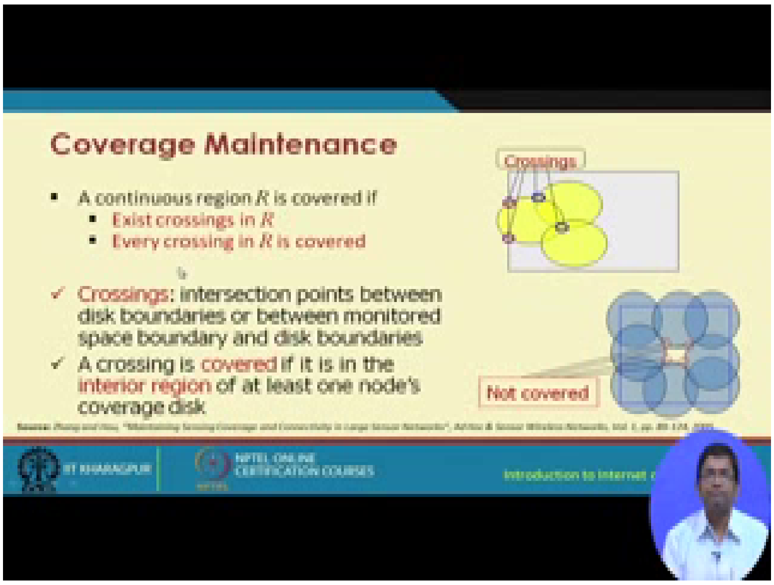

So, what is required is to continuously ensure that the coverage criterion is mate at all points of time and we have to activate the nodes in that manner. Maybe if it is a random deployment there could be some redundant nodes and it there is no point of two nodes doing the same thing at the same time, so maybe you put one node to the slip state the other one could be active and then this cycle can be changed over time. So, a region like this has to be covered. So, in this particular region, we have these different sensors we have these different sensors. So, we have to ensure that each and every point is covered.

So, how do we do that, we keep on placing this sensor nodes. And let us say that this is the sensing range of this node. This is the sensing range of the second node and this is the sensing range of the third node. So, these points that are shown over here are termed as the crossings these points and these points. What is the difference over here, these points are crossings between two circles, two or more circles, whereas these points are crossing between a circle and the boundary.

So, we have 1, 2, 3 and 4, 4-crossings. So, a continuous region R is covered if there exists crossings in R and every crossing in R is covered. So, we have to ensure that there are crossing in this particular region and we do see that there a crossings in this region and then we have to ensure that every crossing like this crossing, this crossing, this crossing each and every crossing again has to be covered. Like this crossing in this particular figure is not covered, this crossing is not covered, whereas this particular crossing which was formed out of these two circles is covered by this circle. So, this crossing is covered, whereas this crossing this crossing or these crossing these are not covered. So, this is what has to be ensured and this is shown in a different way in this particular diagram.

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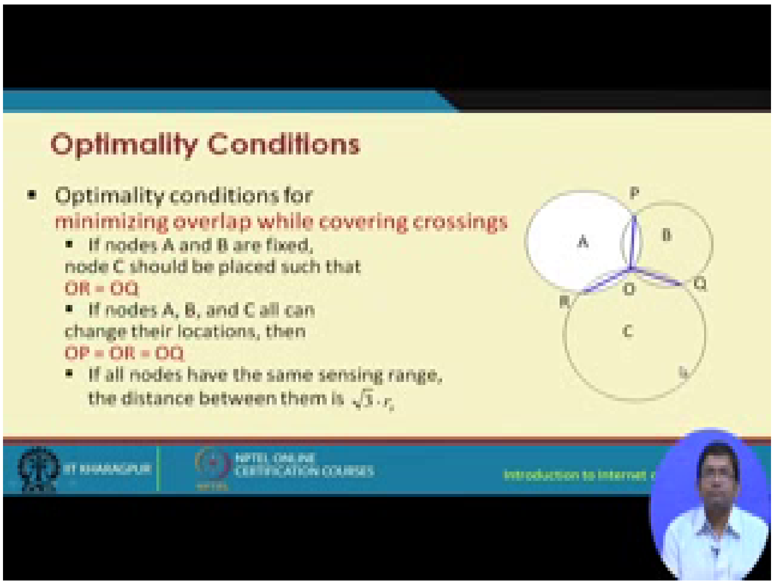

So, now let us look at a little bit of geometry. So, you know we have to come up with some optimality conditions. Optimality conditions for minimizing the overlap while covering the crossings and that way we have to ensure that minimum number of sensor nodes are utilized in order to cover covered the crossings. So, if nodes A and B are fixed like in this particular figure. So, if nodes A and B are fixed, we have to place a nodes C we have to place a node C in such a way that O are equal to OQ. So, A, B we have to place C in such a way that OR equal to OQ. If nodes A, B and C all can change their locations then and that is quite possible. So, if nodes A, B and C all can change their locations then we can even have OP equal to OR equal to OQ. So, OP equal to OR equal to OQ that can be very well done and if all nodes have the same sensing range that means, the circles have the same radius.

