

( 700.460 )

# Pulse - Coupled Clocks

Sensor Networks

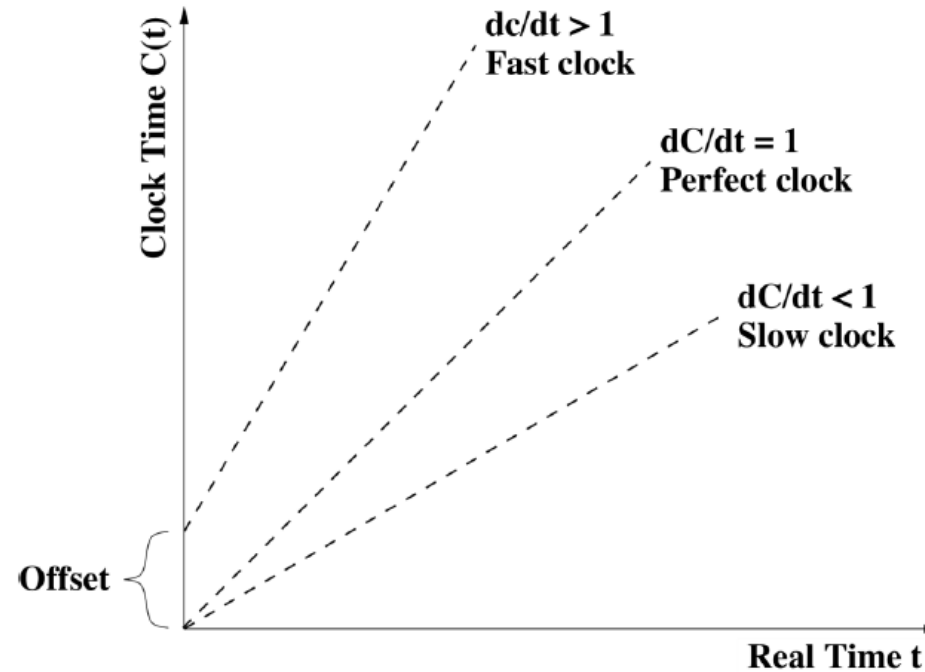
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# What Is Synchronization?

- Clocks
- Coupling
- Drift & offset



# Synchronization Process

## Packet Coupling

- Time stamps
- PtP or Broadcast
- Two – way message exchange
- RBS, LTS...
- Delays

