Wireless Sensor Network (BCO056A)

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Unit-I

Topics:-

- Comparison of Wired and Wireless Technologies
- Introduction to WSN
- Characteristics of WSN
- Differences with ad hoc networks Applications
- Challenges
- Sensor Node Architecture

Topics Cont..

Topics:-

- Energy Consumption of Sensor Node
- Network Architecture
- Types of sources and sinks, multiple sinks and sources
- single hop versus multi-hop networks
- design principles of wsn

The Disadvantages of Wired Technology

- **Damage**

  wires can be easily damaged, which is not as large of a concern with wireless technology.

- **Cost**

  The cost of wired technology can be quite expensive when used in large area. In comparison, wireless technology would not require expensive underground cables or any significant damage to building structures.

- **Expansion**

  The scalability of wired technology can be both costly and time consuming. In comparison, wireless networks can be set up relatively cheaply using multiple access points.

The Disadvantages of Wired Technology

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- **Mobility**

The biggest disadvantage of wired technology is that it lacks the mobility that wireless technology provides You are physically limited to the reach of the cable, whereas wireless technology allows users to move great distances freely and without hassle.

The Disadvantages of Wireless Technology

- Data transfer speeds are normally slower with wireless networks than they are with cabled. The speeds can also vary considerably according to your location in relation to the network.
- The general speed of a wireless connection is also usually much slower than a wired one. The connection also gets worse the farther you are from the router, which can be a problem in a large building or space.
- Wireless connections can be obstructed by various items and structures such as walls, hills, environment conditions.
- Wireless networks are generally less secure. Information is also less secure too and can be easier to hack into.

Introduction

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- Wireless Sensor Networks are networks that consists of sensors which are distributed in an ad hoc manner.
- These sensors work with each other to sense some physical phenomenon and then the information gathered is processed to get relevant results.
- Wireless sensor networks consists of protocols and algorithms with self-organizing capabilities.

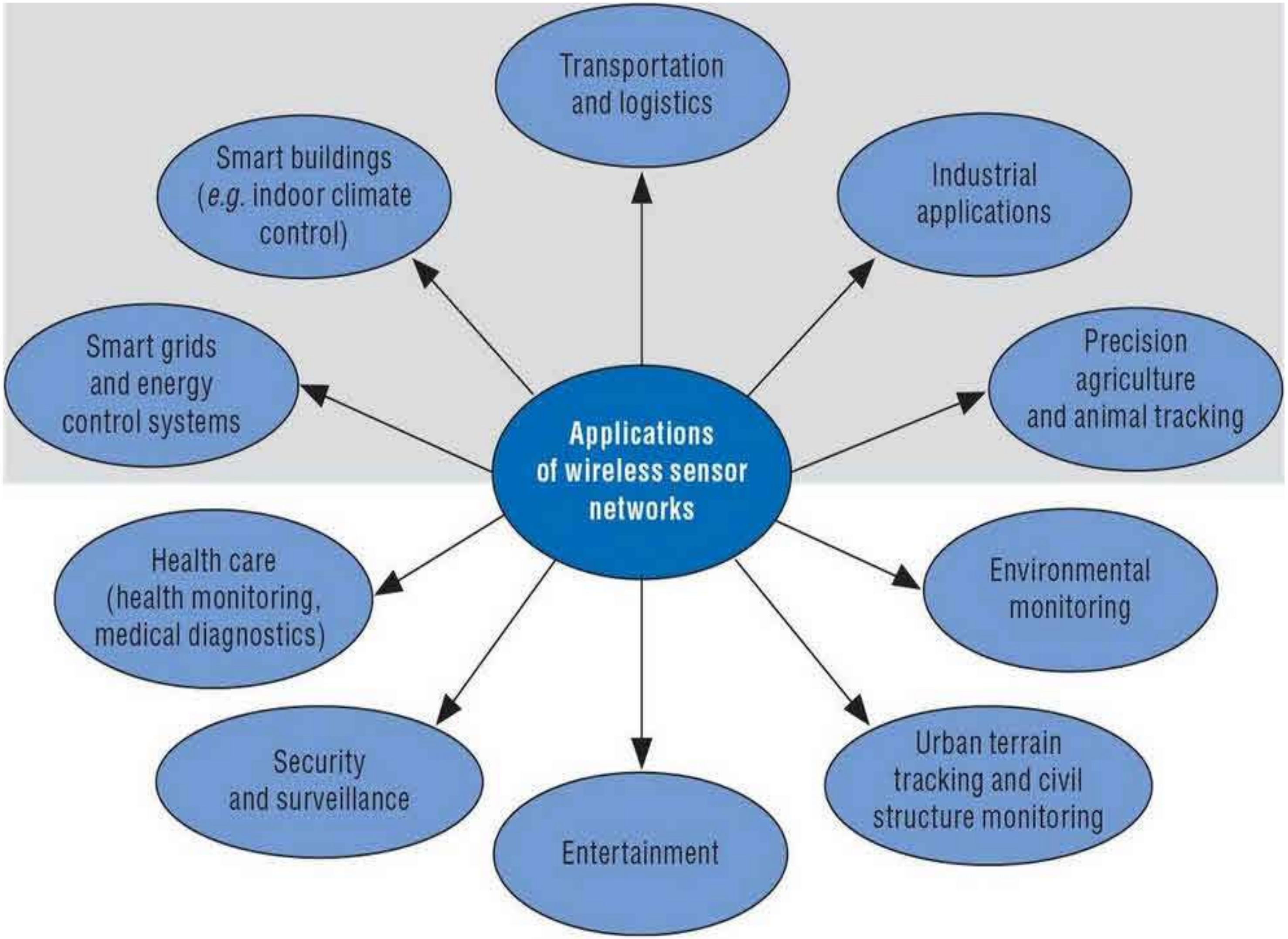
Characteristics of Wireless Sensor Networks

- Wireless Sensor Networks mainly consists of **sensors. Sensors** are -
  - low power
  - limited memory
  - energy constrained due to their small size.

- Wireless networks can also be deployed in **extreme environmental** conditions and may be prone to enemy attacks.

- Although deployed in an ad hoc manner they need to be **self organized** and **self healing** and can face constant reconfiguration.

