Continuously Coupled Clocks

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Contents

A clock is…

- A clock is a measurement device consisting of an oscillator and an accumulator.

- Synchronization of local clocks enables a wealth of signal processing and communication applications in wireless networks.

- The goal of a coupling mechanism among the clocks is to drive the latter to synchronicity, possibly within a given tolerance.

Analog Clocks

Oscillator

$$Si(t) = cos\emptyset i(t)$$

Accumulator

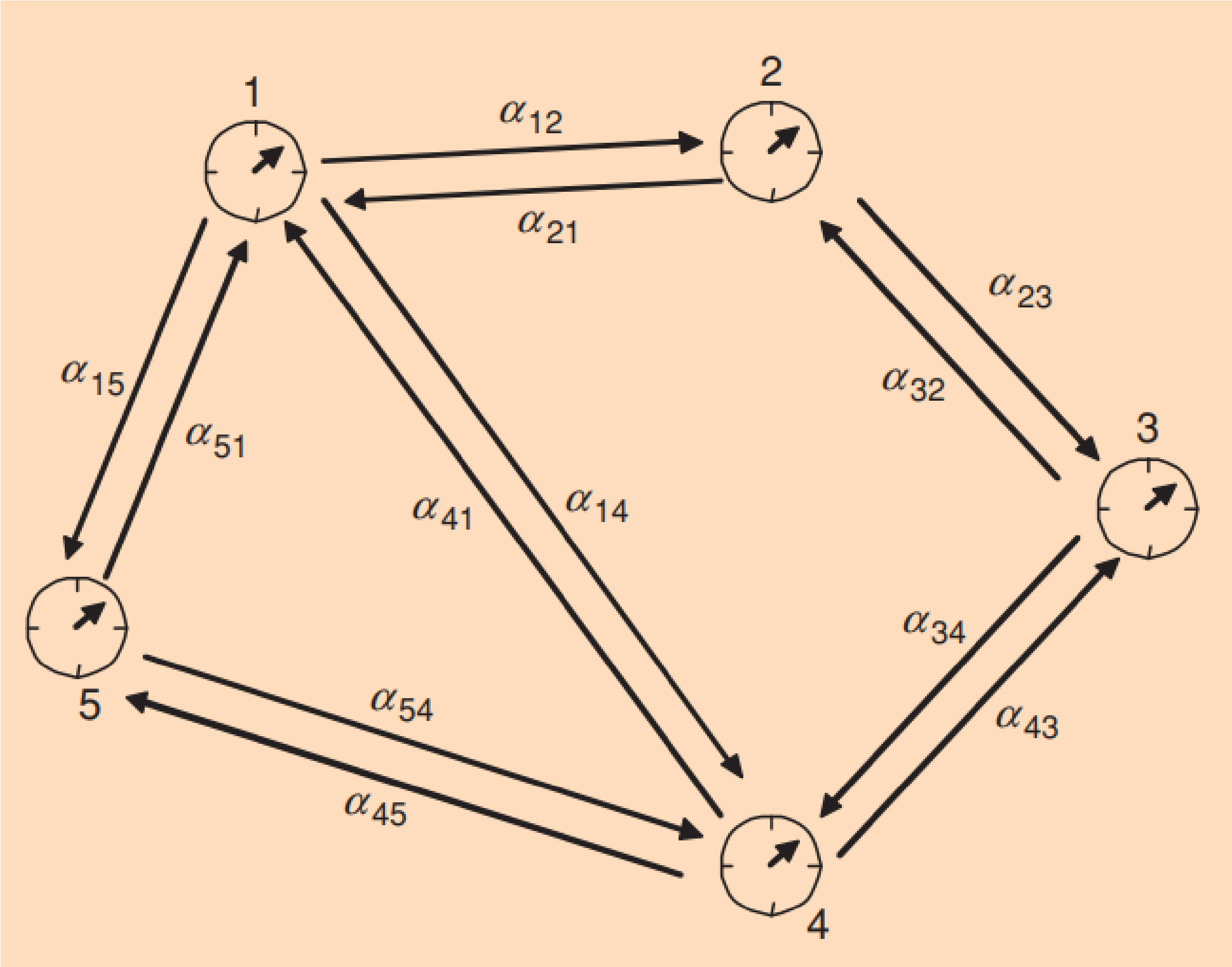
$$\emptyset i(t) = \ \emptyset i(0) + \frac{2\pi}{Ti}\ t + \delta(t)$$

Where:

