innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

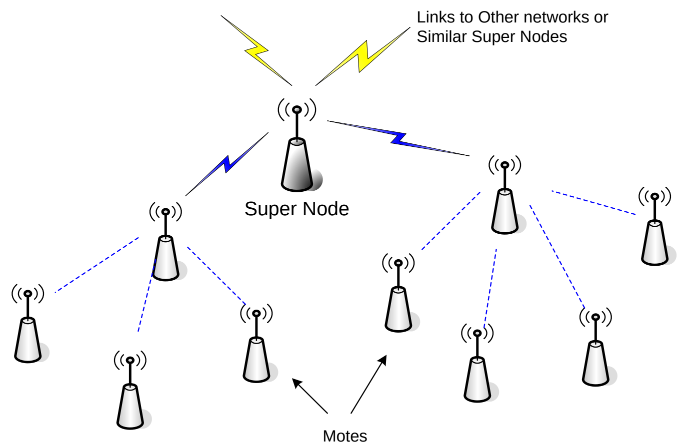
Wireless sensor networks: Introduction

Wireless sensor networks

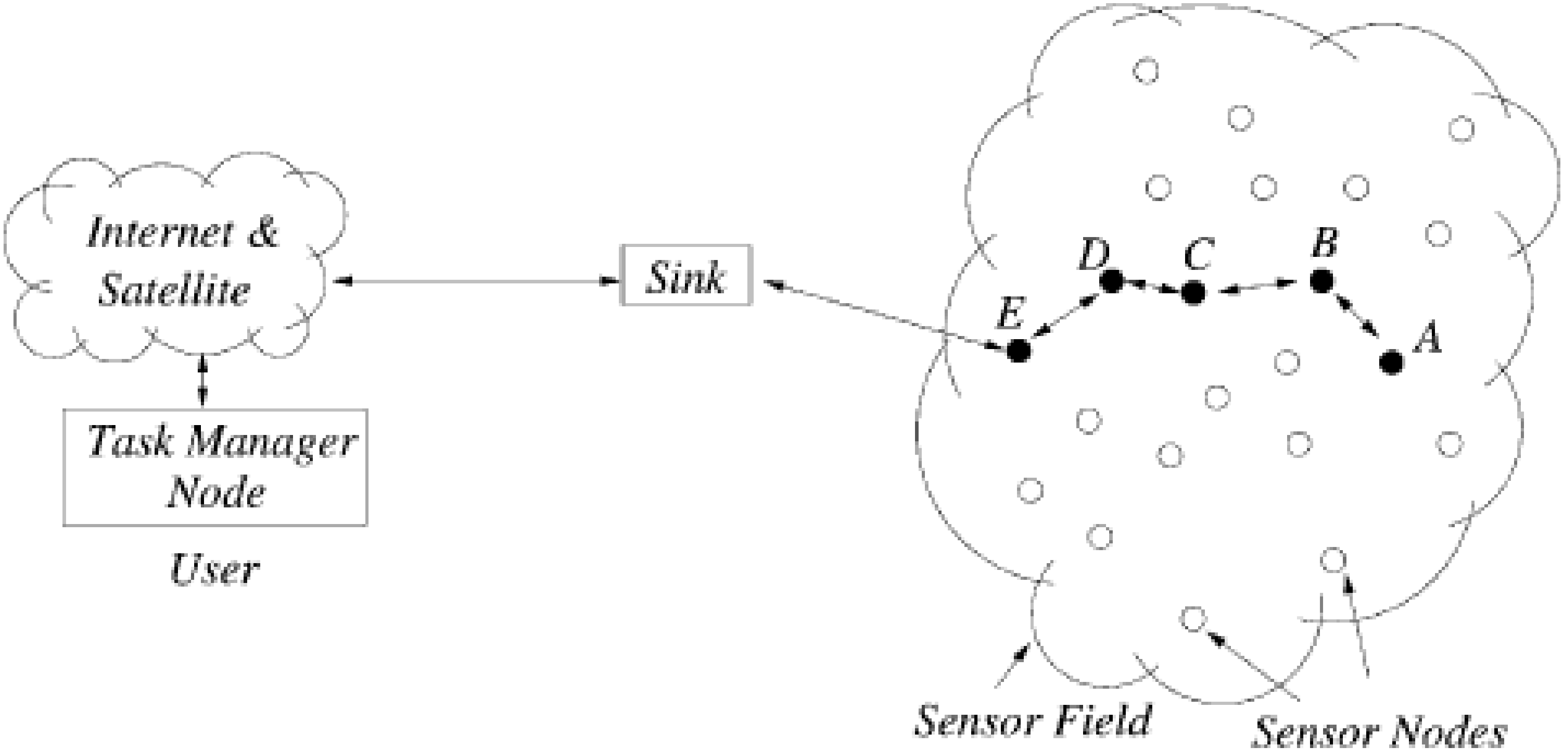
BITS Pilani

- *A **wireless sensor network** (WSN) is a wireless network consisting of **spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions**, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations*

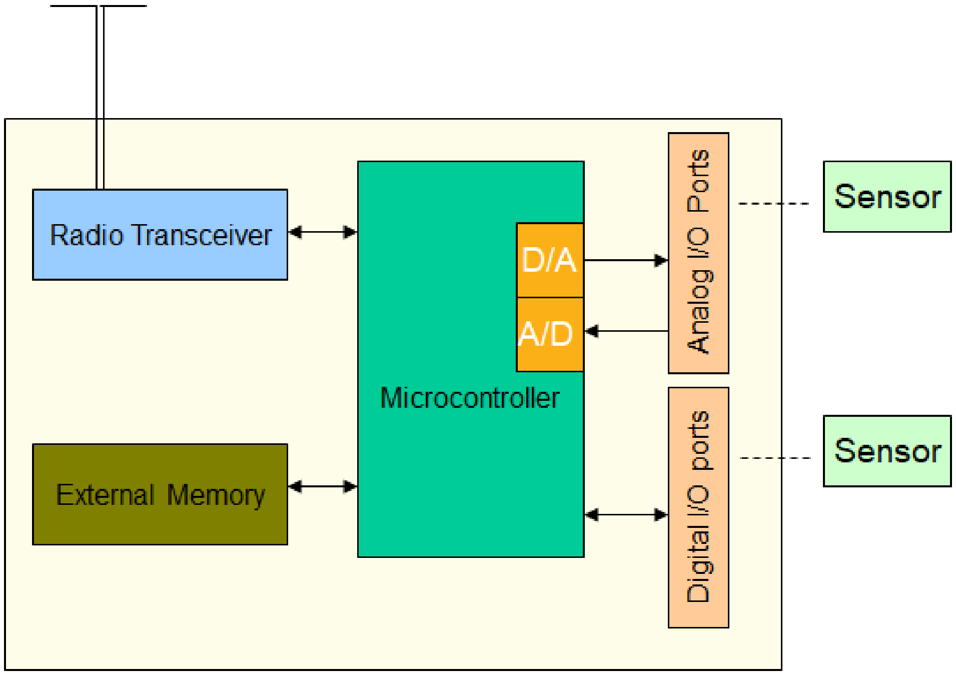
- Formed by hundreds or thousands of motes that communicate with each other and pass data along from one to another



IOT context


Internet &
Satellite
Sink
Task Manager
Node
User
D
C
B
E
A
Sensor Field
Sensor Nodes

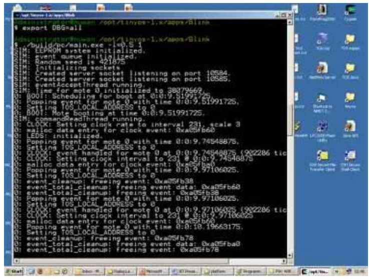
Motes: the building blocks of WSN



- A very low cost low power computer
- Monitors one or more sensors
- A Radio Link to the outside world
- Are the building blocks of Wireless Sensor Networks (WSN)

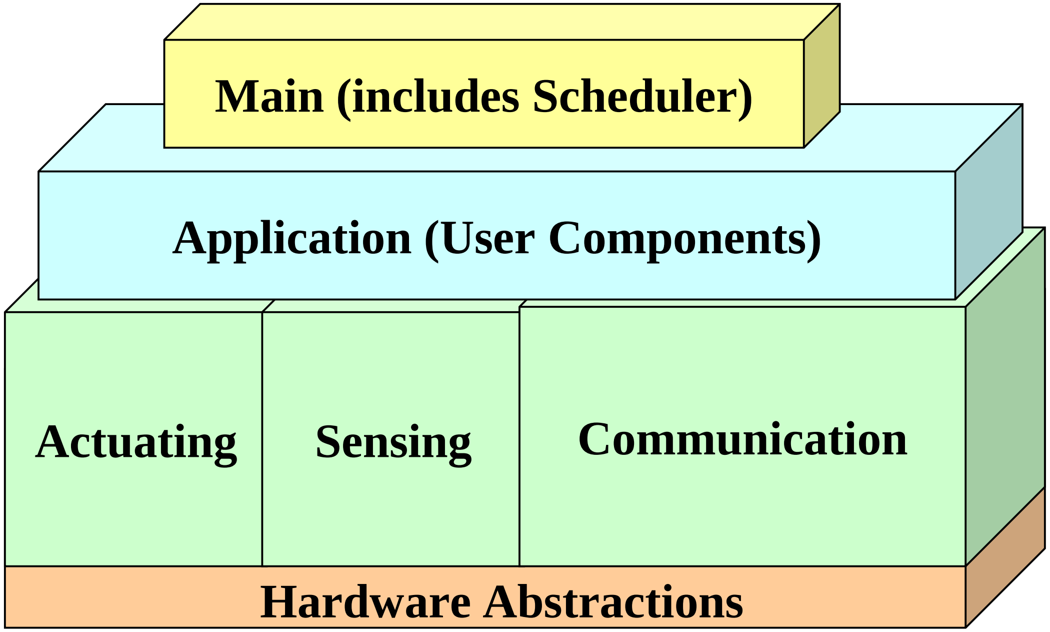
Example of motes

BITS Pilani

mica 	mica2 	mica2dot 	micaz 
telos 	telosb 	rene2 	pc 

TinyOS

- Event-driven programming model instead of multithreading
- TinyOS and its programs written in nesC

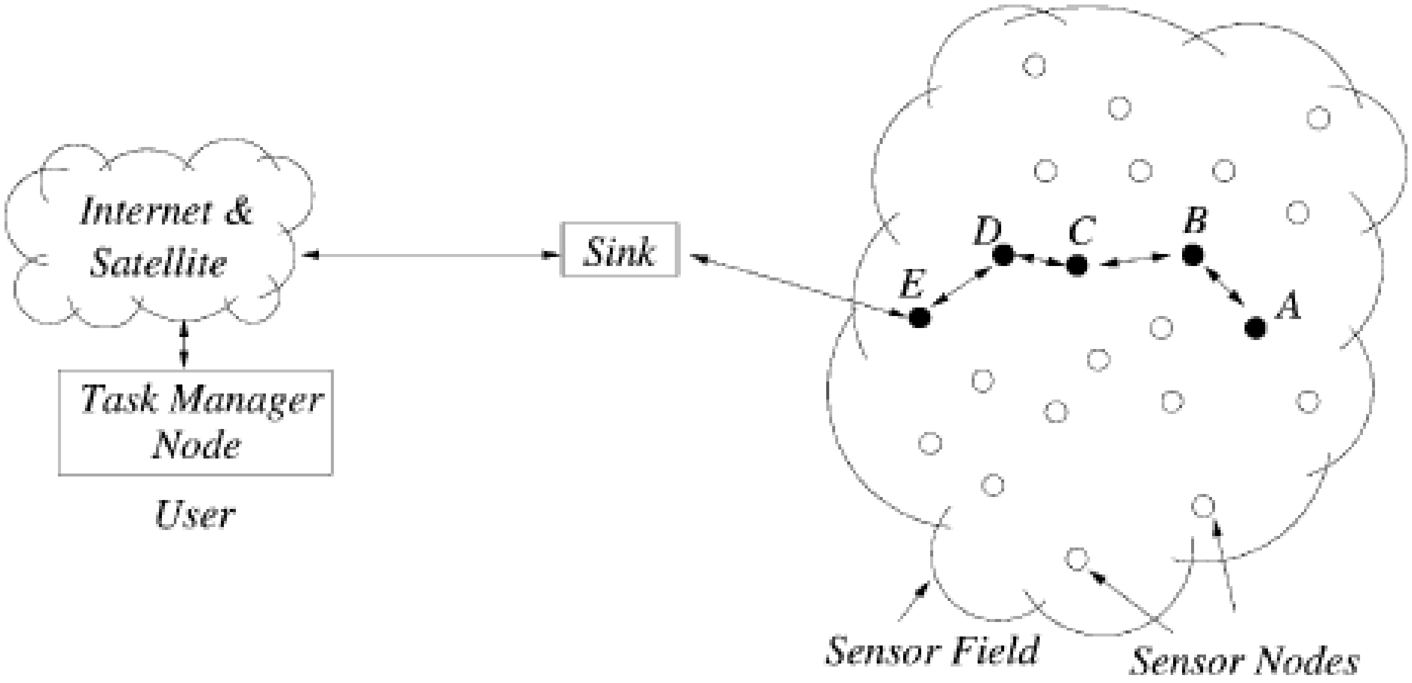


Characteristics of TinyOS

- Small memory footprint
  - non-pre emptable FIFO task scheduling
- Power Efficient
  - Puts microcontroller to sleep
  - Puts radio to sleep
- Concurrency-Intensive Operations
  - Event-driven architecture
  - Efficient Interrupts and event handling
- No Real-time guarantees

WSN Broad Applications

- Monitoring **Space**
- Monitoring **Objects**
- Monitoring **Interactions of Objects & Space**



Monitoring Space

- Environmental and Habitat Monitoring
- Precision Agriculture
- Indoor Climate Control
- Military Surveillance
- Intelligent Alarms

Monitoring objects

BITS Pilani

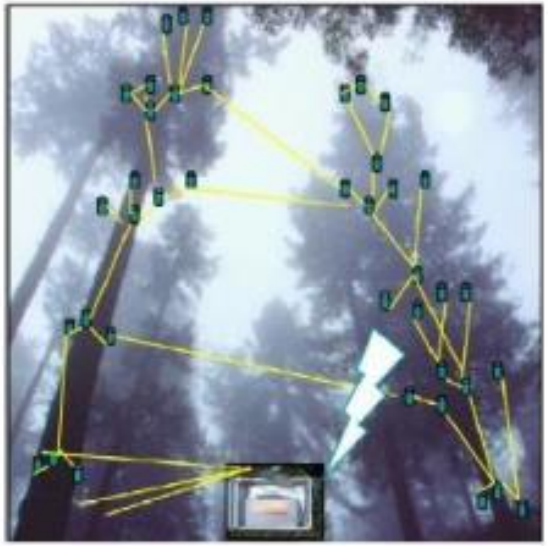
- Structural Monitoring
- Condition-based Maintenance
- Medical Diagnostics
- Urban terrain mapping

Monitoring Interactions of objects and space

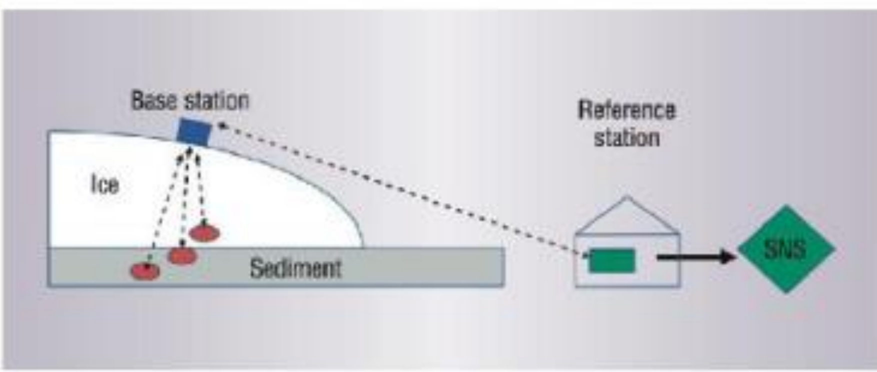
BITS Pilani

- Wildlife Habitats
- Disaster Management
- Emergency Response
- Asset Tracking
- Health Care
- Manufacturing Process Flows

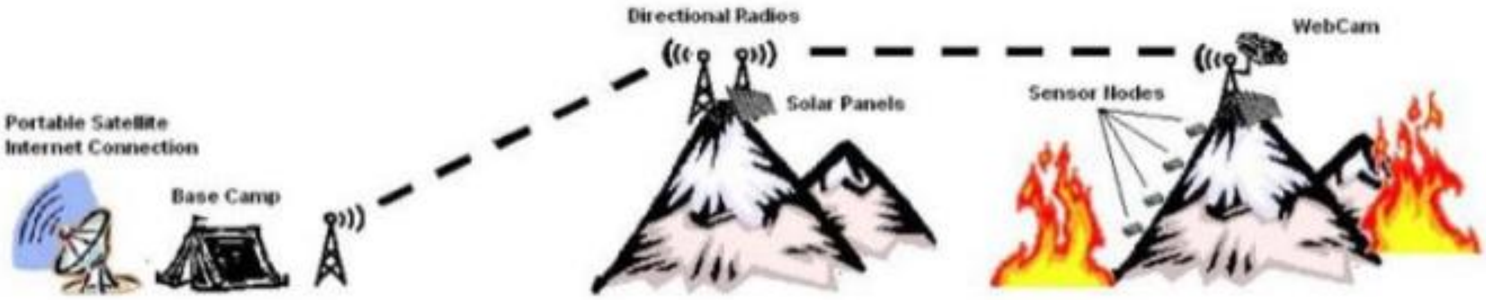
BITS Pilani



Environmental Monitoring

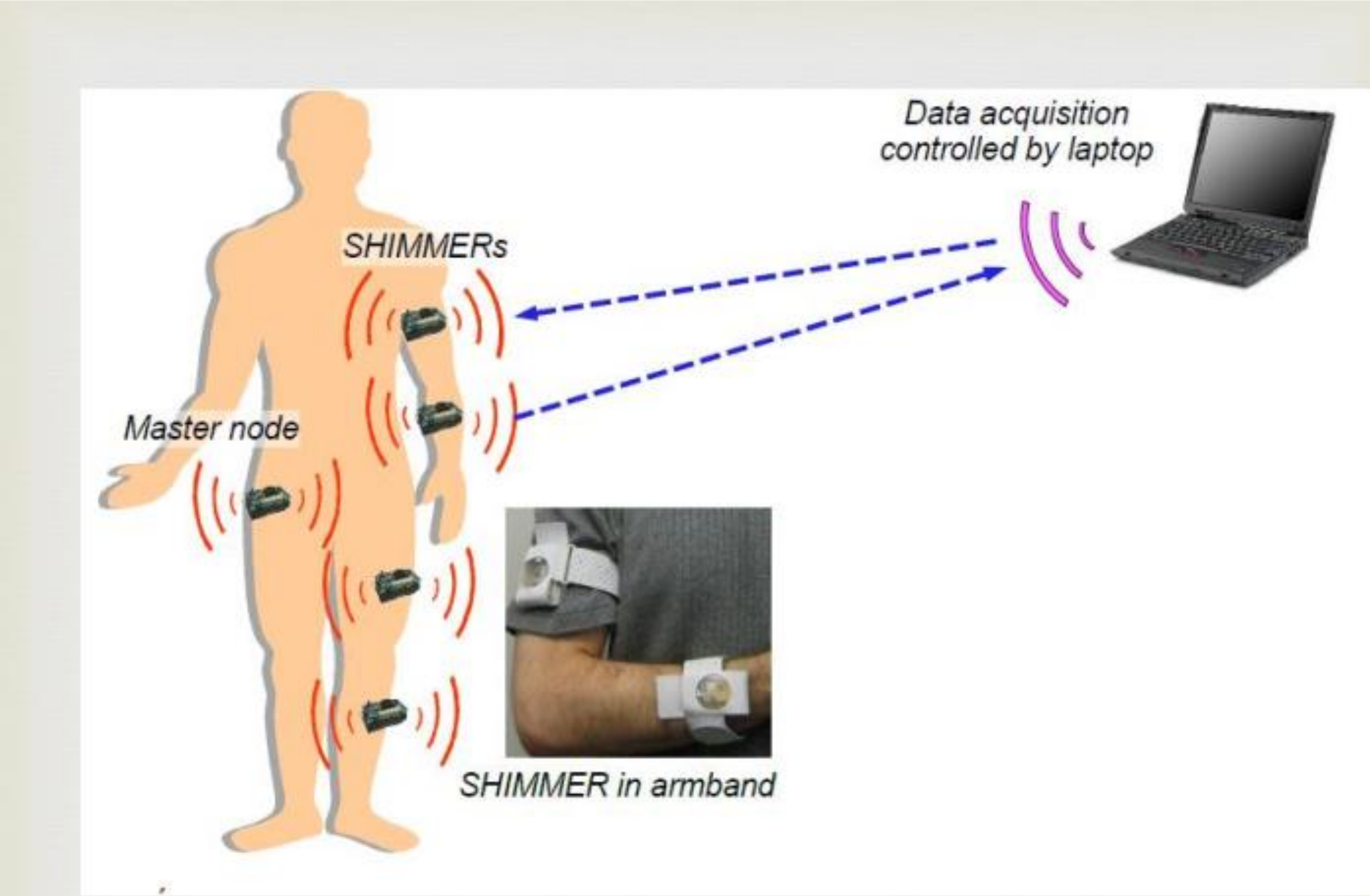


Glacier Monitoring



Forest Fire Monitoring

BITS Pilani

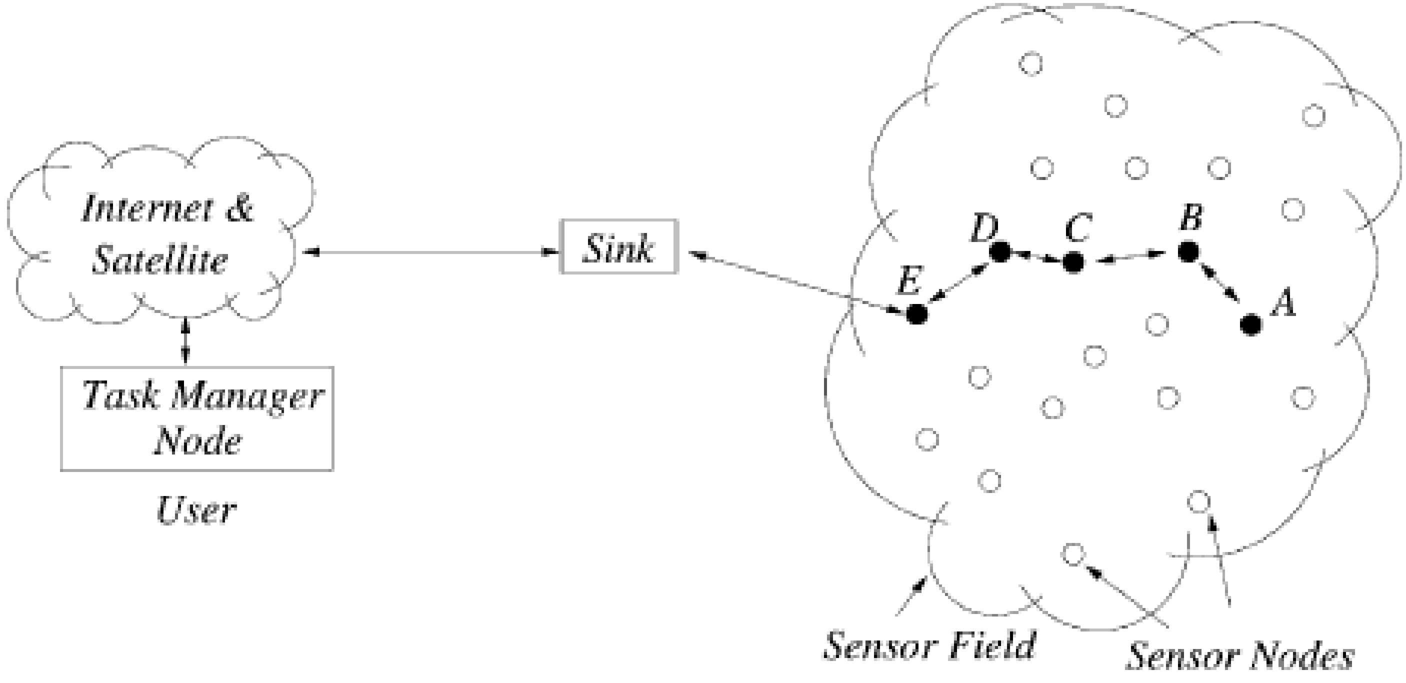


Nueromotor Disease Monitoring

Requirements for WSN

BITS Pilani

- Long Life
- Small Sized nodes
- Less cost



Constraints on locally available resources

- Limited Energy
- Limited Processing power
- Limited Memory
- Limited Bandwidth

Diversity of WSN nodes and dynamics

- Motes
- Sensors
- Nodes Deployed Randomly – Mobile
- Motes are subject to energy budget
- Motes may die
- Wireless Communication Media – dynamic

Characteristic features

- The large density of nodes - sensors that are **cheap to manufacture and ready to deploy**
- The **application diversity**, which requires different kinds of **application specific sensor** devices
- The **tight limitations in energy, processing power and memory**, which call for highly optimized and lightweight protocols
- The **collaborative objective** for which all the sensor nodes cooperate with one another

Challenges

BITS Pilani

- Sensor networks are prone to **frequent topology changes** due to several reason hardware failure
- **depleted batteries**
- intermittent **radio interference**
- **environmental factors**
- addition of sensor nodes
- applications require a degree of inherent **fault tolerance** and the ability to reconfigure themselves as the network topology evolves

Advantages

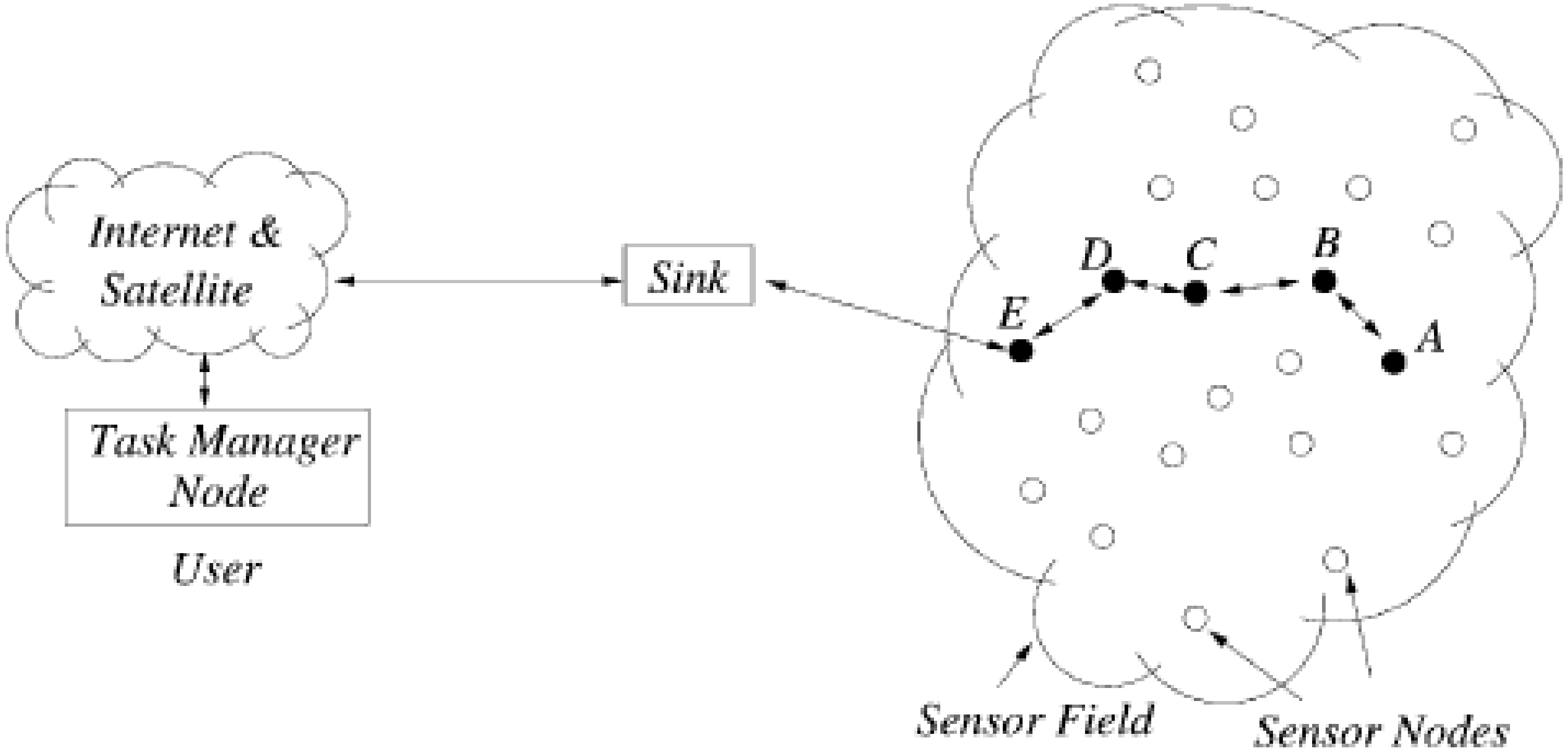
- Due to the dense deployment of a greater number of nodes - higher level of **fault tolerance** is achievable in WSN
- **Coverage of a large area is possible** through the union of coverage of several small sensors
- Coverage of a particular area and terrain shaped as needed to overcome any potential barriers or holes in the area under observation
- It is **possible to incrementally extend coverage** of the observed area & density by deploying additional sensor nodes within the region of interest

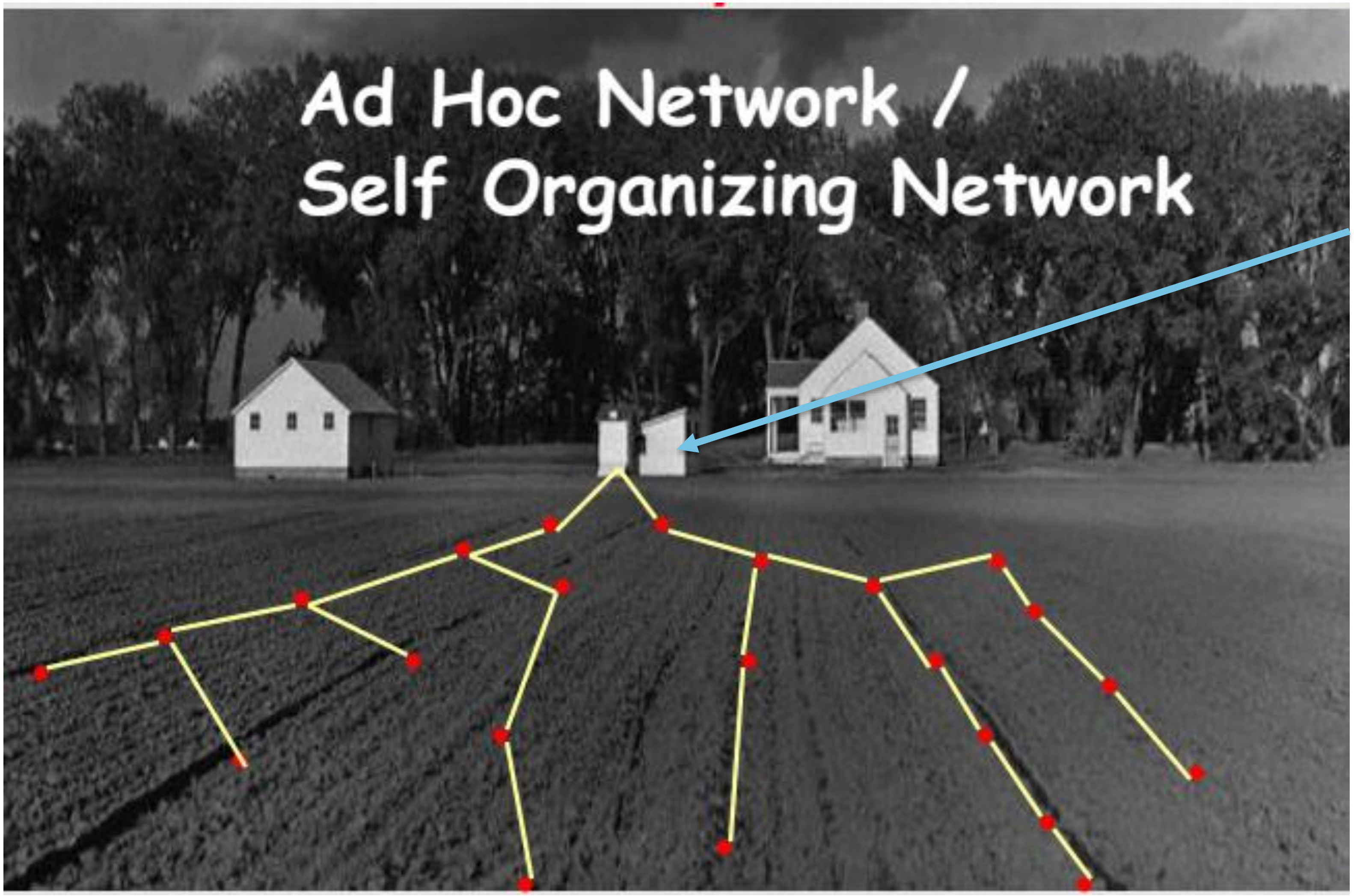
Advantages/ Considerations

- An improvement in sensing quality is achieved by combining multiple, independent sensor readings.
- **Local collaboration** between nearby sensor nodes achieves a higher level of confidence in observed phenomena.
- Since **nodes are deployed in close proximity to the sensed event**- this overcomes any ambient environmental factors that might otherwise interfere with observation of the desired phenomenon

Network architectures in WSN

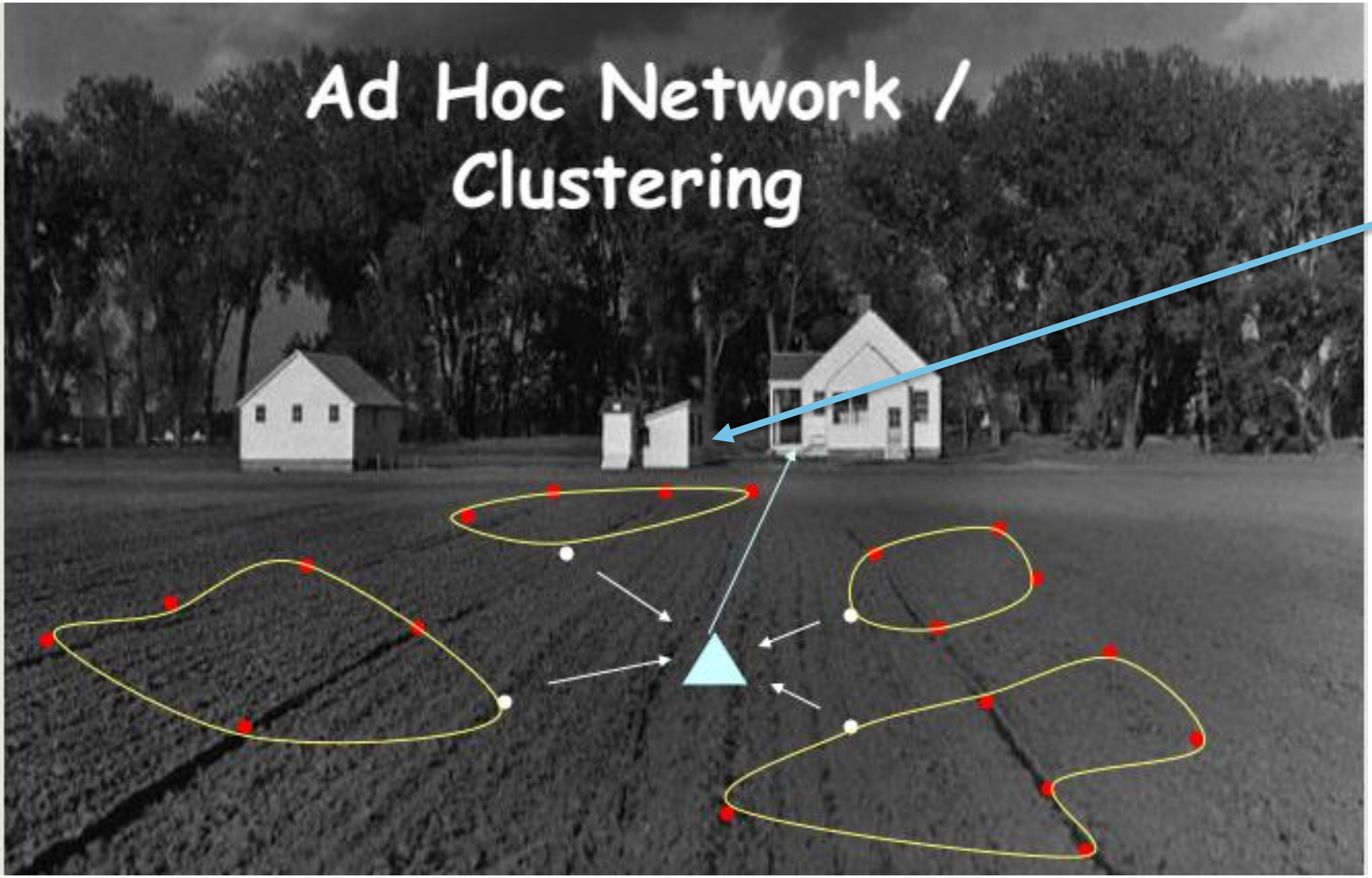
- How are the sensor nodes teamed up





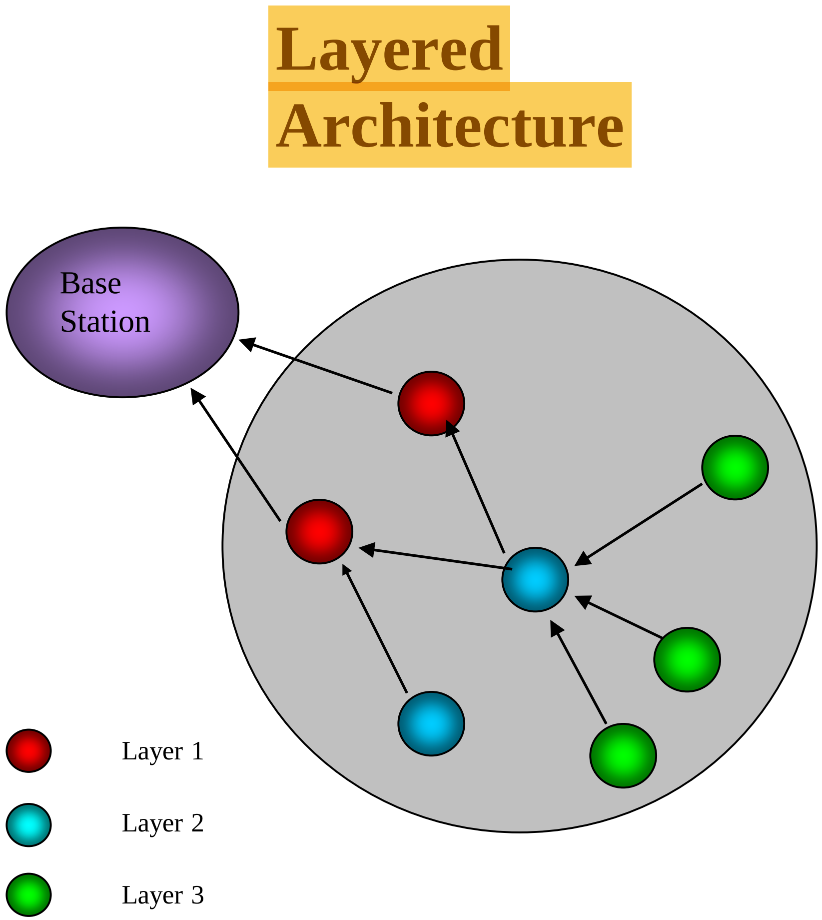
SINK/ Base station/ Gateway

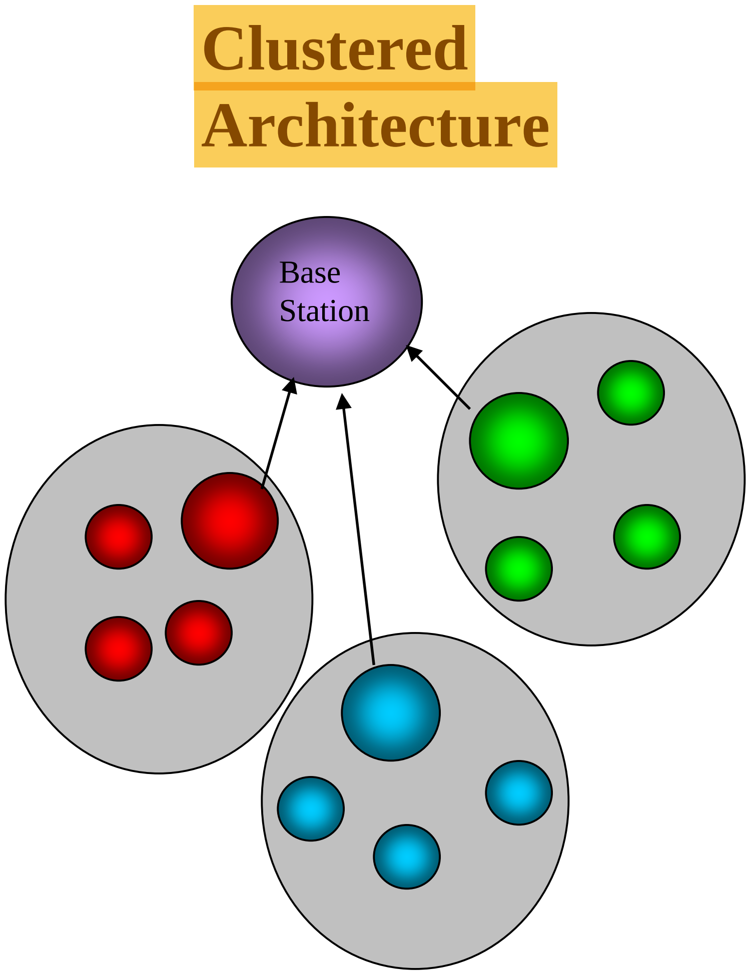
BITS Pilani



SINK

Network Architectures: Layered vs Clustered





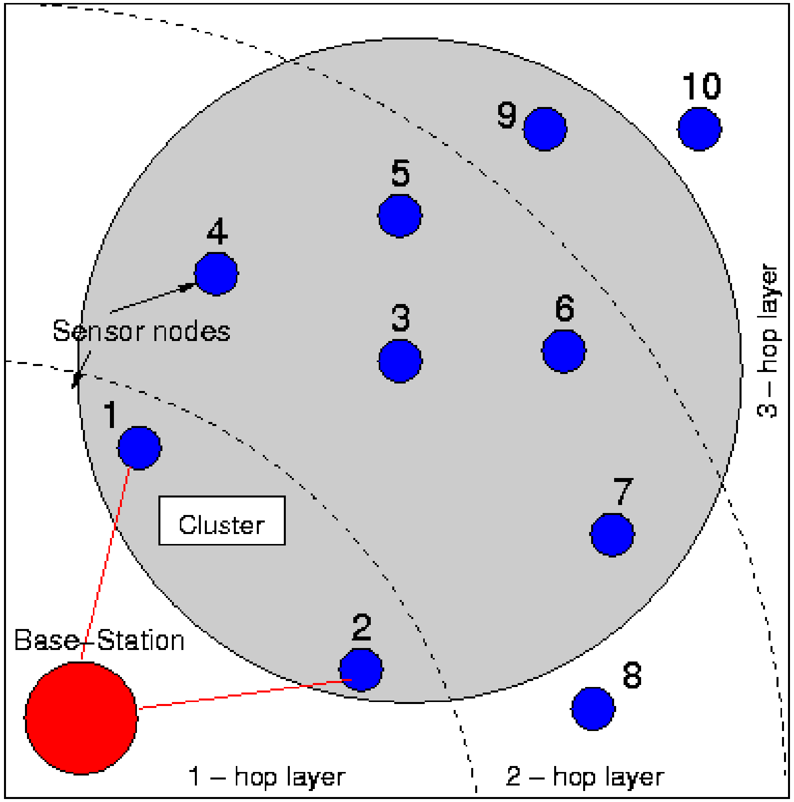
Larger Nodes denote Cluster Heads

Layered network architecture

A few hundred sensor nodes (half/full duplex)

A single powerful base-station
Network nodes are organized into concentric ***Layers***

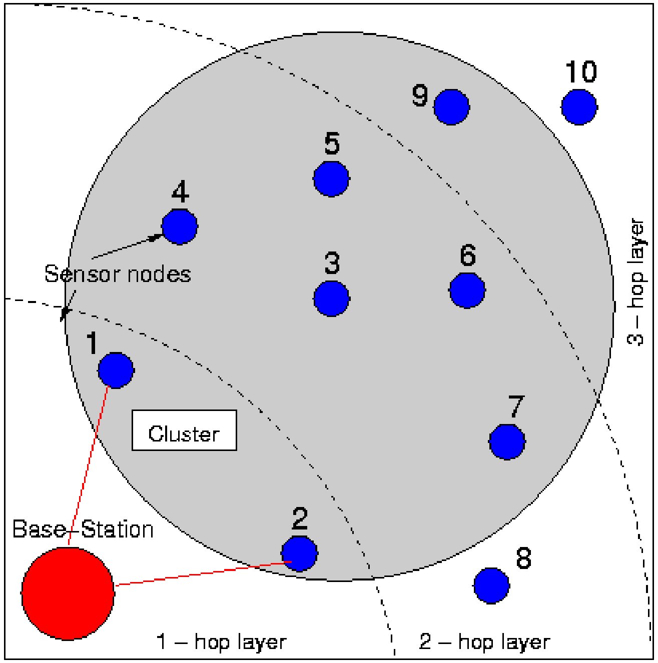
Layer: Set of nodes that have the same hop-count to the base-statior



Layered network architecture (cont.)

