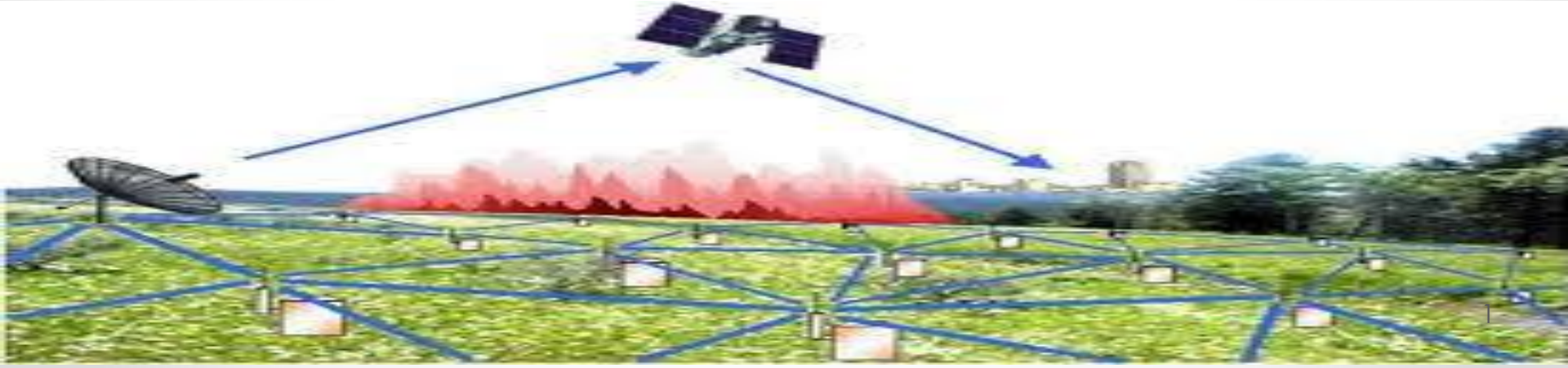
Wireless Sensor and Actuator Network

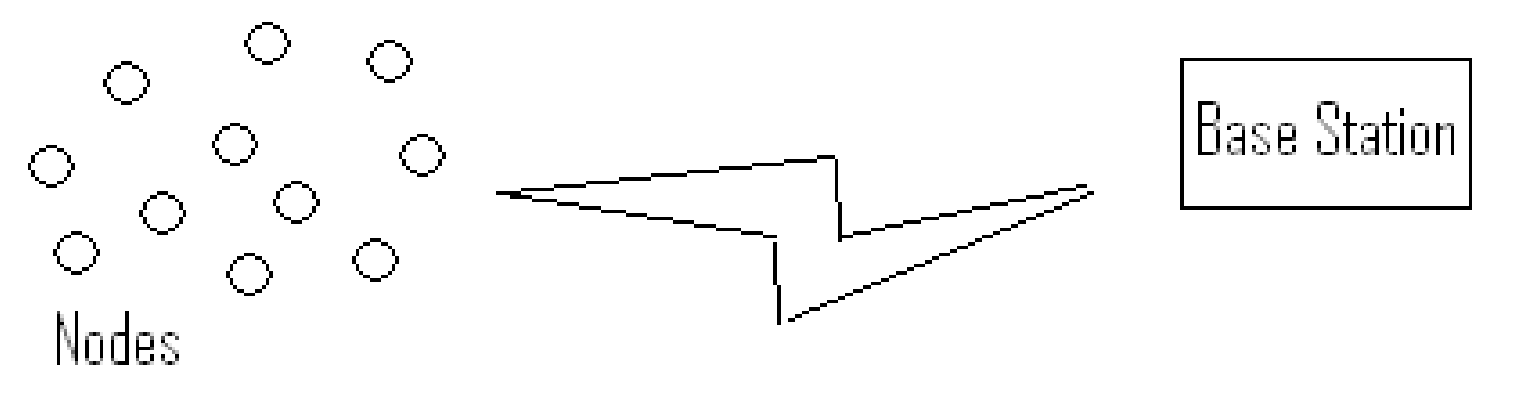


Outline

- What is Wireless Sensor and Actuator Network
- WSAN Basics
- WSAN Architecture
- Characteristics of WSAN
- The Need for WSAN
- What is Ad Hoc Wireless Networks
- WSAN in IoT
- Actors
- WSAN Protocol Stack
- WSN Operating System
- WSAN Simulation Scenario

WSN Basics

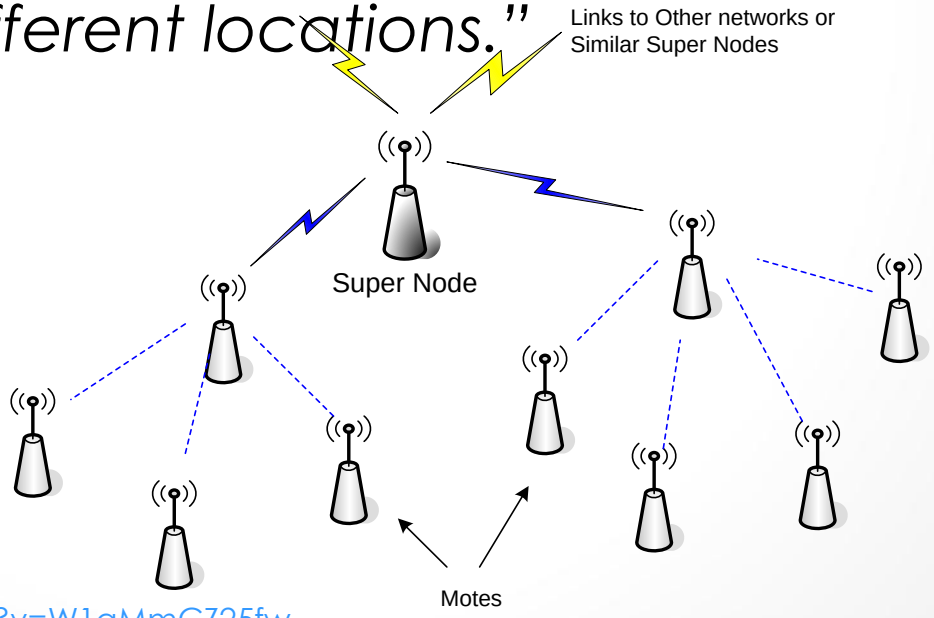
- A Wireless Sensor Network (WSN) consists of base stations and a number of wireless sensors (nodes).



Wireless Sensor Networks (WSN)

"*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.*"

- Wikipedia



https://www.youtube.com/watch?v=W1aMmCZ25fw
https://www.youtube.com/watch?v=2Q8DMoGIC78

Wireless Sensor Network vs Wireless Actuator Network

- WSNs provide extensive information from the physical world through distributed sensing solutions. Generally, this information is processed at the sink node(s) for the detection of events that occur in the physical world. In this respect, WSNs result in one-way information delivery, where information from the physical world is provided to the "cyber world."
- With the emergence of low-cost actuators and robots that can affect the environment, a two-way information exchange is possible. As a result, information that is sensed from the environment can be utilized to act on the environment

Wireless Sensor Network vs Wireless Actuator Network

- Sensor networks are gaining popularity in pervasive environment for tracking events such as habitat monitoring, weather monitoring, hazard detection
- Deployed to create **"smart environments**" which are useful in monitoring conditions such as temperature, sound, movement, location, light and others
- Deployed in hostile and **remote geographical** locations without being unattended and requires minimal supervision
- Used in many areas such as environmental and habitat monitoring, indoor climate control, medical diagnostics, intelligent alarms, surveillance and many more

WSAN

- This led to the emergence of distributed wireless sensor and actor networks (WSANs) that are capable of observing the physical world, processing the data, making decisions based on the observations, and performing appropriate actions.

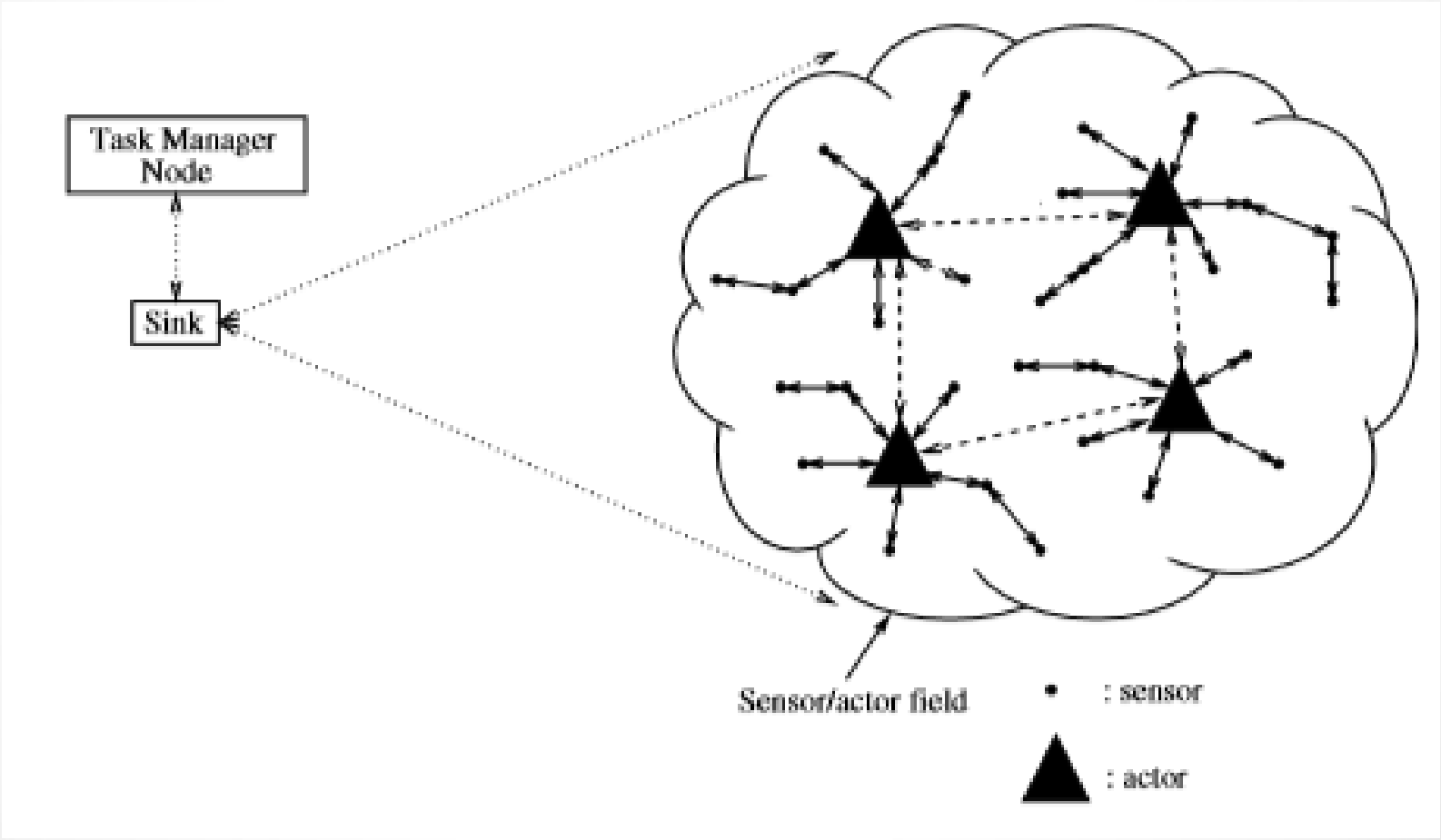
- A WSAN can be an integral part of systems such as battlefield surveillance and microclimate control in buildings, nuclear, biological, and chemical attack detection, home automation and environmental monitoring

Components of WSAN

- **Sensors:** Sensors are low-cost, low-power devices with limited sensing, computation, and wireless communication capabilities. A sensor node may consist of multiple sensors and observe different physical phenomena through these sensors.

