CSE 425: Internet of Things

Dept. of CSE, BUBT| Summer 2021

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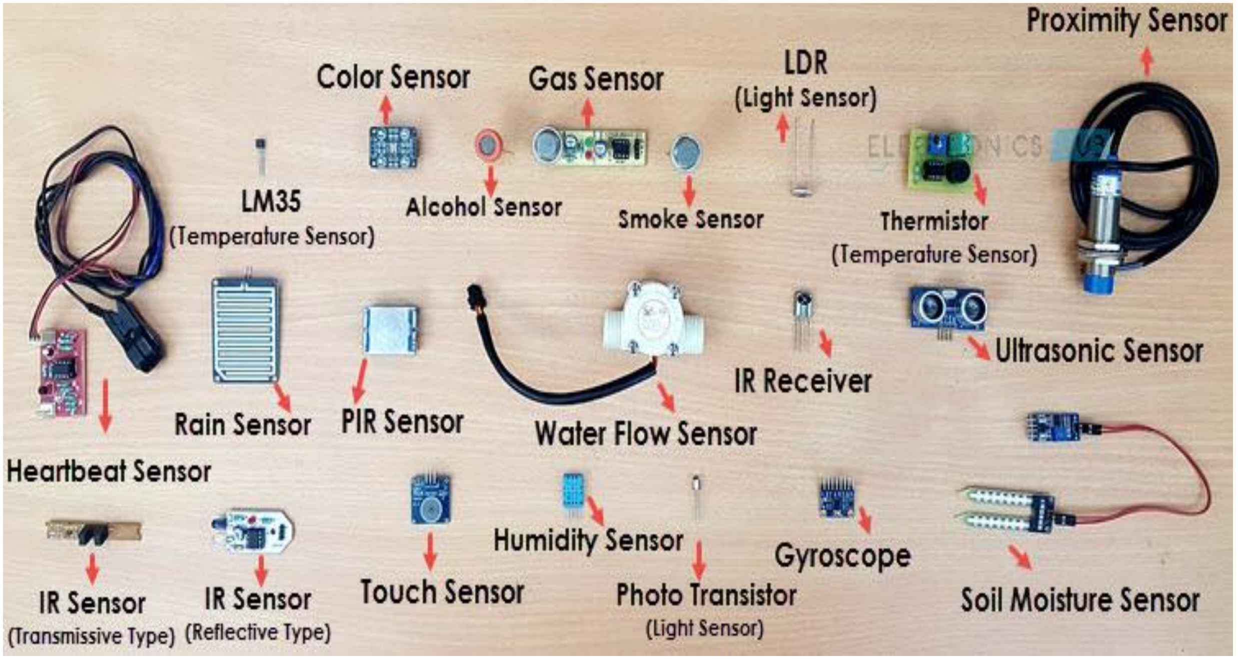
Smart Objects: The “Things” in IoT

Courtesy: David Hanes and Co.,Many Websites, and Google

Sensors, Actuators, and Smart Objects

- Sensors are *fundamental building blocks* of IoT networks. In fact, they are the foundational elements found in smart objects—the “things” in the Internet of Things.
- Smart objects are any physical objects that contain embedded technology to *sense and/or interact* with their environment in a meaningful way by being interconnected and *enabling communication* among themselves or an external agent.
- A sensor *measures some physical quantity and converts that measurement reading into a digital representation*. *That digital representation is typically passed to another device for transformation into useful data that can be consumed by intelligent devices or humans.*
- Sensors are not limited to human-like.



Groupings of Sensors

Active or passive: Sensors can be categorized based on whether they produce an energy output and typically require an external power supply (active) or whether they simply receive energy and typically require no external power supply (passive).

Invasive or non-invasive: Sensors can be categorized based on whether a sensor is part of the environment it is measuring (invasive) or external to it (non-invasive).

Contact or no-contact: Sensors can be categorized based on whether they require physical contact with what they are measuring (contact) or not (no-contact).

Absolute or relative: Sensors can be categorized based on whether they measure on an absolute scale (absolute) or based on a difference with a fixed or variable reference value (relative).

Area of application: Sensors can be categorized based on the specific industry or vertical where they are being used.

How sensors measure: Sensors can be categorized based on the physical mechanism used to measure sensory input (for example, thermoelectric, electrochemical, piezoresistive, optic, electric, fluid mechanic, photoelastic).

What sensors measure: Sensors can be categorized based on their applications or what physical variables they measure.

Types of Sensors

Sensor Types	Description	Examples
Position	A position sensor measures the position of an object; the position measurement can be either in absolute terms (absolute position sensor) or in relative terms (displacement sensor). Position sensors can be linear, angular, or multi-axis.	Potentiometer, proximity sensor
Occupancy and motion	Occupancy sensors detect the presence of people and animals in a surveillance area, while motion sensors detect movement of people and objects. The difference between the two is that occupancy sensors generate a signal even when a person is stationary, whereas motion sensors do not.	Electric eye, radar
Velocity and acceleration	Velocity (speed of motion) sensors may be linear or angular, indicating how fast an object moves along a straight line or how fast it rotates. Acceleration sensors measure changes in velocity.	Accelerometer, gyroscope

Types of Sensors

Sensor Types	Description	Examples
Force	Force sensors detect whether a physical force is applied and whether the magnitude of force is beyond a threshold.	Force gauge, viscometer, tactile sensor (touch sensor)
Pressure	Pressure sensors are related to force sensors, measuring force applied by liquids or gases. Pressure is measured in terms of force per unit area.	Barometer, Bourdon gauge, piezometer
Acoustic	Acoustic sensors measure sound levels and convert that information into digital or analog data signals.	Microphone, geophone, hydrophone
Flow	Flow sensors detect the rate of fluid flow. They measure the volume (mass flow) or rate (flow velocity) of fluid that has passed through a system in a given period of time.	Anemometer, mass flow sensor, water meter

Types of Sensors

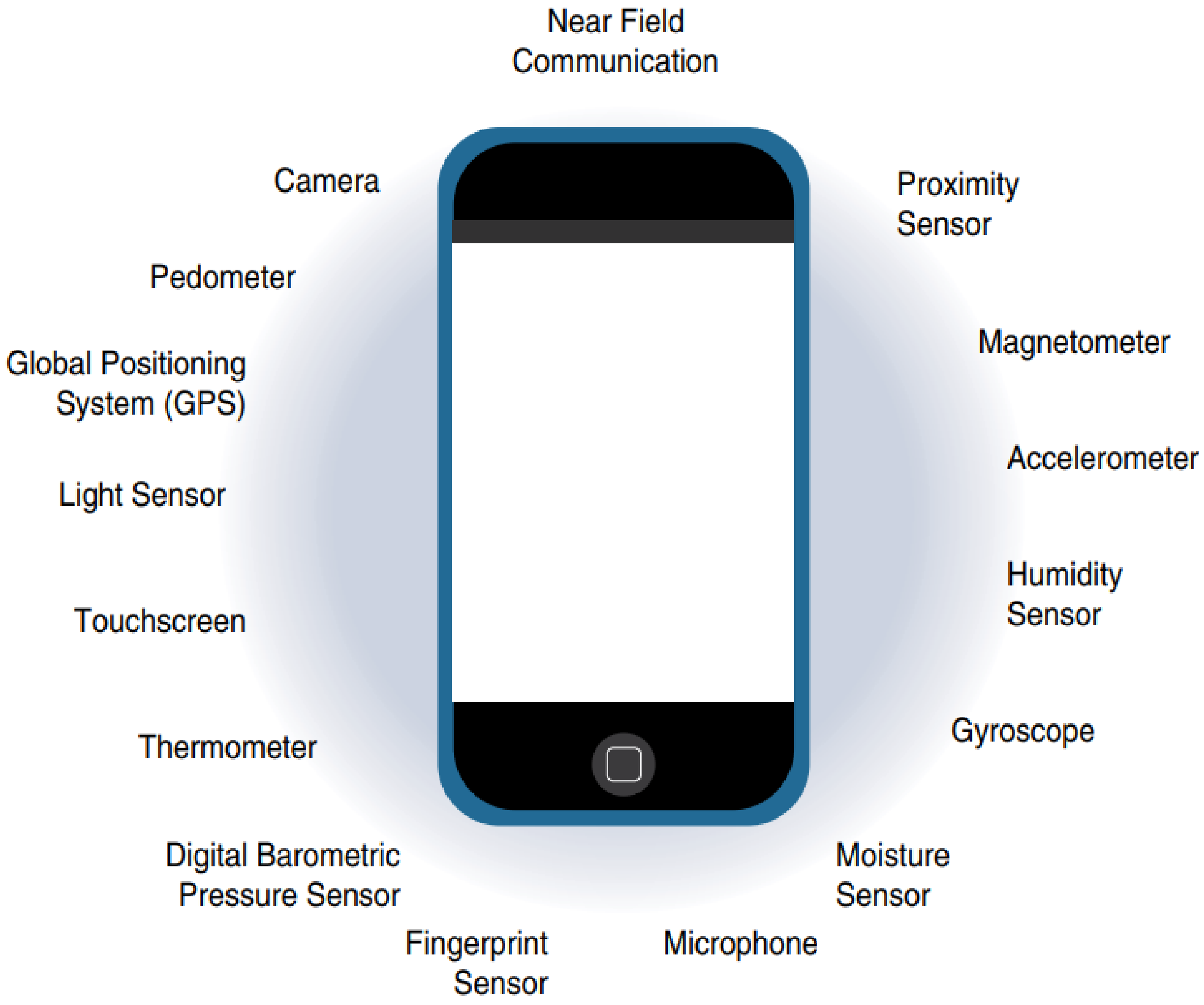
Sensor Types	Description	Examples
Humidity	Humidity sensors detect humidity (amount of water vapor) in the air or a mass. Humidity levels can be measured in various ways: absolute humidity, relative humidity, mass ratio, and so on.	Hygrometer, humistor, soil moisture sensor
Light	Light sensors detect the presence of light (visible or invisible).	Infrared sensor, photodetector, flame detector
Radiation	Radiation sensors detect radiation in the environment. Radiation can be sensed by scintillating or ionization detection.	Geiger-Müller counter, scintillator, neutron detector
Temperature	Temperature sensors measure the amount of heat or cold that is present in a system. They can be broadly of two types: contact and non-contact.	Thermometer, calorimeter, temperature gauge

