Wireless Sensor Networks

Dr. E.SURESH BABU
Assistant Professor
Computer Science and Engineering Department
National Institute of Technology, Warangal.
Warangal, TS, India.

Session Outline

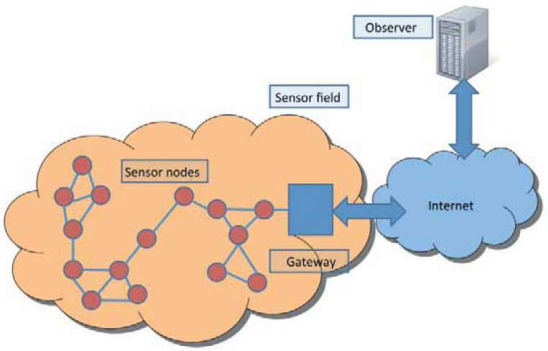
1. Overview of Wireless Sensor Networks
2. Challenges in Designing a Sensor Network
3. Routing Protocols in Wireless Sensor Networks
4. Routing Protocols in WSNs: A Taxonomy
5. SPIN : Sensor Protocols for Information via Negotiation
6. Wireless Sensor Network (WSN) in IoT

Overview of Wireless Sensor Networks

Wireless Sensor Networks

- **Wireless Sensor Networks** are a special category of **ad hoc networks**
  - ✓ Used to provide a **wireless communication infrastructure** among the **sensors**
  - ✓ Deployed in a **specific application domain.**
- A sensor network is a **collection of a large number of sensor nodes** that are deployed in a particular region.

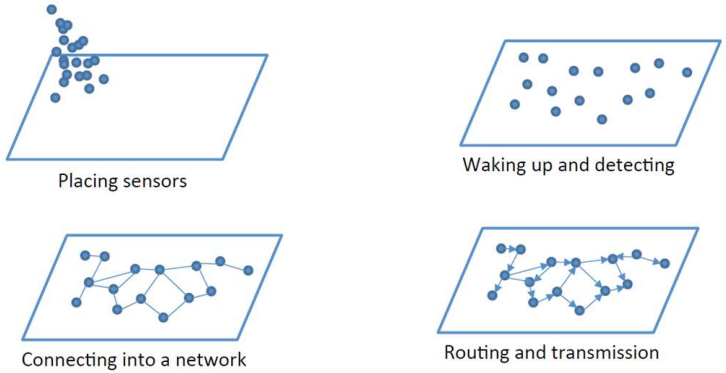
Wireless Sensor Networks



Wireless Sensor Networks

- The **sensor network nodes broadcast** their status to the **surroundings and receive status** from other nodes to detect each other.
- The sensor network nodes are **organized into a connected network** according to a **certain topology (linear, star, tree, mesh, etc.).**
- **Suitable paths** are computed on the **constructed network** for transmitting the sensing data.

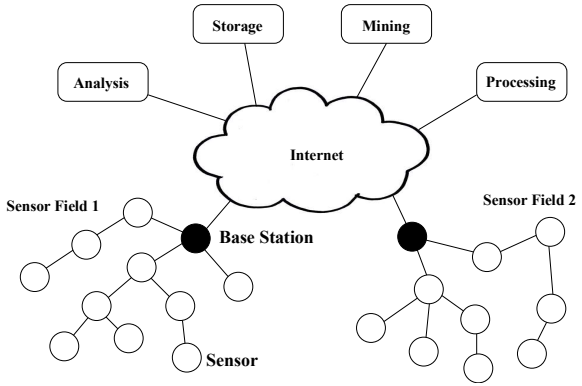
Distributed Collection of Networked Sensors



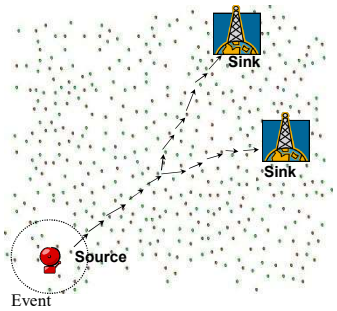
Distinct Properties of Wireless Sensor Networks:

- **Mobility of nodes** are not needed in all cases
- The **size of the network** is much larger than that in a **typical ad hoc wireless network.**
- The **density of nodes in a sensor network** varies with the **domain of application.**
- The **power constraints in sensor networks** are much more stringent than those in **ad hoc wireless networks.**

WSN monitor large or complex physical environments



Common Network Architecture

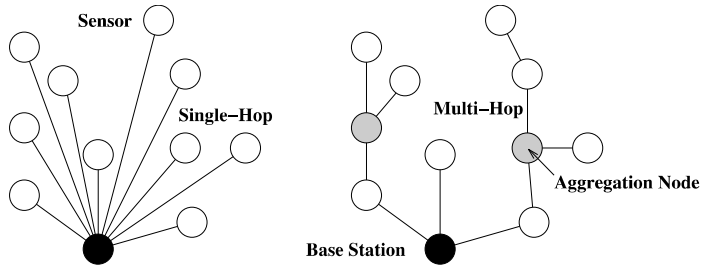


- **Sensor Nodes** are responsible for
  - ✓ **Detection of events**
  - ✓ **Observation of environments**
  - ✓ **Relaying of third party messages**
- Information is generally **gathered at sinks**
  - ✓ Sinks are responsible for **higher level processing** and **decision making**

