Results: Time-Invariant Single Path Channels

Assumptions and Simulation Parameters:

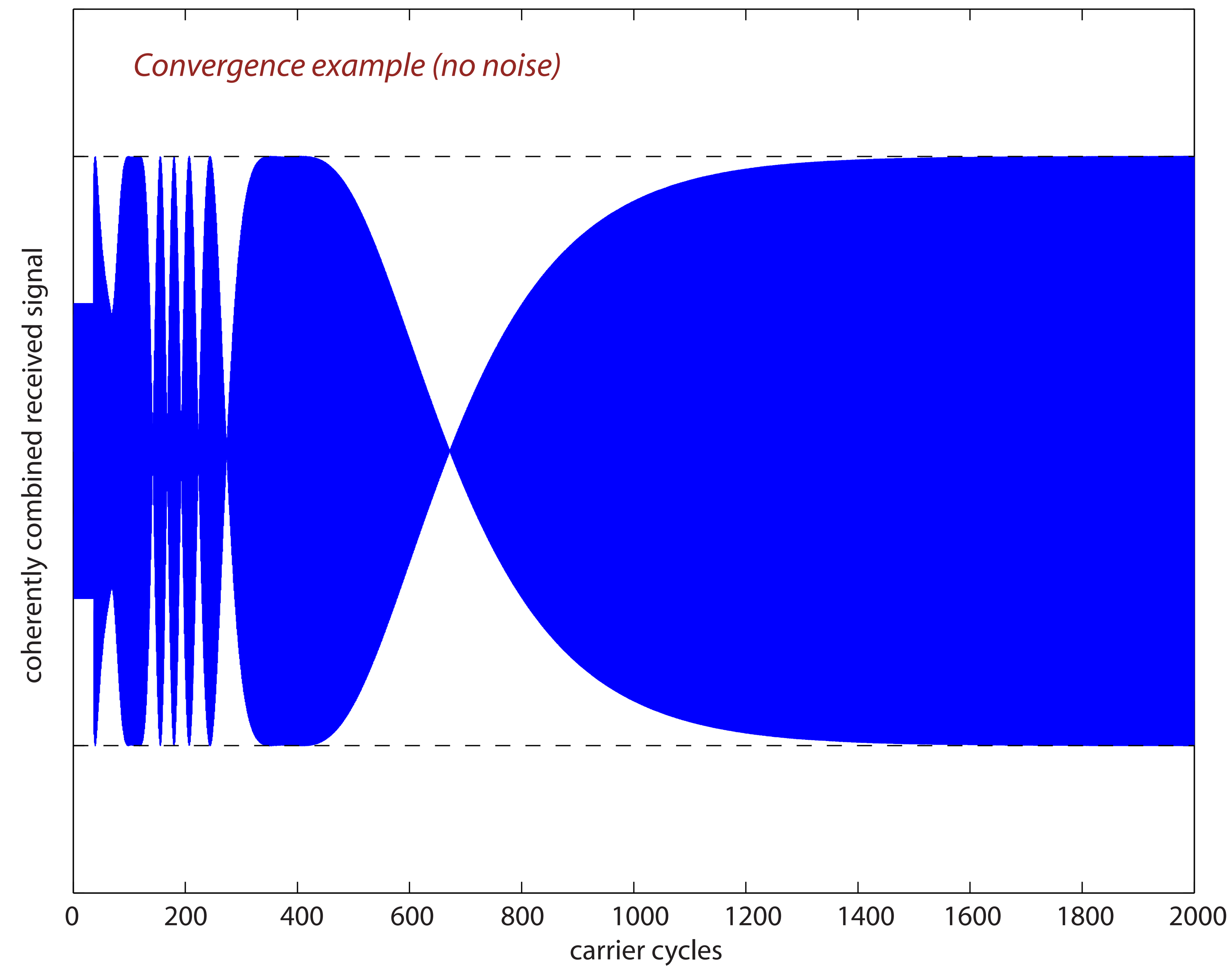
- Single-path, unit-gain channels $g_{ij} = g_{ji} = \delta(t - \tau_{ij})$.
- Randomly generated time-invariant channel propagation delays.
- Randomly generated initial VCO phases.
- Primary beacon frequency $\omega_0 = 2\pi\, 800 \cdot 10^6$ rad/sec.
- Unmodulated unit-amplitude carriers at $\omega_c = 2\pi\, 3.2 \cdot 10^9$ rad/sec.

FS-PLL parameters:

- Three-state phase-frequency detectors with slope $K_d = 1$ V/rad.
- VCO sensitivity $K_0 = 2\pi \cdot 10^5$ rad/s·V.
- FS-PLL dividers set to $M_1 = M_2 = 1$ and $N_1 = N_2 = 2$.
- Analog loop filter transfer function

$$F(s) \;=\; \frac{RC_2 s + 1}{RC_1 C_2 s^2 + C_2 s}.$$

Each loop filter's bandwidth is set to 10 MHz to facilitate rapid convergence to locked state.