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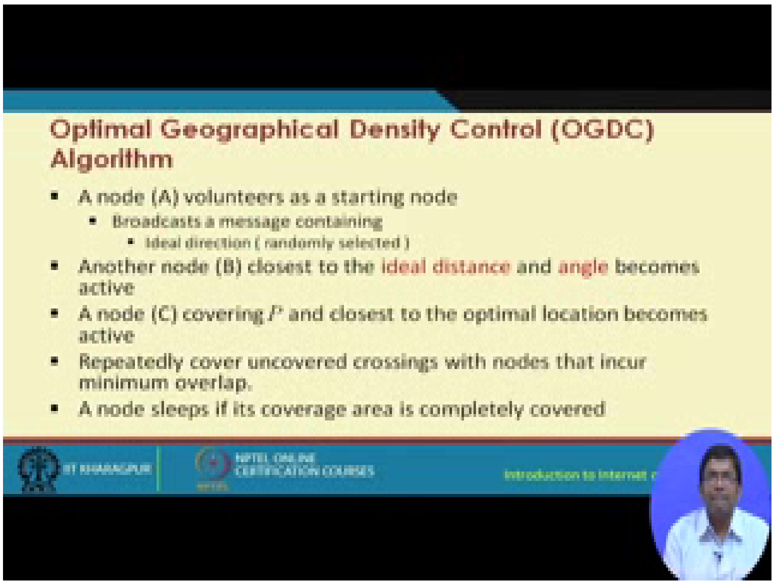

Then the distance between them is square root of three times R s the sensing range. So, a node in the OGDC algorithm what happened is first a node volunteers as a starting node and it starts broadcasting a message containing the ideal direction which is randomly selected. If another node B which is closest to the ideal distance and angle becomes active a node C covering P and closest to the optimal location becomes active and repeatedly, it is required to cover the crossings uncovered crossings with notes that incur minimum overlap.

So, a node sleeps if its coverage area is completely covered. So, let me show you this particular concept it to really. So, what we have one node we have another node both have the same radius. So, and these are the crossings this is one crossing and this is another crossing. So, the point that was made earlier was that we have to place this another node in such a way sorry this is not correct. So, we have to place it in this way not this in such a way that this is again let me do it once again.

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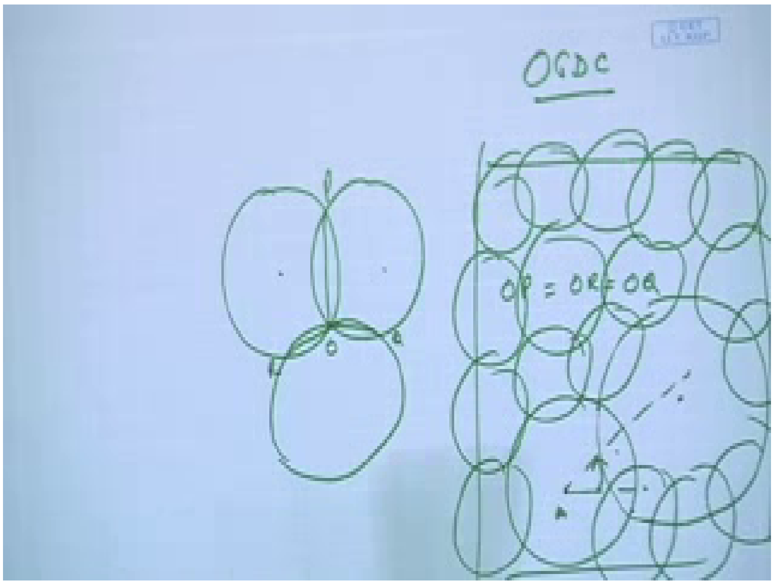

So, let us say that we have two different nodes and we have to place third node in such a way that this one, this one and this one at the same. So, in this diagram actually it is not very precise. So, we have to do it in such a way OP, OR, OQ. So, OP equal to OR equal to OQ. So, what happens is that one node what it will do it will at a particular angle it will start broadcasting a message. Then another node which is in this particular direction and in this angle that means in this particular direction and it is closest to this particular node that node has to be placed in this manner. And like this if you consider this whole area you keep on doing the same thing and ensure that the crossings are also covered. So, what is going to happen like this you know. So, what we are going to get is all the crossings getting covered like this with a minimum number of sensor nodes. So, this is how the OGDC algorithm works.