Applications of Wireless Sensor networks



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Biomedical / Medical

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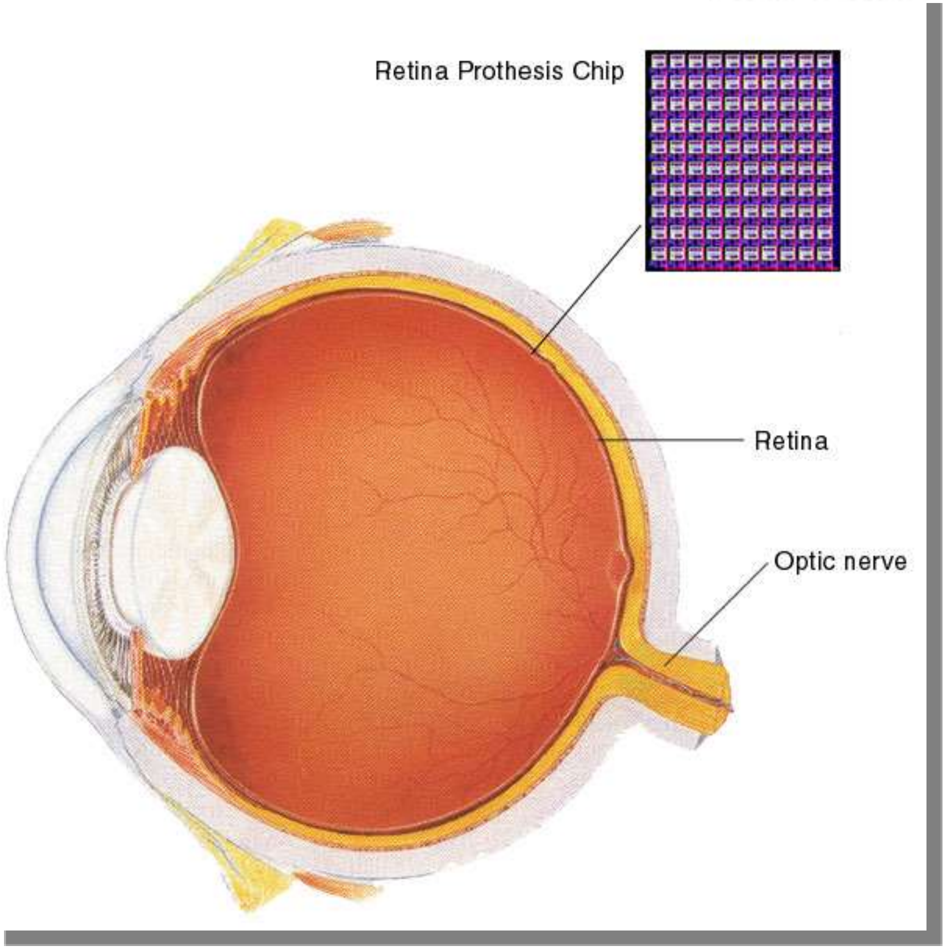
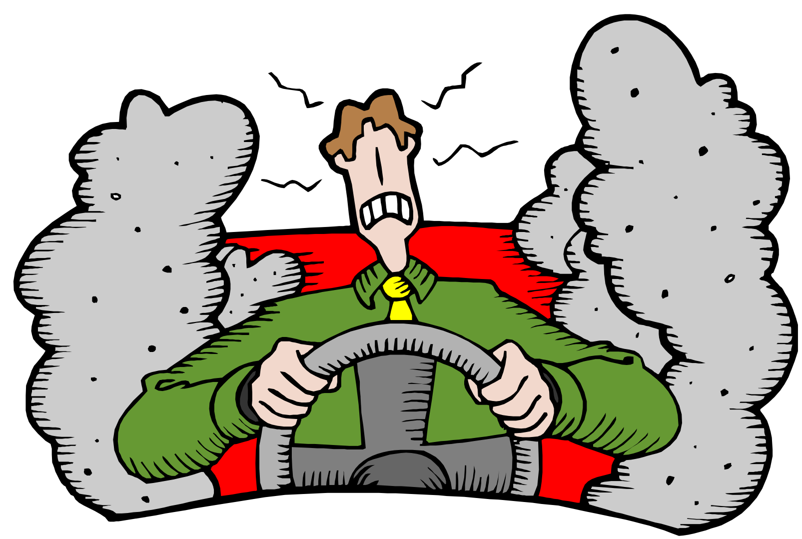
- Health Monitors
  - Glucose
  - Heart rate
  - Cancer detection
- Chronic Diseases
  - Artificial retina
  - Cochlear implants
- Hospital Sensors
  - Monitor vital signs
  - Record anomalies



Traffic Management & Monitoring

- Future cars could use wireless sensors to:
  - Handle Accidents
  - Handle Thefts



✓Sensors embedded in the roads to:

- –Monitor traffic flows
- –Provide real-time route updates

Area monitoring

- Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored.
- A military example is the use of sensors to detect enemy intrusion;
- A civilian example is the geo-fencing of gas or oil pipelines.

Health care monitoring

- There are several types of sensor networks for medical applications:
- Implanted
- Wearable
- and environment-embedded.

Environmental/Earth sensing

There are many applications in monitoring environmental parameters, examples of which are given below. They share the extra challenges of harsh environments and reduced power supply.

- **Air pollution monitoring**]

Wireless sensor networks have been deployed in several cities to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas.

- **Forest fire detection**

A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; with the help of Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

Landslide detection

- A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the impending occurrence of landslides long before it actually happens.

Water quality monitoring

- Water quality monitoring involves analyzing water properties in dams, rivers, lakes and oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.[7]

Natural disaster prevention

- Wireless sensor networks can be effective in preventing adverse consequences of natural disasters, like floods. Wireless nodes have been deployed successfully in rivers, where changes in water levels must be monitored in real time.

Industrial monitoring

Machine health monitoring

- Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality.
- Wireless sensors can be placed in locations difficult or impossible to reach with a wired system, such as rotating machinery and untethered vehicles.

Water/waste water monitoring

Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country's water infrastructure for the benefit of both human and animal. It may be used to protect the wastage of water.

Comparision of WSN & mobile adhoc network(MANET)

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- An ad hoc network is a network that is setup, literally, for a specific purpose, to meet a quickly appearing communication need. The simplest example of an ad hoc network is perhaps a set of computers connected together via cables to form a small network, like a few laptops in a meeting room. In this example, the aspect of *self-configuration* is crucial – the network is expected to work without manual management or configuration.
- Usually, however, the notion of a MANET is associated with wireless communication and specifically *wireless* multihop communication. Examples for such networks are disaster relief operations – firefighters communicate

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- with each other – or networks in difficult locations like large construction sites, where the deployment of wireless infrastructure (access points etc.), let alone cables, is not a feasible option. In such networks, the individual nodes together form a network that relays packets between nodes to extend the reach of a single node, allowing the network to span larger geographical areas than would be possible with direct sender – receiver communication. The two basic challenges in a MANET are the reorganization of the network as nodes move about and handling the problems of the limited reach of wireless communication.