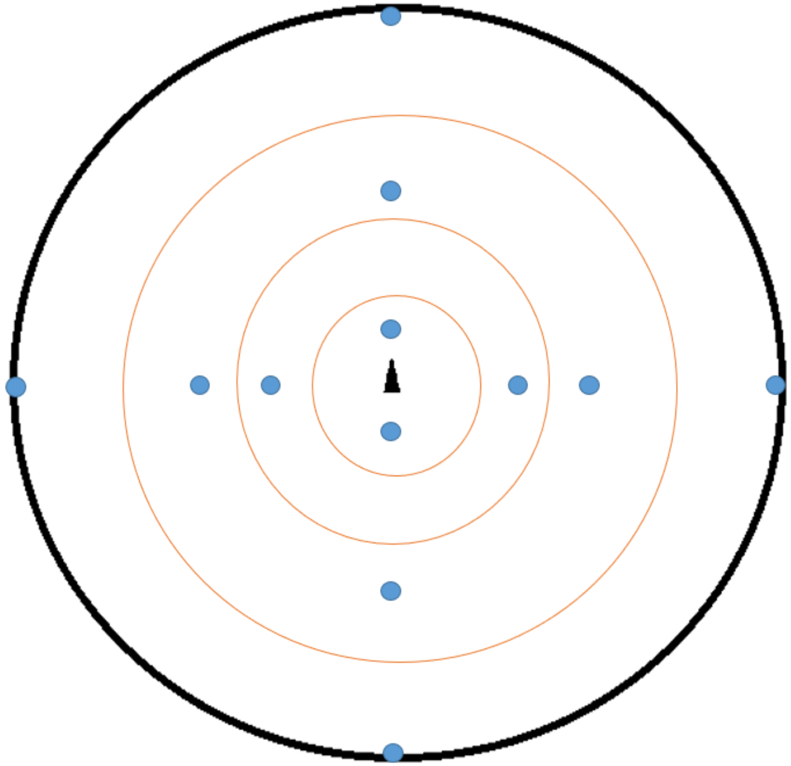
BITS Pilani

- Set of wireless sensor nodes create an infrastructure – provide sensing and data forwarding functionality
- BS is data gathering, processing entity and communication link to larger network
- Shorter-range, low-power transmissions preferred to conserve power



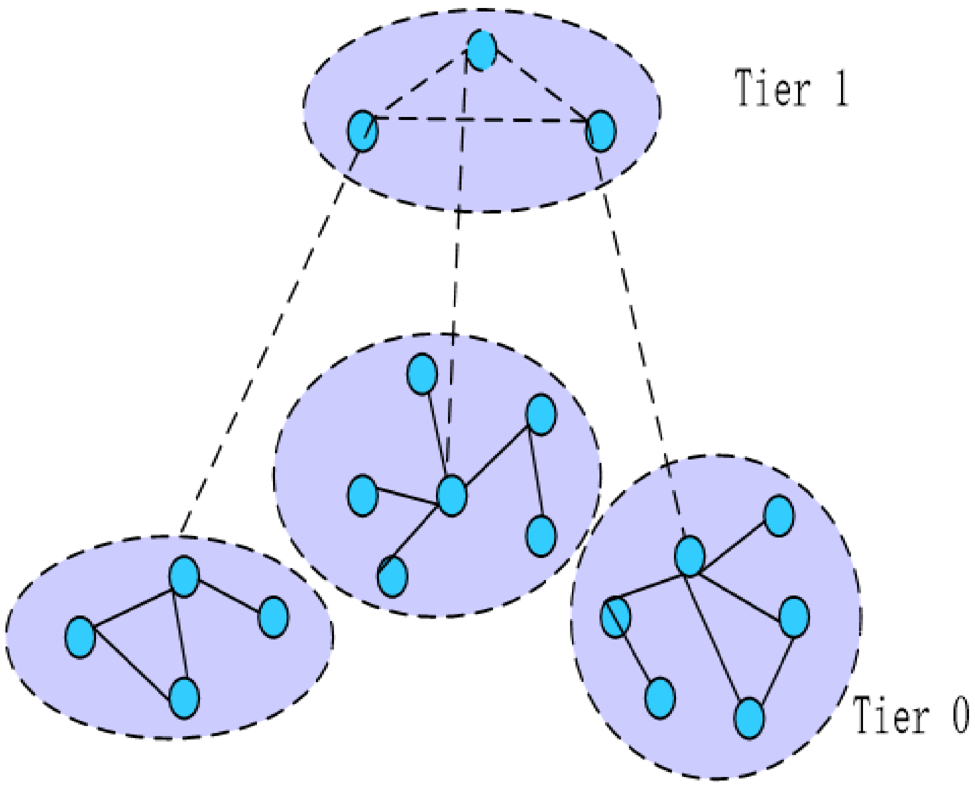
Case scenario

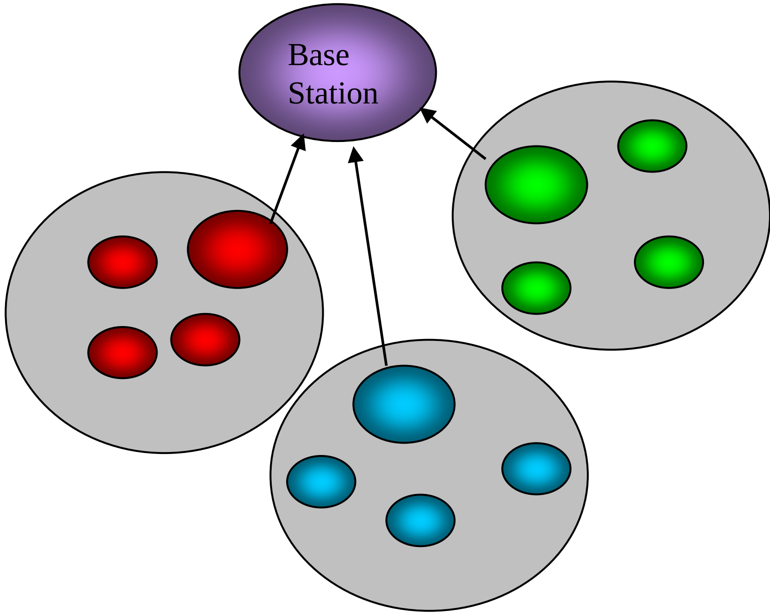
Assume that in the network shown below the transmission range of a mote is 2m. How many layers are there in the network given that the base station is in the center of the network and each consecutive red concentric circle is 1m apart from each other (thus leading to the outermost circle



Clustered Network architecture

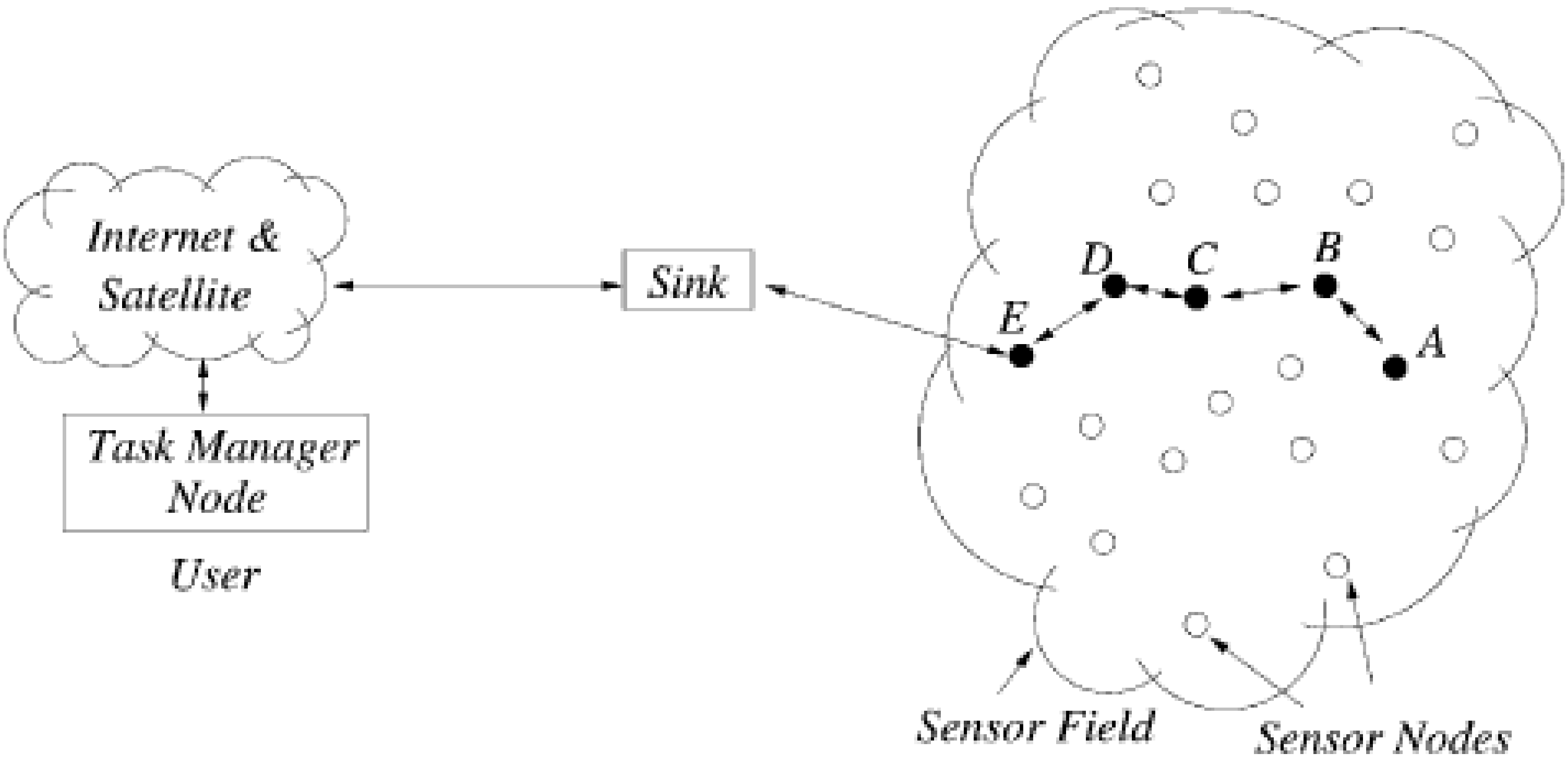
- Sensor nodes autonomously form a group called **clusters**.
- The clustering process is applied recursively to form a hierarchy of clusters





WSN Routing

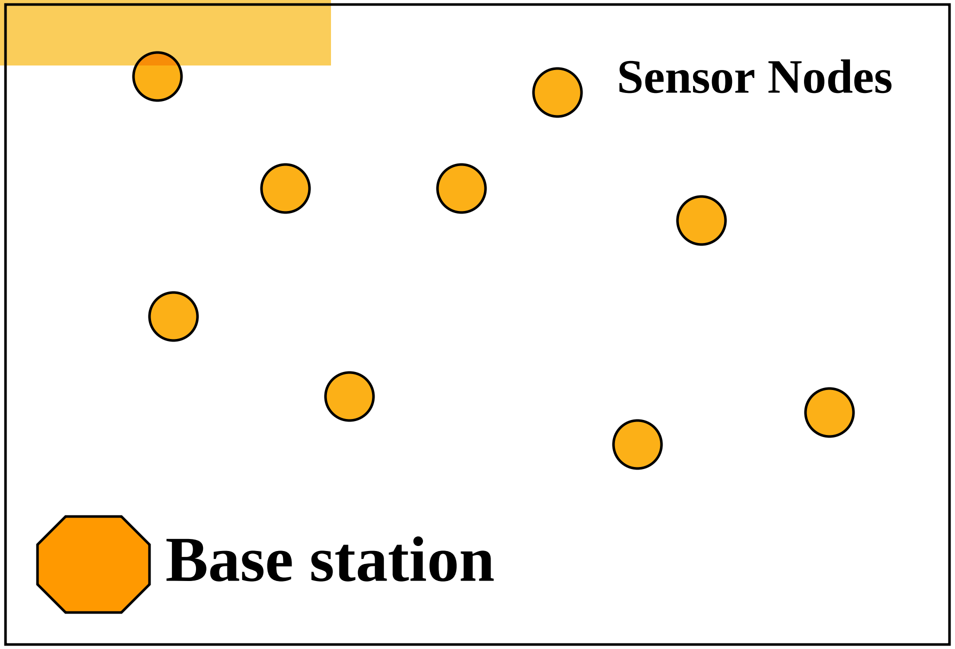
- Deals with details of : How does A send data to sink/user



Routing

BITS Pilani

- **Objective**: Transmit sensed data from each sensor node to a base station
  - One round = BS collecting data from all nodes
- Goal is to **maximize the number of rounds of communication** before nodes die and network is inoperable
- Minimize energy AND reduce delay
  - Conflicting requirements

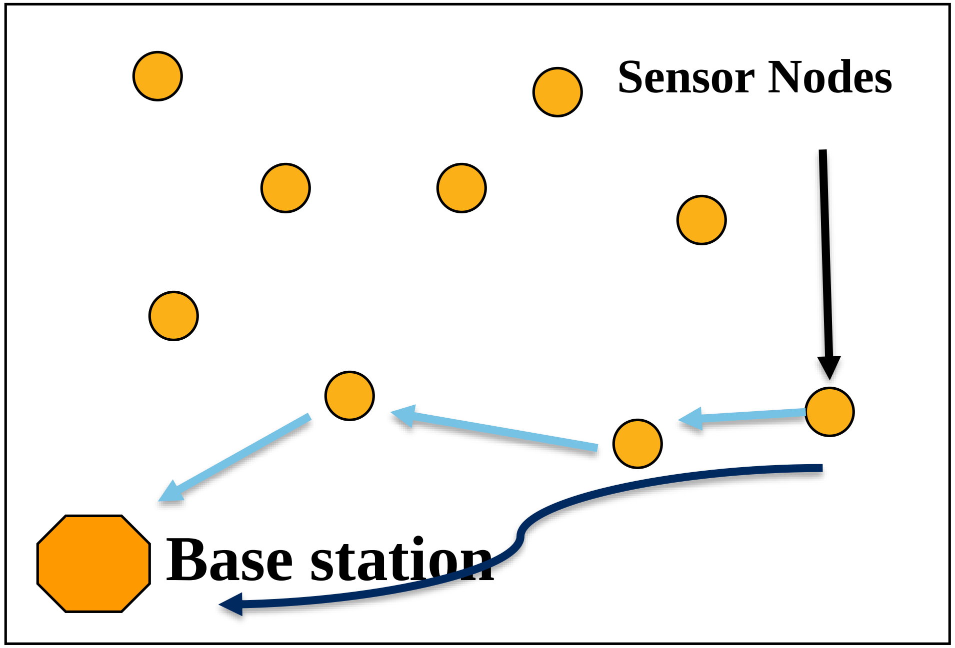


Energy * Delay metric

BITS Pilani

- Why **energy * delay** metric?
  - Find optimal balance to gather data quickly but in an energy efficient manner
  - Energy = Energy consumed per round
  - Delay = Delay per round (I.e. for all nodes to send packet to BS)

- Why is this metric important?
  - Time and energy critical applications



Direct transmission

- All nodes transmit to the base station (BS)
- Very expensive since BS may be located very far away and **nodes need more energy to transmit over longer distances**
- Farther the distance, greater the **propagation losses,** and hence higher the transmission power
- All **nodes must take turns** transmitting to the BS so delay is high (N units for a N-node network)
- Better scheme is to have fewer nodes transmit this far distance to lower energy costs and more simultaneous transmissions to lower delay

Routing protocols

BITS Pilani

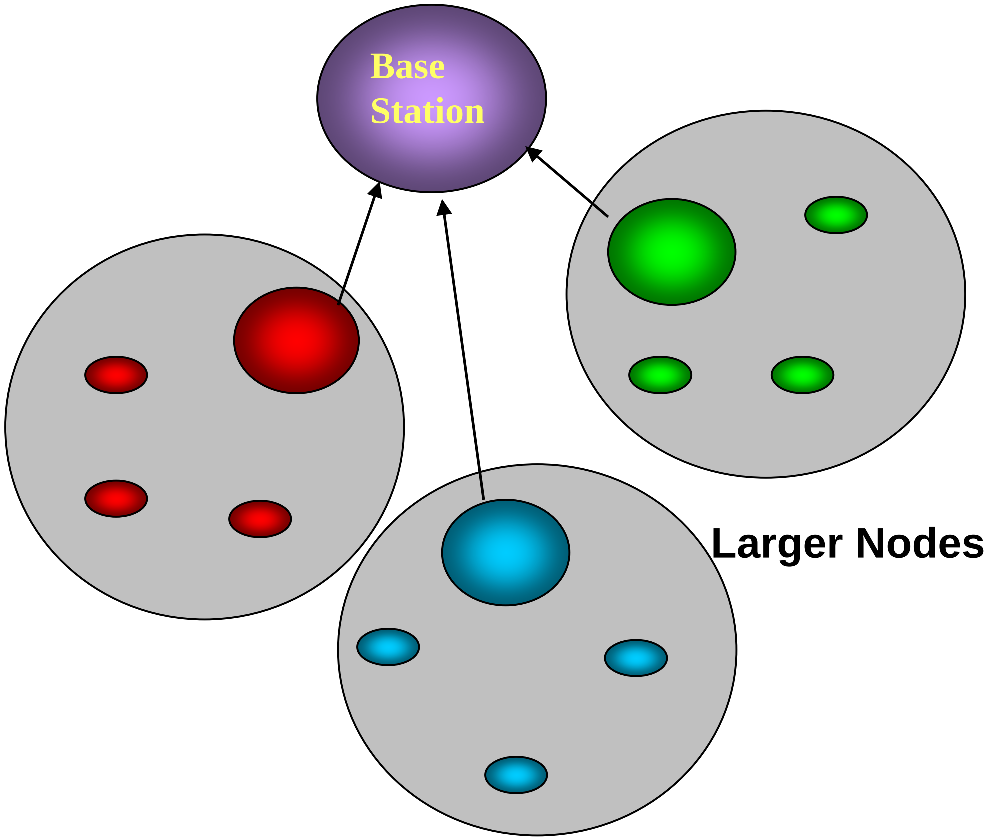
- LEACH
- PEGASIS
- Directed Diffusion
- TEEN
- APTEEN
- Etc…

- **Considerations:**

- Energy, network lifetime, accuracy, query response time etc.

LEACH

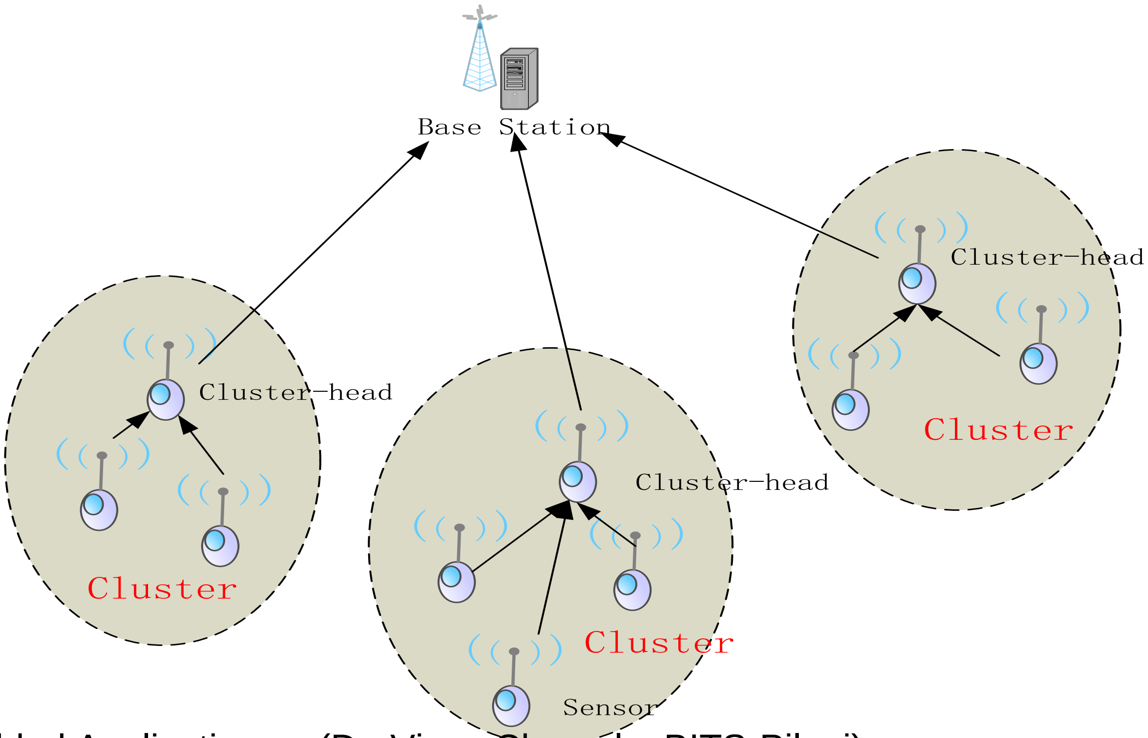
- Low Energy Adaptive Clustering Hierarchy
  - Two-level hierarchy



Larger Nodes denote Cluster Heads

Leach protocol

- It uses distributed algorithm to organize the sensor nodes into clusters.
- The cluster-head nodes create TDMA schedules.
- Nodes transmit data during their assigned slots.
- The energy efficiency of the LEACH is mainly due to data fusion.



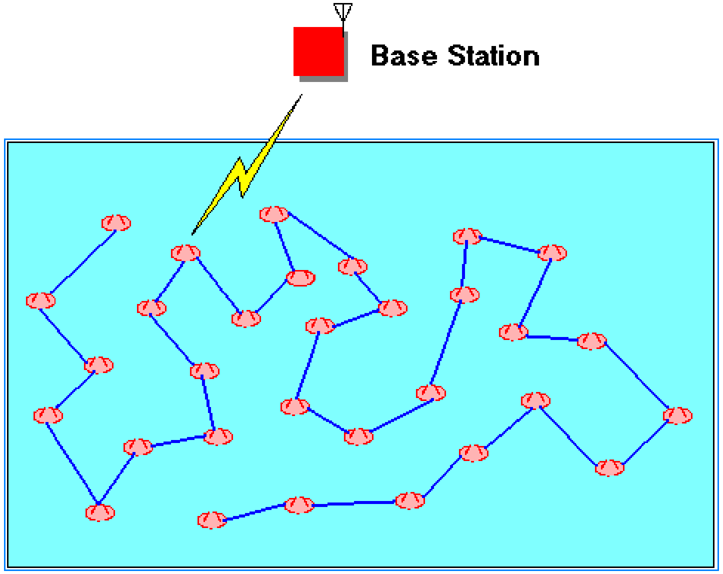
Scheme: PEGASIS

- Goals of PEGASIS (<u>Power-Efficient GAthering for Sensor Information Systems)</u>
  - ➢ Minimize distant nodes transmitting directly
  - ➢ Minimize number of leaders that transmit to BS
  - ➢ Minimize broadcasting overhead
  - ➢ Minimize number or messages leader needs to receive
  - ➢ Distribute work more equally among all nodes

PEGASIS (cont.)

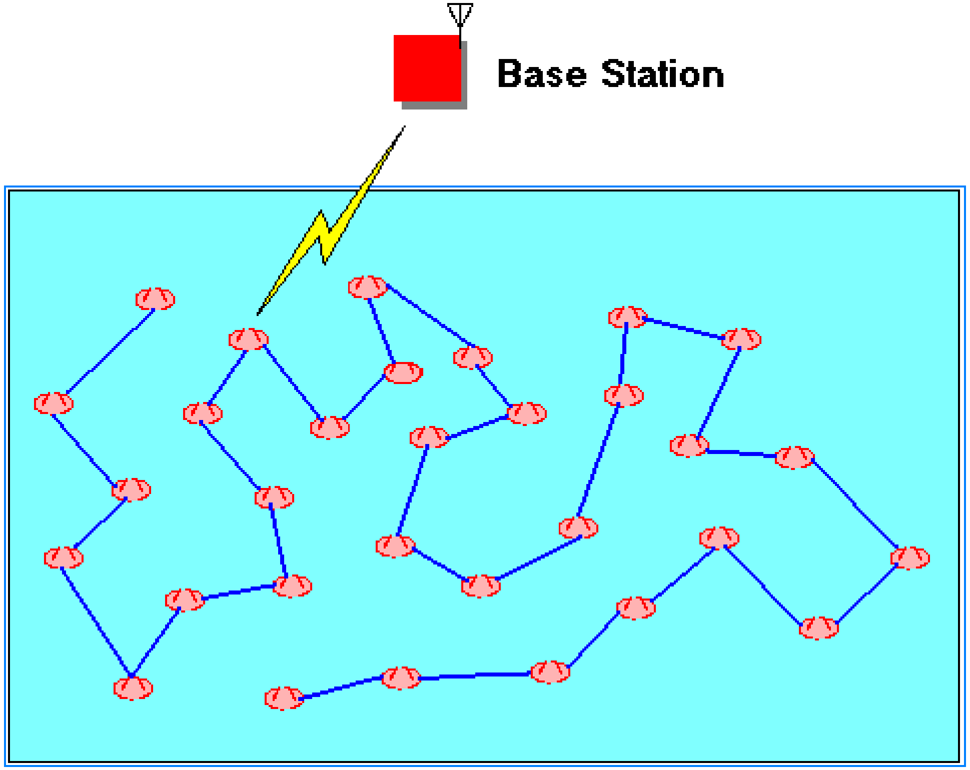
BITS Pilani

- Greedy Chain Algorithm
  - ➢Start with node furthest away from BS
  - ➢Add to chain closest neighbor to this node that has not been visited
  - ➢Repeat until all nodes have been added to chain
  - ➢Constructed before 1st round of communication and then reconstructed when nodes die



PEGASIS

- Data fusion at each node (except end nodes)
  - Only one message is passed at every node
- Delay calculation: N units for an N-node network
  - Sequential transmission is assumed



PEGASIS

- **Leader Selection**
  - Nodes become leaders in sequential order
  - Allows random deaths
  - Nodes will not become leader if the distance between neighbors is higher than a certain threshold
  - Token is passed so that all nodes will know who is leader and which direction to pass message

WSN Protocol stack

Protocol Stack - Issues

- Dynamic environment
- Power control - Longetivity
- Protocol place in the sensor node architecture
- Protocol availability

Dynamic Environment

- Sensor nodes address a dynamic environment
  - Nodes have to reconfigure themselves –
  - to adapt to the changes.
- resources are very limited
- Network - adapts its functionality to a new situation

  -lower the use of the scarce energy & memory -

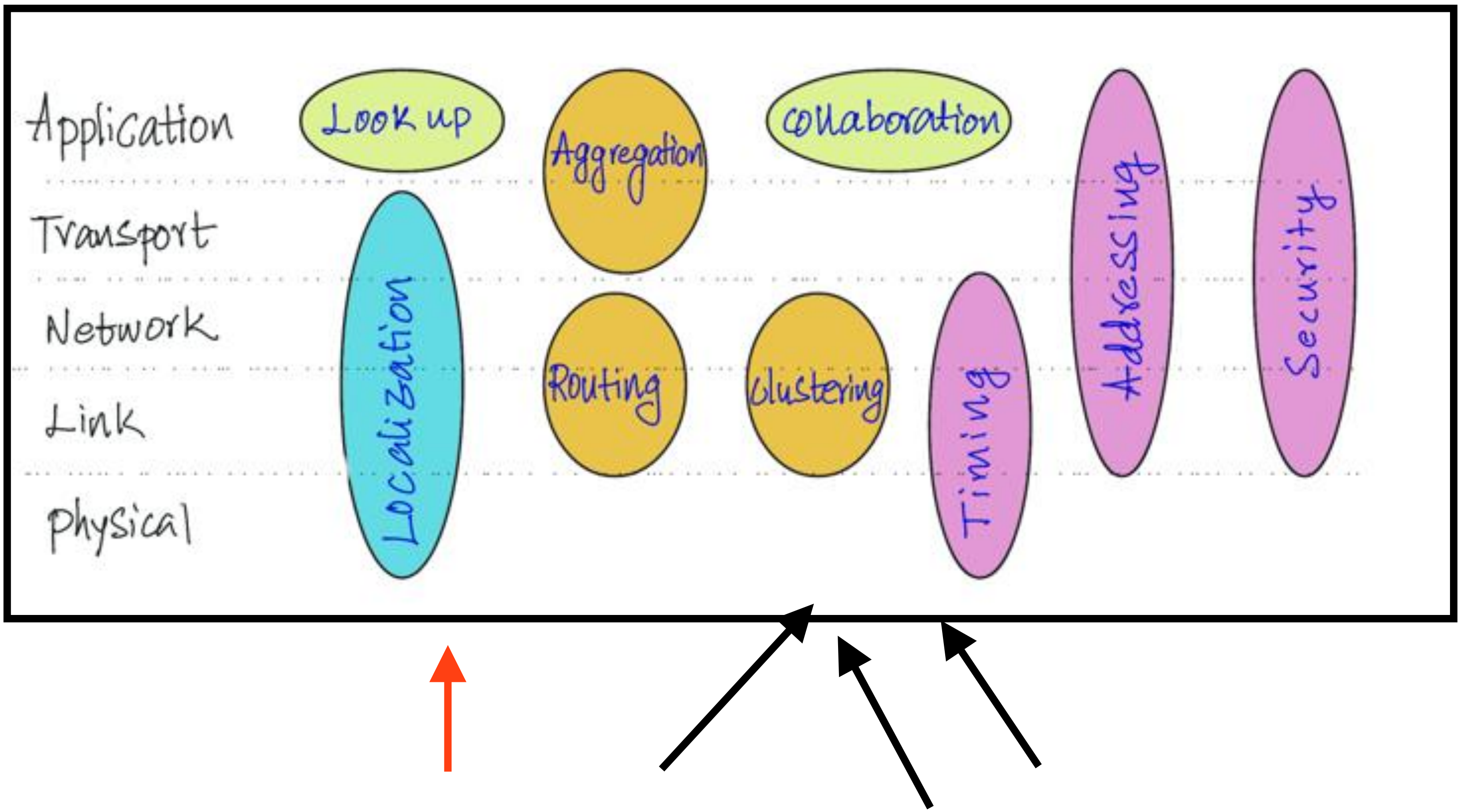
  maintain the integrity of its operation

WSN

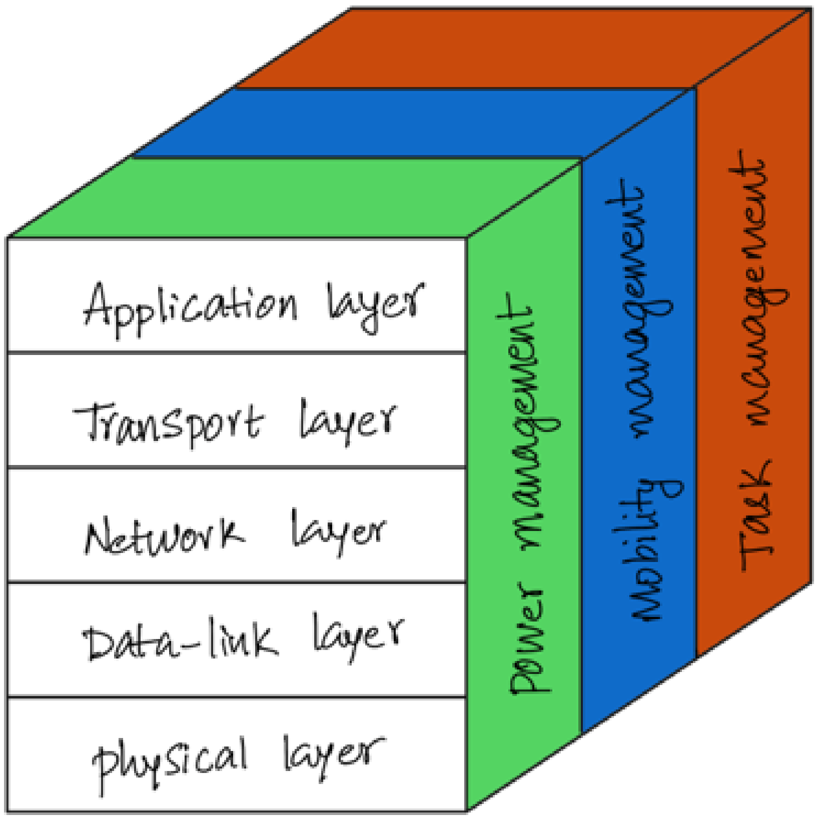
operation modes

- Initialization mode
  - detect neighbours
  - network topology
  - Synchronizing
  - location detection
- Operation mode
  - Query processing
  - Computations
  - Sensing & Actuation

WSN – Protocol stack approach



WSN – Protocol stack approach



WSN – Protocol stack approach

Physical layer

-- Operating frequency

* ISM vs. Licensed

-- Modulation type

* complex vs. simple

-- Hardware/software interfaces etc.

WSN – Protocol stack approach

Data Link layer

-- MAC

* accommodating sleeping nodes
* avoiding message collisions, overhearing and idle listening
* ARQ and Forward error correction
* creating & maintaining a list of neighboring nodes
* Overlapping channels

WSN – Protocol stack approach

Network Layer

-- Routing packets

-- Data centric routing

$ Interest dissemination

* Request broadcast

* Information publication

-- Data aggregation techniques

WSN – Protocol stack approach

BITS Pilani

Transport layer

-- Connecting WSN to external network
-- Gateways with superior resources

Power Control

- Traditionally done only at the physical layer,
- Energy consumption- is a major design constraint

  found in all

Error Control

- Normally resides in all protocol layers – worst case scenarios are handled
- WSN this redundancy- too expensive
- Adopting a central view on how error control is performed and cross-layer design reduces the resources spent for error control

innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Multi-sensor Fusion: Introduction

Multi-sensor Fusion- Introduction

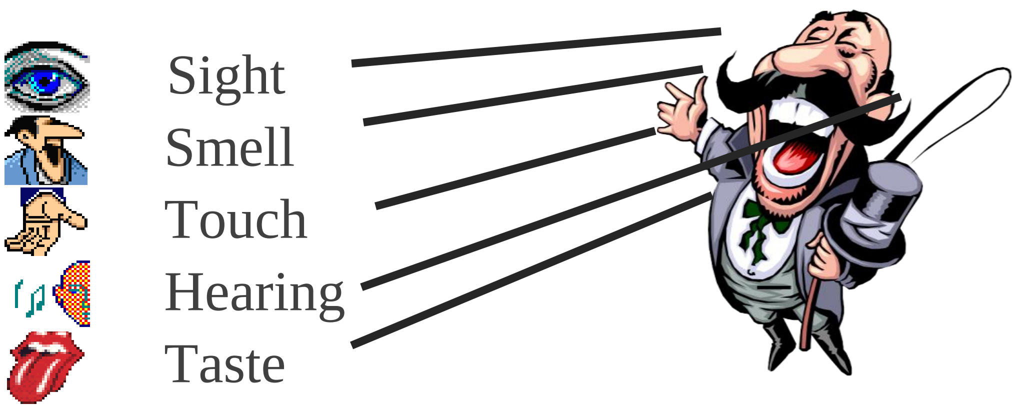
BITS Pilani

- Process of **combining data or information from various sensors to provide a robust and complete description** of an process of interest

Goal:

- To obtain a better understanding of some phenomenon introduce or enhance intelligence and system control functions

Human brain: Multi-sensor fusion



Advantages of Multi-sensor fusion

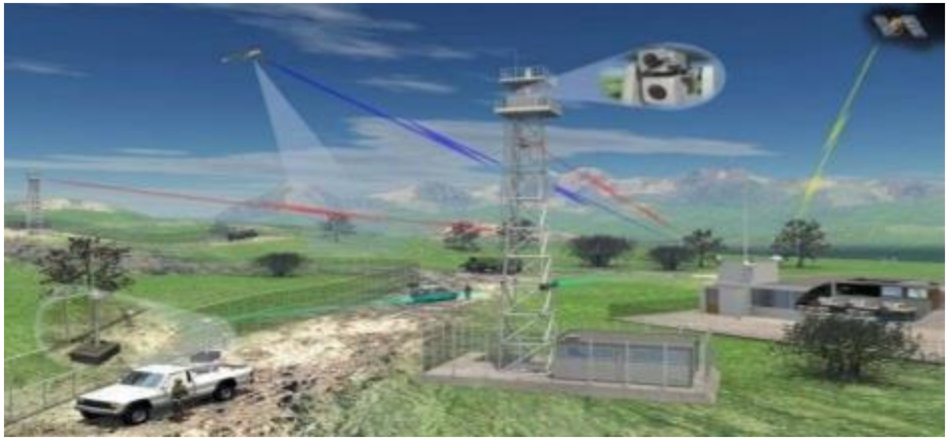
MDF provides following advantages over a single sensor :

- Improves accuracy
- Improves availability
- Reduces uncertainty
- Supports effective decision making
- Reduces transmission energy requirement as less data to be transmitted (thus increasing network battery lifetime).

