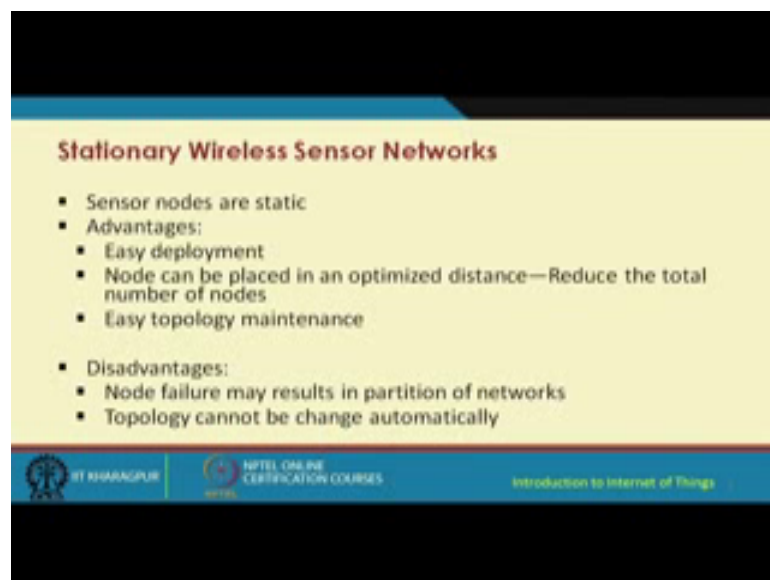


Introduction to Internet of Things
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Lecture - 18
Sensor Networks- V

So finally, we come to the last lecture of the series on sensor networks. So, here basically I would like to highlight some of the concepts of mobility. So, more specifically I would like to explain the concept of mobile sensor networks.

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Stationary Wireless Sensor Networks

- Sensor nodes are static
- Advantages:
 - Easy deployment
 - Node can be placed in an optimized distance—Reduce the total number of nodes
 - Easy topology maintenance
- Disadvantages:
 - Node failure may results in partition of networks
 - Topology cannot be change automatically

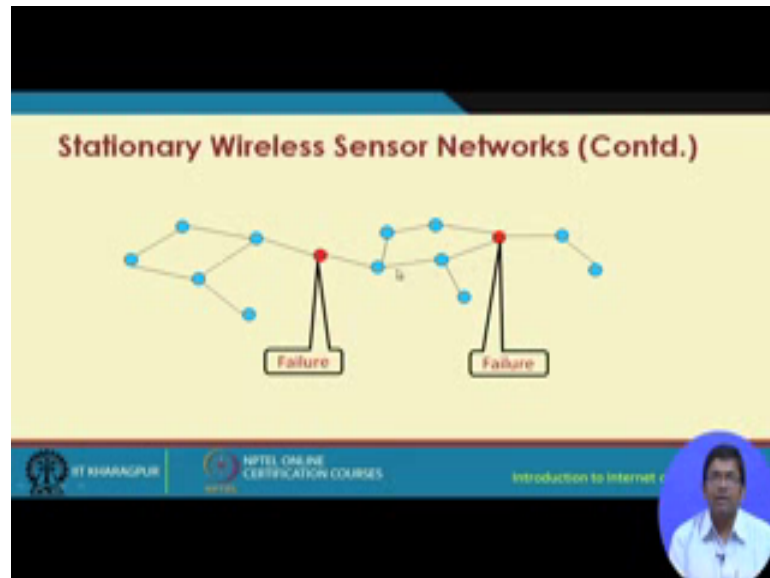
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So, let us first look at the static variant sometimes it is also known as the stationary sensor network. So, here basically as the name suggests the nodes are stationary or static. So, they do not move; once deployed they will maintain their positions at later instants of time as well. So, the advantage is basically it is easier to deploy sensor nodes in a stationary sensor network, the nodes can be placed in an optimized manner, then it there maintenance of the topology is easier and so on and so forth.

