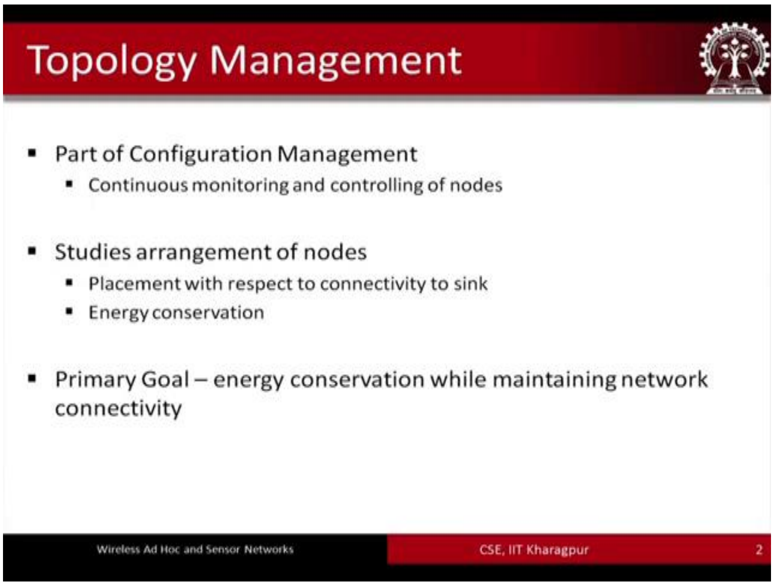
Wireless Ad Hoc and Sensor Networks
Prof. Sudip Misra
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture - 25
Topology Management in Wireless Networks

Our topic is topology management in wireless sensor networks. So, topology management is a topic which concerns part of configuration management. So, configuration management is about continuous monitoring and management of nodes in a network and topology management is strongly linked with configuration management. So, in topology management as the name suggests. So, the concern is that you know how to manage the topology of the network with respect to time.

(Refer Slide Time: 00:52)



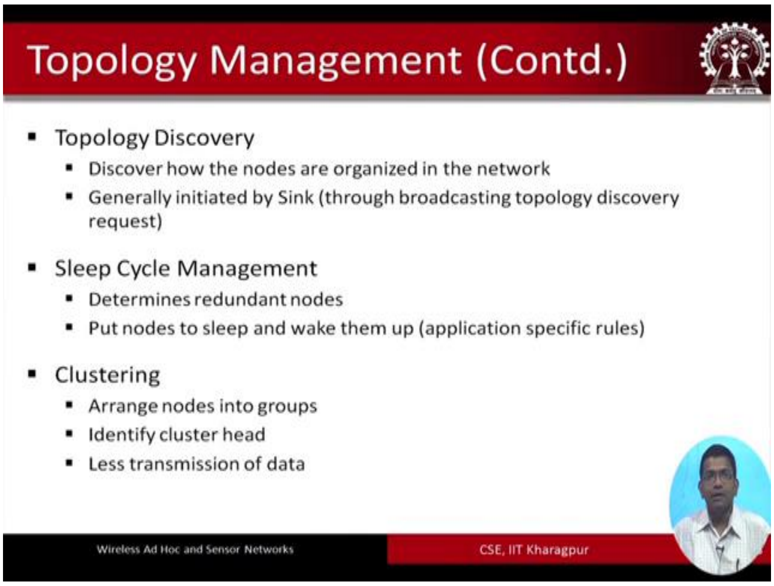
Now, topology management in the case of MANETs, we have already studied that in MANETs, we have nodes which are mobile and topology itself continuously changes over time, but that is due to the mobility of the nodes. In a sensor network particularly is you know sensor networks where the nodes are stationary even if the nodes are stationary still there is lot of different types of dynamism and dynamism in the network traffic and the way their nodes are going to be you know active and they are going to be in the sleeps states and so on.

So, depending on all of these topology management will deal about how to continuously monitor these nodes for these different functions and how to manage the topology of the network over time and these topology typically changes the nature of the topology it changes over time even if the nodes are not mobile.

So, there are 2 issues that are very important in topology management. So, one is how you are going to place the difference nodes the placement of the nodes. So, that the nodes have to you placed in the sensor network in such a way that you know there is connectivity from each and every node to the sink node. So, this is very important because you know individually these nodes they are going to sense the physical phenomena around them and so, these that information the sensed information has to be finally, relate to the sink node and that is possible only if there is end to end connectivity between each of these sensor nodes which have sense the information and the sink node which is going to be the receiver or the final destination of the information that is sensed. So, this is one aspect, the second thing is the energy issue.

So, you know, there are very decent algorithms that can be easily thought about how to maintain end to end connectivity between the source sensor nodes and the sink node; however, you know whatever we design we have to keep in mind that energy consumed by these algorithms should be minimum. So, energy conservation is very important issues to keep you know putting these 2 together the overall goal overall primary objective of topology management is basically energy conservation while maintaining the network connectivity this is the overall objective of topology management.

(Refer Slide Time: 03:33)



So, sensor networks; there are lots of different aspects of topology management that have been studied in the literature.

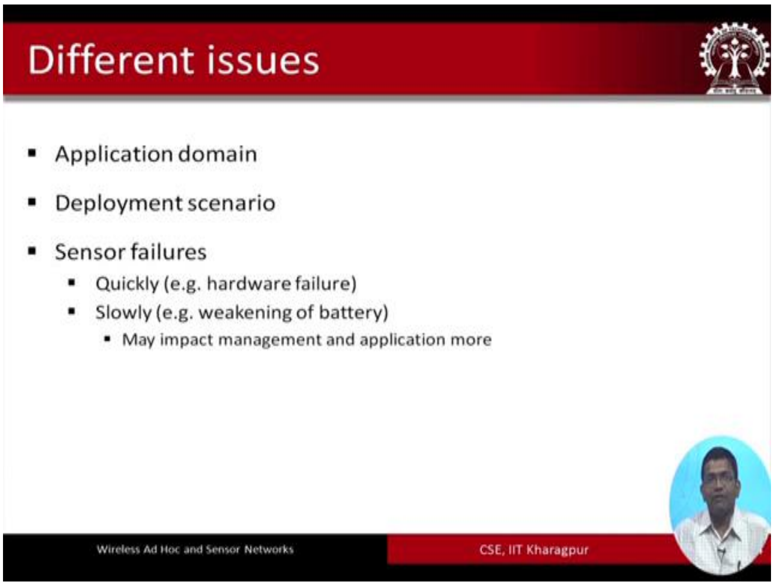
Now, so these different problems these different issues they can be classified into primarily 3 categories one is topology discovery the second is sleep management sleep cycle management and third is clustering. So, topology discovery as this name suggests these algorithms they attempt to discover how the nodes in the network are organized with respect to one another and that that idea about the topology the rest of the nodes how they are placed with respect to one another that is done with respect to the sink so, with respect to the sink, the rest of the nodes how they are placed with respect to each other.

So, this topology discovery algorithms are typically initiated by the sink node by broadcasting some discovery requests topology discovery requests. So, this is one class of topology management algorithms called the topology discovery algorithms the second is the sleep cycle management algorithm. So, the sleep cycle management these algorithms they basically what they do is the determine which nodes are the redundant nodes and then these redundant nodes are put to the sleep state, and they are woken up periodically at certain times depending on the requirements of the application and these requirements of the application are encoded in form of application specific rules.