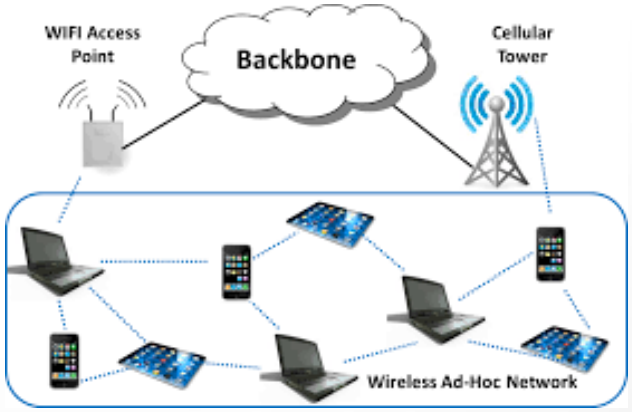
- **Actors:** Actors are resource-rich nodes equipped with higher processing capabilities, higher transmission power, and potentially longer battery life. In addition, actors may be mobile, which improves the effective areas in which they can act.

WSAN Architecture



What is Ad Hoc Wireless Networks

- Large number of self-organizing static or mobile nodes that are possibly randomly deployed
- Near(est)-neighbor communication
- Wireless connections
  - Links are fragile, possibly asymmetric
  - Connectivity depends on power levels and fading
  - Interference is high for omnidirectional antennas
- Sensor Networks and Sensor-Actuator Networks are a prominent example.



Characteristics of Wireless Sensor and Actuator Networks

- **Requirement**s: small size, large number, tether-less, and low cost. Constrained by
  - Energy, computation, and communication
- Small size implies small battery
- Low cost & energy implies low power CPU, radio with minimum bandwidth and range
- Ad-hoc deployment implies no maintenance or battery replacement
- To increase network lifetime, no raw data is transmitted

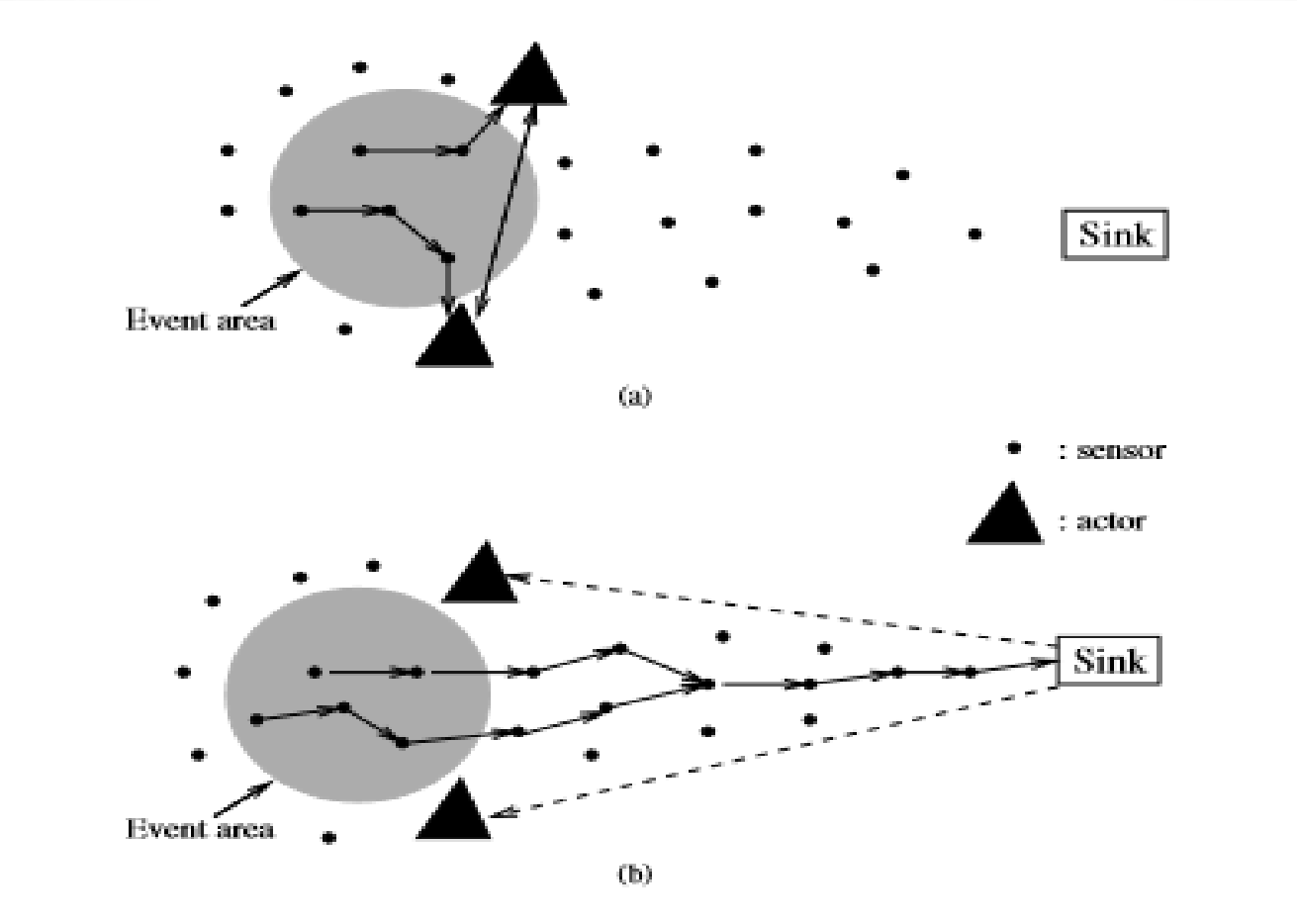
Characteristics of Wireless Sensor and Actuator Networks

- **Heterogeneity**: WSANs consist of heterogeneous components including low-end sensor nodes and more powerful actor nodes.
- **Real-time requirement**: In many applications where a timely response by actors to the input from sensors is important, real-time guarantees should be provided by the network protocols. As an example,in the fire monitoring application
- **Coordination**: Unlike WSNs where a central entity, i.e., the sink, performs the functions of data collection and coordination, in WSANs, new networking phenomena called sensor–actor

Network Architecture

- **Automated architecture**: Sensors send their observations to appropriate actors. The actors may coordinate among each other to decide on the appropriate action and perform task assignment. Due to the non-existence of a central controller, e.g., sink or human interaction, this architecture is called automated. In this case, the observations are distributed among actors and they need to coordinate to make decisions.
- **Semi-automated architecture**: In this case, the sink, i.e., central controller, collects data and coordinates the acting process. Sensors detecting a phenomenon route data back to the sink, which may issue action commands to actors

Network Architecture



Advantages of Automated Architecture

- **Lower latency**: Actors are generally located in the sensor/actor field or nearby. As a result, communication of the observed information from sensors to actors has a much smaller latency compared to sending this information to the sink
- **Longer network lifetime**: Information delivery in the semi-automated architecture results in higher load for the sensors located close to the sink. This increases the load on those sensors
- **Lower network resource consumption**: The semi-automated architecture requires network-wide support by the sensors on the path from the eventarea to the sink

The Need for WSAN

- Fault tolerance
- Scalability – Large number of nodes
- Long duration
- Connected to deeper infrastructure
- Loss & interference
- Hardware constraints
- Sensor network topology
- Environment
- Irregular, varying connectivity
- Transmission media
- Power Consumption
  - Sensing
  - Communication
  - Data processing

Overview

Distinguishing Features

WSNs are ad hoc networks (wireless nodes that self-organize into an infrastructureless network).

BUT, in contrast to other ad hoc networks:

- Sensing and data processing are essential
- WSNs have many more nodes and are more densely deployed
- Hardware must be cheap; nodes are more prone to failures
- WSNs operate under very strict energy constraints
- WSN nodes are typically static
- The communication scheme is many-to-one (data collected at a base station) rather than peer-to-peer

Overview

Lifetime

- Nodes are battery-powered
- Nobody is going to change the batteries. So, each operation brings the node closer to death.

"**Lifetime is crucial!"**

To save energy:

- Sleep as much as possible.
- Acquire data only if indispensable.
- Use data fusion and compression.
- Transmit and receive only if necessary. Receiving is just as costly as sending.

Overview

Scalability and Reliability

WSNs should

- self-configure and be robust to topology changes (e.g., death of a node)
- maintain connectivity: can the Base Station reach all nodes?
- ensure coverage: are we able to observe all phenomena of interest?

Maintenance

- Reprogramming is the only practical kind of maintenance.
- It is highly desirable to reprogram wirelessly.

Overview

Data Collection

- Centralized data collection puts extra burden on nodes close to the base station. Clever routing can alleviate that problem
- Clustering: data from groups of nodes are fused before being transmitted, so that fewer transmissions are needed
- Often getting measurements from a particular area is more important than getting data from each node
- Security and authenticity should be guaranteed. However, the CPUs on the sensing nodes cannot handle fancy encryption schemes.

Overview

Power Supply

- AA batteries power the vast majority of existing platforms. They dominate the node size.
- Alkaline batteries offer a high energy density at a cheap price. The discharge curve is far from flat, though.
- Lithium coin cells are more compact and boast a flat discharge curve.
- Rechargeable batteries: *Who does the recharging?*
- Solar cells are an option for some applications.
- Fuel cells may be an alternative in the future.
- Energy scavenging techniques are a hot research topic (mechanical, thermodynamical, electromagnetic).

Overview

Radio

- Commercially-available chips
- Available bands: 433 and 916MHz, 2.4GHz ISM bands
- Typical transmit power: 0dBm.

Power control

- Sensitivity: as low as -110dBm
- Narrowband (FSK) or Spread Spectrum communication. DS-SS (e.g., ZigBee) or FH-SS (e.g., Bluetooth)
- Relatively low rates (<100 kbps) save power.

Overview

CPU

- The Microcontroller Unit (MCU) is the primary choice for in-node processing.
- Power consumption is the key metric in MCU selection.
- The MCU should be able to sleep whenever possible, like the radio.
- Memory requirements depend on the application
- ATmega128L and MSP430 are popular choices

