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Networked Embedded Applications

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CS3: (WSN Time Synchronization)

3	➢ WSN Time Synchronization ➢ Time Synchronization Requirements and Issues ➢ Sender- Receiver Synchronization ➢ Receiver- Receiver Synchronization ➢ NTP, HBS, TDP, RBD

WSN Time Synchronization

Time synchronization is important because:

➢Events such as target tracking, speed estimation, ocean current monitoring etc require the knowledge of time between sensor nodes.

➢For security reasons, sensor nodes may have to time stamp the packets.

➢Voice, and video data from different sensor nodes need to be merged and displayed in a meaningful manner

➢Medium access schemes such as TDMA requires the nodes to be synchronized

➢Also, sensor nodes may be unattended for a long time. So the time data being received from them may be erroneous

The purpose of any time synchronization technique is to maintain a common time within a certain tolerance throughout the lifetime of the network or among set of nodes in the network.

WSN Time Synchronization

Application where we Require the Sensor network to be time Synchronized :

1. Target Tracking
2. Speed Estimation
3. Ocean Current monitoring
4. Event Detection
5. Voice & Video Sync
6. Security
7. MAC-TDMA
8. Local Clocks with crystal instability tend to drift

Factors Influencing Time Synchronization

- *Temperature*: Since sensor nodes are deployed in various places, the temperature variation throughout the day may cause the clock to speed up or slow down. For a typical PC, the clock drifts few parts per million during the day. For low-end sensor nodes, the drifting may be even worse.
- *Phase noise*: Some of the causes of phase noise are due to access fluctuation at the hardware interface, response variation of the operating system to interrupts, and jitter in the network delay.The jitter in the network delay may be due to medium access and queueing delays.

Factors Influencing Time Synchronization

- *Frequency noise*: The frequency noise is due to the unstability of the clock crystal. A low-end crystal may experience large frequency fluctuation, because the frequency spectrum of the crystal has large sidebands on adjacent frequencies. The ρ values for quartz oscillators are between 10^{-4} and 10^{-6}.
- *Clock glitches*: Clock glitches are sudden jumps in time. This may be caused by hardware or software anomalies such as frequency and time steps.

Factors Influencing Time Synchronization

- *Asymmetric delay*: Since sensor nodes communicate with each other through the wireless medium, the delay of the path from one node to another may be different than the return path. As a result, an asymmetric delay may cause an offset to the clock that cannot be detected by a variance type method . If the asymmetric delay is static, the time offset between any two nodes is also static. The asymmetric delay is bounded by one-half the round-trip time between the two nodes.
- Since sensor nodes are randomly deployed and their broadcast ranges are small, the influencing factors may shape the design of the time synchronization protocol. In addition, the links between the sensor nodes may not be reliable.