Types of Sensors

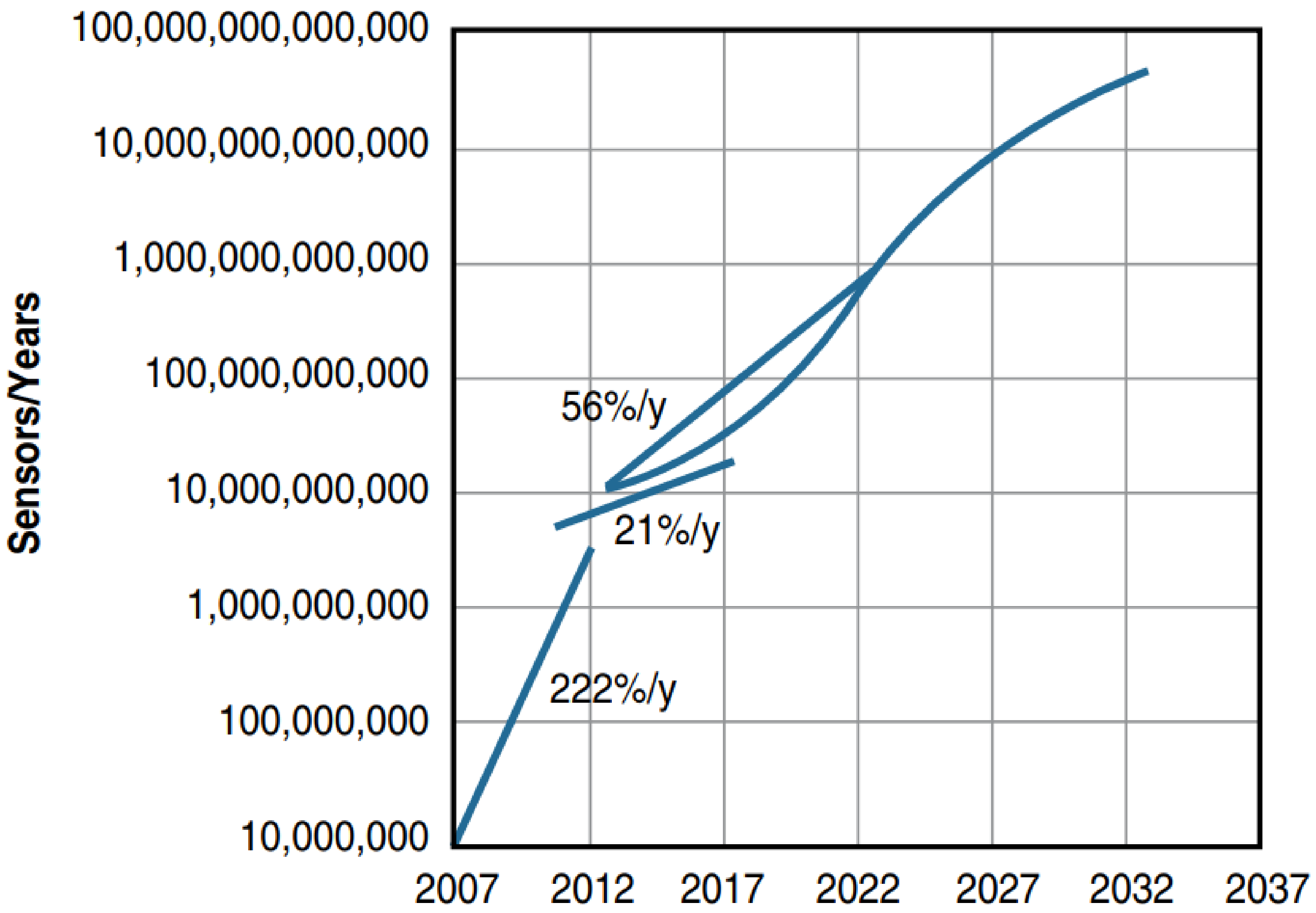
Sensor Types	Description	Examples
Chemical	Chemical sensors measure the concentration of chemicals in a system. When subjected to a mix of chemicals, chemical sensors are typically selective for a target type of chemical (for example, a CO_2 sensor senses only carbon dioxide).	Breathalyzer, olfactometer, smoke detector
Biosensors	Biosensors detect various biological elements, such as organisms, tissues, cells, enzymes, antibodies, and nucleic acid.	Blood glucose biosensor, pulse oximetry, electrocardiograph

Discussion: Assume an IoT based system and find the importance of different sensor in that system.

Growth and Predictions in the Number of Sensors

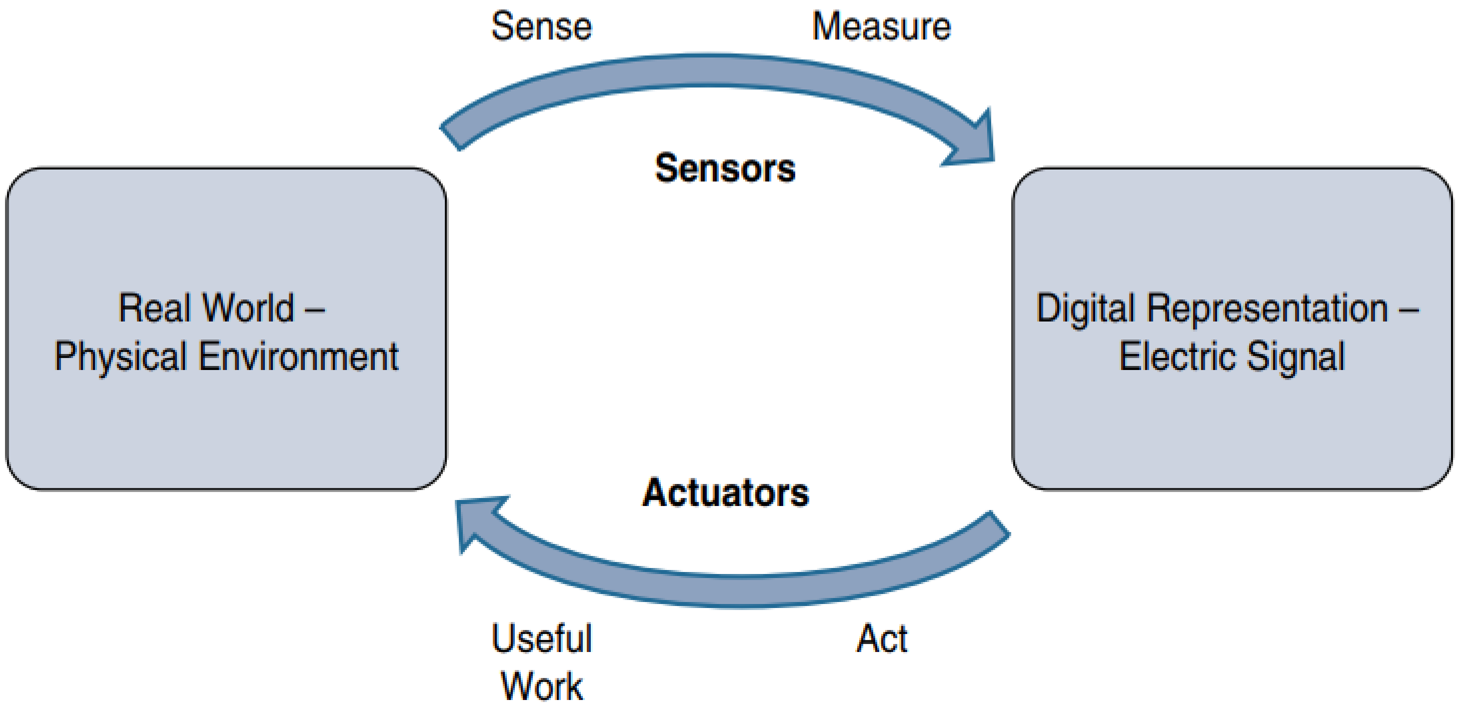


Sensors in a Smart Phone

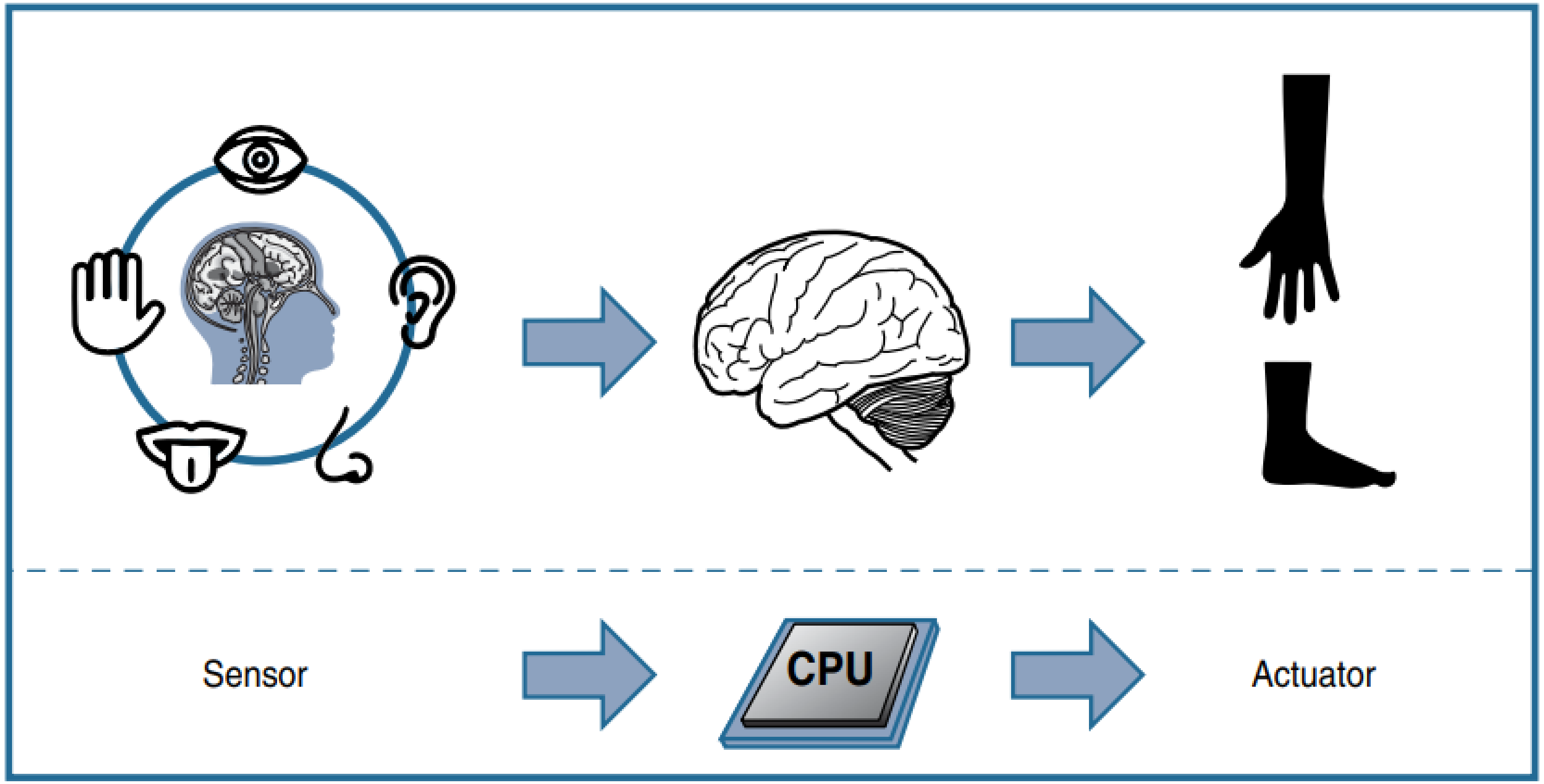


Actuators

- Actuators receive some type of control signal (commonly an electric signal or digital command) that triggers a physical effect, usually some type of motion, force, and so on.
- Sensors provide the information, actuators provide the action.
- Interaction between sensor and actuator are as following figure



Comparison of Sensor and Actuator Functionality with Humans



Classification of Actuators

Type of motion: Actuators can be classified based on the type of motion they produce (for example, linear, rotary, one/two/three-axes).