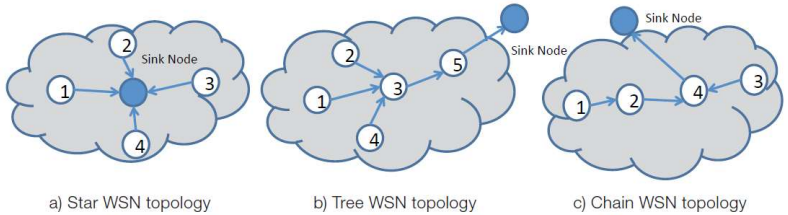
Hopping

- Sensor nodes monitor the **collected data** to transmit along to other sensor nodes by **hopping.**
- During the **process of transmission**
  - ✓ Monitored data may be handled by multiple nodes to get to **gateway node** after **multi-hop routing**
  - ✓ finally reach the **management node** through the **internet or satellite**.

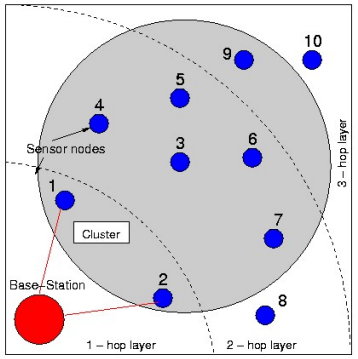
Single-Hop vs. Multi-Hop

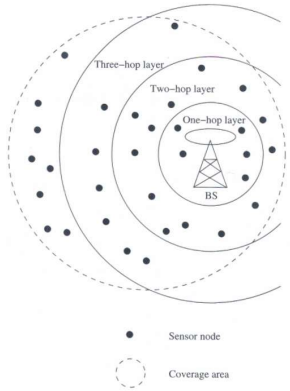


WSN Topology



Distributed Collection of Networked Sensors





Topology

- **Star topology**
  - ✓ Every sensor communicates directly (single-hop) with the base station
  - ✓ May require large transmit powers and may be infeasible in large geographic areas
- **Mesh topology**
  - ✓ Sensors serve as relays (forwarders) for other sensor nodes (multi-hop)
  - ✓ May reduce power consumption and allows for larger coverage
  - ✓ Introduces the problem of routing

Routing Protocols in Wireless Sensor Networks

Challenges of WSN

- **No Global Addressing**
  - ✓ Classical IP-based protocols cannot be applied to sensor networks
- **Redundant Data Traffic**
  - ✓ Multiple sensors may generate same data within the vicinity of a phenomenon
  - ✓ Such redundancy needs to be exploited by the routing protocols to **improve energy and bandwidth utilization**
- **Multiple-Source Single-Destination Network**
  - ✓ Almost all applications of sensor networks require the flow of sensed data from **multiple regions (sources)** to a **particular sink**

Challenges of WSN

- **Careful Resource Management**
  - ✓ Sensor nodes are tightly constrained in terms of:
    - Transmission power
    - On-board energy
    - Processing capacity
    - Storage
- WSNs are generally **stationary** after deployment

Location Specific

- Sensor Networks Are **Application Specific**
- Position awareness of sensor nodes is important since **data collection** is normally based on the **location.**
- **Data collected** by many sensors in WSNs is typically based on common phenomena. Hence some **redundancy** of data does exist.

Routing Challenges in WSN

- The task of **finding and maintaining routes** in WSNs is nontrivial
  - ✓ Energy restrictions and sudden changes in node status
  - ✓ Cause frequent failure and
  - ✓ Unpredictable topological changes.

Routing in WSN

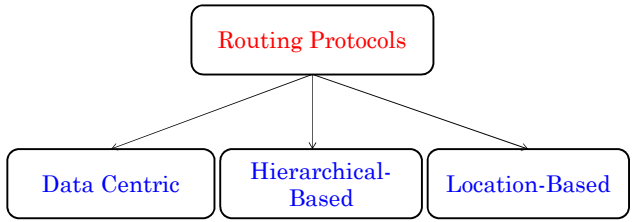
- The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs.
  - ✓ **Node deployment**
  - ✓ **Energy considerations**
  - ✓ **Data delivery model**
  - ✓ **Node/link heterogeneity**
  - ✓ **Fault tolerance**
  - ✓ **Scalability**
  - ✓ **Network dynamics**
  - ✓ **Transmission media**
  - ✓ **Connectivity**
  - ✓ **Coverage**
  - ✓ **Data aggregation/converge cast**
  - ✓ **Quality of service**