So, this is the second class of topology management algorithms and the third is clustering and is the as the name suggests over here as well clustering. It is about that in a particular terrain we have different nodes which are placed at different points, they are deployed at different locations clustering talks about how to arrange these nodes into different clusters or groups how to group them together you know into I know in the how to cluster them how to group them into different formations

So, in each of these groups there is a leader node which is called the cluster head and the cluster head typically has higher configuration better configuration better energy you know storage and better you know communication computation and power and so on compared to the rest of the nodes in the cluster which are the cluster member. So, the whole idea of clustering is that by doing this by grouping these different nodes in the network into different clusters you are trying to reduce the total amount of transmission of data in the network.

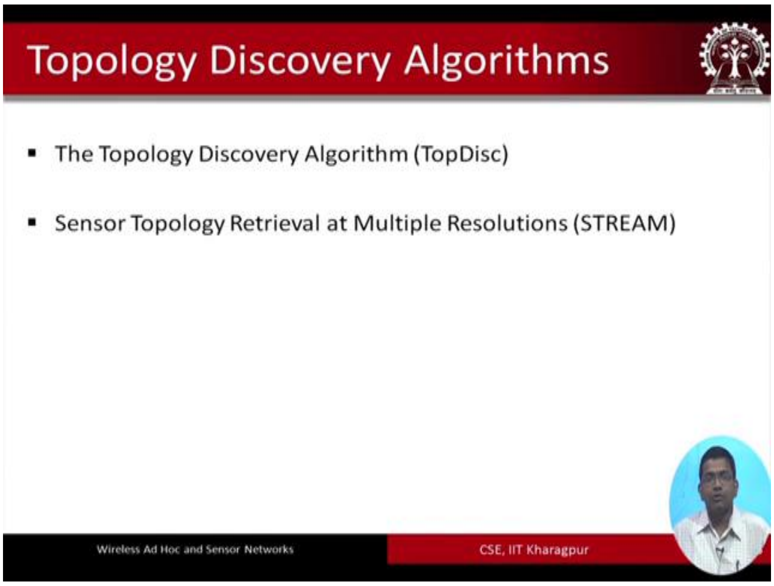
(Refer Slide Time: 06:27)



So, there are different issues that affect topology management topology management algorithms will have to take into consideration the application domain specific requirements then the deployment scenario the specific deployment scenario that is adopted random deployment plan deployment and so on, and the other very important factor that affects topology management are the failure of the sensors now the sensor node they can fail in broadly to 2 different ways. So, one thing is that these nodes can fail due to maybe some hardware or software failure and that failure is fast faster than the weakening of battery which occurs slowly. So, that is the slow slower failure of the sensor nodes.

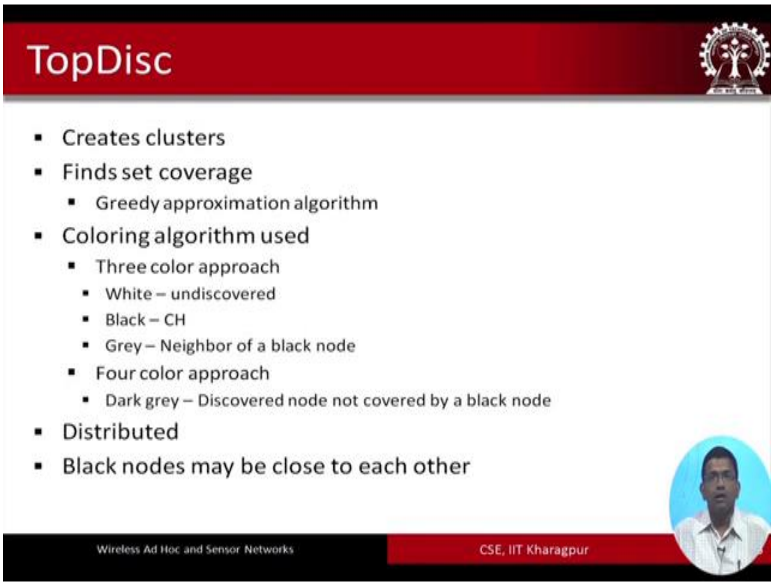
So, either it can fail quickly or a sensor node can fail quickly or it can fail slowly, but whether it is you know failing quickly or slowly. So, these basically impact the overall management of the topology of these networks.

(Refer Slide Time: 07:34)



So, the first class of algorithms topology discovery algorithms. Let us look at 2 topology discovery algorithms, let me just remind you that there are several topology discovery algorithms that have been proposed in the literature and we are going to just talk about the highlights only the highlights of 2 important to well known algorithms one is called the top disc algorithm the other one is called the string algorithm.

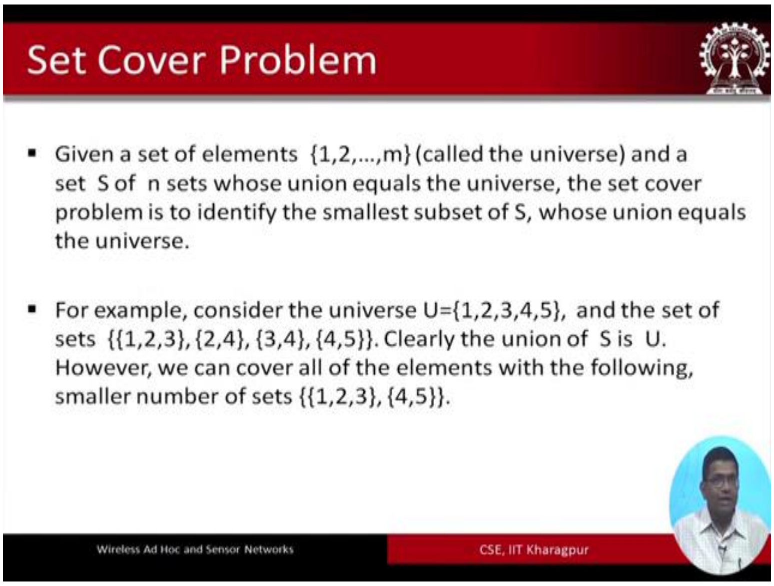
(Refer Slide Time: 08:04)



So, again in top disk there are 2 variants of this top disc algorithm depending on the method of coloring that is used either it is a 3 color approach that is used or there is a 4 color approach in a 3 color approach of the top disc algorithm the 3 colors that are used are white black and grey white black and grey. The white nodes basically signify the undiscovered node the nodes that are yet to be discovered in the network the black nodes are denoted black nodes basically denote the cluster heads and the gray nodes are basically they denote the neighbors of the black nodes; that means, the neighbors of the cluster heads. So, cluster heads are black the neighbors one hop neighbors are gray and the undiscovered nodes are quite.

So, this is the 3 color approach and in the 4 color approach there is a 4th color that is used which is the dark gray and these dark gray nodes are the discover nodes that are not covered by a black node. So, these are the 4 different types of colors that are used in the top disc algorithm depending on whether it is a 3 color approach or a 4 color approach these different colors are used.