Results: Time-Varying Single Path Channels

Assumptions and Simulation Parameters:

- Single-path, unit-gain channels $g_{ij} = g_{ji} = \delta(t - \tau_{ij}(t))$.
- Piecewise-constant source/destination acceleration model (0.5 second intervals, uniformly distributed on [-10,10] m/s^2).
- Randomly initialized time-varying propagation delays.

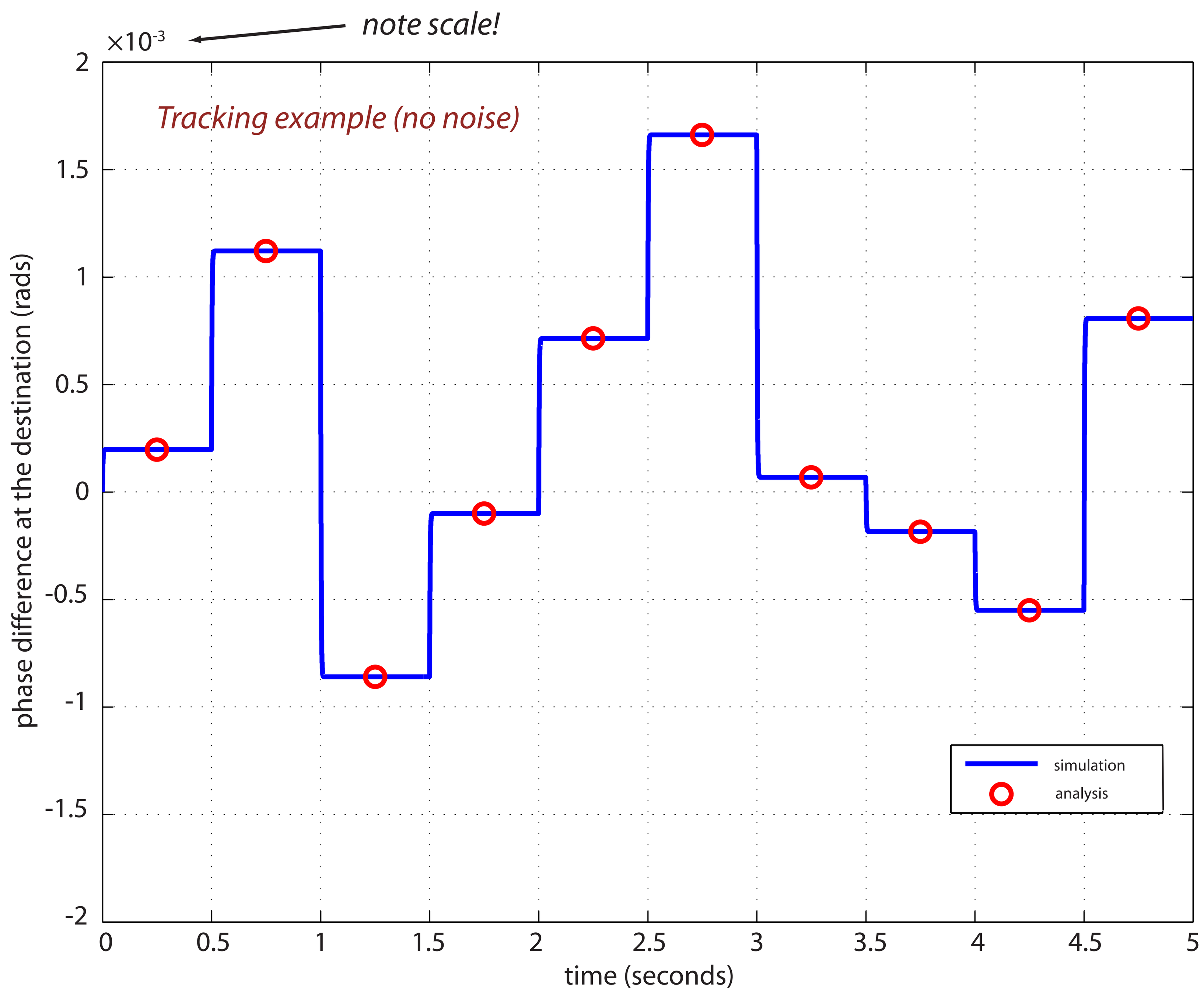
FS-PLL parameters:

- All same as before except 500 Hz PLL loop filter bandwidth.

Each PLL must track a linear frequency ramp. Tracking errors will result in phase offset at the destination. Analysis of PLL steady-state phase error shows that the phase offset at destination is

$$\phi_\Delta \;=\; (N_1\kappa_1 + N_2\kappa_2)(\alpha_{01} - \alpha_{02})\frac{\omega_c}{c}$$

where κ_i is inversely proportional to the square of the closed loop bandwidth of the PLLs and α_{0i} is the constant acceleration in the path between source i and the destination. The analysis assumes that the PLL remains in the locked state.



