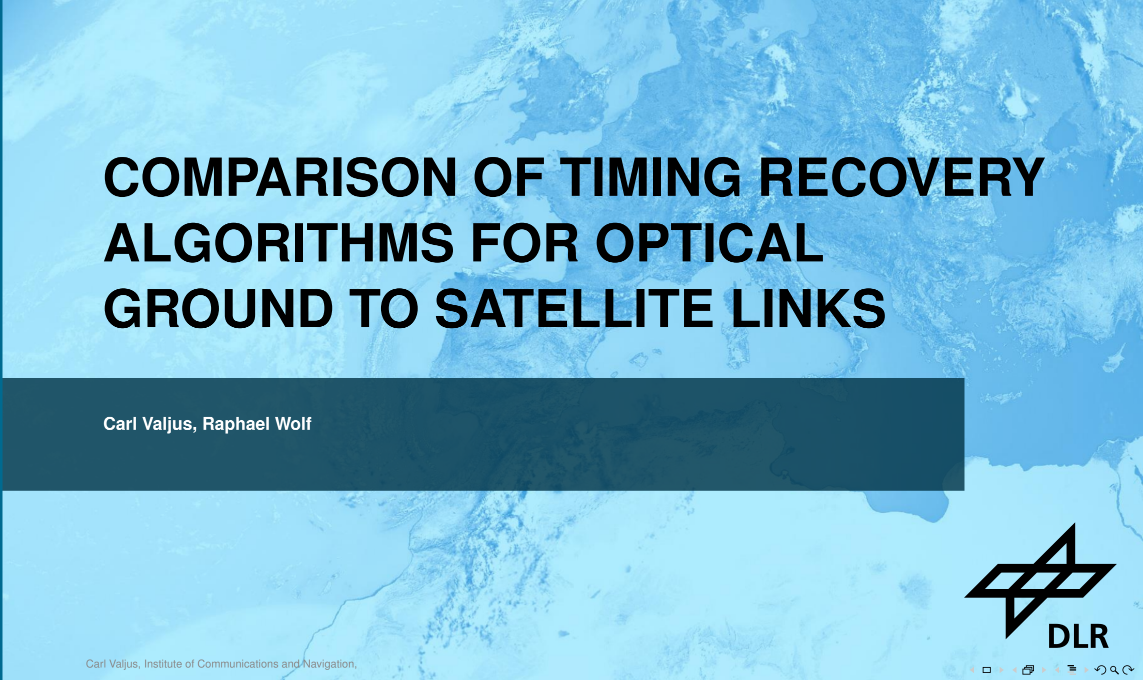


COMPARISON OF TIMING RECOVERY ALGORITHMS FOR OPTICAL GROUND TO SATELLITE LINKS

Carl Valjus, Raphael Wolf

Agenda

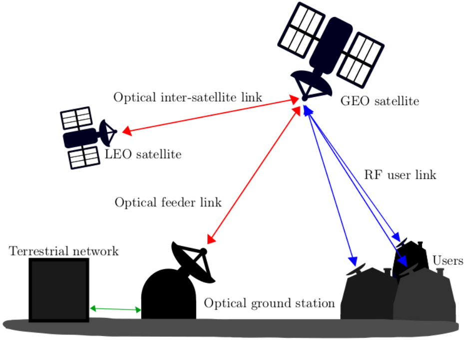
- Introduction
- Challenges
- Common Methods
- Simulation Results
- Summary

Coherent Free-space Optical Communication

- Atmospheric turbulence
- Beam wander
- High-data rate (Towards 100Gb/s)
    - Have to process many samples in parallel (~32-256)
    - Have to keep algorithms at low complexity
- Space-environment

Question:

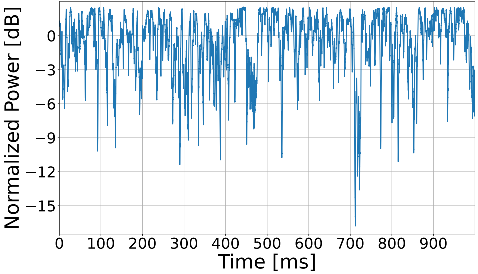
What impact does the dynamic channel have on timing recovery algorithms?