The disadvantage is that if there is a failure in the static sensor network then it is likely that that point of failure can partition the network into two or more fragments, two or more partitions. So, it is quite likely that there can happen. And particularly if it is a critical node, so in that node failing means that you know it is likely to partition the network. So, one part of the network will not be able to talk with another part of the

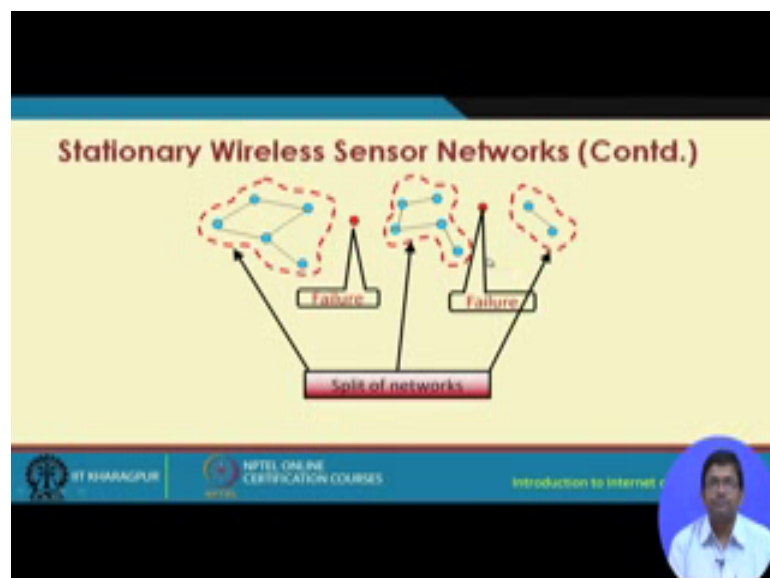
network. And topology cannot be changed automatically is also another disadvantage of a stationary sensor network.

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So, let us consider a state stationary sensor network as shown in this particular slide. So, we have these red colored nodes as points of failure because if this particular node dies for one reason or other for example, the hardware in it has failed it has stopped functioning or maybe that you know the battery that was powering that particular node it is exhausted.

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So, what is going to happen? As a consequence these nodes are positioned in such a way that these network partitions will be created. So, three network partitions would be created if these two nodes fail. So, as a consequence what is going to happen is that we would have three partitions or three split ups of the network due to these points of failure.

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The slide is titled "Stationary Wireless Sensor Networks (Contd.)". It features a diagram of a network with three distinct clusters of nodes, each enclosed in a red dashed line. Two red dots are placed between these clusters, representing points of failure. Below the diagram, the text reads "Solution?" followed by "To mobilize the sensor nodes" and "Mobile Wireless Sensor Networks (MWSN)". The slide footer includes the IIT Kharagpur logo, the text "NPTEL ONLINE CERTIFICATION COURSES", and "Introduction to Internet of Things". A small circular inset in the bottom right corner shows a man in a white shirt.

So, what is the solution? So, one way to address this is to have some node maybe some external node, external to this particular network or among these if we can have one of these nodes mobile nodes which can move. Then what it can do is one of these nodes let us say this particular node can come and take the position of these red colored node and this network will be joined these partitions will be joined. Likewise maybe this node can come over here and likewise these two partitions can be joined. So, these three partitions can be joined if some of these nodes one of these nodes is mobile.

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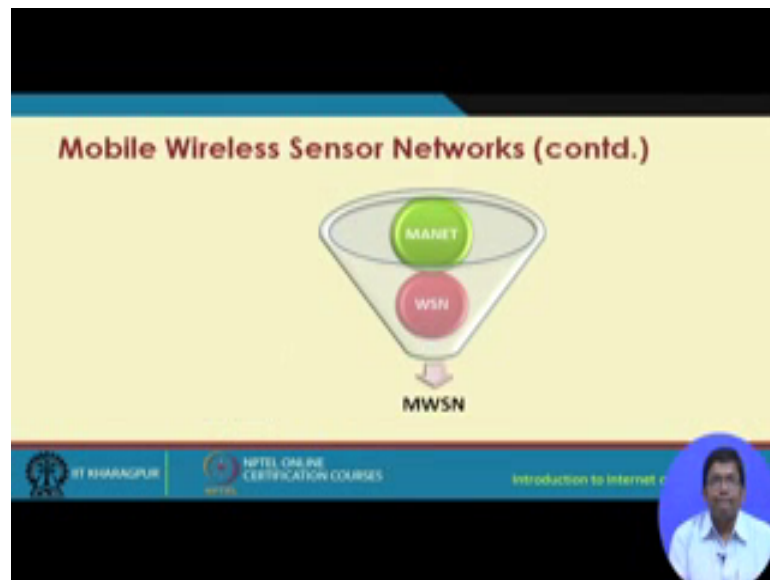
Mobile Wireless Sensor Networks