Results: Time-Varying Multipath Channels

To understand how the synchronization performance degrades from single-path to general multipath, we consider a Ricean channel model with Rice factor K. The phase of the Ricean channel can be written as

$$\theta \;=\; \theta_{LOS} + \Theta. \quad \leftarrow \text{Random component}$$

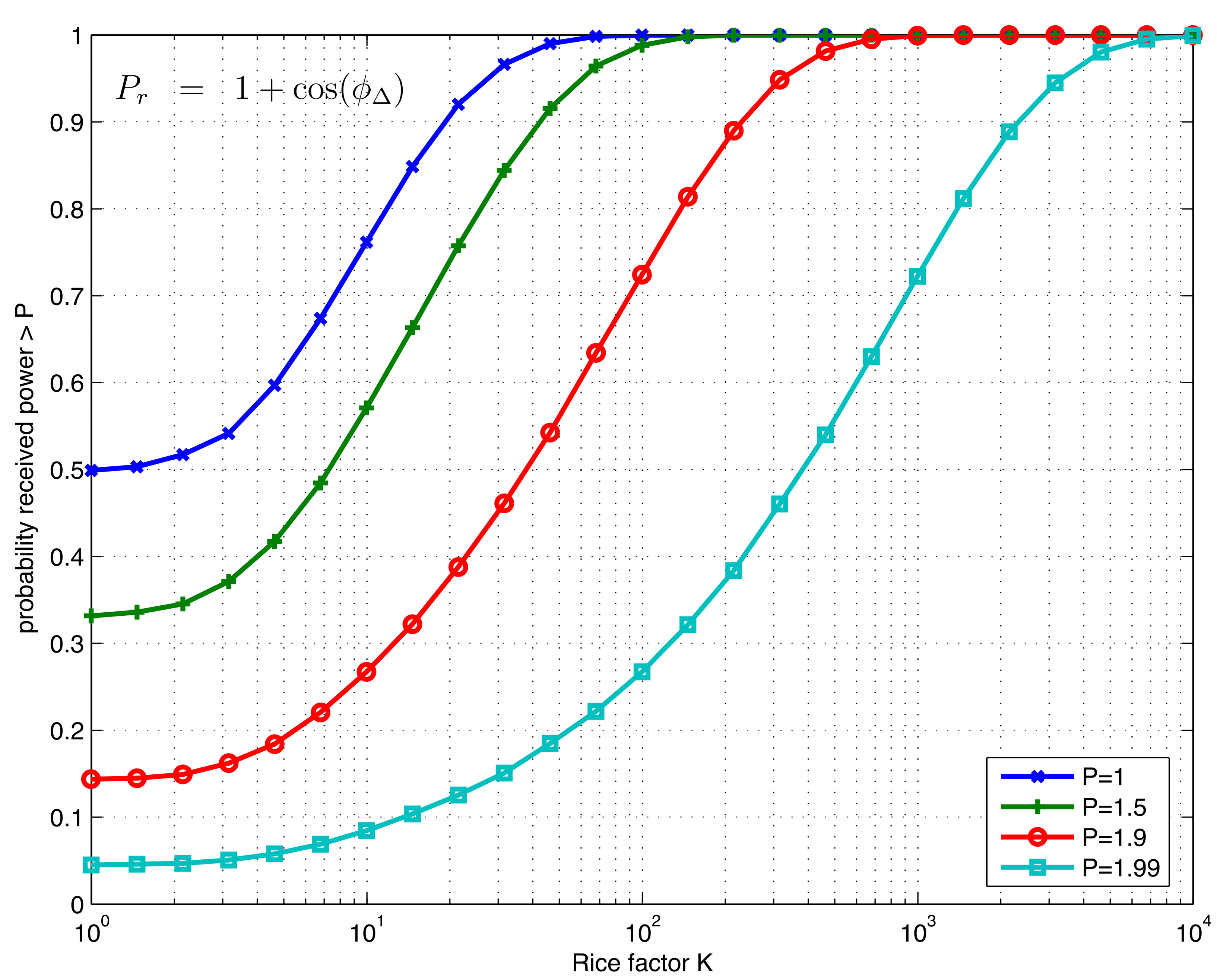
The random carrier phase offset at the destination can be written as

$$\phi_\Delta \;=\; \frac{N_1 N_2}{M_1 M_2}\Theta_{01} - \Theta_{10} + \frac{N_1 N_2}{M_1 M_2}\Theta_{02} - \Theta_{20}$$

where Θ_{0i} is the phase perturbation at ω_0 and Θ_{i0} is the phase perturbation at ω_c. Distribution for Θ given in the paper.

Assumptions and Simulation Parameters:

- Unit-gain Ricean channels (to isolate the effect of phase offsets).
- Each channel's has the same Rice factor K.
- Line-of-sight component is identical in both directions.
- Time-variations of the channel are sufficiently slow such that any PLL phase tracking error is negligible.



Conclusions:

» Explicit method proposed for two-source carrier phase and frequency synchronization.

» Evaluated in three channel models.

» Method allows for high levels of source/destination mobility.

» Explicit description of performance degradation to general multipath channels.

» Paper provides more details and discusses practical considerations.

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