Power: Actuators can be classified based on their power output (for example, high power, low power, micro power)

Binary or continuous: Actuators can be classified based on the number of stable-state outputs.

Area of application: Actuators can be classified based on the specific industry or vertical where they are used.

Type of energy: Actuators can be classified based on their energy type.

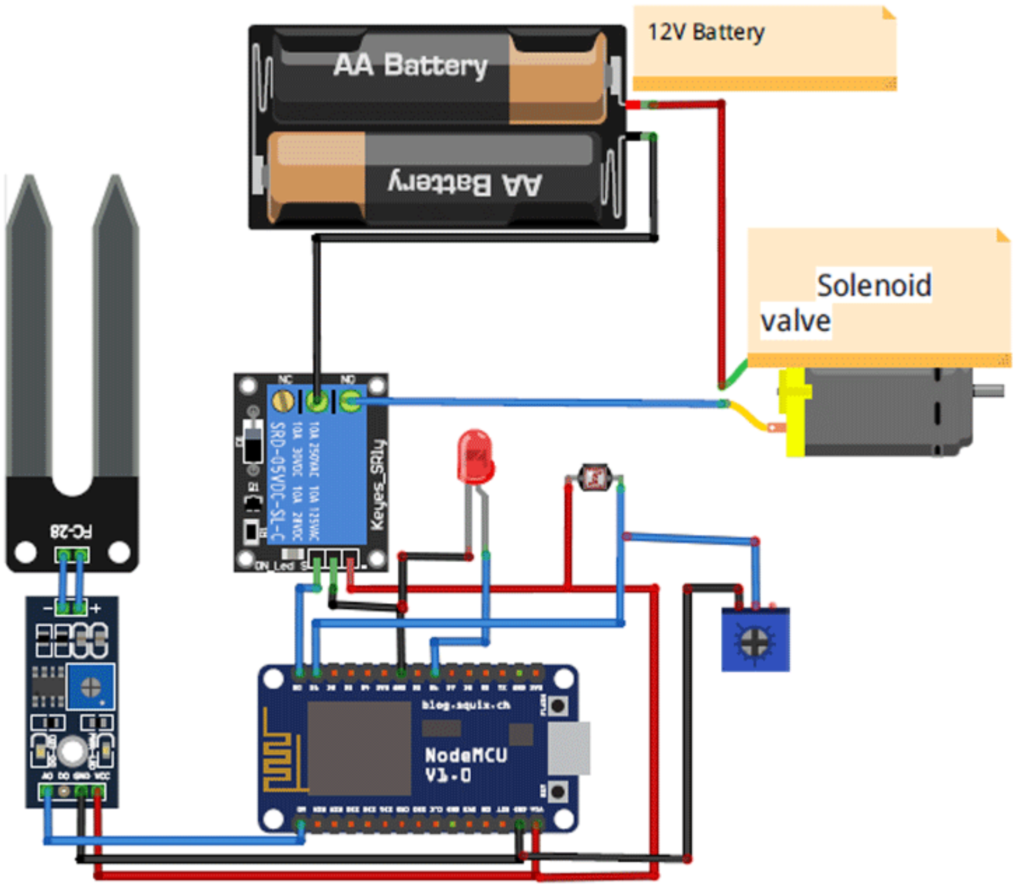
Actuator Classification by Energy Type

Type	Examples
Mechanical actuators	Lever, screw jack, hand crank
Electrical actuators	Thyristor, biopolar transistor, diode
Electromechanical actuators	AC motor, DC motor, step motor
Electromagnetic actuators	Electromagnet, linear solenoid
Hydraulic and pneumatic actuators	Hydraulic cylinder, pneumatic cylinder, piston, pressure control valves, air motors
Smart material actuators (includes thermal and magnetic actuators)	Shape memory alloy (SMA), ion exchange fluid, magnetorestrictive material, bimetallic strip, piezoelectric bimorph
Micro- and nanoactuators	Electrostatic motor, microvalve, comb drive

Micro-Electro-Mechanical Systems (MEMS)

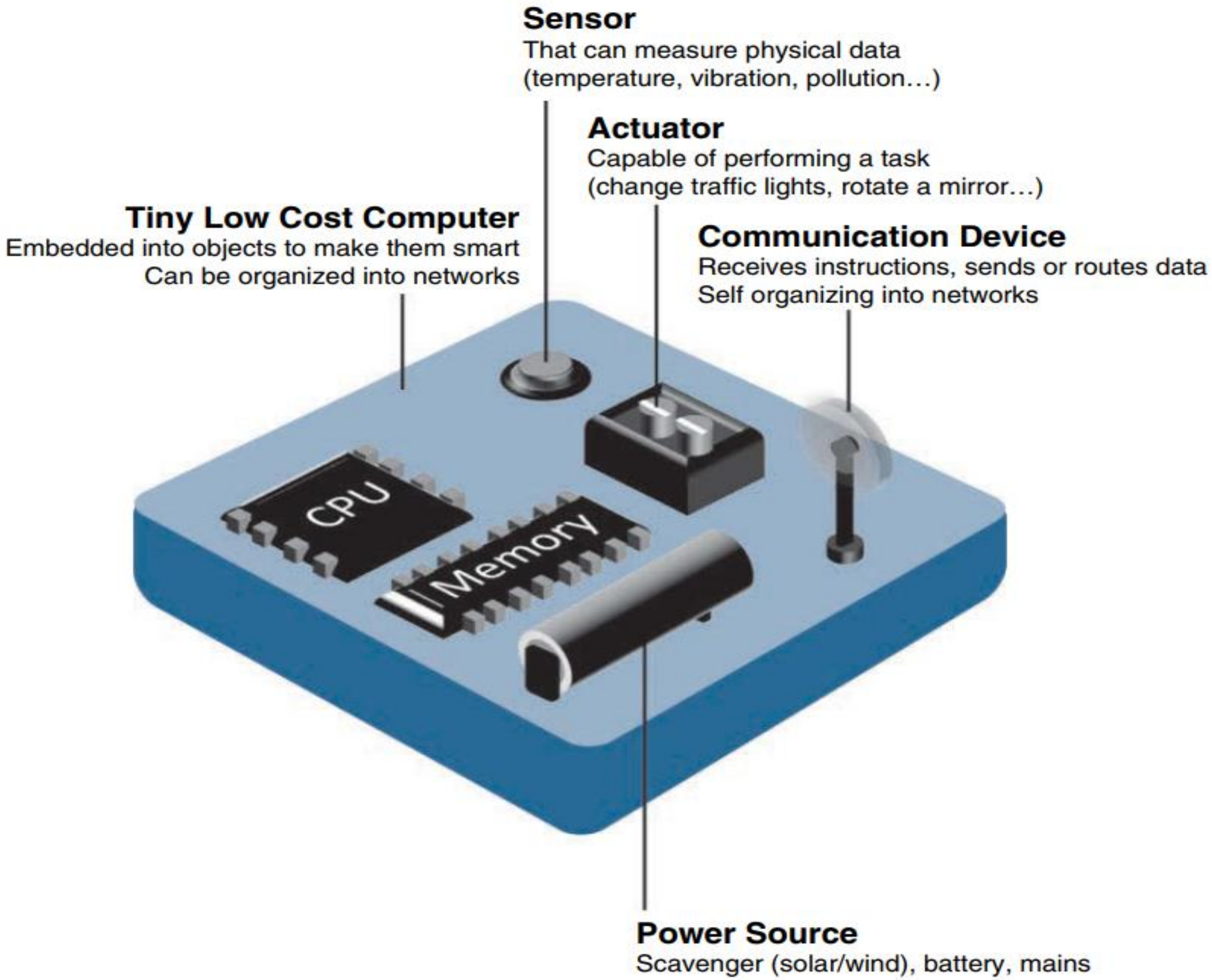
- Micro-electro-mechanical systems (MEMS), sometimes simply referred to as micro-machines, can integrate and combine electric and mechanical elements, such as sensors and actuators, on a very small (millimeter or less) scale.
- Smart phones use MEMS technologies.

Smart Objects



- If a sensor is a standalone device that simply measures the humidity of the soil, it is interesting and useful, but it isn’t revolutionary. If that same sensor is connected as part of an intelligent network that is able to coordinate intelligently with actuators to trigger irrigation systems as needed based on those sensor readings, we have something far more powerful.
- Extending that even further, imagine that the coordinated sensor/ actuator set is intelligently interconnected with other sensor/actuator sets to further coordinate fertilization, pest control, and so on—and even communicate with an intelligent backend to calculate crop yield potential.

Smart Objects: Definition



Smart Objects: Definition

A smart object is a device that has, at a minimum, the following four defining characteristics:

Processing unit: a microcontroller because of its small form factor, flexibility, programming simplicity, ubiquity, low power consumption, and low cost.

Sensor(s) and/or actuator(s): A smart object is capable of interacting with the physical world through sensors and actuators.

Communication device: The communication unit is responsible for connecting a smart object with other smart objects and the outside world (via the network).

Power source: Smart objects have components that need to be powered. Interestingly, the most significant power consumption usually comes from the communication unit of a smart object. Typically, smart objects are limited in power, are deployed for a very long time, and are not easily accessible. This combination, especially when the smart object relies on battery power, implies that power efficiency, judicious power management, sleep modes, ultra-low power consumption hardware, and so on are critical design elements

Trends in Smart Objects

Size is decreasing: As discussed earlier, in reference to MEMS, there is a clear trend of ever-decreasing size. Some smart objects are so small they are not even visible to the naked eye. This reduced size makes smart objects easier to embed in everyday objects.

Power consumption is decreasing: The different hardware components of a smart object continually consume less power. This is especially true for sensors, many of which are completely passive. Some battery-powered sensors last 10 or more years without battery replacement.

Processing power is increasing: Processors are continually getting more powerful and smaller. This is a key advancement for smart objects, as they become increasingly complex and connected.

Communication capabilities are improving: It's no big surprise that wireless speeds are continually increasing, but they are also increasing in range. IoT is driving the development of more and more specialized communication protocols covering a greater diversity of use cases and environments.