(Refer Slide Time: 09:31)

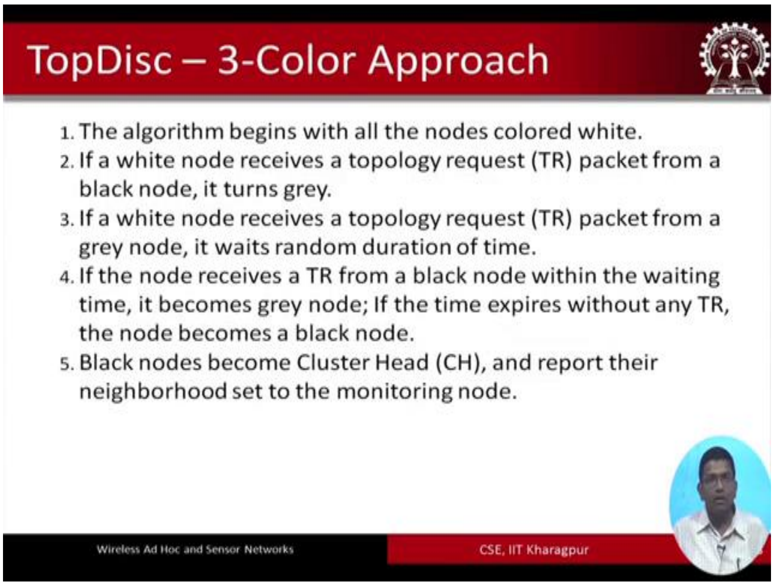


So, let us first try to understand how the top disc algorithm functions, but before that we need to understand another simple algorithmic concept a concept from discrete maps or algorithms which is called the set cover problem.

So, this covering the set covering approach is basically used in the top disc algorithm and that is why we need to understand this first. So, let me first read out the statement of the set cover problem. So, it reads like this, given a set of elements one through m and this set is called the universe and a set capital s of n sets whose union equals the universe the set cover problem is to identify the smallest subset of S whose union equals the universe, I think it is a fairly simple concept to understand although the statement looks little you know cryptic, but it is actually not and that we can understand through this example. So, let us look at this particular in example in order to understand the set cover problem easily.

So, let us consider the universe the universal set which is the one u equal to 1, 2, 3, 4 and 5 and the set of sets; that means, capital S is 1, 2, 3, 2, 4, 3, 4 and 4, 5 now; obviously, if you take a union of 1, 2, 3 to 4, 3, 4 and 4, 5 then the union of this particular set S is U which is the universe 1, 2, 3, 4, 5; however, we can cover all the elements within with the following smaller number of sets which is the 1, 2, 3, this set and the set 4, 5. So, taking these 2 together we can have the set U.

(Refer Slide Time: 11:53)

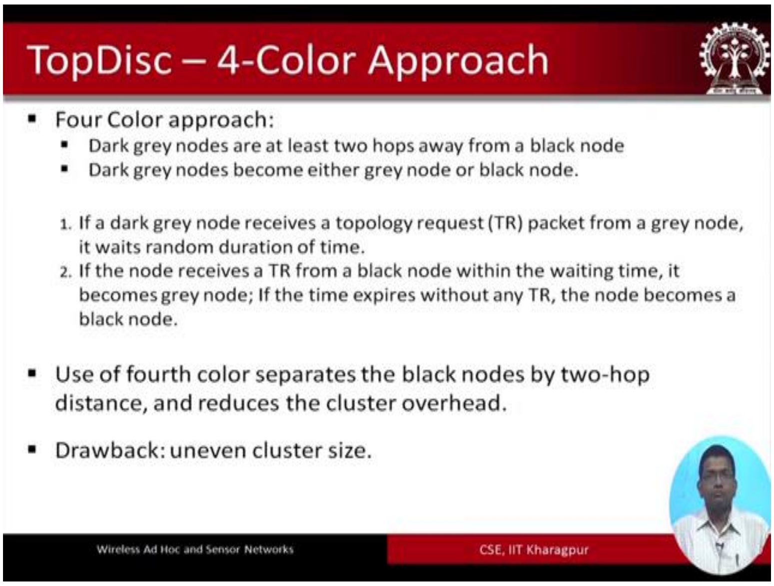


So, this we can do by using only a subset of these sets which is which are basically 1, 2, 3 and 4, 5. Now with this understanding about the set covering problem let us now try to understand the different steps the most important steps in the top disc algorithm using the 3 color approach and as I told you already that here we just want to get the highlights of these algorithms we do not want to get into the depth of these algorithms we just want to understand broadly that how each of these algorithms function. So, it starts like this the algorithm first begins with all the nodes colored white and that is quite obvious because none of the nodes initially are discovered. So, all the undiscovered nodes are colored white.

Now, step 2 if a white node receives a topology request packet. So, a white node to receive a TR packet from a black node black node means what the clustered head. So, in white node a undiscovered node receives a packet from a cluster head first what it does is it turns gray if a white node receives it TR packet from a gray node it waits for a random duration of time why does it wait for random duration of time. It wants to check that whether there is a chance that you know it is going to receive any other packet from any other black node if not then it has a chance to declare itself as the black node to; that means, the cluster head I hope this concept is clear.

So, it has read the step 3 once again. So, if a white node receives a TR packet from a gray node it waits for a random duration of time if the node receives a TR packet from a black node within the waiting time it removes sorry it becomes the gray node if the time expired without any TR the node becomes a black node. So, basically in that case it knows that there is no other cluster head units vicinity. So, basically it can declare itself as the cluster head itself. So, this is the whole idea behind having the steps 3 and 4 the black nodes become cluster heads and report their neighbor neighborhood set to the monitoring node.

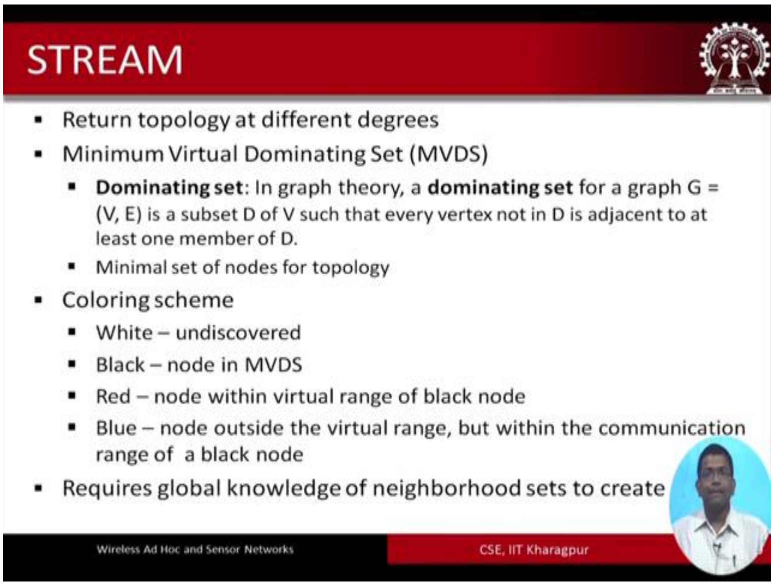
(Refer Slide Time: 14:13)



So, that was the 3 color approach, now we are going to look at the 4 color approach where there is a 4th color which is the dark gray color which is used to color these nodes which are at least 2 hops away from a black node the; so the dark gray nodes become either gray node or black node. So, if a dark gray node receives a TR packet from a gray node it waits for a random duration of time if the node receives a TR packet from a black node within the waiting time it becomes a gray node if the time expires without any TR the node becomes a black node. So, the whole idea of using this 4th color of dark gray is just to separate the black nodes by at least 2 hop distance and reduce the overall cluster overhead.

