Pulse-Coupled Clocks

COURSE CODE:
Sensor Networks
700.460 (24S)

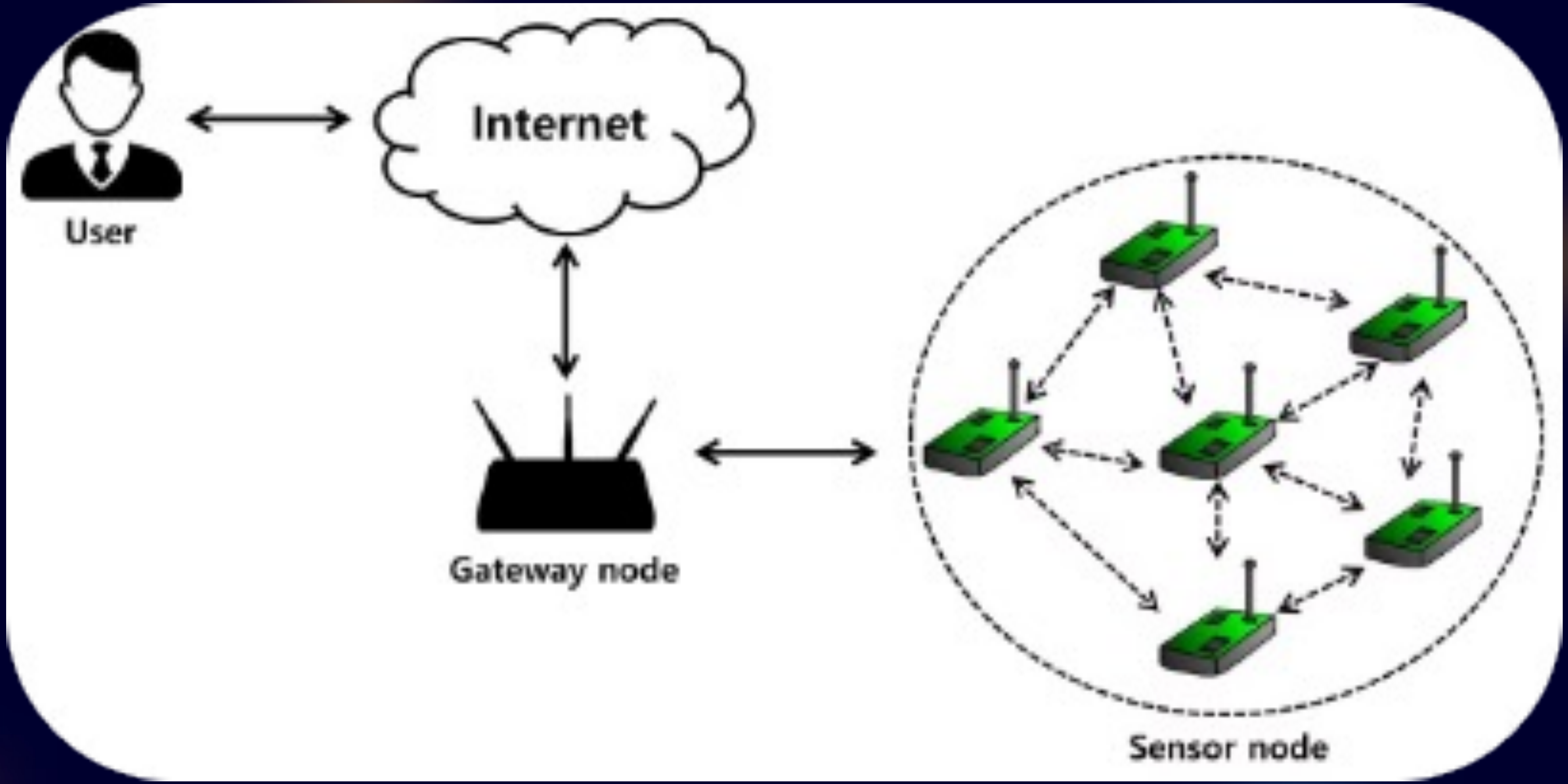
BY:

Muaadh Nasr

LECTURER :
Univ.-Prof. Bernhard Rinner

UNIVERSITÄT KLAGENFURT

Pulse-Coupled Clocks in Wireless Sensor Networks



Wireless sensor networks (WSNs) play a vital role in various applications, but their performance relies heavily on synchronized clocks across distributed nodes.