- (i) is the free-running oscillation period reads Ti = Tnom + Ti,
- with Tnom being the nominal period
- Ti a random offset from the nominal value
- ζ(t) is a typically nonstationary random process modelling phase noise

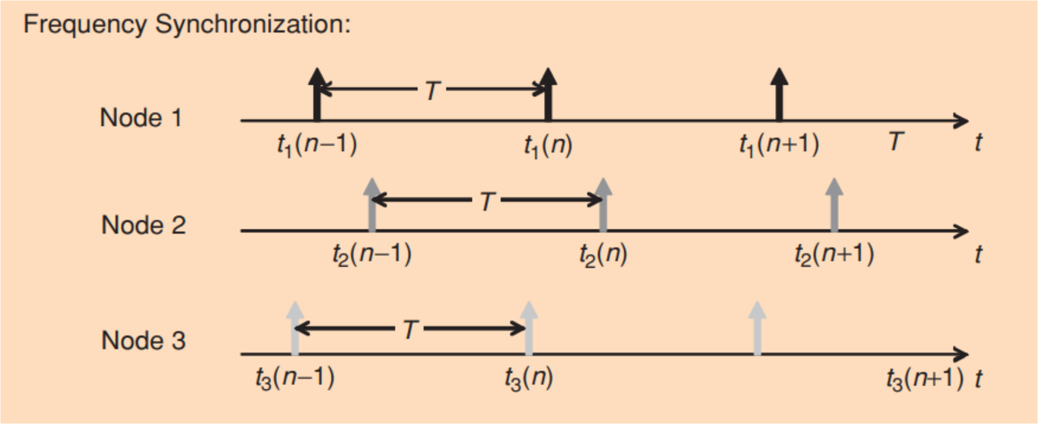
CONNECTIVITY GRAPH

$$\propto ij = \frac{P\ ij}{\sum P\ ij}$$

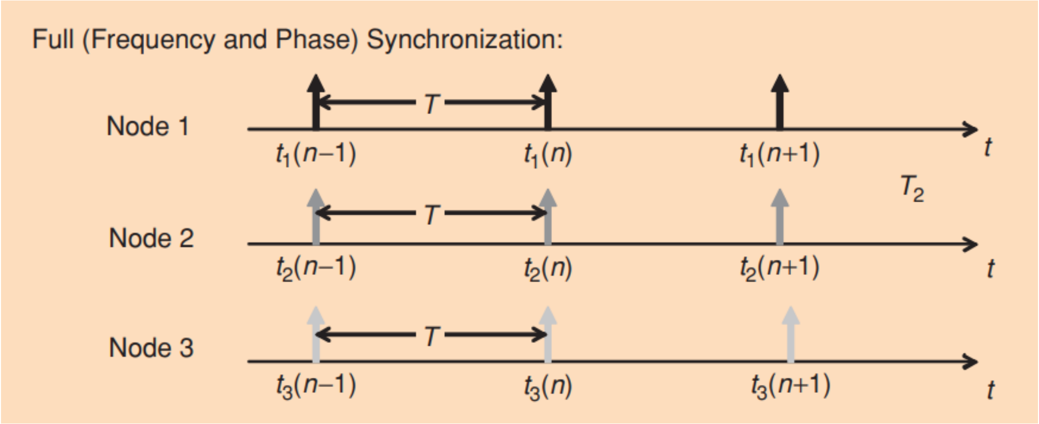


Synchronization Conditions of Interest

FREQUENCY SYNCHRONIZATION



FULL SYNCHRONIZATION



Continuously coupled analog clocks

- The first studied model of distributed synchronization.
- Studied problem: distributed synchronization of coupled analog clocks.