Example 1: Military applications

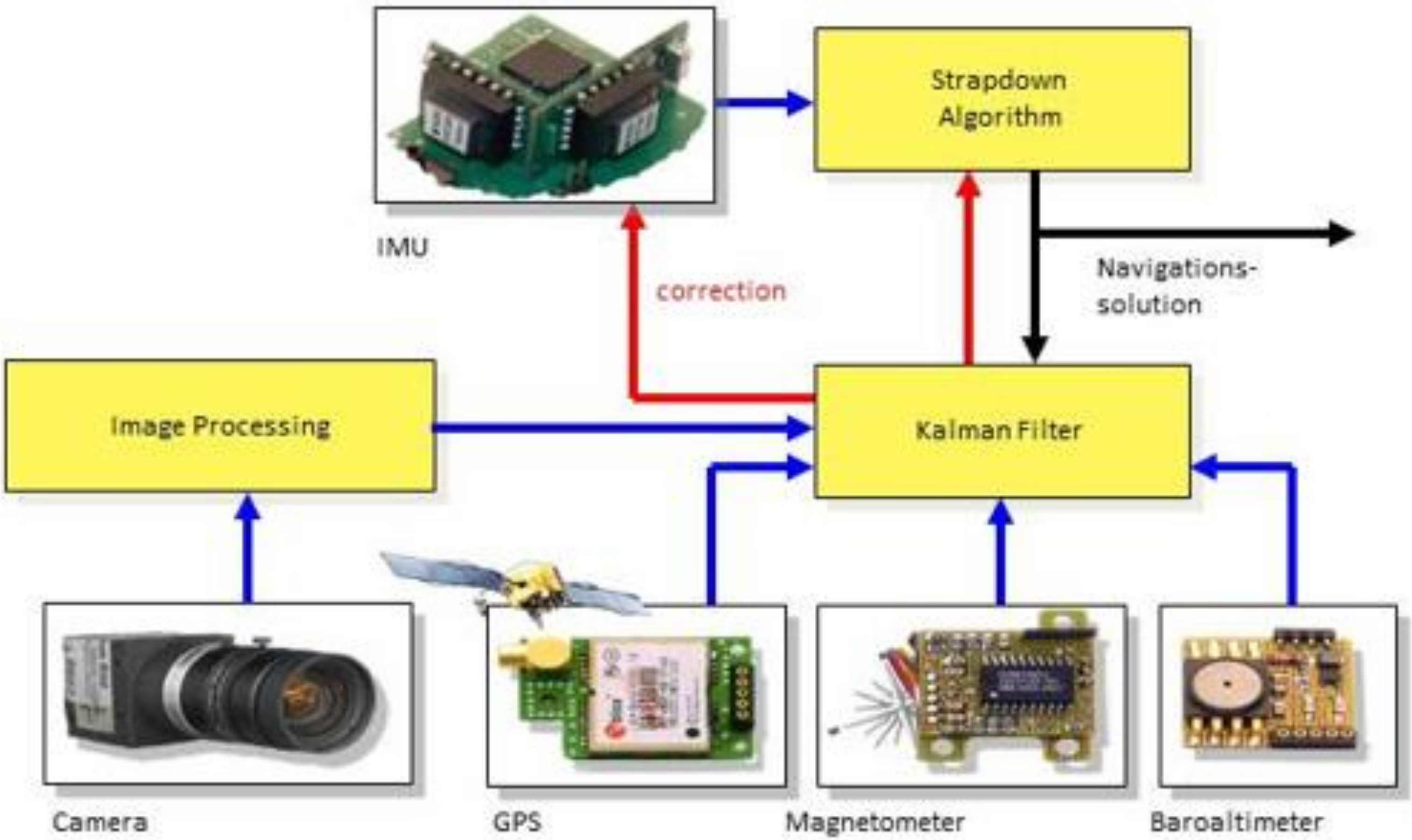
BITS Pilani

- Detection, location , tracking and identification of military entities.
- **Sensors**: radar, sonar, infrared, synthetic aperture radar (SAR), electro-optic imaging sensors etc.
- Complex problem
- Large number and types of sensors and targets
- Size of the surveillance volume
- Real-time operational requirements
- Signal propagation difficulties



Example 2: Navigation

- Smart Auto navigation of vehicle (based on sensor fusion on sensor data from camera, gps etc.)



https://www.ite.kit.edu/english/datenfusion.php

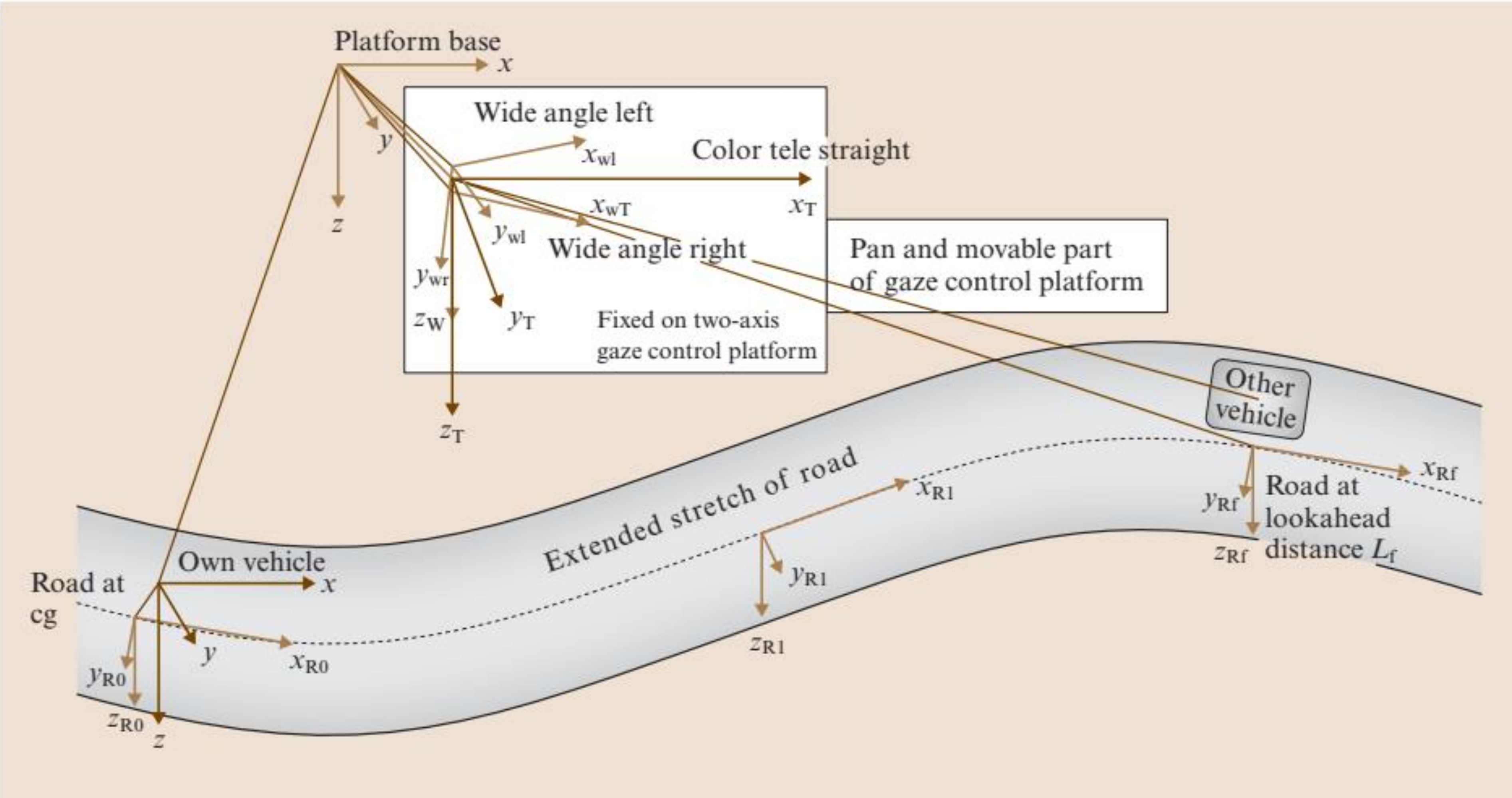
Case Study: Navigation

First fully autonomous vehicle on German autobahn

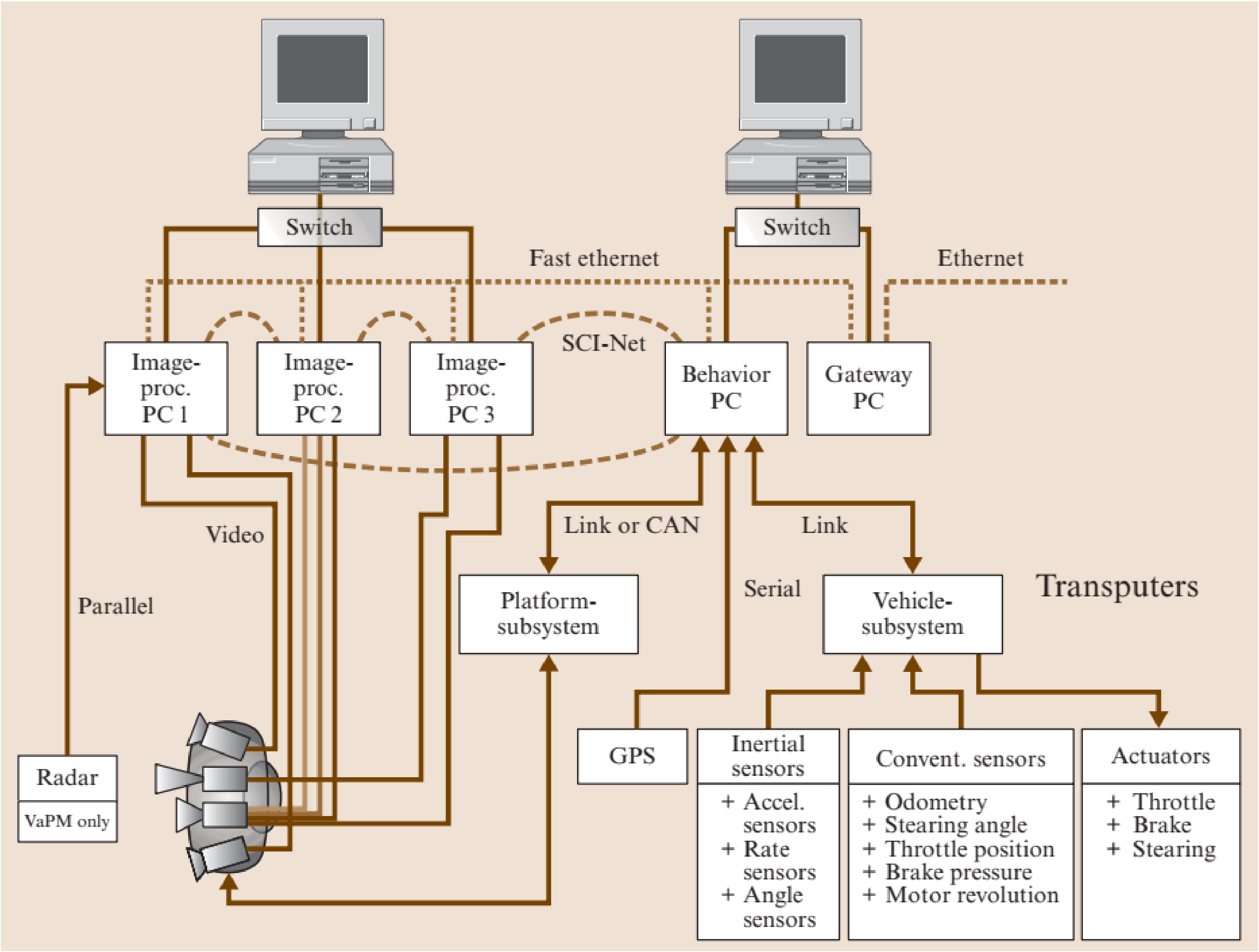
The first vehicle to drive fully autonomously on the German autobahn for 20 km and at speeds up to 96 km/h

Vehicle road scene

- Information from inertial and vision sensors is combined to produce a road scene



Vehicle sensing hardware

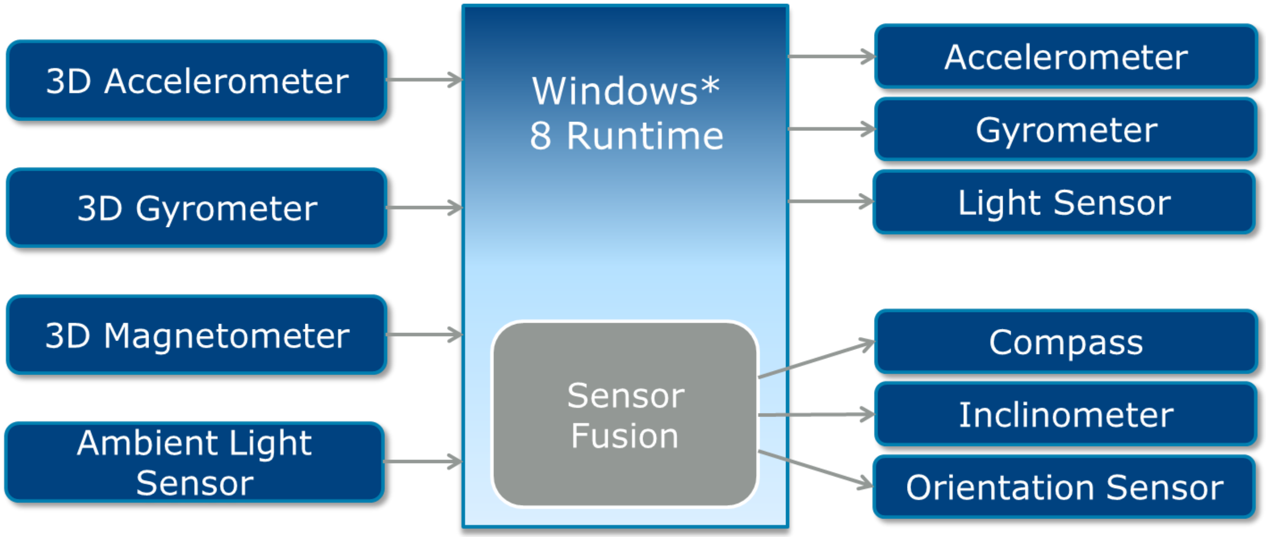


BITS Pilani

Example 3: Motion application

Applications:

- Augmented Reality
- Games
- Orientation
- Pedometer
- Navigation
- Remotely-controlled Devices
- Biofeedback

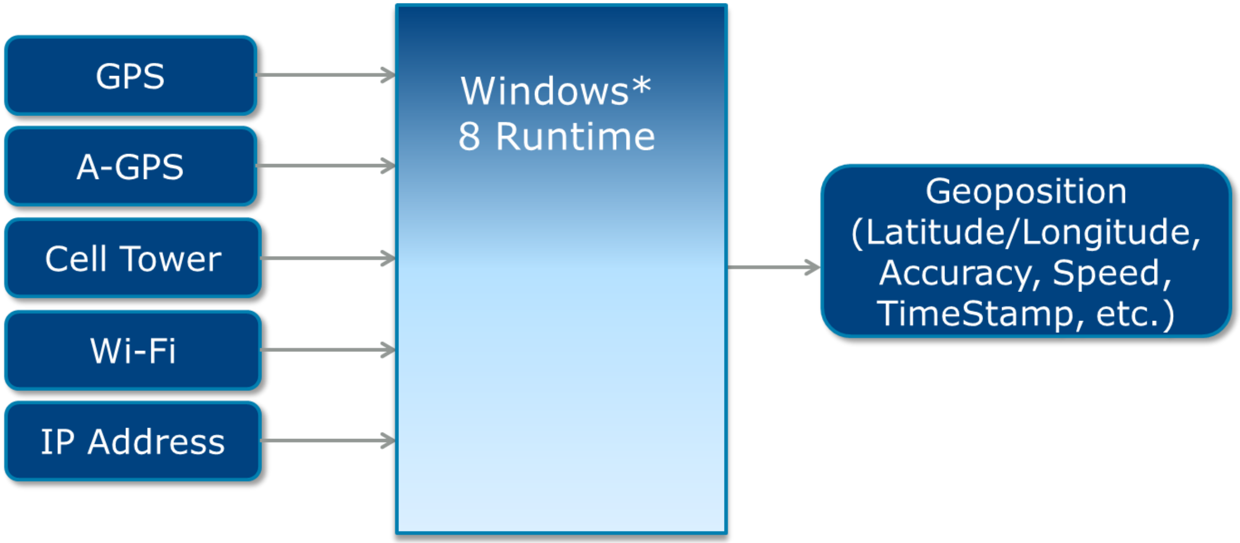


https://software.intel.com/en-us/articles/using-sensors-and-location-data-for-cutting-edge-user-experiences-in-mobile-applications

Example 4: Location detection

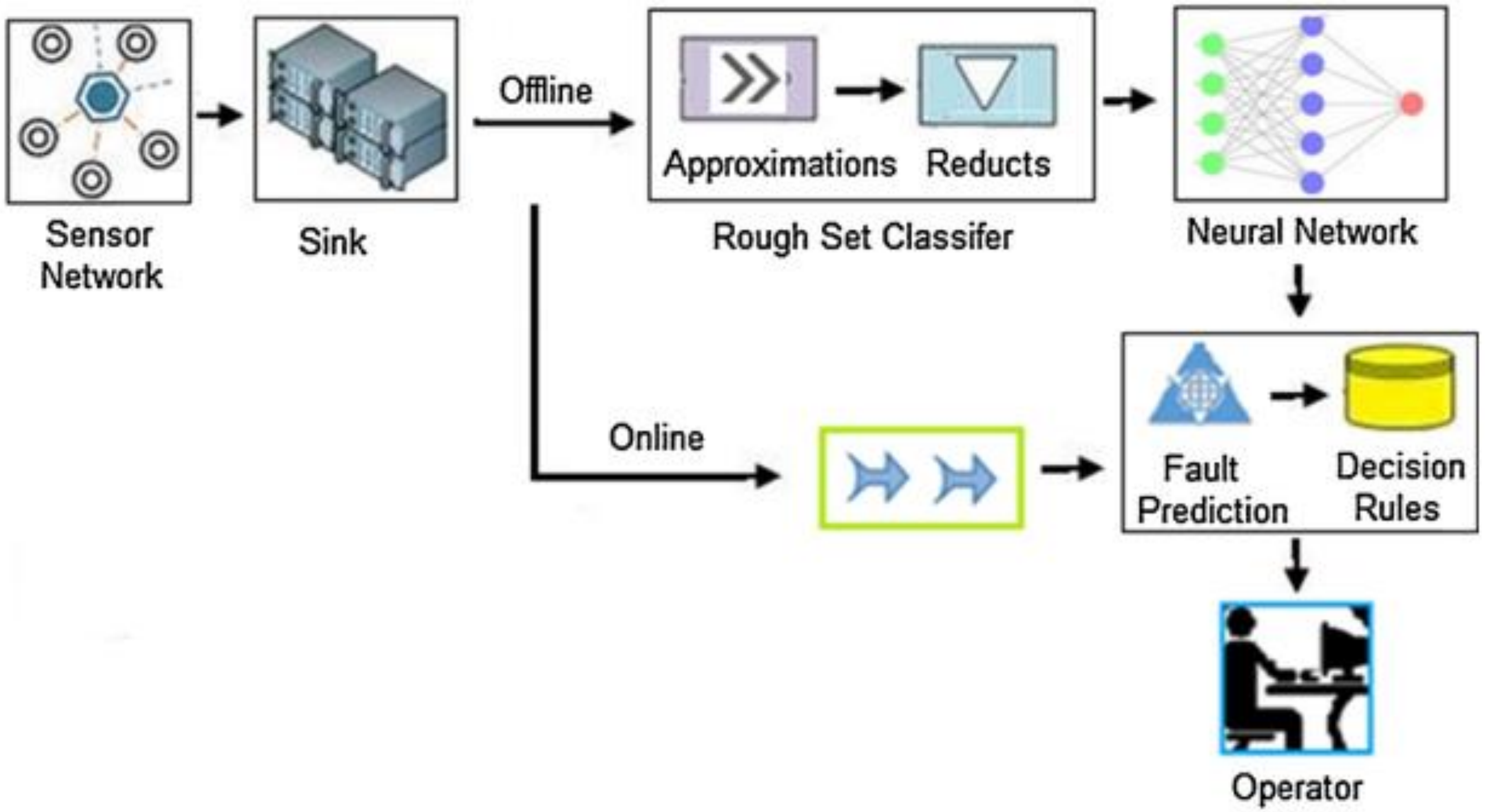
Applications:

- Search for Points of Interest (POIs)
- Geotagging ? adding location information to files such photos
- Games ? Geocaching
- Outdoors and fitness
- Pedestrian or vehicle navigation



https://software.intel.com/en-us/articles/using-sensors-and-location-data-for-cutting-edge-user-experiences-in-mobile-applications

Example 5: Water pollution monitoring



Sarvesh Rawat a,*, Surabhi Rawat "Multi-sensor data fusion by a hybrid methodology – comparative study" Elseiver Computers in Industry 75 (2016) 27–34

Challenges in MDF (Multi sensor data fusion)

BITS Pilani

Many challenges primarily arising from :

- sensor **data** to be fused
- **Imperfections** in sensor data
- **diversity** of the sensor technologies
- nature of the **application** environment

Challenges in MDF (Multi sensor data fusion)

BITS Pilani

Data imperfection:

Some **inaccuracy** in the sensor data from one of the inputs can produce completely different result

Outliers and spurious data:

One needs to accommodate/ identify outliers and check if they are right values or due to sensor fault

Static vs. dynamic phenomena:

- the phenomenon under observation may be time-invariant or varying with time. In the latter case, it **may be necessary for the data fusion algorithm to incorporate a recent history of measurements into the fusion process**.

Challenges in MDF (Multi sensor data fusion)

Conflicting data:

- At times different sensors may give inputs indicating different conclusion

Data modality:

- The data may be coming from **different kind of sensors like audio, visual** etc. , fusing which is a challenge.

Data alignment

- One needs to account/ be careful of the **calibration error** induced by individual sensor nodes.

Challenges in MDF (Multi sensor data fusion)

BITS Pilani

Processing framework:

- data fusion processing can be performed in a **centralized or decentralized manner**.

Operational timing:

- the area covered by sensors may span a vast environment composed of different aspects varying in different rates. Also, in the case of homogeneous sensors, the operation frequency of the sensors may be different. A well-designed data fusion **method should incorporate multiple time scales** in order to deal with such timing variations in data. In distributed fusion settings, different parts of the data may **traverse different routes** before reaching the fusion center, which may cause **out of-sequence arrival of data**. This issue needs to be handled properly, especially in real-time applications, to avoid potential performance degradation.

Fusion architectures

BITS Pilani

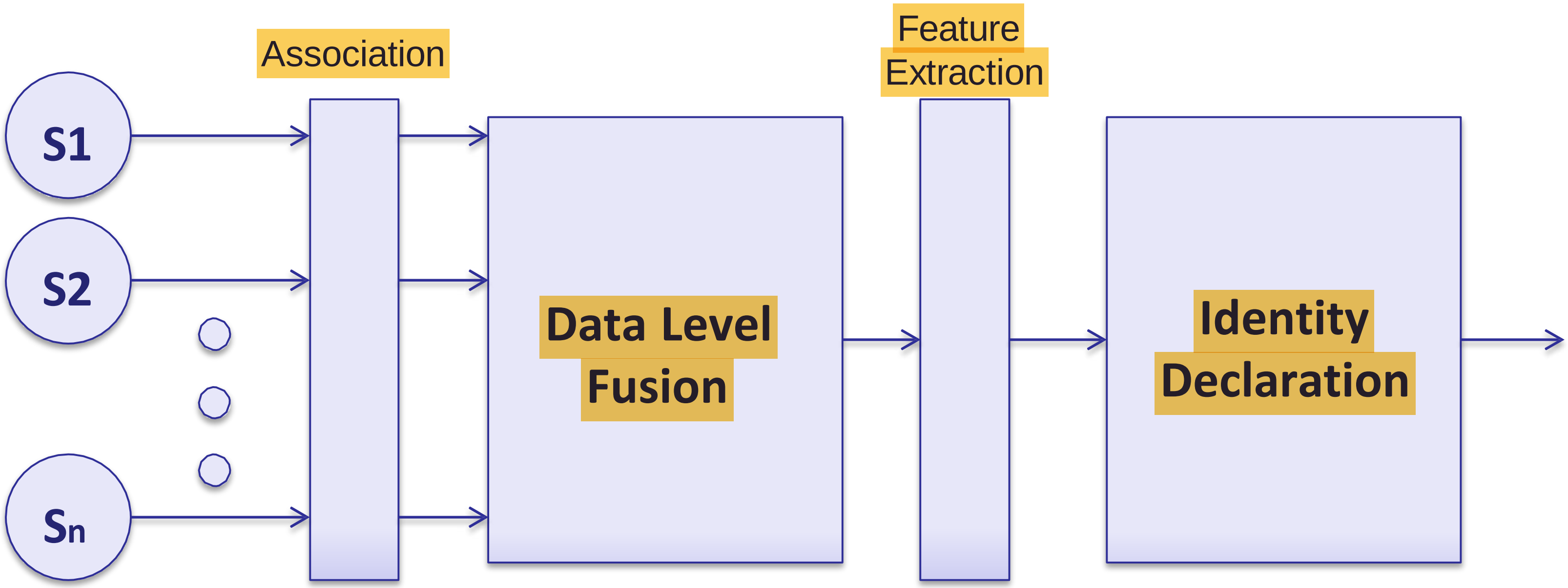
Data fusion can be categorized into 3 main classes based on the level of data abstraction used for fusion :

- Measurement Fusion (Sensor data Fusion)
- Feature-level Fusion
- Decision-level Fusion (High-level data Fusion)

Measurement Fusion

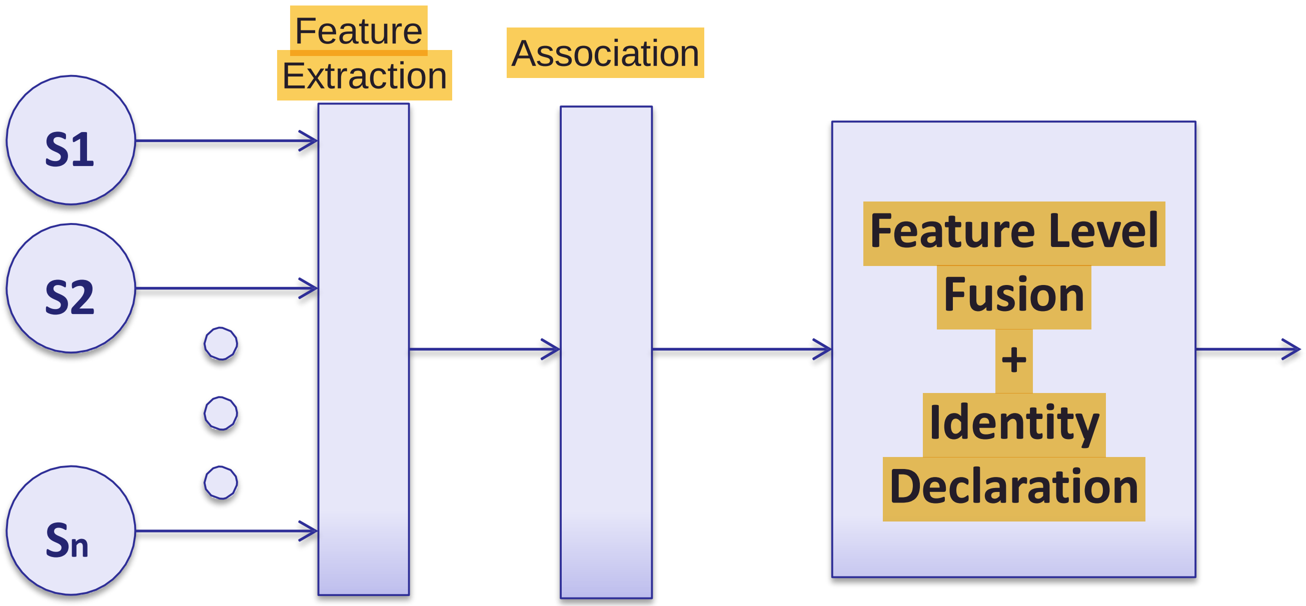
BITS Pilani

- Direct fusion of sensor data
- The sensors measuring the **same physical phenomena** are required.



Feature level Fusion

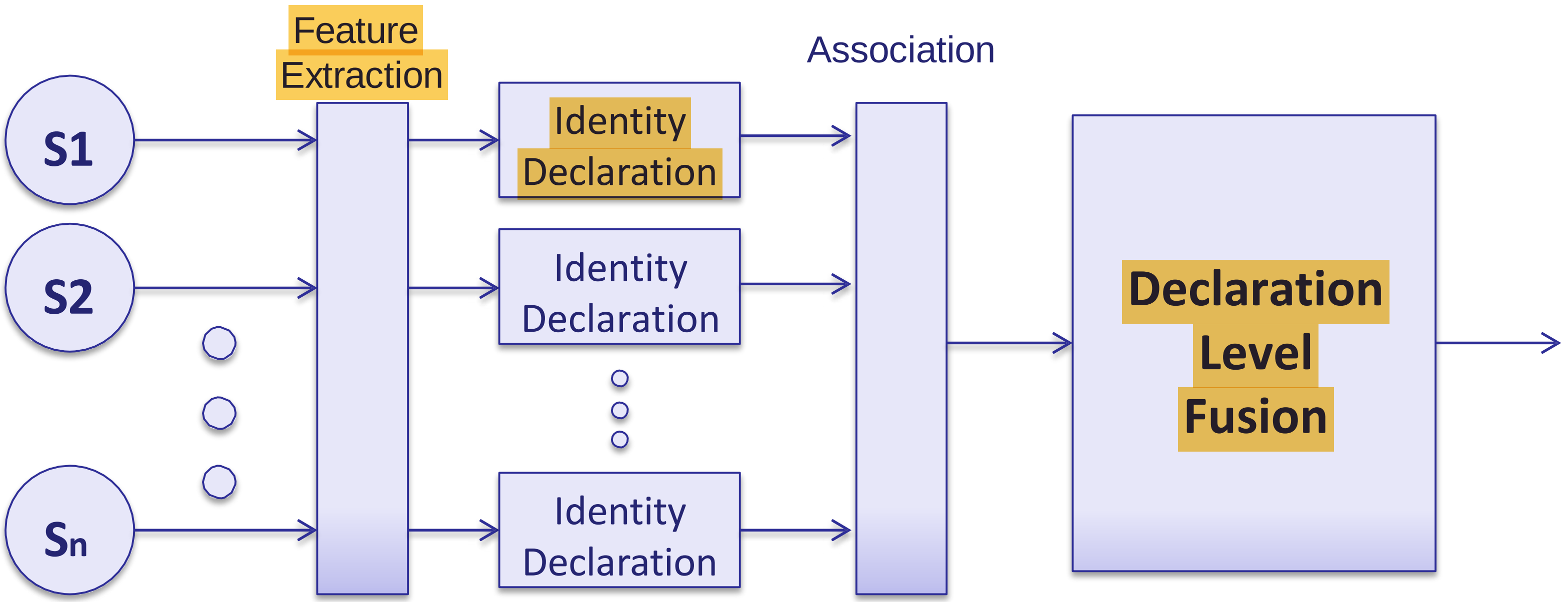
- Involves the extraction of representative features from sensor data
- Features are combined into a single concatenated feature vector that is an input to a fusion node



Decision-level Fusion

BITS Pilani

- Each sensor has made a preliminary determination of an entity's location, attributes and identity before combining



innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network – Deployment

Deployment Objectives

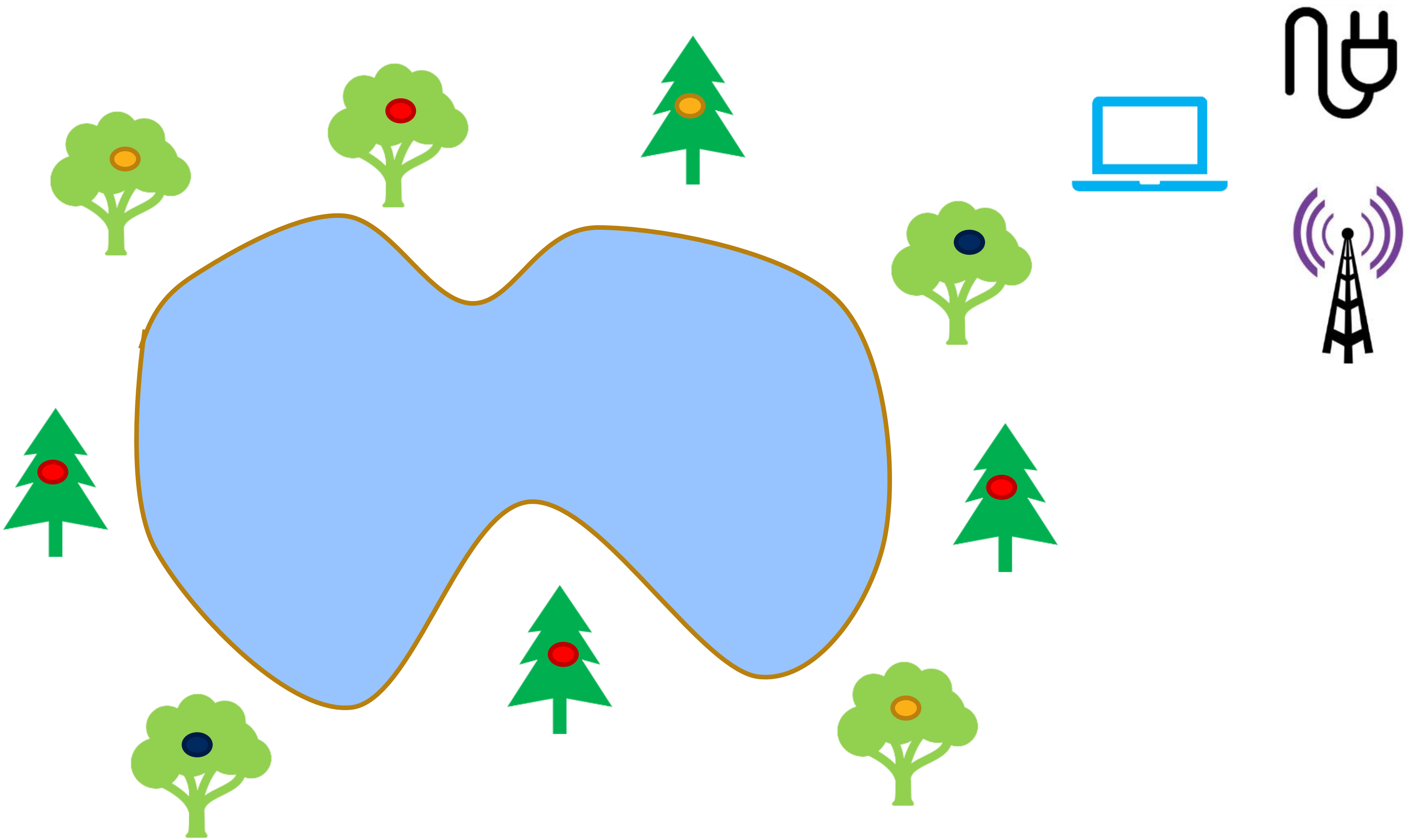
- Coverage
- Connectivity
- Topology

Deployment - Issues

BITS Pilani

- Structured Vs Random Deployment
- Over Deployment Vs Incremental Deployment
- Network Topology
- Homogeneous Vs Heterogeneous Deployment

Ideal Deployment



Random Deployment

innovate achieve lead

BITS Pilani

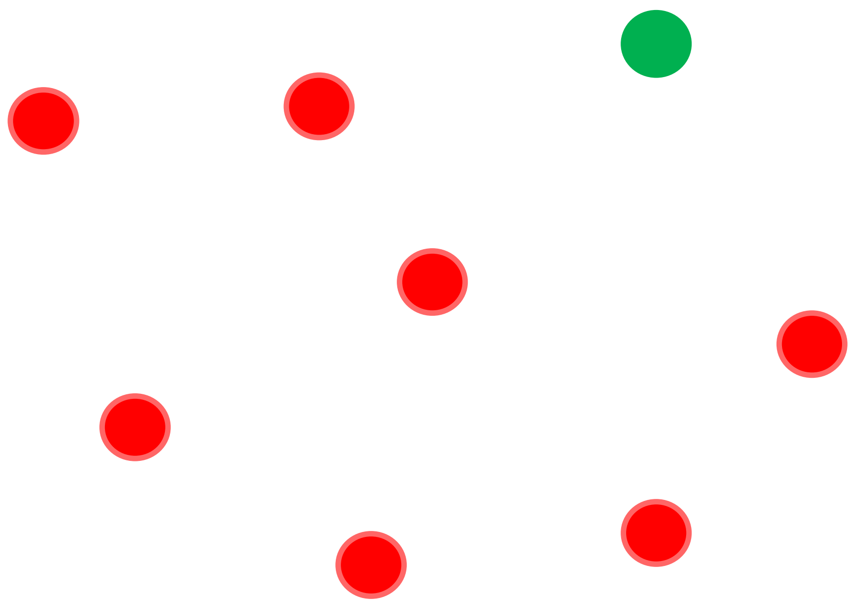
Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network – Deployment Pattern

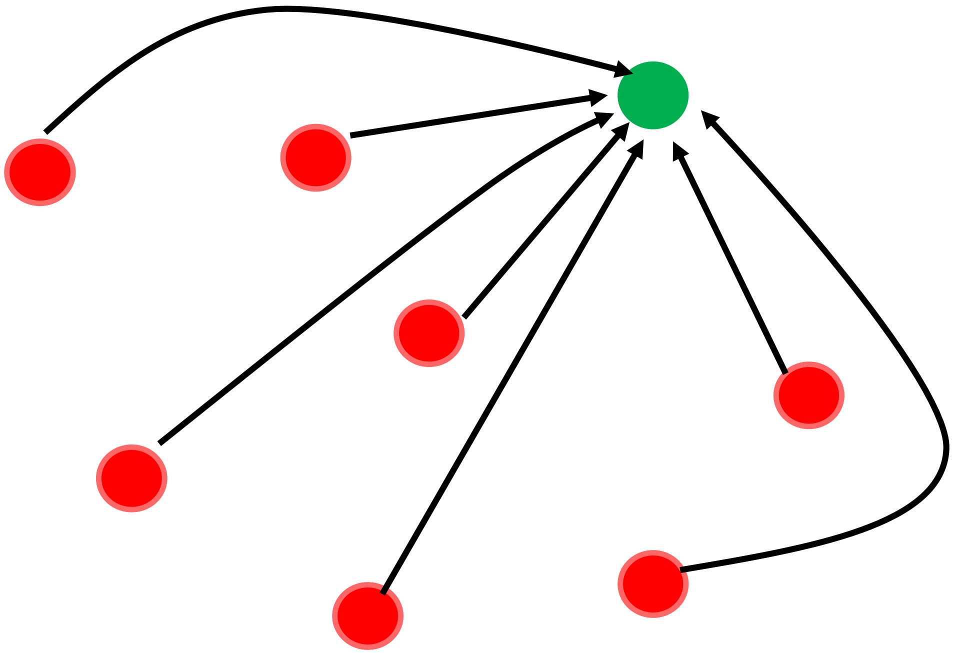
EEE G627: Networked Embedded Applications (Dr. Vinay Chamola, BITS-Pilani)