So, the drawback of this approach is basically that this algorithm leads to uneven cluster size.

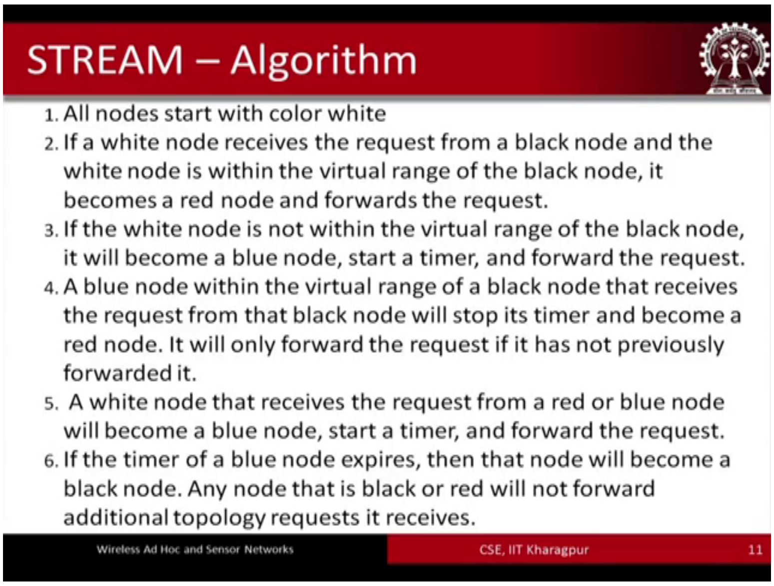
(Refer Slide Time: 15:18)



The other topology discovery algorithm if any popular one is the stream algorithm. So, the stream algorithm is based on the concept of the minimum virtual dominating set MVDS. So, in order to understand MVDS, let us first look at the definition of dominating set d s. So, it is a graph theoretic concept and in graph theory the dominating set concept for a graph is a subset of the set of vertices such that every vertex not in the subset is adjacent to at least one member of this subset.

So, this concept finally, you know MVDS is obtained by having a minimum number of minimum set of nodes that can use for topology management topology discovery. So, here also like in top disc a coloring approach is used. So, white undiscovered like before black earlier in top disc it was for denoting the cluster head here it is for denoting the MVDS node. The red color which was not present you know before in the top disc algorithm that basically denotes nodes which are within the virtual range of a black node and the blue color basically denotes nodes which are outside the virtual range, but within the communication range of a black node.

(Refer Slide Time: 16:59)

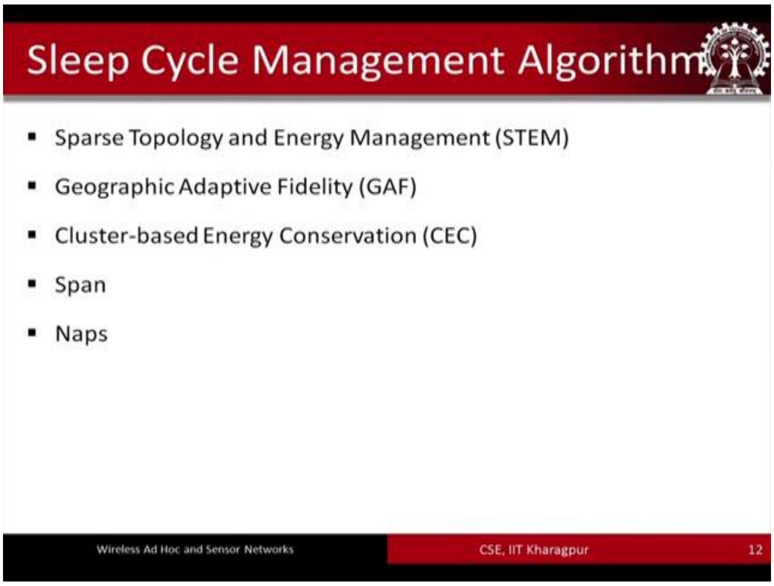


So, this is the whole idea of how the stream protocol works. So, those were the different properties of the stream protocol and next I am just going to read out the different steps there are 6 steps of the stream algorithm. So, I am read I am going to read out all the 6 steps.

So, the first step all nodes start with a color white like in the top disc as well here white means that none of the nodes is un is discovered. So, they start with the white color. So, if a white node receives the request from a black node and the white node is within the virtual range of a black node it becomes a red node and forwards the request if the white node is not within the virtual range of the black node it will become a blue node starts a timer and forwards the request. A blue node which is within the virtual range of a black node that receives the request from the black node will stop its timer it will stop its timer and become a red node it will only forward the request. If it has not previously forwarded it a white node that receives the request from a red or a blue node will become a blue node start a timer and forward the request if the timer of a blue node expires then that node will become a black node any node that is black or red will not forward the additional topology request that it receives.

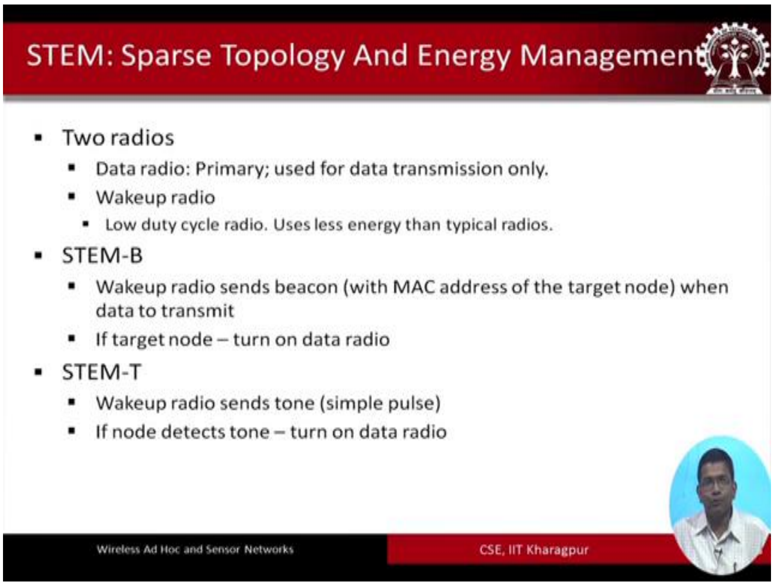
So, these are broadly does different steps of the stream algorithm. So, as it happens with any algorithm and particularly stream and top disc. So, in order to understand these algorithms it is encouraged to draw a small graph and try to understand how these nodes are how the colors of these nodes are changed over time depending on the different conditions. So, you know going through these different steps that I have just mentioned and working out with a small graph example will be basically make it easier for give to understand.

(Refer Slide Time: 19:14)



So, those were the stream and top disc where the topology discovery algorithms the second class of algorithms is the sleep cycle management algorithms in this we have very popular sleep cycle management algorithms stem is one gap is another CEC is the third one 4th is span and fifth is maps. So, these are the algorithms that I will mention explicitly one slight par algorithm I am going to mention, but what I am going to do is I am going to talk about only their characteristics at a high level stem I will talk a little bit more, but gap CEC span and naps these are the algorithms that I am just going to mention at a very high level without going through them.