Communication is being increasingly standardized: There is a strong push in the industry to develop open standards for IoT communication protocols. In addition, there are more and more open source efforts to advance IoT.

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Sensor Networks – Part I

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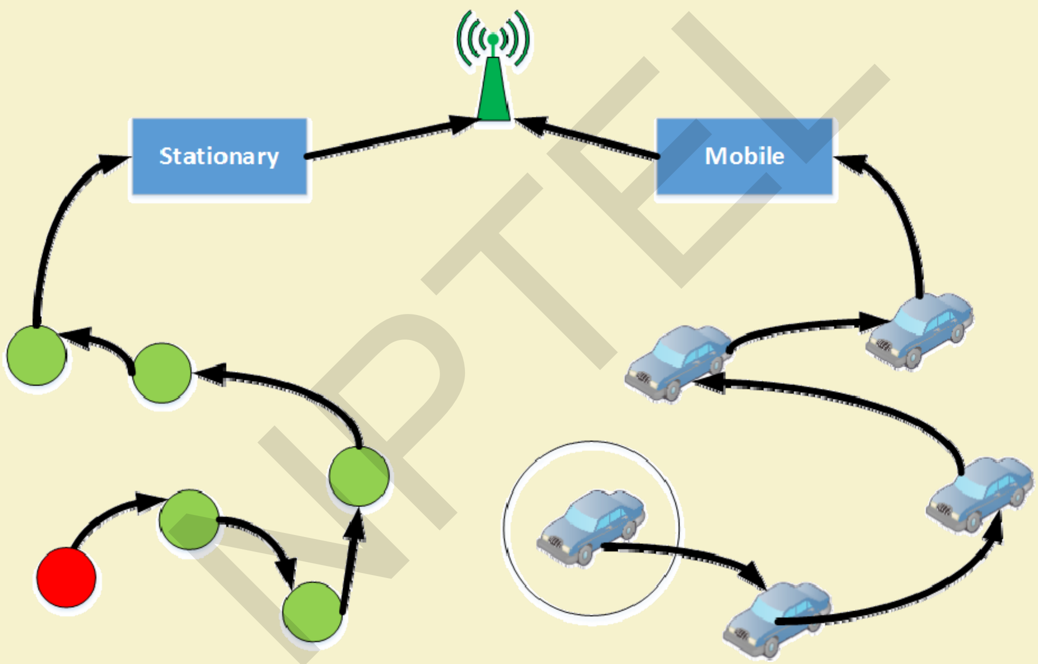
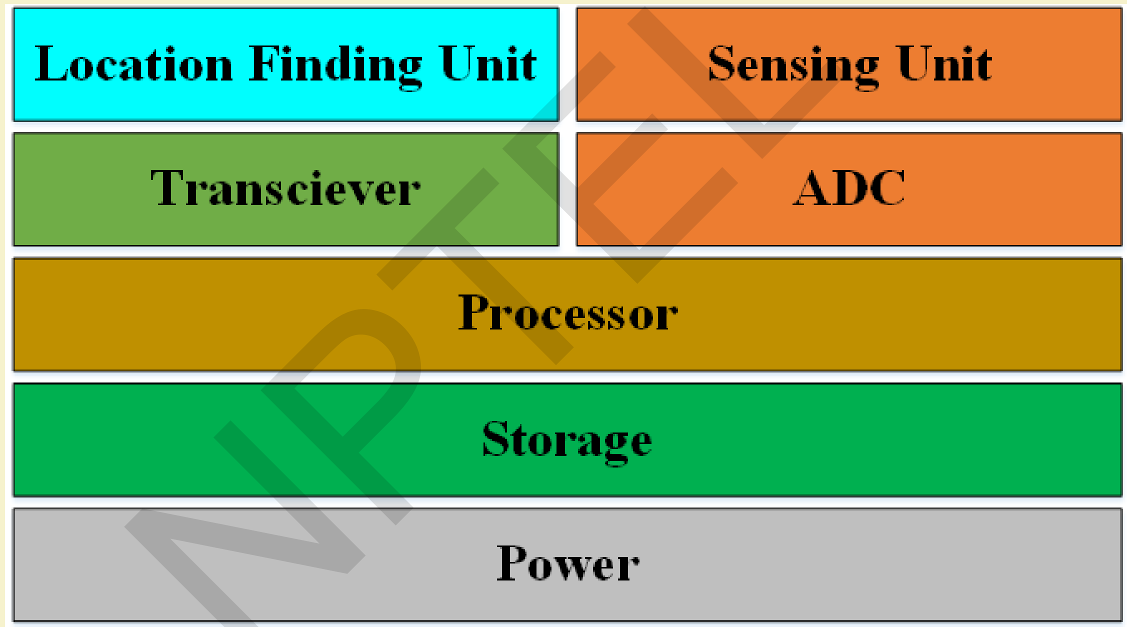
Wireless Sensor Networks (WSNs)

- 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).
- The sensed measurements are then transformed into digital signals and processed to reveal some properties of the phenomena around sensors.
- Due to the fact that the sensor nodes in WSNs have short radio transmission range, intermediate nodes act as relay nodes to transmit data towards the sink node using a multi-hop path.

Multi-hop Path in WSNs



Basic Components of a Sensor Node



Sensor Nodes

- **Multifunctional**
  - The number of sensor nodes used depends on the application type.
- **Short transmission ranges**
- **Have OS** (e.g., TinyOS).
- **Battery Powered** – Have limited life.

Image source: Wikimedia Commons

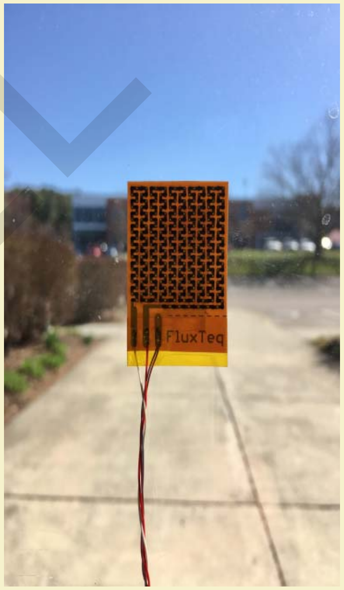
Constraints on Sensor Nodes

- Small size, typically less than a cubic cm.
- Must consume extremely low power
- Operate in an unattended manner in a highly dense area.
- Should have low production cost and be dispensable
- Be autonomous
- Be adaptive to the environment

Applications

- Temperature measurement
- Humidity level
- Lighting condition
- Air pressure
- Soil makeup
- Noise level
- Vibration