Overview

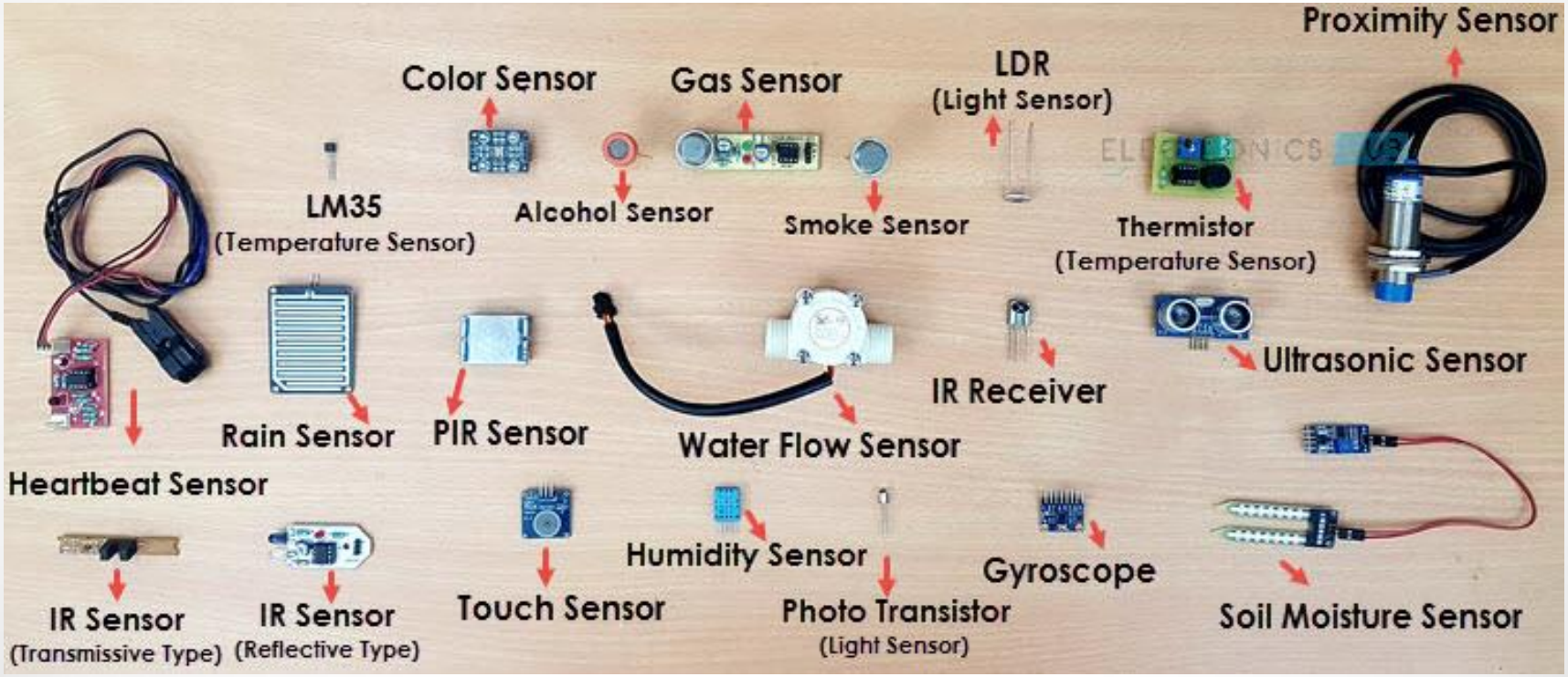
Sensors

- The power efficiency of the sensors is also crucial, as well as their duty cycle.
- MEMS techniques allow miniaturization.

Types of Sensors

- Temperature/ Thermal Sensor.
- Proximity Sensor.
- Accelerometer.
- IR Sensor (Infrared Sensor)
- Pressure Sensor.
- Light Sensor.
- Sound analysis
- Ultrasonic Sensor.
- Smoke, Gas and Alcohol Sensor - Chemical, electronic nose, CO2, moisture, microbial cloud
- Magnetic (metals)

Types of Sensors



Motivation for WSAN in IoT

There are six fundamental building blocks that constitute the components of the Internet of Things:

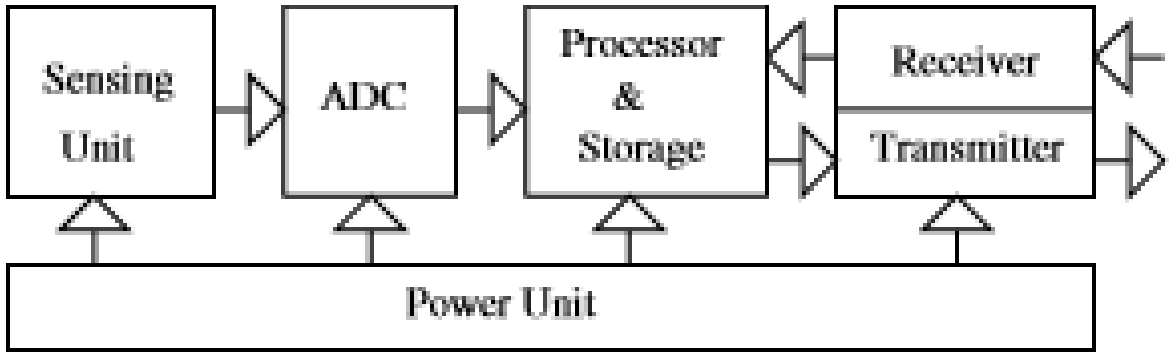
- sensors – for tracking and measuring activity
- connectivity – internet or cloud infrastructure
- processors – contain some computing power
- energy efficiency – difficult for access to charge and replace battery
- cost-effectiveness – easily available
- quality and reliability – need to operate in harsh environments for longer period
- security – need to relay sensitive information

Terms

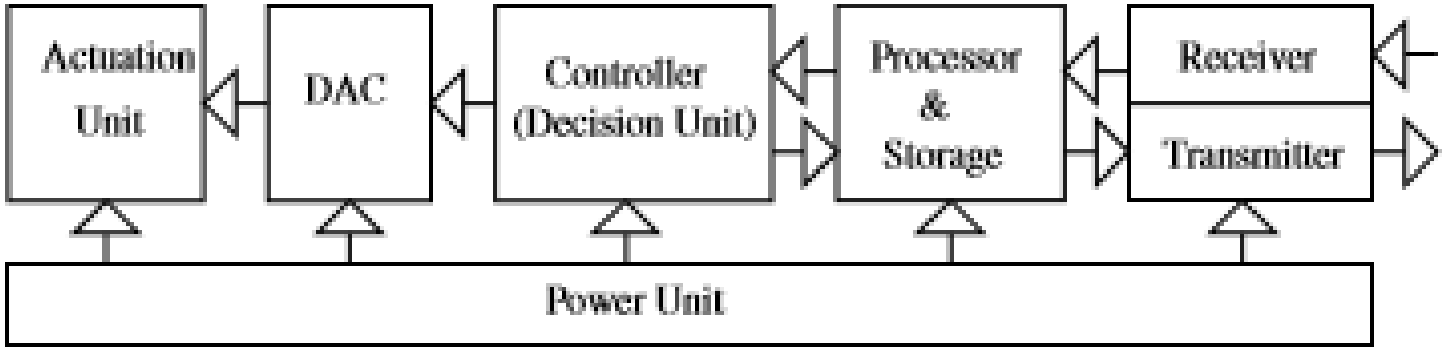
- sensor
  - A transducer
  - converts physical phenomenon e.g. heat, light, motion, vibration, and sound into electrical signals
- sensor node
  - basic unit in sensor network
  - contains on-board sensors, processor, memory, transceiver, and power supply
- sensor network
  - consists of a large number of sensor nodes
  - nodes deployed either inside or very close to the sensed phenomenon

The Components

- (a) sensors (b) actuators



(a)



(b)

Actors

(a)

(b)

(c)

(d)

Sensor–Actor Coordination

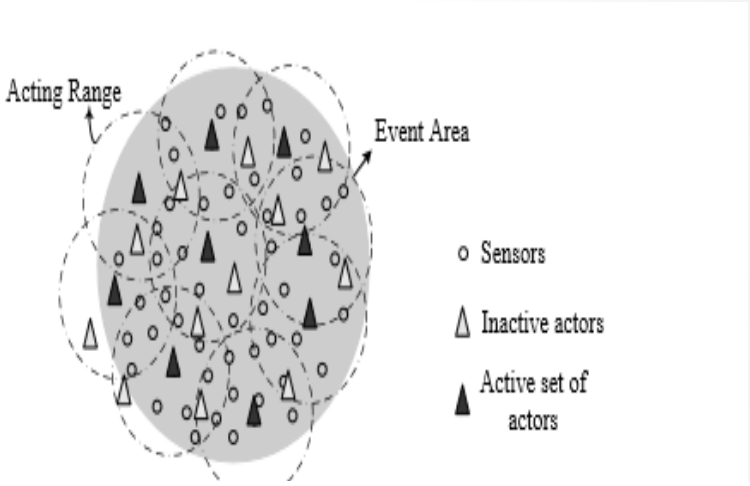
- Requirements of sensor–actor communication: One of the main requirements of sensor–actor communication is energy efficiency as in WSNs
- WSANs multiple actors can be in the vicinity of the event area and sensors can use any of these actors to send their information. Therefore, actor selection as a destination for sensor–actor communication is an important challenge
- Communication technique: Given the communication requirements and the selected actors, the best communication technique in terms of reliability, delay, and energy should be chosen for the heterogeneous WSAN architecture.

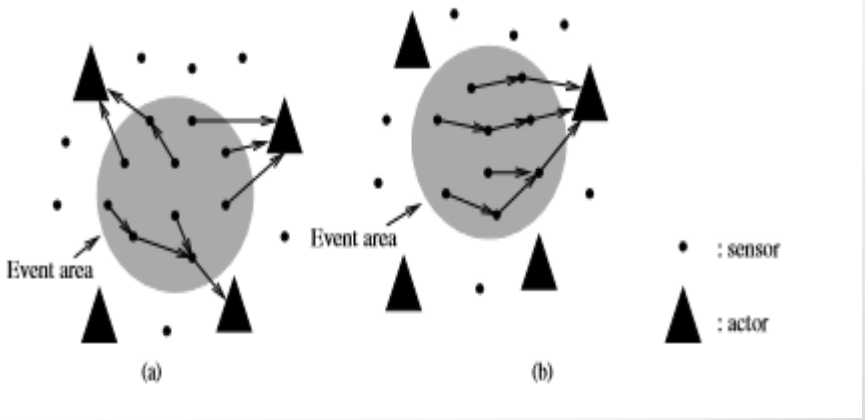
Requirements for sensor–actor communication

- • Real-time bounds: Protocols should provide real-time services with given delay bounds according to the application constraints.
- Energy efficiency: WSAN protocols should ensure energy-efficient communication among sensors and actors.
- Event ordering: The different events should be appropriately ordered as they are reported to the actors.
- Event synchronization: Communication protocols should also provide synchronization among different sensors reporting the same event to multiple actors or the same actor.

Actor Selection

- **Minimum actor set:** A minimal set of actors to cover the event region.
- **Minimum sensor set**: The minimum number of sensors to report the sensed event.
- **Minimum actor and sensor set:** Both cases above.
- **Area-based set**: The entire set of actors and sensors in the vicinity of the region.

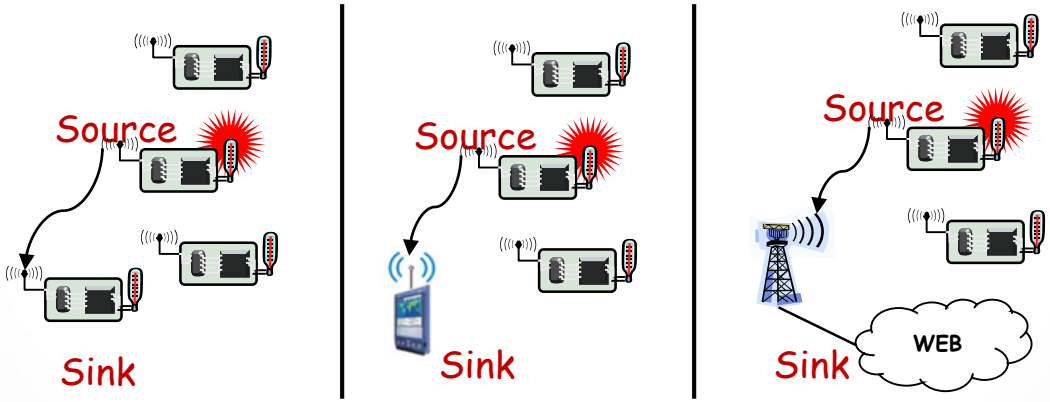




- **Task distribution**: the actor that receives the sensor data may not act on the event area due to a small action range or insufficient energy.
- **Eventinformation exchange**: If multiple actors receive the same event information, only partial informationisavailableateach
- **Task coordination**: In certain applications, if multiple actors are required to cover the entire event region, it may be necessary to ensure that these regions are non-overlapping
- **Synchronization**:Ifmultipleactorsreceiveinformationfrommultiplesensorsforthesameevent, it may be necessary to ensure that these multiple actors act on the environment at the same

Sensor Network Scenario

- Sensor network scenario
  - Sources: any entity that provides data/measurements
  - Sinks: nodes where information is required
    - Can belong to the sensor network as such
    - Can be an external entity, e.g., a smartphone, directly connected to the WSN
      - Main difference: comes and goes, often moves around, …
    - Can be a part of an external network (e.g., internet), connected to the WSN