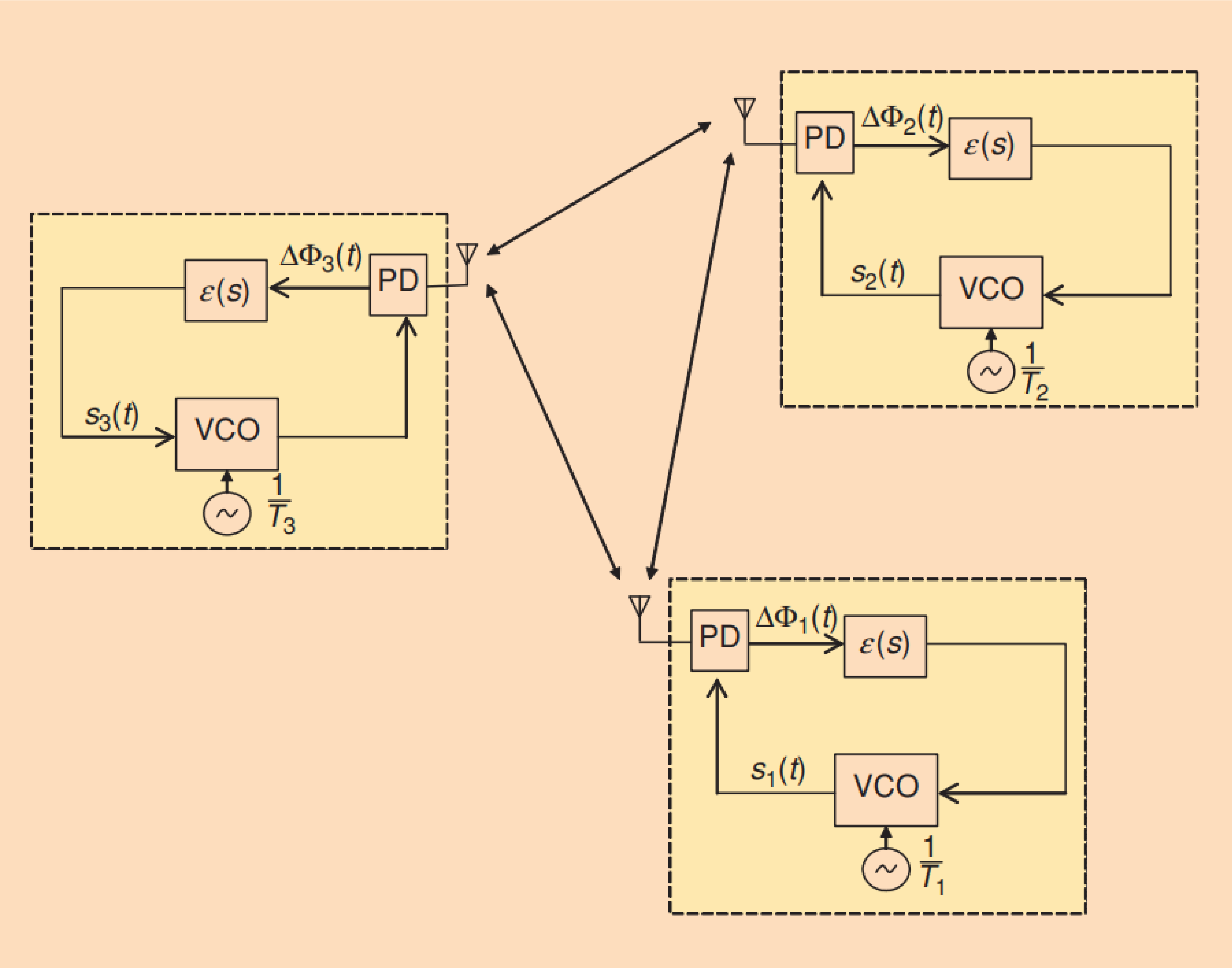
Applications on which the solved problem can help:

- ✓ cooperative beamforming.
- ✓ frequency division multiple access in ad hoc networks.

Block Diagram of Continuously Coupled Oscillators

PD: phase detector

VCO: voltage controlled oscillator



Phase Locking Mechanism

1. each node transmits a signal proportional to its local and updates the instantaneous phase.
2. Each node, measures through its phase detector (PD) the convex combination of phase differences.

$$\Delta\, \emptyset i(t) = \sum \propto ij \,.\, f(\, \emptyset j(t) - \, \emptyset i(t))$$

1. Finally, the difference is fed to a loop filter ε(s), whose output drives the voltage controlled oscillator (VCO) and updates the local phase.

Kuramoto’s Model

- The first model of coupled analog oscillators

- The basic model corresponds to:

1. the general system with a sinusoidal phase detector $f(x) = \sin(x)$
2. all-to-all connectivity
3. a simple loop filter

Kuramoto’s Model

The model is not easily applicable to wireless networks, for two main reasons:

1. The assumption of continuous coupling among the clocks, which requires full-duplex transceivers.
2. The assumption on all-to-all (mesh) connectivity.

References

- O. Simeone, U. Spagnolini, Y. Bar-Ness and S. H. Strogatz, "Distributed synchronization in wireless networks," in IEEE Signal Processing Magazine, vol. 25, no. 5, pp. 81-97, September 2008, doi: 10.1109/MSP.2008.926661.