a) Soil sensor node

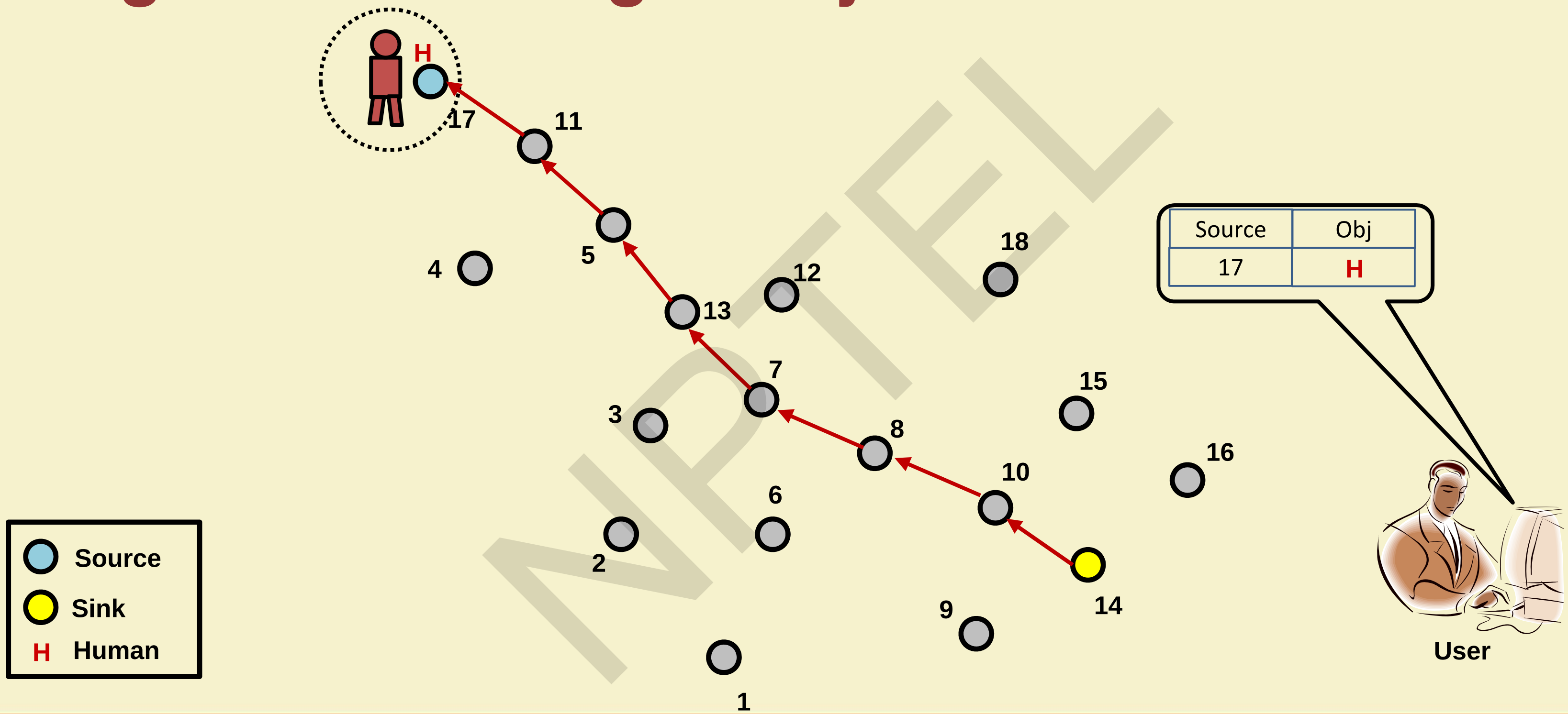


b) Temperature Flux sensor node

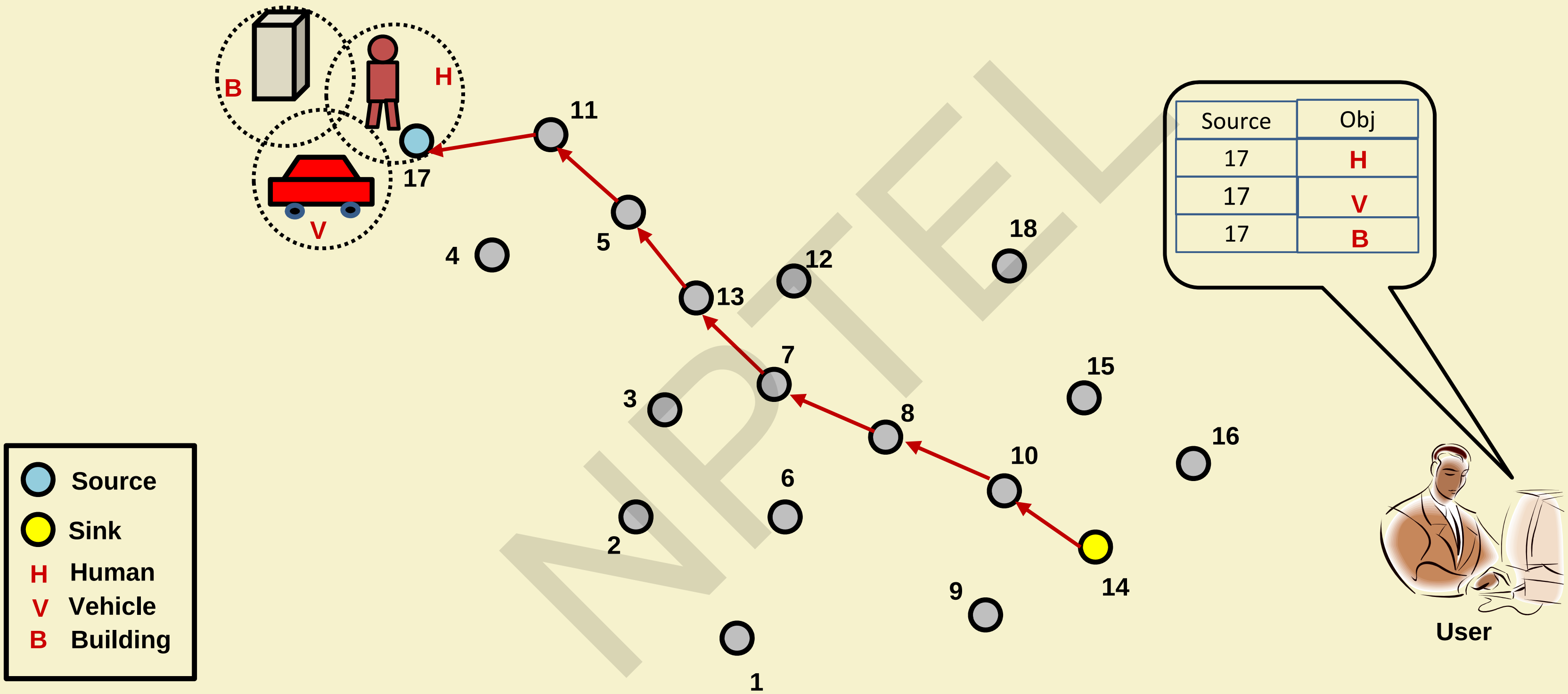
c) Weather sensor node

Image source: Wikimedia Commons

Single Source Single Object Detection

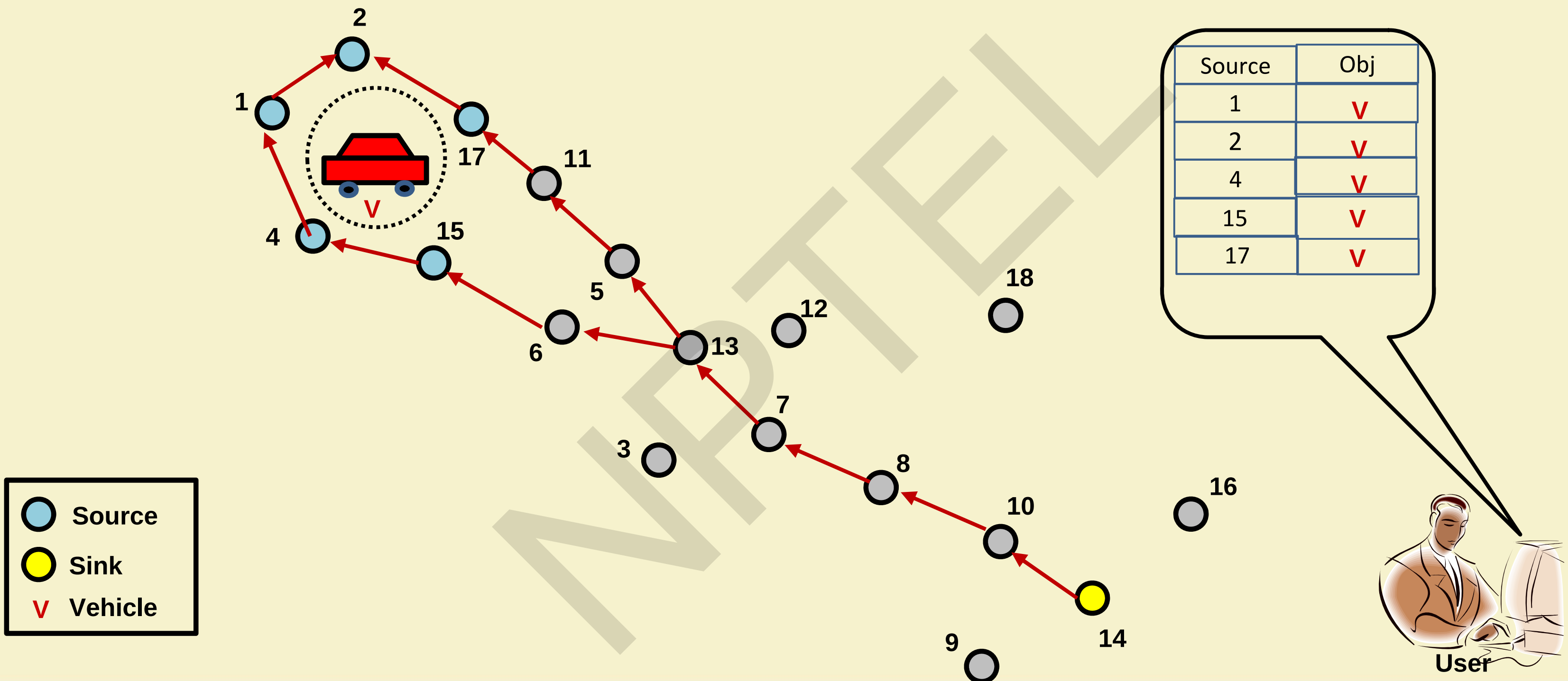


Single Source Multiple Object Detection



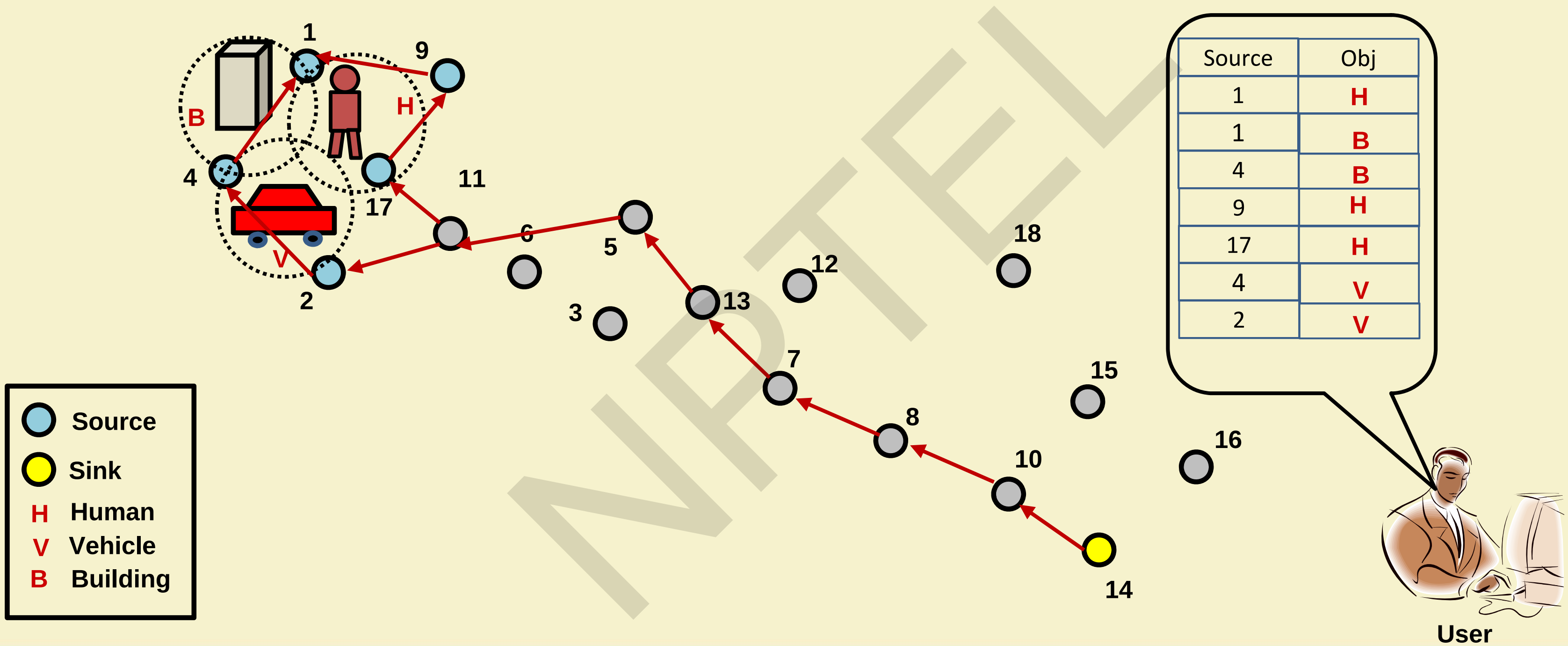
Source	Obj
17	H
17	V
17	B

Multiple Source Single Object Detection

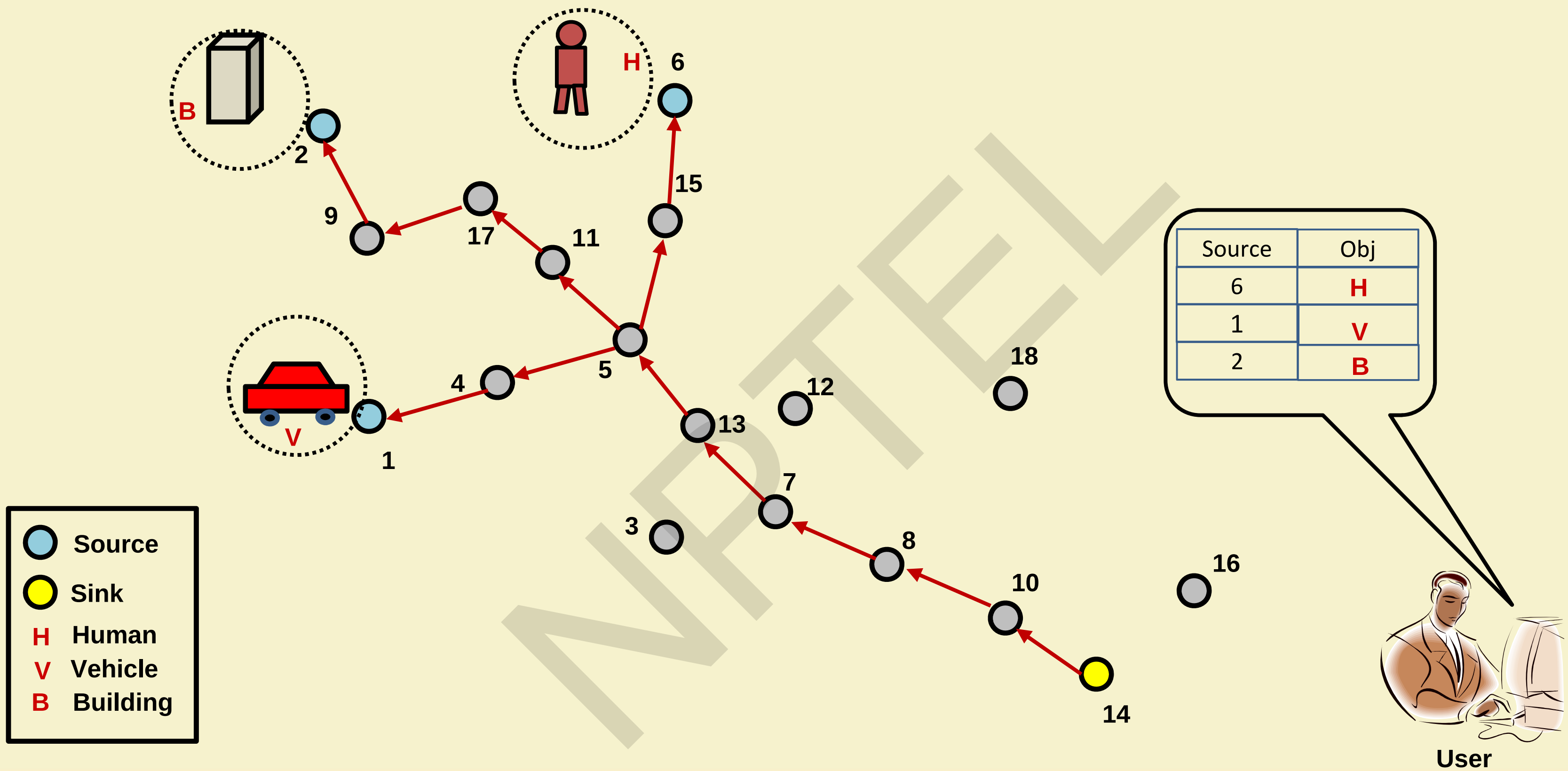


Source	Obj
1	V
2	V
4	V
15	V
17	V

Multiple Source Multiple Object Detection



Source	Obj
1	H
1	B
4	B
9	H
17	H
4	V
2	V



Source	Obj
6	H
1	V
2	B

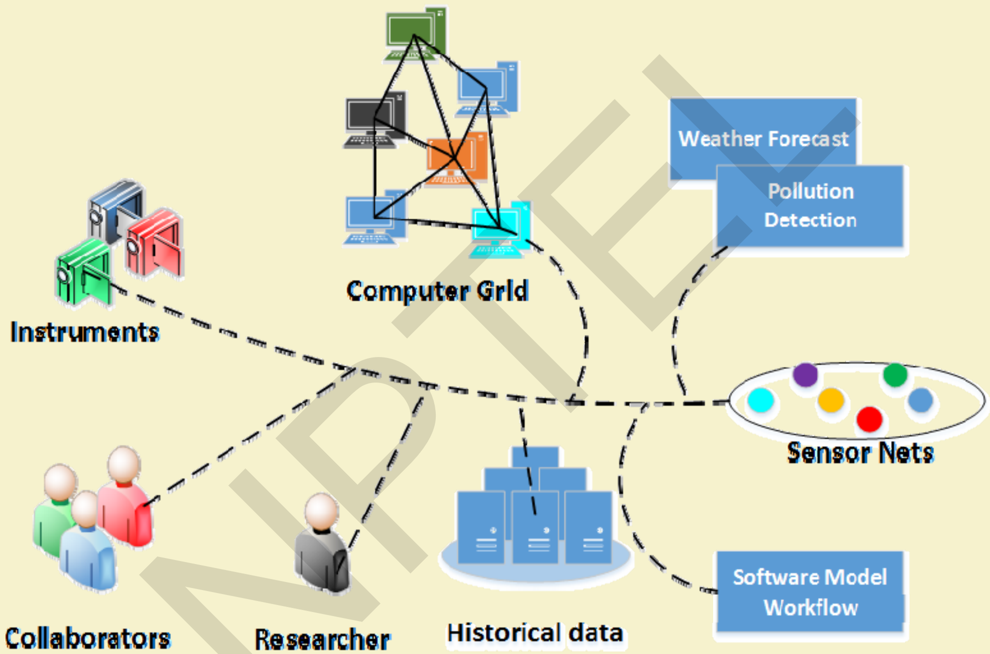
Challenges

- Scalability
  - Providing acceptable levels of service in the presence of large number of nodes.
  - Typically, throughput decreases at a rate of $1/\sqrt{N}$, N = number of nodes.
- Quality of service
  - Offering guarantees in terms of bandwidth, delay, jitter, packet loss probability.
  - Limited bandwidth, unpredictable changes in RF channel characteristics.

Challenges (contd.)

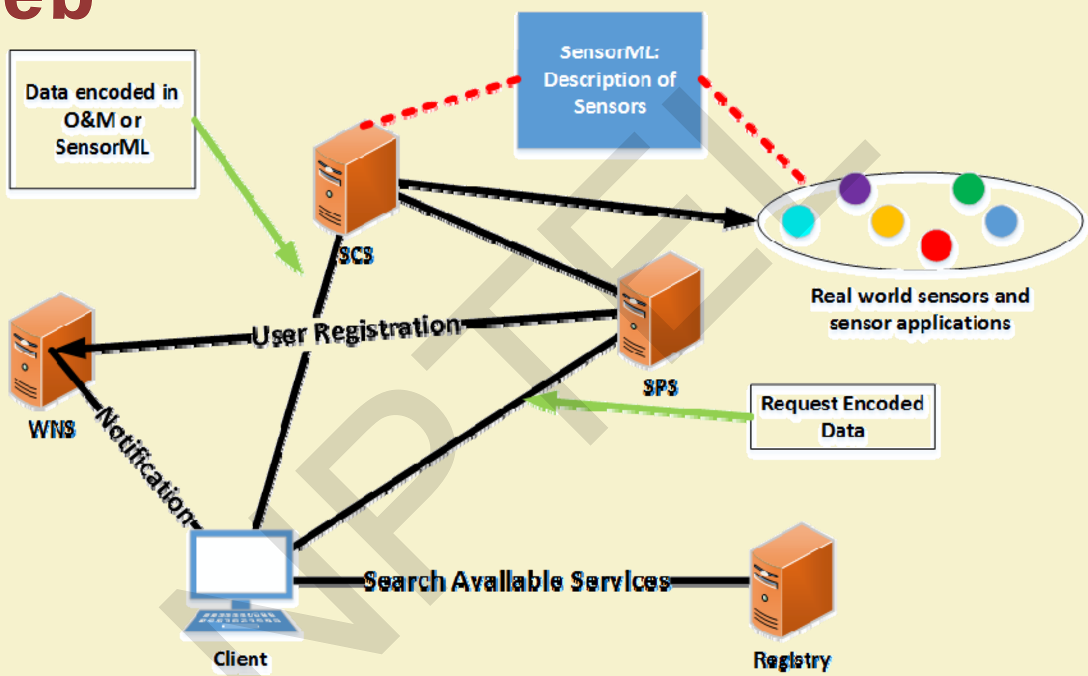
- Energy efficiency
  - Nodes have limited battery power
  - Nodes need to cooperate with other nodes for relaying their information.
- Security
  - Open medium.
  - Nodes prone to malicious attacks, infiltration, eavesdropping, interference.

Sensor Web



Source: X. Chu and R. Buyya, "Service Oriented Sensor Web", Sensor Networks and Configuration, Springer, 2007, pp. 51-74.

Sensor Web



WNS: Web Notification Services

SCS: Sensor Collection Services

SPS: Sensor Planning Services