(Refer Slide Time: 20:05)

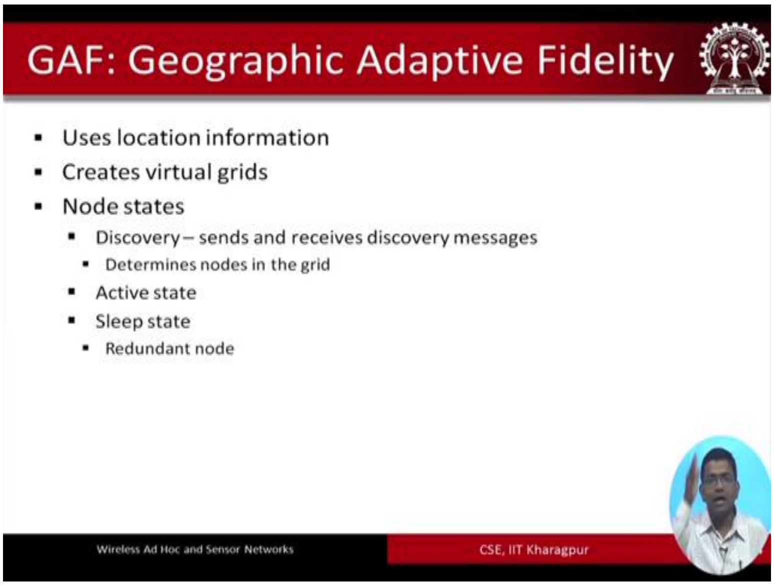


So, the whole idea behind the stem protocol is basically to have dual radio. So, dual radio one radio is called the data radio the other one is called the wake up radio typically we have been using only one radio in all the protocols that we have been discussing so far only a single radio taking care of control plus data and even if it is wake up cycle management it says everything is done through a single radio.

So, far, but stem basically suggests that we could have 2 radios one radio explicitly for transmitting data only and the other radio which is the wake up radio that will basically have a very low duty cycle and which will use very less energy than the typical radios or data radios or other radios. So, this is going to be a very less energy consuming load very low duty cycle radio this is the wake up radio. So, 2 radios data radio and wake up radio these 2 are used in the case of the STEM algorithm the stem algorithms come algorithm comes in 2 flavors one is STEM B, B stands for beacon and the second one is STEM T where T stands for tone.

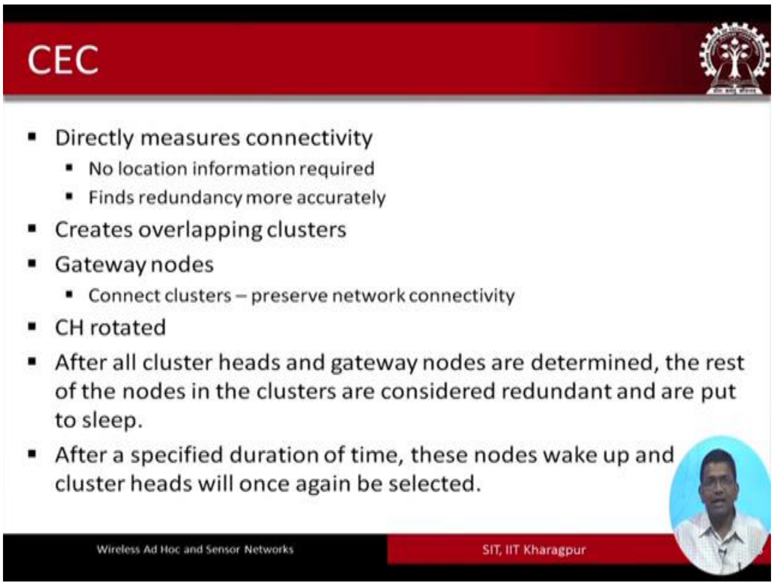
So, the beacon is basically unicast message which is sent with the MAC address of the target node when data has to be transmitted. So, if the target node basically receives it turns on the data radio STEM T, basically it works more like is you know controlled broadcast kind of fashion. So, initially the wake up radio sends a simple pulse which is called the tone so and that tone is received in a broadcast manner to the neighbors these neighbors also keep on doing the same and if the node detects a tone then it turns on the data radio.

(Refer Slide Time: 22:32)



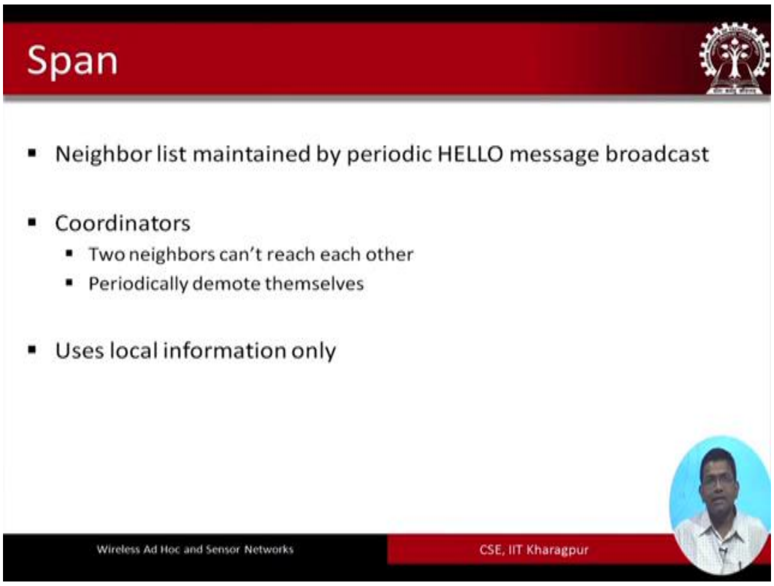
So, this is the difference main difference between B and T variants of the STEM protocol, STEM algorithm. So, as I told you before at the outset I am not going to go through the other algorithms GAF which uses virtual grids virtual grids are sort of like the entire terrain where the sensor nodes are deployed are divided into rectangular shaped kids.

(Refer Slide Time: 22:53)



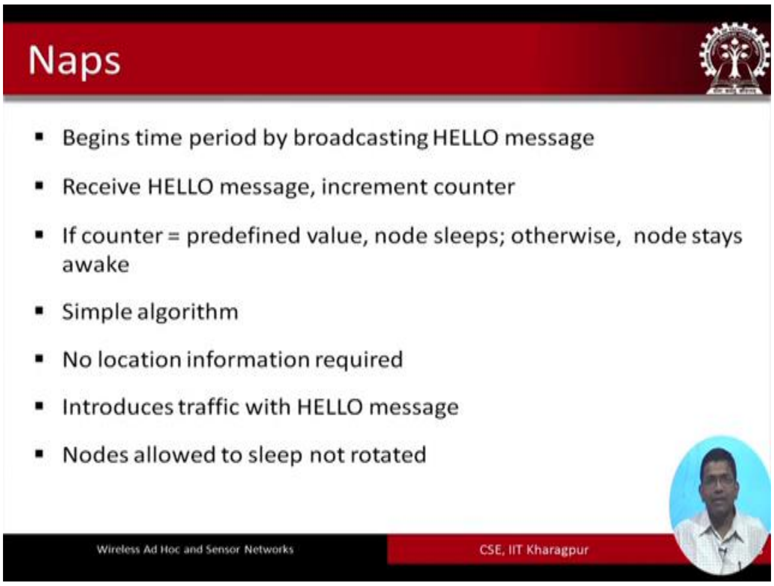
So, GAF CEC is another sleep cycle management algorithm which basically rotates the cluster heads with time and after all cluster heads and gateway nodes the determined the rest of the nodes in the clusters are consider redundant and or put to the sleep state this is the whole idea behind the CEC.

