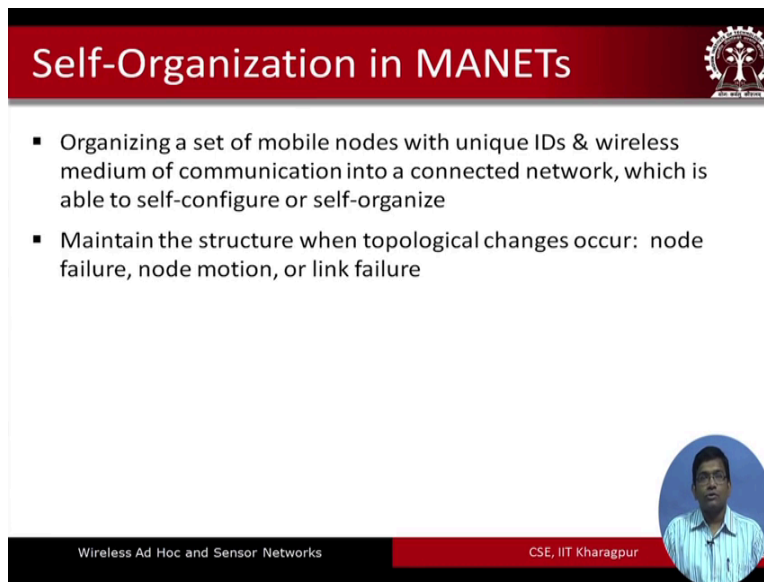


Wireless Ad Hoc and Sensor Networks
Prof. Sudip Misra
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture – 03
Self-organizing Behavior of Wireless Ad Hoc Networks

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The slide features a red header with the title "Self-Organization in MANETs" and the IIT Kharagpur logo. Below the header, there is a bulleted list of two points. At the bottom right, there is a circular portrait of Prof. Sudip Misra. The footer contains the text "Wireless Ad Hoc and Sensor Networks" and "CSE, IIT Kharagpur".

- Organizing a set of mobile nodes with unique IDs & wireless medium of communication into a connected network, which is able to self-configure or self-organize
- Maintain the structure when topological changes occur: node failure, node motion, or link failure

Our next topic is self-organizing behavior of wireless ad hoc networks. Self-organization concerns organizing a set of mobile nodes with unique identifiers and wireless medium of communication into a connected network; which is able to do things like self-configure or self-organize. It concerns maintaining the structure when the topological changes occur for instance with respect to node failure, node motion or link failure.

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What is Self-Organization


- Self-Organization – Important concept in building scalable systems made up of a large number of subsystems.
- Primary Objectives of Self-Organization
 - Co-ordination and Collaboration to achieve shared goal
 - Achieve Collaboration without central entity
 - Reliability, Scalability and Availability of the system
- Self-Organization Design Goals in MANETs
 - Neighbor Discovery
 - Topology Configuration
 - Topology Maintenance

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Self-organization is very important in building scalable systems, particularly systems such as MANETs which are decentralized, and which is composed of typically large number of subsystems. The primary objectives of self-organization include coordination and collaboration to achieve shared goal, achieving collaboration without central entity, and improving or ensuring the reliability, the scalability and availability of the system.

So, availability is all about probabilistically ensuring that as per the SLA the system will be made available to the users for a certain duration of time. Scalability concerns that how the system would scale up, how the system is going to perform when the number of nodes in the MANET, in the case of MANETs, when the number of nodes in the system is going to increase. And reliability is all about probabilistically ensuring that the system is overall going to behave reliably at all durations of time when it is supposed to operate. So, there are different design goals of self-organization in MANETs with respect to neighbor discovery, topology configuration and topology maintenance. So, we are going to talk about each of these in more detail later on.

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Self-Organization

Principles of Self-Organization evolved in nature

- Self-Organized Behavior – Pattern emerges at the global level using only local information generated by interaction between lower level components
- Emergent Behavior – Behavior of complex system generated by simple interaction between lower level entities is more than the sum of their behaviors.
- Thus Self-Organization from a networking perspective includes the myriad of algorithms and protocols that govern global system behavior based on simple interaction between nodes.
- E.g. simple message exchange among neighboring nodes leading to packet transmission from source to sink node.

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So, self-organization is a behavior that has, that occurs in the nature, and that has been inspired from different natural phenomena and has been adopted in network systems, in the specific case it has been adopted in mobile ad hoc network systems.

So, in self-organized behavior there are patterns which emerges at the global level using only local information generated by interaction between the low level components. So, for example, in the case of MANETs you know local interactions between the different nodes which are within a particular local area etc etc, and together, you know they would, that information would scale up to the overall network level, overall system level and you know a pattern would emerge from that. Emergent behavior is another concept that comes very close when we talk about self-organization. It basically is a behavior of a complex system that is generated by simple interaction between lower level entities in more than, to ensure that it is more than the sum of their behaviors. So, the self-organization from a networking perspective includes the set of algorithms and protocols that govern global system behavior based on simple interactions between different nodes; for instance, simple message exchange between the neighbor nodes in a MANET that would lead to packet transmission from the source to the same node. So, as we have seen in the previous lectures that in MANETs we have the scenario of multi hop communication, and there are intermediate nodes, neighboring nodes which basically help in

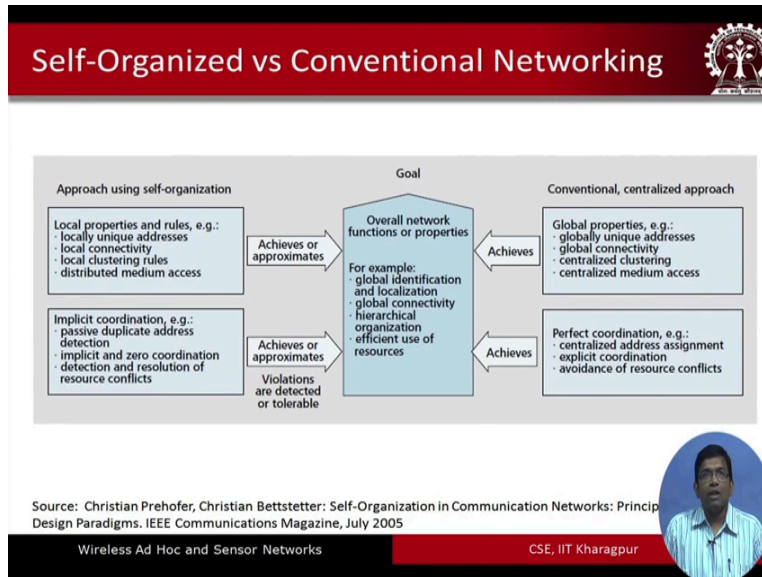
relaying the information between these two source and destination nodes. So, these things are powered by the self-organizing behavior and this is very important, this example concerns message exchange, but similar kind of phenomena is observed in other aspects that basically contribute to powering the MANETs.