Routing in WSN

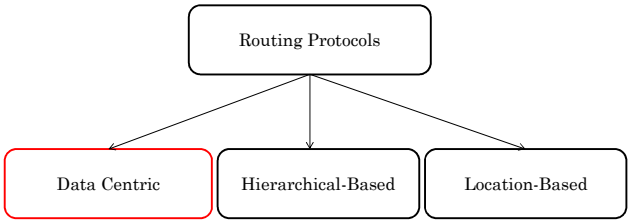
- To **Minimize Energy Consumption**, routing techniques proposed for WSNs employ some well-known routing strategies,
  - ✓ **Data Aggregation And**
  - ✓ **In-network Processing,**
  - ✓ **Clustering,**
  - ✓ **Different Node Role Assignment,**
  - ✓ **Data-centric Methods**

Routing Protocols in WSNs: A Taxonomy

Routing Protocols in WSNs: A Taxonomy

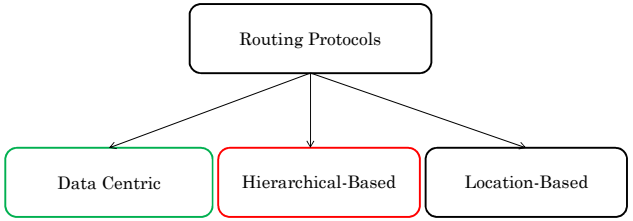


Routing Protocols in WSNs: A Taxonomy



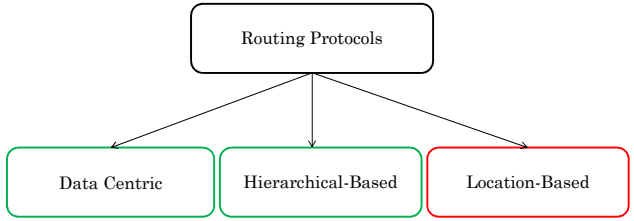
- All the nodes are treated equally and have the same functionality

Routing Protocols in WSNs: A Taxonomy



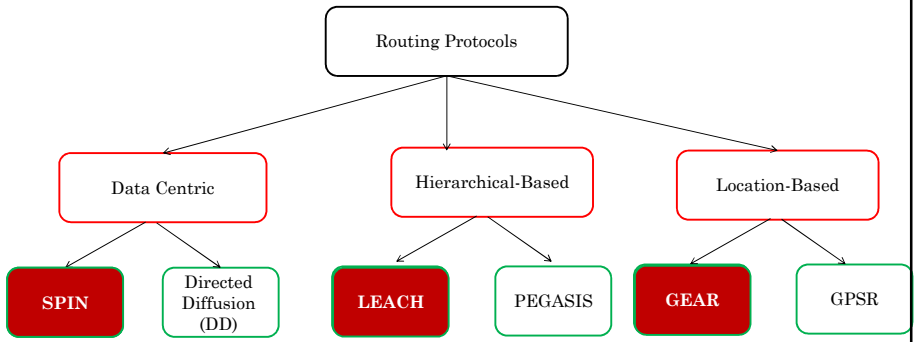
- Higher energy nodes for transmission, lower energy nodes for sensing
- Two layer routing
- Increasing the life time

Routing Protocols in WSNs: A Taxonomy



- Sensor nodes are addressed based on their location
- Location are acquired by GPS or via coordination among nodes

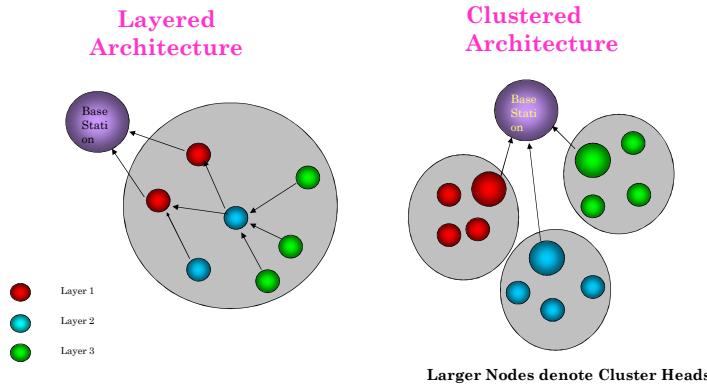
Routing Protocols in WSNs: A Taxonomy



Routing Protocols in WSNs: Classification

- **Data Centric:**
  - ✓ Data-centric protocols are query-based
- **Hierarchical:**
  - ✓ Aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy
- **Location-based:**
  - ✓ Utilize the position information to relay the data to the desired regions rather than the whole network.

