Correlation-agnostic Fusion for Improved Signals of Opportunity-based Navigation

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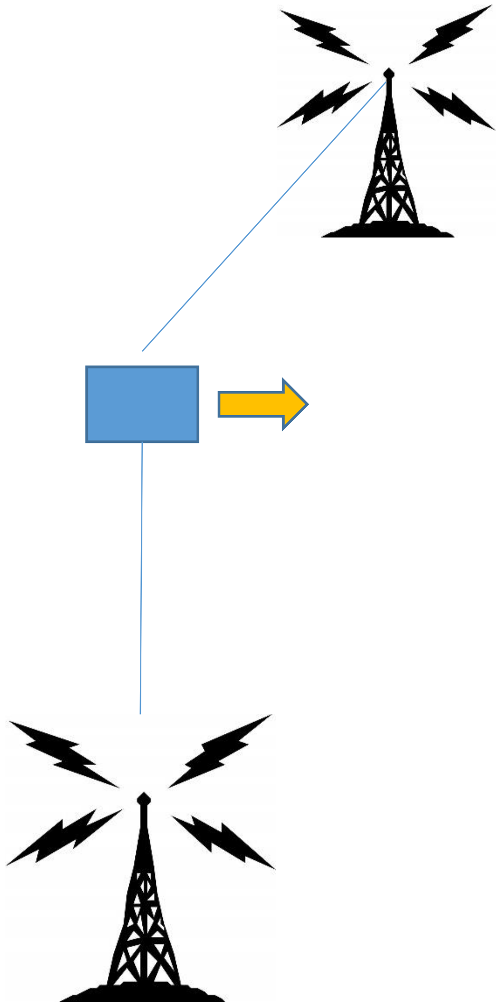
RF-based Velocity Estimation

- Assume known location of emitters (GNSS, Signals of opportunity, etc.)
- Doppler shift from each signal can be used to create a 1d “velocity vector”
- Multiple vectors used to create overall velocity estimate
- Base frequency of each emitter depends on local clocks
  - Clocks may be correlated -> correlated errors between velocity measurements
  - Do not know correlation at estimator



Does Correlation Matter? (1/3)

- Outputs must include more than just the “best estimate”
  - Requires uncertainty information
- Accurate uncertainty matters
  - Example 1: Geo-location
  - Example 2: Path planning
    - Autonomous system desires to drive between two buildings 10m apart.
    - Is uncertainty of position 1m or 20m?

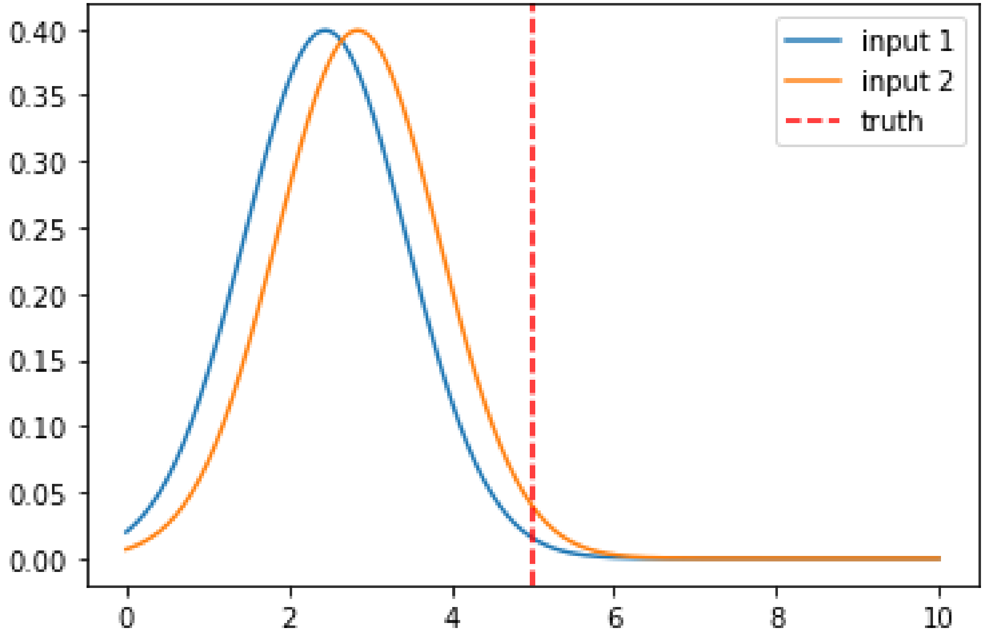
Something of interest is here…

Does Correlation Matter (2/3)