(Refer Slide Time: 23:13)



And there is a span algorithm which basically maintains the neighbor list by periodically sending HELLO message broadcast.

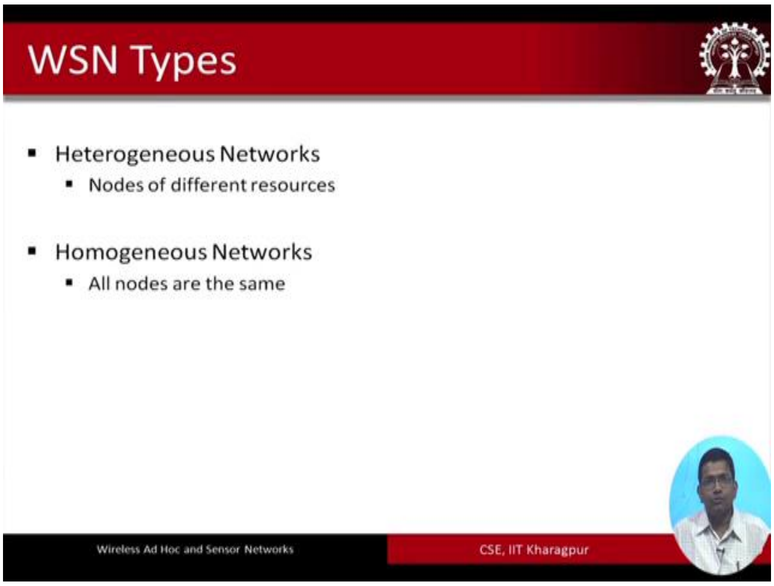
(Refer Slide Time: 23:24)



And the last one is a Naps, the Naps algorithm basically is another sleep cycle management algorithm it begins the time period by broadcasting a particular message and then if this.

So, this particular message is then received and whoever receives it is a counter is incremented if the counter is a predefined value then the nodes sleeps otherwise the nodes stays awake and so, it the benefit of naps is basically that no location information is required and it; however, introduces the traffic with hello message.

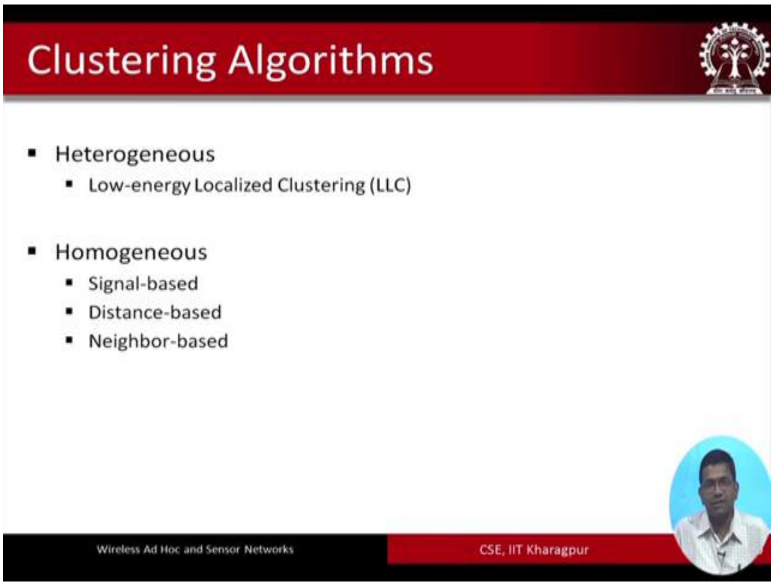
(Refer Slide Time: 24:04)



So, sensor networks can be broadly classified into 2 types the heterogeneous sensor networks and the homogeneous sensor networks heterogeneous networks are the ones where the nodes are different that different the different nodes have different resources and inhomogeneous networks all the nodes are the same and all the resources that they have are also the same.

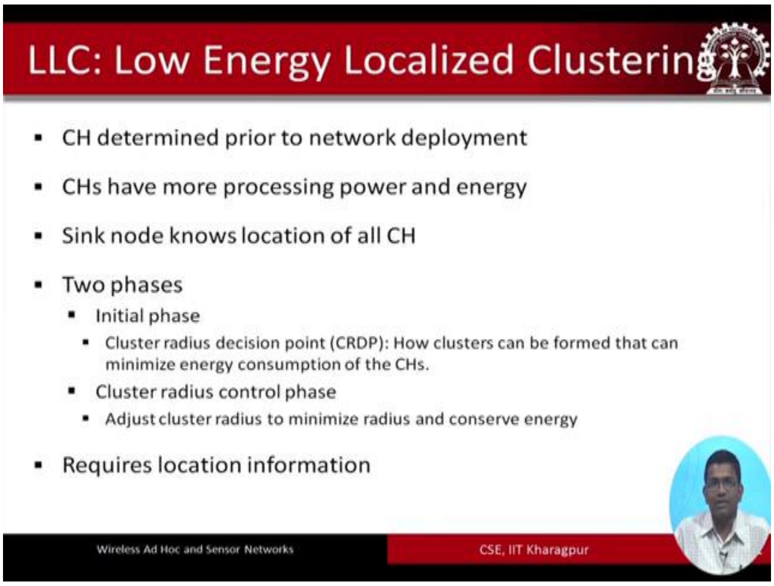
So, consequently what happens, we can infer that in a heterogeneous network the radii of the different nodes the transmission radii of the different nodes basically a are different, but in a homogeneous network basically they all these nodes they all have the same transmission range.

(Refer Slide Time: 24:46)



Clustering algorithms basically you know LLC; low energy localized clustering algorithm is a popular algorithm that is propose for heterogeneous sensor networks and for homogeneous very single sorry, signal based algorithm distance based algorithm and never based algorithm.

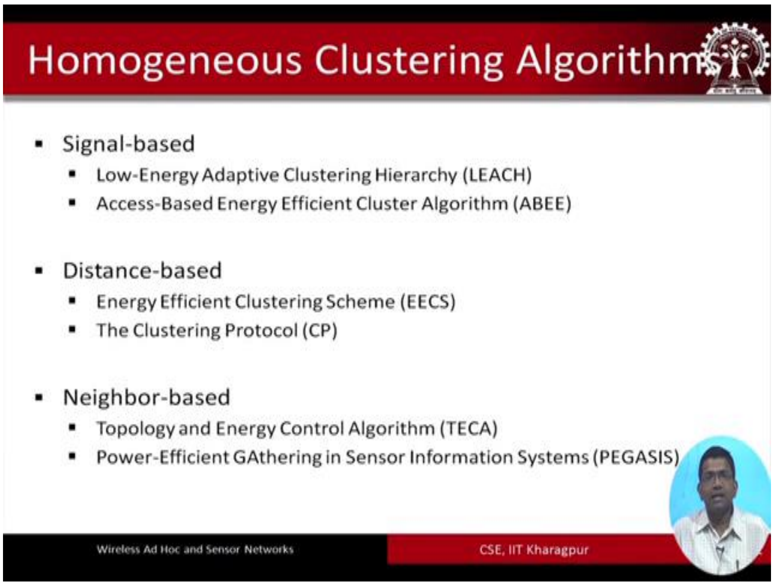
(Refer Slide Time: 25:08)



So, the LLC algorithm is a clustering based it uses a clustering based approach where the cluster head is determined prior to network deployment these cluster heads have more processing power and energy the sink node knows the location of all the cluster heads and there are 2 phases that are executed the initial phase and the cluster radius control phase the in the initial phase the cluster radius decision point algorithm is implemented. So, it talks about how the clusters can be formed that can minimize the energy consumption of the cluster heads.