Routing Protocols in WSNs: Network Architectures



Data-Centric Protocols

Data-Centric Protocols

- In many applications of sensor networks, it is not feasible to **assign global identifiers** to each node
- **Data-centric protocols** are query-based
- Sink sends queries to certain regions and waits data from sensors located in that region
- Attribute-based naming is necessary to specify properties of data

Data-Centric Routing

- Flooding
- Gossiping
- Sensor Protocols for Information via Negotiation (SPIN)
- Directed Diffusion
- Energy-aware Routing
- Rumor Routing
- Gradient-Based Routing (GBR)
- Constrained Anisotropic Diffusion Routing (CADR)
- ACtive QUery forwarding In sensoR nEtworks (ACQUIRE)

SPIN

Sensor **P**rotocols for **I**nformation via **N**egotiation

SPIN -Motivation

- Sensor Protocols for Information via Negotiation**, SPIN**
- A Negotiation-Based Protocols for Disseminating Information in Wireless Sensor Networks.
- **Dissemination** is the process of **distributing** individual sensor observations to the whole network, treating all sensors as sink nodes
  - ✓ Replicate complete view of the environment
  - ✓ Enhance fault tolerance
  - ✓ Broadcast critical piece of information

SPIN (cont.)- SPIN family

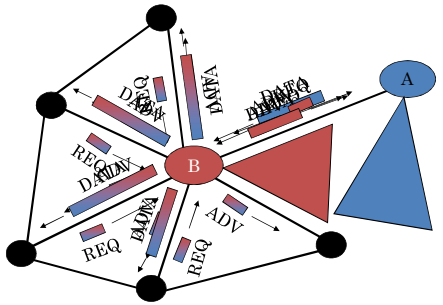
- Protocols of the SPIN family

1. **SPIN-PP**
   - ✓ It is designed for a point to point communication, i.e., hop-by-hop routing
2. **SPIN-EC**
   - ✓ It works similar to SPIN-PP, but, with an energy heuristic added to it
3. **SPIN-BC**
   - ✓ It is designed for broadcast channels
4. **SPIN-RL**
   - ✓ When a channel is lossy, a protocol called SPIN-RL is used

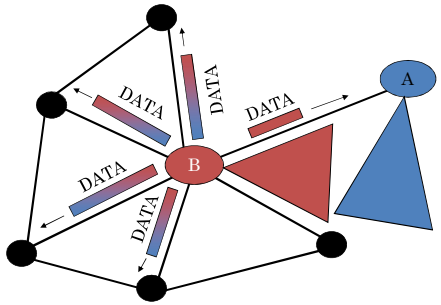
SPIN (cont.)- SPIN-PP

- **SPIN-PP:** A three-stage handshake protocol for point-to-point media
  1. **ADV** – data advertisement
     - ✓ Node that has data to share can advertise this by transmitting an ADV with meta-data attached
  2. **REQ** – request for data
     - ✓ Node sends a request when it wishes to receive some actual data
  3. **DATA** – data message
     - ✓ Contain actual sensor data with a meta-data header
     - ✓ Usually much bigger than ADV or REQ messages

SPIN (3-Step Protocol)

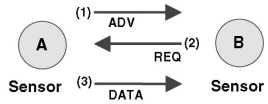


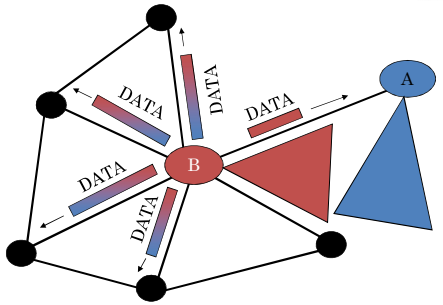
SPIN (3-Step Protocol)



Notice the color of the data packets sent by node B

SPIN (3-Step Protocol)



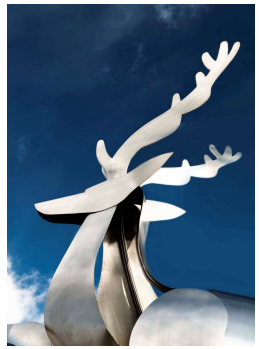


SPIN effective when DATA sizes are large : REQ, ADV overhead gets amortized

SPIN (cont.)- Conclusion

- SPIN protocols hold the promise of achieving high performance at a low cost in terms of complexity, energy, computation, and communication
- **Pros**
  - ✓ Each node only needs to know its one-hop neighbors
  - ✓ Significantly reduce energy consumption compared to flooding
- **Cons**
  - Data advertisement cannot guarantee the delivery of data
  - If the node interested in the data are far from the source, data will not be delivered
  - Not good for applications requiring reliable data delivery, e.g., intrusion detection

Thank U



Hierarchical Routing Protocols

Hierarchical Routing Protocols

- **Scalability** is one of the major design attributes of sensor networks
- A single-tier network can cause the **gateway to overload** with the increase in sensors density
  - ✓ Such overload might cause latency in communication and inadequate tracking of events
- The single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest