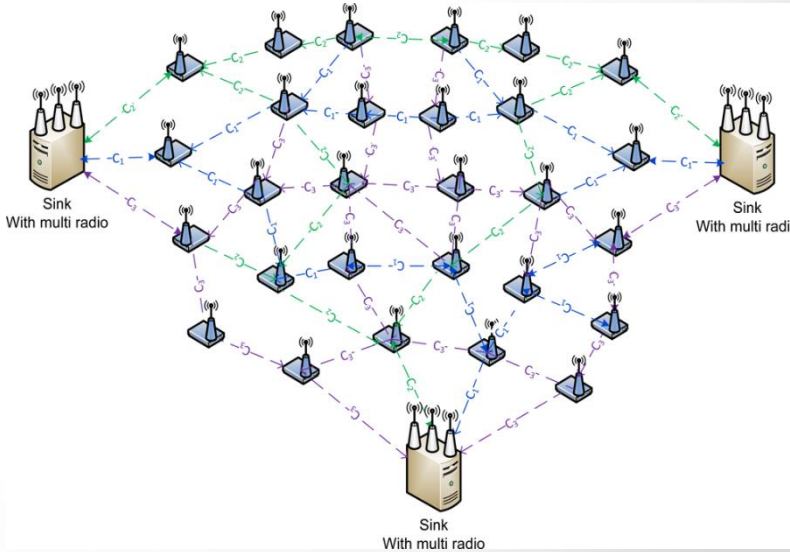


  - Applications: limited amounts of data, different notions of importance

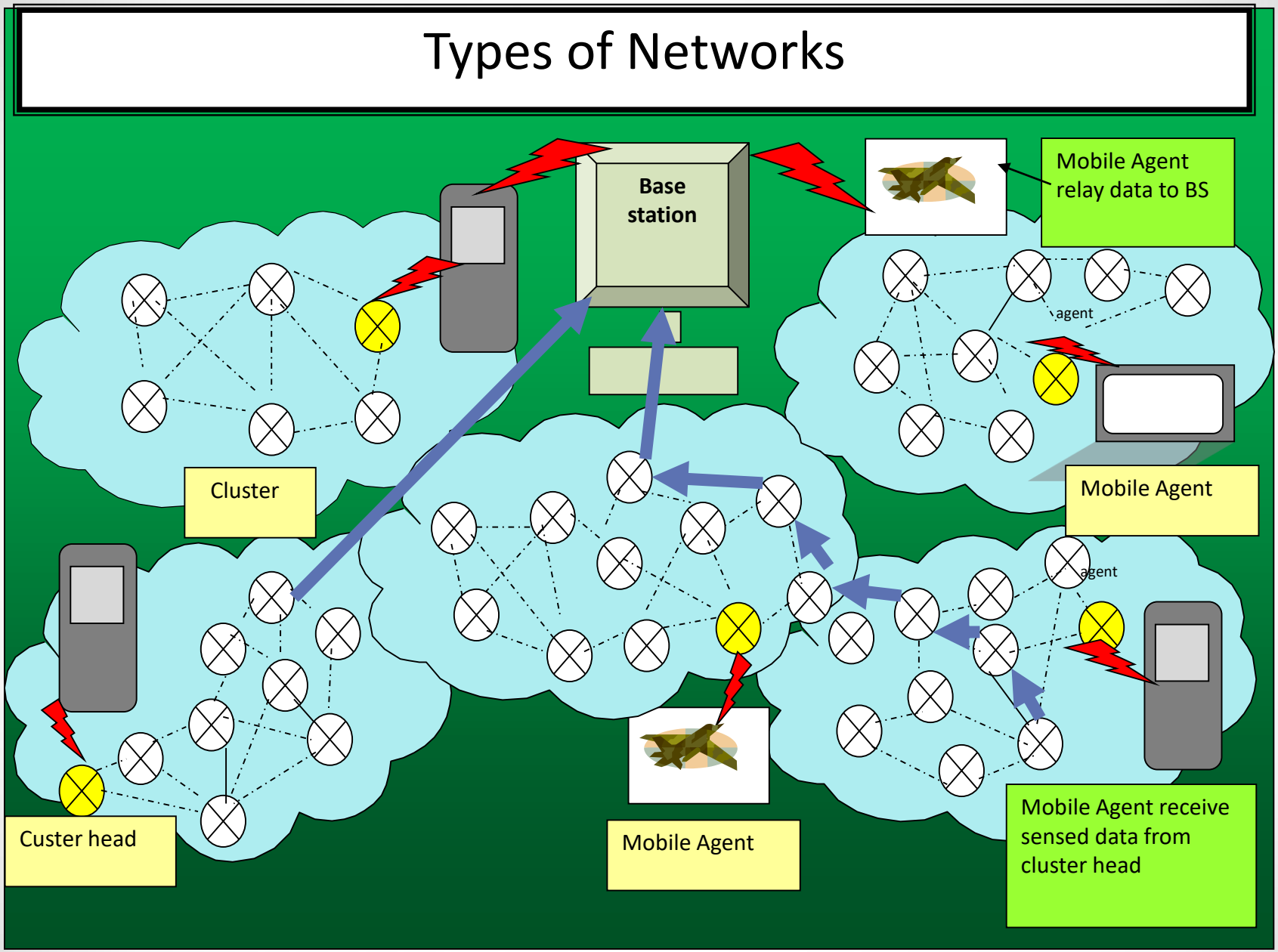
Types of Networks

- Single Hop Networks
- Multi Hop Networks
  - Send packets to an intermediate node
  - Intermediate node forwards packet to its destination
  - Store-and-forward multi-hop network

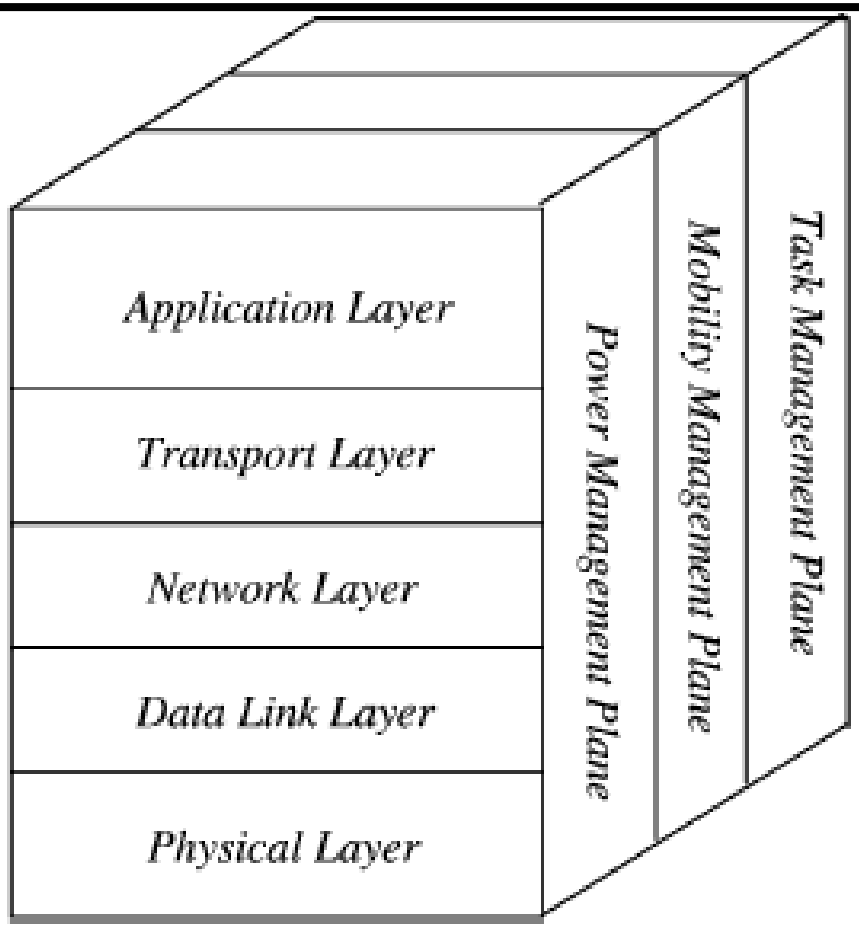
- Multiple Sinks, Multiple Sources



Types of Networks



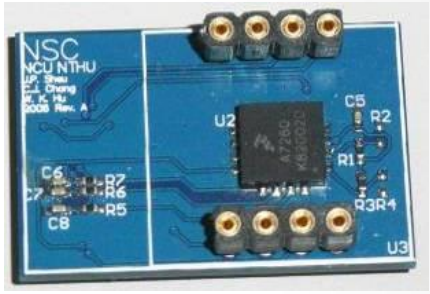
WSN Protocol Stack



Main Components of a Sensor Node: Sensing Module

Infar sensor

Electronic compass



Triple axis accelerometer

Ultrasonic

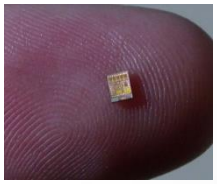
Pressure Sensor

Temperature and Humidity Sensor

Gyroscope

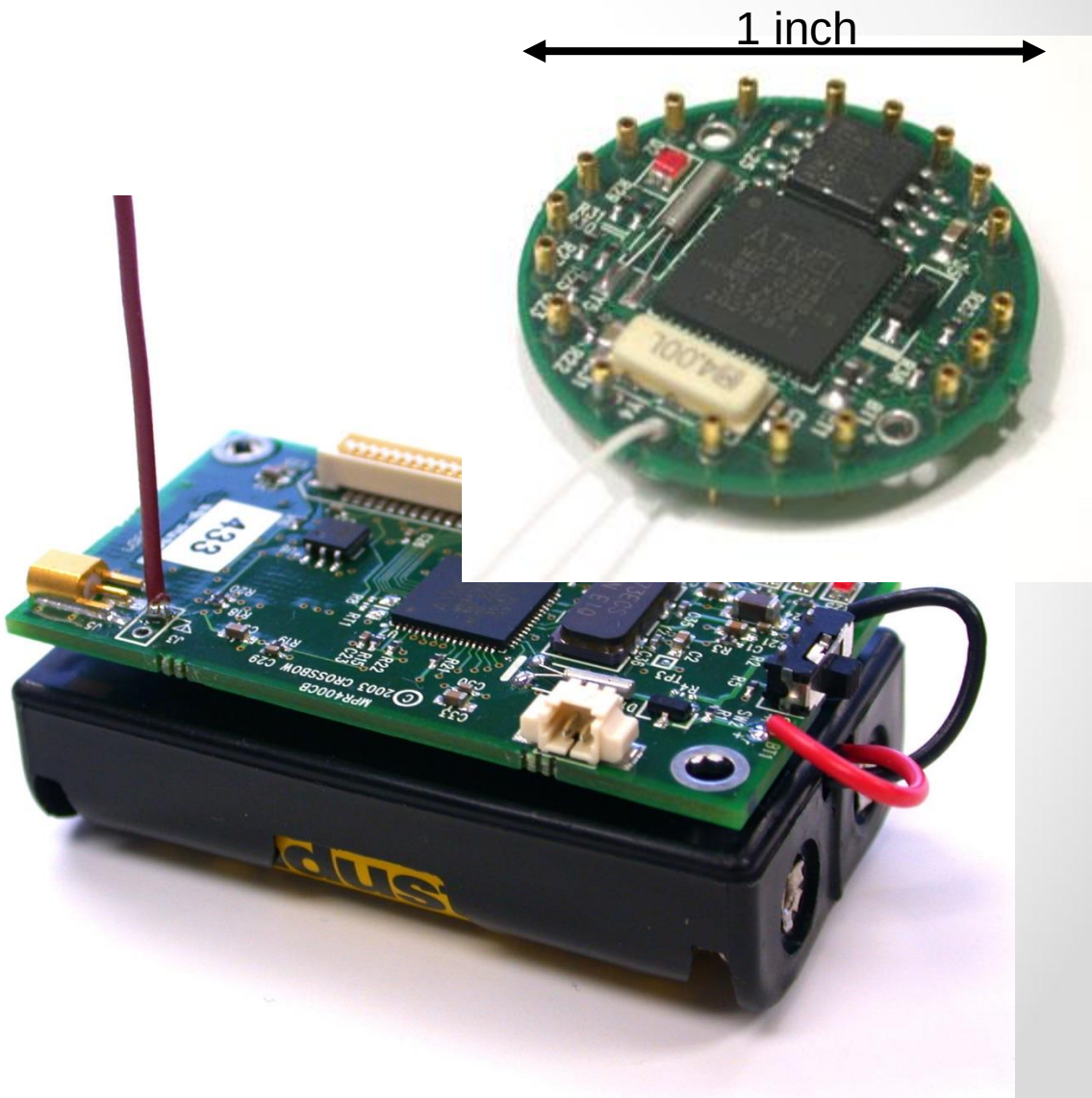
Types of sensor platforms

- RFID equipped sensors
- Smart-dust tags- typically act as data-collectors or "trip-wires" limited processing and communications
- Mote/Stargate-scale nodes more flexible processing and communications
- More powerful gateway nodes, potentially using wall power