Challenges of Synchronization in WSNs

1. **Distributed nature:** Nodes are spread out, making central synchronization difficult.
2. **Energy efficiency:** Frequent communication for synchronization drains battery life.

Pulse-Coupled Clocks: A Decentralized Approach

1

Internal Clock

Each node has its own internal clock with an oscillator and accumulator.

2

Neighbor Interaction

Nodes interact with neighbors to achieve synchronization.

3

Distributed Networks

Distributed networks make central control difficult, requiring decentralized solutions.

Mathematical Model of Clock Behavior

1 Integrate-and-Fire Oscillators

- Internal timer with an oscillator (generates pulses) and accumulator (tracks time).
- Each node in the network has a state variable denoted as xi(t)x_i(t)xi(t) .

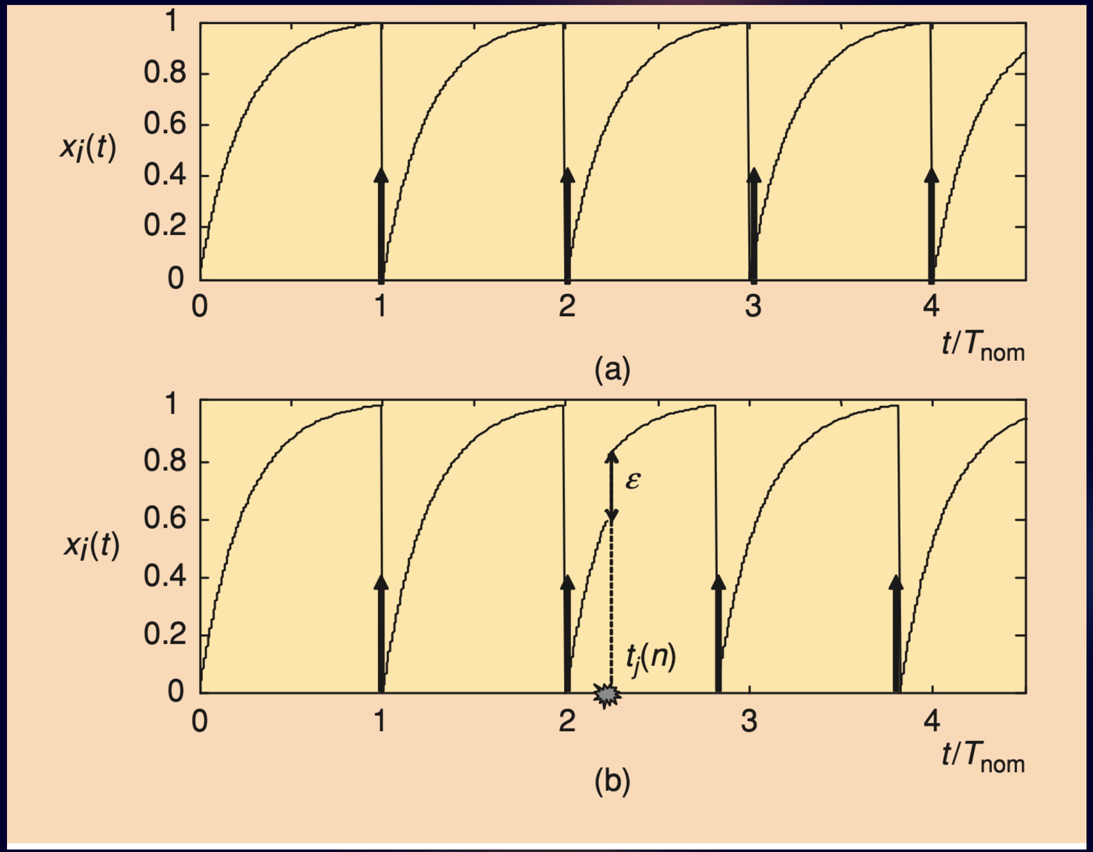


Figure: figure shows the state function xi(t)x_i(t)xi(t) for isolated clocks and in the presence of a received pulse.