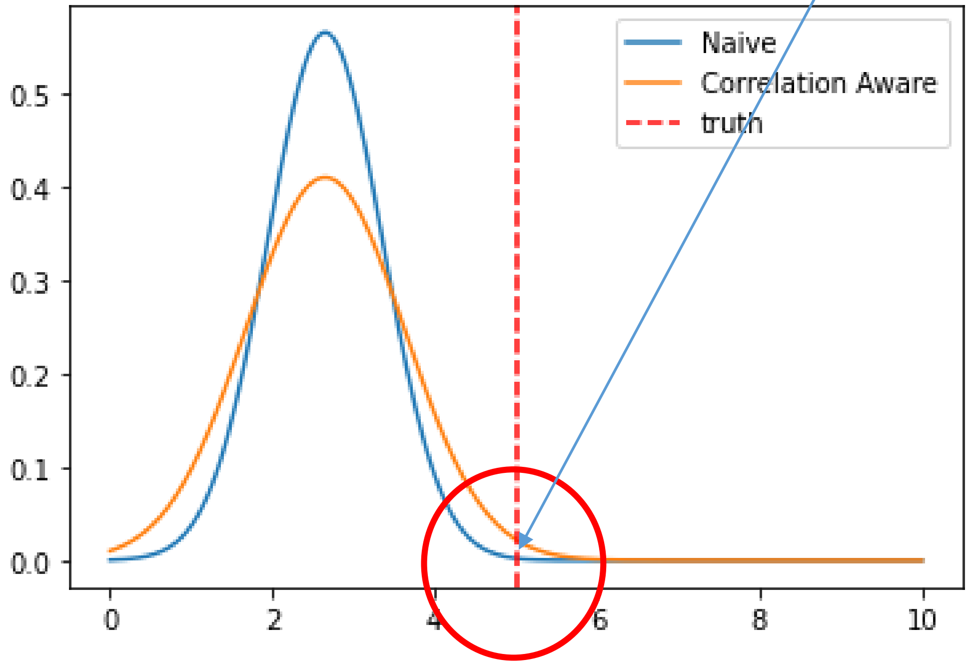
- Correlated errors can lead to:
  - Significant Over-confidence
  - Incorrect estimates
- Example:

Truth is highly unlikely when correlation is ignored

Input PDFs (highly correlated)



Fused PDFs



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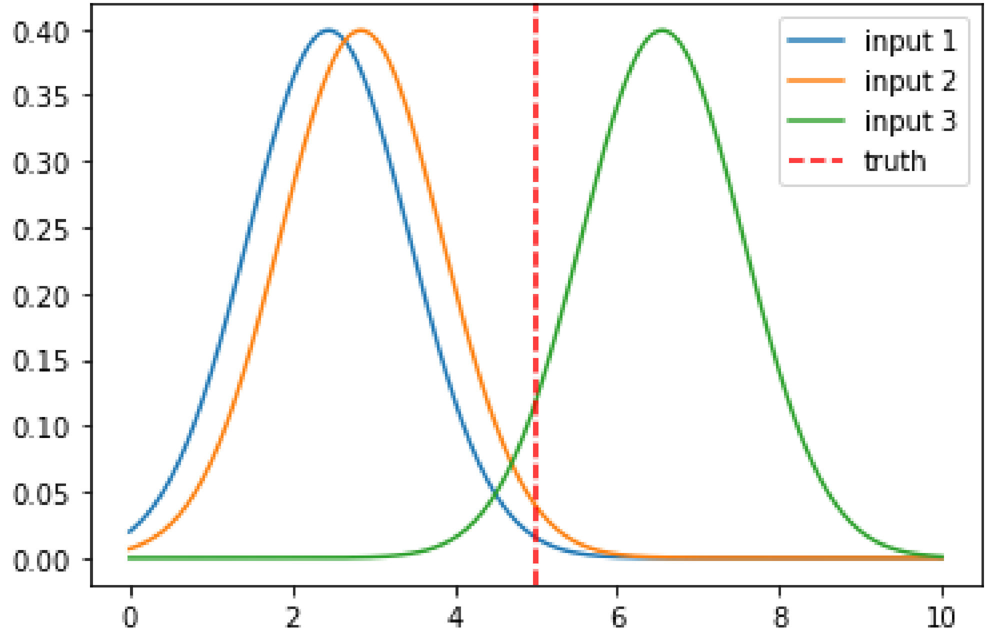
Does Correlation Matter (2/3)