Deployment Patterns

BITS Pilani

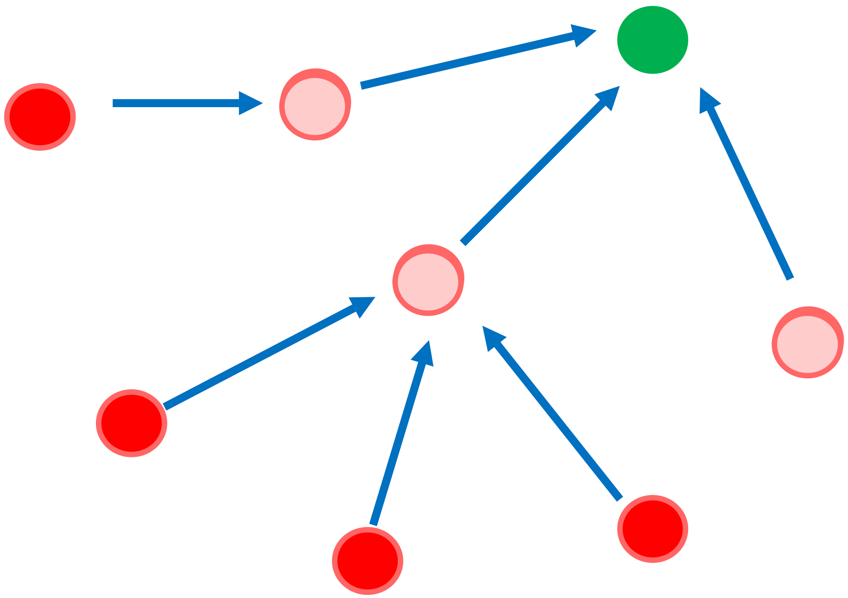


Deployment Patterns - Star

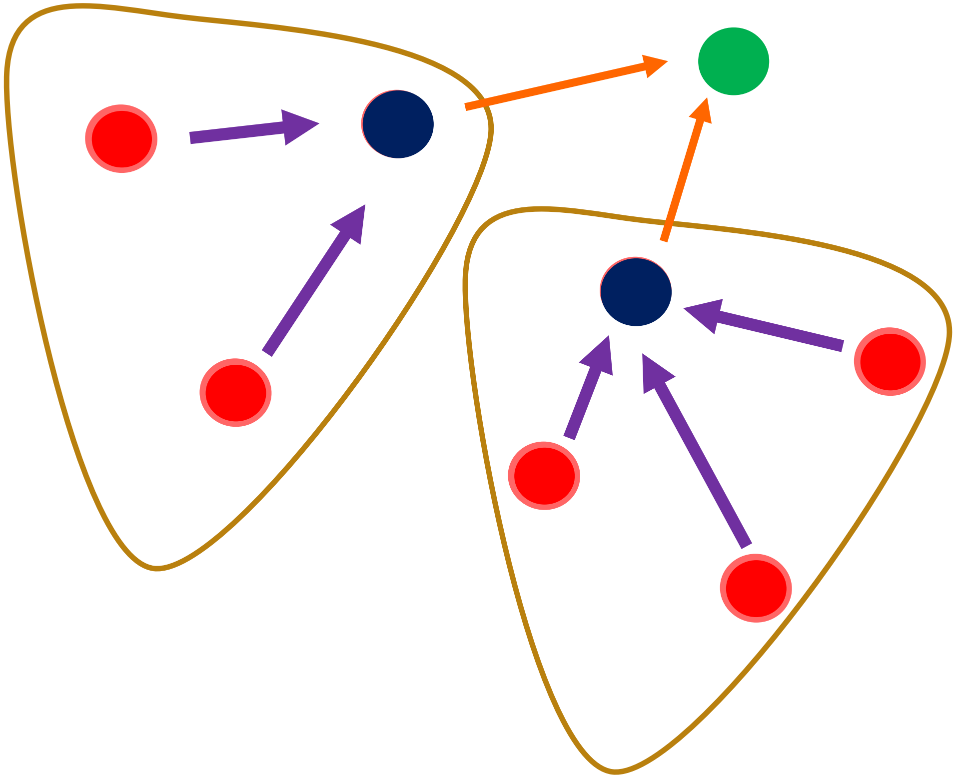


Energy Consumption

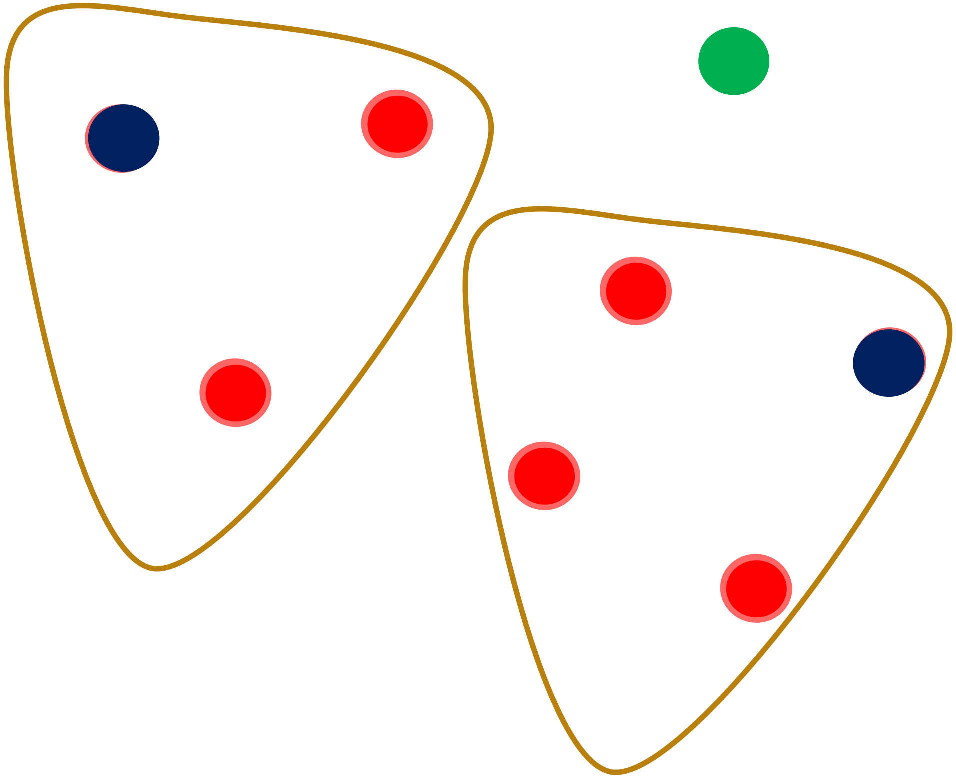
Deployment Patterns – Multi Hop



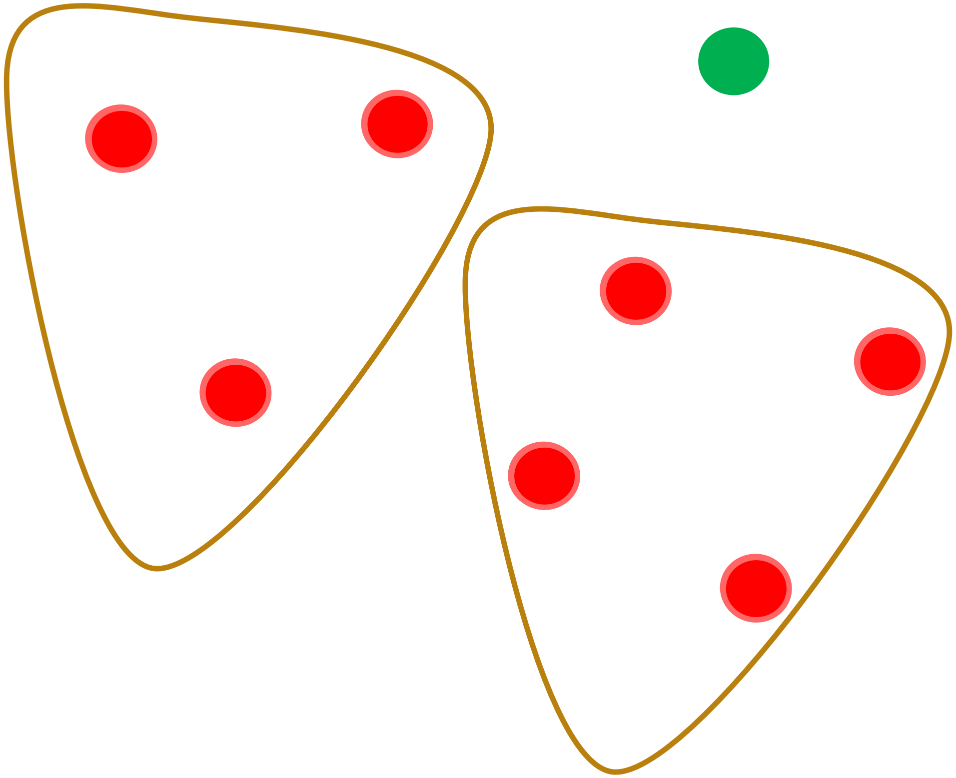
Deployment Patterns - Cluster



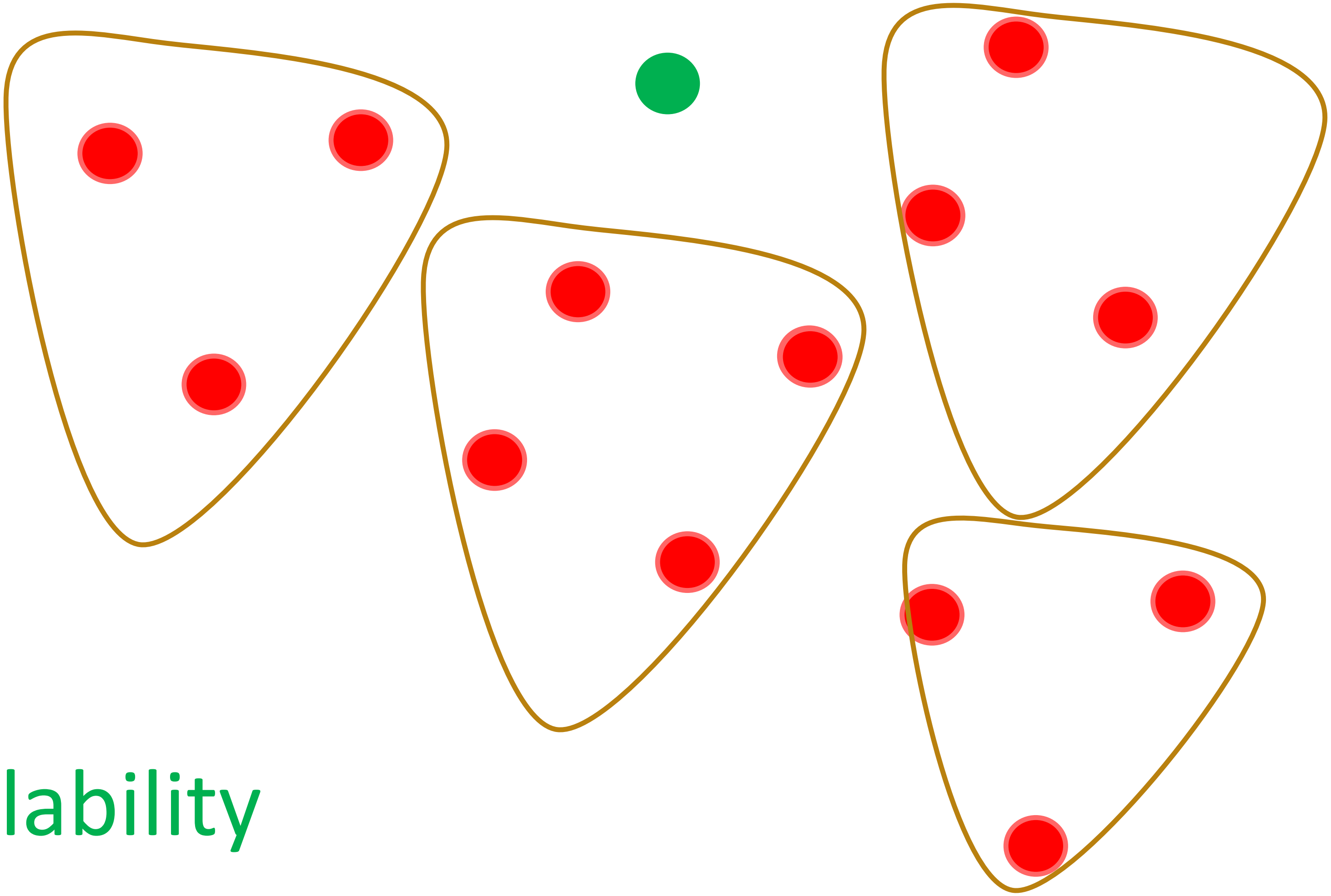
Deployment Patterns - Cluster



Deployment Patterns - Cluster



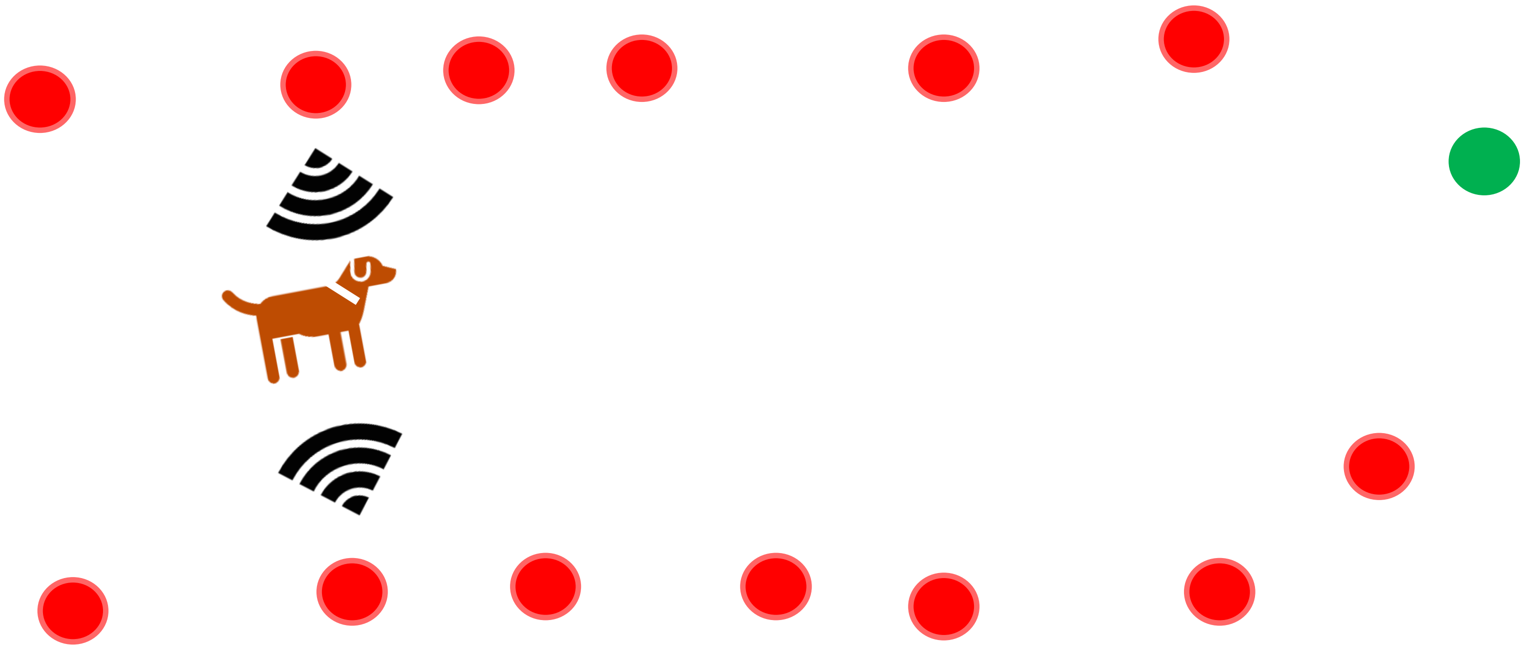
Deployment Patterns - Cluster



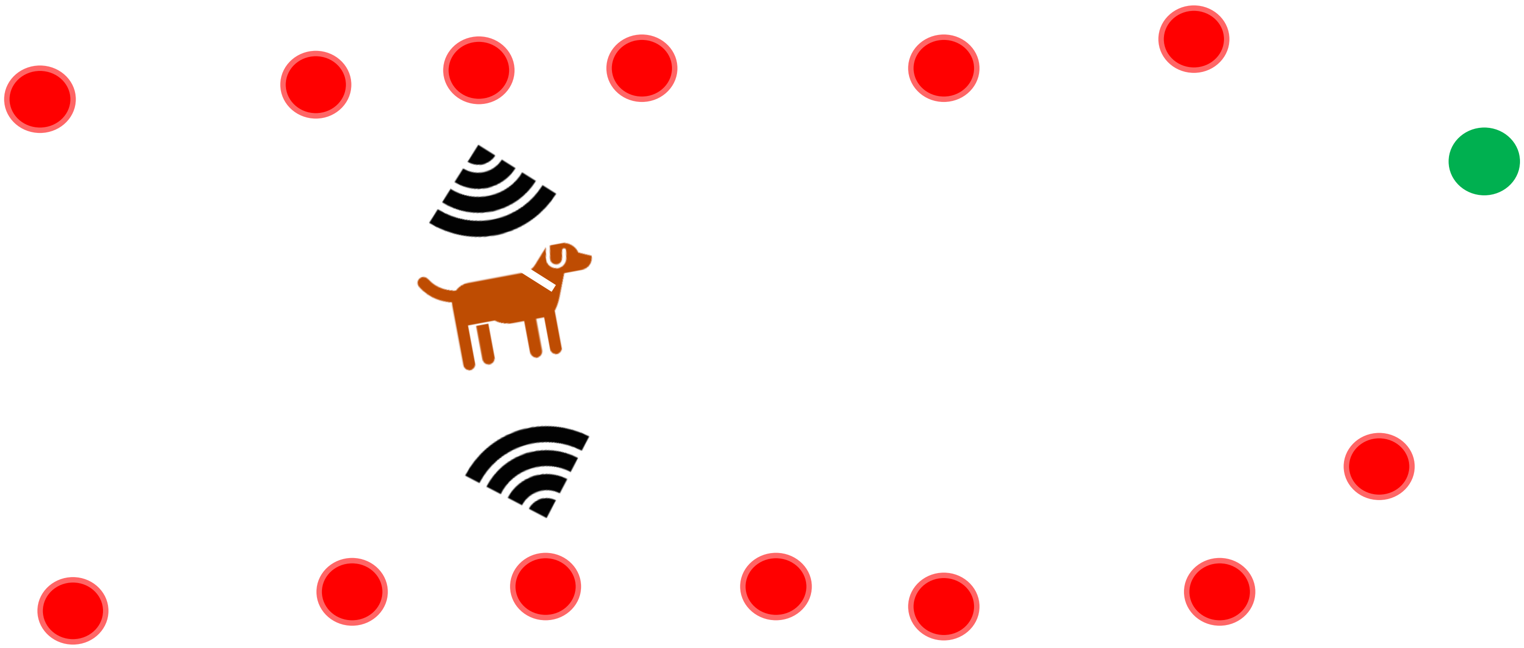
Scalability

Deployment Patterns – Data Mule

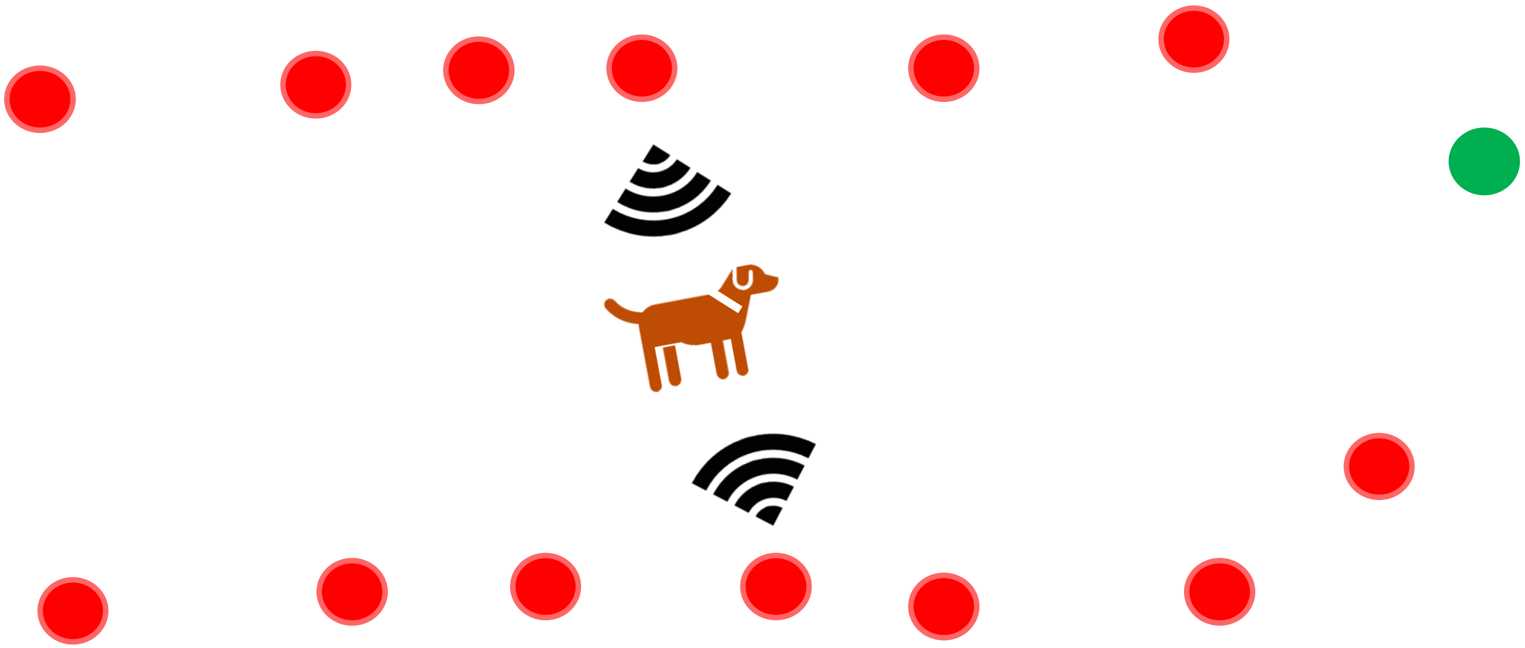
Deployment Patterns – Data Mule



Deployment Patterns – Data Mule

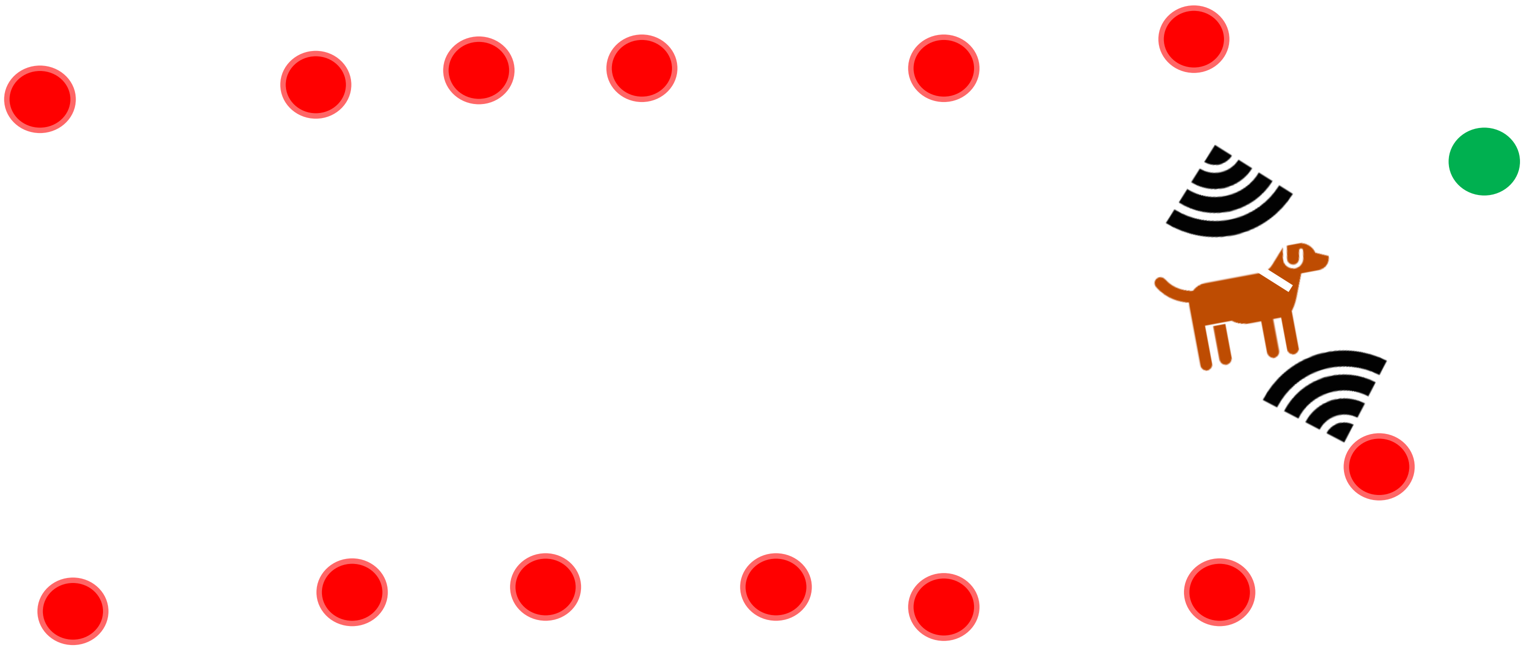


Deployment Patterns – Data Mule



EEE G627: Networked Embedded Applications (Dr. Vinay Chamola, BITS-Pilani)

Deployment Patterns – Data Mule



innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless sensor networks: Time Synchronization

Time Sync ??

BITS Pilani

- All nodes in the network have a common view of time

Why Time Sync ??

BITS Pilani

- Target Tracking
- Speed estimation
- Event Detection
- Voice & Video Sync
- Security
- MAC-TDMA
- Local Clocks with crystal instability tend to drift

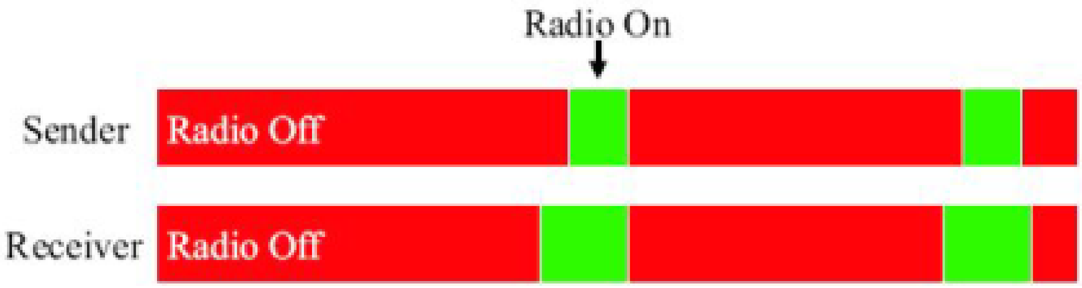
Specific examples

- **Link to the physical world!**
  - When does an event take place?
- **Key basic service of sensor networks**
  - Fundamental to data fusion.
- **Crucial to the efficient working of other basic services**
  - Localization, Calibration, In-network processing etc.
- **Several protocols require time synchronization**
  - Cryptography, MAC, Topology management ….

Case study…

BITS Pilani

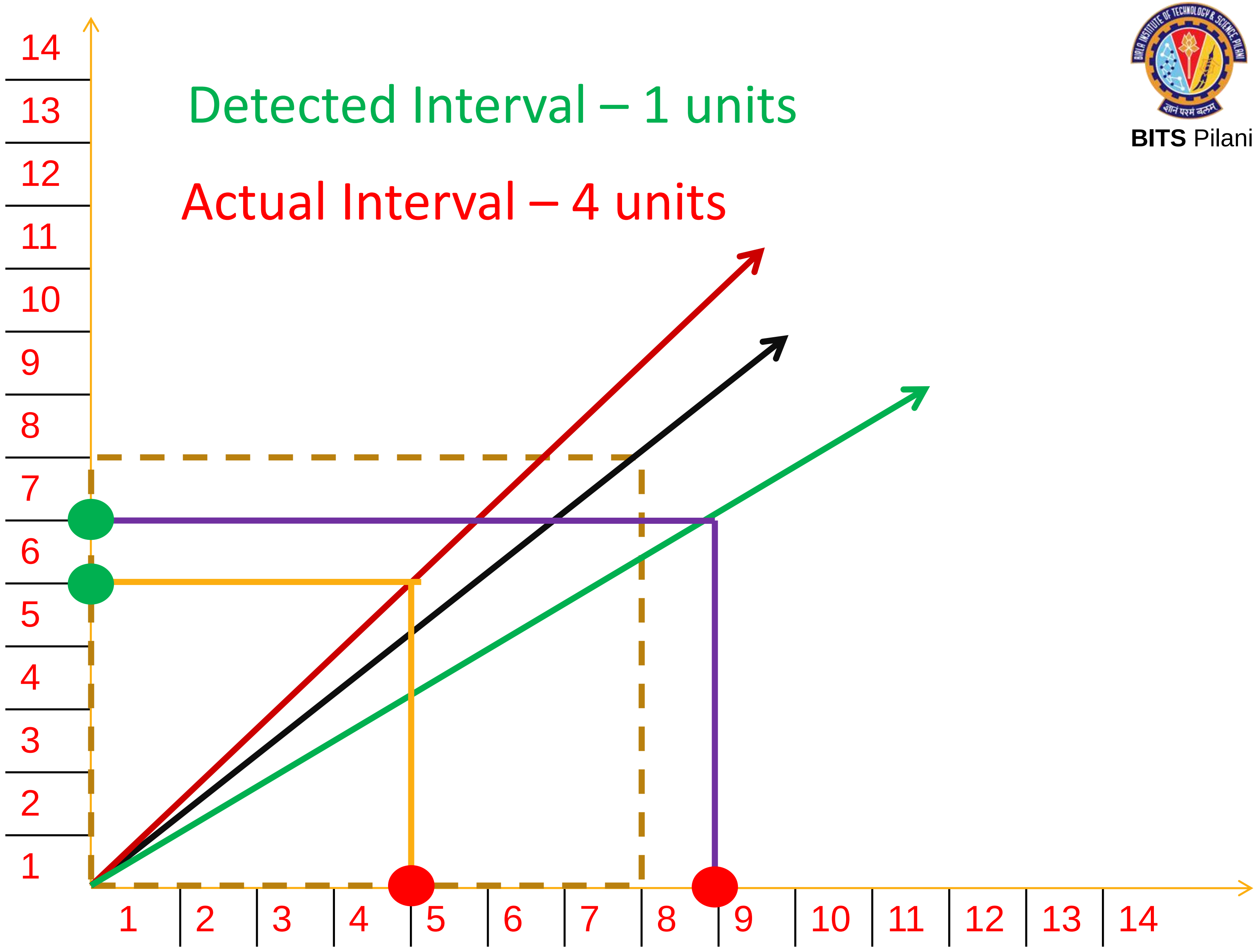
- **Energy-efficient Radio Scheduling**
  - **TDMA, Guard band**



Reasons for drift

BITS Pilani

- Temperature – few ppm in PC
- Frequency noise (10^{-4} - 10^{-6})
- Phase Noise
- Asymmetric Delay



Detected Interval – 1 units
Actual Interval – 4 units
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Time Sync Protocol - Requirements

- Robust
- Precision
- Energy Aware
- Server-Less
- Light Weight
- Tunable
- Immediacy

Performance Metrics and Fundamental Structure

Precision:

maximum synchronization error for deterministic algorithms, mean error /stddev /quantiles for stochastic ones

Energy costs,

e.g. # of exchanged packets, computational costs

Memory requirements

Fault tolerance:

what happens when nodes die?

Why not GPS ?

BITS Pilani

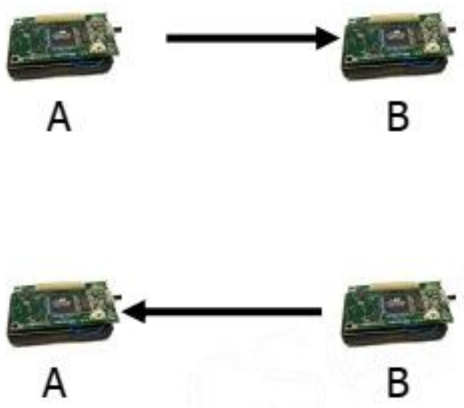
- **Cost**
  - **300$ (achieve < 20ns phase error to UTC)**
- **Practical Limitations**
  - **Cannot be used under special environment where is no free line of sight to the GPS satellites**
    - **e.g. dense foliage or inside buildings**
- **Policy Limitations**
  - **Military Applications**

Wireless Sensor Network – Time Sync Protocols

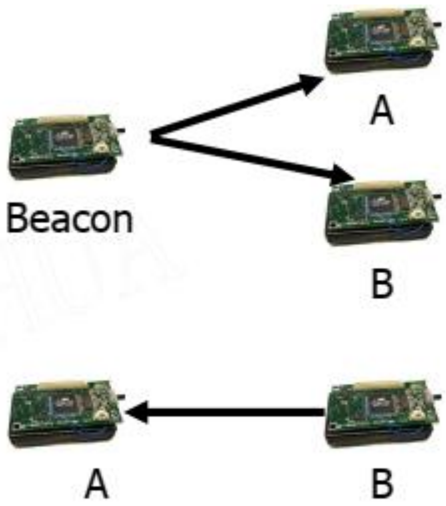
Time Sync Types

BITS Pilani

- Sender – Receiver synchronization
- Receiver – Receiver synchronization



S – R



R – R

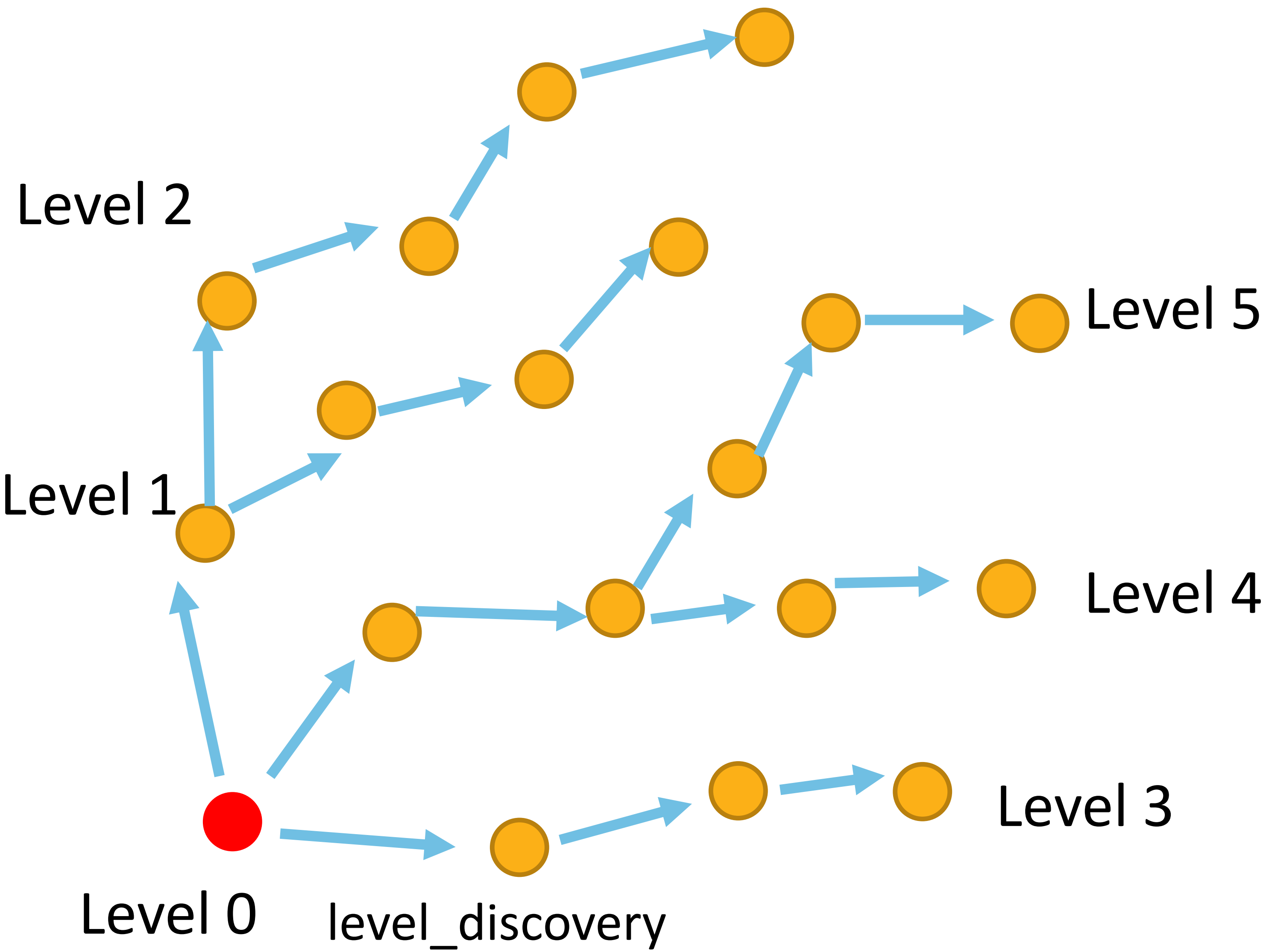
Sender – Receiver Synch

Time Sync Protocol for Sensor Networks (TPSN)

- Level Discovery
- Sync

TPSN – Level discovery

BITS Pilani



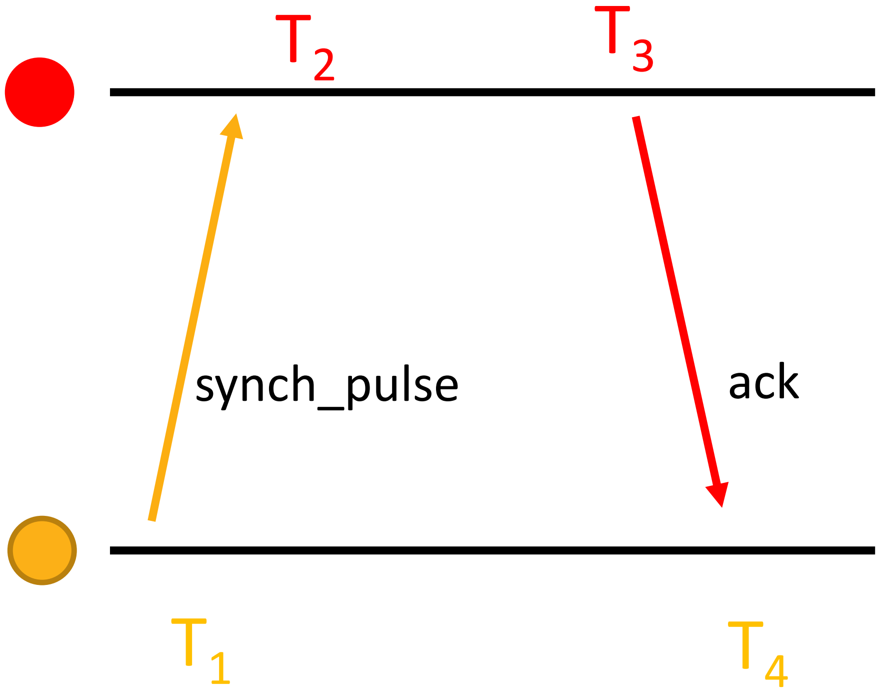
TPSN - Sync

BITS Pilani

- Root node initiates – time sync
- Level 1 nodes – each wait for random time
  - Reduce probability of collision at MAC

TPSN – Sync

BITS Pilani



$T_2 = T_1 + \Delta + d$

Δ - clock drift

d – propagation delay

$$\Delta = \frac{(T_2 - T_1) - (T_4 - T_3)}{2}$$

$$d = \frac{(T_2 - T_1) + (T_4 - T_3)}{2}$$

TPSN - Sync

BITS Pilani

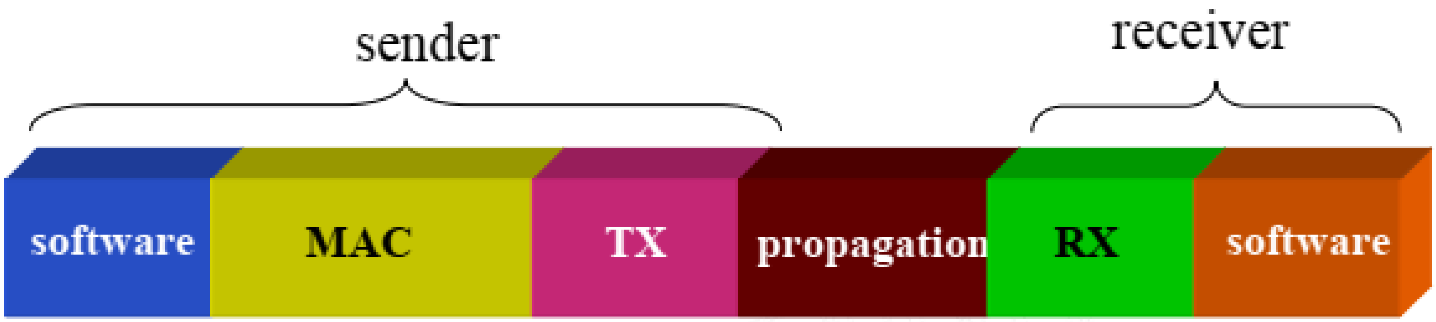
- Nodes at Level 2 will be able to hear sync pulses of nodes at Level 1
- Wait for a random time
- Attempt to sync with nodes at Level1

TPSN - Issues

- Unable to hear level_discovery from higher level nodes – then wait and send level request
- Hear from different nodes – different levels – pick smallest level
- No response to sync pulse as node at higher level dead – send level request at higher energy levels

Sources of error

BITS Pilani



ALL DELAYS ARE VARIABLE !

Sources of error

BITS Pilani

- **Send time**
  - Kernel processing
  - Context switches
  - Interrupt Processing
- **Access time**
  - Specific to MAC protocol
    - E.g. in Ethernet, sender must wait for clear channel
- **Transmission Time**
- **Propagation time**
  - Very small in WSNs, can be omitted
- **Reception time**
- **Receive time**

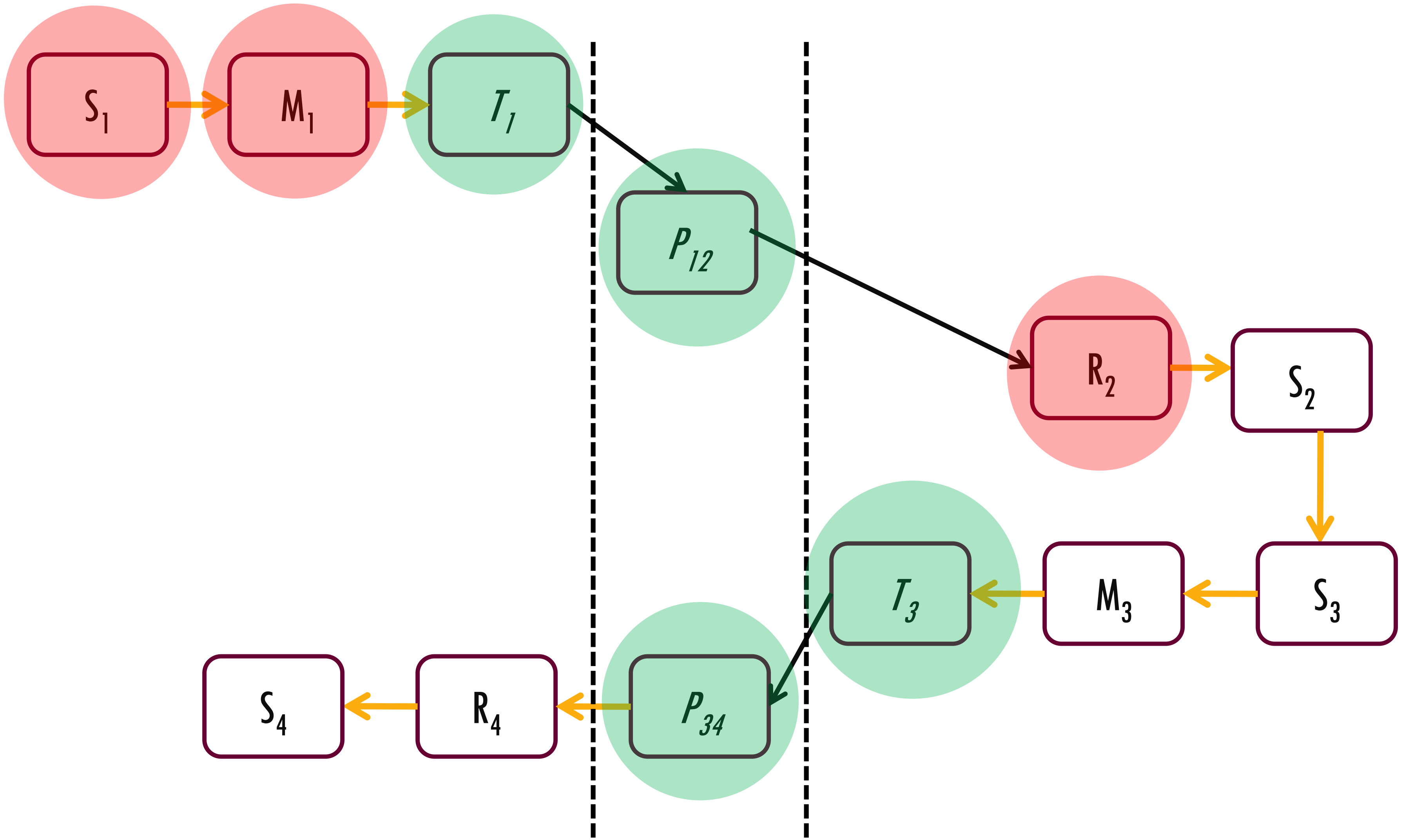
Common denominator:

(1) non-determinism

(2) difficult to estimate

Send, access, receive

TPSN - Inaccuracies



Flooding Time Synchronization Protocol (FTSP)

- Introduction

Solves one of the problems of TPSN

- Linear regression is used in FTSP to compensate for clock drift

Flooding Time Synchronization Protocol (FTSP)

Network Model

- Every node in the network has a unique ID

- Each synchronization message contains three fields:

TimeStamp

RootID

SeqNum

-The node with the smallest ID will be only one root in the whole network

Flooding Time Synchronization Protocol (FTSP)

- The root election phase
  FTSP utilizes a simple election process based on unique node IDs

- Synchronization phase

Flooding Time Synchronization Protocol (FTSP)

BITS Pilani

The root election phase

When a node does not receive new time synchronization messages for a number of message broadcast periods

The node declares itself to be the root

Whenever a node receives a message, the node with higher IDs give up being root

Eventually there will be only one root

Flooding Time Synchronization Protocol (FTSP)

BITS Pilani

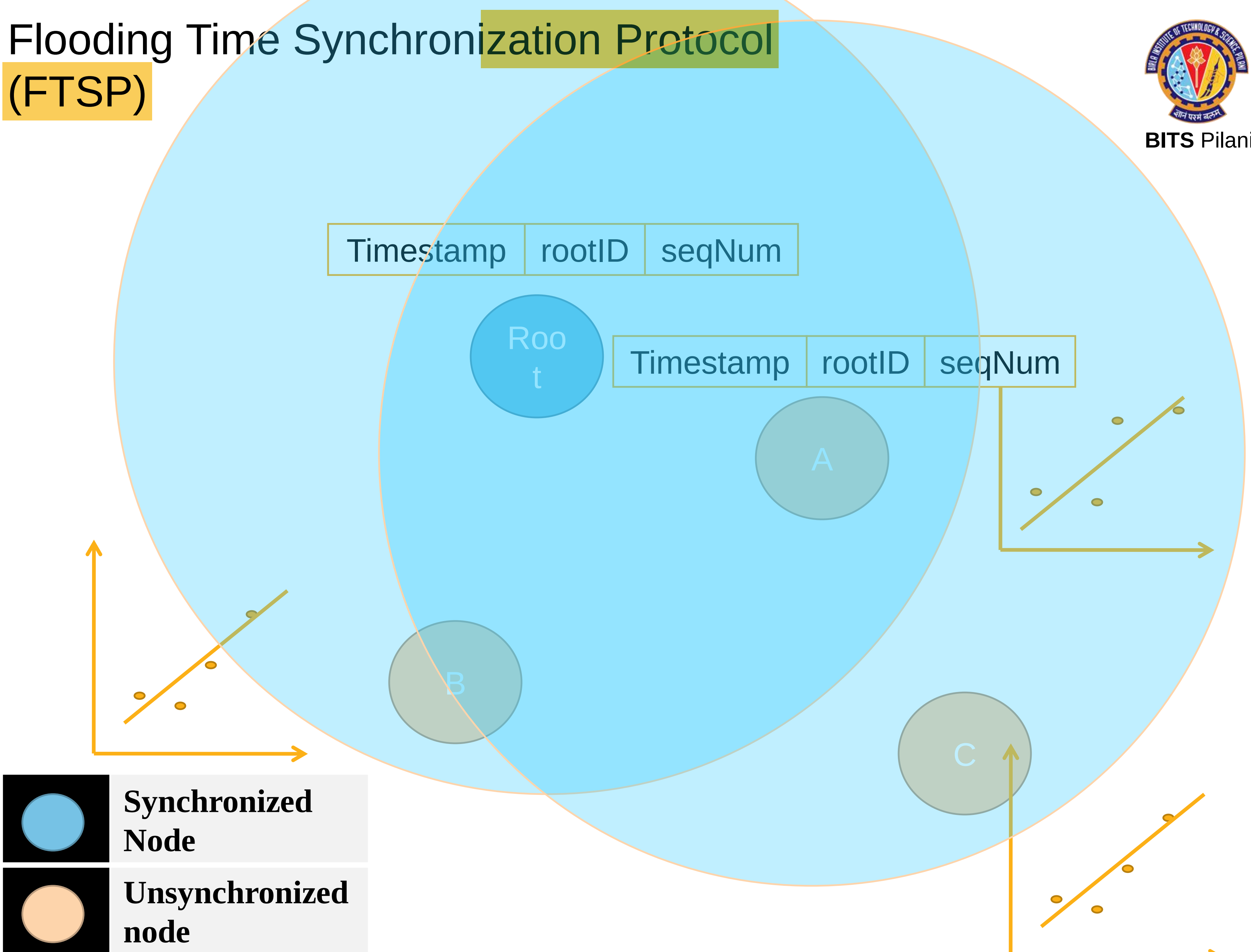
Synchronization phase

Root and synchronized node broadcast synchronization message

Nodes receive synchronization message from root or synchronized node

When a node collects enough synchronization message, it estimates the offset and becomes synchronized node

Flooding Time Synchronization Protocol (FTSP)



BITS Pilani

BITS Pilani

Wireless Sensor Network – Time Sync Protocols

Time Sync Types

BITS Pilani

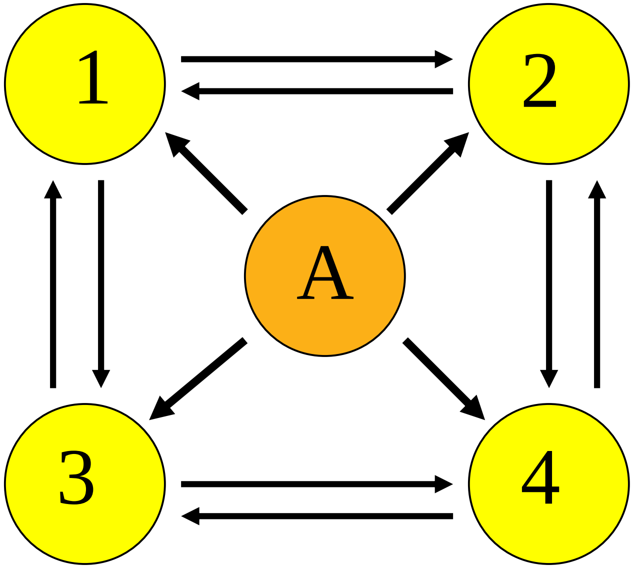
- Sender – Receiver synchronization
- Receiver – Receiver synchronization

Receiver – Receiver Synch

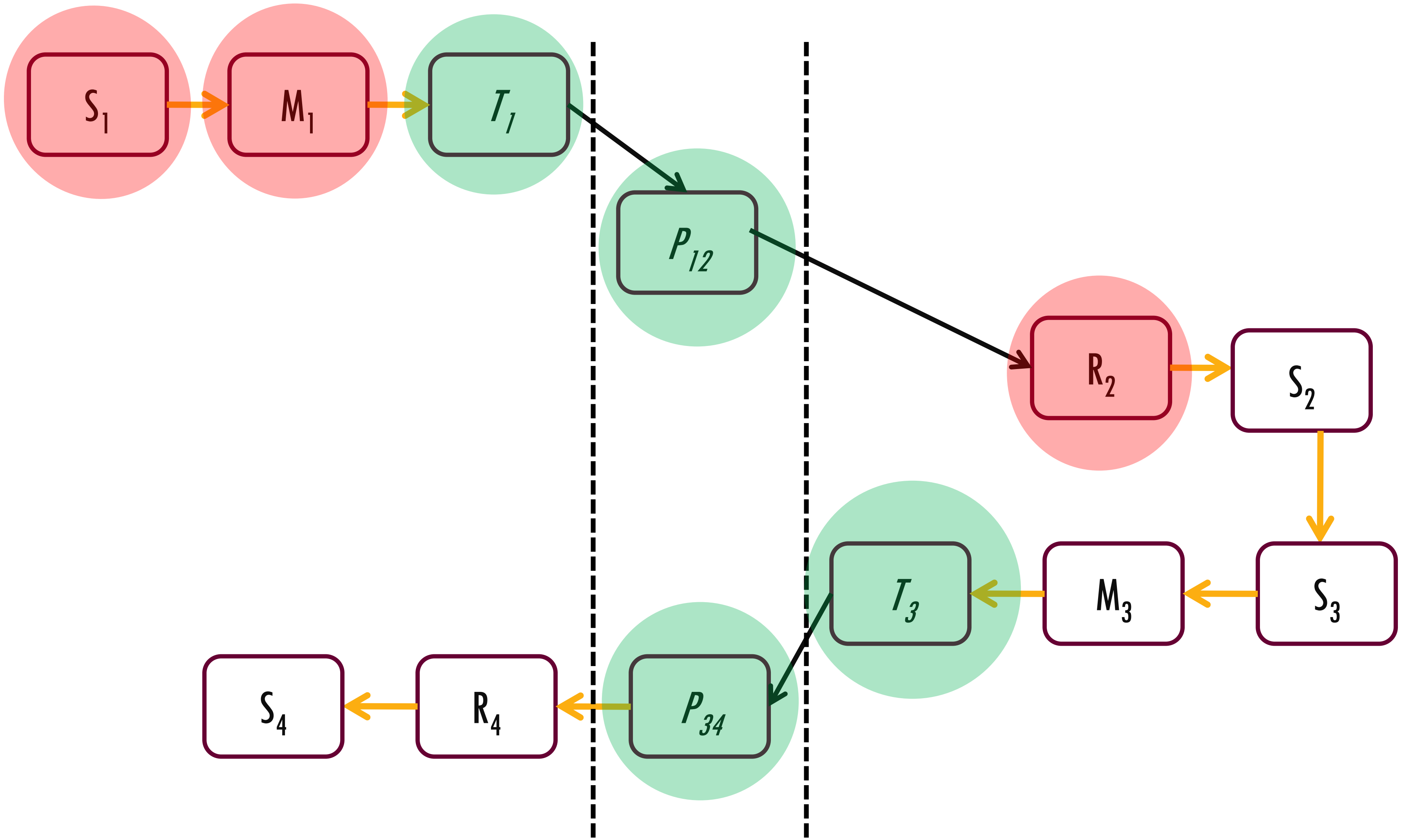
Receiver Broadcasting Service (RBS)

- Three stages
- Transmitter broadcasts clock time
- Each rx records the time that the ref was rxed-local clock
- Receivers exchange observations

RBS

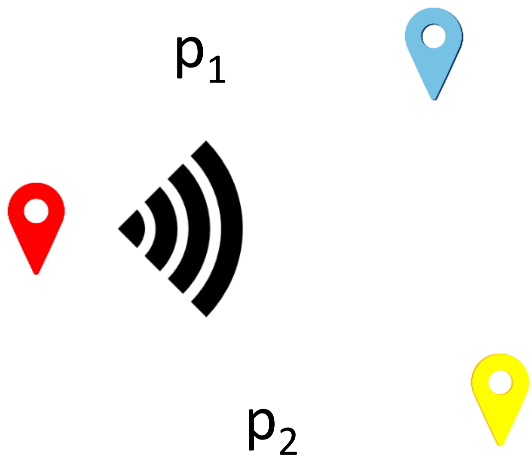


TPSN - Inaccuracies



Inaccuracies Removed ??