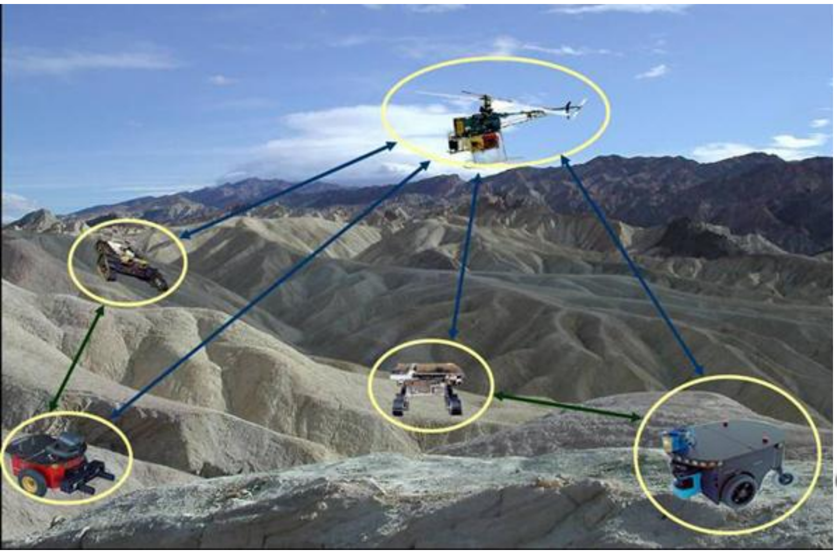
WSN Time Synchronization

Reasons for drift

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

WSN Time Synchronization

1. Target Tracking



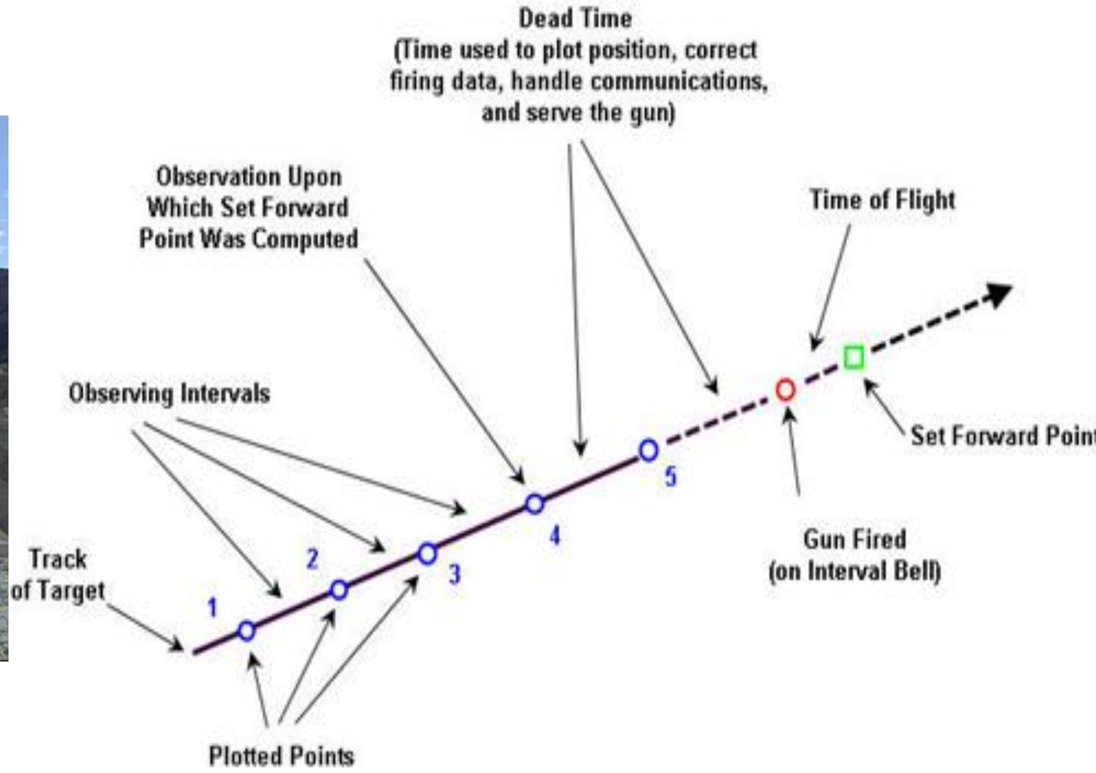
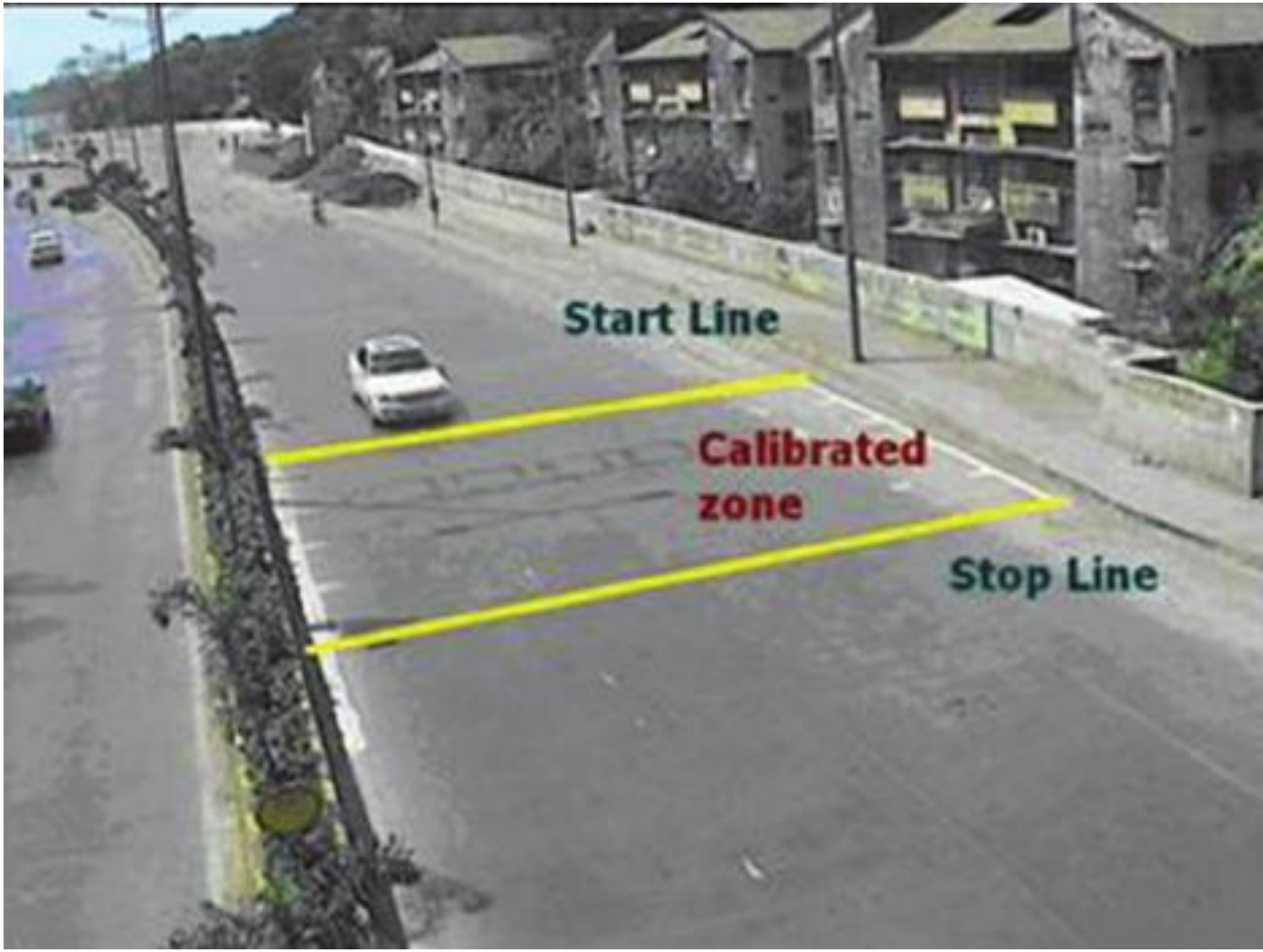


Figure 1
Relationship Between Observing Interval, Plotted Positions, Firing, and Set Foward Points