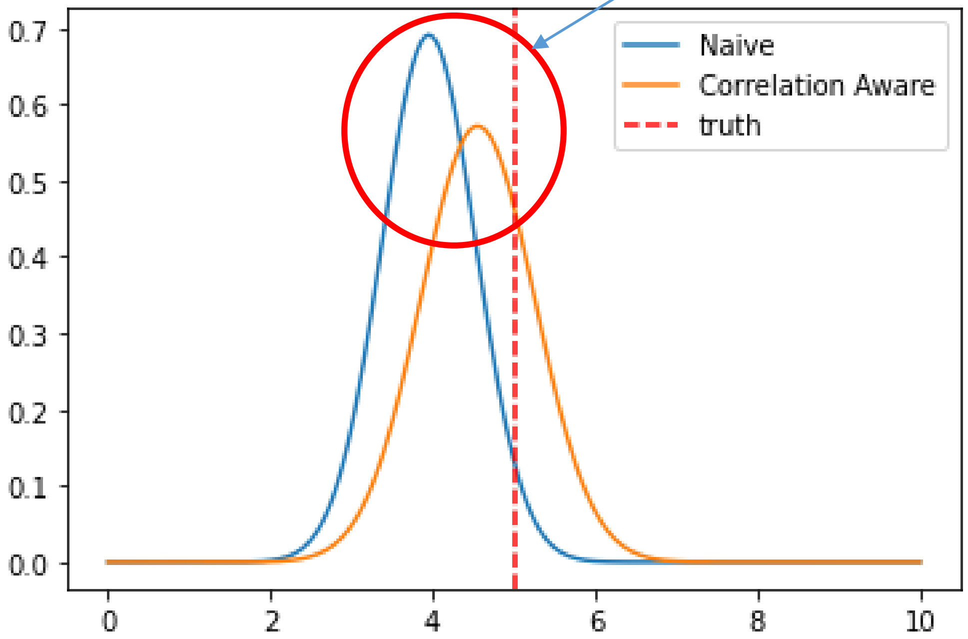
- Correlated errors can lead to:
  - Significant Over-confidence
  - Incorrect estimates
- Example:

Knowing two left inputs are correlated leads to more accurate state estimate

Input PDFs (two are highly correlated)