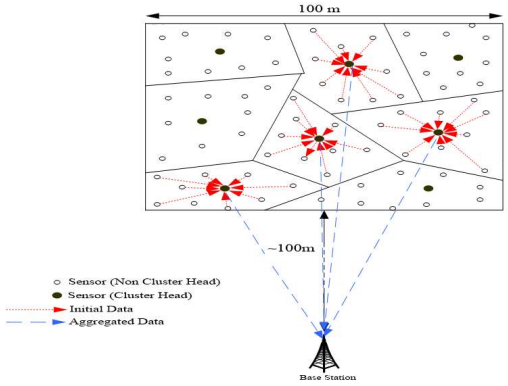
LEACH

Low-Energy Adaptive Clustering Hierarchy

LEACH Routing Protocols

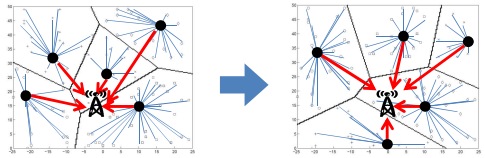
- **LEACH (Low-Energy Adaptive Clustering Hierarchy),** a clustering-based protocol that minimizes energy dissipation in sensor networks.
- **LEACH** outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system to be distributed among all the sensors.
- **LEACH** is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station.

LEACH Routing Protocols



LEACH: Adaptive Clustering

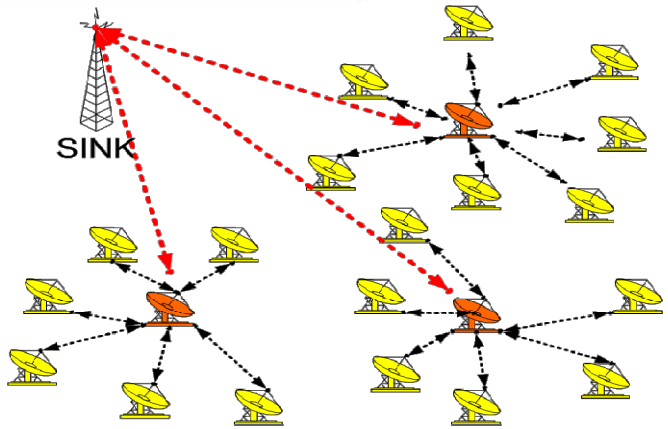
- Periodic independent self-election
  - ✓ Probabilistic
- CSMA MAC used to advertise
- Nodes select advertisement with strongest signal strength
- Dynamic TDMA cycles



All nodes marked with a given symbol belong to the same cluster, and the cluster head nodes are marked with a •.

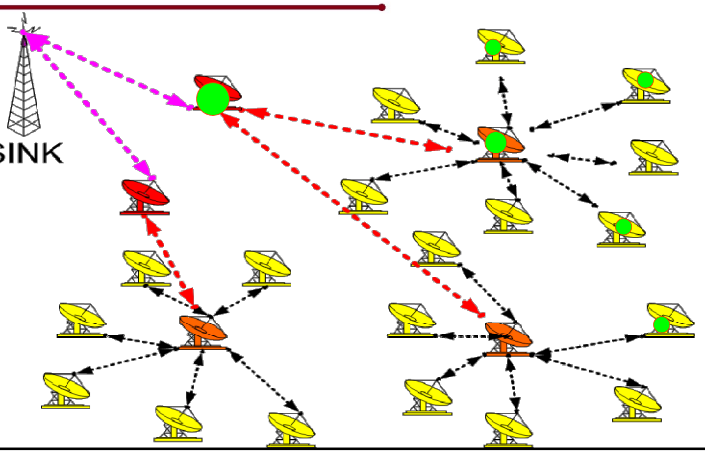
LEACH Algorithm

Illustrations



LEACH Algorithm

Illustrations



Wireless Sensor Network (WSN) and Internet

Integrating WSNs into IoT

- **Wireless Sensors** are used to measure and keep track of energy consumption and production in order to **optimize energy usage.**
- **Internet things** communicate by **producing and consuming information** and **execute smart algorithms** to **interact intelligently with other things** in the **Internet.**

Low cost IP Interconnection Technology

- The design of **early sensor networks** commonly used **internal addresses** to manage the **sensor network nodes.**
  - ✓ The address length was **relatively short**
  - ✓ Suitable for implementing in **low-power sensor network nodes.**