- MWSN is Mobile Ad hoc Network (MANET)
- Let us remember from previous lectures:-
- MANET-**infrastructure less** network of mobile devices connected wirelessly which follow the **self-CHOP** properties
 - Self-Configure
 - Self-Heal
 - Self-Optimize
 - Self-Protect
- Wireless Sensor Networks-
 - Consists of a large number of sensor nodes, densely deployed over an area.
 - Sensor nodes are capable of **collaborating with one another** and measuring the condition of their surrounding environments (I.e. Light, temperature, sound, vibration).

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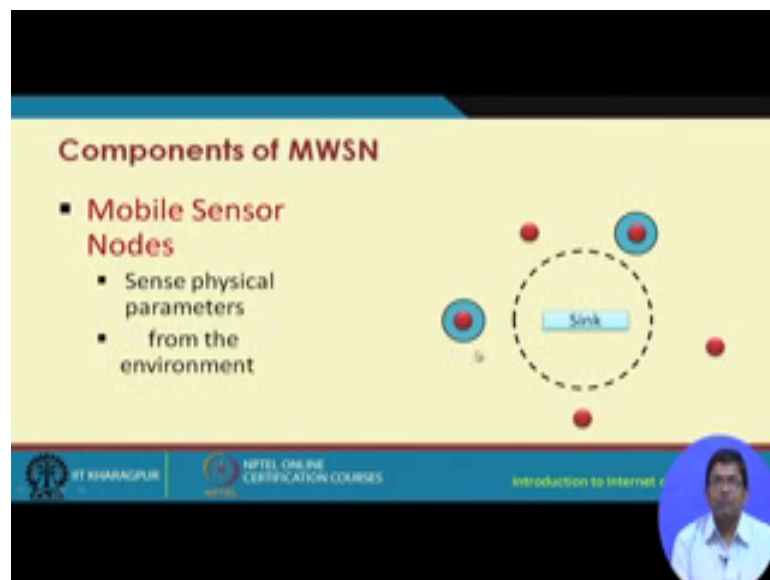
So, we have a mobile wireless sensor network which is basically a sensor network, a stationary sensor network conceptually integrated with a mobile ad hoc network. So, this is not physically integrated conceptually. So, take the features of mobile ad hoc networks, take the few features of stationary sensor networks put them together and then you get the mobile wireless sensor networks. And as we know that MANETs mobile ad hoc networks are infrastructure less and infrastructure less. So, basically what happens is the topology basically becomes dynamic dynamically changing topologies that basically invites following properties like self configuring, self healing, self optimizing, self protecting and so on. So, these have to be there these are infrastructure less networks these do not have any centralized entity which will control the network management functions. So, this self job properties basically are going to take effect.

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So, this is what I was telling you little while back. So, mobile wireless sensor networks are basically a conceptual integration of MANETs with wireless sensor networks.

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So, components of a mobile wireless sensor network one is the mobile sensor node the nodes themselves could be mobile. So, these nodes we have a sink, these nodes can move all around the sink. So, the sensor nodes, these mobile sensor nodes they would be sensing some physical parameters from the environment like the way it is shown over

here. So, this node this red color node is sensing some physical parameter around the environment.