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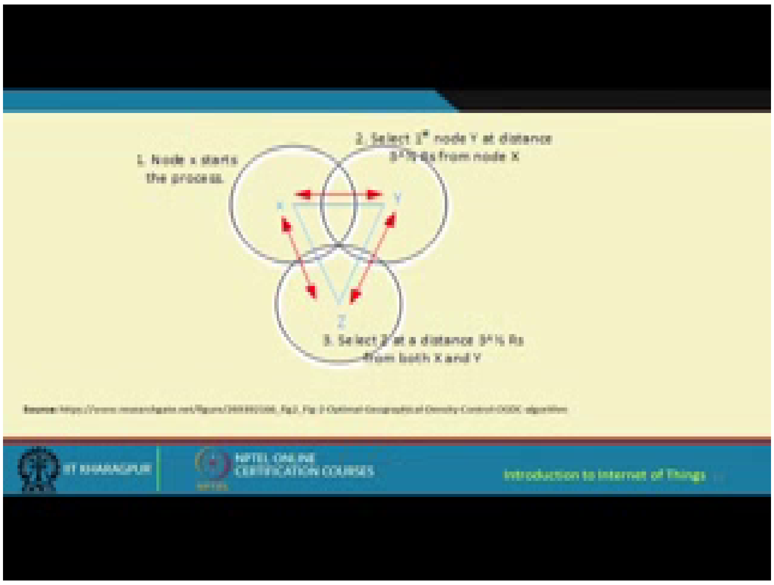

So, node x starts the process it selects the first node Y at a distance some distance from this particular node. So, this distance is what square root of three times R s square root of 3 times R s it will choose this node then this node Z is selected at a distance square root of 3 times R s from both X and Y. So, from both X and Y this has to be put square root of R s distance square root of 3 times R s distance. So, this is square root of 3 times R s this is square root of 3 times R s and this is square root of 3 times R s.

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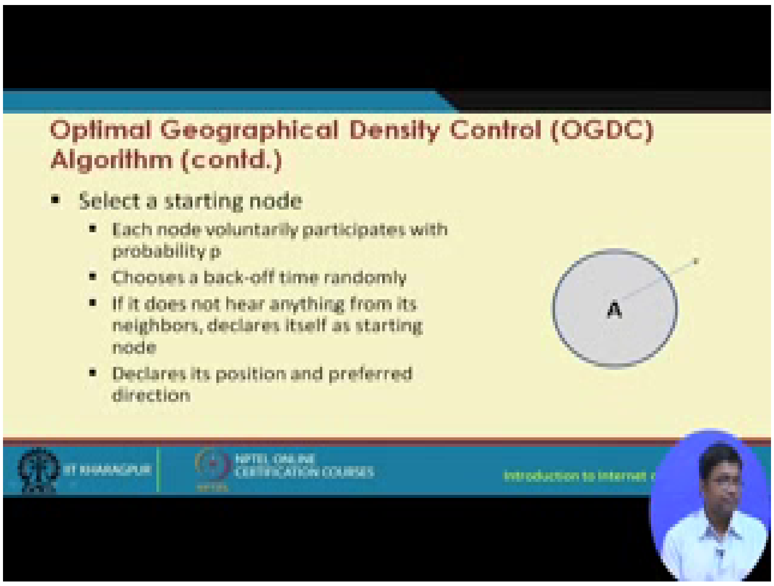

So, let us go through this algorithm once again each node voluntarily participates with probability P in this case this node A participates with probability P. It chooses a back of time randomly. If it does not hear anything from its neighbors, it declares itself as a starting node, it declares its position and preferred direction. So, in this case it declares its current position and the direction alpha.

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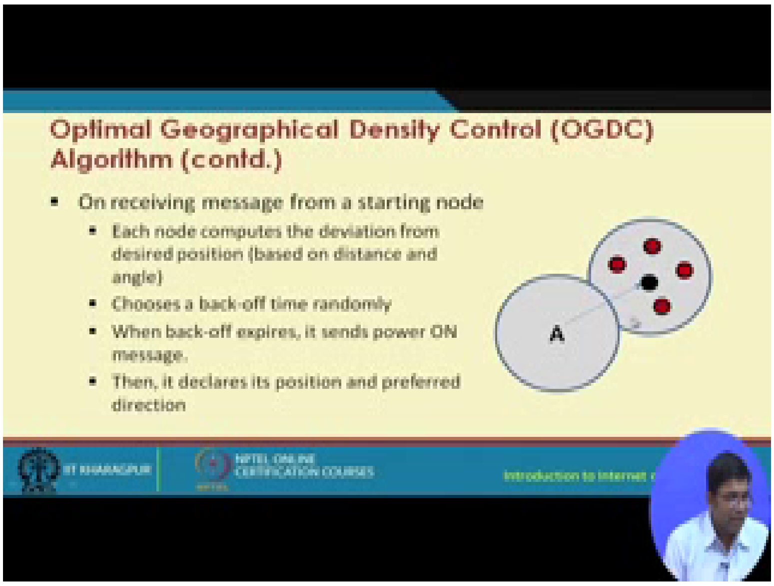

On receiving messages from the starting node, each node computes the deviation from the desired position. It chooses a back off time randomly when the back off time expires it sense the power on message then it declares its position and the preferred direction. The process continues until the entire area is covered as in this particular figure.