WSN Time Synchronization

Speed Estimation



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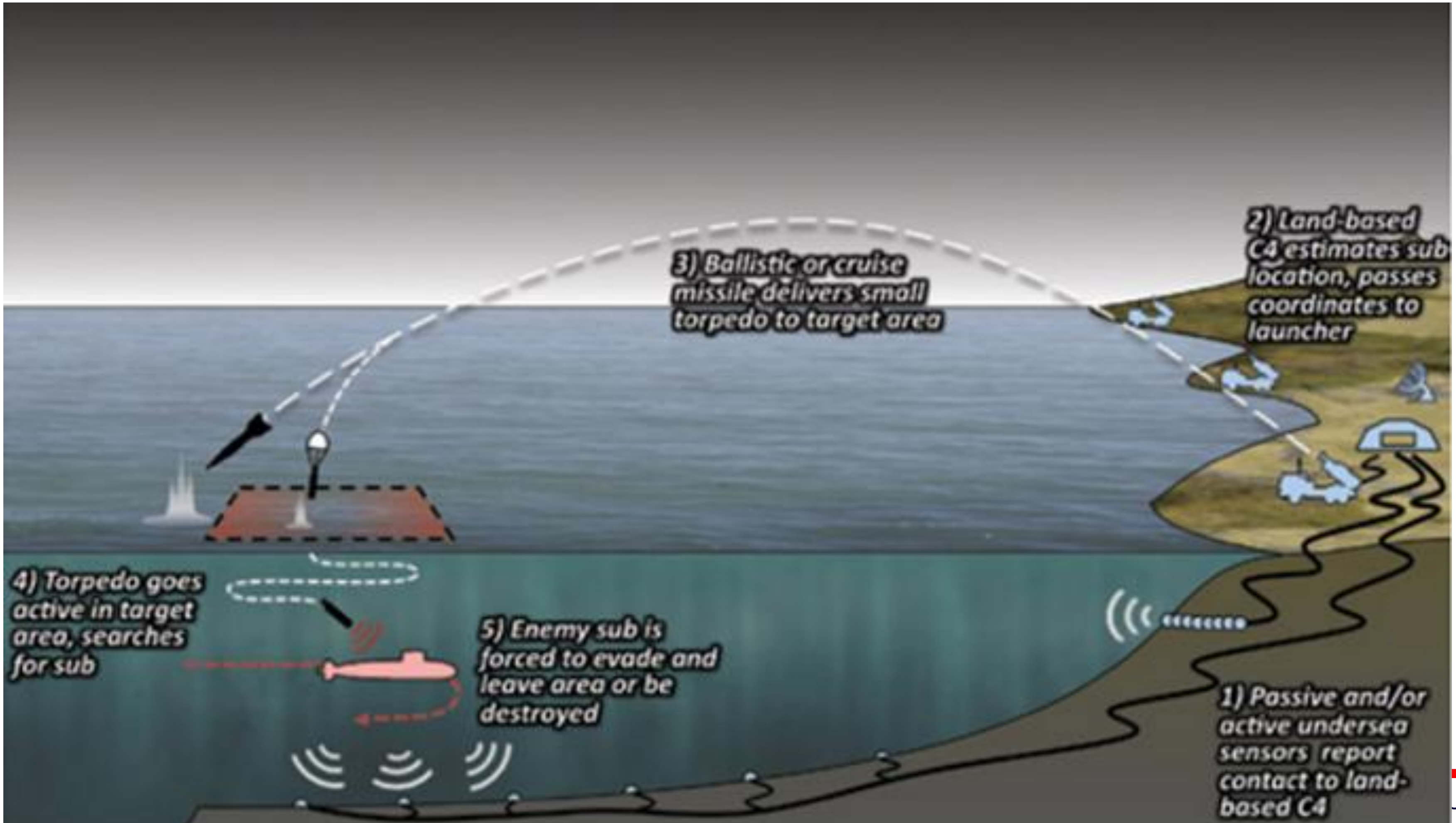