Low cost IP Interconnection Technology

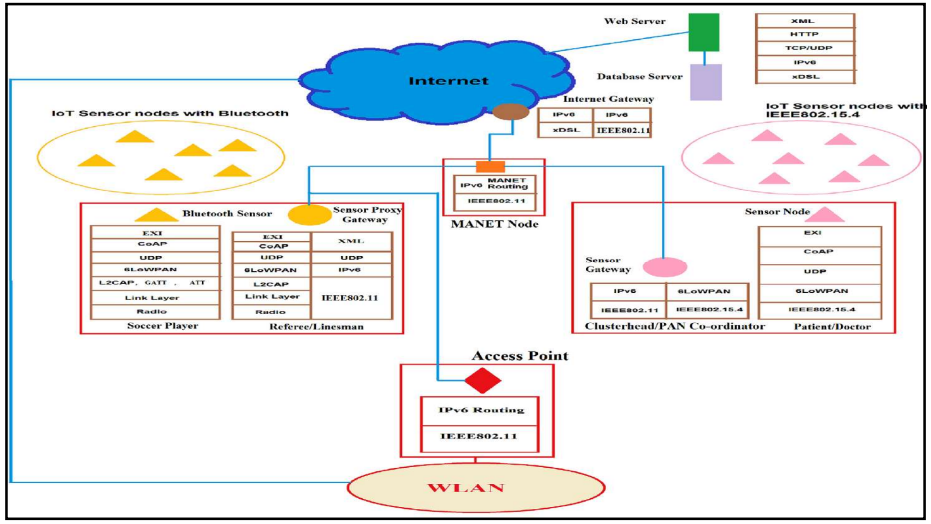
- The **internal address Method of Sensor** is not compatible with the **IP method of the internet.**
- **Wireless Sensor Networks (WSNs)** are connecting **things to the Internet** through a **gateway** that interfaces the **WSN to the Internet.**

Challenge

- **Various Devices** in WSN
  - ✓ Uses **different protocols** to connect to the network using **Wi-Fi, Bluetooth, Ethernet, MQTT, ZigBee** and others.
  - ✓ May connect to **different control environments** and
  - ✓ Different **models for management** and **security**
  - ✓ Some **Sensors Devices** and **controllers** use **very low energy** and don't support **energy-intensive protocols** like **Wi-Fi or Bluetooth**, and therefore **can't connect directly** to the Internet.

Challenge

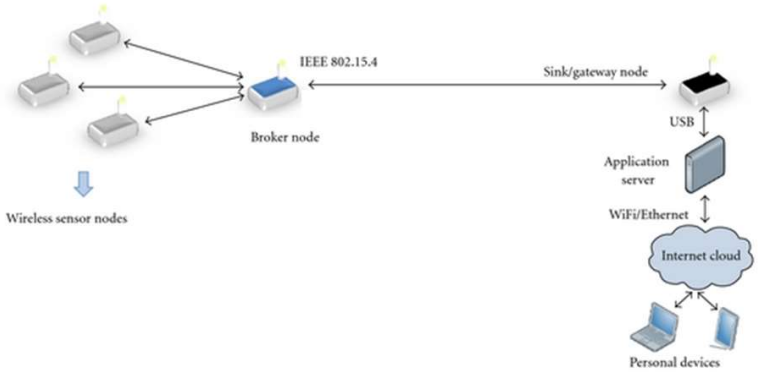
- The Success for WSNs and IoT applications, Low energy consumption is
  - ✓ To support the **long flow of independent battery-powered** devices and
  - ✓ To reduce **maintenance cost.**



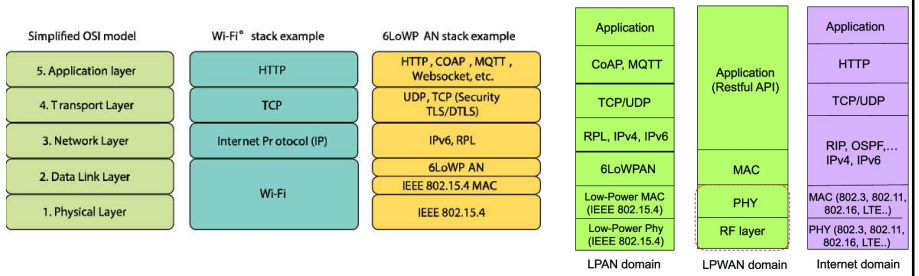
Integration to Connect WSN and Internet

- The **integration to connect** to both **WSN and the Internet infrastructures**
- **Classification:**
  1. **Stack based**
  2. **Topology based**

Integration to Connect WSN and Internet



Integration to Connect WSN and Internet



Stack based Classification

- In **Stack Based Classification**
  - ✓ Integration level depends on **similarities** between **network stacks of WSN and Internet**
  - ✓ Classification: **Front End, Gateway or TCP/IP**

Stack-based Classification

- A **WSN** can be **completely independent** from the **Internet (*Front-End*)**
- **A WSN** can **Exchange information** with **Internet hosts (*Gateway*),** or
- **A WSN** can share a **compatible network layer protocol (*TCP/IP*).**