Comparison b/w Wireless and Adhoc N/W

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Feature	Wireless Sensor Network	Ad hoc Network
Number of sensor nodes or motes	Large in quantity	Medium in quantity
Deployment type	Very much dense	Scattered
Rate of failure	More	Very rare
Change in network topology	Frequently	rare
Communication mode	Broadcast	point to point
Battery	Not replaceable	Replaceable
Identifiers (IDs) in the network	No unique IDs	Unique IDs
Centric mode	based on data	based on address
Fusion/Aggregation	Possible	Not suitable
Computation capacity & mem req	Limited	Not limited
Data rate support provided	Lower	Higher
Redundancy	High	Low

Design Challenges

- **Heterogeneity**
  - The devices deployed maybe of various types and need to collaborate with each other.
- **Distributed Processing**
  - The algorithms need to be centralized as the processing is carried out on different nodes.
- **Low Bandwidth Communication**
  - The data should be transferred efficiently between sensors

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- **Large Scale Coordination**
  - The sensors need to coordinate with each other to produce required results.
- **Utilization of Sensors**
  - The sensors should be utilized in a ways that produce the maximum performance and use less energy.
- **Real Time Computation**
  - The computation should be done quickly as new data is always being generated.

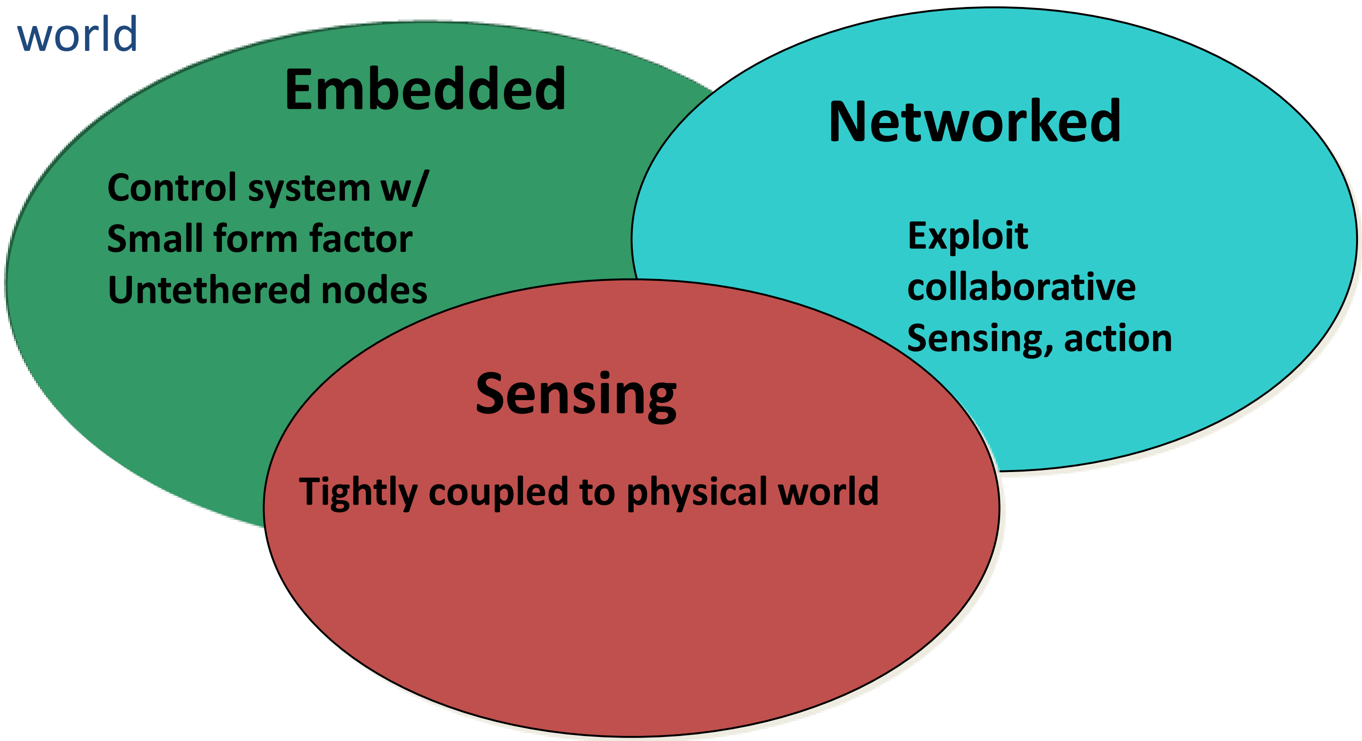
Operational Challenges of Wireless Sensor Networks

- Energy Efficiency
- Limited storage and computation
- Low bandwidth and high error rates
- Errors are common
  - Wireless communication
  - Noisy measurements
  - Node failure are expected
- Scalability to a large number of sensor nodes
- Survivability in harsh environments
- Experiments are time- and space-intensive

Enabling Technologies

Embed numerous distributed devices to monitor and interact with physical world

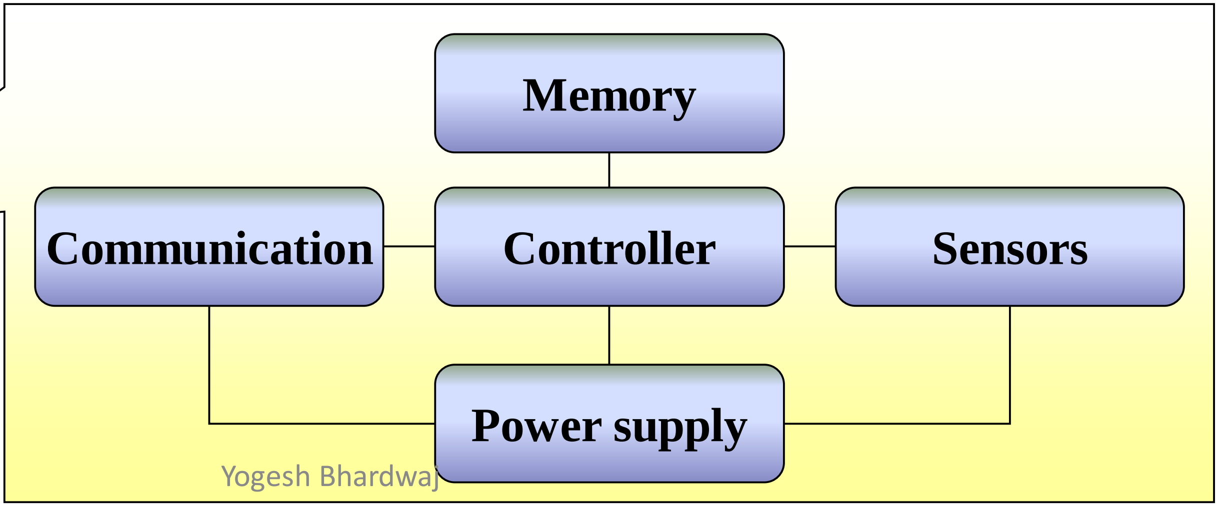
Network devices to coordinate and perform higher-level tasks



Exploit spatially and temporally dense, in situ, sensing and actuation

Main Architecture of Sensor Node

- The main architecture of sensor node includes following components:
  - Controller module
  - Memory module
  - Communication module
  - Sensing modules
  - Power supply module