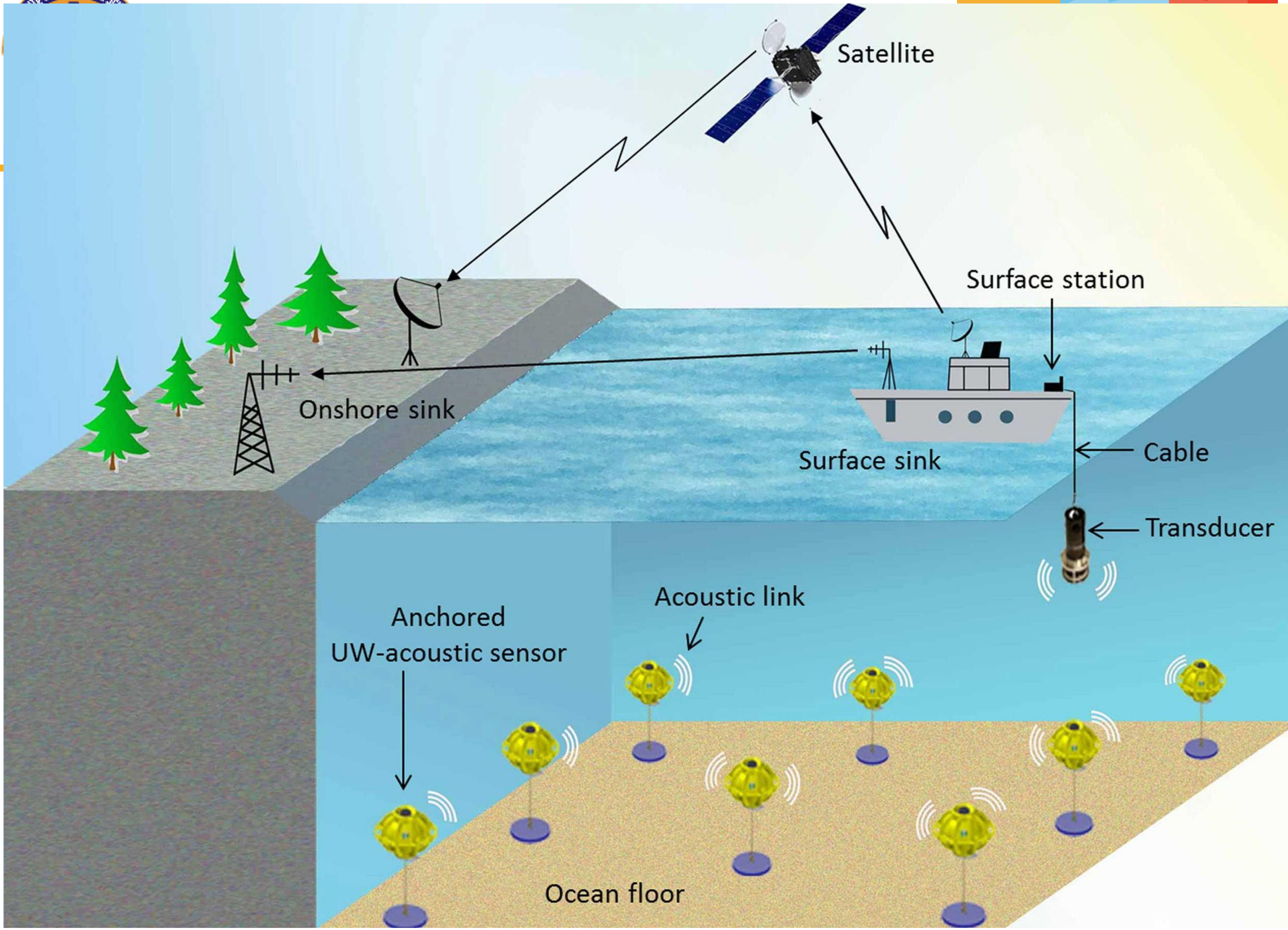
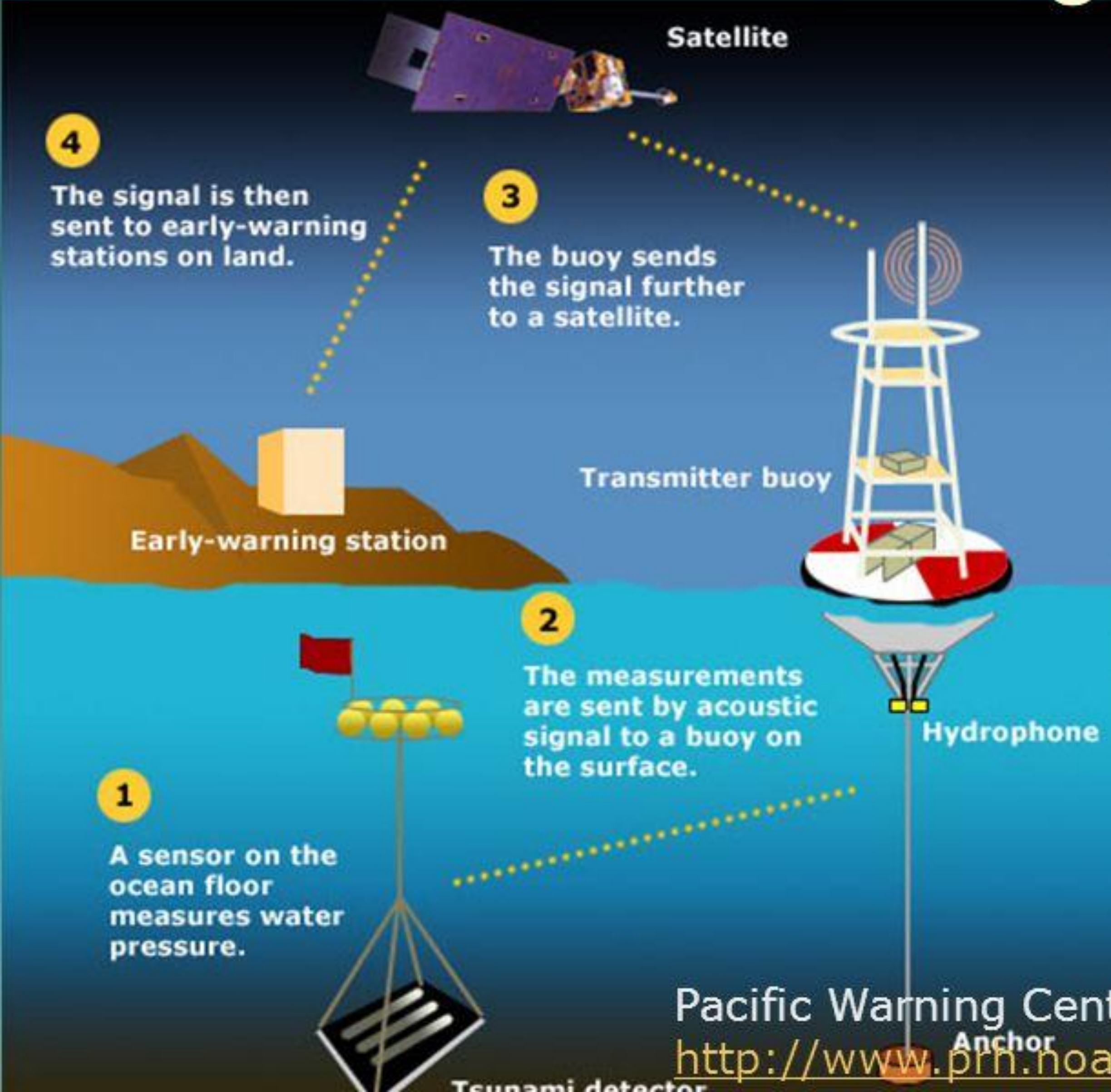
WSN Time Synchronization