BITS Pilani



$r_1 = T + p_1$

$r_2 = T + p_2$

Propagation delay - negligible

$T_2 = T_1 + \Delta +$

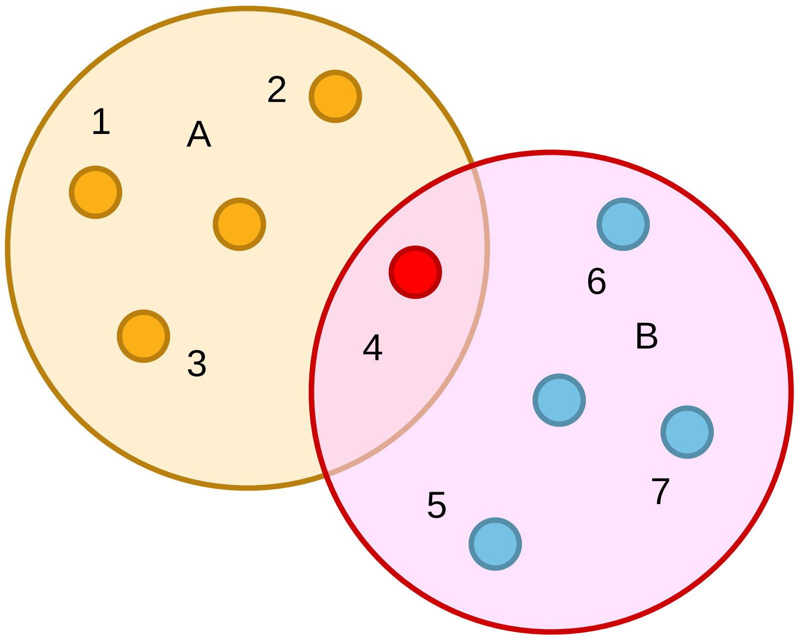
Is RBS extremely accurate ?

BITS Pilani

- No as both skew and offset contribute to lack of sync
- Offset – as each node may start at different time
- Works well in single – hop
- Requires Time Translation in case of multi-hop

Time Translation

BITS Pilani



P_A sent

E_1 occurs 2 units later

E_2 occurs

P_B sent 4 units later

P_B sent 10 units before P_A

$E_1 = P_A + 2$

$E_2 = P_B - 4$

$P_A = P_B + 10$

$E_1 - E_2 = P_B + 10 + 2 - P_B + 4$

$E_1 - E_2 = 16$

Time Sync Protocols

BITS Pilani

- Type1 : Time servers
- Type2 : Translate time thro’ ntk
- Type3 : Self-organize to sync clock

innovate achieve lead

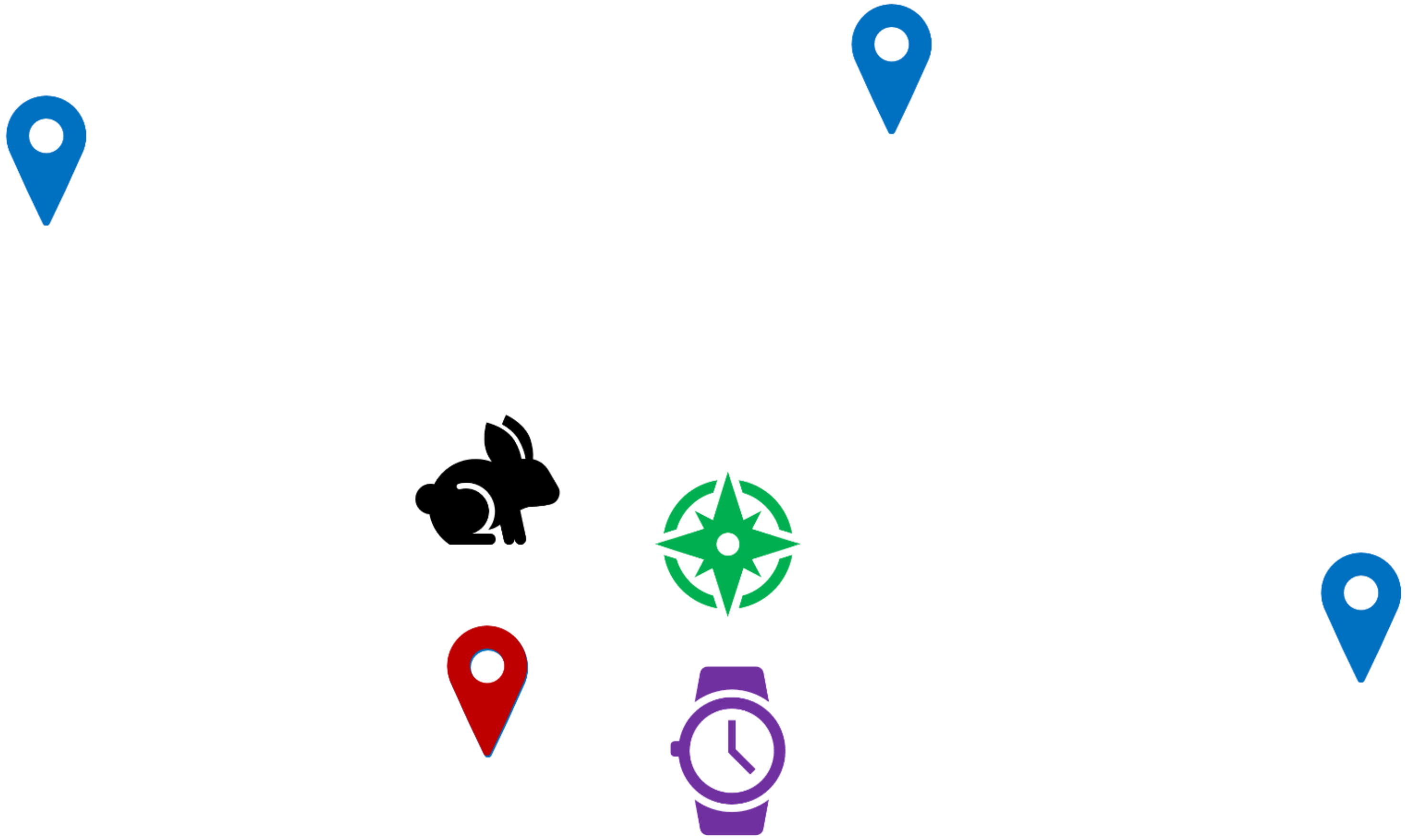
BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network - Localization

Habitat Monitoring

BITS Pilani



Localization??

BITS Pilani

- All nodes in the network have an idea about their absolute/relative position

Localization

BITS Pilani

- Dynamic environment
- Hundreds of sensors are placed randomly – over a large area
- Initial location of the nodes may been unknown
- Estimation of a nodes position used
  - Measurement without position is useless
  - Allows energy efficient geographic routing
  - Self-organization and Self- healing is easier
  - Obstacles can be found and by-passed
  - Tracking – Measurement itself

Position Estimation

BITS Pilani

- Not possible to equip every node with GPS
- Anchors, beacons, landmark nodes
  - Triangulation
  - Tri-Lateration
  - Multi-Lateration

Method to estimate distances based on

Time Period
- ToA
- TDoA

Signal Attenuation
- RSS
- MTP

Neighborhood Information
- Connectivity
- Hop Count

Localization– Modes of Operation

- Initialization
- Post – Deployment Operation - Mobile

innovate achieve lead

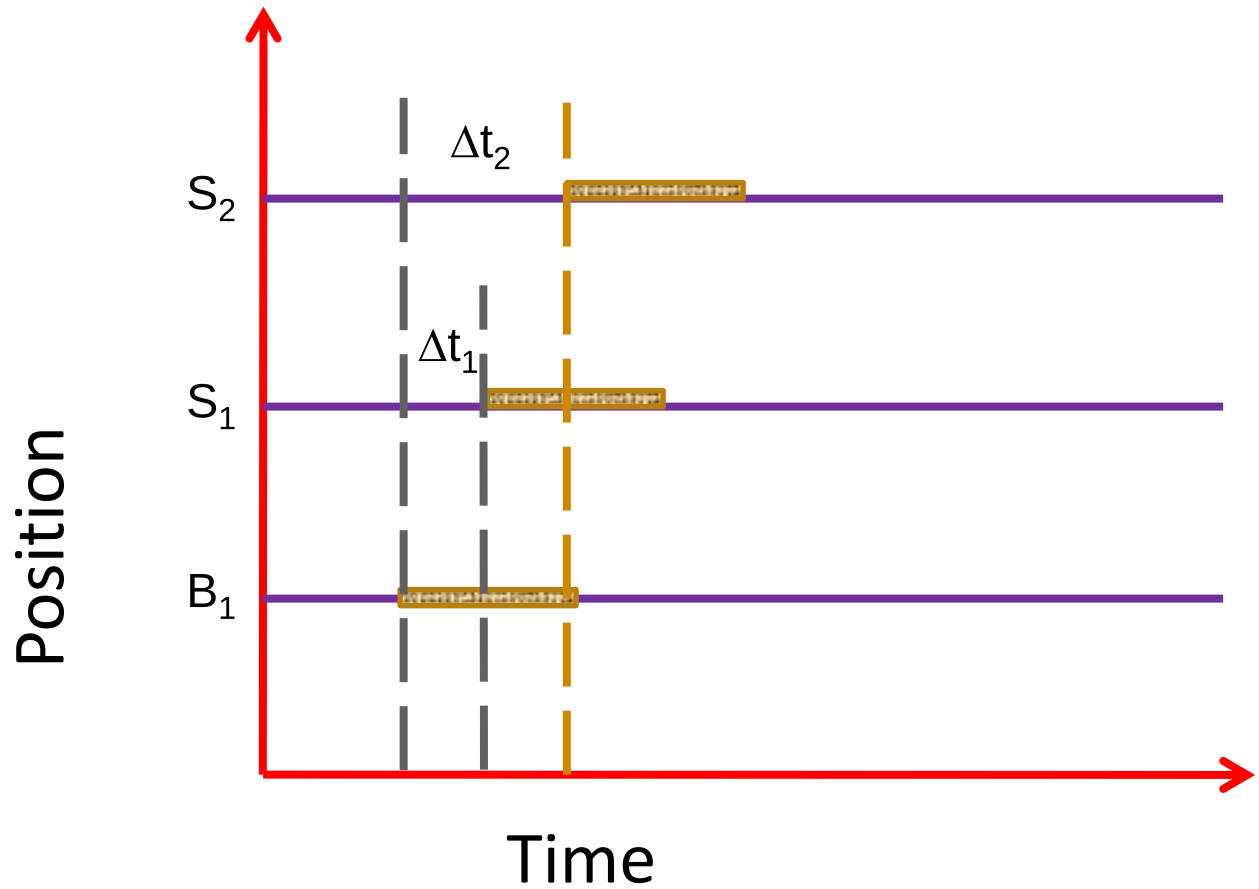
BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network - Localization – Distance Estimation

Time of Arrival (ToA)

BITS Pilani



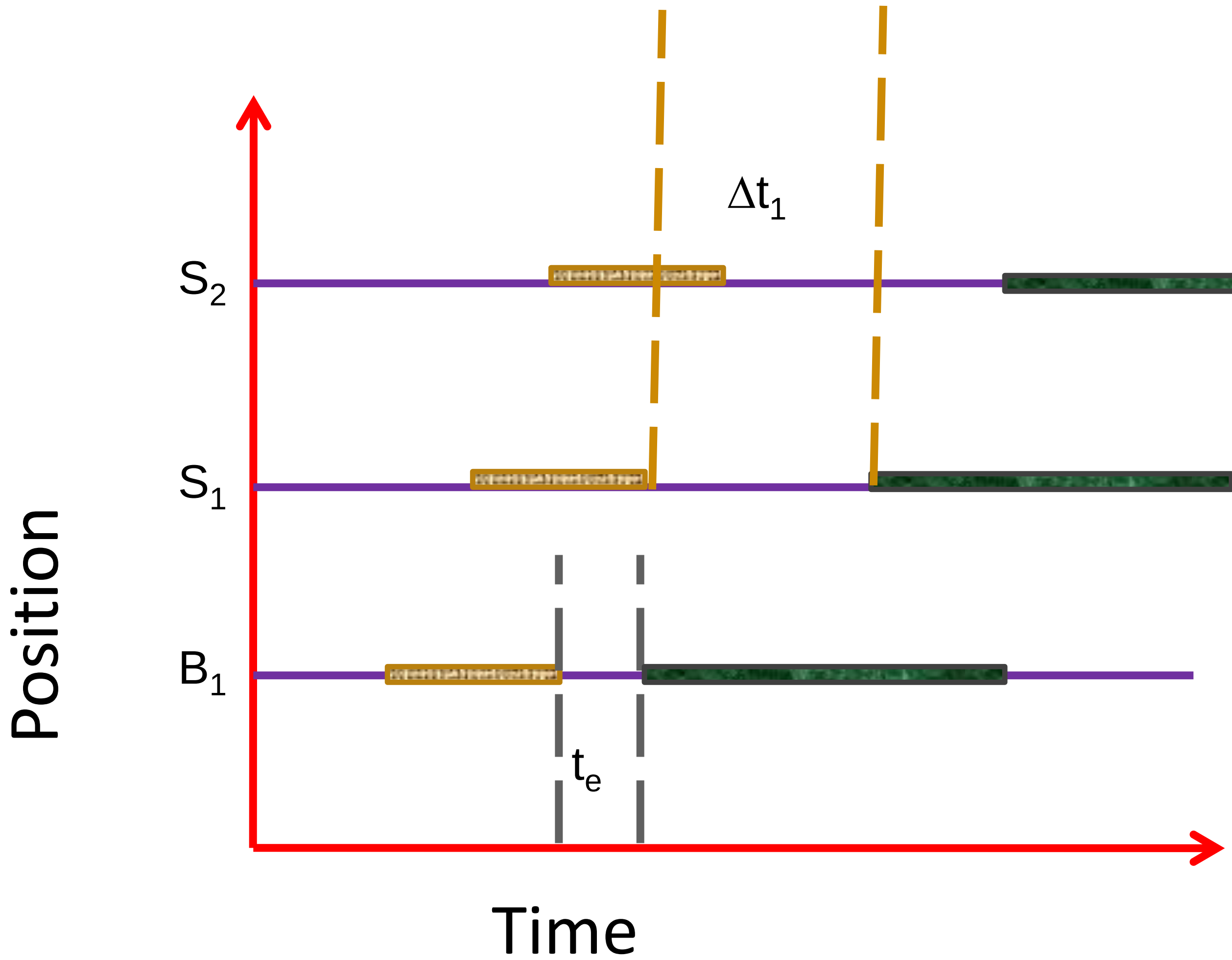
$$d = c_{AIR}\Delta t$$

Issues with ToA??

BITS Pilani

- C_{AIR} - 297,702 km/s ≈ $3x10^6$ m/s
- d = 30cm btwn B1 & S1
- Δt = 1ns

Time of Arrival (ToA)



$$\mathbf{d = c_S * (\Delta t_1 - t_e)}$$

Improvement??

- C_S - 340 m/s
- All time measurements will not be affected by lack of time sync
- Sound unpredictable medium
- Additional hardware

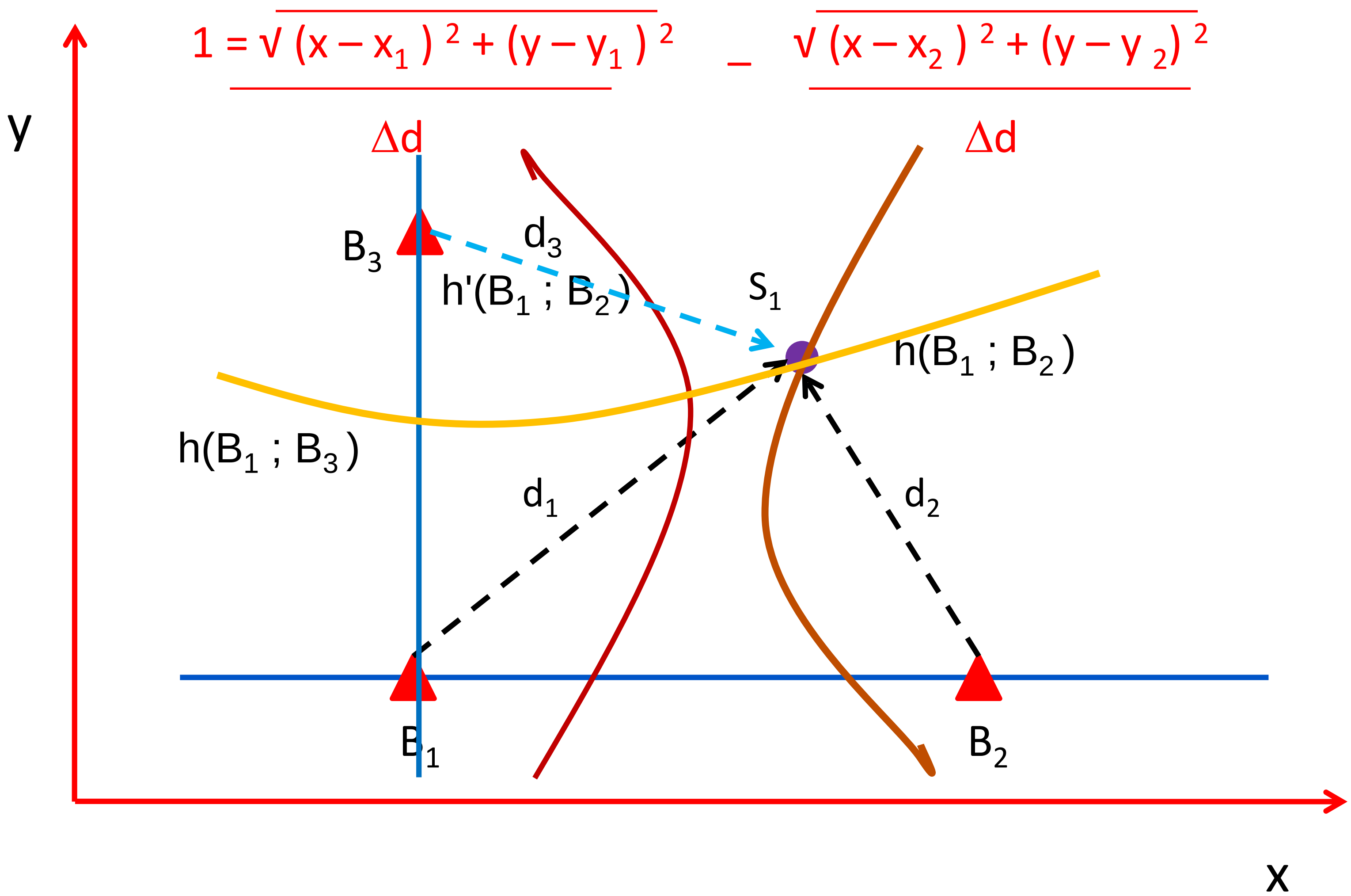
innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network - Localization – Distance Estimation

Time Difference of Arrival (TDoA)



$d_1 - d_2 = \Delta t.c = \Delta d \qquad \Delta t = t_{end} - t_{start}$

Issues with TDoA??

BITS Pilani

- No. of Beacons required
- Localized nodes can act as beacons themselves

innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

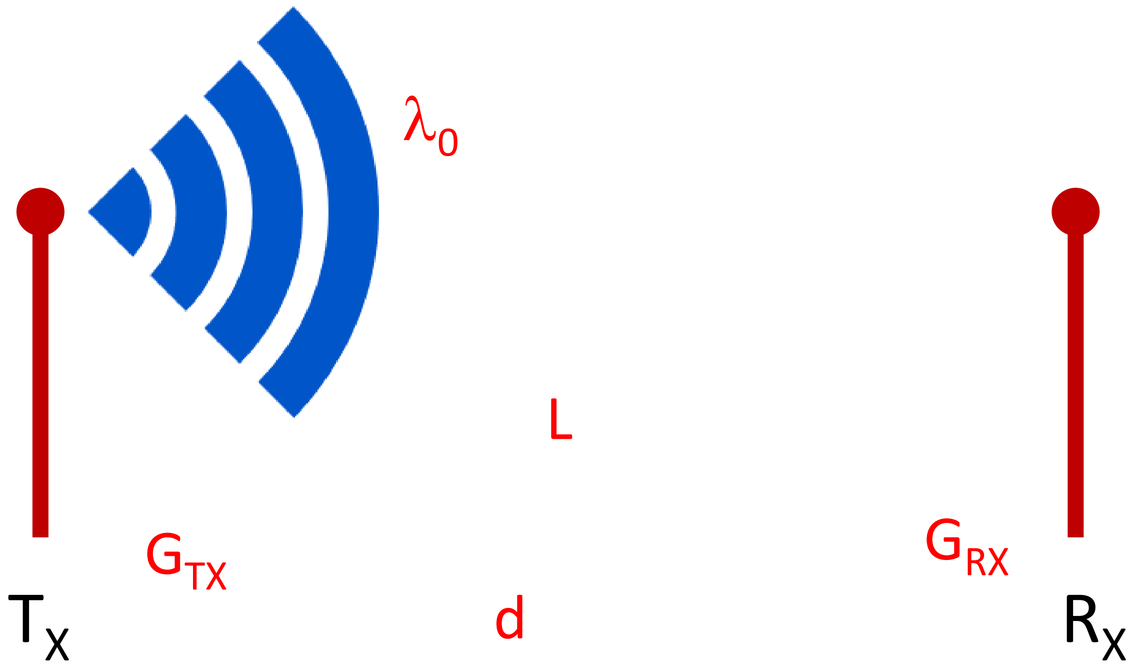
Wireless Sensor Network - Localization – Distance Estimation

Received Signal Strength (RSSI)

$$\frac{P_{RX}}{P_{TX}} =$$

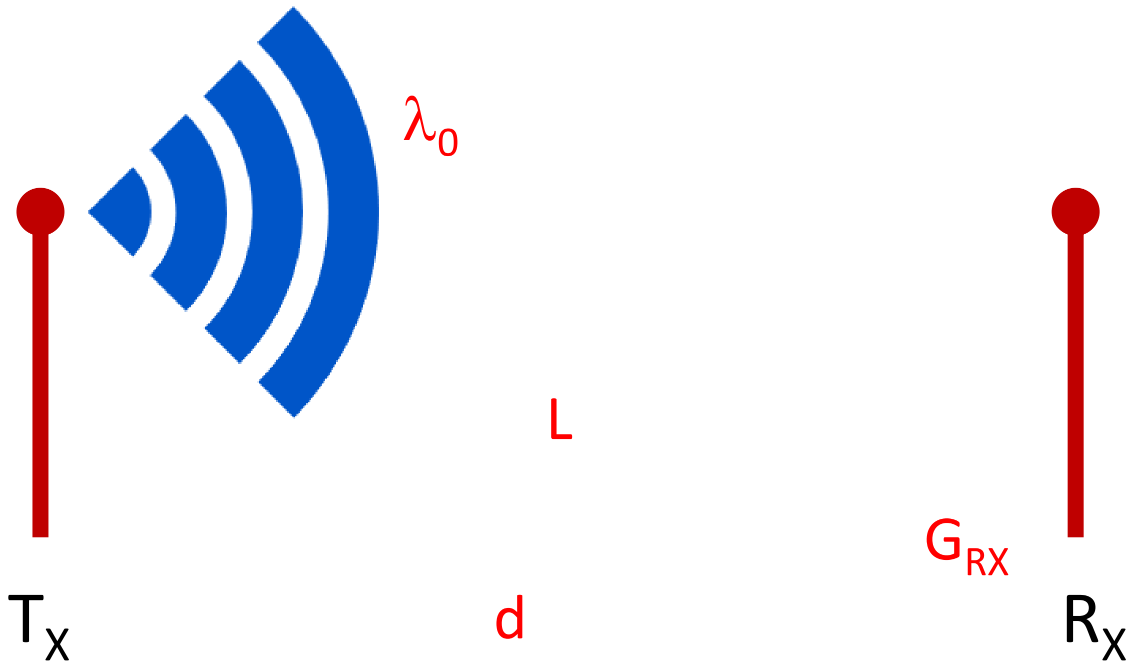
Received Signal Strength (RSSI)

BITS Pilani



$$\frac{P_{RX}}{P_{TX}} =$$

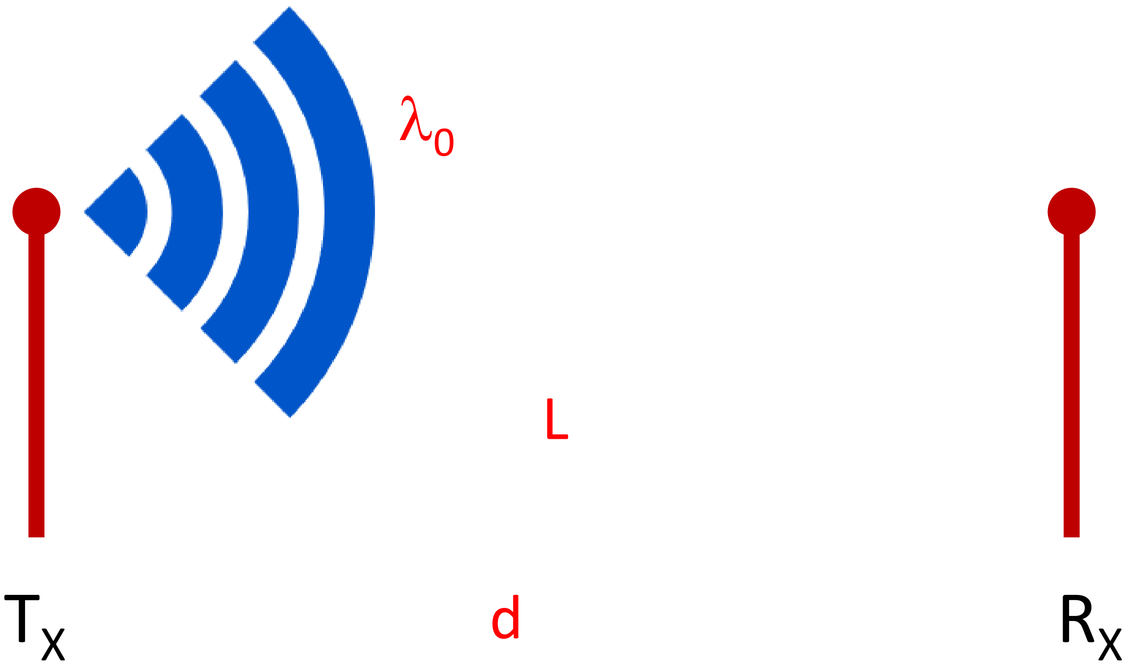
Received Signal Strength (RSSI)



$$\frac{P_{RX}}{P_{TX}} = G_{TX}$$

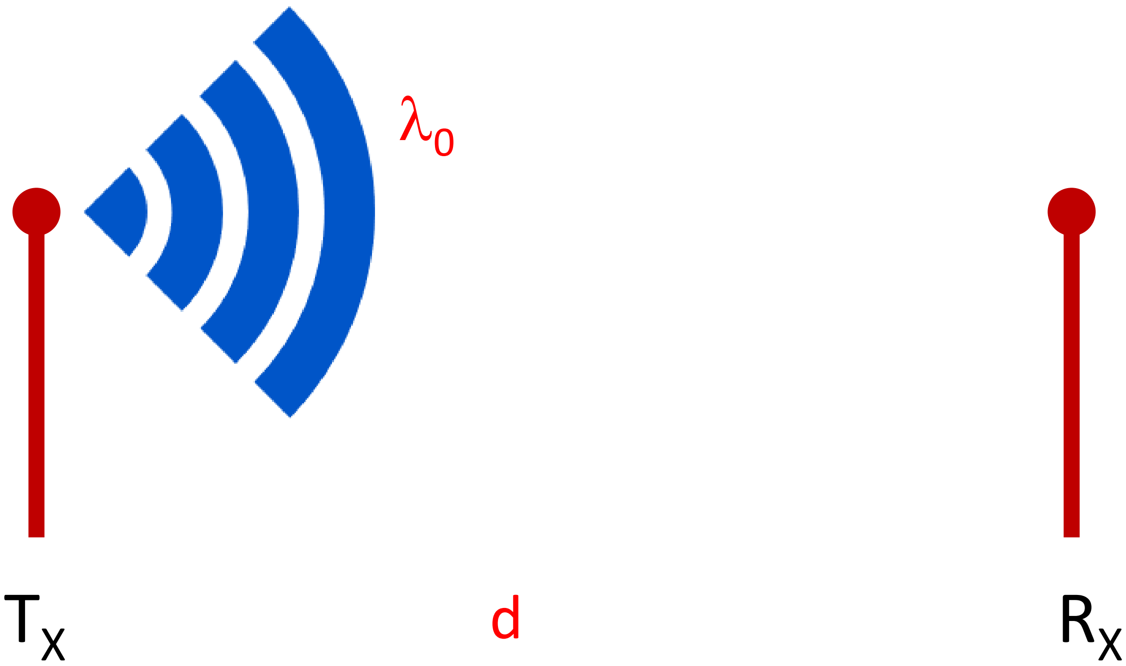
Received Signal Strength (RSSI)

BITS Pilani



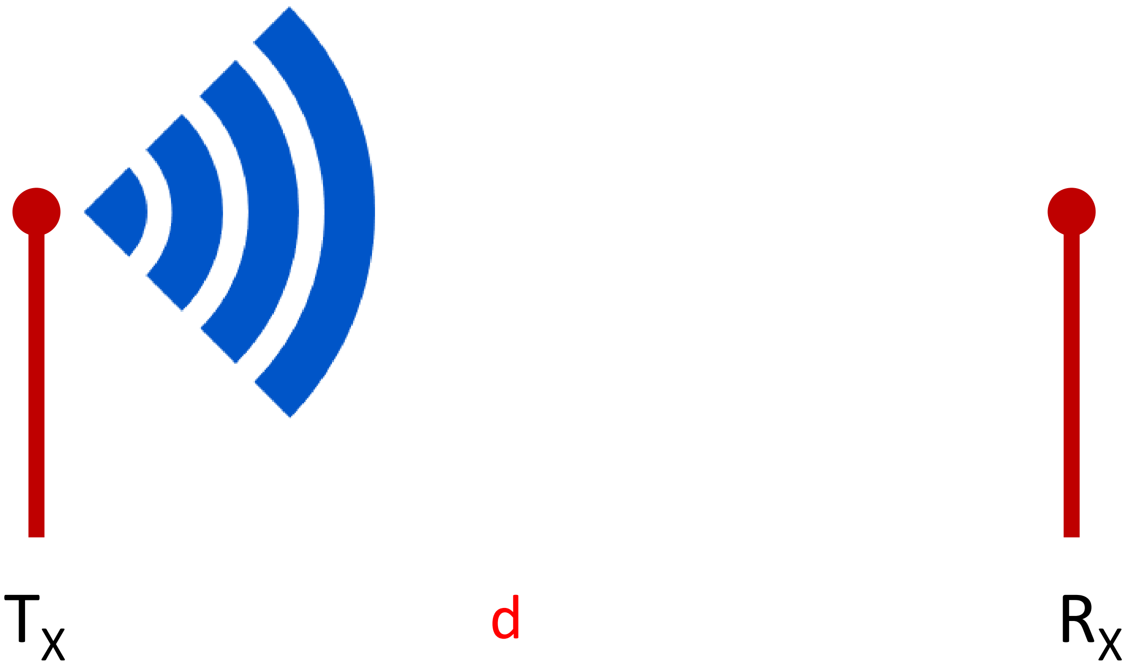
$$\frac{P_{RX}}{P_{TX}} = G_{TX}\ G_{RX}$$

Received Signal Strength (RSSI)



$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX}\ G_{RX}}{L}$$

Received Signal Strength (RSSI)



$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX} \; G_{RX}}{L} \qquad \lambda_0$$

Received Signal Strength (RSSI)

BITS Pilani

$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX}\ G_{RX}}{L} \qquad \lambda_0$$

d

Received Signal Strength (RSSI)

BITS Pilani

$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX}\ G_{RX}}{L}\left\{\frac{\lambda_0}{4\pi d}\right\}^2$$

Received Signal Strength (RSSI)

BITS Pilani

$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX}\ G_{RX}}{L}\left\{\frac{\lambda_0}{4\pi d}\right\}^2$$

FRIIS Equation

$$PL = 10\log \frac{G_{TX}\ G_{RX}}{L}\left\{\frac{\lambda_0}{4\pi d}\right\}^2$$

$$d_{max} = \frac{\lambda_0}{4\pi 10^{-PLmax/20}}$$

Issues with RSSI??

BITS Pilani

- Ideal Gain & No Loss Assumption
- Loss is unpredictable
- Need for measurement technique

Minimum Transmission Power (MTP)

BITS Pilani

- Motes allow multiple power levels

Wireless Sensor Network - Localization – Algorithms

EEE G627: Networked Embedded Applications (Dr. Vinay Chamola, BITS-Pilani)

Issues ??

BITS Pilani

- Resource Constraints
- Node Density
- Non-Convex Topology – Border Node Problems
- Environmental Obstacles & Terrain Irregularities

Requirements of LA

BITS Pilani

- High Precision
- Minimal cost
- Fully distributed – robust & reliable
- Adaptive to environmental changes
- Mobility must be accommodated
- Resource- Efficient

Types

- Approximate Vs Precise
- Central Vs Distributed
- Range based Vs Range Free
- Relative Vs Absolute
- Indoor Vs Outdoor
- Beacon-Free Vs Beacon based

innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

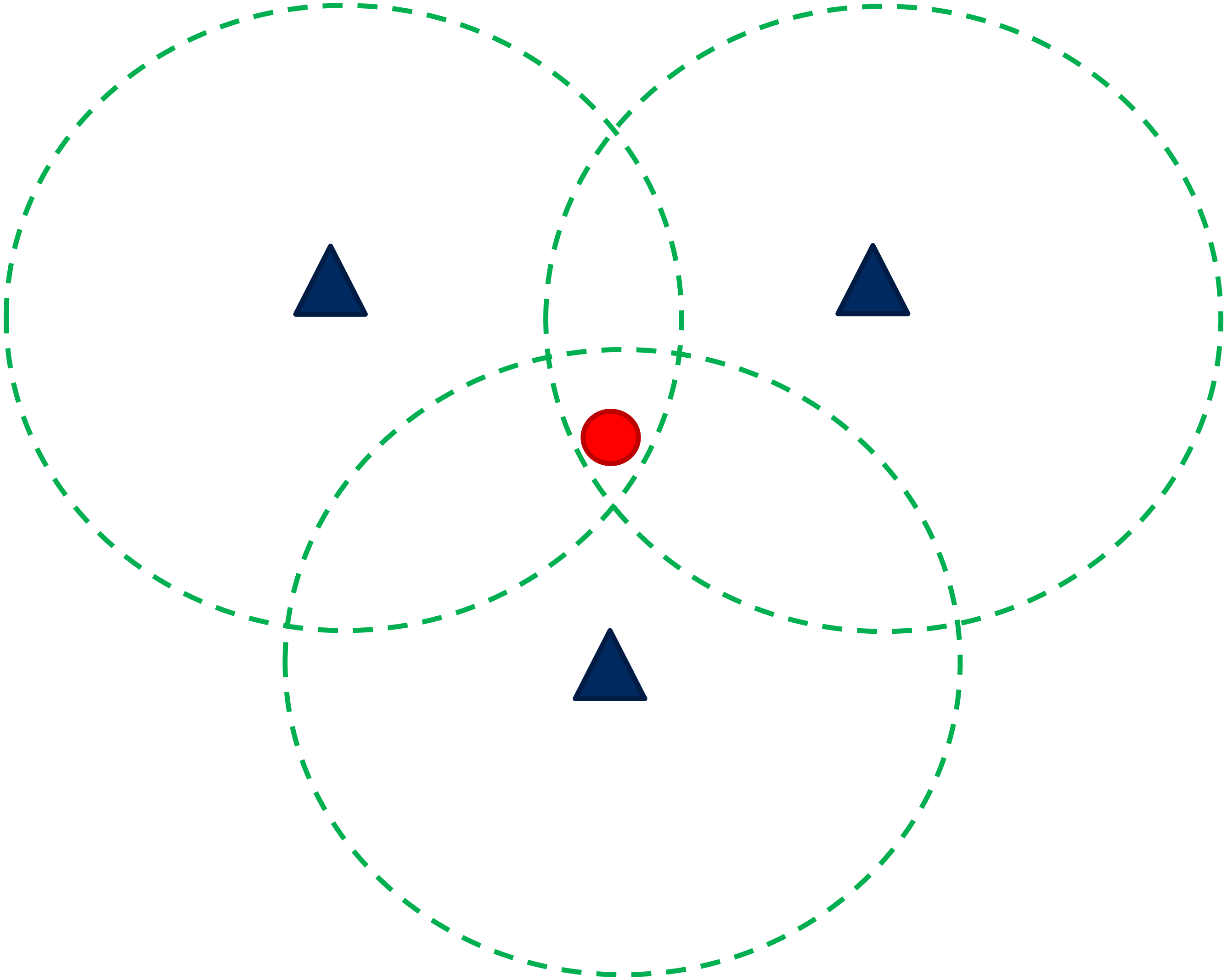
Wireless Sensor Network - Localization – Algorithms

EEE G627: Networked Embedded Applications (Dr. Vinay Chamola, BITS-Pilani)

Centroid Localization

- Based on the concept of Trilateration
- Extended to Multilateration

Trilateration



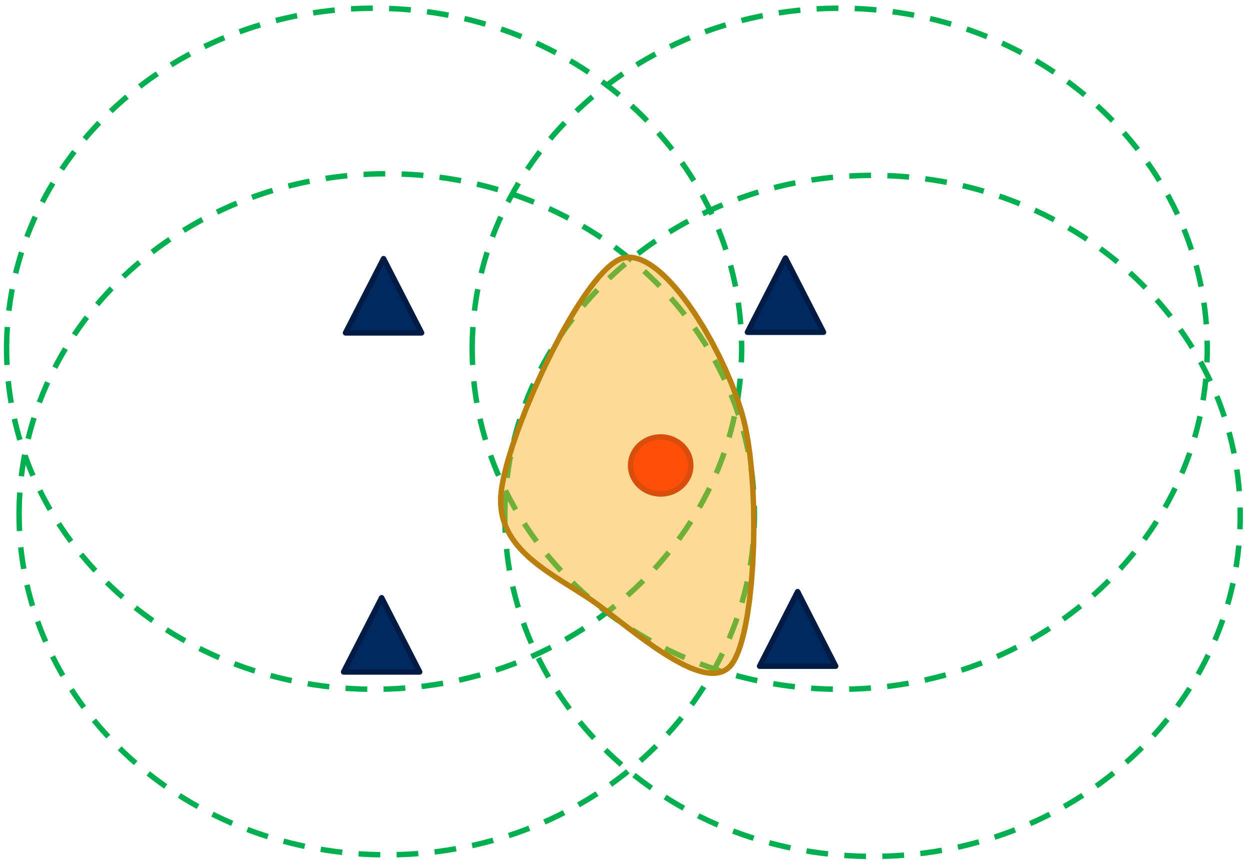
$(B_iS)^2 = (B_i(x_i) - S(x))^2 + (B_i(y_i) - S(y))^2$

Assumptions

BITS Pilani

- Perfect Spherical Radio Propagation
- Identical Tx range for all radios
- The neighbouring signal points can be sync so that they do not overlap in time

Multi-Lateration

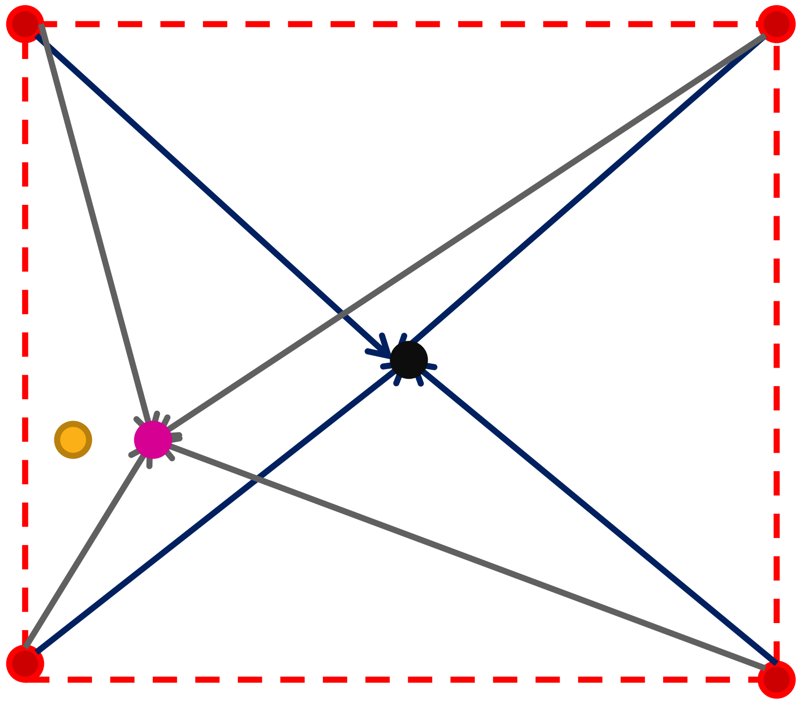


Position Estimation

BITS Pilani

$$S(x,y) = 1/n \sum_n B(x_i,y_i)$$

Issues with Centroid



Assign Weights

Weighted Centroid

- Weights
- RSSI
- ToA

H-SATS- Simple Hierarchical Time Synchronization Algorithm for WSNs

Outline

1. Motivation
2. Existing synchronization schemes
3. H-SATS
4. Experimental Setup
5. Results
6. Discussion

Motivation

BITS Pilani

1. Time Synchronization Protocols (TSPs) give a common reference of time for a distributed network like WSN
2. Essential for data-fusion, TDMA based communication, power management protocols
3. Different levels of Time-synchronization
4. Cannot do it using GPS or standard protocols like NTP used for traditional networks

Motivation…

BITS Pilani

1. Clustering technique is an important and energy-efficient technique especially for data-gathering, fusion, etc.
2. Most of the TSPs are simulation based works
3. Effectiveness for practical WSNs questionable
4. cannot give a complete picture
5. make many assumptions at a high level of abstraction, do not consider packet loss and its effect on synchronization accuracy
6. Also do not state the Line-of-Sight (LOS) conditions in which the experiments are performed
7. LOS conditions can have significant effect on the performance of TSP