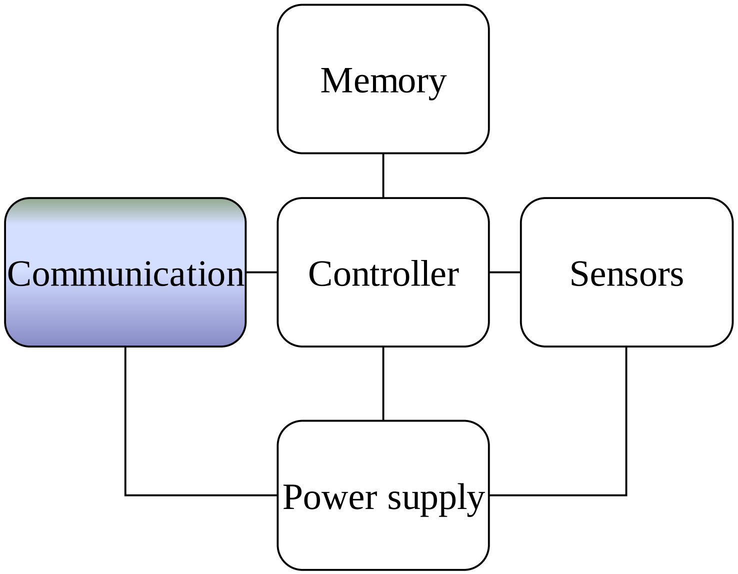


Main Components of a Sensor Node

- A basic sensor node comprises five main components :
- **Controller** A controller to process all the relevant data, of executing arbitrary code.
- **Memory** Some memory to store programs and intermediate data; usually, different types of memory are used for programs and data.
- **Sensors and actuators** The actual interface to the physical world: devices that can observe or control physical parameters of the environment.
- **Communication** Turning nodes into a network requires a device for sending and receiving information over a wireless channel.
- **Power supply** As usually no tethered power supply is available, some form of batteries are necessary to provide energy. Sometimes, some form of recharging by obtaining energy from the environment is available as well (e.g. solar cells).
- For example, both the communication device and the controller should be turned off as long as possible.

Main Components of a Sensor Node: Communication Module

- The communication module of a sensor node is called “Radio Transceiver”
- The essentially tasks of transceiver is to “transmit” and “receive” data between a pair of nodes
- Which characteristics of the transceiver should be consider for sensor nodes?
  - Capabilities
  - Energy characteristics
  - Radio performance



Main Components of a Sensor Node: Communication Module

- Transceiver characteristics
  - Capabilities
    - Interface to upper layers
    - Supported frequency range
      - Typically, somewhere in 433 MHz – 2.4 GHz, ISM band
    - Supported multiple channels?
    - Transmission data rates?
    - Communication range?
  - Energy characteristics
    - Power consumption to send/receive data?
    - Time and energy consumption to change between different states?
    - Supported transmission power control?
    - Power efficiency

Main Components of a Sensor Node: Communication Module

- Radio performance
  - Modulation
    - ASK, FSK, PSK
    - Noise figure: SNR
  - Gain: the ratio of the output signal power to the input power signal
  - Carrier sensing characteristics
  - Frequency stability (Ex: towards temperature changes)
  - Voltage range

Main Components of a Sensor Node: Communication module

- Transceivers typically has several different **states/modes** :
- (i) Active mode:

  Transmit mode
    - Transmitting data

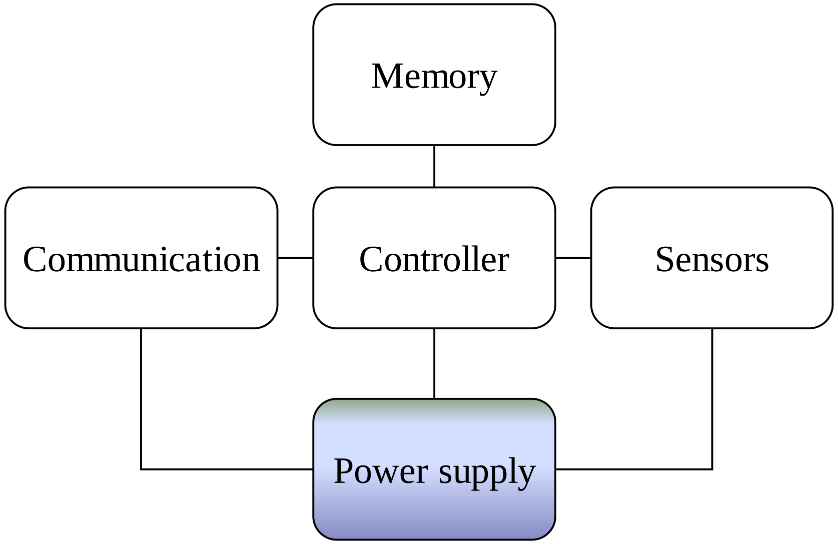
  Receive mode
    - Receiving data

  (ii) Idle mode
    - Ready to receive, but not doing so
    - Some functions in hardware can be switched off
    - Reducing energy consumption a little

  (iii) Sleep mode
    - Significant parts of the transceiver are switched off
    - Not able to immediately receive something
    - Recovery time and startup energy in sleep state can be significant

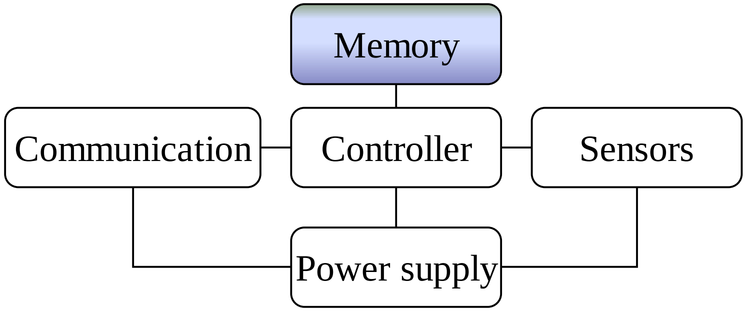
Main Components of a Sensor Node: Power supply module

- Power supply module
  - provides as much energy as possible
  - includes following requirements
    - Longevity (long shelf live)
    - Low self-discharge
    - Voltage stability
    - Smallest cost
    - High capacity/volume
    - Efficient recharging at low current
    - Shorter recharge time
- Options of power supply module
  - Can optional Power generator module – solar cell etc.