In addition, the sensor nodes may be **left unattended for a long period of time**, for example, in deep space or on an ocean floor.




Satellite
Surface station
Onshore sink
Surface sink
Cable
Transducer
Acoustic link
Anchored
UW-acoustic sensor
Ocean floor

Tsunami Warning System



The Wave Watchdog

When an earthquake strikes on the bed of the ocean, millions of tons of water are suddenly pushed upwards -- or sinks dramatically downwards -- thus generating a powerful wave. In deep water, the wave travels at extremely high rates of speed. The wave can be identified by a tsunami detector, which then transmits a warning via satellite.

With the help of data received from transmitter buoys and prediction models, it is possible, even just 15 minutes after an earthquake strikes, to determine the path and the strength of a tsunami. Warnings can be sent out to the endangered regions immediately.

Pacific Warning Centre
http://www.prh.noaa.gov/ptwc/

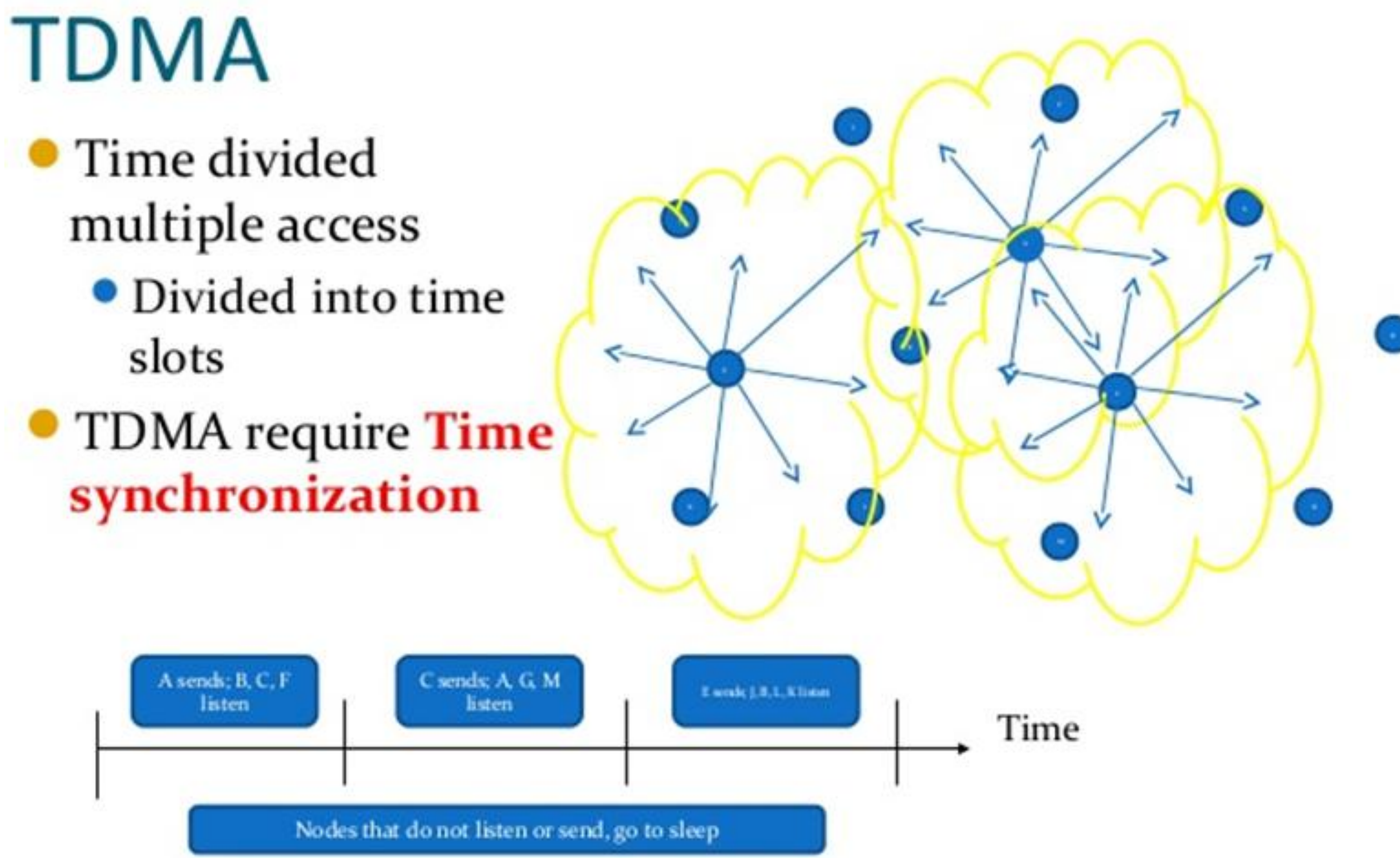
WSN Time Synchronization

1. In addition, the sensor nodes may be **left unattended for a long period of time**, for example, in deep space or on an ocean floor.
2. When messages are exchanged using **short distance multihop broadcast**, the software and medium access time and the **variation of the access time** may contribute the most in time **fluctuations and differences in the path delays**.
3. Also, the time difference between sensor nodes may be significant over time due to the **drifting effect of the local clocks.**

WSN Time Synchronization

Purpose of Time Synchronization:

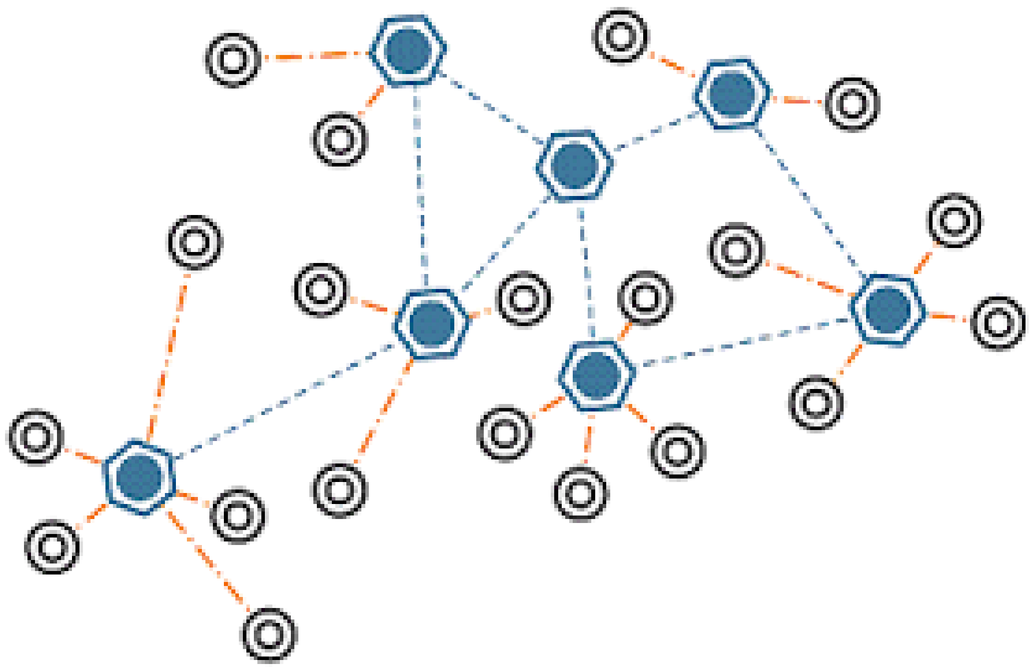
1. To increase the life time of network



WSN Time Synchronization

Design Challenges :

Time Synchronization for WSN



Design Challenges : Time Synchronization for WSN

- **Many low-end sensor nodes** will be deployed to minimize the cost of the sensor networks
- These nodes may **work collaboratively** together to provide time synchronization for the whole sensor network.
- **"The precision of the synchronized clocks depends on the needs of the applications."**
- For example:
  - **A sensor network requiring TDMA** service may require **microseconds** difference among the neighbor nodes
  - While a **Data Gathering Application** for sensor networks requires only milliseconds of precision.

WSN Time Synchronization

Features of a time synchronization protocol for sensor networks are :

1. Robust
2. Energy Aware
3. Server-less
4. Light-weight
5. Tunable Service

WSN Time Synchronization

1. Robust:

- Sensor nodes may fail, and the failures should not have significant effect on the time synchronization error.
- If sensor nodes depend on **a specific master to synchronize** their clocks, a failure or anomaly of the master's clock may create a cascade effect that nodes in the network may become unsynchronized.
- So, a time synchronization protocol **has to handle the unexpected or periodic failures** of the sensor nodes.
- If **failures do occur**, the errors caused by these failures **should not be propagated** throughout the network.

WSN Time Synchronization

2. Energy aware :

- Since each node is battery limited, the use of resources should be evenly **spread and controlled.**
- A time synchronization protocol should use the **minimum number of messages** to synchronize
- In addition, the load for time synchronization should be **shared**, so some nodes in the network do not fail earlier than others.
- If some parts of the **network fail earlier than others**, the partitioned networks may **drift apart** from each other and become unsynchronized.