Mathematical Model of Clock Behavior

2 Pulse-Coupled Discrete-Time PLLs

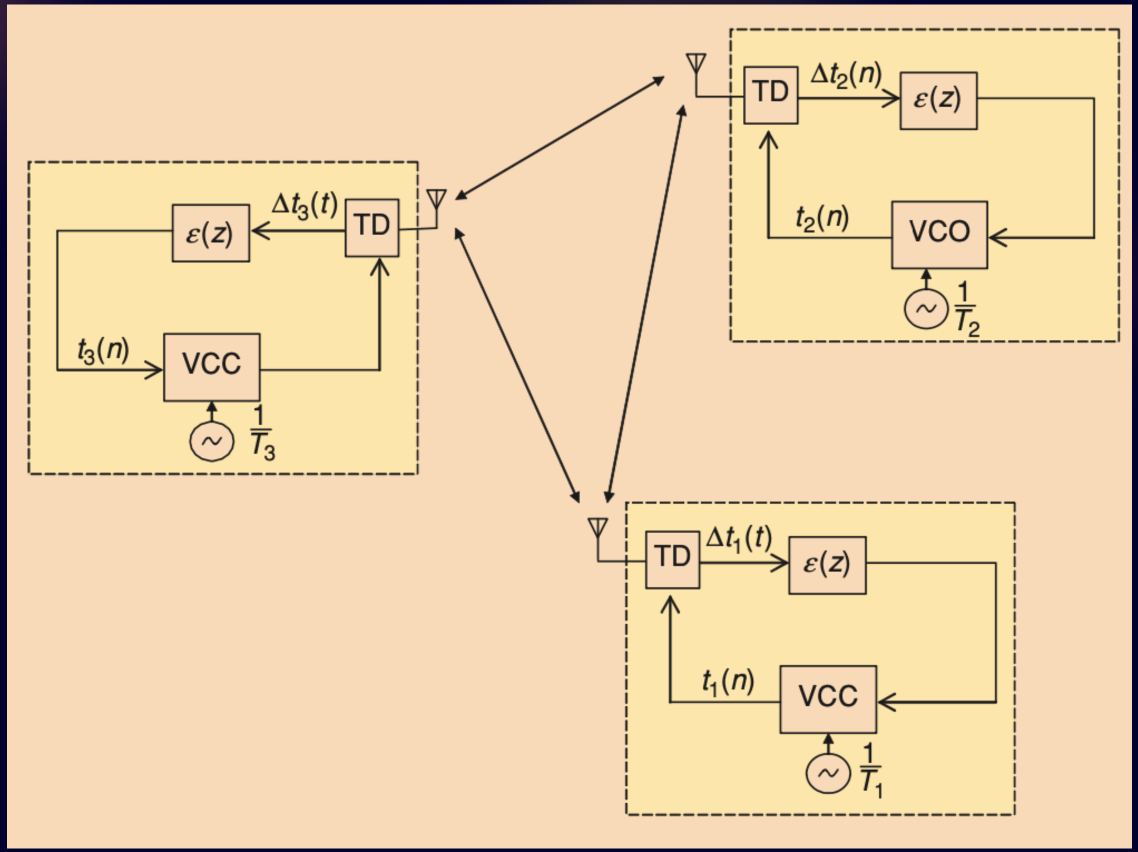
- Equations represent clock behavior and how nodes connect.
- Nodes use a time difference detector to measure the time differences with their neighbors.

$$\Delta t_i(n) = \sum_{j=1, i \neq j}^{N} \alpha_{ij} \cdot (t_j(n) - t_i(n)), \qquad (15)$$

that is fed to a loop filter $\varepsilon(z)$. Considering for simplicity loop filters $\varepsilon(z) = \varepsilon_0$ (first-order PLLs), we have

$$t_i(n+1) = t_i(n) + T_i + \varepsilon_0 \cdot \sum_{j=1, i \neq j}^{N} \alpha_{ij} \cdot (t_j(n) - t_i(n)).$$