Main Components of a Sensor Node: Memory Module

- The memory module of a sensor node has two major tasks
  - To store intermediate sensor readings, packets from other nodes, and so on.
  - To store program code



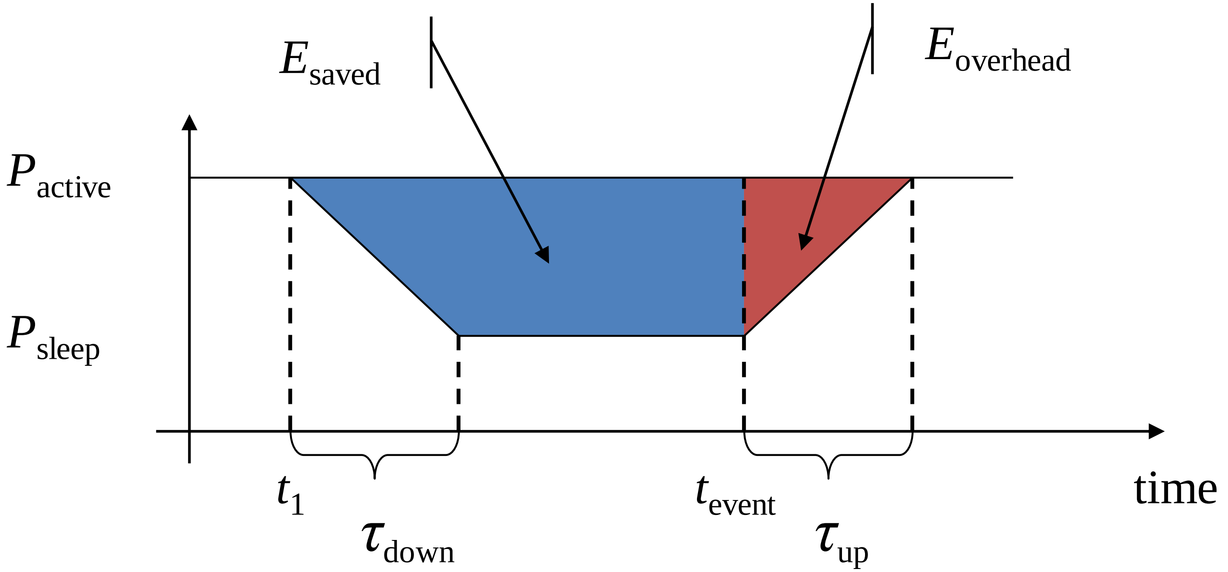
- For the first task
  - Random Access Memory (RAM) is suitable
  - The advantage of RAM is fast
  - The main disadvantage is that it loses its content if power supply is interrupted
- For the second task
  - Read-Only Memory (ROM)
  - Electrically Erasable Programmable Read-Only Memory (EEPROM)
  - Flash memory (allowing data to be erased or written in blocks)
    - can also serve as intermediate storage of data in case RAM is insufficient or when the power supply of RAM should be shut down for some time
    - long read and write access delays
    - high required energy

Some Energy Consumption Figures

- Microcontroller power consumption
  - TI MSP 430 (@ 1 MHz, 3V)
    - Fully operation : 1.2 mW
    - Deepest sleep mode : 0.3 μW
      - ✓ Only wake up by external interrupts (not even timer is running any more)
  - Atmel ATMega128L
    - Operational mode:
      - ✓ Active : 15 mW
      - ✓ Idle : 6 mW
    - Sleep mode : 75 μW

Switching Between Modes

- Simplest idea: Greedily switch to lower mode whenever possible
- Problem: Time and power consumption required to reach higher modes not negligible
  - Introduces overhead
  - Switching only pays off if $E_{saved} > E_{overhead}$
- Example: Event-triggered wake up from sleep mode
- Scheduling problem with uncertainty



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- At time $t1$*, the decision whether or not a component (say, the microcontroller) is to be* put into sleep mode should be taken to reduce power consumption from *Pactive to Psleep. If it remains* active and the next event occurs at time *tevent, then a total energy of*
- *Eactive = Pactive(tevent – t1)*
- has be spent uselessly idling. Putting the component into sleep mode, on the other hand, requires a
- time *τdown until sleep mode has been reached; assume that the average power*
- consumption during this phase is *(Pactive + Psleep)/2. Then, Psleep is consumed until tevent.*

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- *In total,*
- $\tau_{down}(P_{active} + P_{sleep})/2 + (t_{event} - t_1 - \tau_{down})P_{sleep}$ *energy is required in sleep mode as opposed to*

$(t_{event} - t_1)P_{active}$ *when remaining active.*

The energy saving is thus

- $E_{saved} = (t_{event} - t_1)P_{active} - (\tau_{down}(P_{active} + P_{sleep})/2 + (t_{event} - t_1 - \tau_{down})P_{sleep})$.

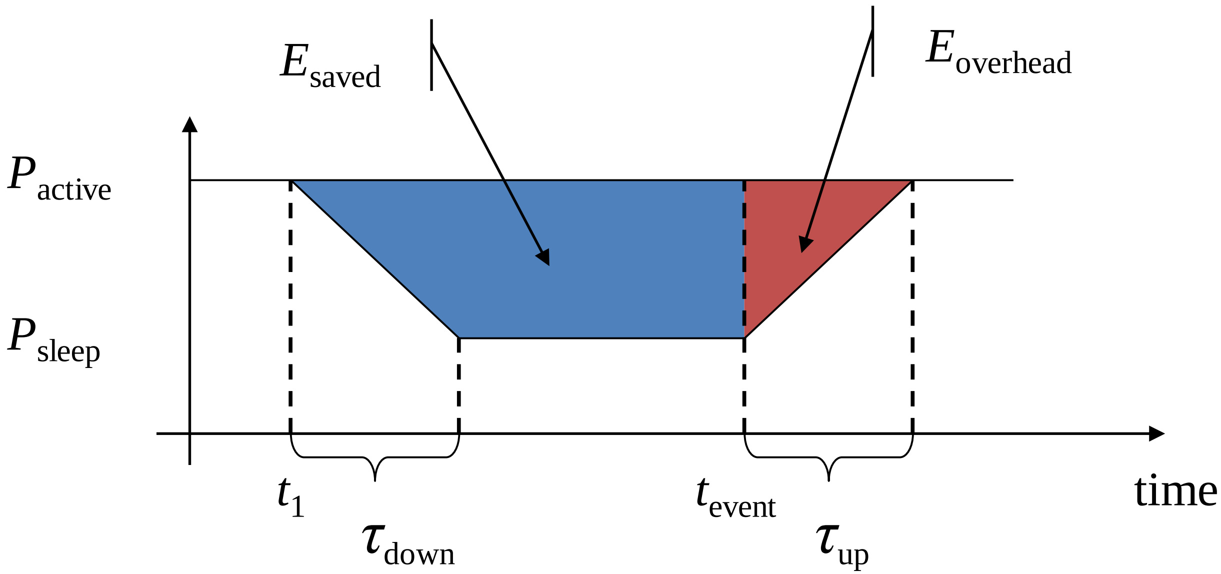
Once the event to be processed occurs, however, an additional overhead of

$E_{overhead} = \tau_{up}(P_{active} + P_{sleep})/2$

Switching Between Modes

- $E_{saved} = (t_{event} - t_1) \times P_{active} - (\tau_{down} \times (P_{active} + P_{sleep}) / 2 +$
  $(t_{event} - t_1 - \tau_{down}) \times P_{sleep})$