WSN Time Synchronization

3. Server-less:

- A precise **time server** may **not be available**.
- In addition, the **time servers may fail** when placed in the sensor field.
- As a result, sensor nodes should be able **to synchronize to a common time** without the precise time servers.
- When the precise time servers are available, **the quality of the synchronized clocks as well as the time to synchronize the clocks** of the network should be much better.
- This server-less feature also helps **to address the robustness** challenge as stated earlier.

WSN Time Synchronization

4. Light-weight:

- The **complexity has to be low** in order to be programmed into the sensor nodes.
- Besides being energy limited, SN are memory limited as well.
- The synchronization protocol may be programmed into (FPGA) or ASIC.
- By having **the time synchronization protocol tightly integrated with the hardware**, the delay and variation of the processing may be smaller.
- With the increase of precision, the **cost of a sensor node is higher.**

WSN Time Synchronization

5. Tunable Service:

- Some services, such as **Medium Access**, may require **time synchronization to be always ON** while others only need it when there is **an event.**
- Since time synchronization can consume a lot of energy, **a tunable time synchronization service is applicable for some applications**.
- Nevertheless, there are needs for both type of synchronization protocols.

WSN Time Synchronization

Time Synchronization Protocols
for
Sensor Networks:

WSN Time Synchronization

Time Synchronization Protocols for Sensor Networks:

1. Network Time Protocol (NTP) ,
   Timing-sync Protocol for Sensor Networks (TPSN)
1. Reference-Broadcast Synchronization (RBS)
2. Time-Diffusion Synchronization Protocol (TDP)

- **Time Sync Types**
  - Sender – Receiver synchronization
  - Receiver – Receiver synchronization

WSN Time Synchronization

1. Network Time Protocol (NTP)

- The NTP is used **to discipline the frequency of each node's oscillator**.
- The accuracy is in the **order of milliseconds.**
- The connection to the **Time Servers** may not be possible because of frequent sensor node failures.
- More problem due to
  - **Interference** from the environment
  - **Large variation of delay** between different parts of the sensor field.
- The interference **can temporarily disjoint the sensor field into multiple smaller** fields causing undisciplined clocks among these smaller fields.

WSN Time Synchronization

Network Time Protocol (NTP)

- NTP is very **computational intensive** and **Requires a precise time server** to synchronize the nodes in the network.
- In addition, it does **not take into account the energy consumption** required for time synchronization.
- The nodes are synchronized in a **hierarchical manner,**
- As a result, the NTP **does not satisfy** the energy aware, server-less, and light-weight design challenges of the sensor networks.
- Although the NTP can be robust, it may suffer large propagation delay when sending timing messages to the time servers.

WSN Time Synchronization

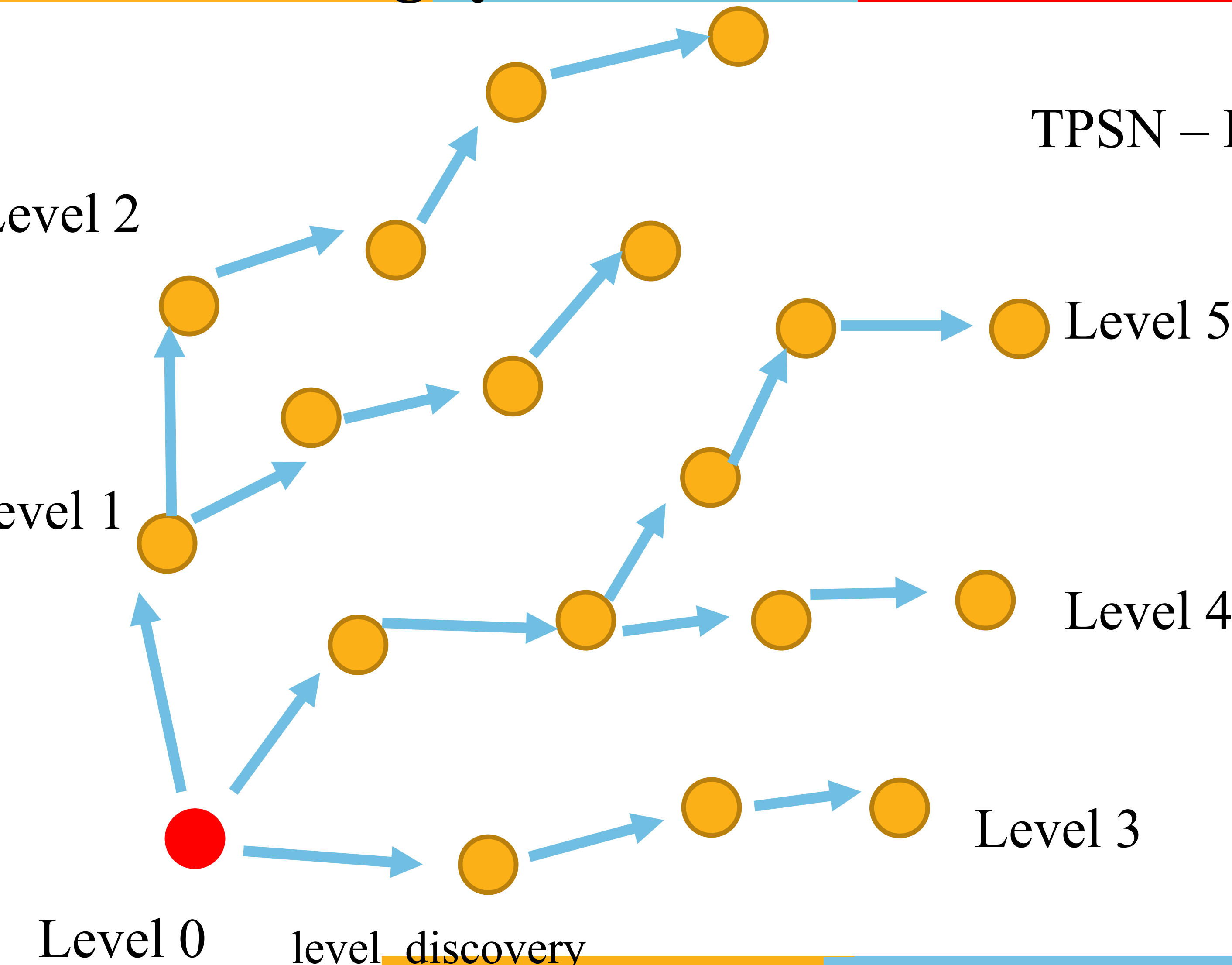
Timing-sync Protocol for Sensor Networks (TPSN)

- Level Discovery
- Sync

1. Adopts some concepts NTP
2. The TPSN requires the root node to synchronize all or part of the nodes in the sensor field.
3. The Root Node synchronizes the nodes in a hierarchical way.
4. Before synchronization, the root node constructs the hierarchy by broadcasting a **level discovery packet**. The first level of the hierarchy is level 0, which is where the root node resides.
5. This process continues until all the nodes in the sensor field has a **level number**.