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The slide features a red header with the title "Self-Organization in Nature" and a logo of a tree with a gear. Below the header is a diagram of a school of blue fish. A central fish is highlighted with dashed lines and arrows pointing to its immediate neighbors. Two text boxes with arrows point to this central fish: the top one says "Local view, peer-to-peer interaction, and simple behavior rules of each individual entity" and the bottom one says "Adaptive, robust, and scalable structure functionality of the overall system". At the bottom left, there is a source citation: "Source: Christian Prehofer, Christian Bettstetter: Self-Organization in Communication Networks: Principles and Design Paradigms. IEEE Communications Magazine, July 2005". At the bottom right, there is a circular portrait of a man and the text "CSE, IIT Kharagpur". The footer contains "Wireless Ad Hoc and Sensor Networks" on the left and "5" on the right.

Let us look at the figure in front of us, to explain this phenomenon of local, sorry, of self-organization, let us look at, you know how the different nodes; so, in this particular figure as we can see that we have a node which interacts with the neighboring nodes; so, these nodes they interact with the neighboring nodes. So, this particular node has local view about the behavior of the peers, and it can interact with the direct neighbors which are the peers and this behavior can be observed by this particular node. Everybody does the same and together when we look at a systemic level, so, you know this particular behavior, the global behavior of the overall system can be observed or it can be approximated from these local observations.

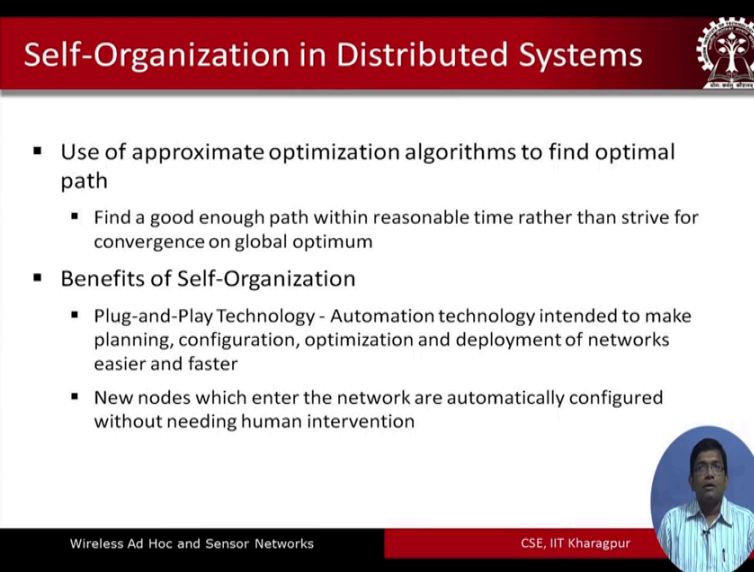
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This is a very important aspect of you know enabling mobile ad hoc networks. So, in this particular figure we see a comparison, a side by side comparison between self-organization and conventional networking; that means, self-organized networks and conventional networks. So, as we can see that in self-organized networks it uses local properties and rules, for example, the locally unique addresses, local connectivity, local clustering rules, distributed medium access so on and so forth. All of these local properties and rules which can achieve or which can approximate the overall network functions or properties, for example, by doing all of these locally, at the global level, at the system level one could be able to get a global identification, a picture of the global context and localization; global connectivity, hierarchical organization efficient use of resources and so on. So in a nutshell what we see is in self-organized networks these local properties and rules can help achieve the overall network functions and properties in a very scalable manner. In contrast if we look at the conventional or the centralized approach, so, there actually we have global properties. For example, globally unique addresses, global connectivity, centralized clustering centralized medium access. So, everything is centralized and it is global, you know the addressing scheme itself is global, whereas, as we have seen in the case of the self-organized systems, you know, the addressing is local right. So this is the contrast between the networking in the conventional context and networking in the self-organized context. And whereas, in the self-organized context we have implicit coordination between the

different nodes, here in the conventional context we have perfect coordination. So these are the main points of difference between the conventional or centralized approach of networking and the self-organized approach to, self-organization approach to networking. So, the corresponding you know paper or the reference that one can read is given over here and in the bottom of the slide. So, one is encouraged to do so.


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Self-Organization in Distributed Systems

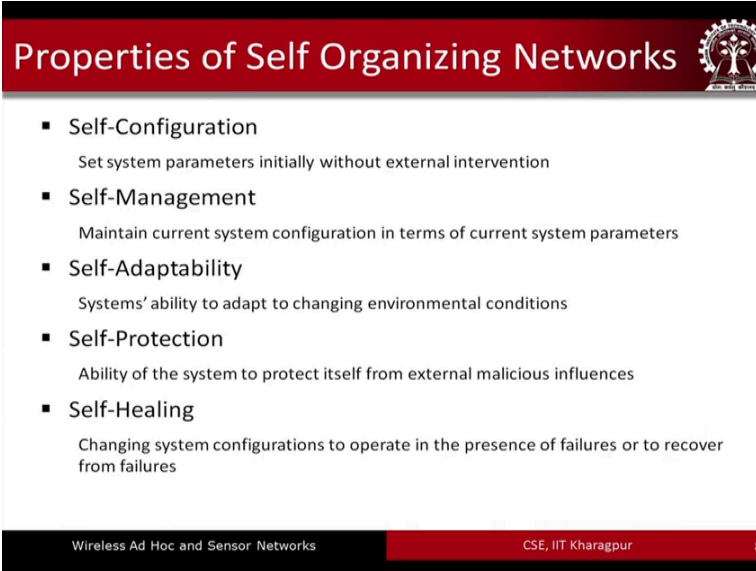
- Use of approximate optimization algorithms to find optimal path
 - Find a good enough path within reasonable time rather than strive for convergence on global optimum
- Benefits of Self-Organization
 - Plug-and-Play Technology - Automation technology intended to make planning, configuration, optimization and deployment of networks easier and faster
 - New nodes which enter the network are automatically configured without needing human intervention

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So, in self-organized systems, these systems basically use different approximate optimization algorithms to find optimal or near optimal paths. And the benefits of self-organization include plug and play right. So, basically you know one would be able to plug into the system and the system will start operating you know, on its own, it is a fully autonomous system. So, plug and play technology and where basically the new nodes which enter the network are automatically configured without needing any human intervention.