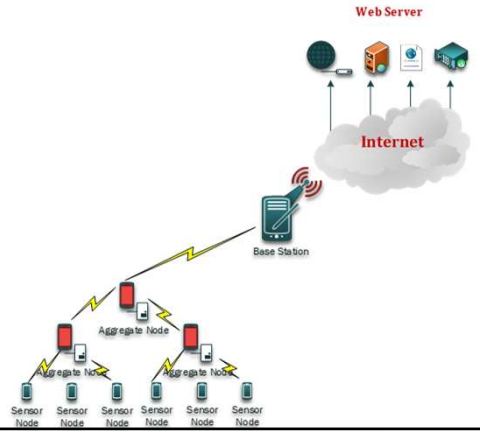
Stack-based Classification

- **Front-end Solution:** WSN independent from the Internet
  - ✓ Implements its own protocols
  - ✓ All interaction managed by a centralized base station
- **Gateway solution:** WSN can exchange information with Internet hosts
  - ✓ Internet hosts and sensor nodes can address each other indirectly through a gateway
  - ✓ Base station acts as application layer gateway; translating lower layer protocols and routing information
- **TCP/IP solution:** WSN shares a compatible network layer protocol
  - ✓ Sensor nodes implement TCP/IP (or 6LoWPAN) to become a part of the Internet
  - ✓ Sensor nodes may not be able to use specific WSN protocols

Stack-based Classification : (1) Front End Solution

- The **external Internet hosts** and the **sensor nodes** never **communicate directly** with each other.
- The WSN is **completely independent** from the Internet,
- All interactions between the **outside world** and the **sensor network** will be managed by a **centralized device**, such as a **base station.**
  - ✓ This **base station** can store all the **data streams** coming from the **WSN**
  - ✓ it also provide the data streams to **external** entities **Web Server**
  - ✓ Any queries coming from Internet hosts(**Web Server**) will always traverse the base station.

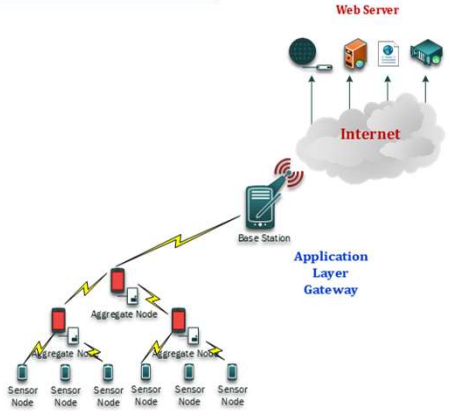
Stack-based Classification: Front End Solution



Stack-based Classification: (2) Gateway solution

- Existence of a **device (e.g. base station)** that acts as an **application layer gateway,**
  - ✓ In charge of translating the **lower layer protocols** from different networks **(WSN and Web Server)**
  - ✓ Routes the **information** from **one point to another.**
  - ✓ **Internet hosts and sensor nodes** will be able to **exchange information** without establishing a **truly direct connection.**

Stack-based Classification: Gateway Solution



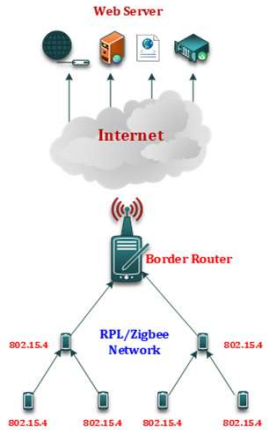
SBC-Gateway solution : Observation

- WSN is **still independent** from the Internet, and **all queries** still need to traverse a **gateway device.**

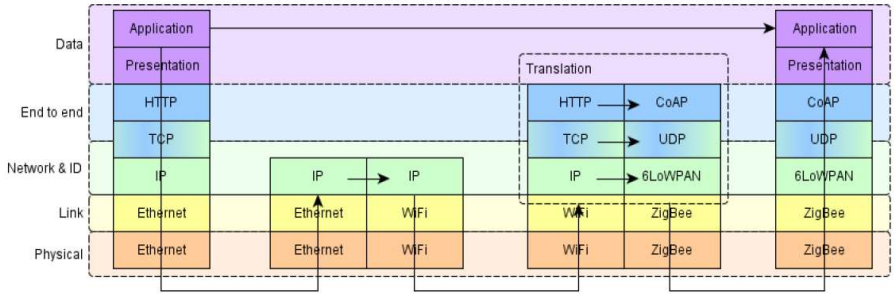
Stack-based Classification: (3) TCP/IP solution

- **Sensor nodes** implement the **TCP/IP stack** (or a compatible set of protocols such as **6LoWPAN in 802.15.4 networks**)
  - ✓ Any **Internet host** can open a **direct connection with them**.
  - ✓ This solution fully **integrates the WSN with the IoT**.
  - ✓ Sensor nodes are **no longer able** to use specific **WSN protocols.**

Stack-based Classification: TCP/IP Solution



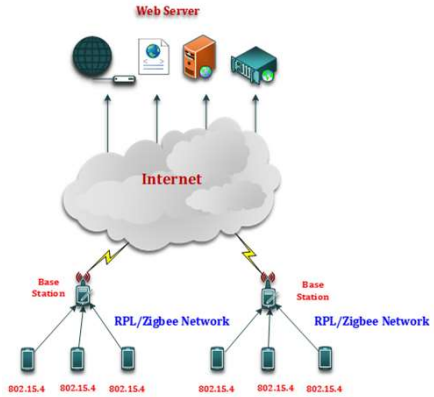
Stack-based Classification: (3) TCP/IP solution