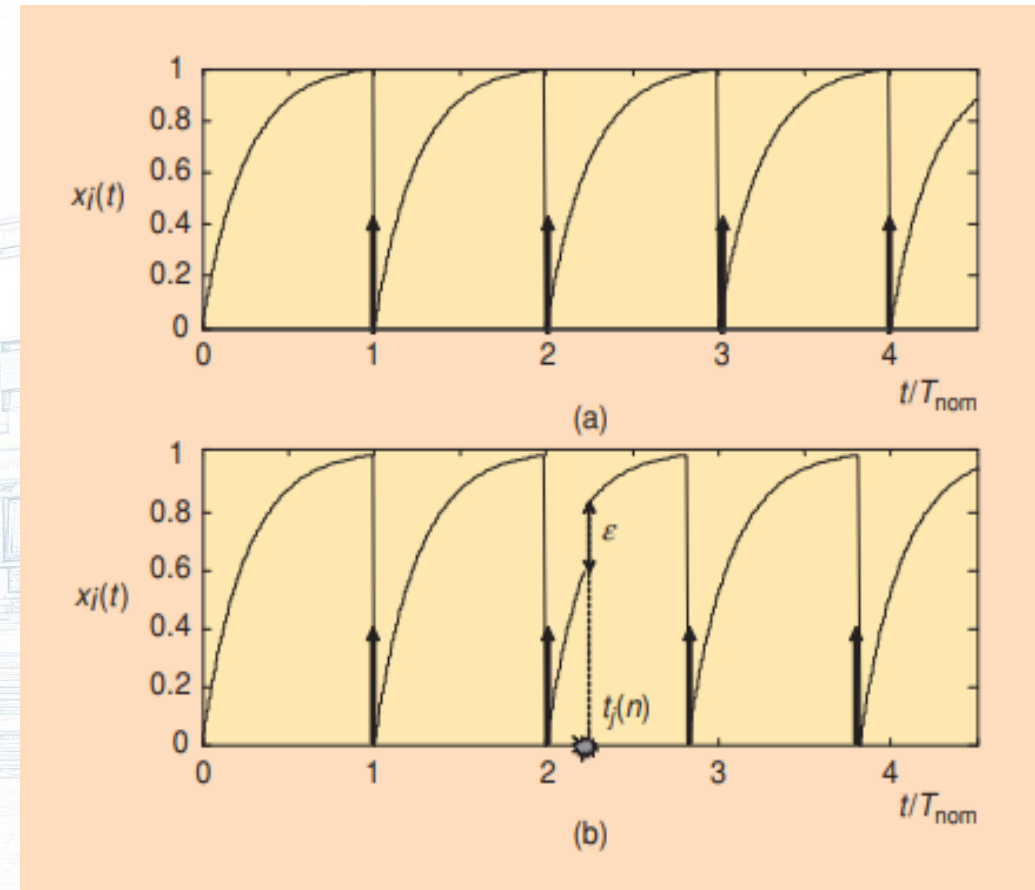
## Pulse Coupling

- Physical layer – based
- Train of Waveforms
- Time – of – arrival estimators
- Scalable

# Pulse – Coupling Approaches

Integrate – and – fire oscillators

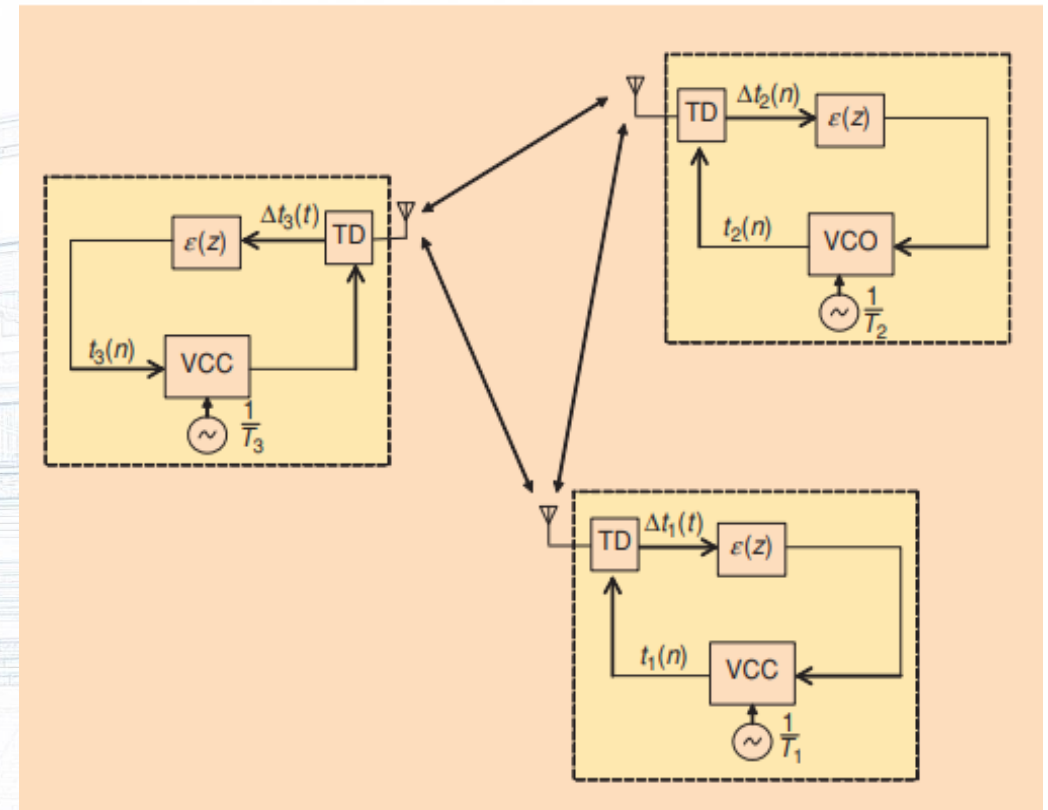
- $x_i(t) = g(\varphi_i(t))$
- Monotonic growth
- Period =  $2\pi$ ; boundaries  $\{0;1\}$
- Phase adjustment
- Practical issues
- Lack of flexibility