So, this basically this algorithm basically takes care of the formation of clusters while minimizing the energy consumption of the cluster heads and the second one the cluster radius control phase basically adjusts the cluster radius to minimize the radius and conserve energy.

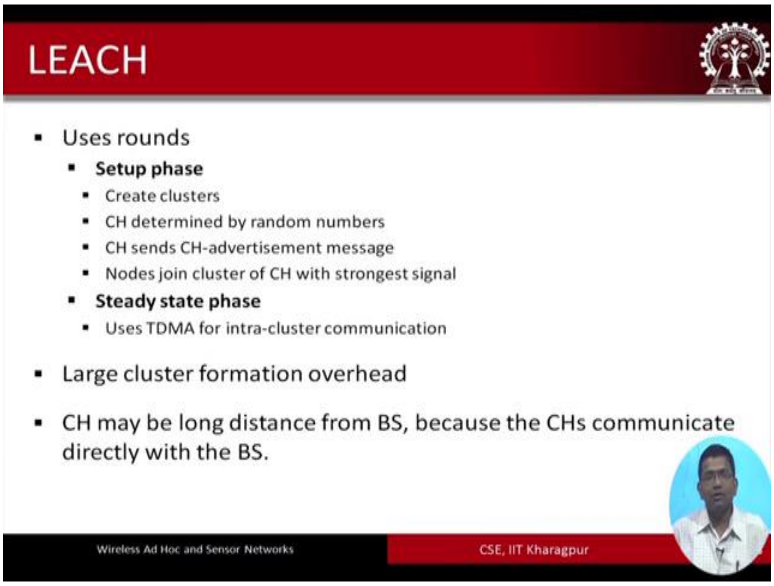
(Refer Slide Time: 26:02)



Homogeneous clustering algorithms signal based clustering basically 2 algorithms belonging to this category are quite popular one is the LEACH algorithm the other one is the ABEE algorithm. So, LEACH particularly is very popular and it is implemented in different solutions in simulators and in different practical deployments as well.

So, then we have the distance based homogeneous clustering algorithm which uses the energy. So, belonging to this category are 2 algorithms to energy efficient clustering algorithm EECS and the clustering protocol CP. The third is the neighbor based algorithms TECA and PEGASIS are algorithms belonging to this category.

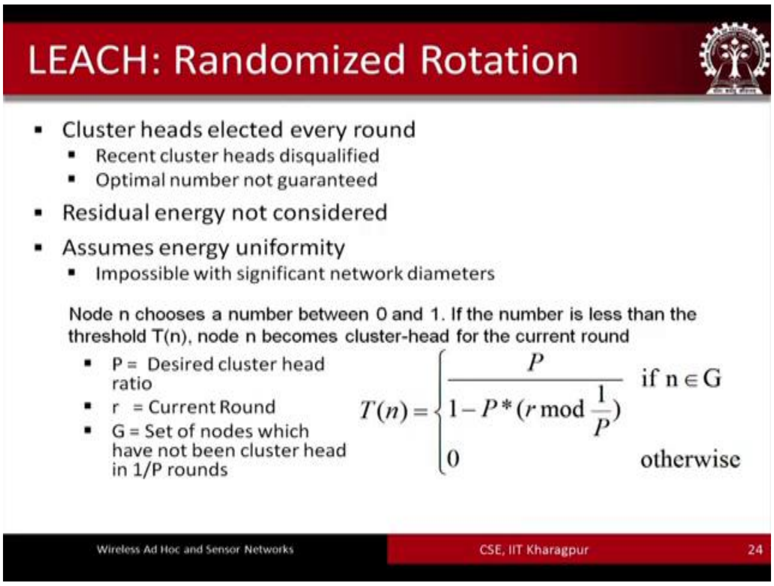
(Refer Slide Time: 26:50)



Now, let me just give you an overview of the LEACH clustering algorithm which is very popular algorithm. So, it basically works in rounds; rounds a; round is basically a simulation run. So, you know. So, one run one round again second run second round third run third round and so on.

So, this leach algorithm basically works in rounds. So, first it starts with the setup phase it creates the clusters the cluster head is determined by random numbers the cluster heads sends cluster head advertisement messages the nodes join the cluster of the cluster of the cluster head with the strongest signal steady state phase it basically is used for representing the intra cluster within the cluster communication. So, what happens is the different nodes in within the clusters they are going to talk to each other via the TDMA protocol using the TDMA protocol. So, use a TDMA for inter class inter class inter cluster communication.

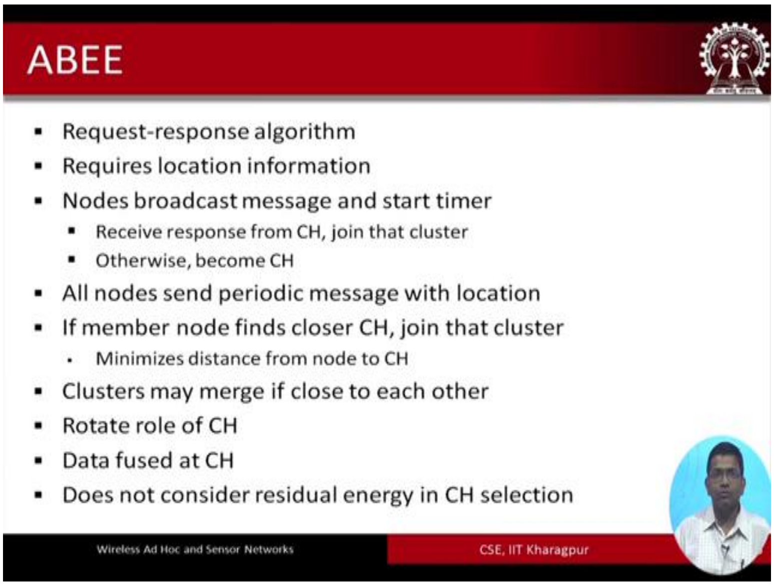
(Refer Slide Time: 28:00)



So, in the LEACH protocol the cluster heads are elected in every round and the recent cluster heads that have been used in the recent times these are disqualified.