Topology-based Classification

- **Hybrid Solution**
- **Access Point Solution**

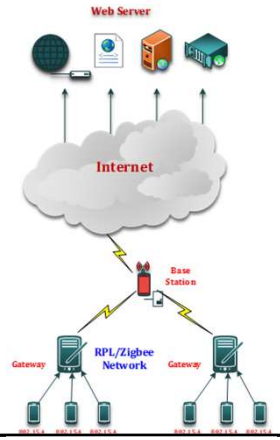
Topology-based Classification : Hybrid Solution



Topology-based Classification : Hybrid Solution

- **Set of nodes** within the WSN, usually located at the **edge of the network**
- These **edge nodes** are able to access the **Internet in a direct way.**
- These **nodes** can be easily mapped to **base stations ,**
- Every **sensor/Edge Node** within the WSN needs to **traverse them** in order to connect the **central system (base stations).**

Topology-based Classification : Access Point Solution



Topology-based Classification : Access Point solution

- WSNs become **unbalanced trees** with **multiple roots,**
  - ✓ Where **leaves** are **normal sensor nodes** and **all other elements** of the tree are **Internet-enabled nodes.**
  - ✓ All sensor nodes can be able to **access the Internet** in just **one hop.**
- One of the main features of this approach is the possibility to increase the capabilities of nodes that belong to the backbone network.
- For example, backbone nodes can have **more resources** than normal nodes, and can implement **faster network standards** (e.g. 802.11 vs 802.15.4).

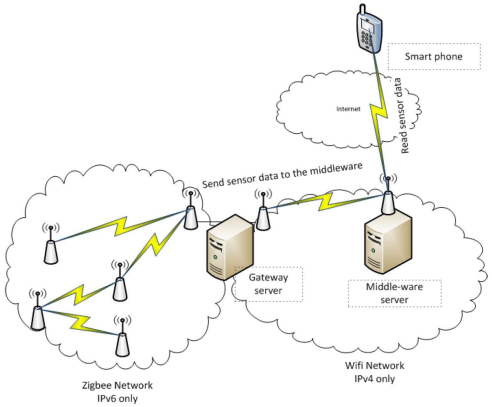
Observation

- The only task of the nodes that **connect the Internet** with the **local network** will be to behave as **translators** (e.g. between **6LoWPAN and IPv6**).

Integrating WSNs into IoT

- To enable the **integration of WSN in the IoT**
  - ✓ The **IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) protocol** should be **implemented and deployed** in Wireless Sensor Networks (WSNs);
  - ✓ **Internet Protocol Version 6 (IPv6)** is used to uniquely **identify the things** in the Internet.

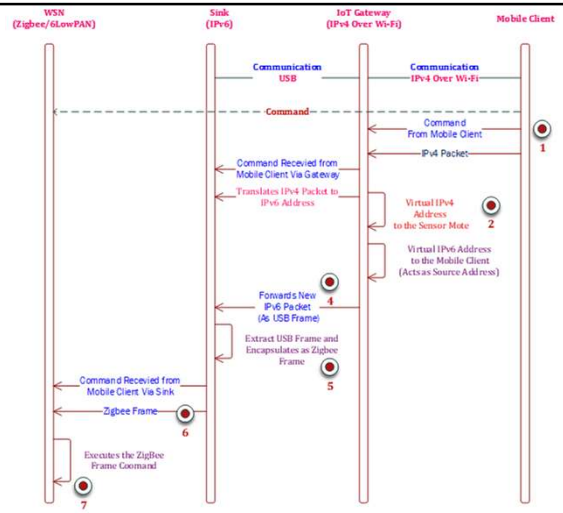
Integrating WSNs into IoT



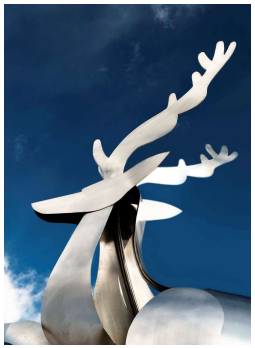
Protocol Description

- The **WSN** uses **Zigbee/6LowPAN** as the **communication medium** and uses **IPv6** in the **network layer**.
- The communication between the **gateway and the Mobile client** is based on **IPv4 over Wi-Fi.**

Protocol Description



Protocol Description

- This architecture enables
  - ✓ **Any device** within the network will communicate with **any other device independently**
  - ✓ Using **communication medium (e.g., Zigbee/6LowPAN or Wi-Fi)**
  - ✓ Using **network protocol (e.g., IPv4 or IPv6).**
- The **connection** between the **sink and the gateway** is based on **Universal Serial Bus (USB) connection.**

Thank U