Mica2 and Mica2Dot

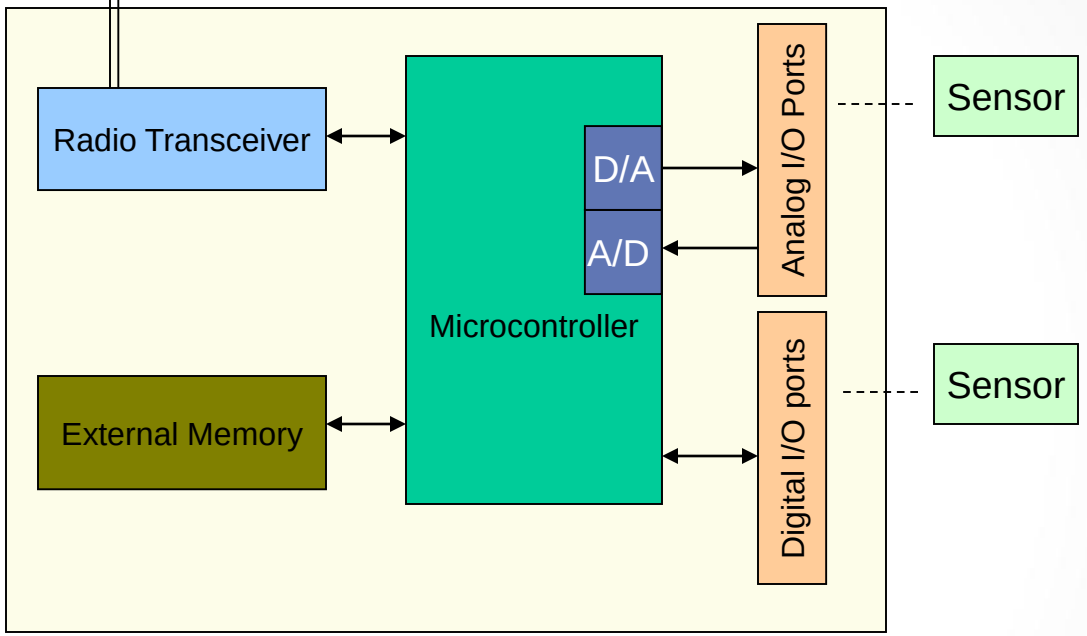
- ATmega128 CPU
  - Self-programming
- Chipcon CC1000
  - FSK
  - Manchester encoding
  - Tunable frequency
- Low power consumption
  - 2 AA battery = 3V



WSAN Operating Systems

- TinyOS
- Contiki
- MANTIS
- BTnut
- SOS
- Nano-RK

Mote



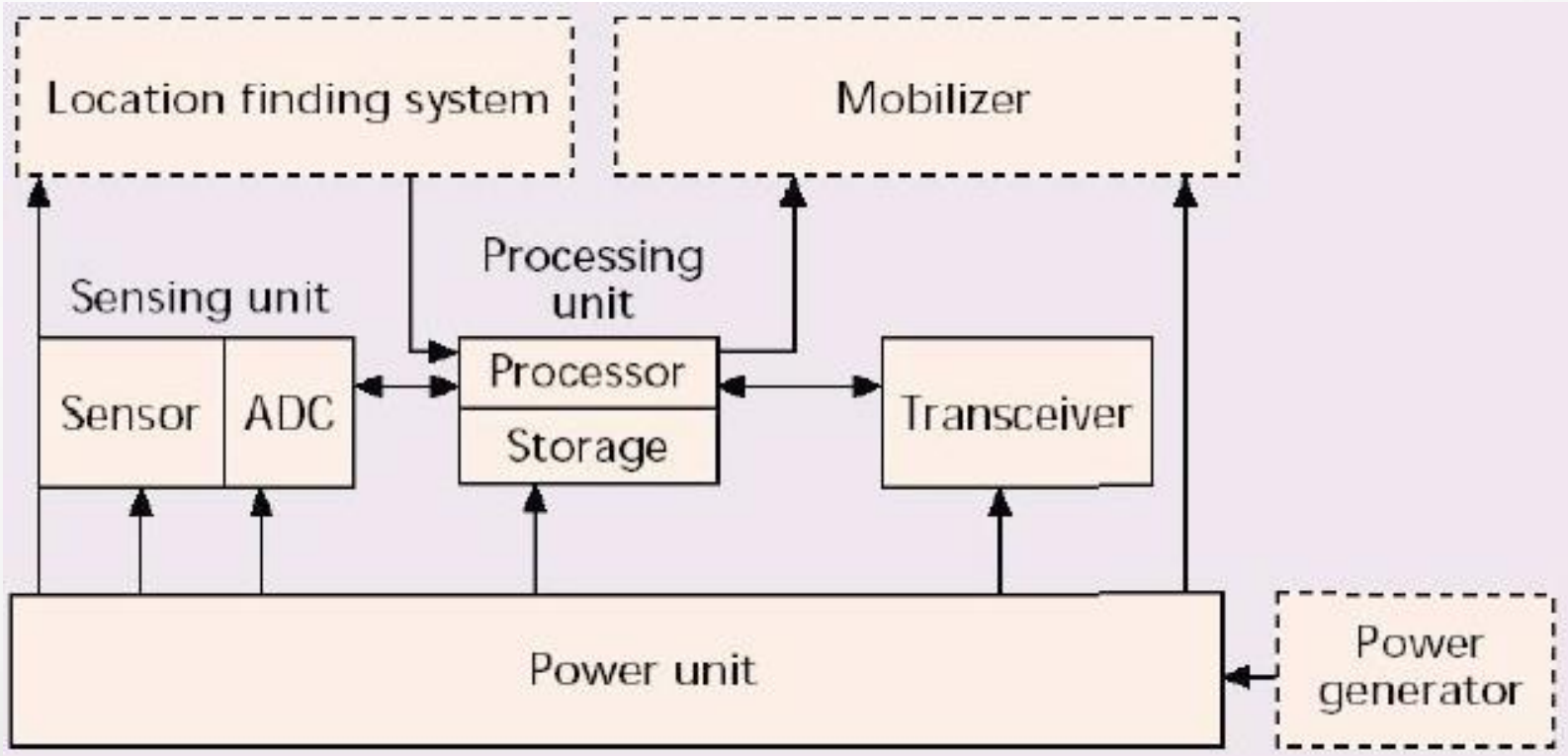
- A very low cost low power computer
- Monitors one or more sensors
- A Radio Link to the outside world
- Are the building blocks of Wireless Sensor Networks (WSN)