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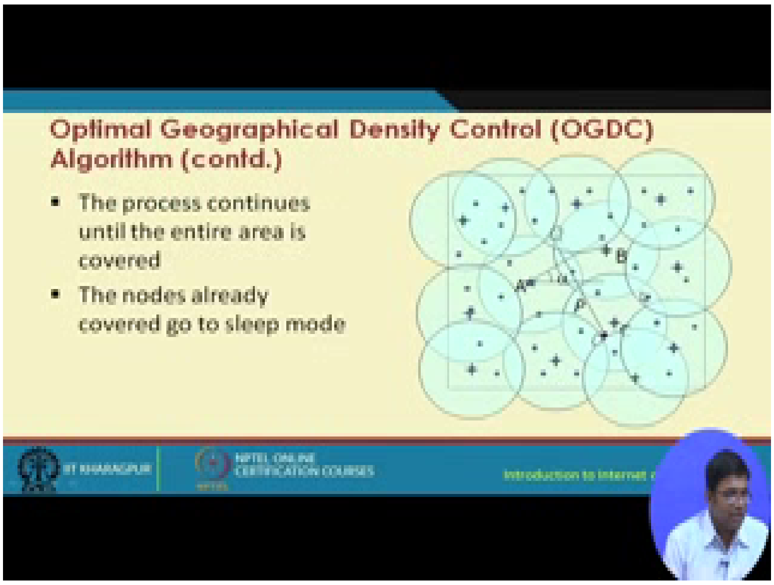

So, this node it started at a particular angle closest to it, another node is chosen this particular node basically will be selected, these crossings are formed another node C is chosen. So, square root of 3 times R s square root of 3 times R s square root of 3 times R s and then we have further crossings. So, you keep on placing the other nodes so that all the crossings are covered.

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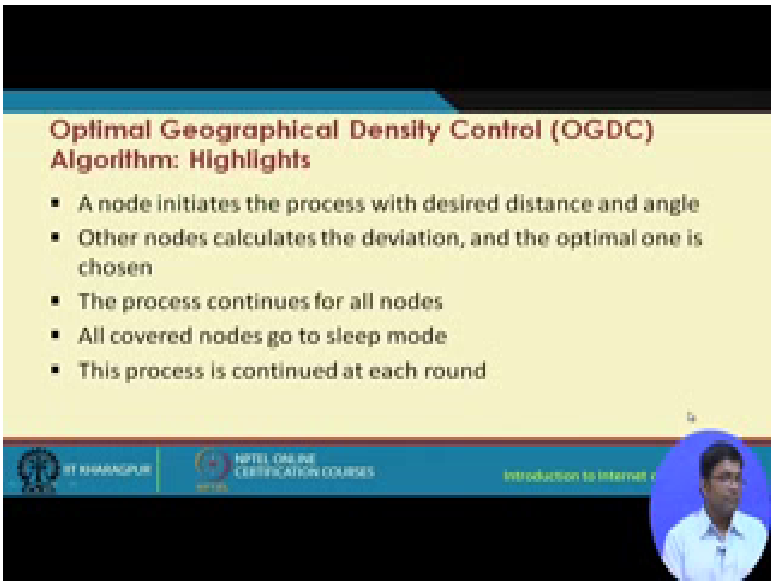

So, some highlights again. A node initiates the process with the desired distance and angle other nodes calculate the deviation and the optimal one is chosen the process continues for all nodes and all cover nodes go to the sleep mode, this process is continued for each round.

So, with this we come to an end of the lecture on coverage and coverage is one of the very important issues in sensor networks, because it ensures that each and every point in the region of interest is covered or a set of points is covered. And if it is each and every point is covered that is that area coverage problem and if it is a set of points that have to be covered then it is a point coverage problem. And it is this area coverage problem that is the most common and most popular form of coverage problem that is addressed in the literature, lot of research works have been gone into it.

Similarly, there is the third type of coverage which is the barrier coverage. Here again you know this is also very important because sensor networks are often used for unmans surveillance in you know bordering areas between two countries and that is where you know this particular rectangular strip or a strip of region between two countries has to be monitored using sensors. So, the coverage while ensuring that minimum number of sensor nodes are used at and has to be placed in that particular border is a very important problem and is known as the problem of barrier coverage. And we have finally, discussed the OGDC algorithm which is one of the important area coverage algorithms that have been proposed and it is quite popularly used in the sensor networks community.

Thank you.