Existing schemes for clustered WSN…

BITS Pilani

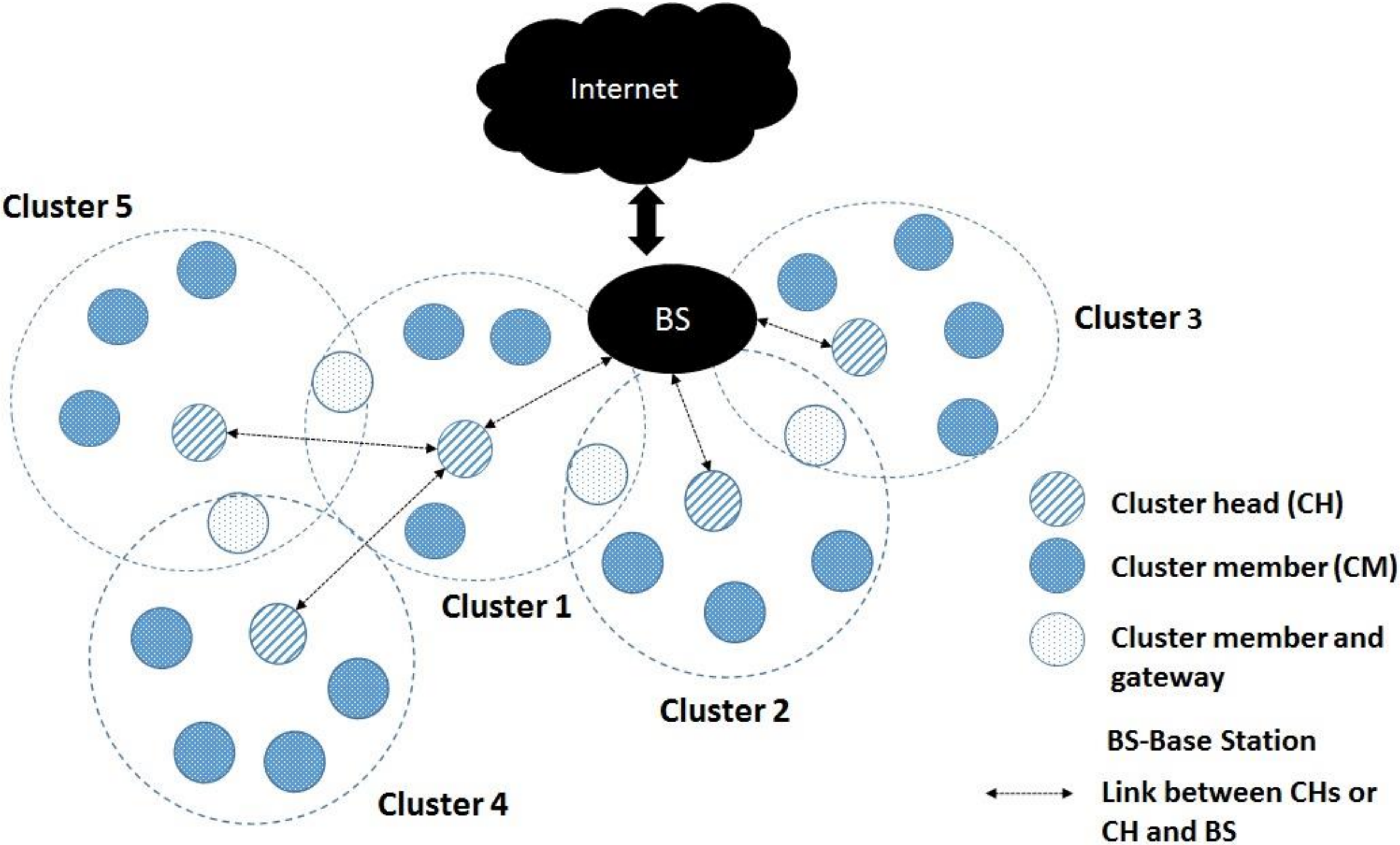
1. SLTP, L-Synch- Regression based schemes

   low accuracy, simulation based works, do not account for deterministic and non-deterministic delays
2. PC-Avg-takes average

   poor synchronization accuracy
3. CCTS, CMTS- high accuracy, but high overhead

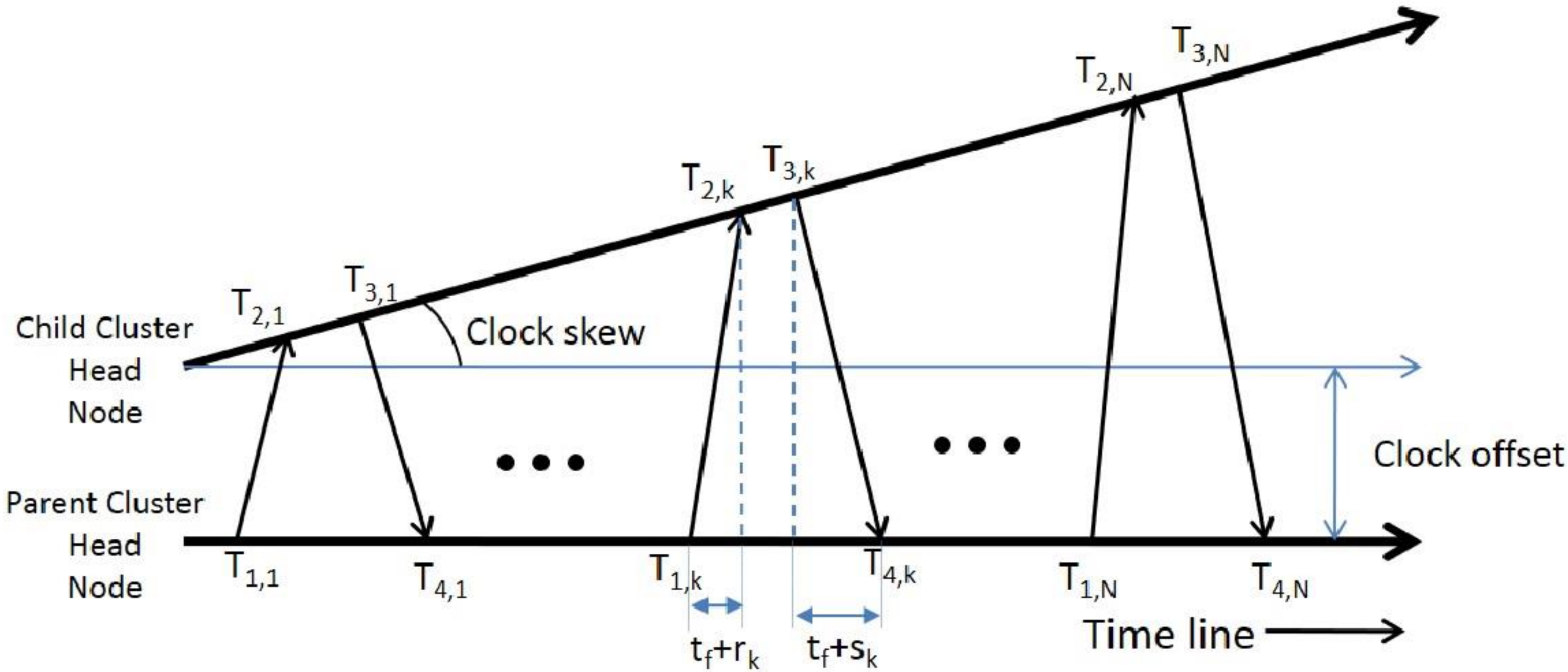
H-SATS

BITS Pilani



H-SATS

BITS Pilani



Mathematical Basis

BITS Pilani

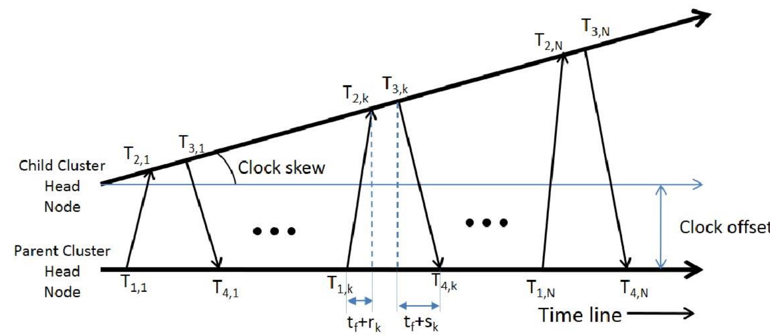
1. Clock Model

offset

$$C_i(t) = \alpha_i \, t + \beta_i,$$

skew

$$C_{ih}(t) = \alpha_{ih} \, C_h + \beta_{ih},$$



2. For a two-way exchange we can write

Det Delay

$$T_{2,k} = \alpha_{ih}(T_{1,k} + t_f + r_k) + \beta_{ih}$$

$$T_{3,k} = \alpha_{ih}(T_{4,k} - t_f - s_k) + \beta_{ih},$$

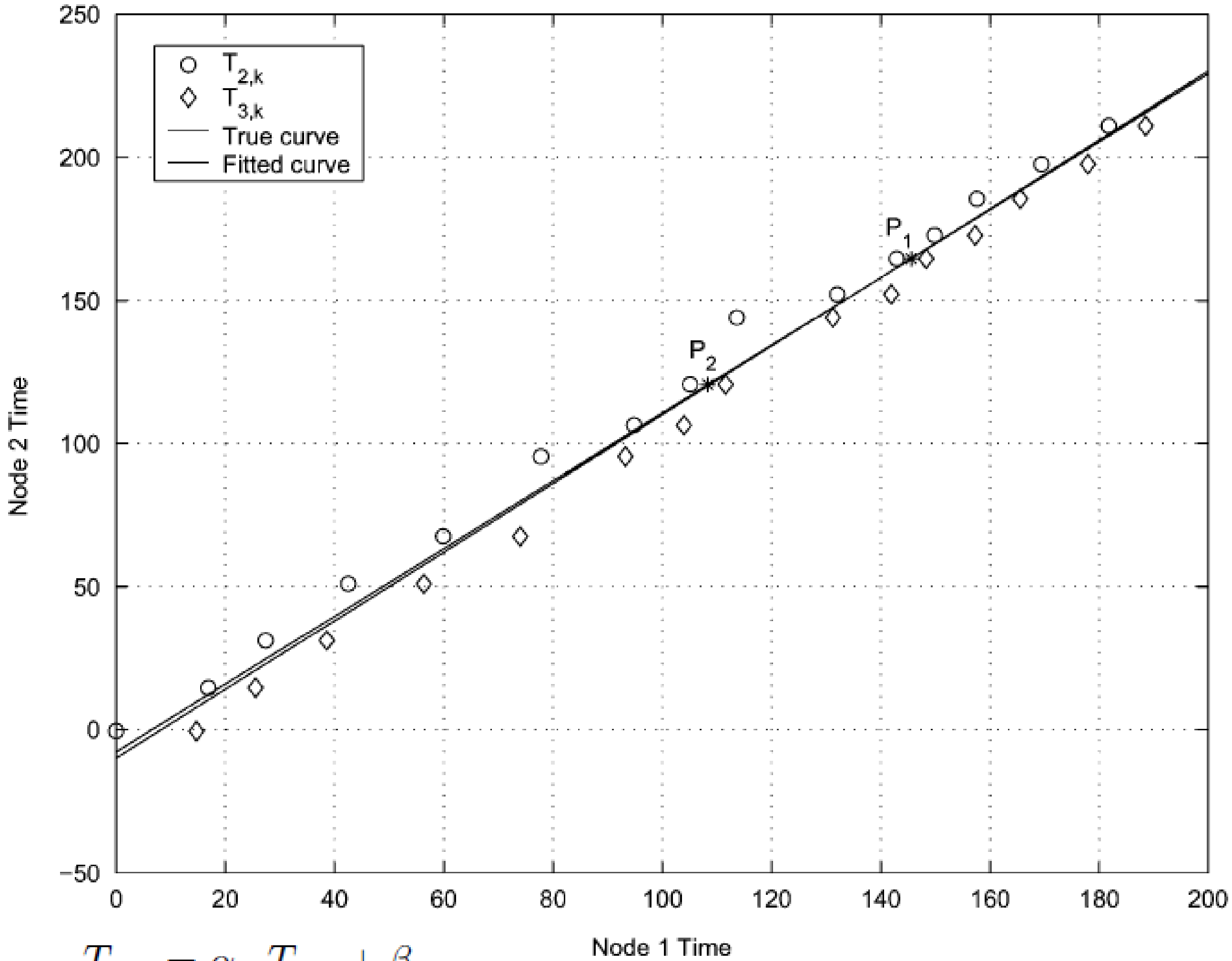
Non-deterministic delay

$$T_{2,k} = \alpha_{ih} T_{1,k} + \beta_{ih} + \alpha_{ih}(t_f + r_k)$$

$$T_{3,k} = \alpha_{ih} T_{4,k} + \beta_{ih} - \alpha_{ih}(t_f + s_k).$$

H-SATS

BITS Pilani



$$T_{2,k} = \alpha_{ih} T_{1,k} + \beta_{ih}$$

$$T_{3,k} = \alpha_{ih} T_{4,k} + \beta_{ih}$$

H-SATS vs regression method

BITS Pilani

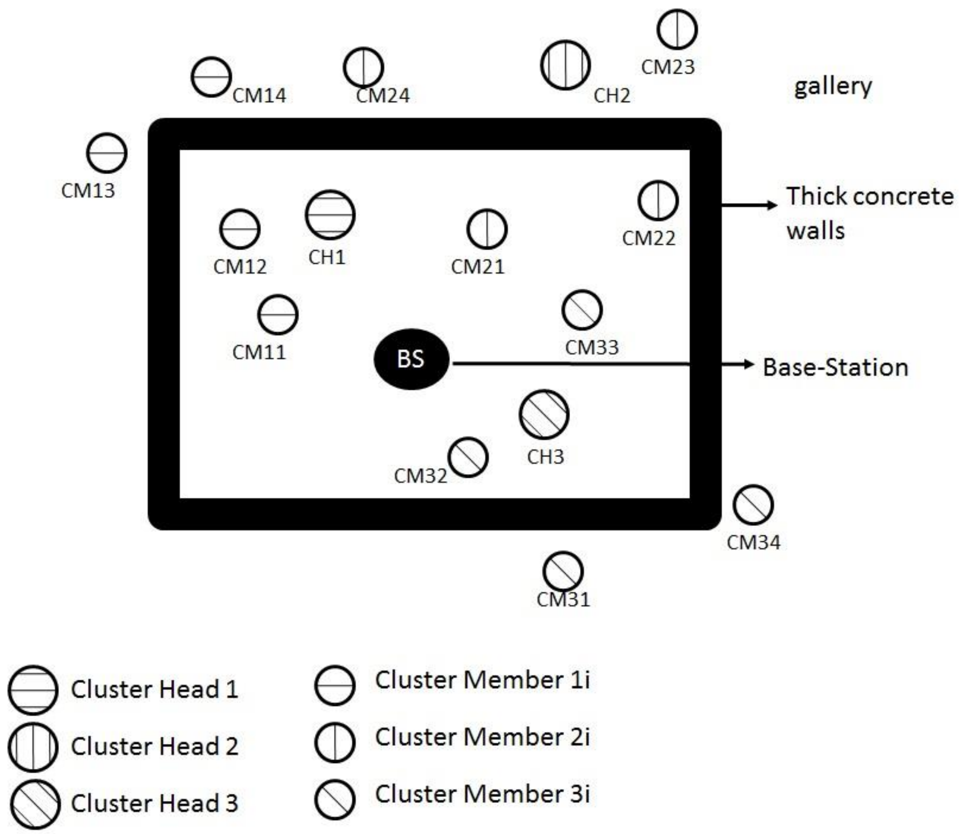
Algorithm Complexity for additions and multiplications

Algorithm	Additions	Multiplications
Regression method	O(N)	O(N)
SATS	O(N)	1

Experimental Setup

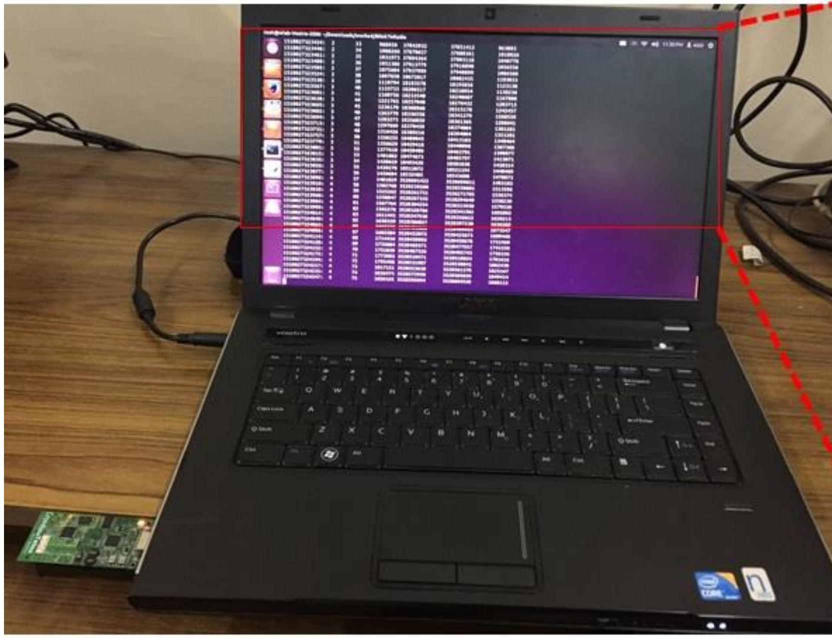
BITS Pilani

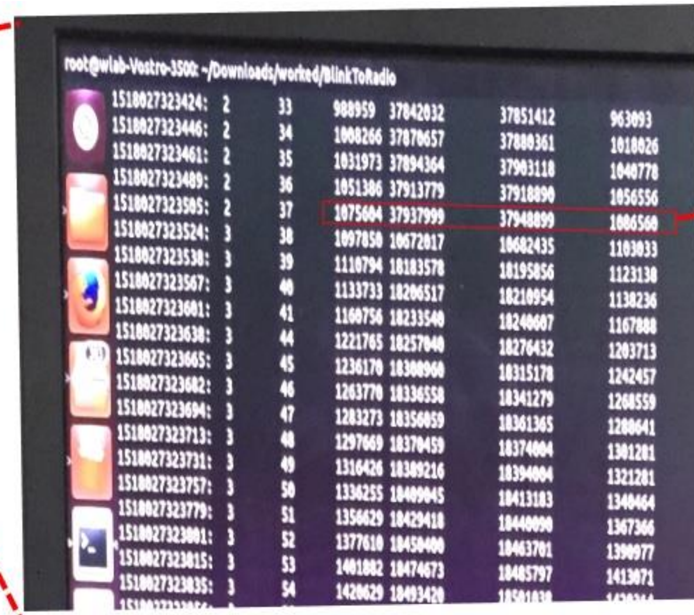
Experimental Setup



Base Station collecting the data

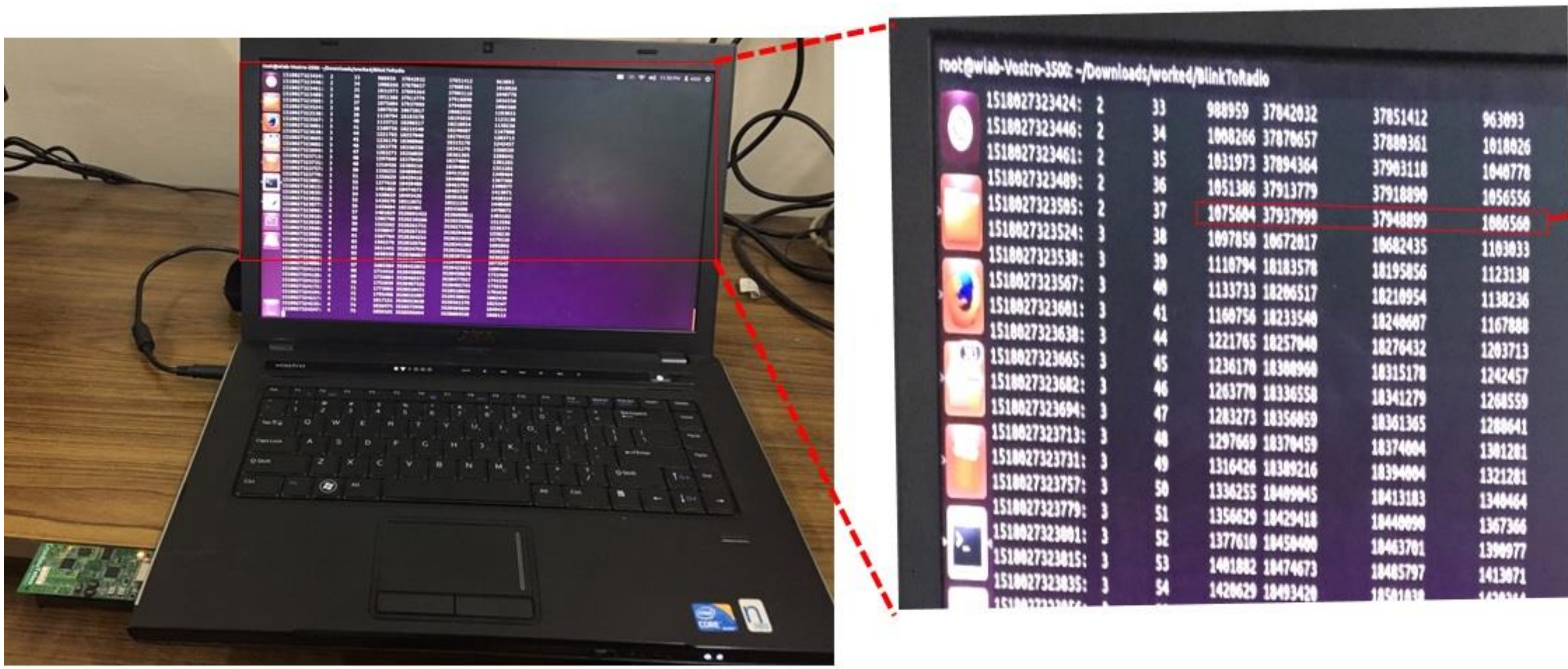
BITS Pilani





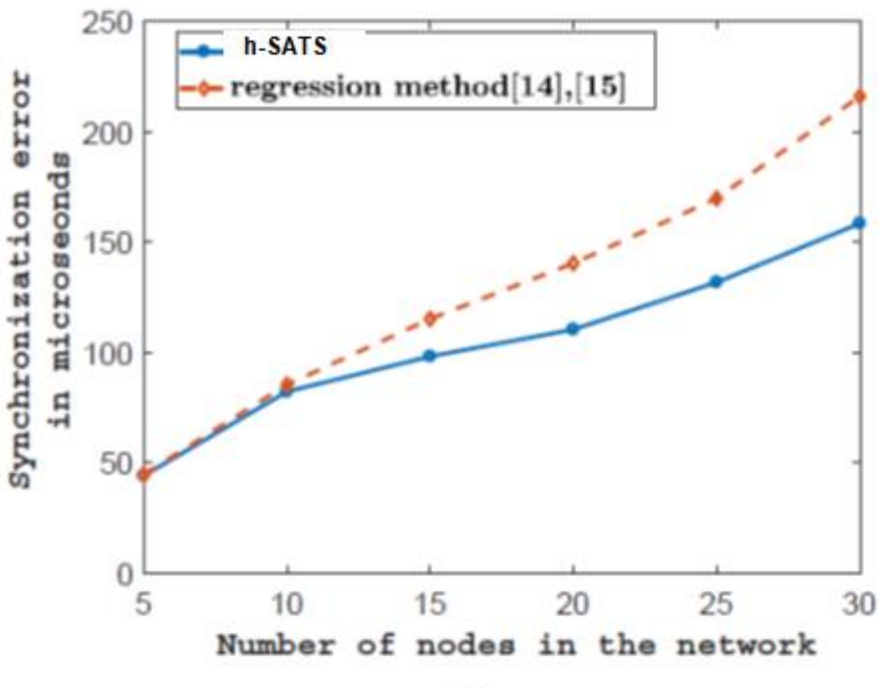
4 time stamps of a two- way exchange

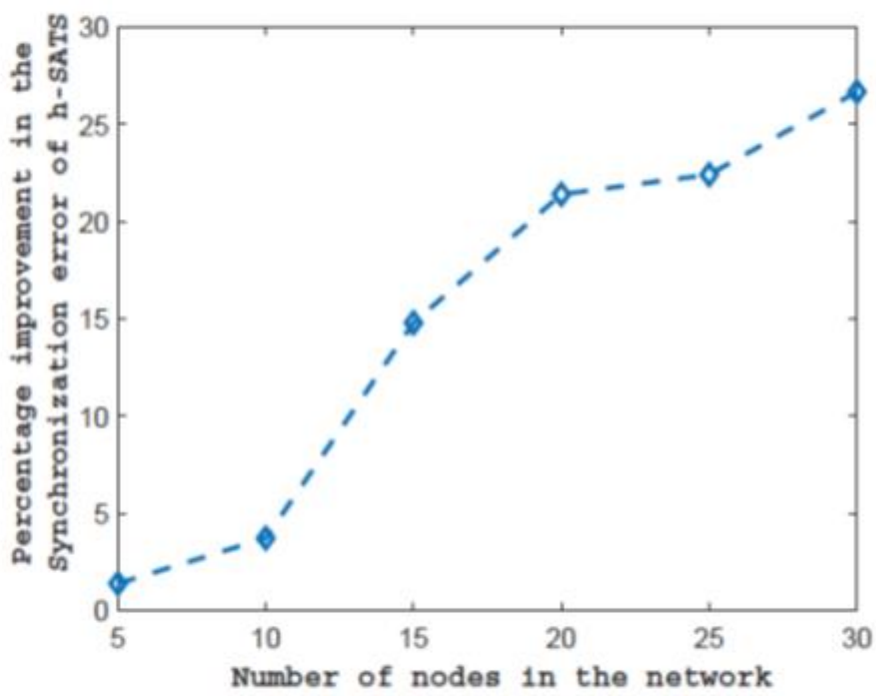
Base Station collecting the data



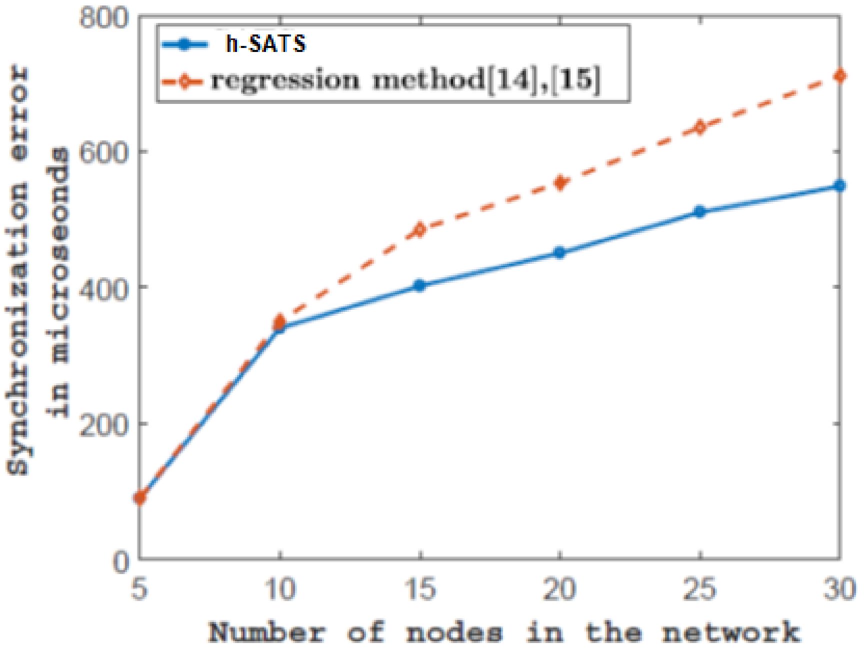
4 time stamps of a two- way exchange

Results-LOS

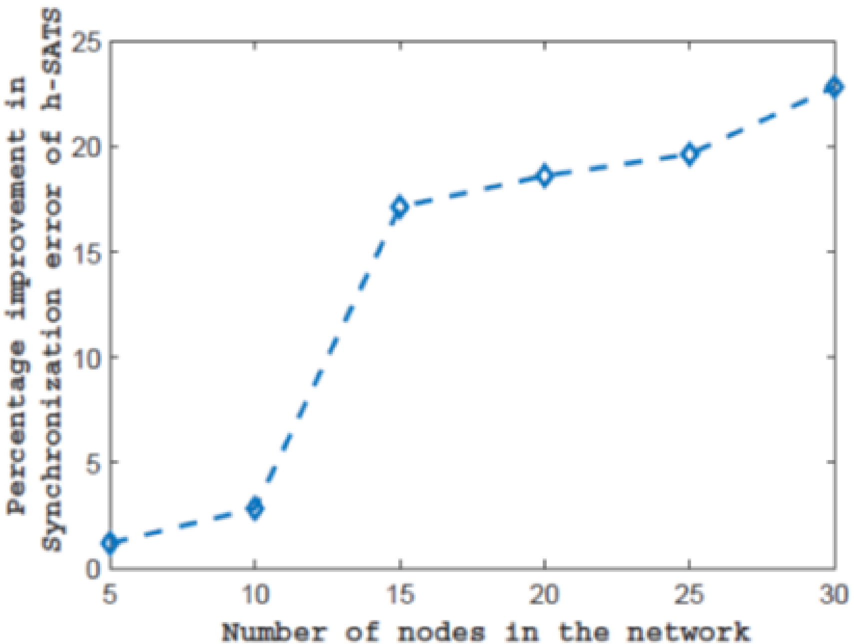

h-SATS
regression method[14],[15]
Synchronization error in microseonds
Number of nodes in the network
0
50
100
150
200
250
5
10
15
20
25
30


Percentage improvement in the Synchronization error of h-SATS
Number of nodes in the network
0
5
10
15
20
25
30
5
10
15
20
25
30

Results-mixed-LOS



(a)



(b)

References

Chalapathi, G.S.S., Manekar, R., Chamola, V., Anupama, K.R. and Gurunarayanan, S., 2016, November. Hardware validated efficient and simple Time Synchronization protocol for clustered WSN. In *Region 10 Conference (TENCON), 2016 IEEE* (pp. 2162-2166). IEEE.

Other works are submitted to Journals for publication

innovate achieve lead

BITS Pilani

Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network - Routing

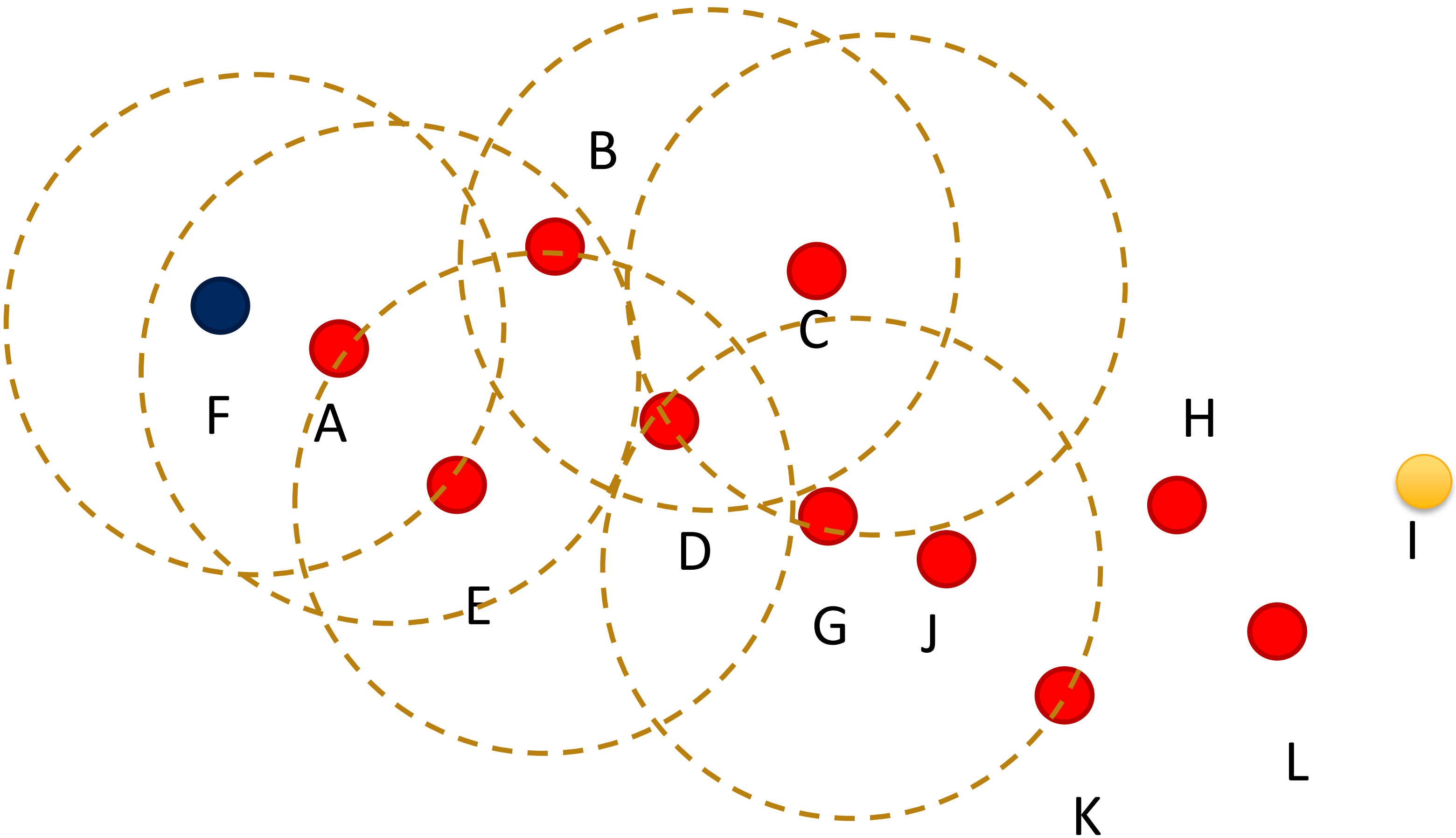
Routing

BITS Pilani

- Flooding
- Gossiping

Flooding

BITS Pilani

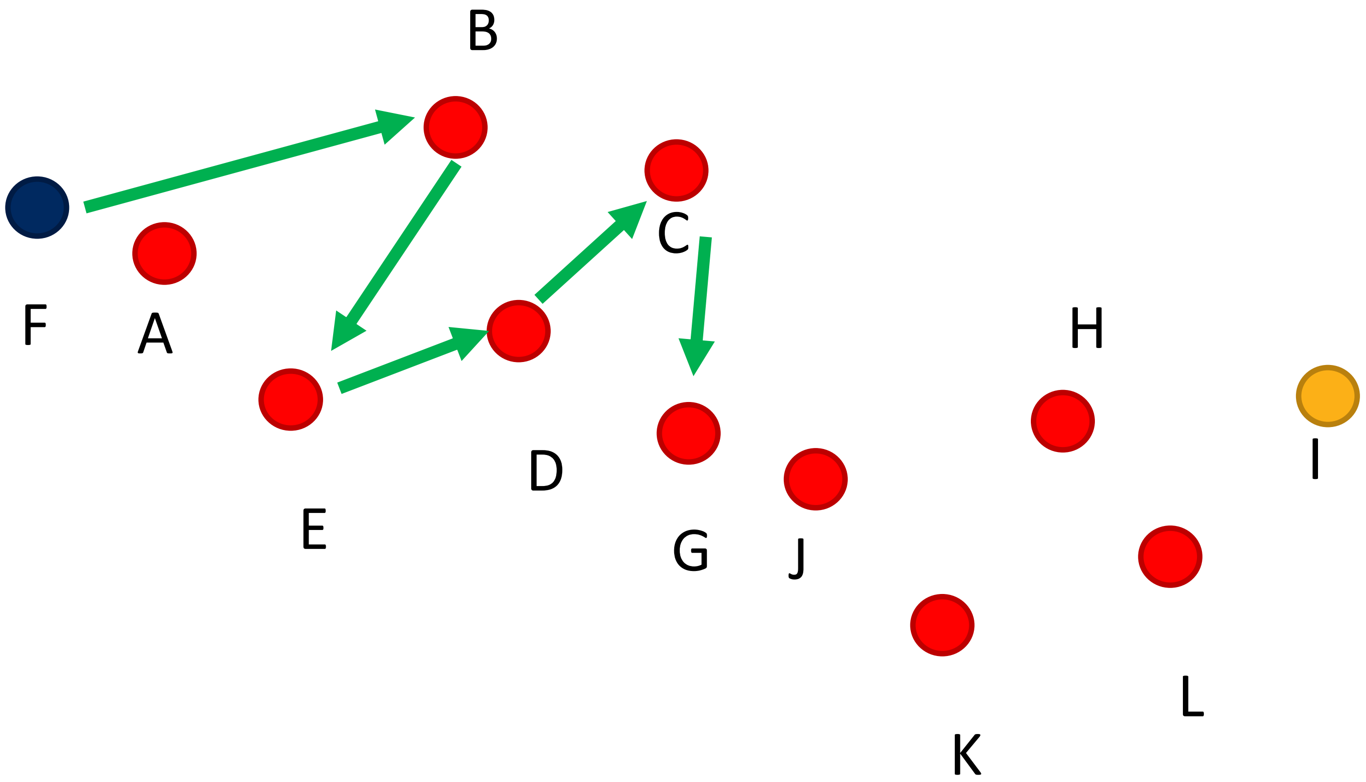


Flooding - Issues

BITS Pilani

- Broadcast Storms

Gossiping



Gossiping - Issues

- No Control over Route Length

Routing - Types

- Proactive
- Reactive
- Multi-hop
- Direct
- Push
- Pull

Routing – Performance Criteria

- Hit-Miss Ratio
- Average Energy Consumption
- Network Life Time

Routing Algorithms

BITS Pilani

- Optimization-based
- Data-centric
- Cluster-based
- Location-based
- QoS Enabled

BITS Pilani
Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network - Clustering

Routing - Clustering

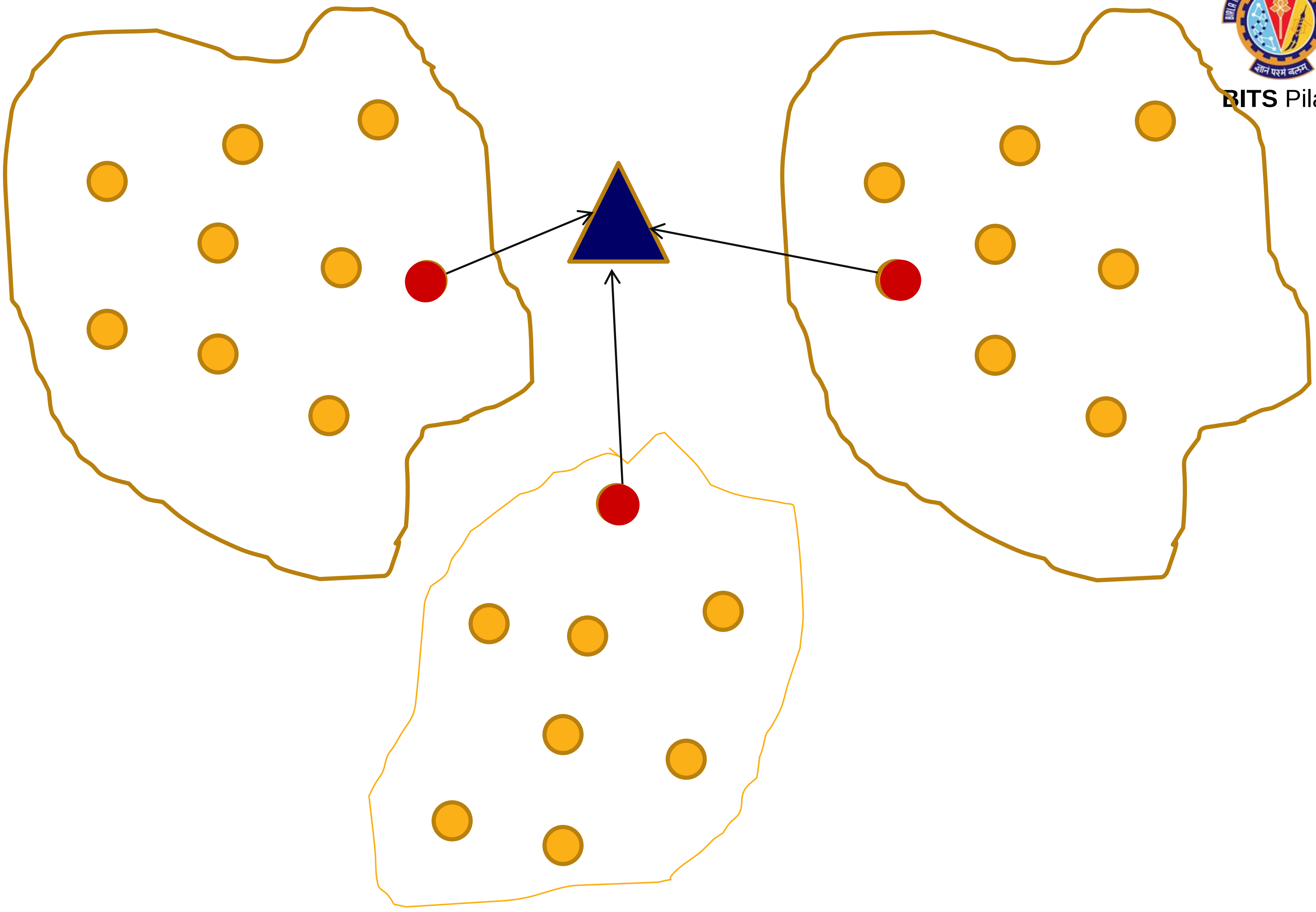
- Low Energy Adaptive Cluster Hierarchy protocol (LEACH)

LEACH - Model

BITS Pilani

- Base Station is fixed and far away from all sensor nodes
- All nodes - energy constrained & homogeneous
- Localized Clustering
- Local Data fusion
- Rotation of Cluster Heads
- Adaptive and Rotating Clustering Algorithm

BITS Pilani



LEACH - Advertisement Phase

- P = Desired % of cluster heads
- r = current round
- G – Nodes not yet cluster head in n rounds

LEACH - Cluster Selection Phase

Each node informs the cluster-head node that it will be a member

Each node transmits this information back to the cluster-head again using a CSMA MAC protocol