# Pulse – Coupling Approaches (cont'd)

## Distributed discrete time Phase Locked Loops (PLLs)

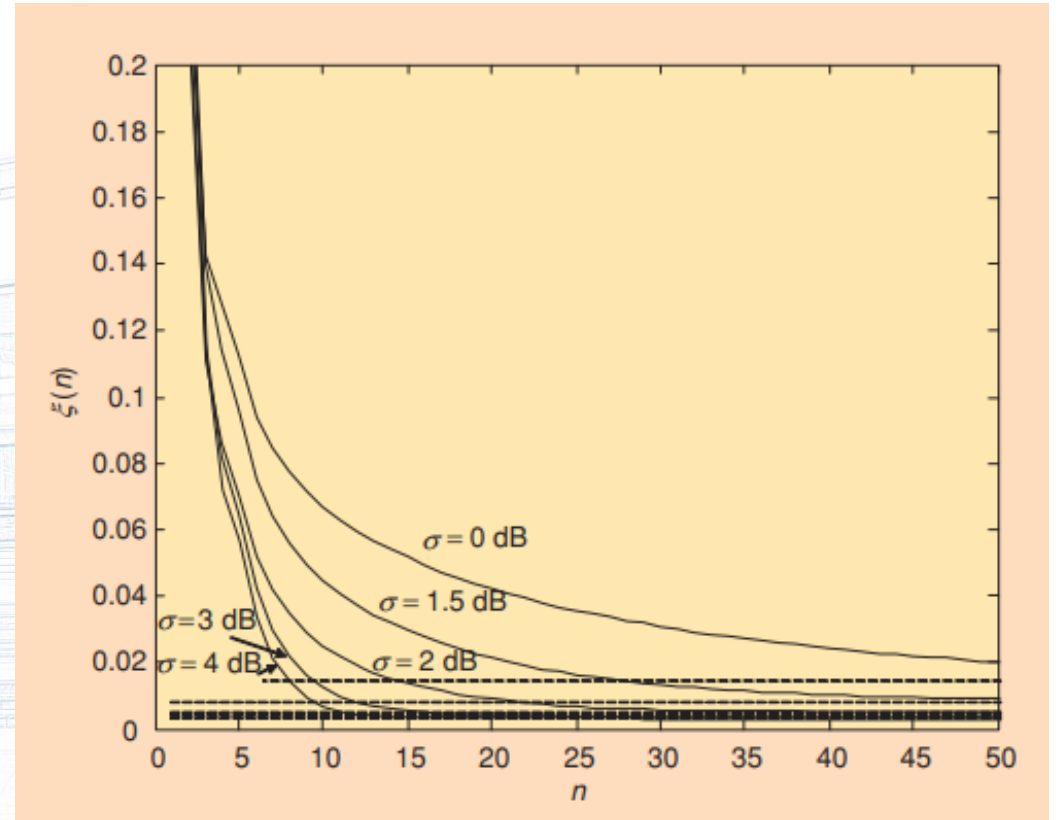
- Flexibility
- Time difference detector (TD)
- Exchange between neighboring nodes
- Pole in LF  $\rightarrow$  less mismatch phases
- LF brings stability
- LF increases computational complexity