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Components of MWSN

- **Mobile Sensor Nodes**
 - Sense physical parameters from the environment
 - When these nodes come in close proximity of sink, deliver data

The diagram shows a central blue box labeled 'Sink' surrounded by a dashed circle. Five red dots representing sensor nodes are positioned around the sink, with two nodes located within the dashed circle's boundary.

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So, they sense the physical parameters from the environment, when these nodes come in close proximity of the sink they would deliver the data as shown

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Components of MWSN

- **Mobile Sensor Nodes**
 - Sense physical parameters from the environment
 - When these nodes come in close proximity of sink, deliver data

The diagram shows a central blue box labeled 'Sink' surrounded by a dashed circle. Five red dots representing sensor nodes are positioned around the sink, with two nodes located within the dashed circle's boundary.

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So, in this particular figure as we can see what happens is these two nodes they have come within the communication range of the sink node, and once they come into the communication range of the sink node they would deliver the sense data. So, maybe they

have sense that data somewhere outside this range then they have moved and then they dump that data once they come into the proximity of the sink node.

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Components of MWSN

- **Mobile Sink**
 - Moves in order to collect data from sensor nodes
 - Based on some algorithm sink moves to different nodes in the networks

The slide features a diagram with a central blue box labeled 'Sink' and five red dots representing sensor nodes scattered around it. The slide footer includes the logos of IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES, along with the text 'Introduction to Internet of Things' and a small video inset of a presenter.

Then we have the mobile sink, which moves in order to collect data from the sensor nodes the sink itself this. So, these sensor nodes in the earlier situation in the earlier example we had considered that the sensor nodes can move; here actually in this particular figure we show that the sensor nodes are all stationary, the sink node can move and can collect data from each of these sensor nodes.

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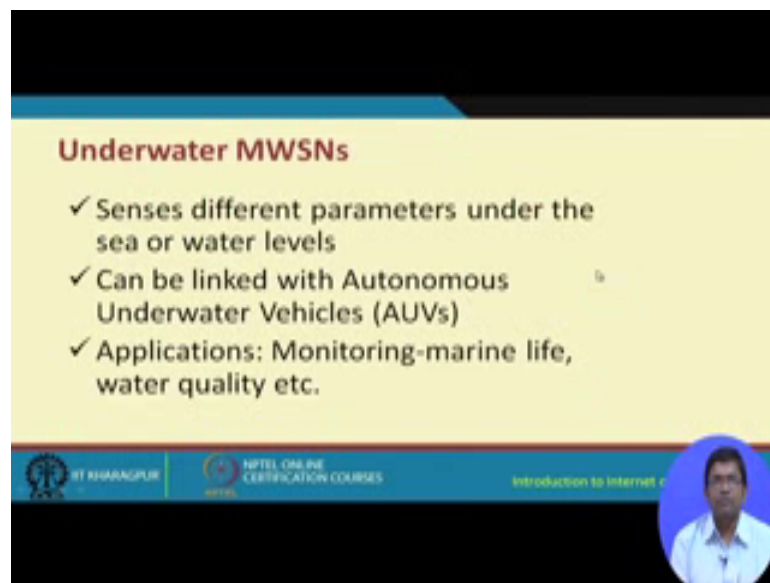
Components of MWSN

- **Data Mules**
 - A mobile entity
 - Collects the data from sensor nodes
 - Goes to the sink and delivers the collected data from different sensor nodes

The slide features a diagram with a central blue box labeled 'Sink' and five red dots representing sensor nodes. A gear icon is positioned above the sink, representing a data mule. The slide footer includes the logos of IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES, along with the text 'Introduction to Internet of Things' and a small video inset of a presenter.

Then we can have data mules future mobile. And these are like external entities which collect the data from the sensor nodes goes to the sink and delivers the collected data from the different sensor nodes. So, this mule can go in close proximity to each of these red colored nodes. And thereafter once it has you know finished collecting the data from these red colored nodes it will come in the close proximity of the sink node and will deliver the message to the messages all these messages to the sink node.