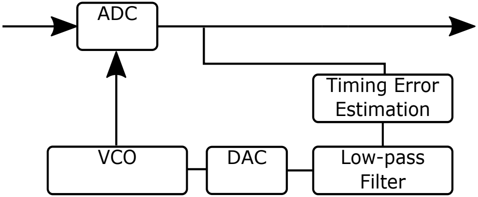
Target scenario: Optical ground-to-GEO link

Clock recovery

- We have to constantly adjust the phase and frequency of the receiver to match the transmitter
- Have to track clock drift during fades or be able to recover after fades



Example of power vector



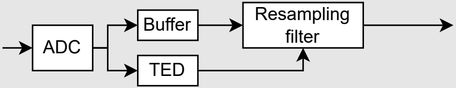
Typical timing recovery solution, the sampling frequency is of the ADC is controlled with a voltage controlled oscillator (VCO).

All-digital solutions

- Let sampling clock be free-running and compensate for sampling offset with digital signal processing

Feedforward

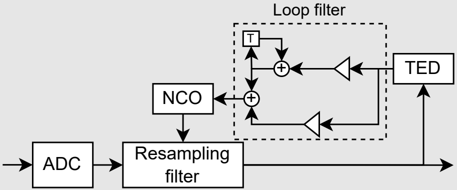
- Absolute phase is estimated
- Instant aquistion
- Higher complexity



Feedforward system

Feedback

- Relative phase error is estimated
- Aquistion time required
- Lower complexity

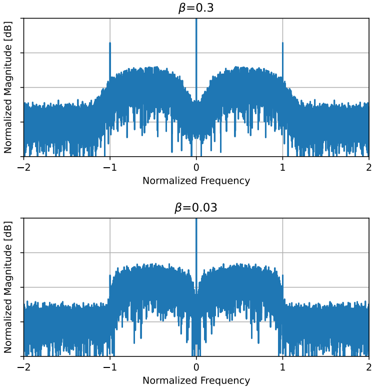


Feedback system

Timing Error Detectors (TED)

- Target: 2x Oversampling, Roll-off $\beta \approx 0.3$

TED	Architecture	Implementation
Gardner[1]	Feedback	Time Domain
Godard[2]	Feedback	FFT
Lee[3]	Feedforward	Spectral Component
GuCui[4]	Feedback	Spectral Component



Spectrum of $\Re(r(2n)(2n+1)) + \Im(r(2n)r(2n+1))$ for roll-off $\beta = 0.3, 0.03$, where r is the received signal

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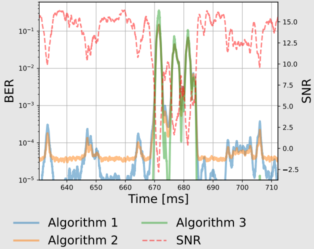
[1] Gardner,“A BPSK/QPSK Timing-Error Detector for Sampled Receivers”,1986
[2] Godard,“Passband Timing Recovery in an All-Digital Modem Receiver”,1978
[3] Lee,“A new non-data-aided feedforward symbol timing estimator using two samples per symbol”,2002
[4] Gu et al.,“All-Digital Timing Recovery for Free Space Optical Communication Signals With a Large Dynamic Range and Low OSNR”,2019

Simulation setup

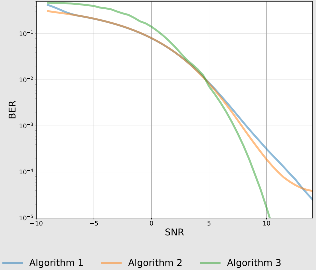
Continous

- Simulation of continous link
- Time consuming



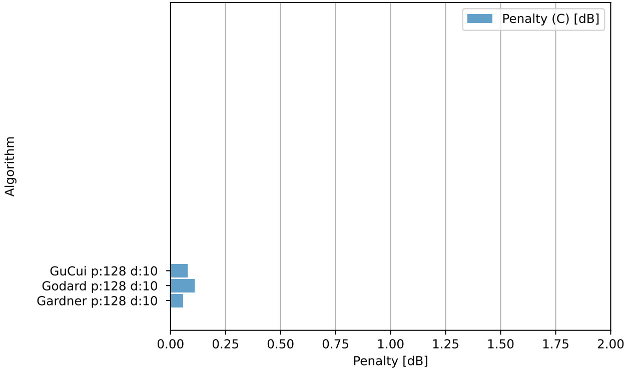
Quasi-static

- Evaluate performance at different values of SNR to map between SNR and BER
- Fast evaluation