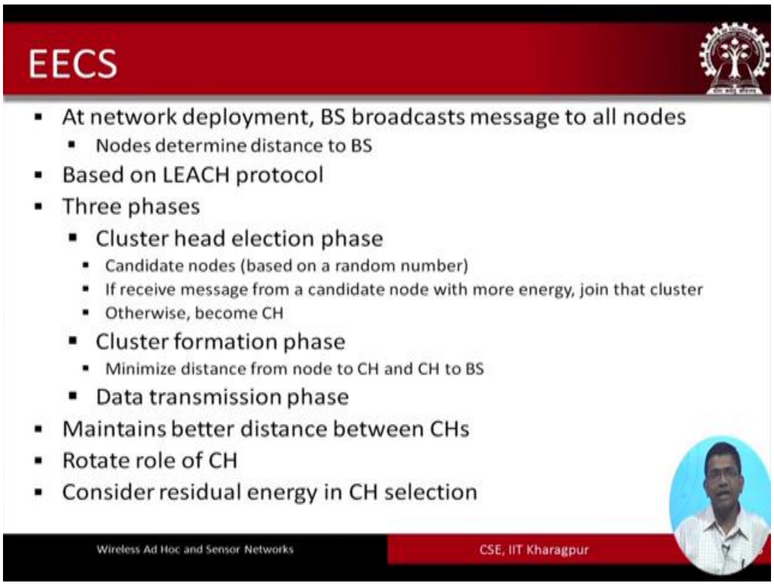
So, the way energy efficiency energy uniformity is maintained is like this that if node in chooses a number between 0. So, initially the node n basically chooses a number between 0 and 1. So, randomly it chooses a number if the number is less than threshold then T n threshold T n sorry, if the number is less than the threshold T n node n becomes the cluster head of the current round. So, this T n which is the threshold of for a particular node n is calculated like this the T n equal to P over 1 minus P star or mod 1 by P, if n belongs to G 0 otherwise where P is the desired cluster head ratio and r is the current round and G is the set of nodes which have not been cluster head in 1 by P rounds.

(Refer Slide Time: 29:28)

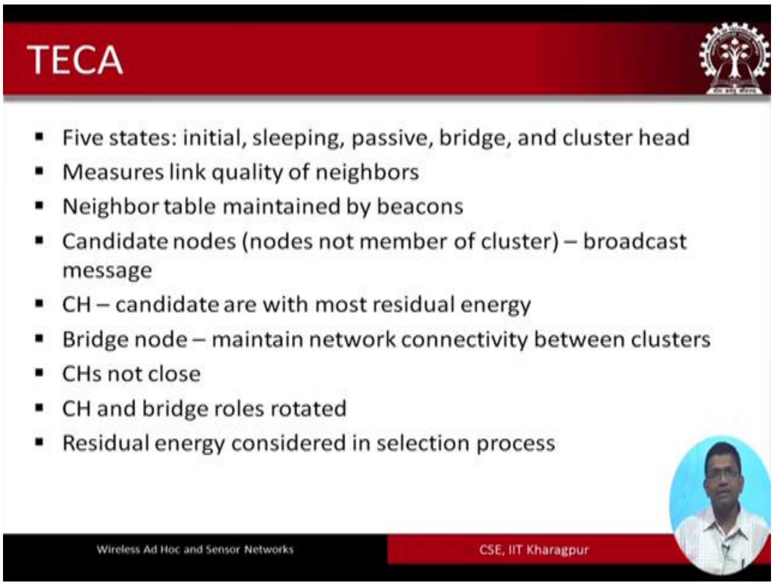


So, this is the formula that is used for selecting the cluster heads ABEE algorithm is also a cluster based algorithm I am not going to go through this in detail, but the features of it are mentioned over here.

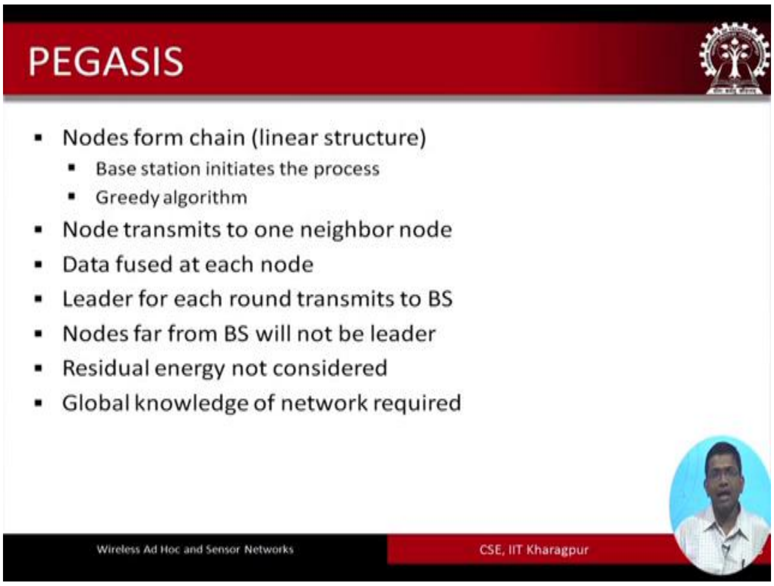
(Refer Slide Time: 29:39)



(Refer Slide Time: 29:43)

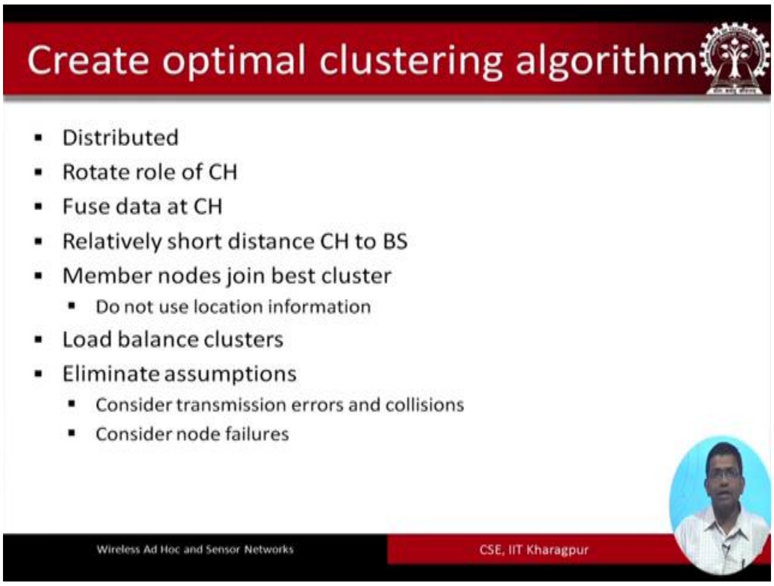


(Refer Slide Time: 29:45)



ECS is another one which is again a cluster based algorithm take I use another cluster based algorithm and finally, PEGASIS which is again like leach is a very popular algorithm, but again due to lack of time you know I am not going to go through PEGASIS in detail. So, these algorithms particular leach PEGASIS etcetera are so popular that one should go through them one should understand them very well particularly you know understanding should be such that one after the class they should be able to go and implement.

(Refer Slide Time: 30:18)



So,. So, clustering basically it should be done in such a way that the cluster heads are distributed uniformly as much as possible and at the same time the cluster heads should be rotated and the cluster head the data that are received from the different sensor nodes which are the member nodes that should be fused and this is how the cluster heads are formed and the function as the cluster heads are implemented. So, the load between the different clusters should also be balanced in order and that basically a optimal clustering algorithm will essentially take care of it.

(Refer Slide Time: 31:04)

So, these are the important references for understanding this particular topic on topology management for wireless sensor networks.

Thank you.