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Underwater MWSNs

- ✓ Senses different parameters under the sea or water levels
- ✓ Can be linked with Autonomous Underwater Vehicles (AUVs)
- ✓ Applications: Monitoring-marine life, water quality etc.

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Now this mobile sensor network it can be used either in the terrestrial environment maybe by fitting sensors to robotic devices or can be used in the aerial environment, flying sensor networks. For example, the sensors the nodes themselves they fly or it can be an underwater sensor network that means that the sensors are fitted to underwater mobile devices like autonomous underwater vehicles, rovers and so on. So, the examples could be to monitor the marine life or water quality. So, we have use of underwater mobile sensor networks which can autonomously automatically sense and remotely send the sensed parameters of different things such as the sea level, water level you know water quality marine life and so on and so forth.

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Terrestrial MWSNs

- ✓ Sensor nodes typically deployed over land surface
- ✓ Can be linked with Unmanned Aerial Vehicles (UAVs)
- ✓ Applications: Wildlife monitoring, surveillance, object tracking

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Terrestrial wireless mobile sensor networks sensor nodes typically deployed over land which can be linked with AUVs; that means, the autonomous unmanned aerial vehicles and the applications would be wife wildlife monitoring, surveillance, object tracking and so on.

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Aerial MWSNs

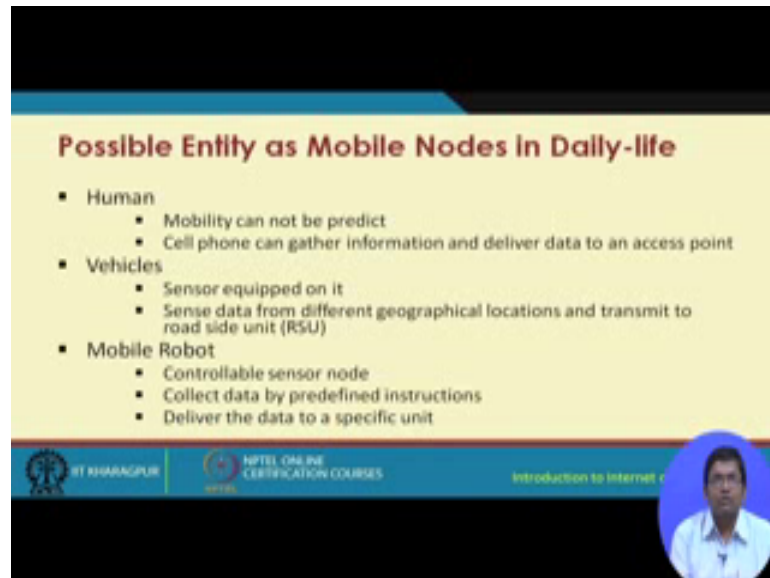
- ✓ Nodes fly on the air and sense data (physical phenomena or multimedia data)
- ✓ Typical example is Unmanned Aerial Vehicles (UAVs)
- ✓ Applications: Surveillance, Multimedia data gathering

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And the aerial version I told you where the nodes they fly. So, when they fly they sense and they form a network through which the data are sent to the surface station. So, the

typical examples is unmanned aerial vehicles fitted with sensors; applications include surveillance, multimedia data gathering and so on.

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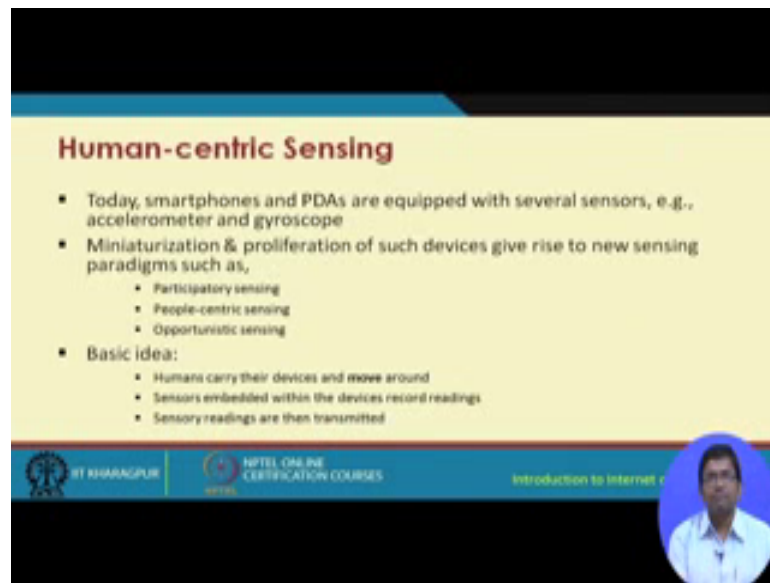
Possible Entity as Mobile Nodes in Daily-life