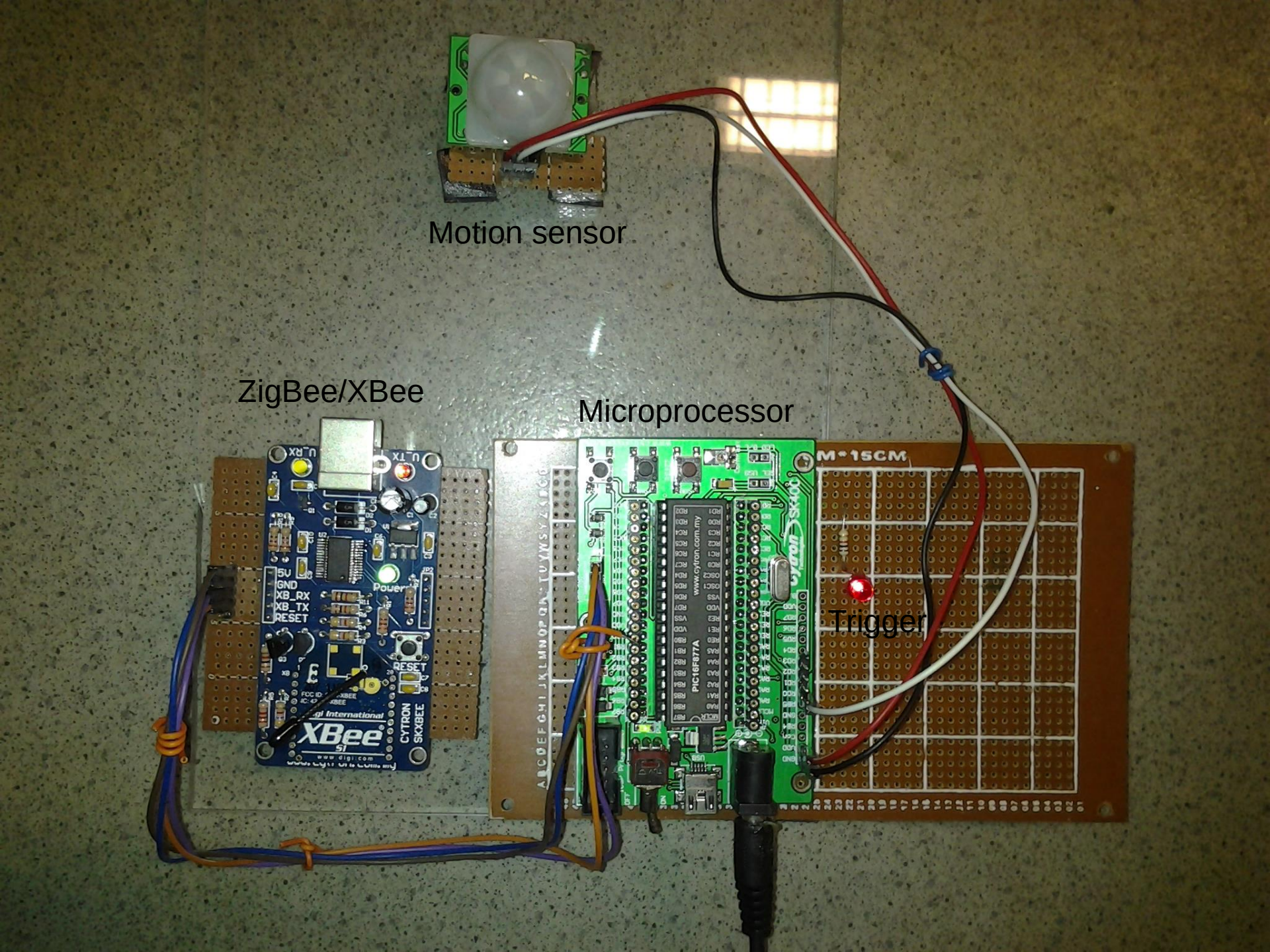
Wireless Sensor Node: Mote Components

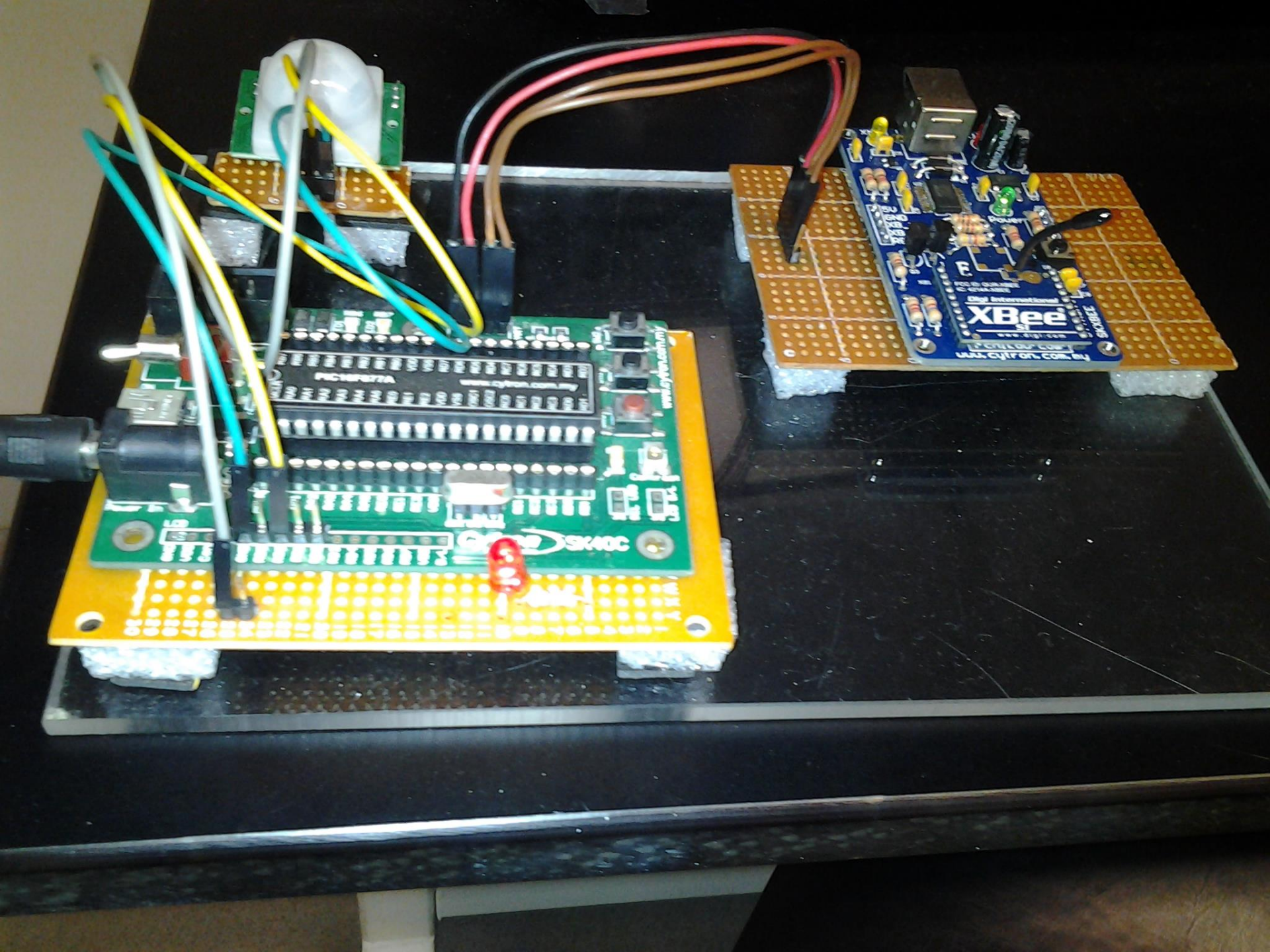
- Sensor unit is composed of computational unit, a sensing unit, a logic unit and a power unit.

- Wireless sensor nodes are the essential building blocks in a wireless sensor network sensing, processing, and communication stores and executes the communication protocols as well as data processing algorithms

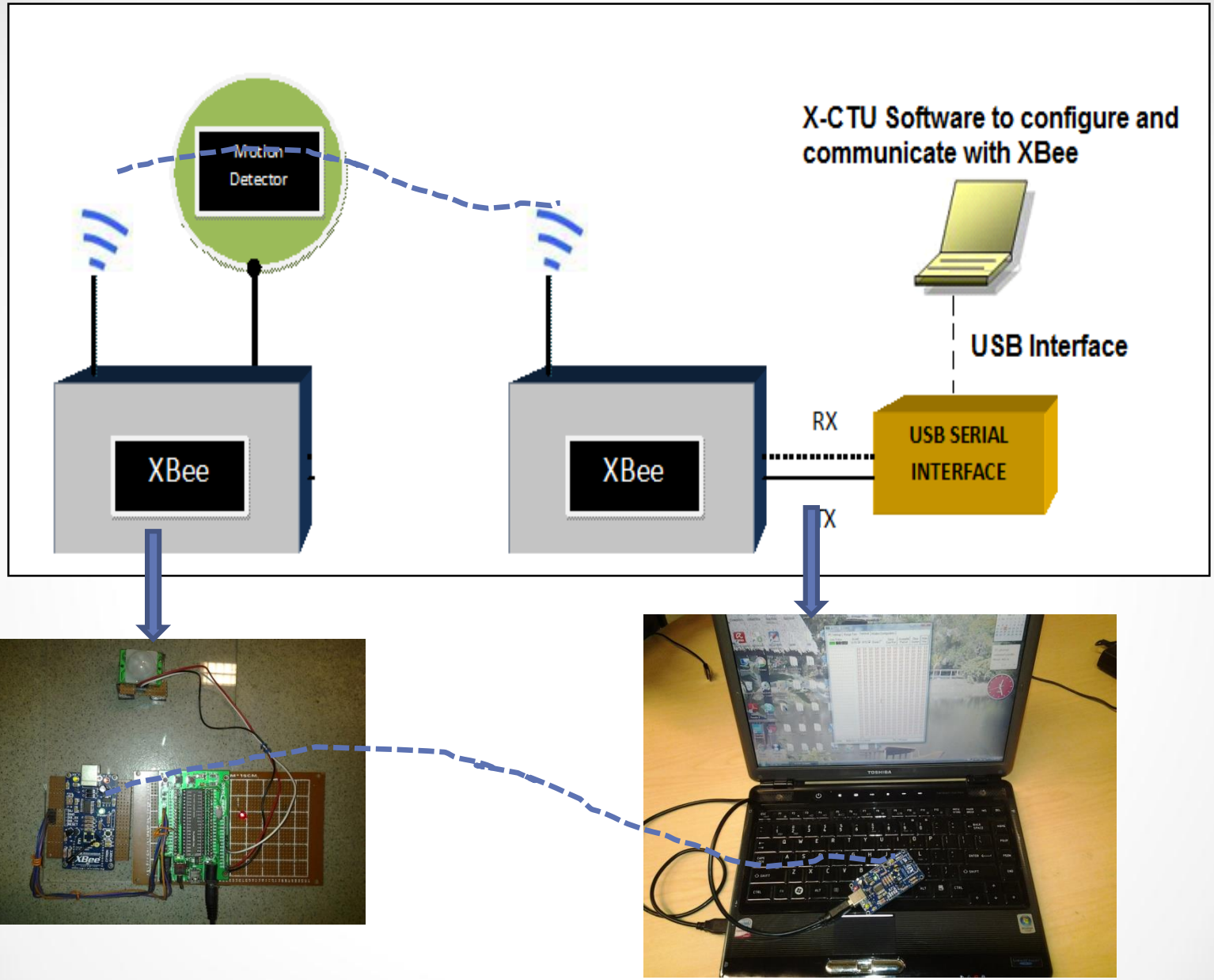
Wireless Sensor Node: Mote Components




Motion sensor
ZigBee/XBee
Microprocessor
Trigger
U_RX
U_TX
5V
GND
XB_RX
XB_TX
RESET
Power
RESET
CYTRON
SK40BEE
XBee
PIC16F877A
www.cytron.com.my