Timing-sync Protocol for Sensor Networks (TPSN)

TPSN – Level discovery

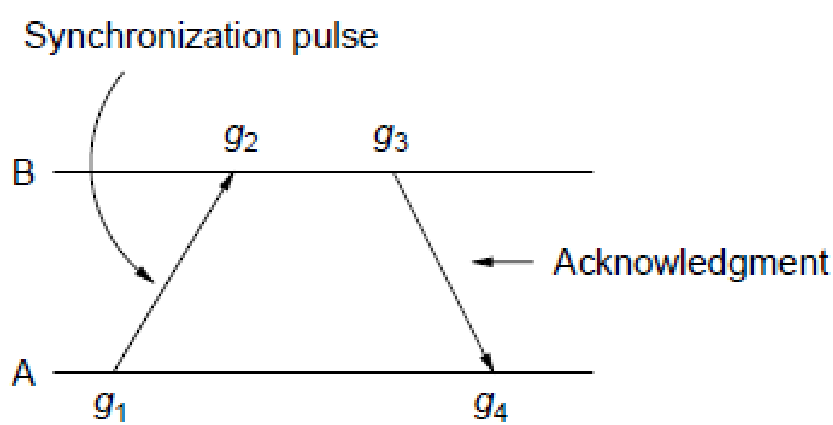


- Root node initiates – time sync
- Level 1 nodes – each wait for random time
  - Reduce probability of collision at MAC

WSN Time Synchronization

Timing-sync Protocol for Sensor Networks (TPSN)

- The root node sends a **time_sync packet** to initialize the time synchronization process.
- Two way handshake is used by the NTP to synchronize the clocks of distributed computer systems.
- The time *g2 and g3 are obtained from the clock of sensor node B while g1 and g4 are from the* ***node A.***



WSN Time Synchronization

- After processing the acknowledgment packet, the node A readjusts its clock by the **clock drift value** ,where
- **Delta t = ((g2 − g1)−(g4 − g3))/2.**

$$\text{Propagation delay } d = \frac{(g_2 - g_1) + (g_4 - g_3)}{2}$$

- At the same time, the **level 2 nodes overhear** this message handshake and wait for a random time before synchronizing with level 1 nodes.
- This synchronization process continues until all the nodes in the network are synchronized.

Timing-sync Protocol for Sensor Networks (TPSN)

Advantages :

- The TPSN is based on a **sender–receiver synchronization** model
- It is trying to provide **a light-weight and tunable time synchronization** service.

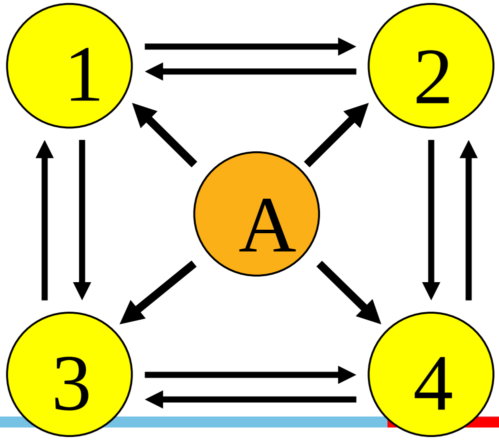
Disadvantage :

- On the other hand, it requires a **time server** and Does not address the robust and energy aware design goal has many Inaccuracies
- Since the design of TPSN is based on a **hierarchical methodology**
- 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

WSN Time Synchronization

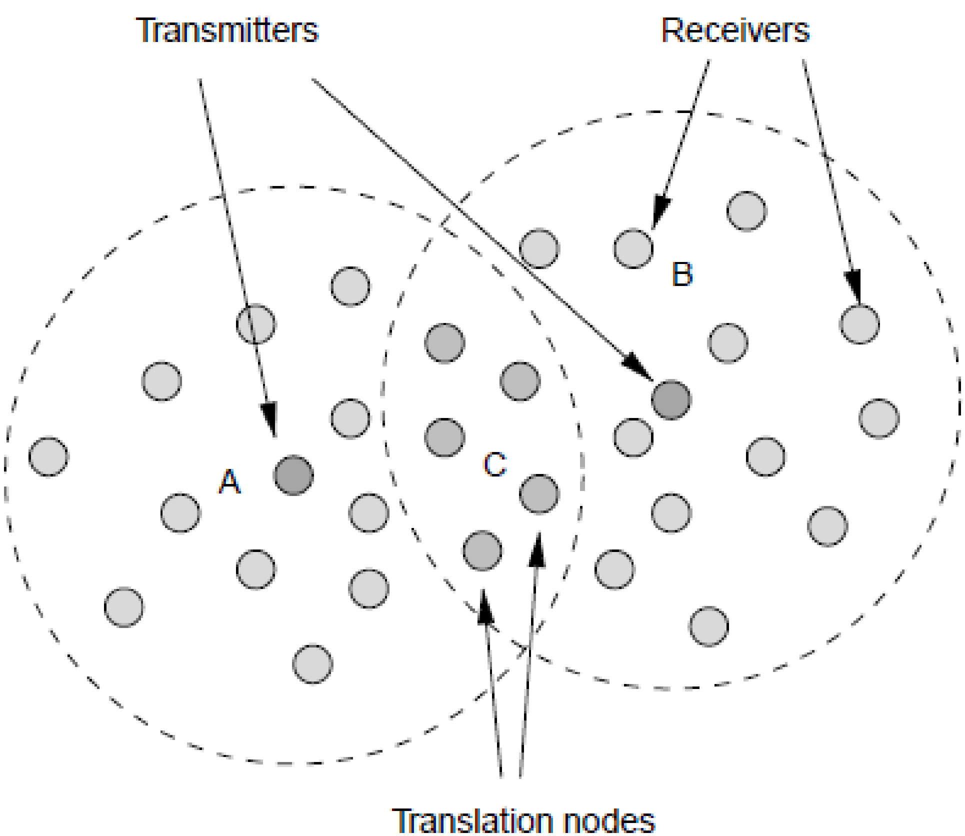
2. Reference /Receiver -Broadcast Synchronization (RBS):

- The RBS provides **an instantaneous time synchronization** among a set of receivers that are within the reference broadcast of the transmitter.
- The transmitter broadcasts **m reference packets**.
- Each of the receivers that are within the broadcast range **records the time-of-arrival of the reference packets.**
- Afterwards, the **receivers communicate with each other to determine the offsets.**



WSN Time Synchronization

2. Reference-Broadcast Synchronization (RBS):



- broadcasts **m reference packets**
- **records the time-of-arrival of the reference packets.**
- **receivers communicate with each other to determine the offsets.**
- **receiving two or more reference broadcasts** from different transmitters as translation nodes.