- Human
 - Mobility can not be predict
 - Cell phone can gather information and deliver data to an access point
- Vehicles
 - Sensor equipped on it
 - Sense data from different geographical locations and transmit to road side unit (RSU)
- Mobile Robot
 - Controllable sensor node
 - Collect data by predefined instructions
 - Deliver the data to a specific unit

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So, what can be mobile, what can be mobile in a mobile sensor network? We can have different types of examples of mobile entities from daily life one is the humans, humans can be mobile and the mobility of humans are unpredictable. For example, if somebody is walking with the cell phone on and then we want to gather the information of the cell phone then it is unpredictable to you know so it is unpredictable how the human being is going to move and consequently it is unpredictable to predict the mobility of the cell phone. For vehicles, for example, sensors are typically used in cars and different modern day vehicles so that becomes vehicular sensor network where these vehicles are fitted with different sensors the sensed data from the different geographical locations and transmit to the roadside unit. And then we have the mobile robots which are controllable sensor nodes that collect data by predefined instructions and deliver the data to a specific unit.

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The slide is titled "Human-centric Sensing" in a bold, dark red font. It features a list of bullet points on a light yellow background. The first bullet point states that smartphones and PDAs have sensors like accelerometers and gyroscopes. The second bullet point discusses the rise of new sensing paradigms due to miniaturization and proliferation, listing participatory, people-centric, and opportunistic sensing. The third bullet point, "Basic idea:", explains that humans carry devices, sensors record readings, and these are then transmitted. At the bottom, there is a blue banner with logos for IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES, and a small video inset of a man in a white shirt.

- Today, smartphones and PDAs are equipped with several sensors, e.g., accelerometer and gyroscope
- Miniaturization & proliferation of such devices give rise to new sensing paradigms such as,
 - Participatory sensing
 - People-centric sensing
 - Opportunistic sensing
- Basic idea:
 - Humans carry their devices and move around
 - Sensors embedded within the devices record readings
 - Sensory readings are then transmitted

Human-centric sensing is possible because of the use of smartphones and PDAs which nowadays are equipped with several sensors typically even up to like several sensors there are lot of smartphones. So, these sensors could be like accelerometer sensor, gyroscope sensor and so on which are commonly available in the modern day smartphones and PDAs. So, miniaturization and proliferation of such devices give rise to new sensing paradigm such as participatory sensing, people centric sensing and opportunistic sensing. Participatory sensing in participatory sensing a crowd, a group of people each having their smartphones equipped with sensors turn on their respective sensors in their mobile phones and then consequently what is going to happen is we are going to form a human-centric sensor network a human centric mobile sensor network.

Then we have the people-centric sensing very similar to the example that I just told you. So, basically you know the previous example I had talked about using peoples people moving. So, a every you know people they can also sense you know we have eyes, ears etcetera. So, through which we can also sense the people can also sense so that becomes people-centric sensing. And then we have opportunistic sensing which basically is that peripheral a particular node moves in that to a different location then opportunistically it is going to sense and then opportunistically it is going to deliver the message if another node comes in proximity.

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Human-centric Sensing (contd.)