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Properties of Self Organizing Networks

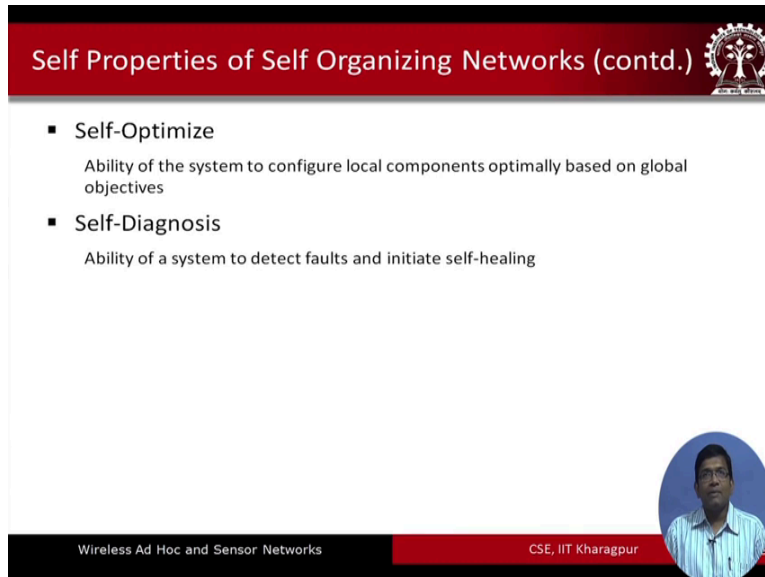
- **Self-Configuration**
Set system parameters initially without external intervention
- **Self-Management**
Maintain current system configuration in terms of current system parameters
- **Self-Adaptability**
Systems' ability to adapt to changing environmental conditions
- **Self-Protection**
Ability of the system to protect itself from external malicious influences
- **Self-Healing**
Changing system configurations to operate in the presence of failures or to recover from failures

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Self-organized networks have very distinct properties. Properties known as self-configuration which concerns, which is basically, which basically concerns setting the system parameters initially without external intervention. Self-management is a second property which basically concerns maintaining the current system configuration in terms of the current system parameters. Self-adaptability, which is basically system's ability to adapt to the changes in the environment around the system; that means, in this particular case of MANETs you know the nodes they are going to interact with the environment around them and the system as a whole, the nodes individually, and the system as a whole would be able to adapt to the changes in the environmental conditions.

Self-protection is basically the ability of the system to protect itself from external malicious influences, because in any networked system and definitely in the case of MANETs, there are you know large number of different external malicious, you know attacks or you know malicious interventions that can come in, and the system should be designed, the MANET should be designed in such a way that it should be able to protect itself from such kind of external malicious interventions. Self-healing behavior is about, as the name suggests that whenever there is some kind of failure then the system should be able to operate in the presence of such failures and it should be able to recover from such failures.

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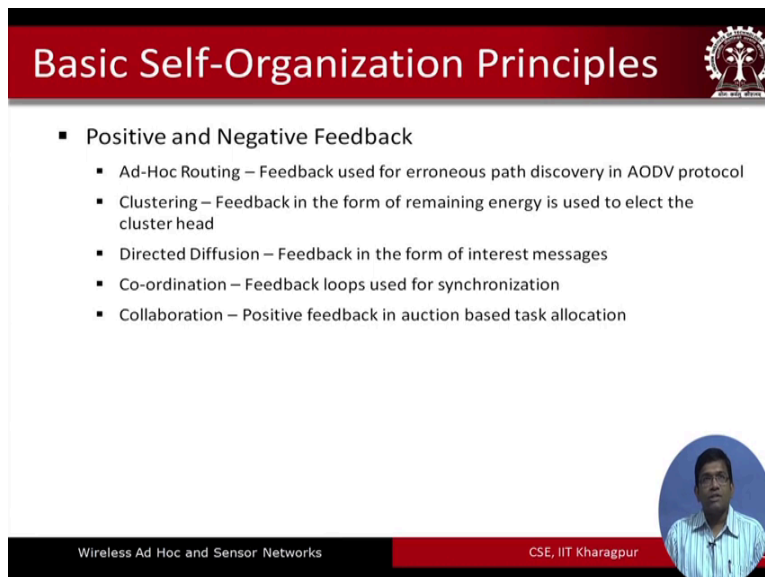
Self Properties of Self Organizing Networks (contd.)

- **Self-Optimize**
Ability of the system to configure local components optimally based on global objectives
- **Self-Diagnosis**
Ability of a system to detect faults and initiate self-healing

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Two other properties of self-organizing networks, self-properties of self-organizing networks, self-optimizing, so, it is basically the ability of the system to configure the local components optimally based on the global objectives. And self diagnosis which is basically the ability of the system to detect faults and initiate self healing.

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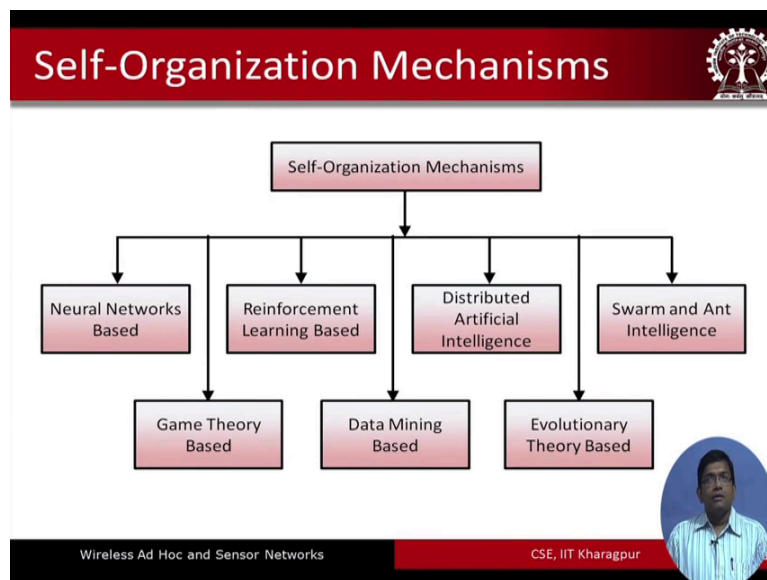
Basic Self-Organization Principles

- **Positive and Negative Feedback**
 - Ad-Hoc Routing – Feedback used for erroneous path discovery in AODV protocol
 - Clustering – Feedback in the form of remaining energy is used to elect the cluster head
 - Directed Diffusion – Feedback in the form of interest messages
 - Co-ordination – Feedback loops used for synchronization
 - Collaboration – Positive feedback in auction based task allocation