WSN Time Synchronization

2. Reference-Broadcast Synchronization (RBS):

- To provide multihop synchronization, it is proposed to use nodes that are **receiving two or more reference broadcasts** from different transmitters as translation nodes.
- These translation nodes are used to translate the time between different broadcast domains.

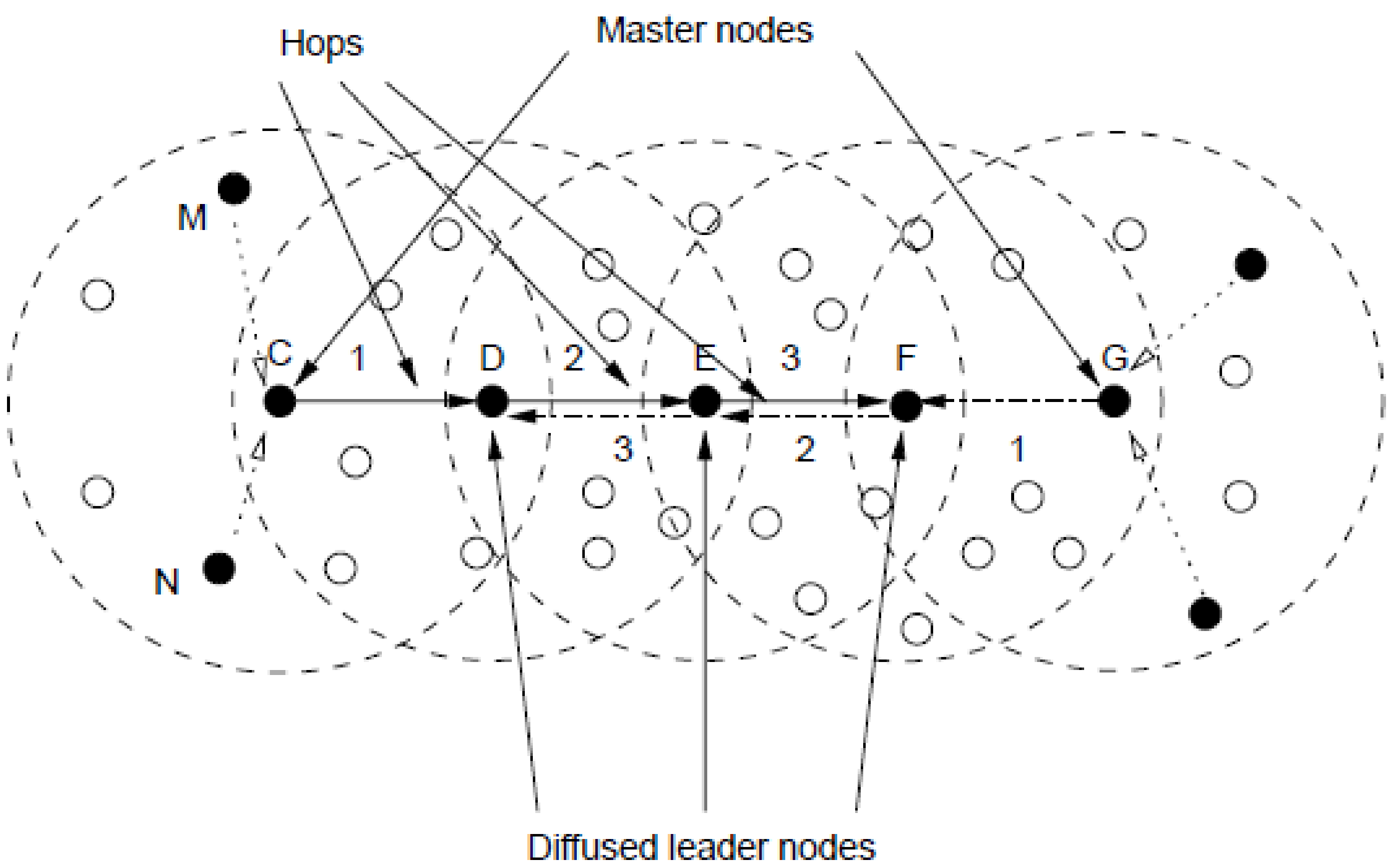
WSN Time Synchronization

2. Reference-Broadcast Synchronization (RBS)

- When an event occurs, a **message describing the event with a time stamp is translated** by the translation nodes when the message is routed back to the sink.
- RBS **tunable and light-weight**
- In addition, this protocol is not suitable for medium access scheme, such as TDMA, since the clocks of all the nodes in the network are not adjusted to a common time.

WSN Time Synchronization

3. Time-Diffusion Synchronization Protocol (TDP)



WSN Time Synchronization

3. Time-Diffusion Synchronization Protocol (TDP):

- The TDP is used to **maintain the time throughout** the network within a certain tolerance.
- The TDP **automatically self-configures** by electing master nodes to synchronize the sensor network.
- In addition, the election process is
  - sensitive to energy requirement
  - quality of the clocks.
- The sensor network may be deployed in unattended areas, and the TDP still synchronizes the unattended network to a common time.

WSN Time Synchronization

3. Time-Diffusion Synchronization Protocol (TDP):

- The master nodes are autonomously elected, so the network is robust to failures.
- Although some of the nodes may die, there are still other nodes in the network that can self-determine to become master nodes.
- This feature also enables the network to become server-less if necessary and to reach an equilibrium time.
- In addition, the master and diffusion leader nodes are **self-determined based on their own energy level.**
- Also, the TDP is light-weight, but it may **not be as tunable** as the RBS.

THANK YOU!!!!!