- $E_{overhead} = \tau_{up} \times (P_{active} + P_{sleep}) / 2$



Clearly, switching to a sleep mode is only beneficial if $E_{overhead} < E_{saved}$ or, equivalently, if the time to the next event is sufficiently large:

$$(t_{event} - t_1) > \frac{1}{2}\left(\tau_{down} + \frac{P_{active} + P_{sleep}}{P_{active} - P_{sleep}}\tau_{up}\right).$$

Computation vs. Communication Energy Cost

- Tradeoff ?
  - It's not possible to directly compare computation/communication energy cost
  - Energy ratio of "sending one bit" vs. "computing one instruction"
  - Communication (send & receive) 1 KB ≒ Computing 3,000,000 (3 million) instructions [10]
- Hence
  - Try to compute instead of communication whenever possible

Energy scavenging

- Some of the unconventional energy stores described above – fuel cells, micro heat engines, radioactivity – convert energy from some stored, secondary form into electricity in a less direct and easy to use way than a normal battery would do. The entire energy supply is stored on the node itself – once the fuel supply is exhausted, the node fails. To ensure truly long-lasting nodes and wireless sensor networks, such a limited energy store is unacceptable. Rather, energy from a node's environment must be tapped into and made available to the node – **energy scavenging should take place. Several approaches exist :**
- **Photovoltaics :**

  The well-known solar cells can be used to power sensor nodes. The available power depends on whether nodes are used outdoors or indoors. Hence, solar cells are usually used to recharge secondary batteries.

- **Temperature gradients :**

  Differences in temperature can be directly converted to electrical energy. Theoretically, even small difference of, for example, 5 K can produce considerable power, thermoelectric generators are commonly considered

- **Vibrations**

  One almost pervasive form of mechanical energy is vibrations: walls or windows in buildings are resonating with cars or trucks passing in the streets, machinery often has lowfrequency vibrations, ventilations also cause it, and so on. The available energy depends on both amplitude and frequency of the vibration. Converting vibrations to electrical energy can be undertaken by various means, based on electromagnetic, electrostatic principles.

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- **Pressure variations**
- Somewhat to vibrations, a variation of pressure can also be used as a power source.
- **Flow of air/liquid:**
- Another often-used power source is the flow of air or liquid in wind mills or turbines. The challenge here is again the miniaturization,

Dynamic voltage scaling

- To use a continuous notion of functionality/power adaptation by adapting the speed with which a controller operates. The idea is to choose the best possible speed with which to compute a task that has to be completed by a given deadline. One obvious solution is to switch the controller in full operation mode, compute the task at highest speed, and go back to a sleep mode as quickly as possible.

- The alternative approach is to compute the task only at the speed that is required to finish it before the deadline. The rationale is the fact that a controller running at lower speed, that is, lower Energy consumption of sensor nodes clock rates, consumes less power than at full speed. This is due to the fact that the supply voltage can be reduced at lower clock rates while still guaranteeing correct operation. This technique is called **Dynamic Voltage Scaling (DVS)** .

Single-hop vs. Multi-hop Networks

- One common problem: limited range of wireless communication
  - Limited transmission power
  - Path loss
  - Obstacles
- Solution: multi-hop networks
  - Send packets to an intermediate node
  - Intermediate node forwards packet to its destination
  - **Store-and-forward** multi-hop network
- Basic technique applies to both WSN and MANET

Challenges for WSNs

- Handling such a wide range of application types will hardly be possible with any single realization of a WSN. Nonetheless, certain common traits appear, especially with respect to the characteristics
- and the required mechanisms of such systems. Realizing these characteristics with new mechanisms is the major challenge of the vision of wireless sensor networks.

(i) Characteristic requirements

(ii) Required mechanisms

Characteristic requirements

The following characteristics are shared among most of the application examples discussed above:

- **Type of service :** it moves bits from one place to another. but a WSN is expected to provide meaningful information and/or actions about a given task:
- **Quality of Service :** In some cases, only occasional delivery of a packet can be more than enough; in other cases, very high reliability requirements exist. In yet other cases, delay *is important when* actuators are to be controlled in a real-time fashion by the sensor network. The packet delivery ratio is an insufficient metric; what is relevant is the amount and quality of information

- **Fault tolerance: Since nodes may run out of energy or might be damaged, or since the wireless** communication between two nodes can be permanently interrupted, it is important that the

WSN as a whole is able to tolerate such faults. To tolerate node failure, redundant deployment is necessary, using more nodes than would be strictly necessary if all nodes functioned correctly.

- **Lifetime: In many scenarios, nodes will have to rely on a limited supply of energy (using batteries).** Replacing these energy sources in the field is usually not practicable, and simultaneously,a WSN must operate at least for a given mission time or as long as possible.

- **Evidently, an energy-efficient** way of operation of the WSN is necessary. As an alternative or supplement to energy supplies, a limited power source (via power sources like solar cells, for example) might also be available on a sensor node. Typically, these sources are not powerful enough to ensure continuous operation but can provide some recharging of batteries. Under such conditions, the lifetime of the network should ideally be infinite.
- **Scalability :**Since a WSN might include a large number of nodes, the employed architectures and protocols must be able scale to these numbers.
- **Wide range of densities:** In a WSN, the number of nodes per unit area – the *density of the network* can vary considerably. Different applications will have very different node densities. Even within a given application, density can vary over time and space because nodes fail or move.

- **Programmability :** Not only will it be necessary for the nodes to process information, but also they will have to react flexibly on changes in their tasks. These nodes should be programmable, and their programming must be changeable during operation when new tasks become important. A fixed way of information processing is insufficient.
- **Maintainability:** As both the environment of a WSN and the WSN itself change (depleted batteries, failing nodes, new tasks), the system has to adapt. It has to monitor its own health and status to change operational parameters or to choose different trade-offs. In this sense, the network has to maintain itself; it could also be able to interact with external maintenance mechanisms .

Required mechanisms

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- To realize these requirements, innovative mechanisms for a communication network have to be found, as well as new architectures, and protocol concepts. A particular challenge here is the need to find mechanisms that are sufficiently specific to the given application to support the specific quality of service, lifetime, and maintainability requirements . Some of the mechanisms that will form typical parts of WSNs are:
- **Multihop wireless communication :**
- While wireless communication will be a core technique, a direct communication between a sender and a receiver is faced with limitations. In particular, communication over long distances is only possible using prohibitively high transmission power. The use of intermediate nodes as relays can reduce the total required power. Hence,
- for many forms of WSNs, *multihop communication will be a necessary ingredient.*

- **Auto-configuration :** A WSN will have to configure most of its operational parameters autonomously, independent of external configuration . As an example, nodes should be able to determine their geographical positions only using other nodes of the network – so called “self-location”. Also, the network should be able to tolerate failing nodes (because of a depleted battery, for example) or to integrate new nodes (because of incremental deployment after failure).
- **Collaboration and in-network processing:** In some applications several sensors have to collaborate to detect an event and only the joint data of many sensors provides enough information. Information is processed in the network itself in various forms to achieve this collaboration, as opposed to having every node transmit all data to an external network and process it “at the edge” of the network. An example is to determine the highest or the average temperature within an area and to report that value to a sink. To solve such tasks efficiently, readings from individual sensors can be *aggregated as they propagate through the network, reducing the amount of data to* be transmitted and hence improving the energy efficiency.