SensorML: Sensor Modeling language

Source: X. Chu and R. Buyya, "Service Oriented Sensor Web", Sensor Networks and Configuration, Springer, 2007, pp. 51-74.

Sensor Web Entanglement

- Observations & measurements (O&M)
- Sensor model language (sensorml)
- Transducer model language (transducerml or TML)
- Sensor observations service (SOS)
- Sensor planning service (SPS)
- Sensor alert service (SAS)
- Web notification services (WNS)

Cooperation in Wireless Ad Hoc and Sensor Networks

- Nodes communicate with other nodes with the help of intermediate nodes.
- The intermediate nodes act as relays.
- Wireless nodes are energy-constrained.
- Nodes may or may not cooperate.

Cooperation in Wireless Ad Hoc and Sensor Networks

- Two extremities:
  - **Total cooperation:** if all relay requests are accepted, nodes will quickly exhaust limited energy.
  - **Total non-cooperation:** if no relay requests are accepted, the network throughput will go down rapidly.
- Issues:
  - Selfishness, self-interests, etc.
  - Symbiotic dependence
  - Tradeoff: individual node's lifetime vs. Throughput.

Security Challenges in Cooperation

- Open, shared radio medium by the nodes, which dynamically change positions.
- No centralized network management or certification authority.
- Existence of malicious nodes.
- Nodes prone to attacks, infiltration, eavesdropping, interference.
- Nodes can be captured, compromised, false routing information can be sent – paralyzing the whole network.
- The cooperating node or the node being cooperated might be victimized.

Thank You!!