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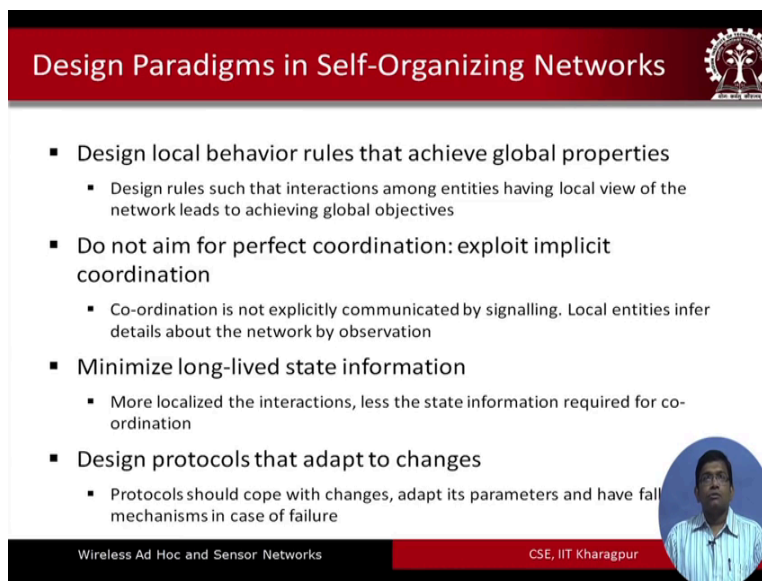
Self organized systems, self organizing systems basically strive on the basis of different kinds of feedbacks that come in by interacting with the system. These feedbacks can be positive or negative. So, when we are concerned specifically on routing, the feedback, negative or positive, is used for erroneous path discovery in the different protocols. AODV as we have seen in a previous lecture is one of the very popular ad hoc routing protocols. Clustering is another where the feedback is in the form of the remaining energy that is used to elect the cluster head. So, how much energy is remaining in the different nodes and then switching between the different cluster heads, this is what this kind of feedback is used for clustering in MANETs. Then directed diffusion is something that is used in routing in specifically in the specific type of ad hoc networks known as the sensor ad hoc networks or ad hoc sensor networks, where the feedback is in the form of interest messages. So, basically the different nodes which want access to the data they are going to propagate interest messages for the data. So, we are going to look at the directed diffusion based routing when we talk about sensor networks, ad hoc sensor networks in more detail in a future lecture. Coordination is another where basically feedback loops are used for synchronization between the different nodes, and collaboration is the last one where positive feedback is used for auction based task allocation.

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There are different mechanisms of self organization. And these can be classified into the different forms as you can see in the figure in front of you. One is the neural based, neural networks based mechanism second is game theory based mechanism, third is reinforcement learning based mechanism, next is the determining based mechanism, distributed artificial intelligence based mechanism, evolutionary theory based mechanism and swarm and ant intelligence is another, you know, soft computing based approach or in mechanism that is typically used in powering or enabling these systems, the self organizing systems.

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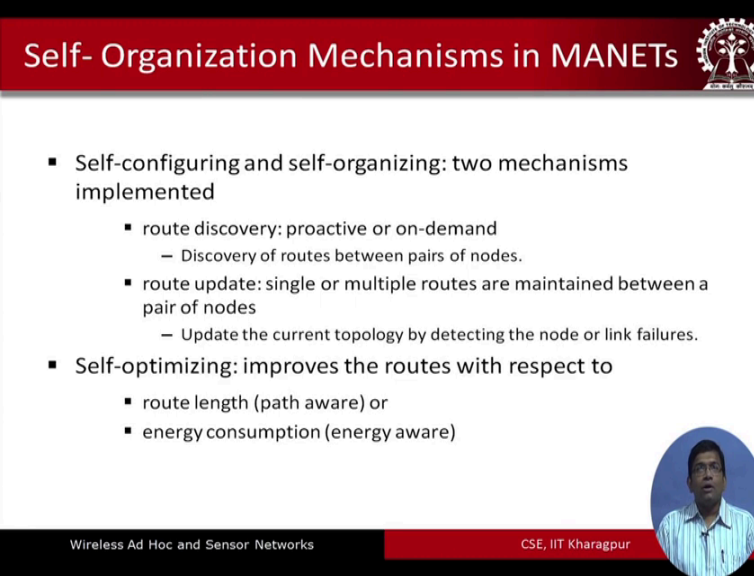
The slide features a red header with the title "Design Paradigms in Self-Organizing Networks" and a logo on the right. The main content is a bulleted list of design principles. A small circular portrait of a man is positioned in the bottom right corner of the slide area. The footer contains the text "Wireless Ad Hoc and Sensor Networks" and "CSE, IIT Kharagpur".

- Design local behavior rules that achieve global properties
 - Design rules such that interactions among entities having local view of the network leads to achieving global objectives
- Do not aim for perfect coordination: exploit implicit coordination
 - Co-ordination is not explicitly communicated by signalling. Local entities infer details about the network by observation
- Minimize long-lived state information
 - More localized the interactions, less the state information required for co-ordination
- Design protocols that adapt to changes
 - Protocols should cope with changes, adapt its parameters and have fall mechanisms in case of failure

So, there are different design paradigms for self organizing systems, designing local behavior rules that achieve global properties and then you know, so, it is basically about designing rules such that the interactions among the entities have local view of the network that leads to achieving global object. This is the most important thing. So, locally, you know individually locally the nodes in the MANET for instance, MANET is a self organizing network is an example of that. So, individually locally these nodes we are going to interact with one another and this local view is going to be projected at the global level for achieving the global objectives. So, this is a very important thing in self organizing MANETs. Then there are other things like it is required not to aim for perfect coordination and exploit the implicit coordination between the different node. So, coordination is not explicitly communicated by signaling all right. So,

basically the local entities are going to infer the details about the network through different local observation and scale it up globally. So, like this there are different other you know design paradigms for use in self organizing networks.