- **Data centric :**In general network the identity of nodes is address-centric. In a WSN, where nodes are typically deployed redundantly to protect against node failures , the identity of the particular node supplying data becomes irrelevant. What is important are the answers and values themselves, not which node has provided them. Hence, switching from an address-centric paradigm to a **data-centric** paradigm in designing architecture and communication protocols is promising. An example for such a data-centric interaction would be to request the average temperature in a given location area, as opposed to requiring temperature readings from individual nodes. Such a data-centric paradigm is used in WSN.

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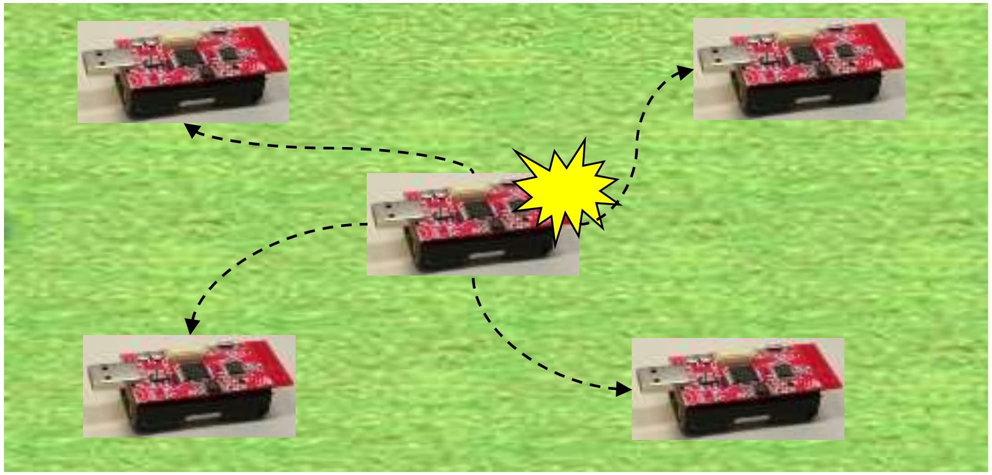
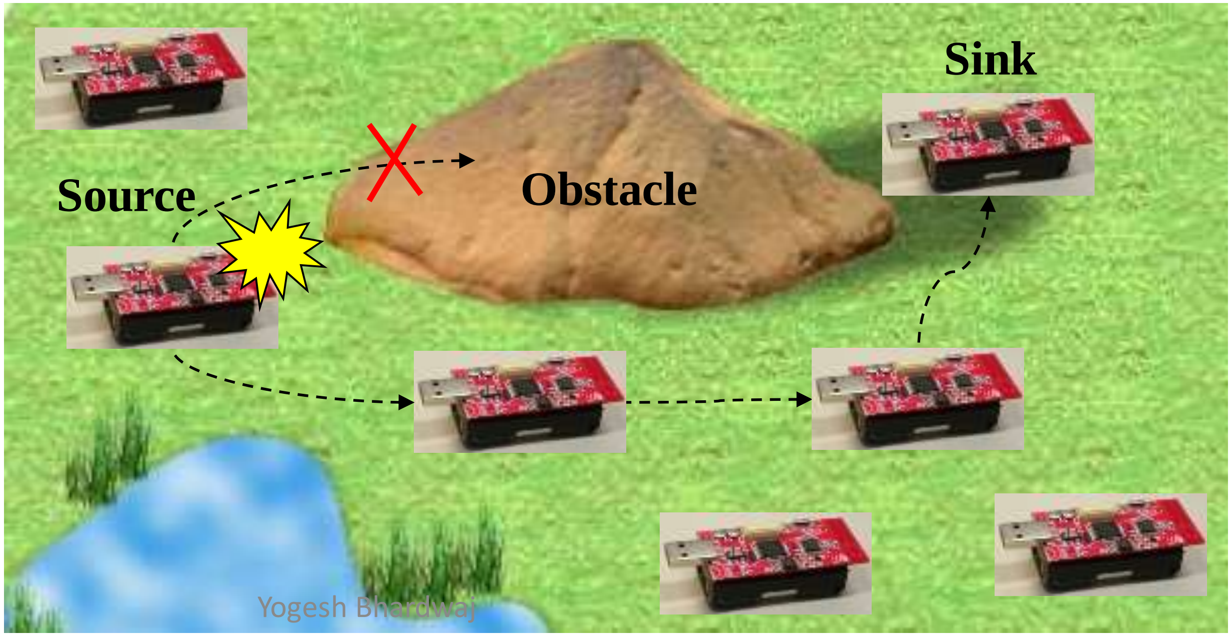
- **Locality:** The principle of locality will have to ensure, scalability. Nodes, which are very limited in resources like memory, should attempt to limit the state that they accumulate to only information about their direct neighbors. The hope is that this will allow the network to scale to large numbers of nodes without having to rely on powerful processing at each single node.
- **Energy-efficient operation :** To support long lifetimes, energy-efficient operation is a key technique.