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Sensor Networks – Part II

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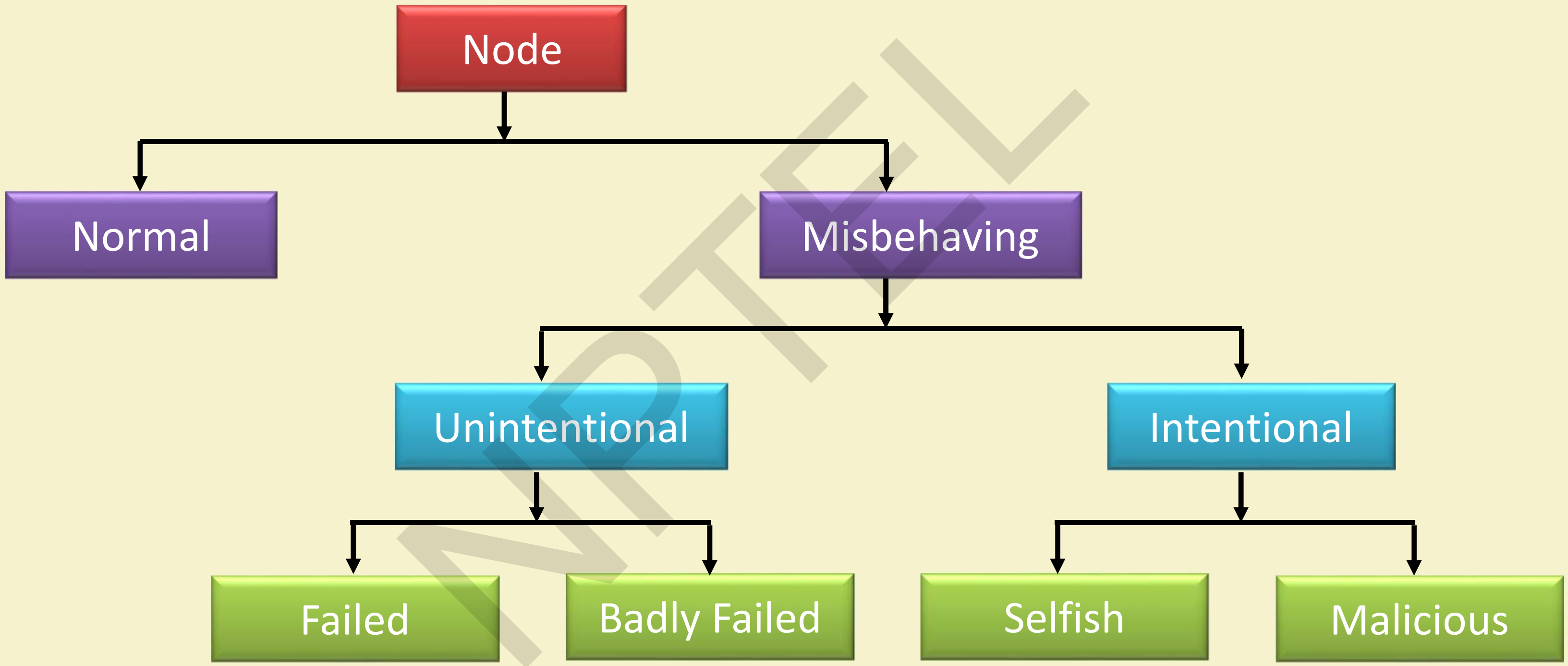
Node Behavior in WSNs



Node Behavior in WSNs (contd.)

- Normal nodes work perfectly in ideal environmental conditions
- Failed nodes are simply those that are unable to perform an operation; this could be because of power failure and environmental events.
- Badly failed nodes exhibit features of failed nodes but they can also send false routing messages which are a threat to the integrity of the network.

Node Behavior in WSNs (contd.)

- Selfish nodes are typified by their unwillingness to cooperate, as the protocol requires whenever there is a personal cost involved. Packet dropping is the main attack by selfish nodes.
- Malicious nodes aim to deliberately disrupt the correct operation of the routing protocol, denying network service if possible.

Dynamic Misbehavior: Dumb Behavior

- Detection of such temporary misbehavior in order to preserve normal functioning of the network – coinage and discovery of dumb behavior
- In the presence of adverse environmental conditions (high temperature, rainfall, and fog) the communication range shrinks
- A sensor node can sense its surroundings but is unable to transmit the sensed data
- With the resumption of favorable environmental conditions, dumb nodes work normally
- Dumb behavior is temporal in nature (as it is dependent on the effects of environmental conditions)

Detection and Connectivity Re-establishment

- The presence of dumb nodes impedes the overall network performance
- Detection, and, subsequently, the re-establishment of network connectivity is crucial
- The sensed information can only be utilized if the connectivity between each dumb node with other nodes in the network could be re-established
- Before restoration of network connectivity, it is essential to detect the dumb nodes in the network.
- CoRD and CoRAD are two popular schemes that re-establish the connectivity between dumb nodes with others.

Event-Aware Topology Management in Wireless Sensor Networks

- Timely detection of an event of interest
- Monitoring the event
- Disseminating event-data to the sink
- Adapting with the changes of event state
  - Event location
  - Event area
  - Event duration

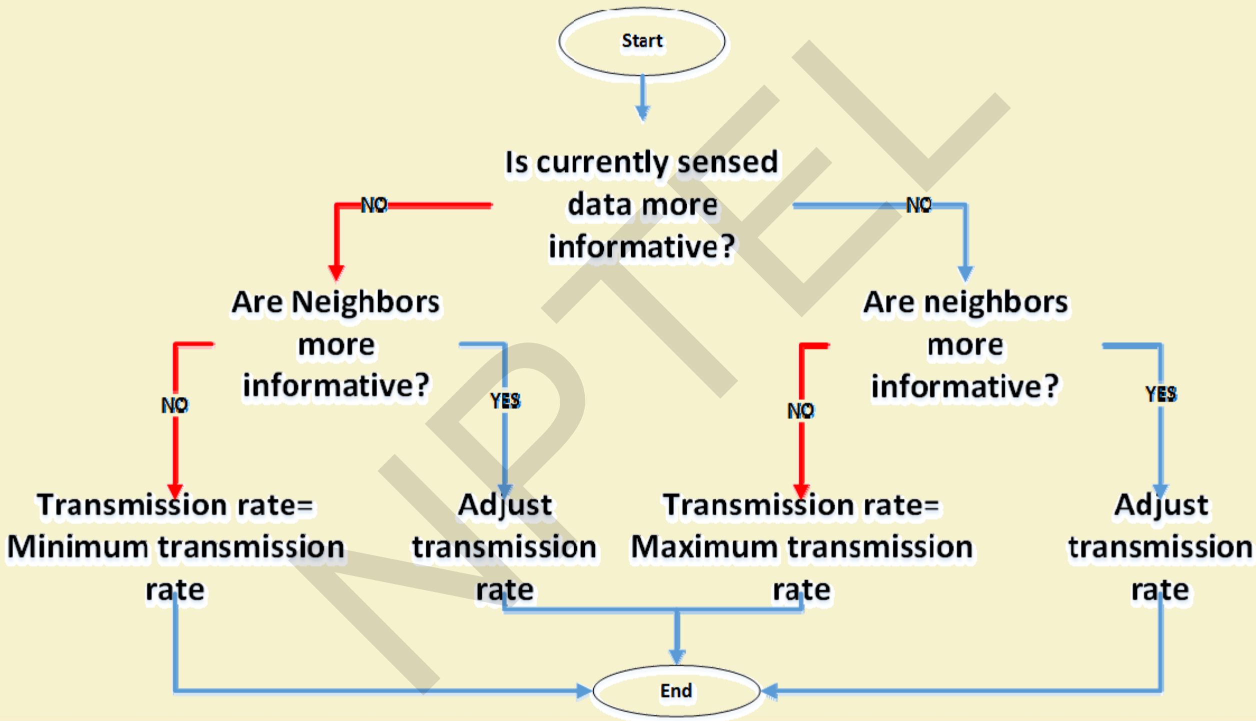
Source: S. N. Das, S. Misra, M. S. Obaidat, "Event-Aware Topology Management in Wireless Sensor Networks", Proceedings of Ubiquitous Information Technologies and Applications (CUTE 2013), Springer Lecture Notes in Electrical Engineering, Vol. 214, 2013, pp. 679-687

Information Theoretic Self-Management of Wireless Sensor Networks

- A WSN is deployed with the intention of acquiring information
- The sensed information are transmitted in the form of packets
- Information theoretic self-management (INTSEM) controls the transmission rate of a node by adjusting a node's sleep time
- Benefits
  - Reduce consumption of transmission energy of transmitters
  - Reduce consumption of receiving energy of relay nodes

S. N. Das and S. Misra, "Information theoretic self-management of Wireless Sensor Networks", Proceedings of NCC 2013.

General Framework of InTSeM



Social Sensing in WSNs

✓ Social Sensing-based Duty Cycle Management for Monitoring Rare Events in Wireless Sensor Networks

- WSNs are energy-constrained
- Scenario:
  - Event monitoring using WSNs
  - WSNs suffer from ineffective sensing for rare events
  - Event monitoring or sensing, even if there is no event to monitor or sense
  - Example: Submarine monitoring in underwater surveillance

Social Sensing in WSNs (contd.)

- Possible Solution Approach: Duty-cycle management

- SMAC [Ye *et al*., INFOCOM, 2002]
- DutyCon [Wang *et al*., ACM TSN, 2013]
- PW-MAC [Tang *et al*., INFOCOM, 2011]

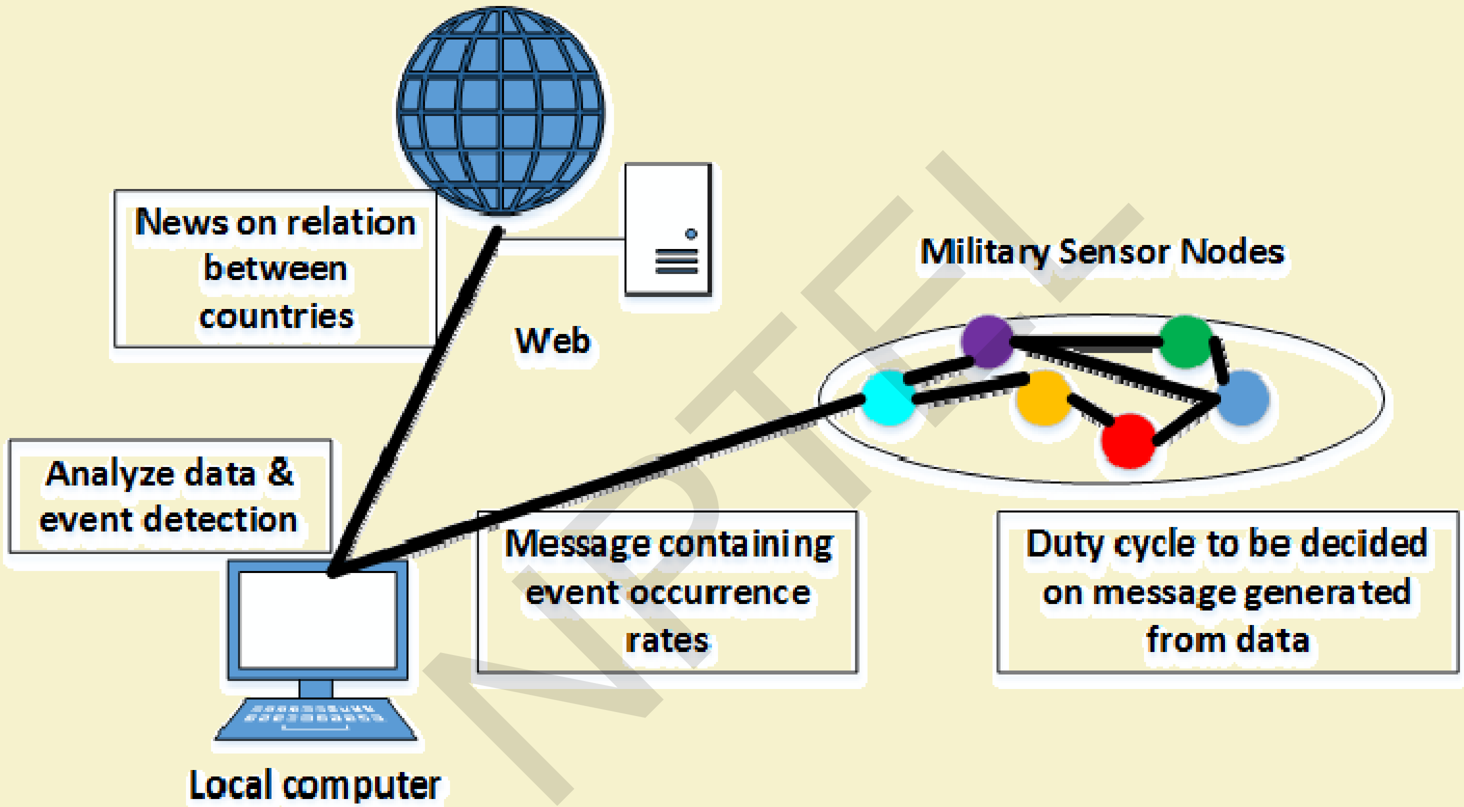
Limitations:

- Do not distinguish the rare events from regular events
- Ineffective wakeup and sensing under rare event monitoring scenario

Source: S. Misra, S. Mishra, M. Khatua, "Social Sensing-based Duty Cycle Management for Monitoring Rare Events in Wireless Sensor Networks", IET Wireless Sensor Systems

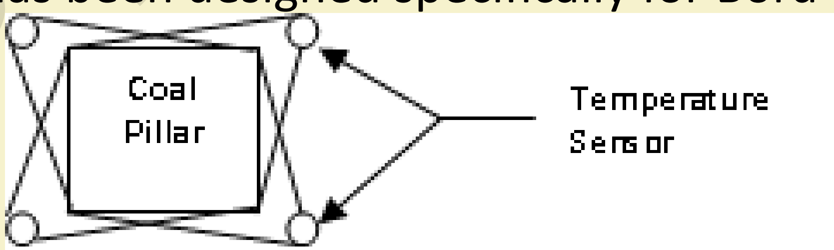
Social Sensing in WSNs (contd.)

- **Challenges**:
  - Distinguish rare events and regular events
  - Adapt the duty-cycle with the event occurrence probability.
- **Contribution**:
  - Probabilistic duty cycle (PDC) in WSNs
  - Accumulates information from the social media to identify the occurrence possibility of rare events
  - Adjusts the duty cycles of sensor nodes using weak estimation learning automata


News on relation between countries
Web
Military Sensor Nodes
Analyze data & event detection
Message containing event occurrence rates
Duty cycle to be decided on message generated from data
Local computer

Applications of WSNs: Mines

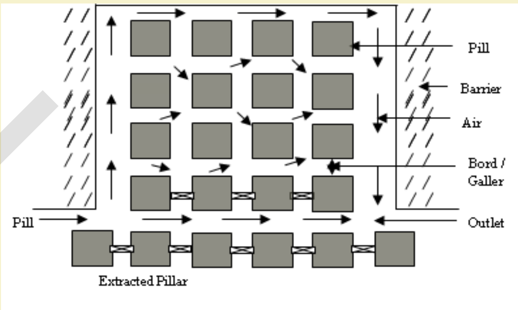
- ✓ Fire Monitoring and Alarm System for Underground Coal Mines Bord-and-Pillar Panel Using Wireless Sensor Networks
  - WSN-based simulation model for building a fire monitoring and alarm (FMA) system for Bord & Pillar coal mine.
  - The fire monitoring system has been designed specifically for Bord & Pillar based mines

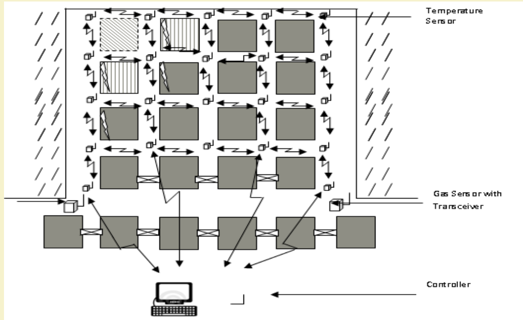


Source: S. Bhattacharjee, P. Roy, S. Ghosh, S. Misra, M. S. Obaidat, "Fire Monitoring and Alarm System for Underground Coal Mines Bord-and-Pillar Panel Using Wireless Sensor Networks", Journal of Systems and Software (Elsevier), Vol. 85, No. 3, March 2012, pp. 571-581.

Applications of WSNs: Mines (contd.)

- It is not only capable of providing real-time monitoring and alarm in case of a fire, but also capable of providing the exact fire location and spreading direction by continuously gathering, analysing, and storing real time information



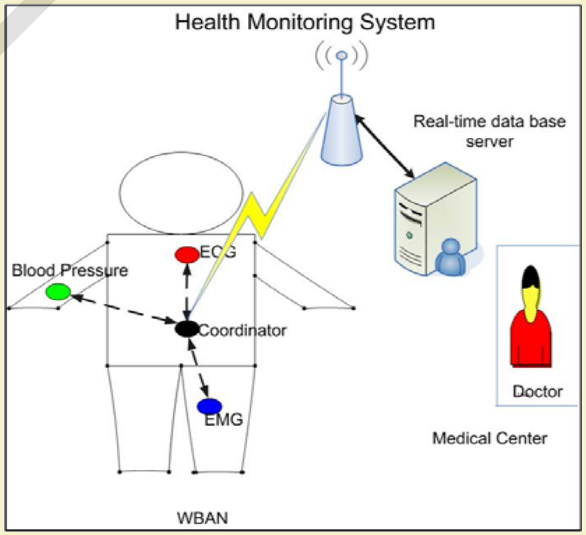


Source: S. Bhattacharjee, P. Roy, S. Ghosh, S. Misra, M. S. Obaidat, "Fire Monitoring and Alarm System for Underground Coal Mines Bord-and-Pillar Panel Using Wireless Sensor Networks", Journal of Systems and Software (Elsevier), Vol. 85, No. 3, March 2012, pp. 571-581.

Applications of WSNs: Healthcare

✓ Wireless Body Area Networks

- Wireless body area networks (WBANs) have recently gained popularity due to their ability in providing innovative, cost-effective, and user-friendly solution for continuous monitoring of vital physiological parameters of patients.
- Monitoring chronic and serious diseases such as cardiovascular diseases and diabetes.
- Could be deployed in elderly persons for monitoring their daily activities.



Applications of WSNs: Healthcare (contd.)

Social Choice Considerations in Cloud-Assisted WBAN Architecture

- A proper aggregation function necessarily needs to be “fair", so that none of the eligible elements are ignored unjustly.
- In a post-disaster environment, it is required to monitor patients' health conditions remotely.
- This includes ambulatory healthcare services where the health status of a patient is examined continuously over time, while the patient is being moved to the emergency healthcare center.

Source: S. Misra, S. Chatterjee, "Social Choice Considerations in Cloud-Assisted WBAN Architecture for Post-Disaster Healthcare: Data Aggregation and Channelization",Information Sciences (Elsevier), 2016

Applications of WSNs: Healthcare (contd.)

- The work focuses on the formation of pseudo-clusters so that the aggregation is not biased towards the leader nodes.
- Data aggregation among the LDPUs is done in a "fair" manner following the Theory of Social Choice.
- Aggregation is performed at mobile aggregation centers, thereby increasing the scalability of the system.
- After the aggregation of data, the gateways are allocated dynamically.

Source: S. Misra, S. Chatterjee, "Social Choice Considerations in Cloud-Assisted WBAN Architecture for Post-Disaster Healthcare: Data Aggregation and Channelization",Information Sciences (Elsevier), 2016

Applications of WSNs: Healthcare (contd.)

✓ Payload tuning mechanism for WBANs

- In addition to the actual health condition, there exists indirect influence of external parameters such as – age, height, weight, and sex on health parameters.
- In crisp set theory, we are unable to interpret how much ‘low’, ‘moderate’, or ‘high’, a particular health parameter is.
- Exclusion of the important external parameters while assessing health and the usage of traditional crisp set theory may result into inefficient decision making.

Source: S. Moulik, S. Misra, C. Chakraborty, M. S. Obaidat, "Prioritized Payload Tuning Mechanism for Wireless Body Area Network-Based Healthcare Systems", Proceedings of IEEE GLOBECOM, 2014

Applications of WSNs: Healthcare (contd.)

- Challenge is to design a dynamic decision making model that can optimize the energy consumption of each physiological sensor
- Fuzzy inference system (FIS) and markov decision process (MDP) are used to optimize energy consumption

Source: S. Moulik, S. Misra, C. Chakraborty, M. S. Obaidat, "Prioritized Payload Tuning Mechanism for Wireless Body Area Network-Based Healthcare Systems", Proceedings of IEEE GLOBECOM, 2014

Applications of WSNs: Healthcare (contd.)

✓ **Priority-Based Time-Slot Allocation in WBANs**

- In medical emergency situations, it is important to discriminate the WBANs transmitting critical heath data from the ones transmitting data of regular importance.
- Existing frequency division-based transmission in a multisource-single-sink network results in flooding of the sink's receiver buffer.
- This leads to packet loss and consequent retransmission of the regenerated packets.

Source: S. Misra, S. Sarkar, "Priority-Based Time-Slot Allocation in Wireless Body Area Networks During Medical Emergency Situations: An Evolutionary Game Theoretic Perspective", IEEE Journal of Biomedical and Health Informatics, 2014

Applications of WSNs: Healthcare (contd.)

- Transmission priority of an local data processing unit (LDPU) is indifferent to the criticality of the health data that is being transmitted by the LDPU.
- Based on LDPU-properties, such as the criticality of health data, energy dissipation factor, and time elapsed since last successful transmission, a fitness parameter is formulated which is a relative measure of node-importance.
- The priority-based allocation of time slots (PATS) algorithm allows the LDPUs to choose their strategies based on their fitness.
- LDPUs with higher fitness are given higher preference, while ensuring minimum waiting time between successive transmission of data-packets.

Source: S. Misra, S. Sarkar, "Priority-Based Time-Slot Allocation in Wireless Body Area Networks During Medical Emergency Situations: An Evolutionary Game Theoretic Perspective", IEEE Journal of Biomedical and Health Informatics, 2014

Thank You!!