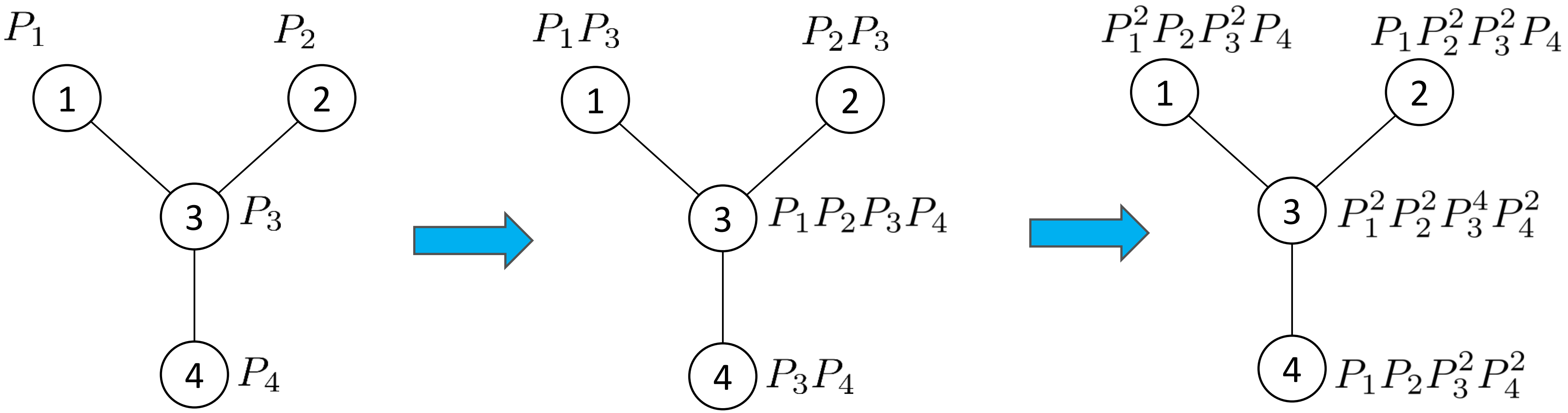


Fused PDFs



Why not just use the correlation information?

- Scenario 1: Distributed estimation in large network
  - Track to track correlation problem