The mathematical expressions governing this model



This figure illustrates the system of pulse-coupled discrete-time PLLs

Pulse-Coupling Strategy for Synchronization

1

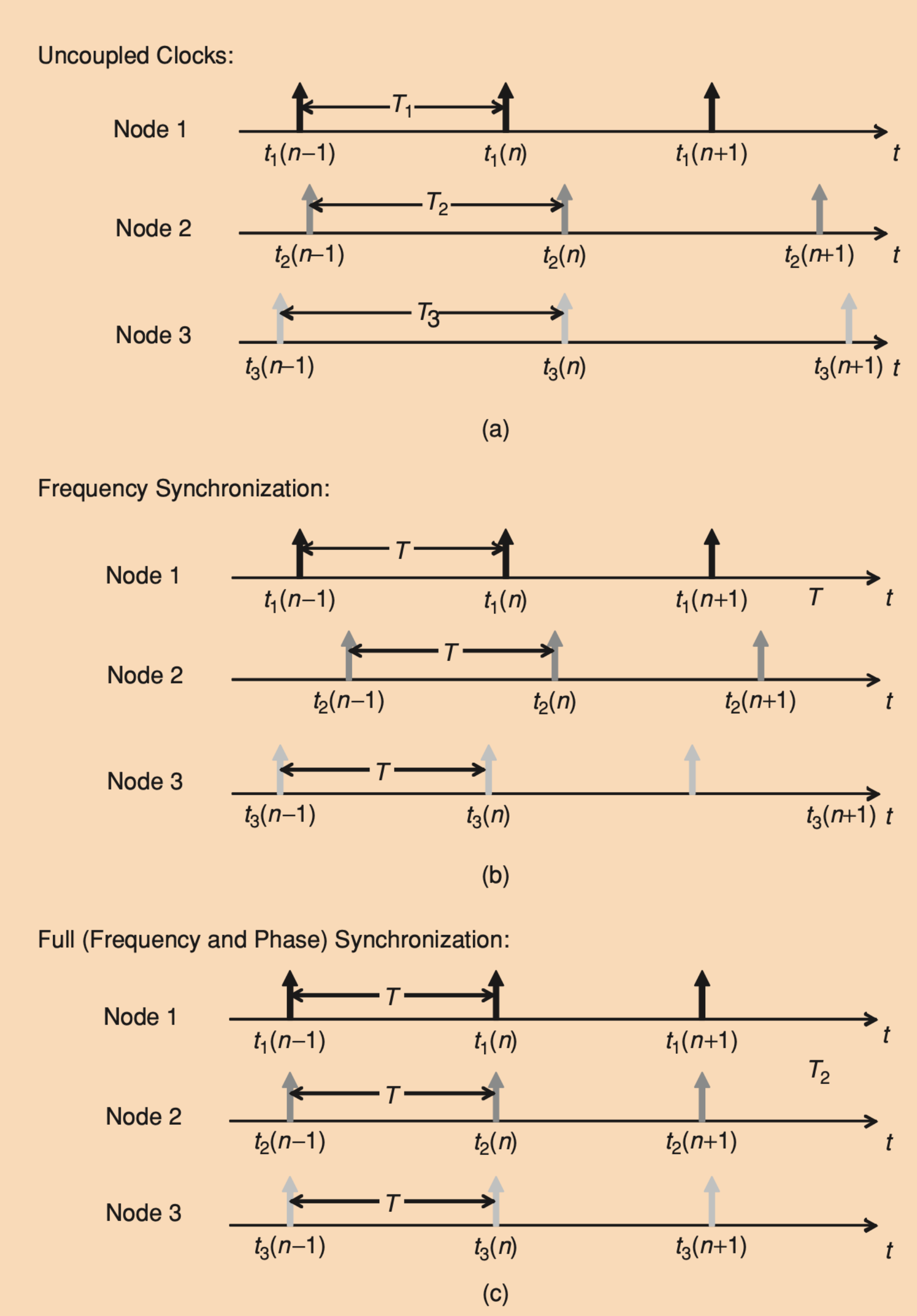
Pulse-Coupling Strategy *(Integrate-and-Fire)*

Nodes exchange synchronization pulses with their neighbors.

2

Time Offset Calculation (*Discrete-Time*)

Nodes calculate the time difference between their clocks and those of their neighbors.



The Coupling Mechanism

Waveform Transmission

Nodes transmit waveforms that carry timing information used for clock adjustments.

Combining Time Differences

Nodes compute a weighted average of the time differences with their neighbors.

Loop Filter

A loop filter processes the time difference information received from neighbors.