All cluster-head nodes must keep their receivers on

Schedule Creation Phase

Slot for Node 1	Slot for Node 2

LEACH

Energy Consumption evenly distributed

Data Aggregation – done at CH

In-built MAC

innovate achieve lead

BITS Pilani

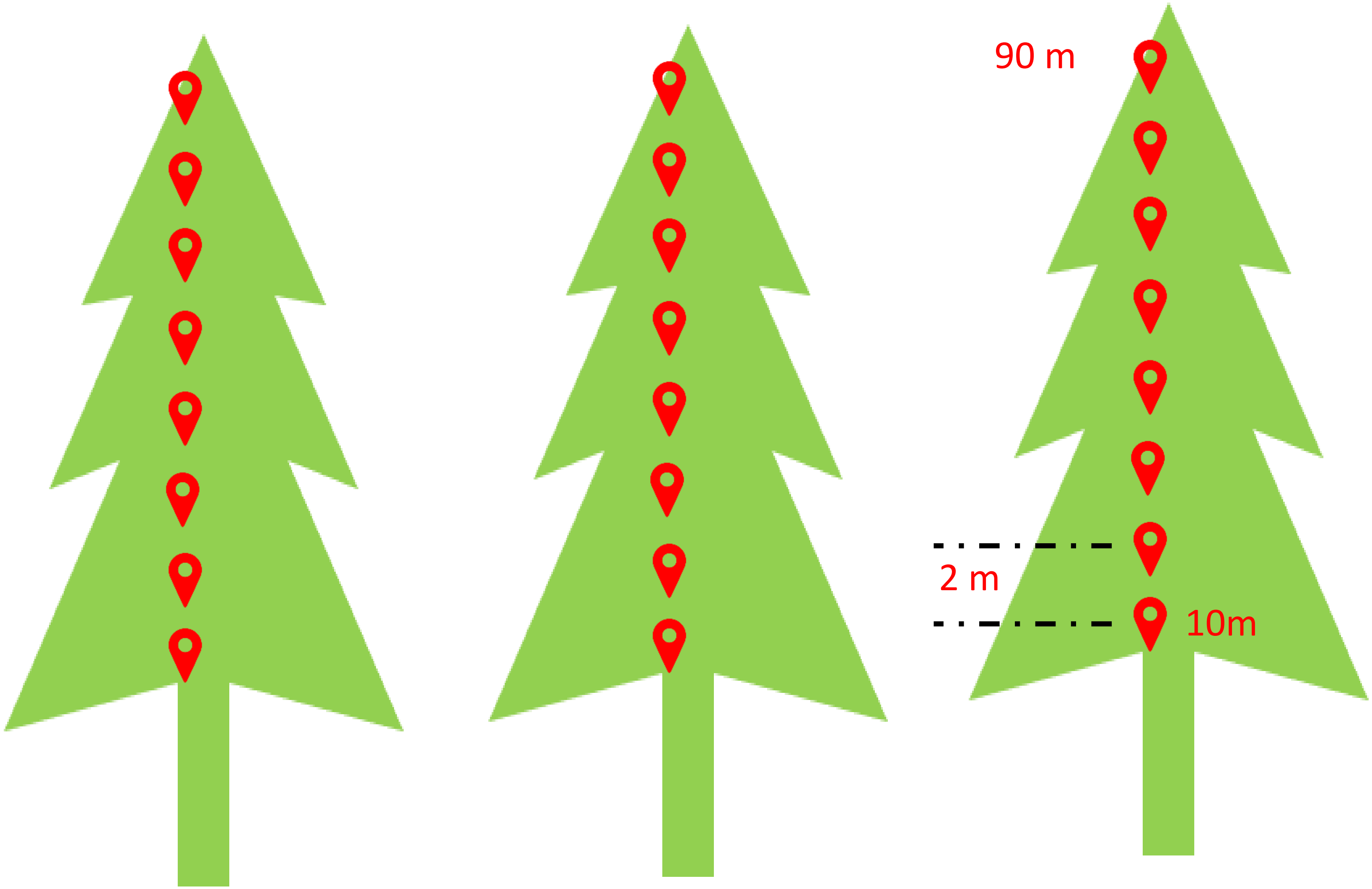
Pilani | Dubai | Goa | Hyderabad

Wireless Sensor Network – case study

Redwood Climate Monitoring

BITS Pilani

Redwood Climate Monitoring

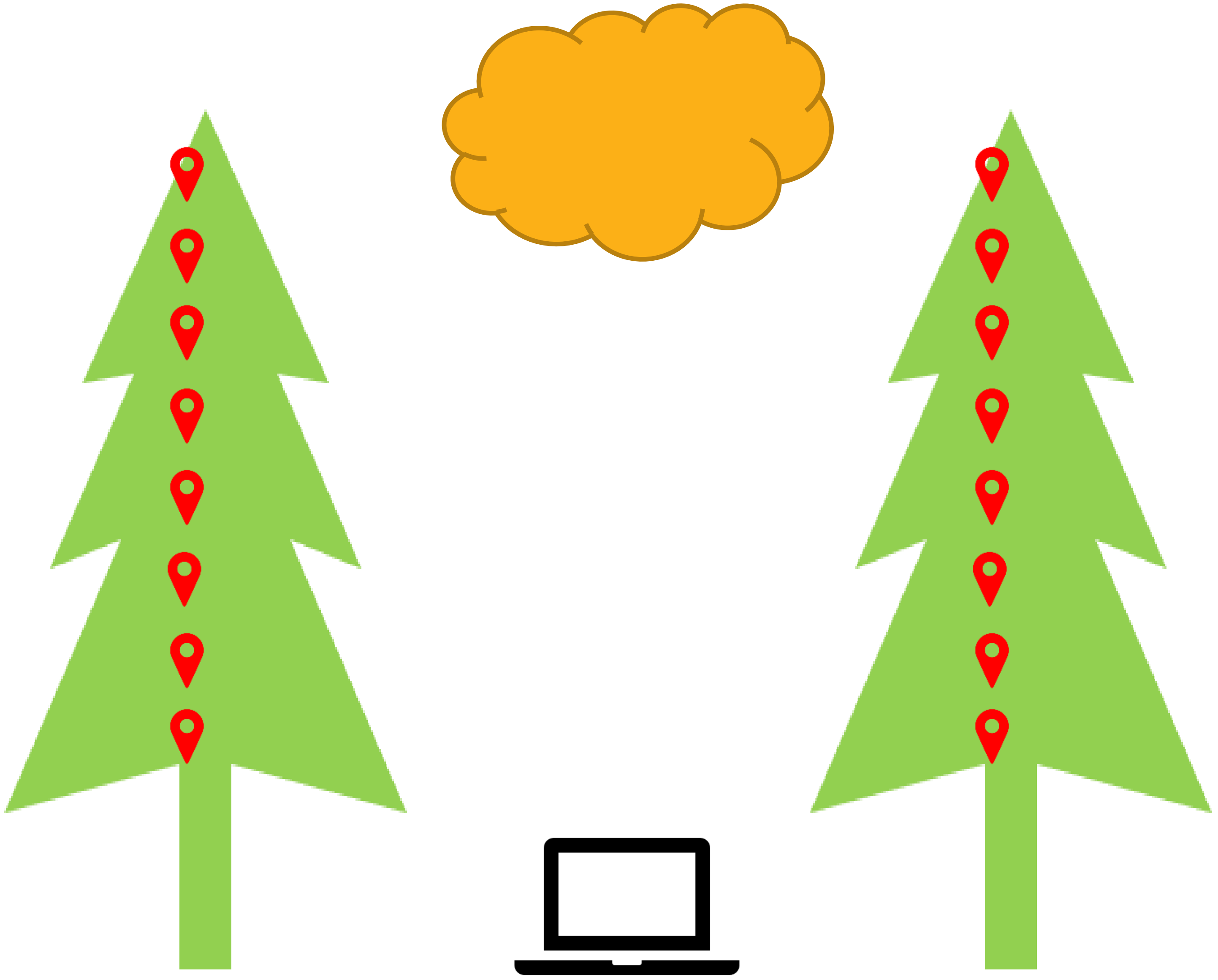


Parameters Monitored

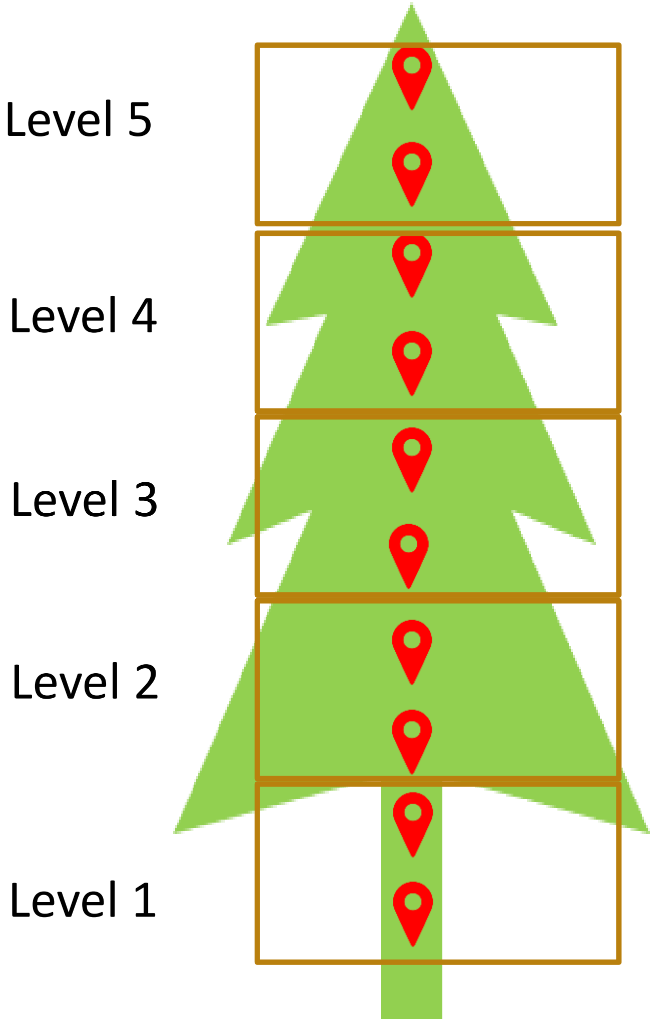
BITS Pilani

- Temperature
- Humidity
- Solar Radiation
- Light Levels
- Photosynthetically active radiation

Ever 5 Minutes



Redwood Climate Monitoring – Deployment Pattern



- Redwood Pine – Tallest Tree
- Grows to height of 90 M
- On a single tree 40 motes

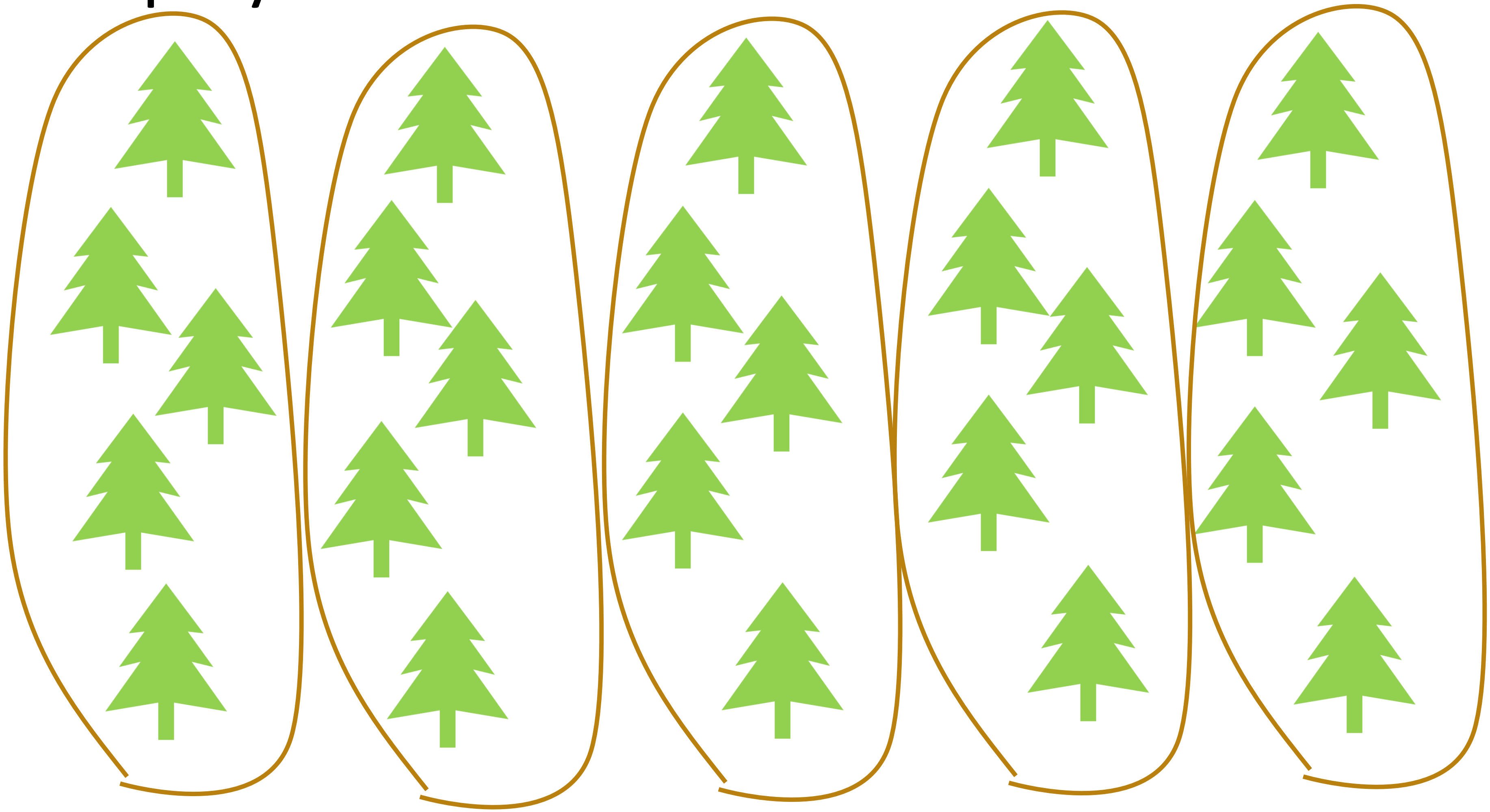
Per Level - 8 nodes

Level - Cluster Level 1 – CL1

Redwood Climate Monitoring – Deployment Pattern

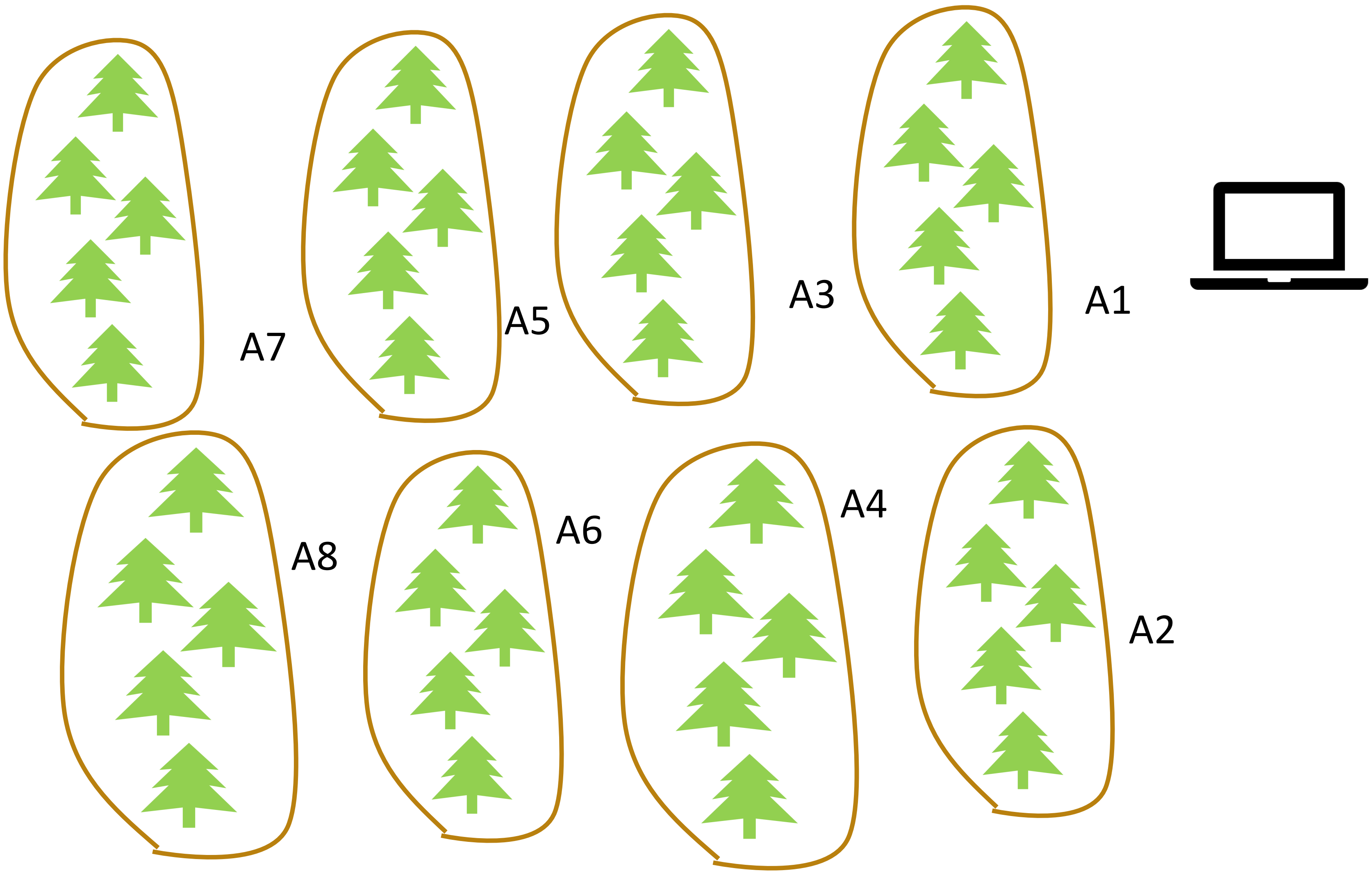
- Every cluster in CL1 will have a Cluster head dynamically elected using LEACH
- Nodes in L5 will send data to CH of L5 – aggregates data and send data to node to CH of L4
- Nodes in L4 will send data to CH of L4 that aggregates the data along with data of L5 and send to CH of L3
- And so on..
- L1 CH – try to connect and send data to BS

Redwood Climate Monitoring – Deployment Pattern



Cluster Level 2

Redwood Climate Monitoring – Deployment Pattern

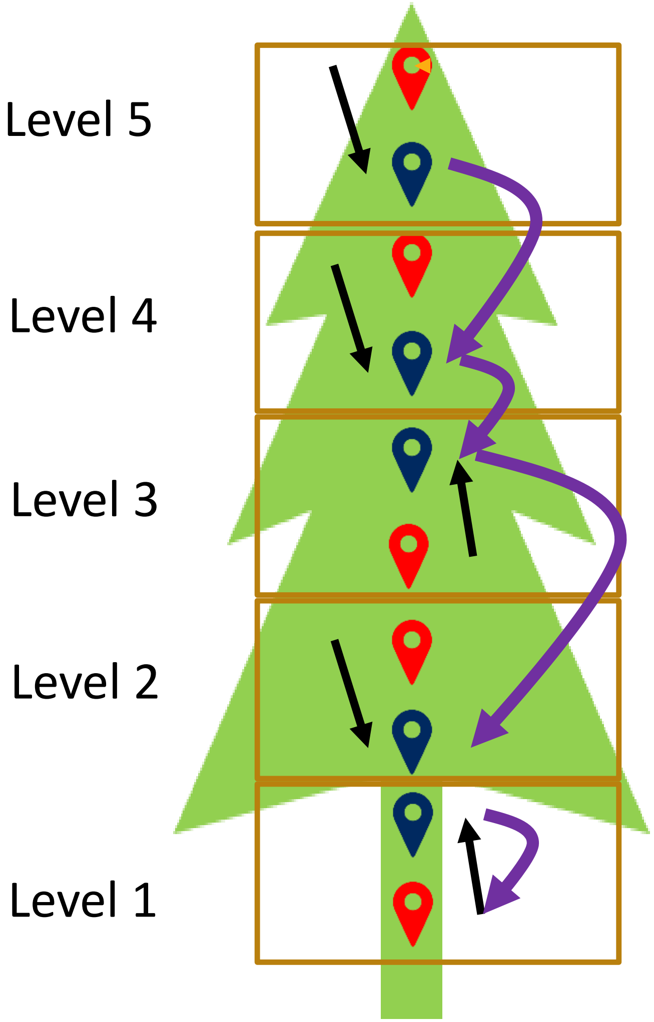


Redwood Climate Monitoring – Deployment Pattern

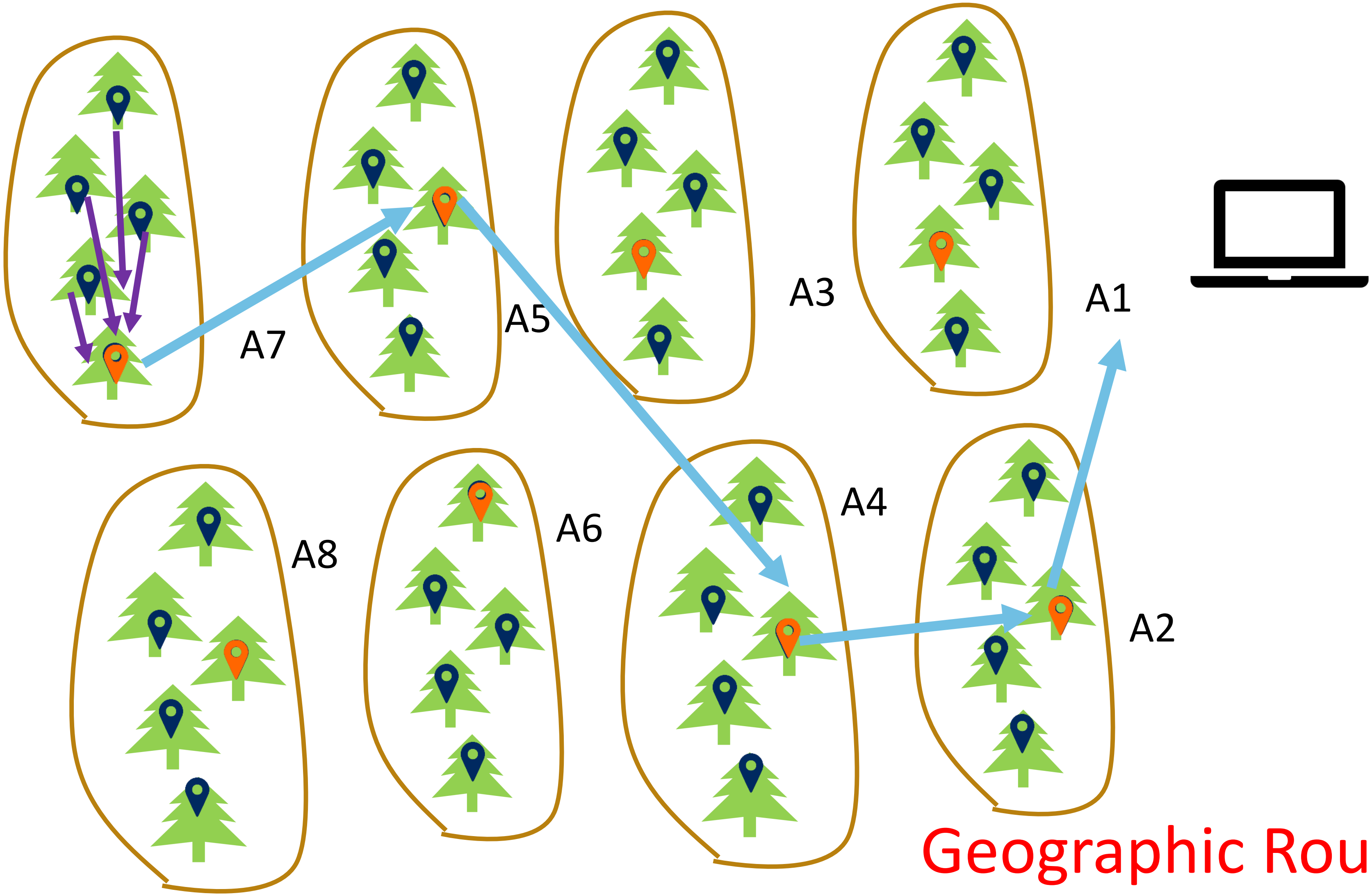
- CH of L1 of all trees within an area (say A7) will be the members of the cluster
- Every cluster in CL2 will have a Cluster head dynamically elected using LEACH
- All member of A7 will send data to CH of A7 – that aggregates the data
- CH of A7/A8 will send data to CH of A5/A6
- And so on..
- Thus data is geographically routed towards BS

Redwood Climate Monitoring – Deployment Pattern

BITS Pilani



Redwood Climate Monitoring – Deployment Pattern



Geographic Routing

Addressing

- Area: Tree: Level: ID
- Geographic Addressing

Network Protocols

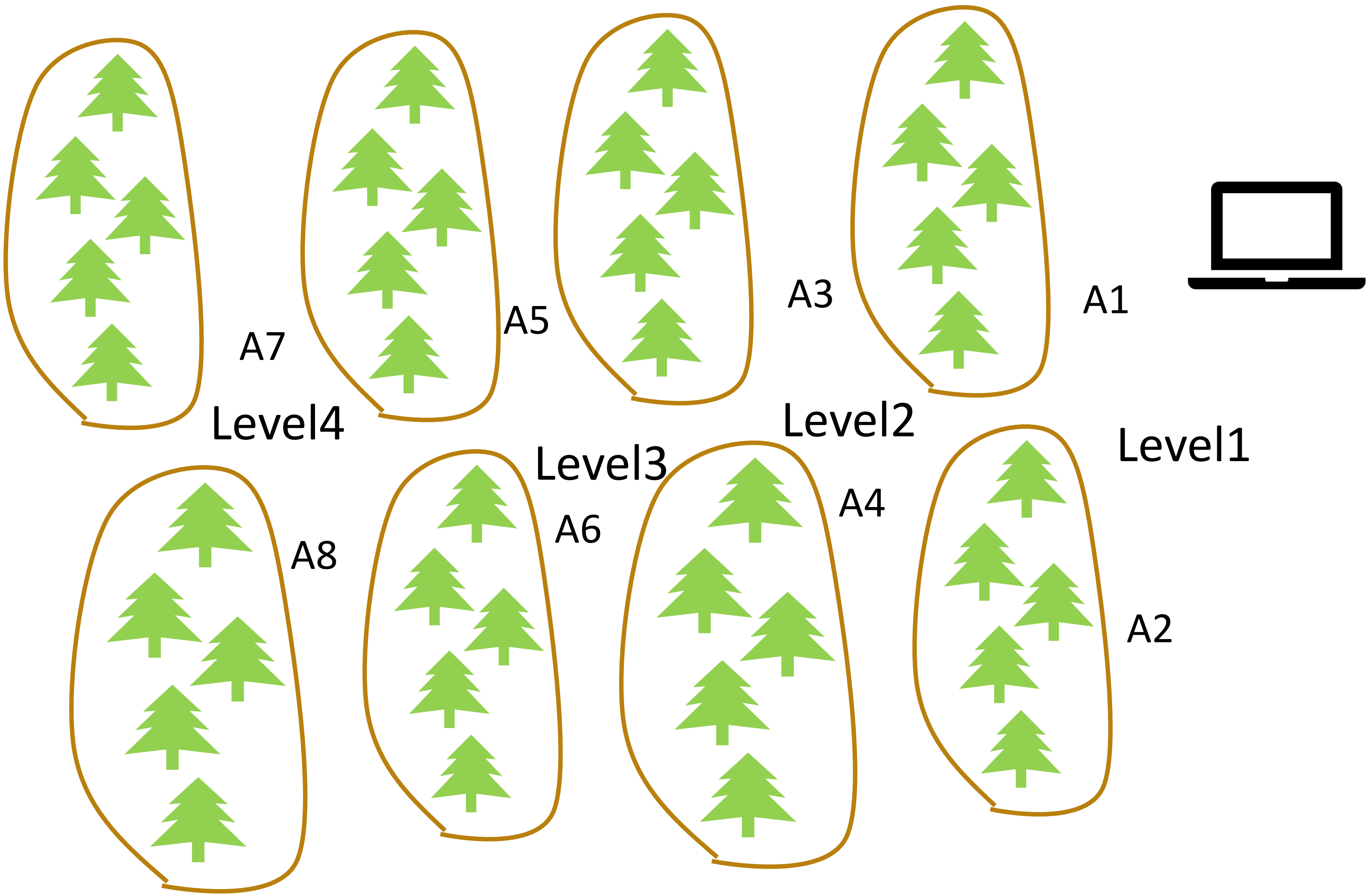
BITS Pilani

- Addressing Scheme
- Routing & Clustering - Proactive
- Topology Control
- MAC & PHY
- Time Sync
- Localization

Network Protocols – Time Sync

- TPSN variant
- Levels already there
- BS – Level 0

Redwood Climate Monitoring – TPSN



Network Protocols – Time Sync

- Process repeated within Cluster Level2
- CH at bottom of tree– Level 0
- CH at next height – Level1

Network Protocols – Time Sync

BITS Pilani

- Process repeated within Cluster Level1
- CH – Level 0
- Other Members – Level1

Localization

- Not Required
- Nodes Placed in preplanned position

Topology Control

- Once only every 5 minutes data communicated
- The whole process may take less than a minute
- All nodes sleep for 4 minutes and are awake for 1 minute
- Duty Cycle – 25%
- All nodes sleep wake at the same time

MAC & PHY

BITS Pilani

- CC 2xxx Radio on motes
- MAC within clusters – TDMA
- Between clusters variant of CSMA – such as SMAC/ DMAC

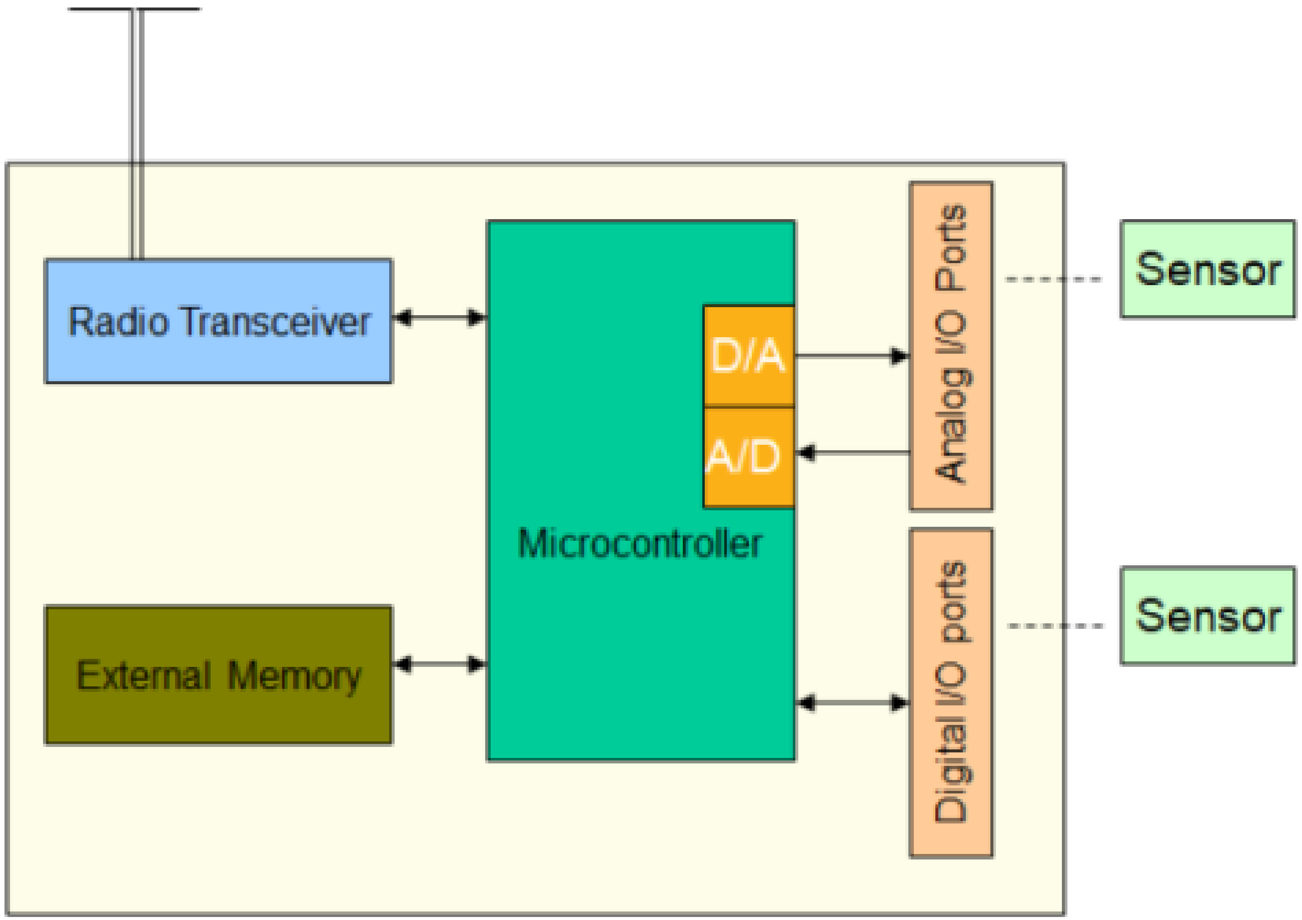
innovate achieve lead

BITS Pilani

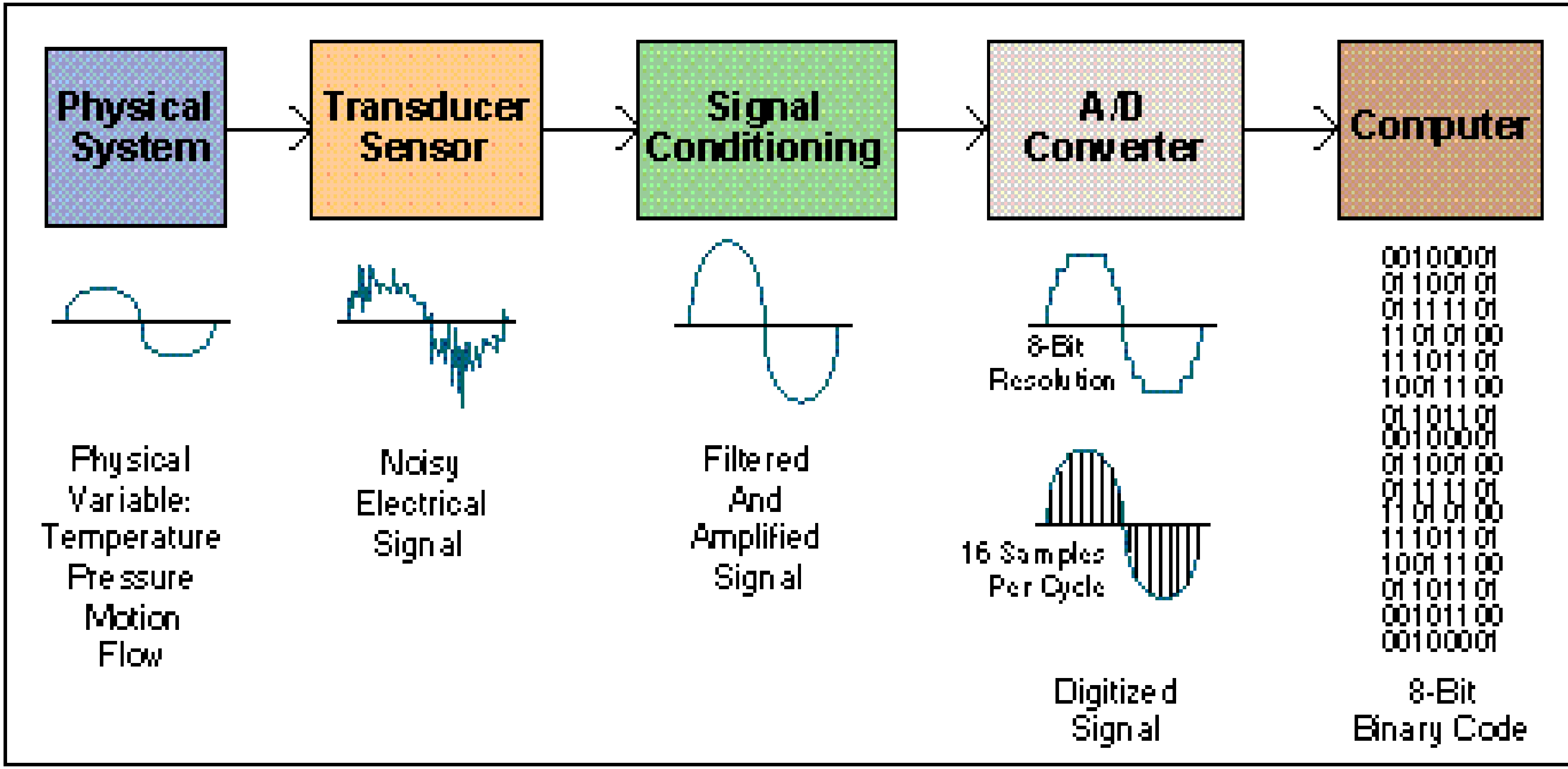
Pilani | Dubai | Goa | Hyderabad

Data acquisition, signal conditioning and Analog to Digital

WSN mote


Radio Transceiver
Microcontroller
D/A
A/D
External Memory
Analog I/O Ports
Digital I/O ports
Sensor
Sensor

Data acquisition by mote- steps involved



Physical System

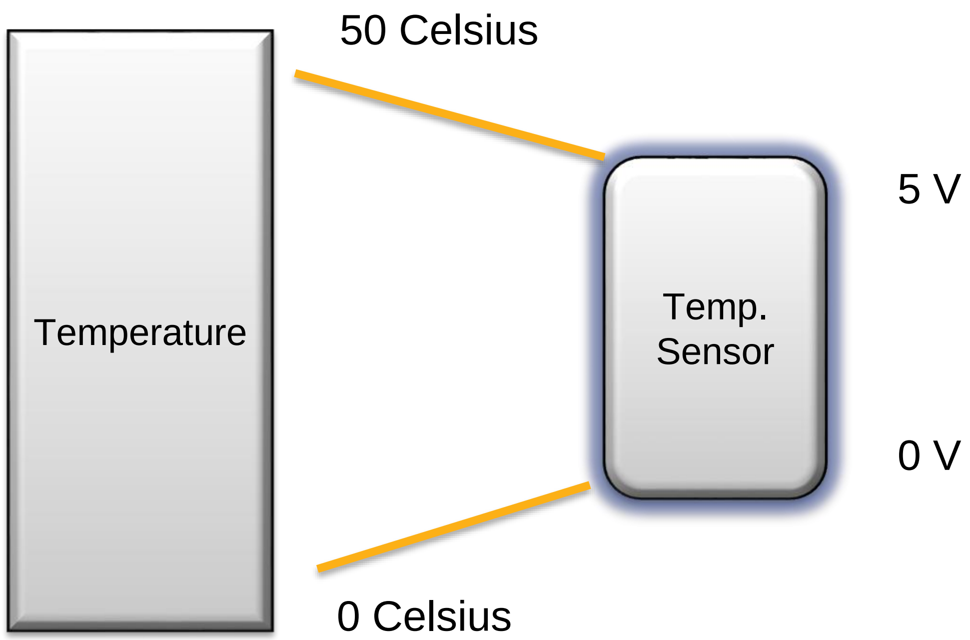
- The **physical system gives input to the DAQ System** for monitoring different system parameters like:

  - Pressure
  - Force
  - Light
  - Temperature
  - Displacement
  - ON/OFF state
  - Level
  - Electrical signals
  - Acceleration

Transducers / Sensors

- A transducer **converts** temperature, pressure, level, length, position, etc. into voltage, current, frequency, pulses or other signals.

- A transducer thus converts the physical conditions in electrical waveform for easy signal processing



Common Sensors and parameters measured

BITS Pilani

Sensor used for DAQ	Physical parameter measured
Resistive temperature device (RTD)	Temperature
Gauge	Pressure
Microphone	Pressure
Accelerometer	Acceleration
Thermocouple	Temperature
Strain gauge	Force
Light sensor	Illuminance
Humidity sensor	Humidity

Signal Conditioning

BITS Pilani

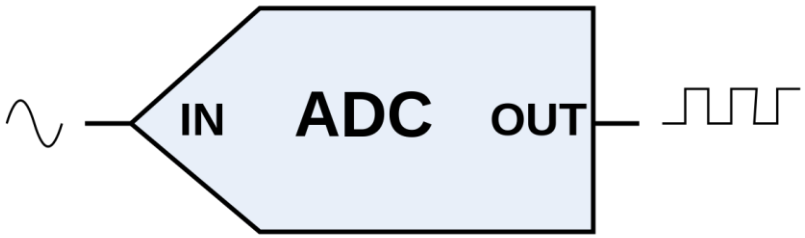
- Signal conditioning circuits **improve the quality of signals** generated by transducers before they are converted into digital signals by the PC's data- acquisition hardware.

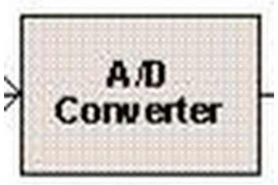
- Most common signal conditioning functions are amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection, and so on.

Analog to Digital convertor

BITS Pilani

- Analog to digital (A/D) conversion **changes analog voltage or current levels into digital information**. The conversion is necessary to enable the microcontroller to process or store the signals.





Microcontroller in Mote

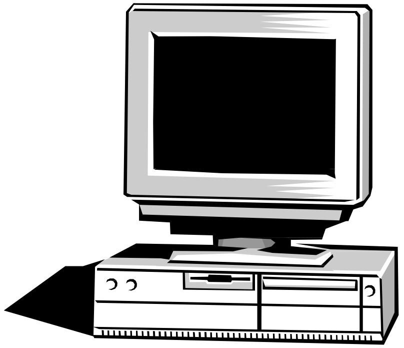
- This processes the digital signal.

Base station (PC)

BITS Pilani

- Can install Data Acquisition Software
- Data Acquisition Software can be the most critical factor in obtaining reliable, high performance operation
- Different alternatives:
  - ➢ Programmable software.
  - ➢ Data acquisition software packages

Base station



Programmable Software

BITS Pilani

- Involves the use of a programming language, such as:
  - C++
  - Visual C++
  - BASIC,
  - Visual Basic + Add-on tools (such as VisuaLab with VTX)

- **Advantage**: flexibility
- **Disadvantages**: complexity and steep learning curve

Data Acquisition Software Packages

- These do not require programming.
- They enable the developers to design the custom instrument best suited to their application.

- Examples: TestPoint, SnapMaster, LabView, MatLab, DADISP, DASYLAB, etc.

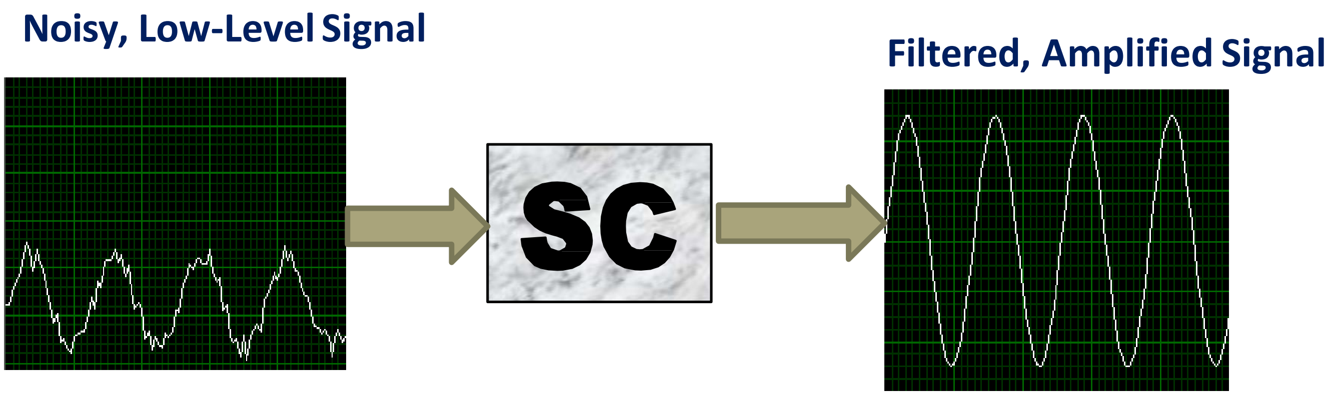
Signal conditioning

- To **remove noise** from the measured sensor data or to improve it for usage

- Common types of signal conditioning include amplification, linearization etc.

- Sensor signals are often incompatible with data acquisition hardware. To overcome this incompatibility, the sensor signal must be conditioned.

Why conditioning



Improving the quality of signals
(e.g. by Amplification Filtering Isolation)

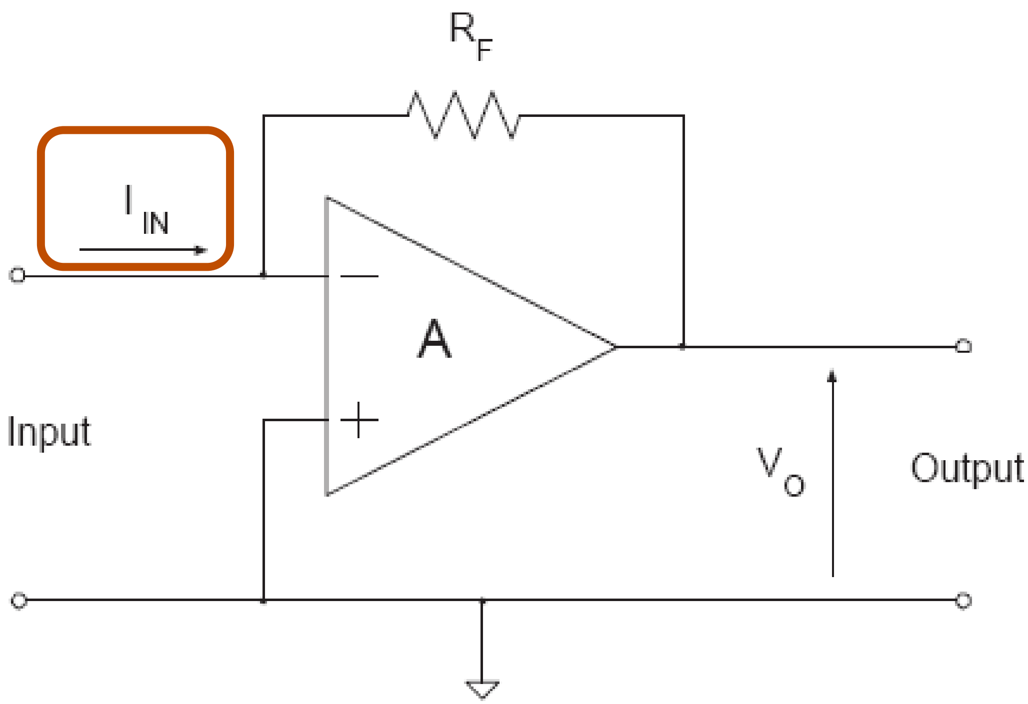
Common ways to condition signals include

BITS Pilani

- Signal Conversion
- Amplification
- Attenuation
- Filtering
- Electrical isolation
- Multiplexing
- Excitation source

Signal Conversion: Ex: Current-to-voltage converter

- Transimpedance amplifier (Feedback Ammeter)
- Recommended connection for **small currents**
- Sensitivity determined by Rf



$$\boxed{V_O = -I_{IN} R_F}$$

Amplification

BITS Pilani

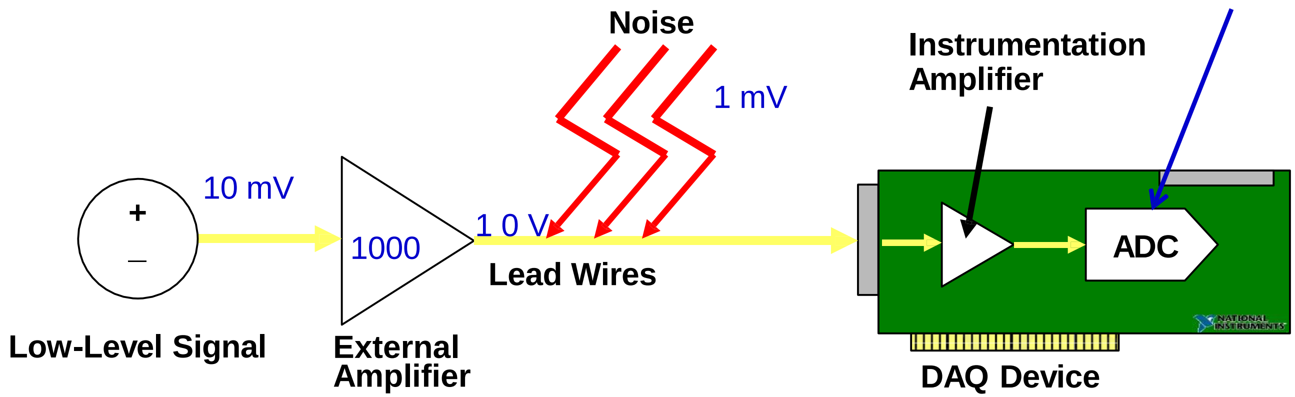
- **When the input signal is as small** as microvolts, electrical noise can drown out the signal itself, leading to meaningless data.