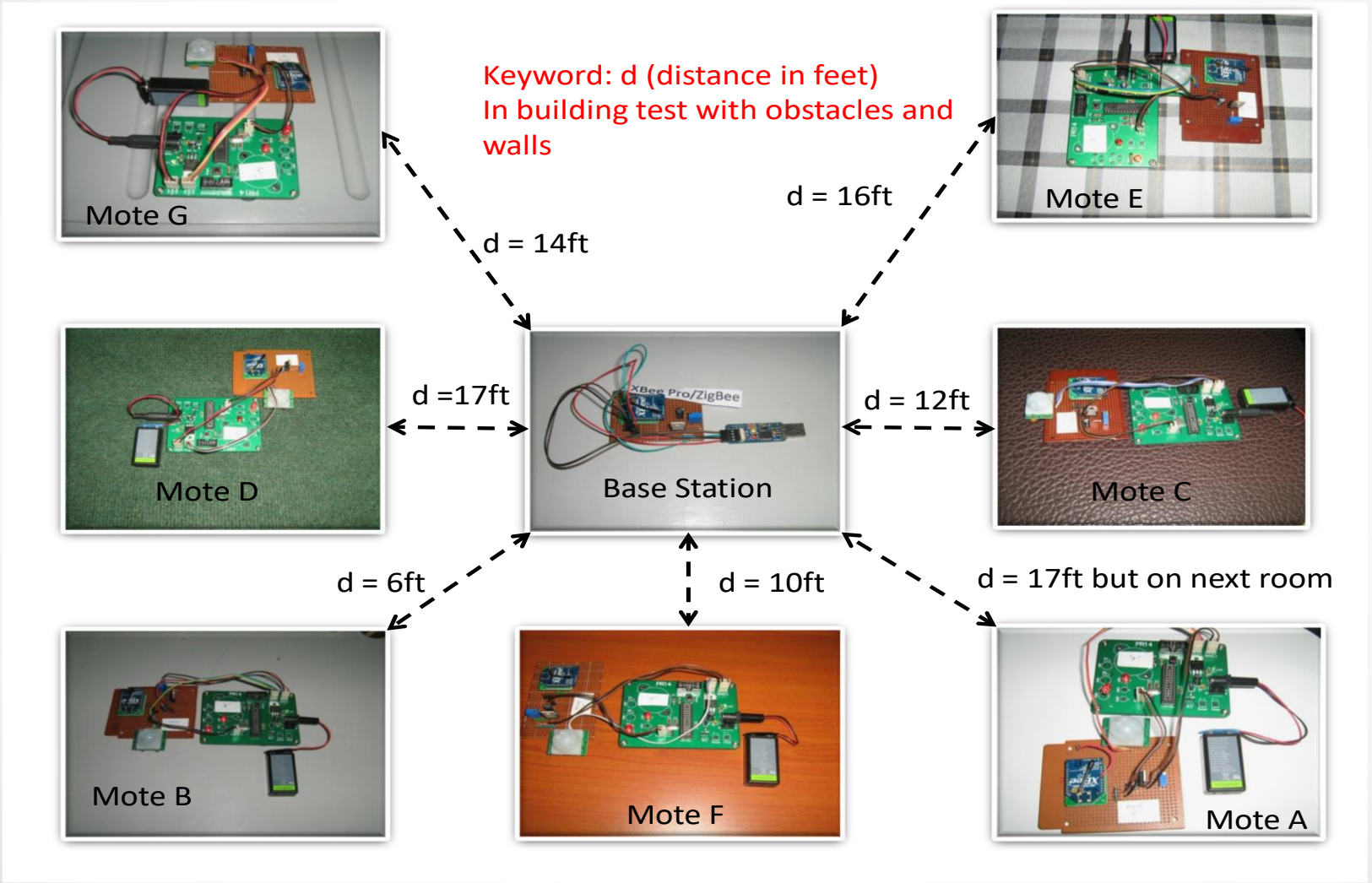

XBee
www.cytron.com.my


XCTU Software
ZigBee/XBee
TOSHIBA

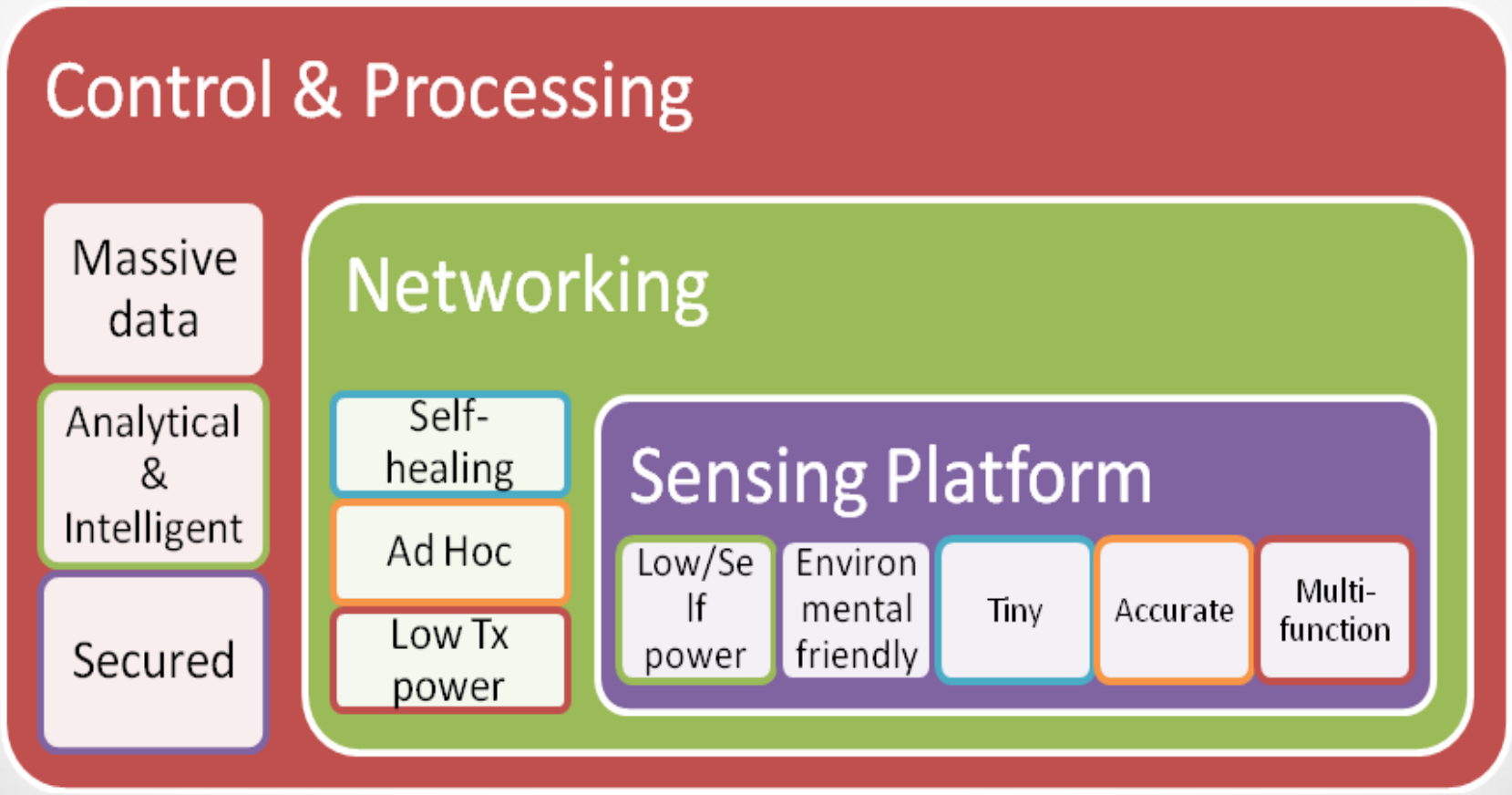

Motion
Detector
X-CTU Software to configure and
communicate with XBee
USB Interface
XBee
XBee
RX
USB SERIAL
INTERFACE
TX


Security Personnel
Mobile Agent
Sensor Unit

Sensor Topology



Sensor Network Overall View



WSN Simulators

- NS-2
- GloMoSim
- OPNET
- SensorSim
- J-Sim
- OMNeT++
- Sidh
- SENS

ns-2 Environment

Simulation Scenario

Tcl Script

```
set ns_ [new Simulator]
set node_(0) [$ns_ node]
set node_(1) [$ns_ node]
```

C++ Implementation

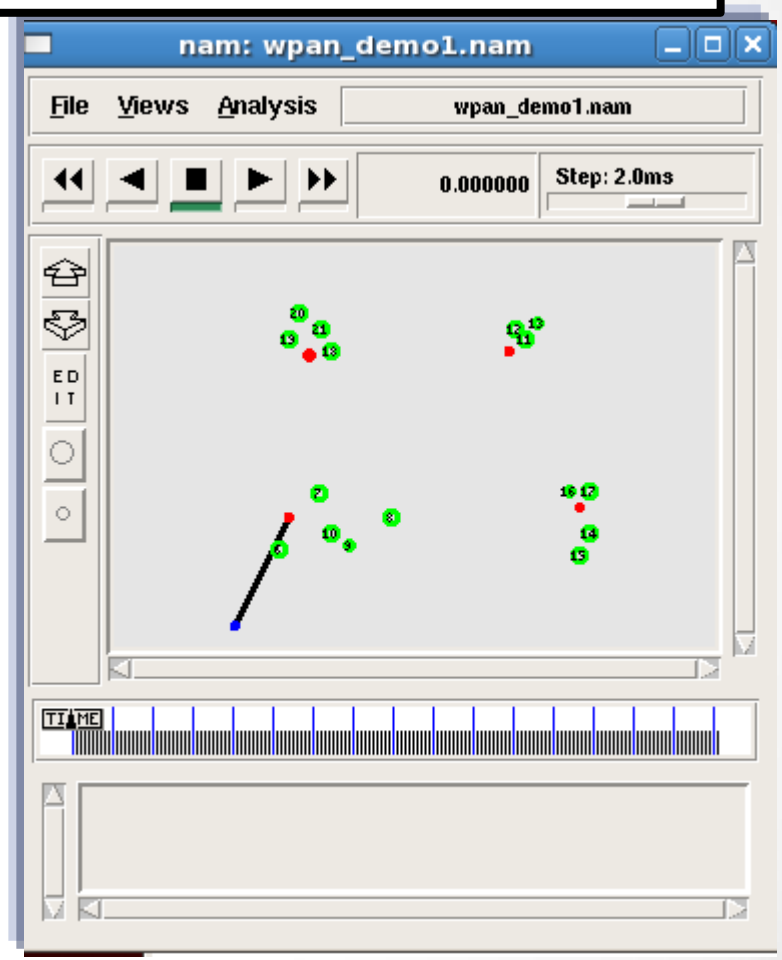
```
class MobileNode : public Node
{
friend class PositionHandler;
public:
        MobileNode()
                •
}
```

WSN Simulation in NS-2

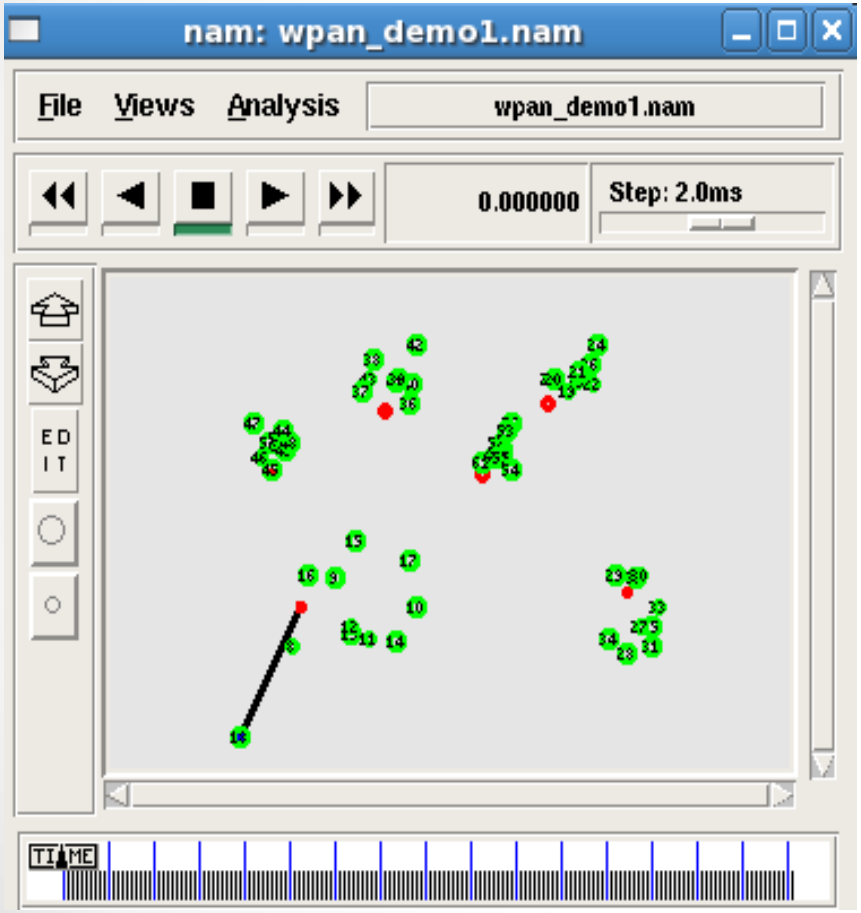
- Contributed from CMU's Monarch project (Wireless extension to ns-2)
- Various modules were added to ns-2 to simulate node mobility and wireless networking
  - Mobile Node
  - Ad-hoc Routing(DSR, DSDV, TORA, AODV)
  - MAC802.11
  - Radio Propagation Model
  - Channel

Simulation Scenario

- 20 sensor nodes(cluster)
- 1 mobile nodes
- moving within 670mX670m flattopology
- using DSDV ad hoc routing protocol/directed diffusion
- Random Waypoint mobility model
- TCP and CBR traffic