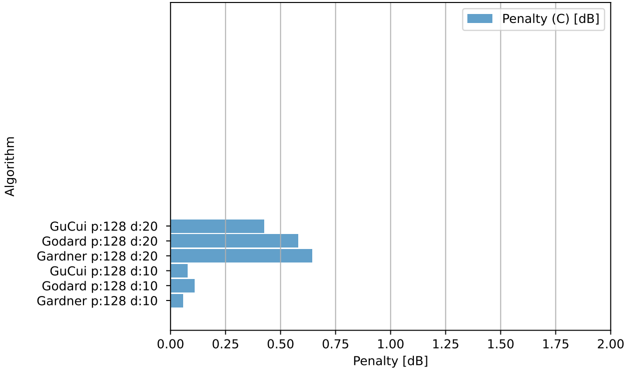
Results

- Simulation setup
  - Continous simulation of 1 second for 25GBaud QPSK receiver
  - Strong turbulence ground-to-GEO scenario: Fades down to -15 dB
  - Average $BER \approx 10^{-3}$
  - Clock offset: 100 ppm
- First let's look at the feedback algorithms: Parallelization factor p=128, Latency d=10 cycles



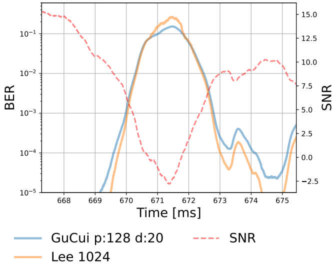
Results

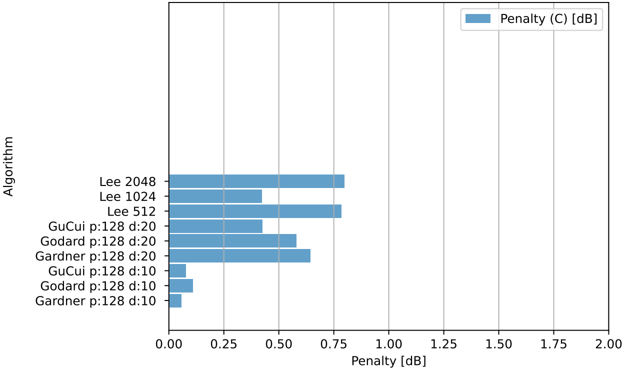
- Latency of 10 cycles is probably too optimistic.
- Increasing the latency of the feedback loop to 20 cycles introduces a larger penalty.



Results

- The feedforward method (Lee) performs worse due to poor performance during deep fades

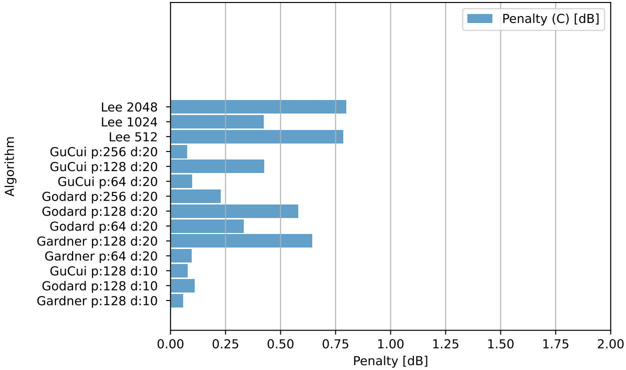




Zoom on deep fade to show the difference between feedback and feedforward algorithms

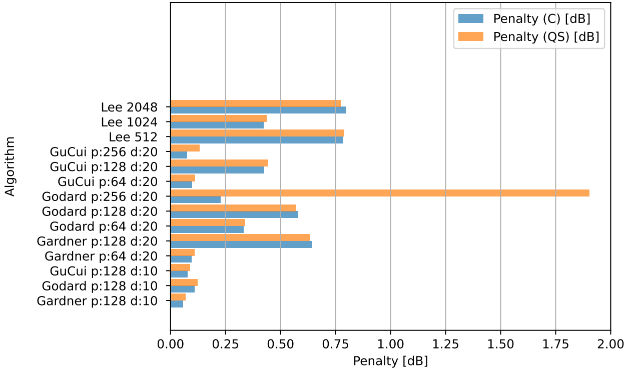
Results

- Higher degree of parallelism/block size decreases tracking speed performance but increases the noise tolerance



Results

- Using the Quasi-static (QS) method we get similar results compared to the continous simulation
- One outlier: Godard p:256 d:20 sometimes converges to a local optimum at low SNR



Conclusion

- Our simulations show that all-digital feedback-based timing recovery is a good solution for optical satellite links, if the latency requirements can be fulfilled
- Feedforward methods are sensitive to deep fades and might therefore not be suitable for optical satellite links
- A quasi-static simulation approach can be used to speed up simulations but might underestimate the performance of edge cases