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Self-Organization Mechanisms in MANETs

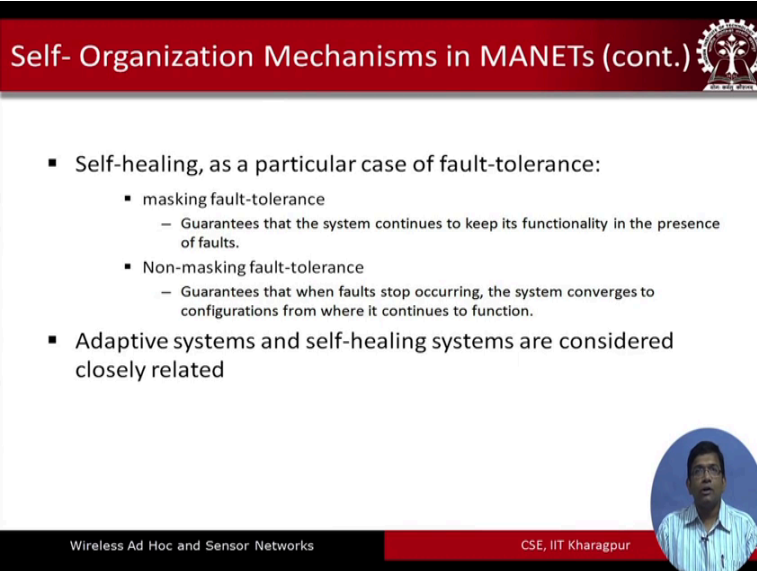
- Self-configuring and self-organizing: two mechanisms implemented
 - route discovery: proactive or on-demand
 - Discovery of routes between pairs of nodes.
 - route update: single or multiple routes are maintained between a pair of nodes
 - Update the current topology by detecting the node or link failures.
- Self-optimizing: improves the routes with respect to
 - route length (path aware) or
 - energy consumption (energy aware)

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So, two very important mechanisms for self organizing behavior, self organizing systems are known as self configuring and self organizing. So, self, you know, so, these self mechanisms these two mechanisms they are basically you know based on typical you know approaches known as you know the first one is the route discovery approach. So, when it concerns routing. So, this is an example that is used in the context of routing and routing is a very important phenomena for any network system and particularly MANET systems. So, route discovery which can be done proactively on demand so where basically the routes are discovered between a pair of different nodes, whenever there is a demand; that means, the you know the path between the source and the destination nodes are not already there it is not already cast and it is not available in the node or the nodes where the packet is currently resident. Route update, single or multiple routes are maintained between a pair of nodes and that you know and updating the current topology by detecting the node or link failures. So, route discovery and route update are two important routing mechanisms that are good examples for self configuring and self organizing behavior of MANETs. Self optimizing is the next which basically helps in improving the routes

you know. Some routes between the different nodes are selected through the routing mechanisms like route discovery or whatever and then self optimizing behavior characteristic, what it ensures is that the routes are optimal during the future time instance. For example, with respect to the route length you know, so, initially may be the route length or the number of hops between the two different nodes might be optimal, but later on also ensuring that the optimal you know path or the optimal route is used between the different nodes, that is what the self optimizing characteristic, self optimizing behavior ensure. Similarly ensuring that it is energy aware, energy efficient is also another very important thing.

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The slide features a red header with the title "Self-Organization Mechanisms in MANETs (cont.)" and a logo on the right. The main content is a bulleted list:

- Self-healing, as a particular case of fault-tolerance:
 - masking fault-tolerance
 - Guarantees that the system continues to keep its functionality in the presence of faults.
 - Non-masking fault-tolerance
 - Guarantees that when faults stop occurring, the system converges to configurations from where it continues to function.
- Adaptive systems and self-healing systems are considered closely related

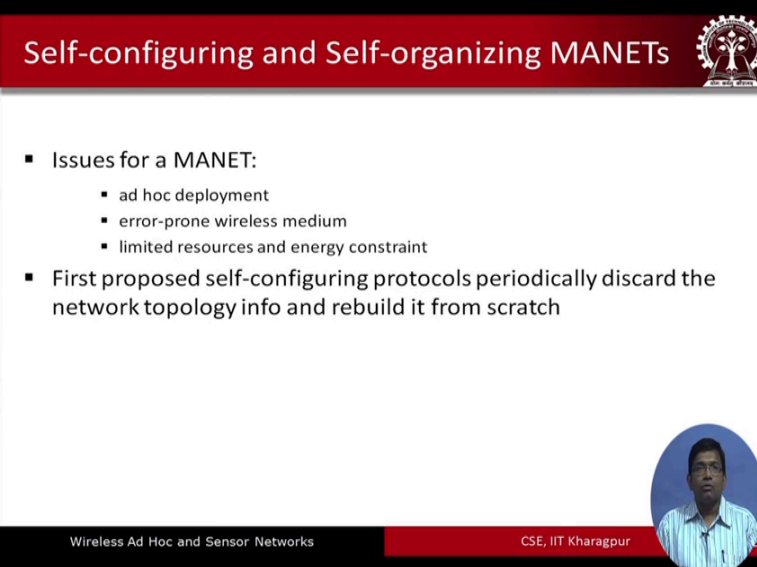
In the bottom right corner, there is a small circular video inset showing a man in a light blue shirt speaking. The footer contains the text "Wireless Ad Hoc and Sensor Networks" on the left and "CSE, IIT Kharagpur" on the right.

Self healing is a very important mechanism self healing characteristic is a very important one, for ensuring fault tolerance in MANETs. So, there are actually two types of fault tolerance, one is called the masking fault tolerance which basically guarantees that the system will continue to function the way it is supposed to in the presence of faults. And the other one is the non masking fault tolerance which basically guarantees that when false stops occurring the system converges to configurations from where it continues to function.

So these are the two different approaches to you know fault tolerance which are used in MANETs and these basically help in making these systems, MANET systems, the self organizing MANET systems self heal whenever there is a fault. So, adaptive systems and self

healing systems are quite closely related. So, adaptive means what, that whenever there is some kind of abnormality, some kind of problem, some unusualness that arises, so, the system will be able to adapt to it. So, that it functions the way it is supposed to function right. So, this is what the adaptive systems does and definitely self healing systems are also supposed to do that, these systems are supposed to heal on their own, whenever there is a problem whenever there is a failure or there is some kind of a fault. So, the system is going to self heal.

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The slide features a red header with the title "Self-configuring and Self-organizing MANETs" and a logo of a tree with a gear. The main content is a list of issues for a MANET. In the bottom right corner, there is a circular portrait of a man in a light blue shirt. The footer contains the text "Wireless Ad Hoc and Sensor Networks" and "CSE, IIT Kharagpur".