- For reducing the effects of noise on your signal is to amplify the signal as close to the source as possible. This increases Signal to Noise Ratio (SNR)

- e.g. A J-type thermocouple outputs a very low-level voltage signal that varies by about 50 µV/°C.

Amplification

- Used on low-level signals (less than around 100 mV)
- Maximizes use of Analog-to-Digital Converter (ADC) range and increases accuracy
- Increases Signal to Noise Ratio (SNR)



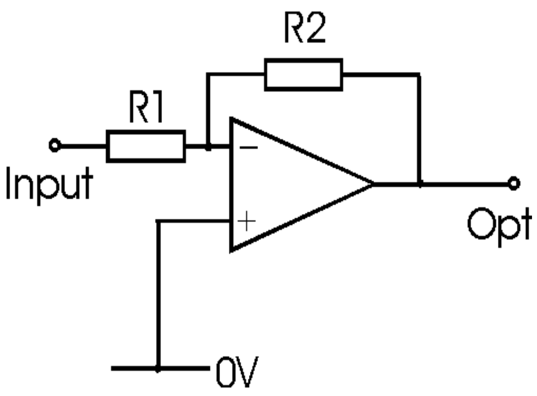
SNR = V_{signal}/V_{noise} = (10 mV * 1000) /1 mV = 10 000

$$SNR = 20\log\left(\frac{V_{signal}}{V_{noise}}\right)$$

Example of amplifier: Operational amplifier (Op-amp)

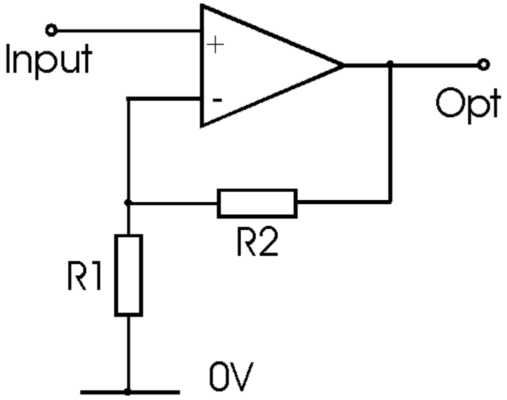
BITS Pilani

- Inverting op-amp amplifier
  - Vo = -R2/R1 * Vi



Inverting Amplifier

- Non-inverting op-amp amplifier
  - Vo = (1+R2/R1) * Vi

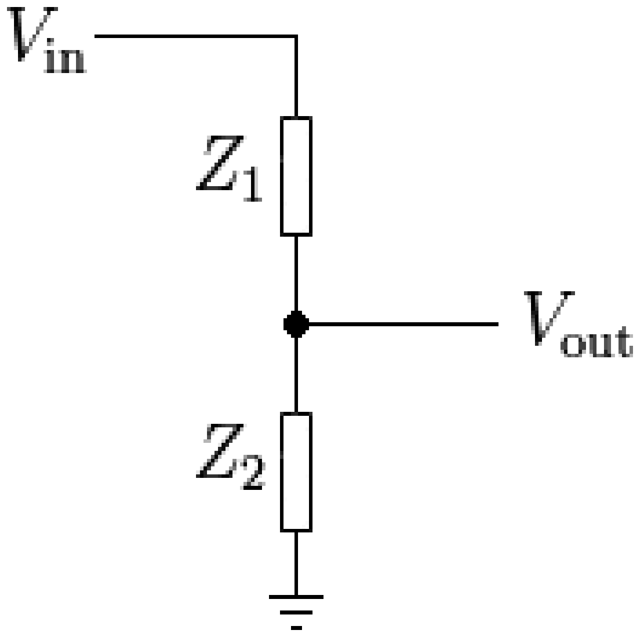


Non-Inverting Amplifier

Attenuation

BITS Pilani

- Voltage divider: A circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin)
- Can be needed to get a high-level signal down to the acceptable DAQ-card range



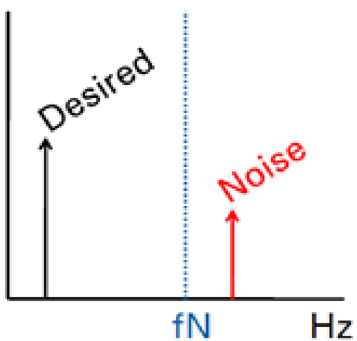
A simple attenuation circuit

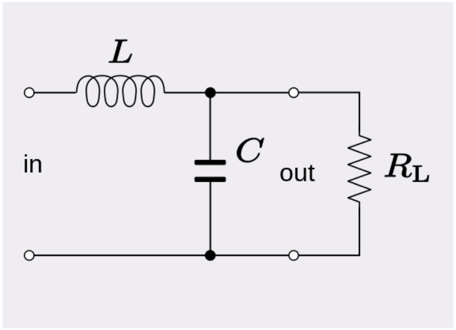
Filtering

- To reject unwanted noise within a certain frequency range.
- Many systems will exhibit periodic noise from sources such as power supplies or machinery.
- Examples of filters:
  - Butterworth Filter
  - Bessel Filter
  - Chebyshev Filter
  - Simple RC Filter
  - Passive & Active Filters

Hardware Filtering

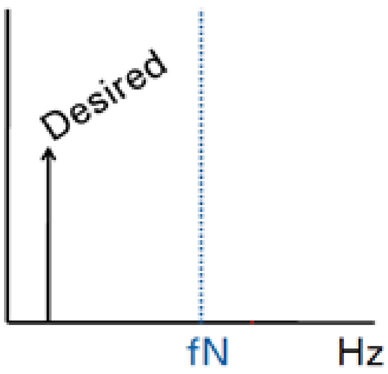
- Purpose:
  - To remove unwanted signals from the signal that you are trying to measure





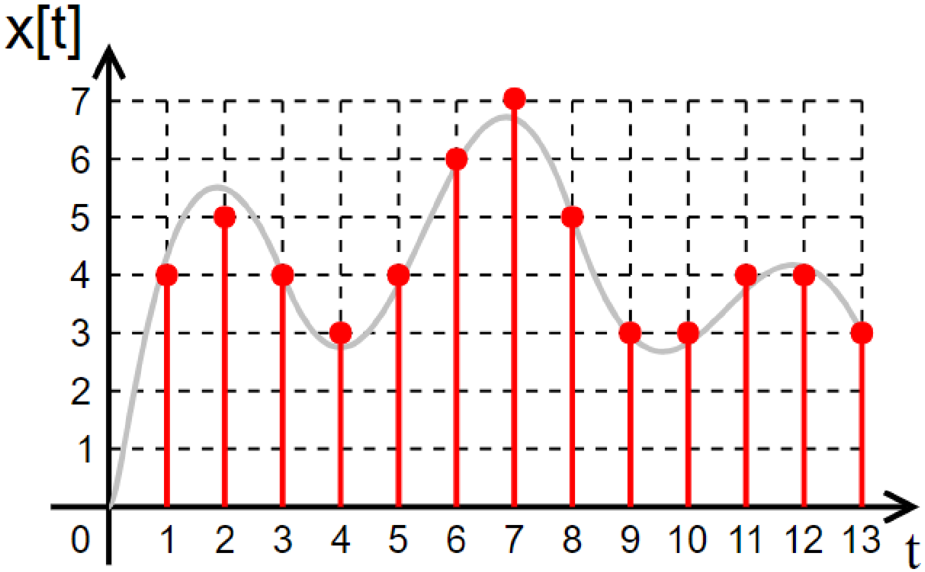
LPF

Low pass filter



A/D conversion

- Digital data is more convenient to process/store by the microcontroller as compared to the analog signal.
- Resort to Analog to Digital conversion



A/D conversion

BITS Pilani

- After the signal conditioning, the signal from the sensor is passed to the analog to digital (A/D) board.

- The **A/D board converts the conditioned analog voltage or current signal into a digital format** which is readable by the microcontroller.

- A/D conversion is a **ratio operation**, where the input signal is compared to a reference and converted into a fraction which is then represented as a coded digital number.

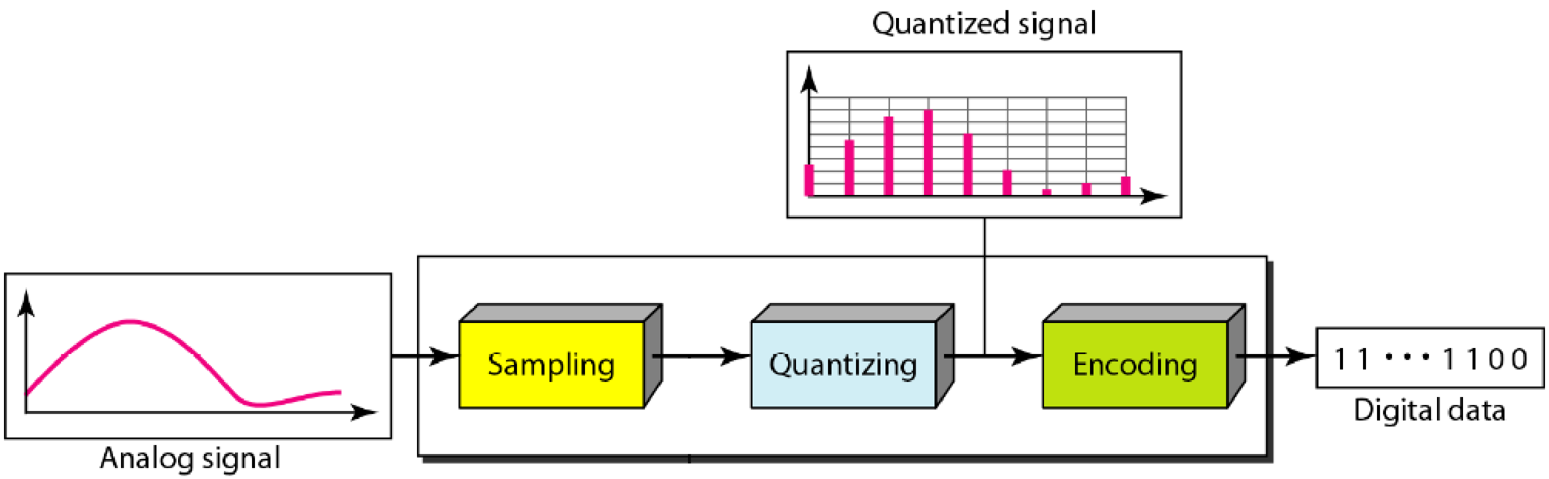
A/D conversion

BITS Pilani

- To optimize measurement accuracy, **there is a minimum and maximum number of data points that need to be acquired**.
- One of the most critical factors when selecting an A/D board is **sampling rate** (speed).
- The sampling rate is a measure of **how rapidly the A/D board can scan the input channel** and identify the discrete value of the signal present with respect to a reference signal.

A/D steps

- Sampling
- Quantization
- Encoding

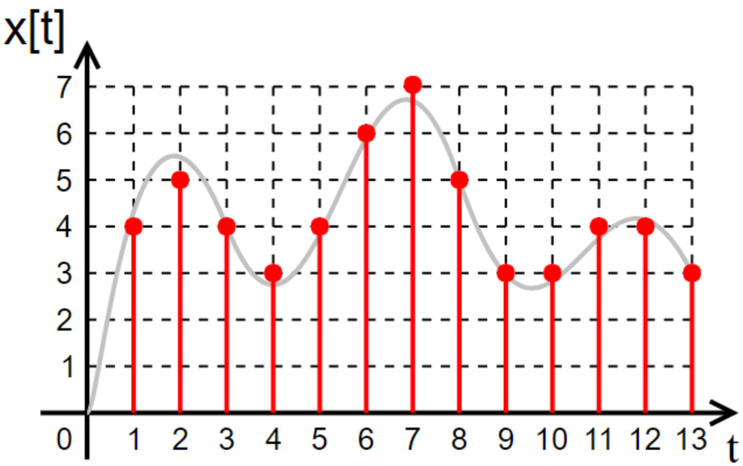


https://sipdtdevelopers.files.wordpress.com/2013/11/quantization.png

Sampling Considerations

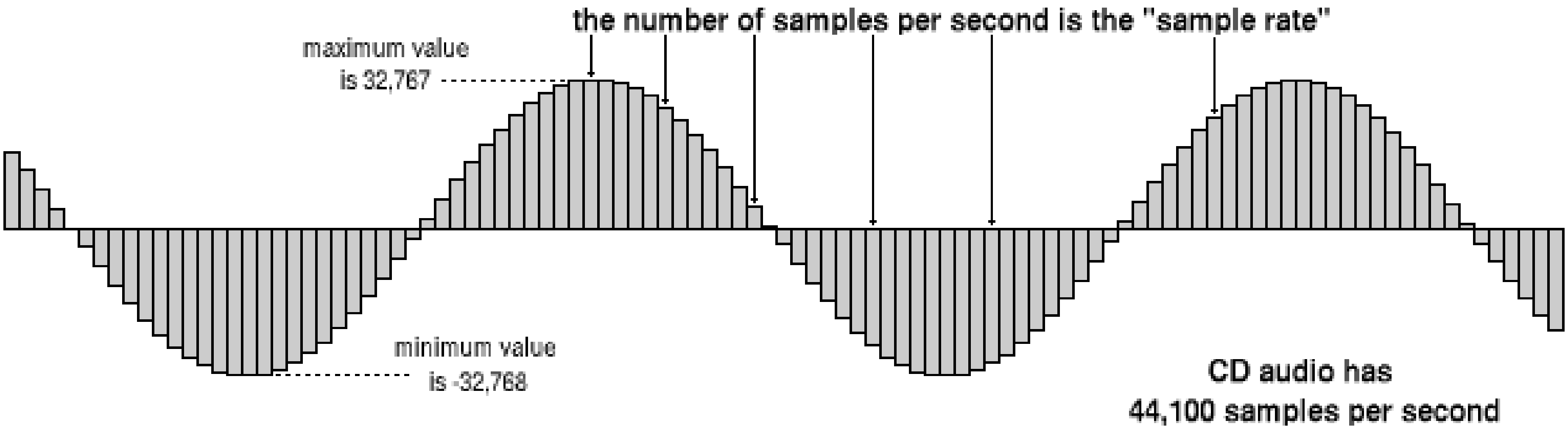
BITS Pilani

- An analog signal is continuous.
- A sampled signal is a series of discrete samples acquired at a specified sampling rate.
- The faster we sample the more our sampled signal will look like our actual signal
- If not sampled fast enough a problem known as aliasing will occur



Sampling rate

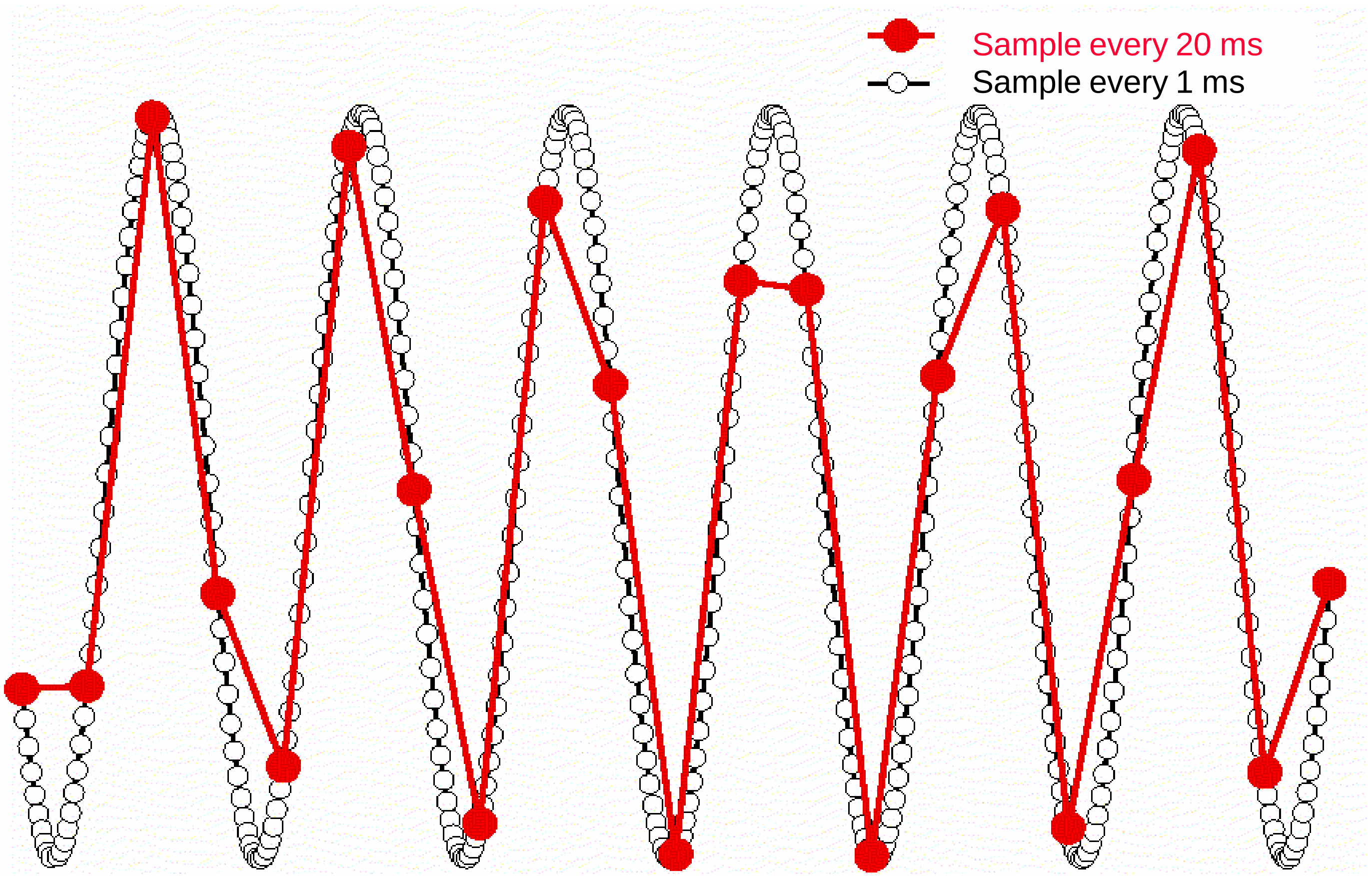
- Sampling an analog signal occurs at discrete time intervals.
- The rate at which the signal is sampled is known as the **sampling frequency.**



http://wiki.hydrogenaud.io/images/3/37/Digital_wave.png

Effect on sampling rate on information captured/lost

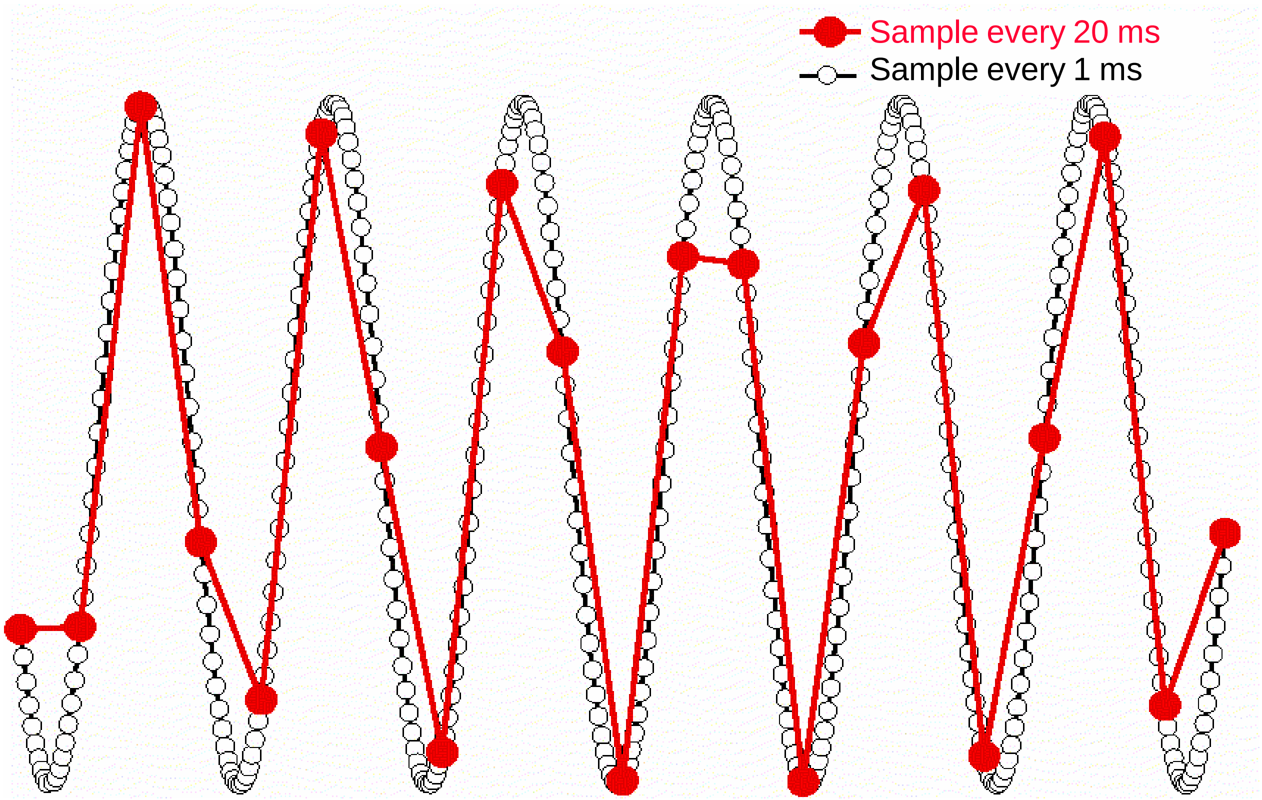
BITS Pilani



Aliasing

BITS Pilani

- **If the sampling rate is too slow, then a completely different waveform of a lower frequency is constructed from the data acquired**. This effect is called aliasing.



Aliasing

- It has the effect of increasing the variance in the recorded signal, i.e. it **adds noise to the signa**l, basically by missing the peaks and troughs of the rapidly changing signal.

- So, even if the signal has the same peak all the time, the board will catch the rising and falling phase but miss the peak giving the appearance that the peak (i.e. the maximum value recorded in each cycle) is changing.

How to avoid aliasing

- To avoid aliasing, it is necessary that the sample rate be at least twice the highest expected frequency input.

Nyquist Sampling Theorem

BITS Pilani

- ***Nyquist sampling theorem tells us that we must sample the signal at more than twice the rate of the maximum frequency component in the analog input signal to accurately represent the frequency of your signal.***

- According to the Nyquist Theorem, the sampling rate
- must be at least $2f_{max}$, where , highest frequency component = f_{max}

Choosing the sampling rate

BITS Pilani

- Application specific
- Eg. Recording the ambient temperature during the day manually at intervals of 30 minutes.

Time	Temperature	Time	Temperature
6.00	10	10.30	15
6.30	11	11.00	15
7.00	11	11.30	17
7.30	12	12.00	18
8.00	13	12.30	19
8.30	13	13.00	19
9.00	14	13.30	18
9.30	14	14	17
10.00	15	14.30	16

Example: Temperature measurement

- A platinum resistance thermometer can be used as the transducer which is a temperature-dependent resistor, and by using an appropriate circuit, a continuous measurement of the actual temperature in the form of a proportional voltage is obtained.

Example: Temperature measurement (cont.)

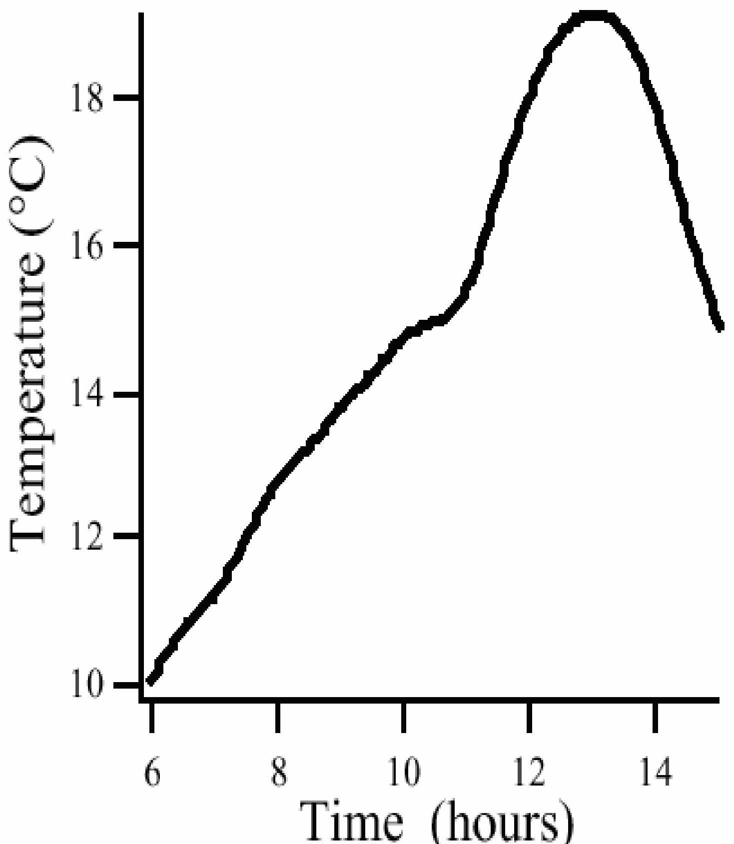
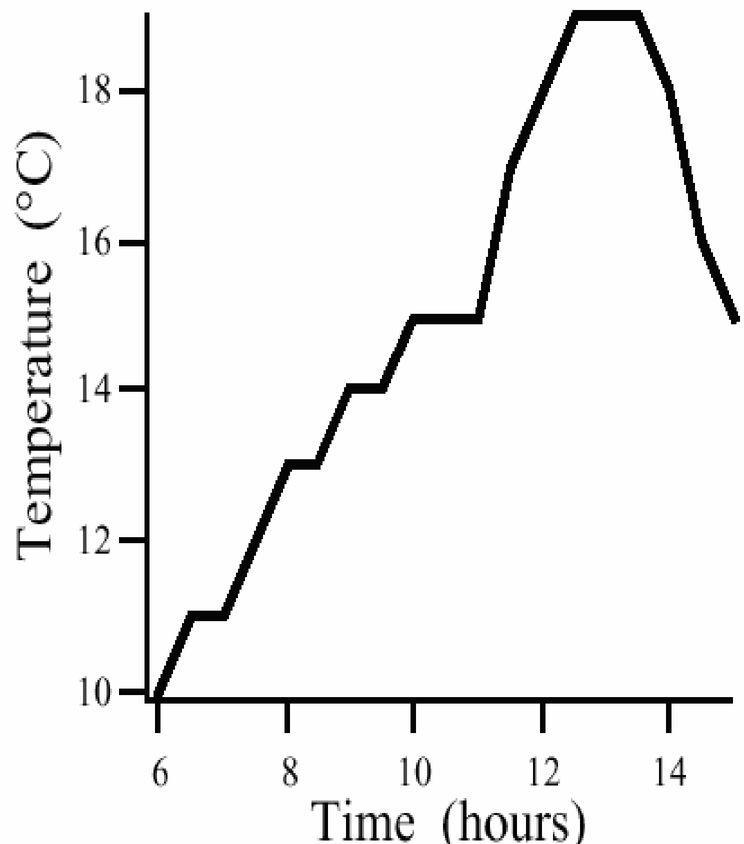
BITS Pilani

- The data acquisition software converts the analog voltage corresponding to the temperature into binary numbers (digital format) in every 30 minutes.

- Assume that the A/D board rounds off all numbers within its operating range to the nearest 1°C. That is although the ambient temperature changes continuously, the A/D board only indicates a change in it when a difference greater than 1°C is observed. The data thus changes in 1°C steps.

Temperature record

BITS Pilani

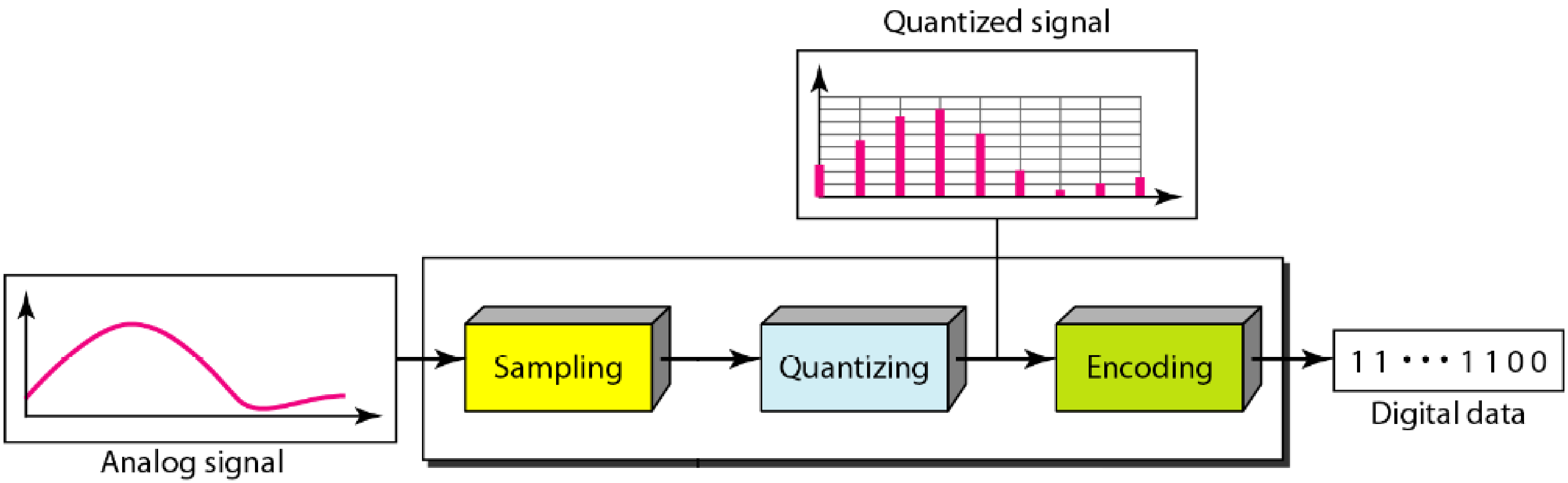
Continuous, analog measurements of temperature	Discrete digital measurements of temperature
	

Applications with high sampling rate requirement

- You can’t have this high a sampling period when you are having a system which is giving real time images of the patient’s heart for a doctor doing a crucial surgery.

A/D steps

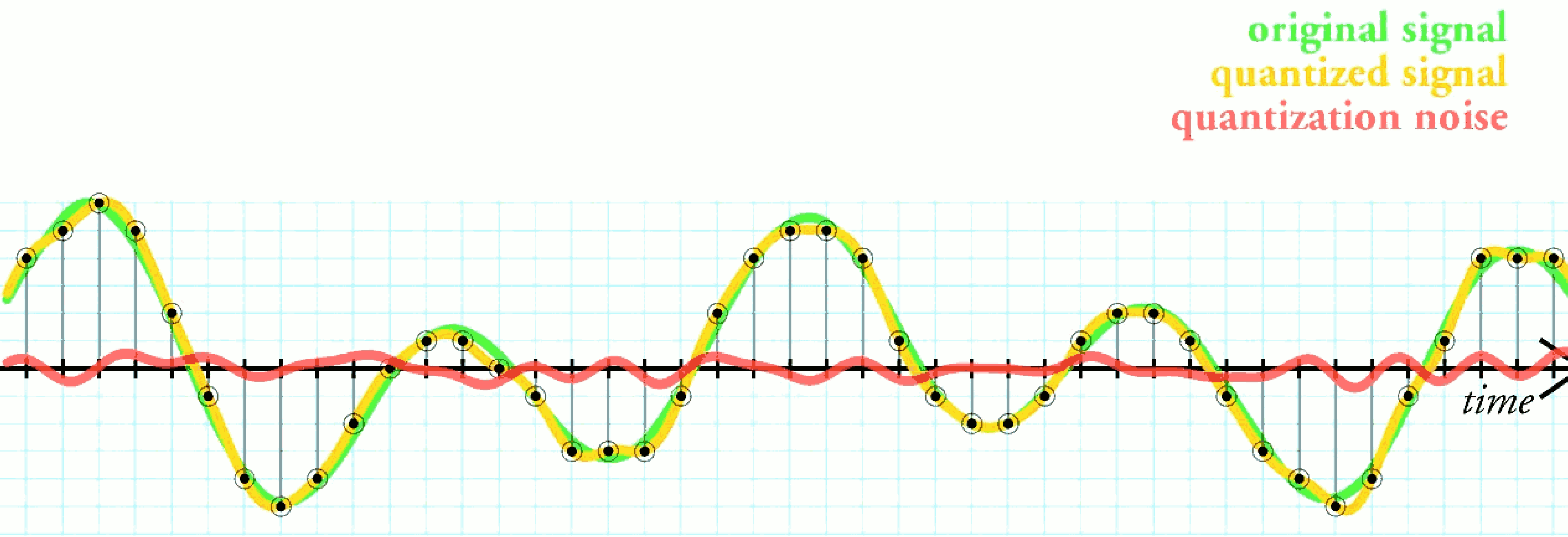
- Sampling
- Quantization
- Encoding



https://sipdtdevelopers.files.wordpress.com/2013/11/quantization.png

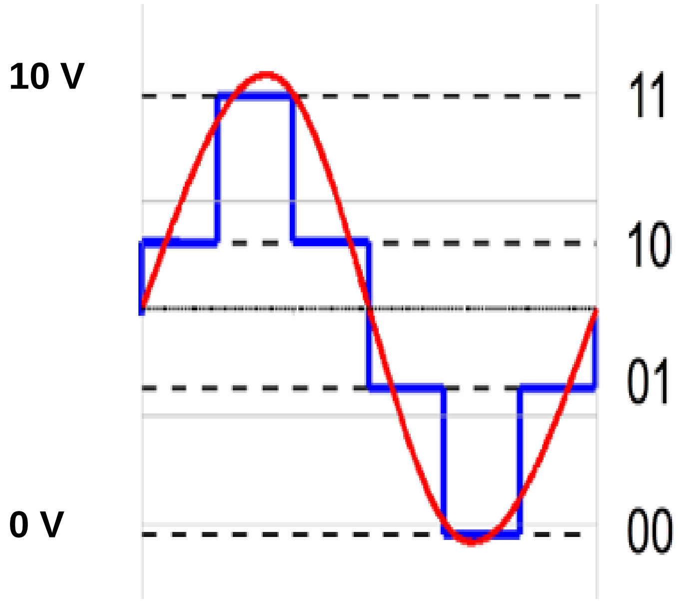
Quantization- Introduction

BITS Pilani

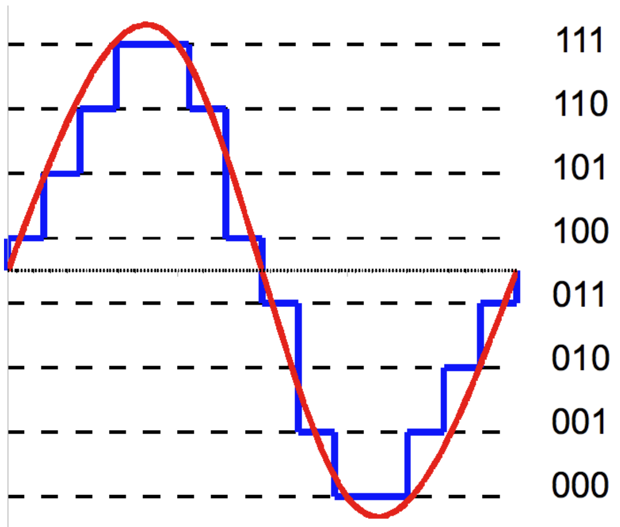


Resolution

- Precision of the analog to digital conversion process is dependent upon the number (n) of bits the ADC of the DAQ uses.
- More the bits used for ADC, more is the number of divisions the voltage range is broken into (2^n), and thus more is the accuracy.
- An 2 bit ADC gives 4 levels (2^2) compared to a 3 bit ADC that has 8 levels (2^3).



2-bit ADC



3-bit ADC

Resolution

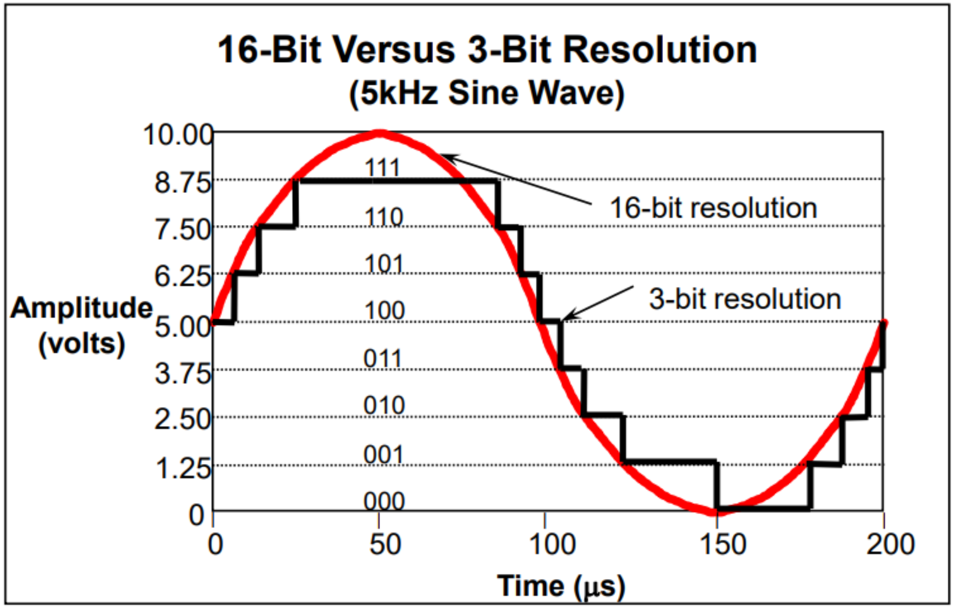
BITS Pilani

- The number of bits used to represent an analog signal determines the resolution of the ADC
- **Larger resolution = more precise representation of your signal**
- The resolution determines the **smallest detectable change in the input signal, referred to as code width** or LSB (least significant bit)

$$code\ width = \frac{device\ range}{2^{resolution}}$$

Example:

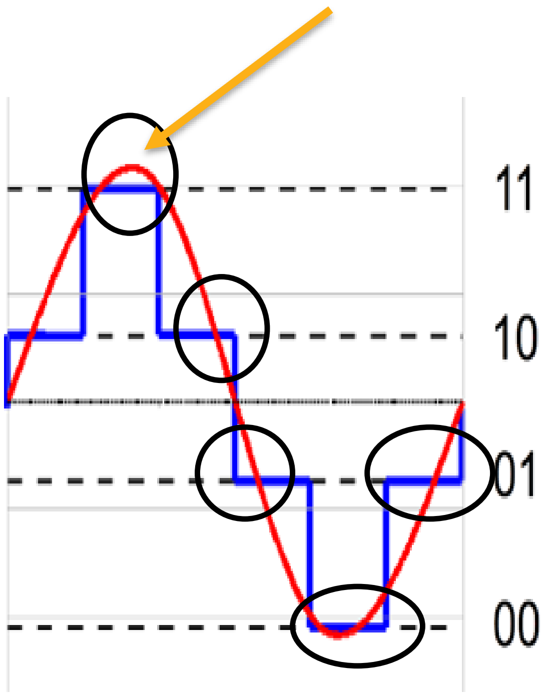
$$\frac{device\ range}{2^{resolution}} = \frac{10}{2^{16}} = .15\ mV$$



Quantization error

BITS Pilani

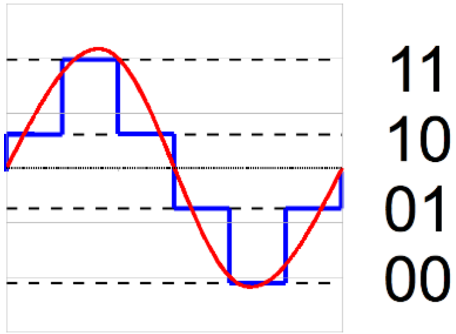
- Error incurred during the process of quantization



2-bit ADC

Encoding

- Encoding is based on sampling and quantization.
- A simple encoding scheme is shown below.



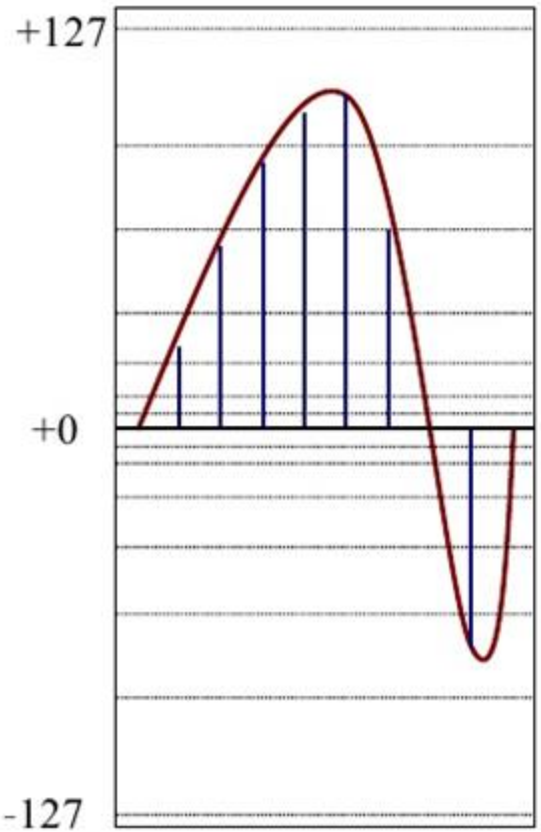
2-bit ADC

Encoder

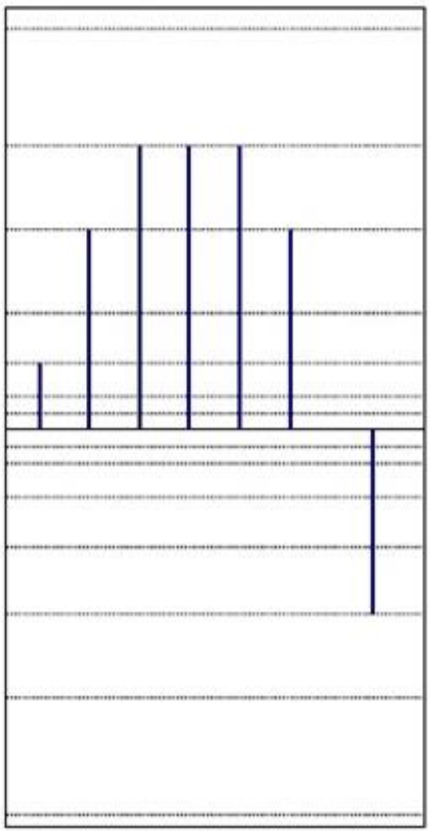
10 11 10 01 00 01

Sampling – Quantization - Encoding

Sampling



Quantization



Encoding

10101111...01101101