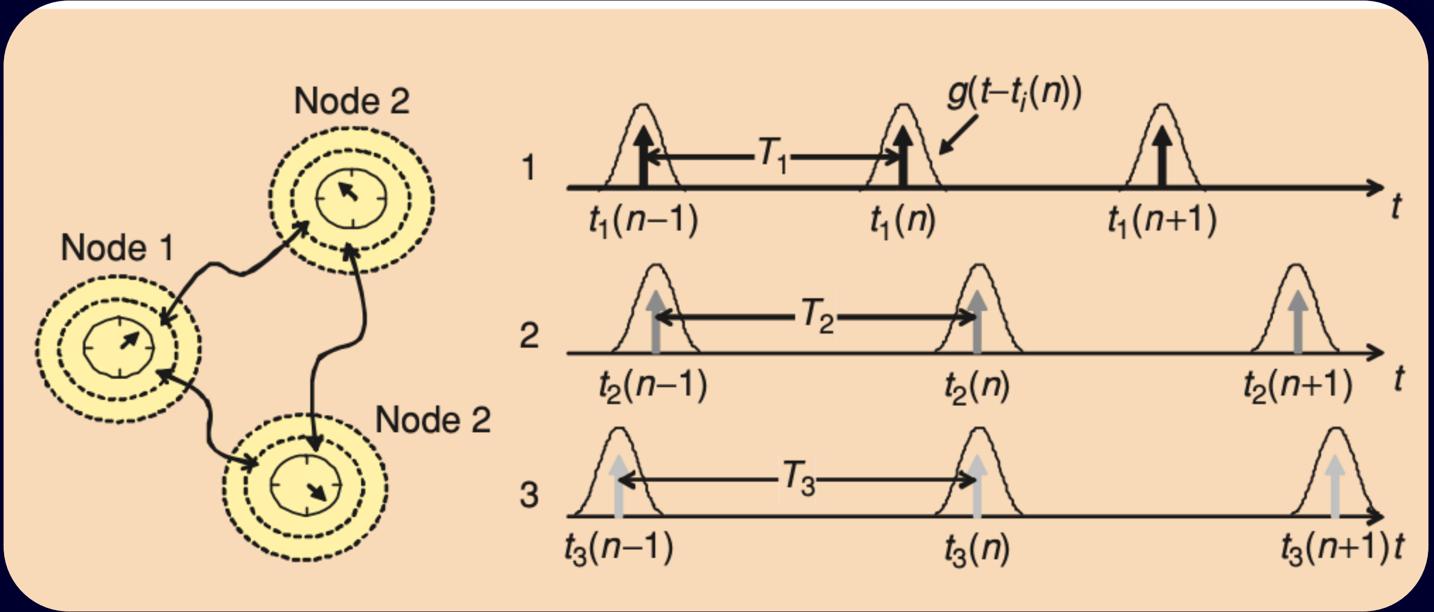


figure shows waveform transmission for clock adjustment.

Advantages of Pulse-Coupled Clocks

1 **Energy Efficiency**

Reduced communication leads to significant energy savings.

2 **High Accuracy**

Can achieve millisecond to microsecond precision.

3 **Scalability**

Efficient synchronization in large networks.

Challenges and Considerations

Half-Duplex Radios

Efficient switching between transmit and receive modes.

Waveform Selection

Choosing the right signal format for accuracy and bandwidth.

Scalability & Robustness

Protocols must handle growing networks and changes.

Conclusion

In conclusion, pulse-coupled clocks provide a sophisticated approach to synchronization in WSNs. By leveraging mathematical models, synchronization mechanisms, and coupling strategies, they enable precise alignment of decentralized clocks.

References

Simeone, O. (2008, September). Stabilized Clocks for Wireless Sensor Networks. In 2008 42nd Conference on Decision and Control (CDC) (pp. 5576-5581). IEEE [Institute of Electrical and Electronics Engineers]. https://pervasive.aau.at/BR/teaching/sn/Simeone_SPM2008.pdf2.

Zong, Y., Dai, X., Gao, Z., Binns, R., & Busawon, K. (2018). Simulation and evaluation of pulse-coupled oscillators in wireless sensor networks. Systems Science & Control Engineering, 6(1), 337–349. https://doi.org/10.1080/21642583.2018.1496043.