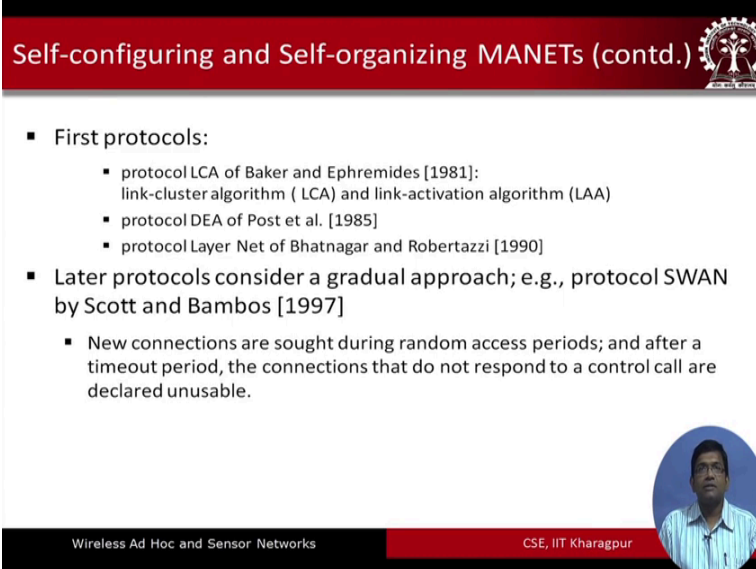
- Issues for a MANET:
 - ad hoc deployment
 - error-prone wireless medium
 - limited resources and energy constraint
- First proposed self-configuring protocols periodically discard the network topology info and rebuild it from scratch

So, there are you know when we are concerned about the self configuring and self organizing properties of MANETs there are different issues of MANETs that should be kept in mind. And these are the ones that we have already seen, but let us look at them once more. So, first one is that ad hoc deployment, this is a very important concepts we do not have a centralized entity centralized coordinator like an access point or something like that, which can help in you know which can help the different nodes you know coordinate between talk to themselves and so on so that becomes a very important challenge a very you know challenging problem in MANETs. The other is that the medium itself is very much error prone where the nodes operate the medium is very much error prone and there are limited resources.

And the constraint on the energy is too high in these ad hoc networks, the MANET ad hoc networks. So, the first proposed self configuring protocols basically periodically discard the

network topology information and what they do is they rebuild everything from scratch; that means, they try to rebuild the topology, understand the topology from scratch every time, every time the network topology changes. So, understanding the topology from scratch, building it from scratch you know every time the nodes move the topology changes and so on and so forth. So, this is what the native, you know the conventional mechanisms, this is how they achieve self organization or self configuration in MANETs.

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The slide features a red header with the title "Self-configuring and Self-organizing MANETs (contd.)" and a logo on the right. The main content is a bulleted list of protocols. In the bottom right corner, there is a circular portrait of a man in a light blue shirt. The footer contains the text "Wireless Ad Hoc and Sensor Networks" on the left and "CSE, IIT Kharagpur" on the right.

- First protocols:
 - protocol LCA of Baker and Ephremides [1981]: link-cluster algorithm (LCA) and link-activation algorithm (LAA)
 - protocol DEA of Post et al. [1985]
 - protocol Layer Net of Bhatnagar and Robertazzi [1990]
- Later protocols consider a gradual approach; e.g., protocol SWAN by Scott and Bambos [1997]
 - New connections are sought during random access periods; and after a timeout period, the connections that do not respond to a control call are declared unusable.

So, different protocols, for example, you know the protocol LCA by Baker and Ephremides and the link cluster algorithm you know say etcetera, these reference is already given over here. So, you know. So, you are encouraged to go through them. So, these are some of the protocols that basically achieved it through the mechanisms the naive mechanism that I just you know talked about. And later protocols, the recent ones basically considered a more gradual approach where new connections are sought during random access periods and after a timeout period the connections that do not respond to a control call are declared unusable.

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Example: LEACH



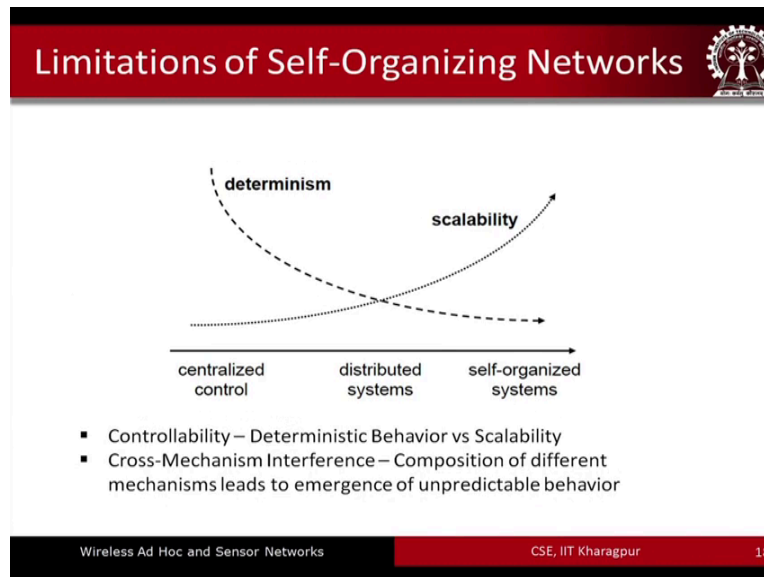
- Protocol : LEACH – Low Energy Adaptive Clustering Hierarchy [Handy, Haase, Timmermann 2002]
- Application
 - Even distribution of power consumption of each node
- Assumptions
 - Each node can either act as regular and cluster head
 - Regular nodes only communicate with cluster head
- Principles
 - Nodes elect themselves to become cluster heads at given time depending on their remaining energy
 - Cluster heads broadcast their status to the nearest nodes in the network
 - Each node chooses the nearest cluster head to minimize communication energy

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One of the very popular self organizing protocol that is used in MANETs is a routing protocol, is a cluster based routing protocol, which is known as LEACH. The protocol LEACH, the full form of LEACH is basically low energy adaptive clustering hierarchy protocol and it was proposed by Handy et al. in 2002.

The application of LEACH protocol is typically found where, you know it is required to have even distribution of power consumption at the different nodes in the network. So, the LEACH protocol works under certain assumptions for example, assuming that each node can either act as regular or cluster head, regular node or a cluster head node. The regular nodes only communicate with the cluster head, this is one of the assumptions that LEACH makes that the regular nodes cannot communicate with one another directly, but they have to communicate via the cluster heads. So, you know. So, they are within the one hop distance to the cluster head. The principles are like this that the nodes they elect themselves to become cluster heads is at a given time depending on their remaining energy. The cluster heads broadcast their status to the nearest nodes in the network and each node chooses the nearest cluster head to minimize communication energy.