# Further Analysis

Impact of topology and small-word effects

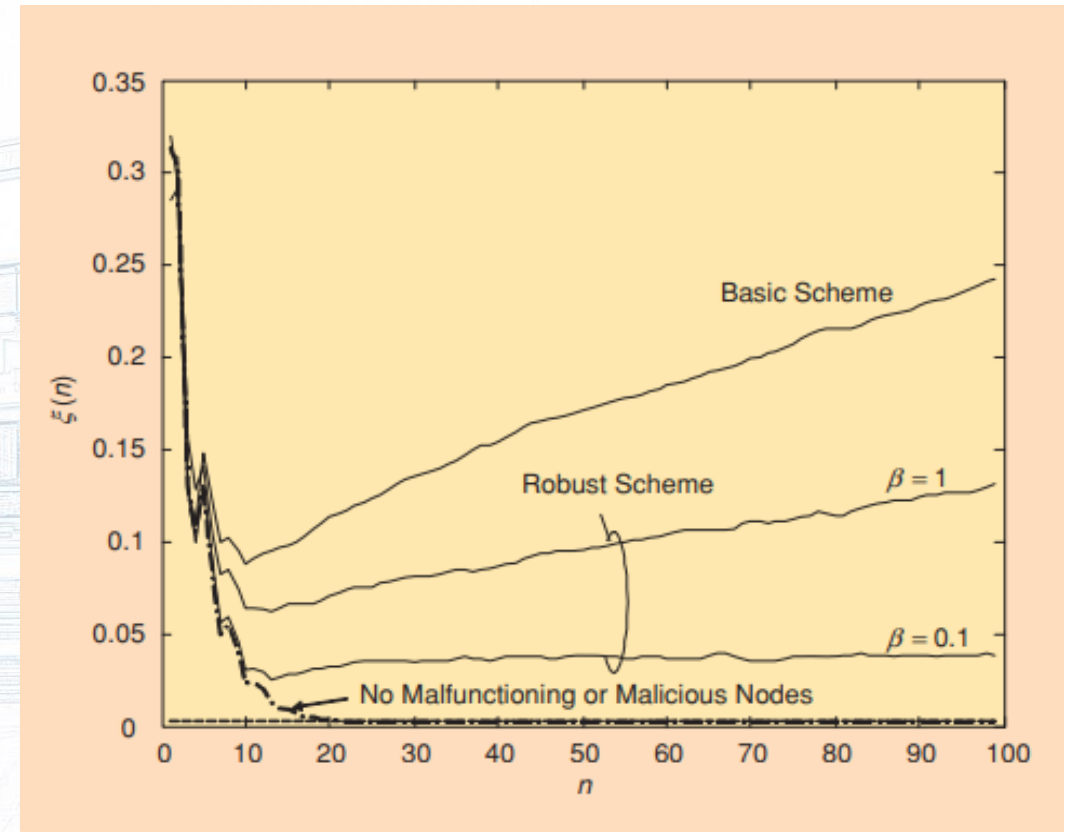
- Amount of shadowing
- Existence of paths with small number of edges between any two nodes
- Close connections
- Long links



# Further Analysis

## Fault tolerance and security

- Resilience of distributed synchronization
- Clock errors
- Outliers
- Synchronization within a limited timing error



# Applications

Distributed consensus for multiagent coordination and distributed estimation/detection in Wireless Sensor Networks

- Achieving consensus on given quantity
- Monitoring, tracking, localization



# Conclusion

- Different approaches
- Packet-coupling vs Pulse-coupling
- Synergy between distributed synchronization and distributed estimation/detection problems

# References

- Osvaldo Simeone, Umberto Spagnolini, Yeheskel Bar-Ness, and Steven H. Strogatz. Distributed Synchronization in Wireless Networks, IEEE SIGNAL PROCESSING MAGAZINE, 2008
- Bernhard Rinner. Lecture Sensor Networks (Chapter 6), 2022.