- Three distinct roles (not necessarily mutually exclusive) played by humans
 - Sensing targets: Humans themselves are sensed, e.g., personal health monitoring
 - Sensor operators: Humans use sensors and applications in smartphones & PDAs to sense surroundings
 - Data source: Humans disseminate & collect data without actually using any sensor, e.g., updates posted in social networking sites
- Challenges in human-centric sensing:
 - Energy of devices
 - Participant selection
 - Privacy of users

Source: M. Srivastava, T. Abdelzaher, and B. Szymanski, "Human-centric sensing," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 369, no. 1928, pp. 119–127, Jan. 2011.

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So, the basic idea is that humans carry their devices and move around sensors embedded with the devices, record the readings and the sensory readings are then transmitted. There are three distinct roles played by humans, one is the sensing of the targets, second is the sensing of the operators and third is the acting as a data source.

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Participatory Sensing

- Proposed by Burke et al., 2006
- Distributed sensing by devices carried by humans
- Goal: Not just collect data, but allow common people to access data and share knowledge
- Collected data provides:
 - Quantitative information, e.g., CO₂ level
 - Endorsement of authenticity, e.g., via geo-tagged location & timestamp

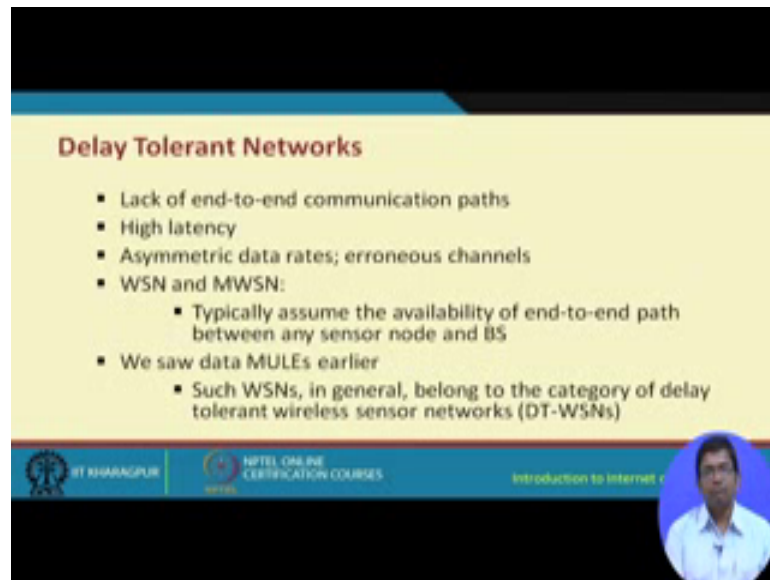
Source: J. Burke, D. Estrin, M. Hansen, A. Parker, N. Ramanathan, S. Reddy, and M. B. Srivastava, "Participatory sensing," in *Workshop on World Sensor Web (WSW'06): Mobile Device-Centric Sensor Networks and Applications*, Boulder, Colorado, USA, 2006, pp. 117–124.

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Now, for human centric sensing there are different challenges, challenges with respect to the energy of the devices, then participants selection, privacy of users and so on. So, I already explain to you the concept of participatory sensing which was proposed by Burke

et al., in 2006 as you can see that it is not a very long or you know old concept. And here basically we are talking about distributed sensing by devices carried by humans and the goal is not just to collect the data, but allow common people to access the data and share the knowledge.

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Delay Tolerant Networks

- Lack of end-to-end communication paths
- High latency
- Asymmetric data rates; erroneous channels
- WSN and MWSN:
 - Typically assume the availability of end-to-end path between any sensor node and BS
- We saw data MULEs earlier
 - Such WSNs, in general, belong to the category of delay tolerant wireless sensor networks (DT-WSNs)

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Delay tolerant networks basically you know from one point to another the sense data will take lot of time to get delivered compared to the regular time. So, with this we come to an end of this series of lectures on sensor networks. We have seen that sensor networks are very much attractive and more importantly sensor network I would think personally to be the most effective most important tool for building internet of things and we have covered the different aspects of sensor networks in detail. There is a separate NPTEL course which is on wireless ad hoc and sensor networks where we discuss about the details of sensor networks in depth.

So, we come to an end of all these lectures on sensor networks for internet of things.