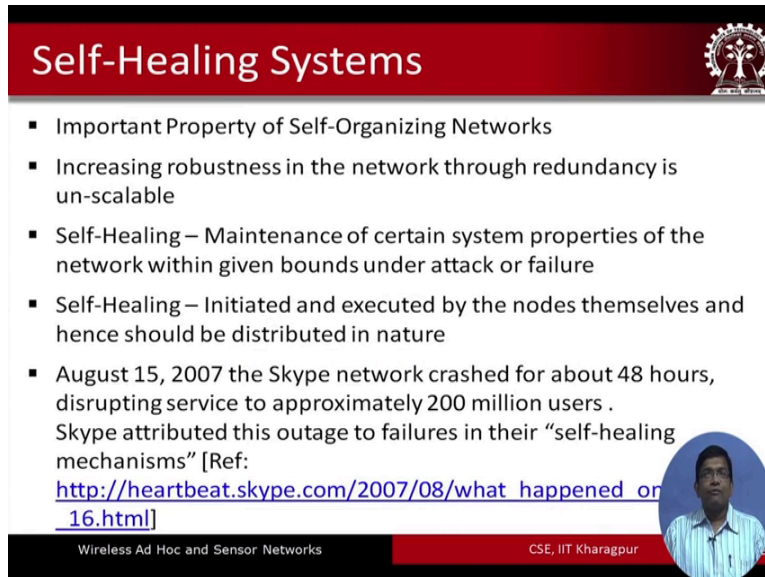
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There are different limitations, it is not like you know, so far what we have seen are all the very glittering aspects of self organizing networks. And it is not that the self organizing networks are all you know all gold and they glitter a lot it is not like that. There are different limitations of self organizing networks. So, if we look at this particular figure in front of us what we see is that, it is a curve, you know 2 curves, which basically shows the tradeoff between determinism and scalability.

With respect to systems which are highly centralized then the distributed systems and the self organizing systems and as we are seeing that MANETs are self organizing systems right. So as we can see that when the systems become more and more self organized, you know the determinism basically the deterministic behavior it reduces. So, the deterministic behavior reduces from centralized systems through the distributed systems to the self organized systems whereas, the trend is completely opposite with respect to the scalability. So, with respect to scalability the self organized systems are much more scalable compared to the distributed systems and the centralized ones.


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Self-Healing Systems

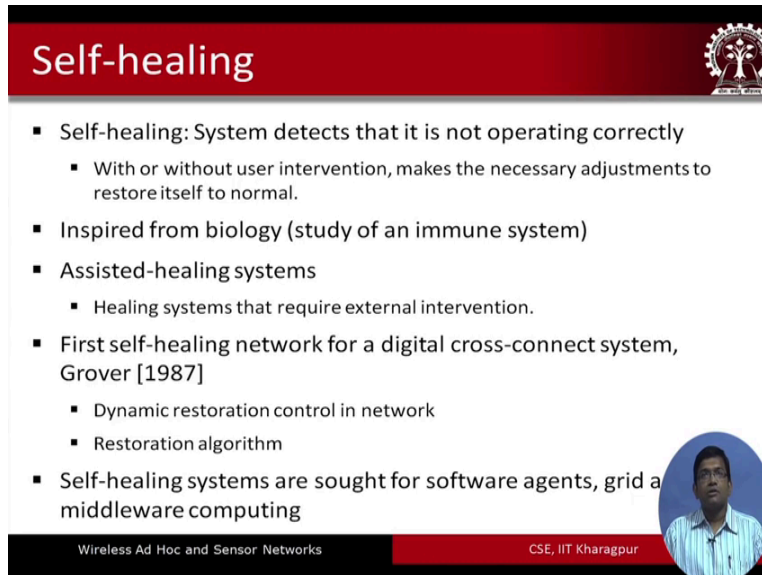
- Important Property of Self-Organizing Networks
- Increasing robustness in the network through redundancy is un-scalable
- Self-Healing – Maintenance of certain system properties of the network within given bounds under attack or failure
- Self-Healing – Initiated and executed by the nodes themselves and hence should be distributed in nature
- August 15, 2007 the Skype network crashed for about 48 hours, disrupting service to approximately 200 million users . Skype attributed this outage to failures in their “self-healing mechanisms” [Ref: http://heartbeat.skype.com/2007/08/what_happened_on_16.html]

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So, self healing is an important property as we have seen of any self organizing networks. Self healing property basically increases the robustness in the network through redundancy. And so what it ensures is that if there is some kind of failure in the system or there is some kind of an attack the system would be able to maintain the properties of it under which you know it is supposed to operate right. So, whatever is the desirable system functionality the system would be able to operate even in spite of the fact that it is under an attack or it is undergoing some kind of failure in some parts of the system or maybe in the extreme case the whole system the different components large number of components in the system fails, the system will still be able to run, this is what the self you know healing behavior tries to achieve.

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Self-healing

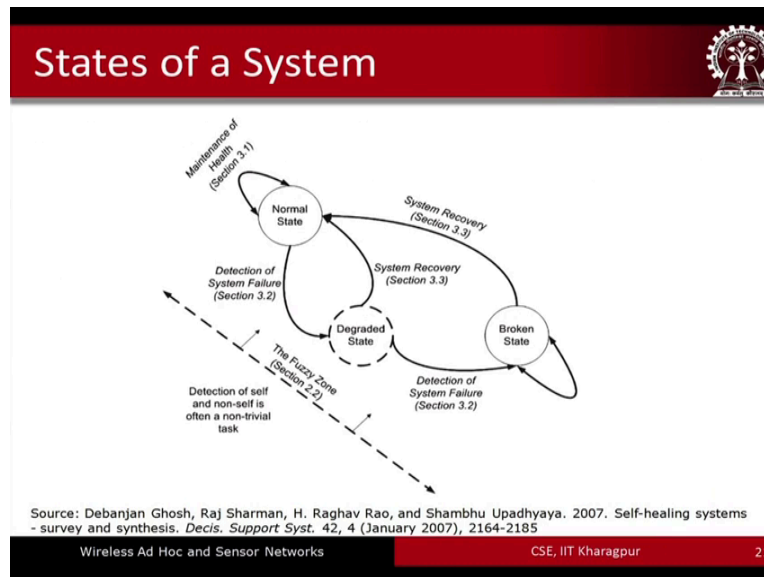
- Self-healing: System detects that it is not operating correctly
 - With or without user intervention, makes the necessary adjustments to restore itself to normal.
- Inspired from biology (study of an immune system)
- Assisted-healing systems
 - Healing systems that require external intervention.
- First self-healing network for a digital cross-connect system, Grover [1987]
 - Dynamic restoration control in network
 - Restoration algorithm
- Self-healing systems are sought for software agents, grid and middleware computing

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So, in self healing the system basically detects that it is not operating correctly. And with or without user intervention it makes the necessary adjustments to restore itself to normal. And most of the self healing mechanisms that you would find that are used in the self organizing systems; that means, MANETs and the like, we will see, it is typically observed that most of these mechanisms are inspired from biology.