Single-hop vs. Multi-hop Networks

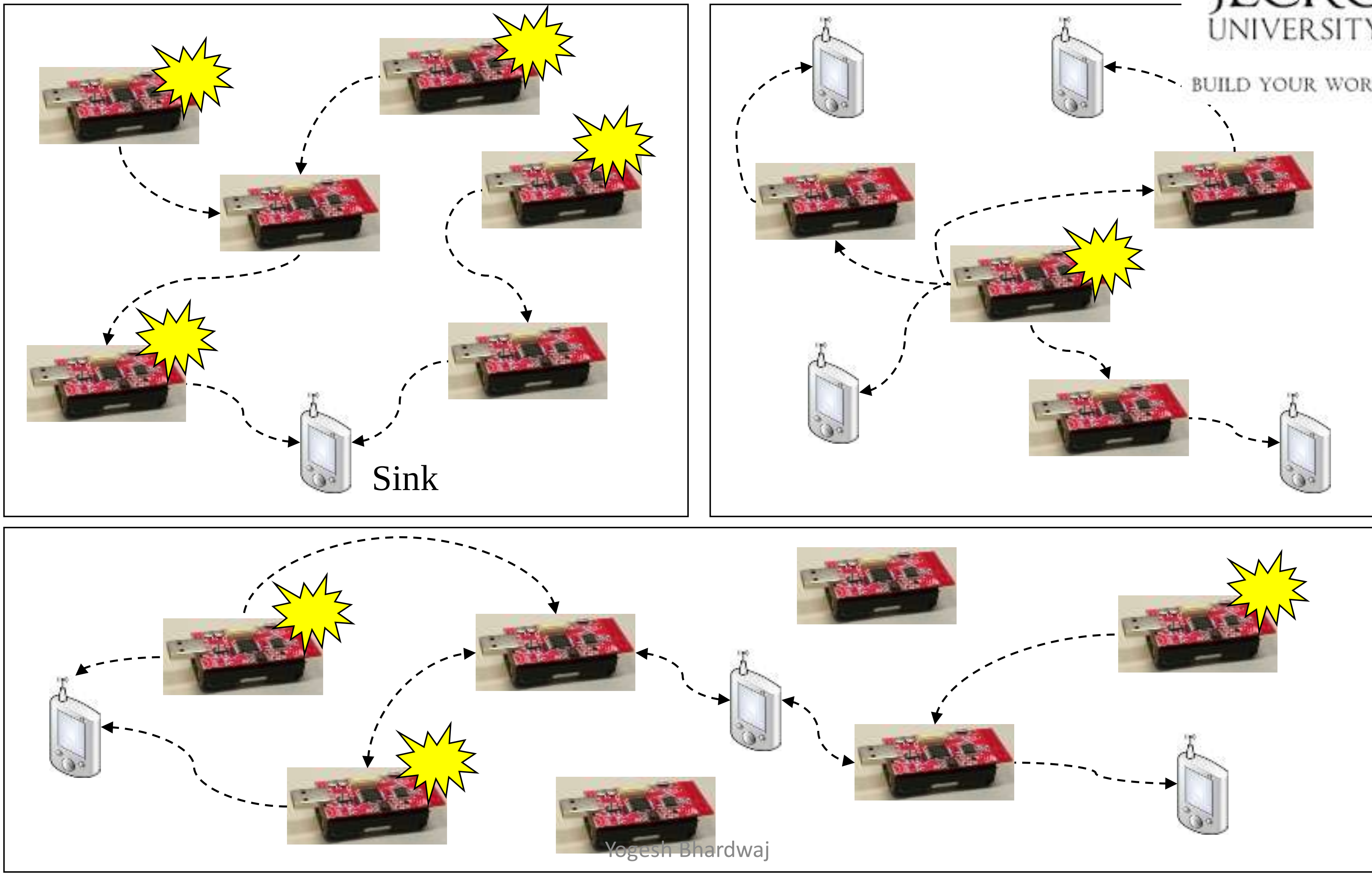


Single-hop networks

Multi-hop networks



Multiple Sinks, Multiple Sources WSN

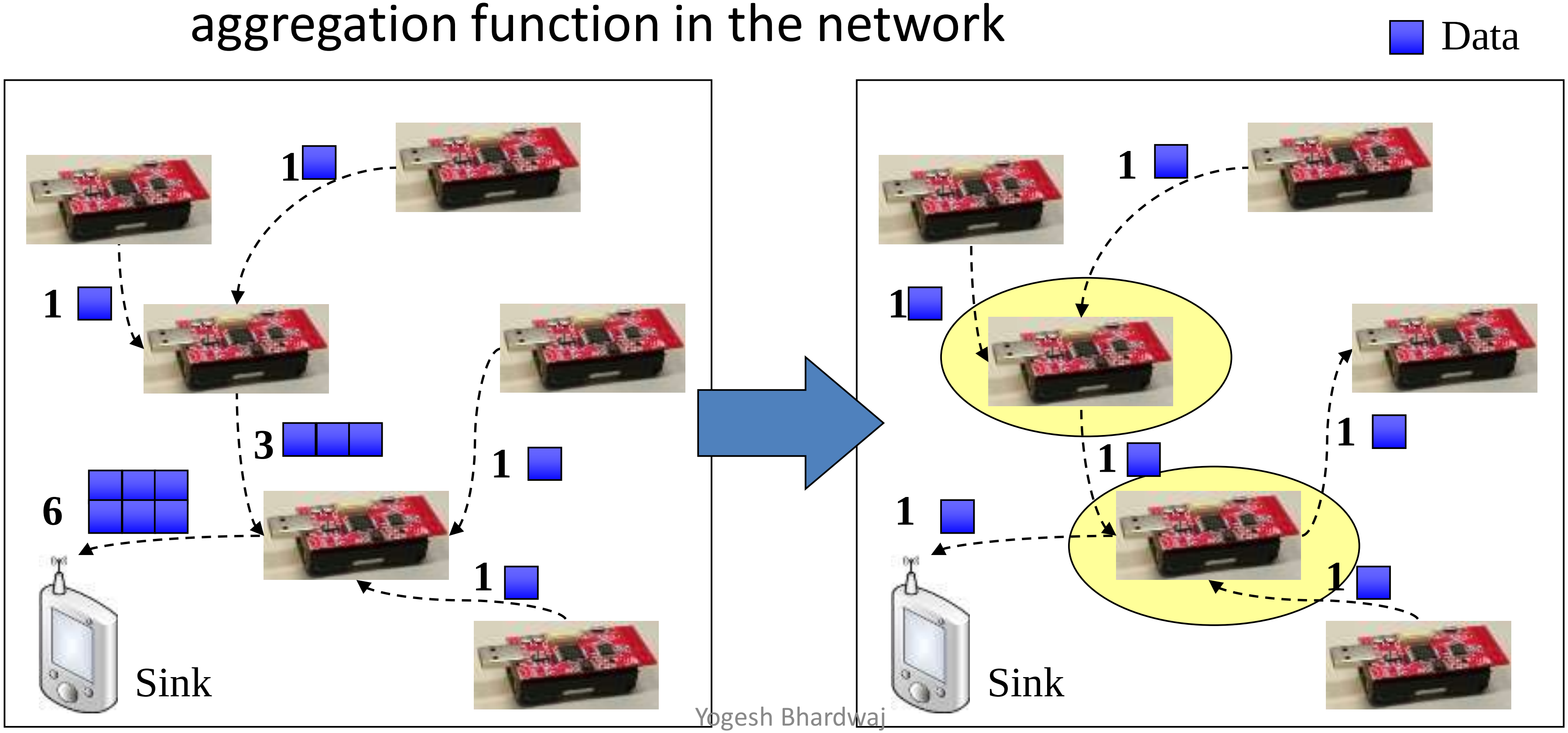


Design principles for WSNs

- **Distributed organization**
- **Innetwork processing**
- **Adaptive fidelity and accuracy**
- **Data Centricity**
- **Energy-efficient operation**

In-network Processing

- Processing Aggregation example
  - The simplest in-network processing technique
  - Reduce number of transmitted bits/packets by applying an aggregation function in the network



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