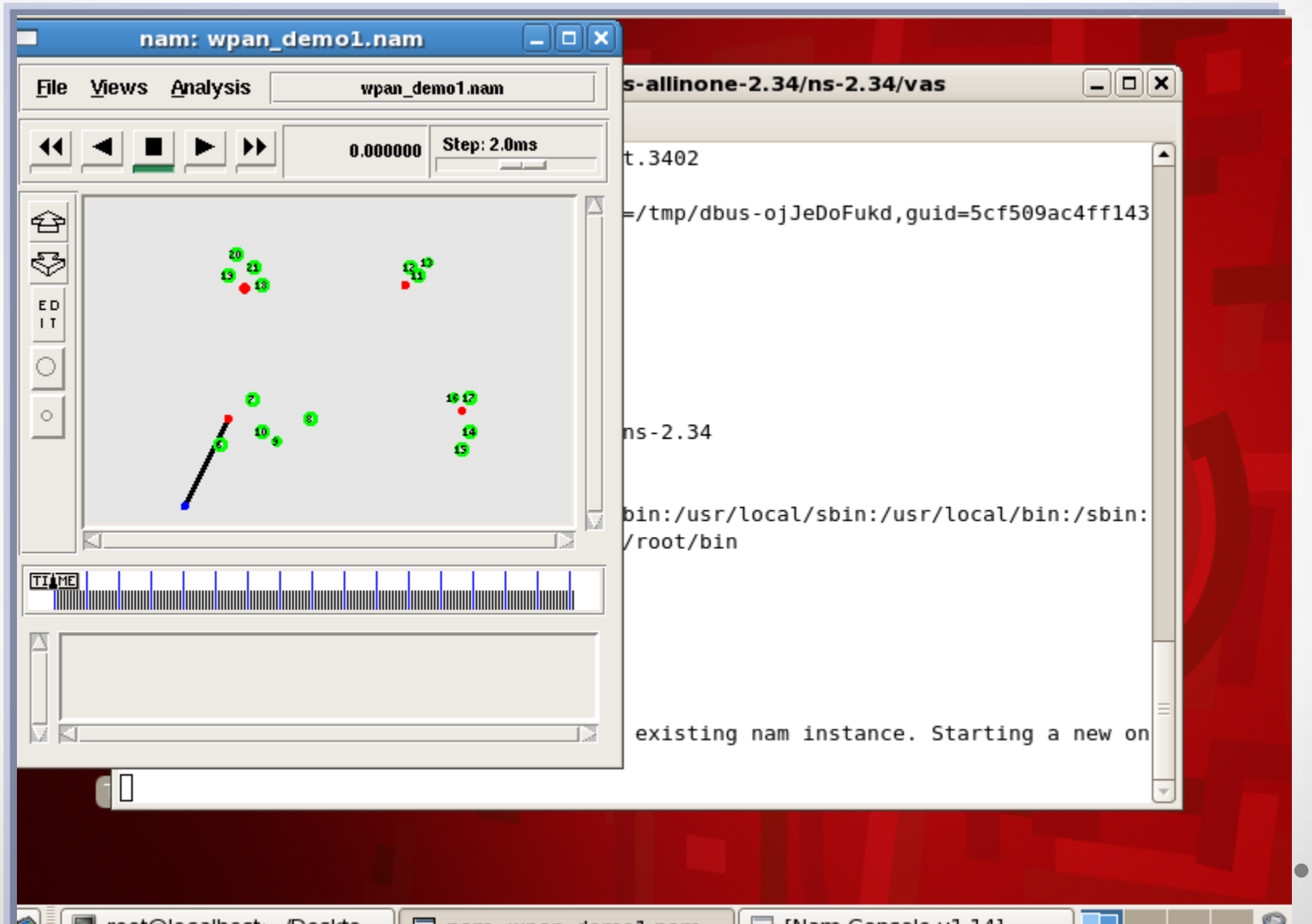


Preliminary Results

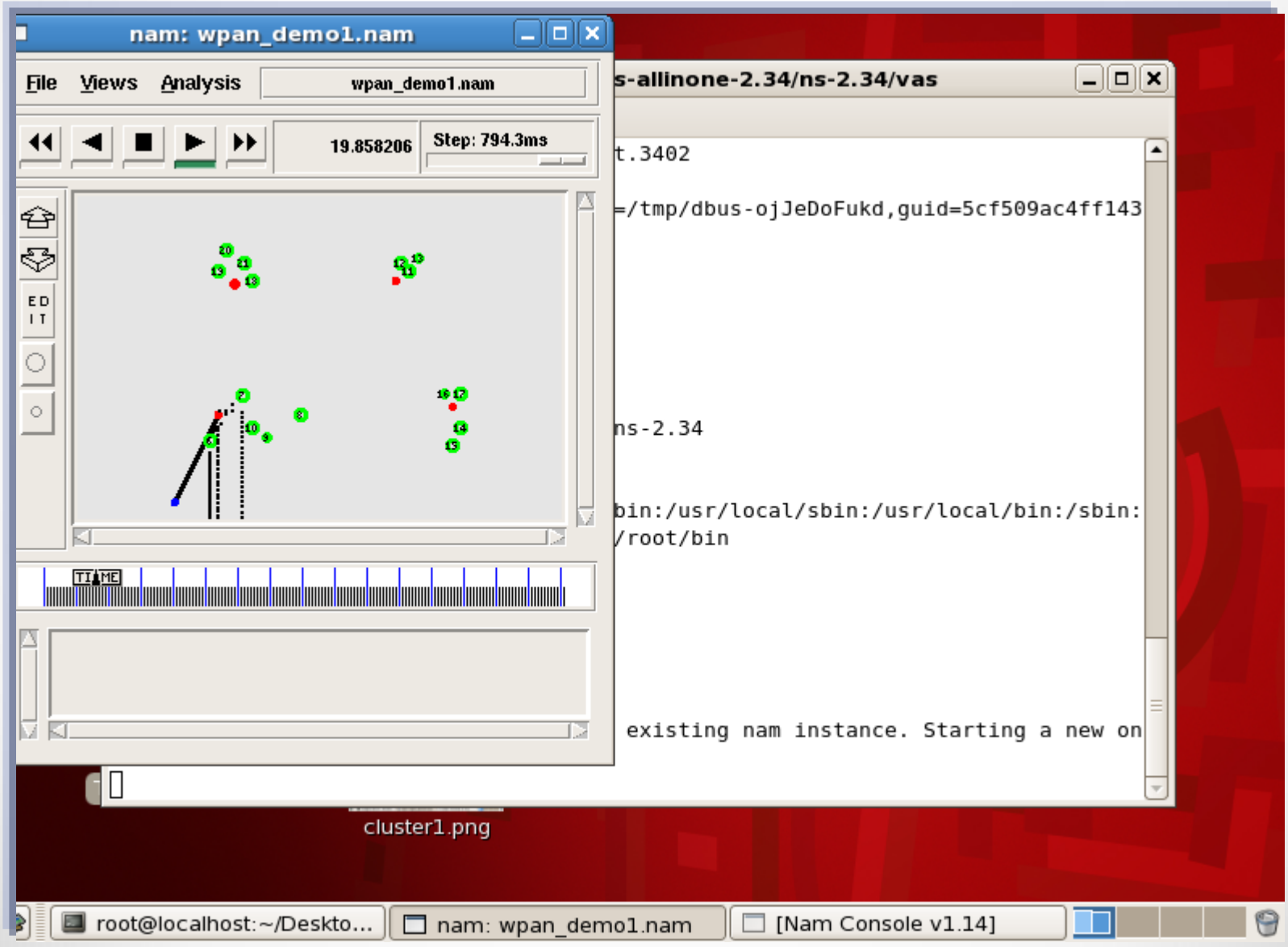


Item	Value
Number of nodes	10, 20, 30, 40, 50, 60
Data packet size	64 bytes
Idle power	0.3J
Receive power	0.3J
Transmit power	0.3J
Node initial energy	1 J
Node radio range	40 m
MAC protocol	IEEE 802.15.4
Simulation Area (A)	670 x 670
No of Mobile agent	1 - 2
Mobile agent velocity	3, 6, 9, 15, 24 m/s

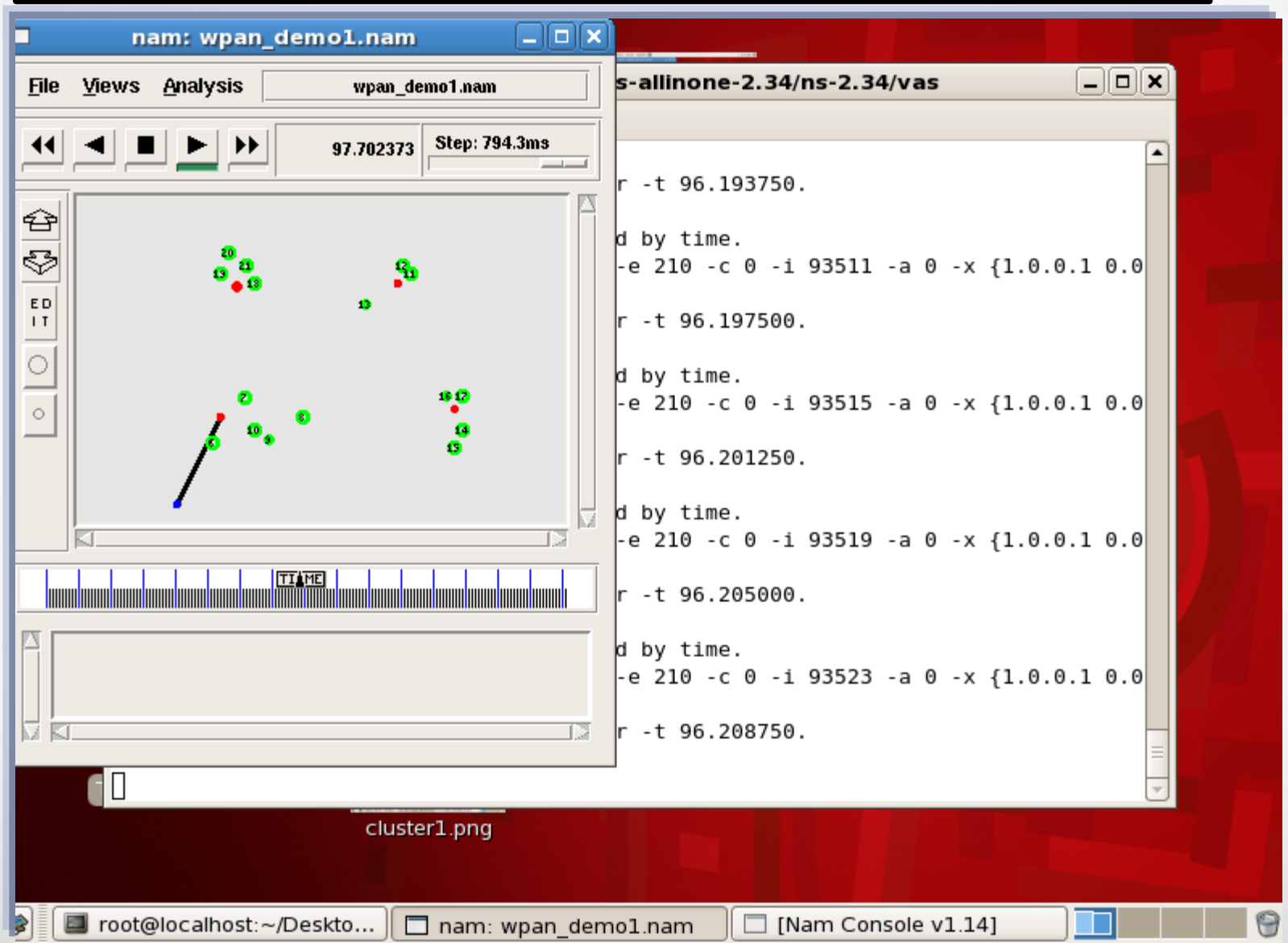
Scenario - cluster



Traffic Analysis



Mobility


nam: wpan_demo1.nam
File
Views
Analysis
wpan_demo1.nam
97.702373
Step: 794.3ms
TIME
s-allinone-2.34/ns-2.34/vas
r -t 96.193750.
d by time.
-e 210 -c 0 -i 93511 -a 0 -x {1.0.0.1 0.0
r -t 96.197500.
d by time.
-e 210 -c 0 -i 93515 -a 0 -x {1.0.0.1 0.0
r -t 96.201250.
d by time.
-e 210 -c 0 -i 93519 -a 0 -x {1.0.0.1 0.0
r -t 96.205000.
d by time.
-e 210 -c 0 -i 93523 -a 0 -x {1.0.0.1 0.0
r -t 96.208750.
cluster1.png
root@localhost:~/Deskto...
nam: wpan_demo1.nam
[Nam Console v1.14]

NS-2 Simulation

- Wireless Sensor Network in NS-2 Analysis (Part-1)
- https://www.youtube.com/watch?v=mM3gEjqN9WA

- Wireless Sensor Network in NS-2 Analysis (Part-2)
- https://www.youtube.com/watch?v=Nbetn7LfbxU

- http://slogix.in/how-to-create-wireless-sensor-network-wsn-in-ns2#Source-code

- http://ns2-master.blogspot.my/2011/04/sample-coding-in-wireless.html

References/Sources