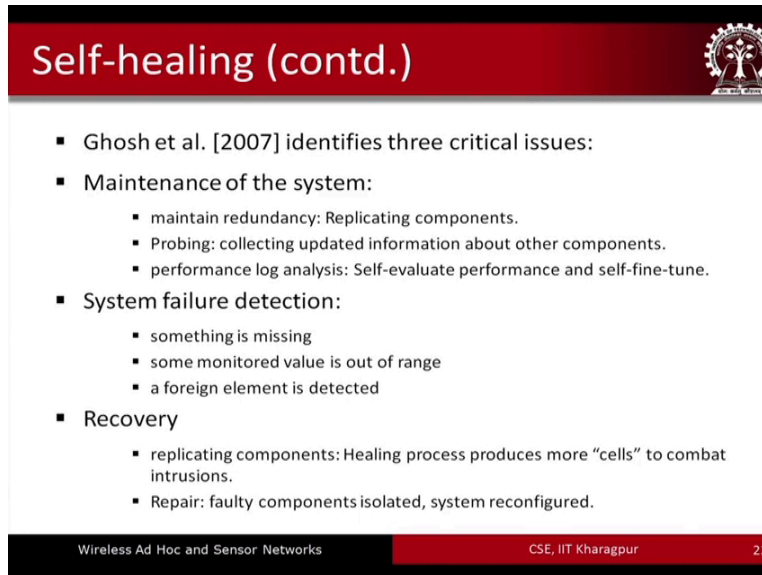
For example the human body, human body or even you know other organisms also, biological organisms typically have a strong immune system and for instance you know, so, if we just focus on the human system we have a very strong immune system. So, what happens is if we have a wound or cut in some part of the body typically the body is going to you know heal by itself. Or for example, if there is some kind of invasion by different microorganisms in our body the body fights and our immune system fights and the immune system would be able to heal on its own would help our body to heal on its own. So most of the, you know, self healing systems are inspired from how the immune systems work in nature in biology.

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A typical system, any system would typically go through three different states as we can see in this figure. In the normal conditions the system would be in the normal state, when there is some kind of failure, some systemic failure, then it goes to the degraded state and after recovery it can come back to the system you know it can recover from the degraded state and it can come back to the normal system state. Or if there is a detection of system failure then it goes to the broken state; that means, fail state. And from the broken state it can still through the recovery processes the system can be brought to the normal state. So, this is typically what happens in any system and definitely for a self organizing system.

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The slide features a red header with the title "Self-healing (contd.)" and a small logo on the right. The main content is a bulleted list of three critical issues identified by Ghosh et al. [2007]: Maintenance of the system, System failure detection, and Recovery. Each issue has sub-bullets detailing specific mechanisms. The footer contains the text "Wireless Ad Hoc and Sensor Networks", "CSE, IIT Kharagpur", and the number "22".

Self-healing (contd.)

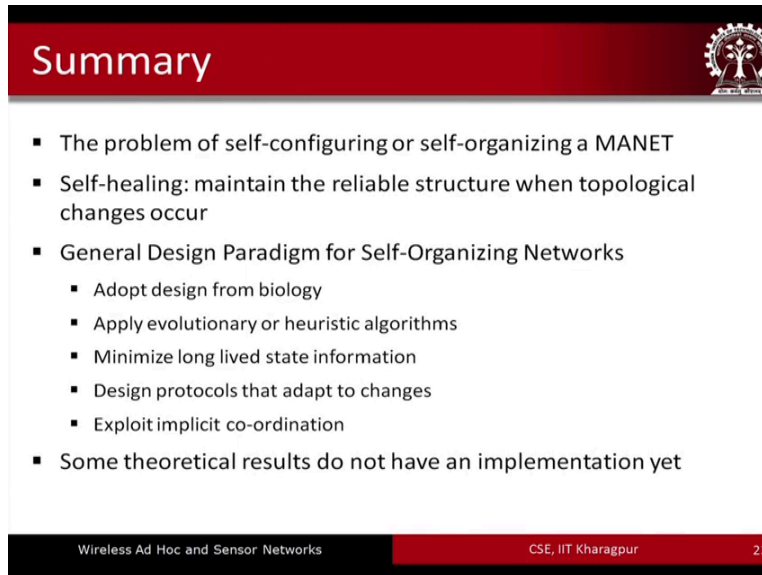
- Ghosh et al. [2007] identifies three critical issues:
 - Maintenance of the system:
 - maintain redundancy: Replicating components.
 - Probing: collecting updated information about other components.
 - performance log analysis: Self-evaluate performance and self-fine-tune.
 - System failure detection:
 - something is missing
 - some monitored value is out of range
 - a foreign element is detected
 - Recovery
 - replicating components: Healing process produces more “cells” to combat intrusions.
 - Repair: faulty components isolated, system reconfigured.

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So, there are 3 different aspects or critical aspects of a self healing system. Maintenance of the system; that means, you know ensuring that there are some components which are replicated. Probing is another mechanism where you know data are collected about different components you know through different probes and the other one is using performance log and analyzing the performance logs. So, this basically helps in evaluating, self evaluating the performance and self fine tuning the system.

So, whenever the system failure is detected, basically what happens is it is detected that something is missing or some monitored value has gone out of range or a foreign element has invaded and that invasion is detected. And the third is that recovery. So, recovery can be obtained through different mechanisms either the system can be repaired; that means, the faulty components can be isolated or the system can repair on its own the fault that has occurred or through proactive mechanisms by ensuring that there are some components which are replicated. And whenever you know one goes down there is another component that is going to take over.

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The slide features a red header with the word "Summary" in white. To the right of the header is a circular logo of IIT Kharagpur. The main content area is white and contains a bulleted list. The footer is black with white text.

- The problem of self-configuring or self-organizing a MANET
- Self-healing: maintain the reliable structure when topological changes occur
- General Design Paradigm for Self-Organizing Networks
 - Adopt design from biology
 - Apply evolutionary or heuristic algorithms
 - Minimize long lived state information
 - Design protocols that adapt to changes
 - Exploit implicit co-ordination
- Some theoretical results do not have an implementation yet

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In summary the problem of self configuring and self organizing behavior in MANETs is what we have discussed today self-healing behavior is a very important behavior of these systems, the MANET systems and the self healing behavior basically ensures maintaining the reliable structure when the topological changes occur when a link has gone down for instance when a node has gone down or maybe there is some other fault or a failure that has occurred in the system. So, there are different general design paradigms for these self-organizing networks. And these are basically adopted from inspirations from biological phenomena, or you know evolutionary mechanisms, heuristic algorithms are used and so on and so forth. And so when we look at this literature we see that there are lots of theoretical approaches, theoretical results that are available in this particular context and, but you know when we look at the real implementation of them they are still not, you know they are not yet implemented in real life systems.

So, there is lot of opportunity of you know using them and implementing them in real life systems to make them truly self-organizing.

Thank you.