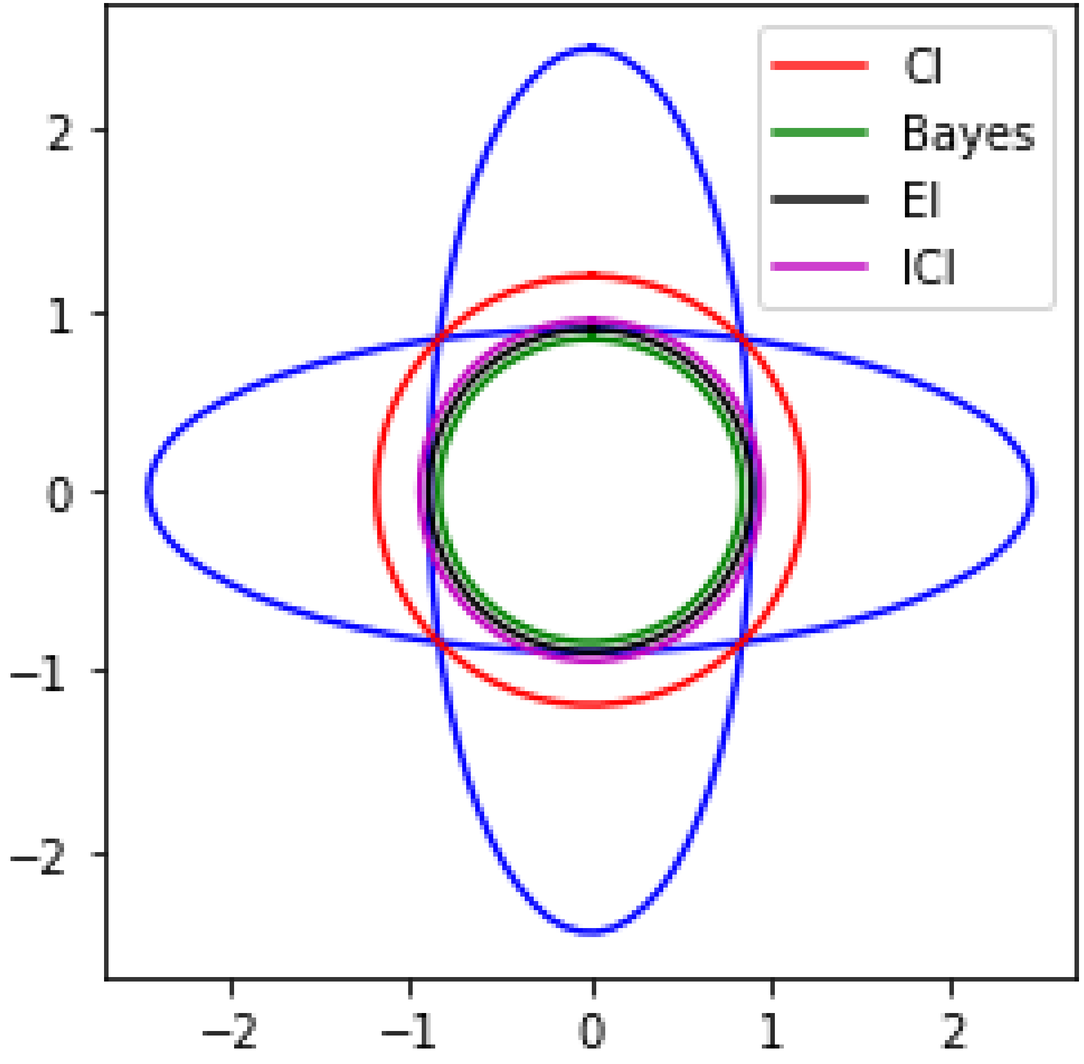


- Scenario 2: Signals of opportunity
  - Clocks may be synchronized -> correlated errors
    - Differences between GNSS systems
    - Ground emitters may be synchronized to a particular clock source

Correlation-agnostic Fusion

- Prior techniques:
  - Covariance Intersection –
    - Find ellipse that bounds common covariance
  - Ellipsoidal Intersection
  - Inverse Covariance Intersection

- All these techniques use only the covariance of the inputs to determine amount of correlated information



Probabilistic Constraint

- Problem setup

$$P_a = P_{a\backslash c} P_c$$

$$P_b = P_{b\backslash c} P_c$$

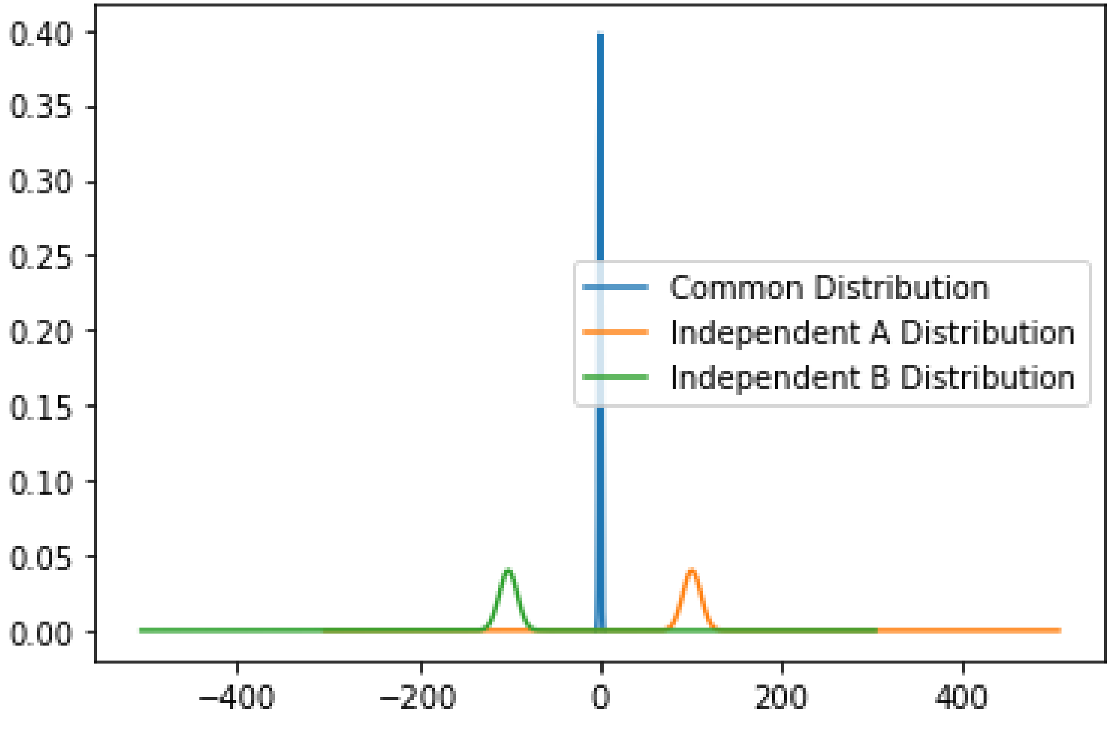
$$P_f = P_{a\backslash c} P_{b\backslash c} P_c$$

- Key Insight:
  - For Gaussian distributions, means should all be within statistical bounds of each other
- We can test for if means came from same distribution
  - Mahalanobis distance between independent distribution is a statistical null hypothesis test of means' being from same distribution

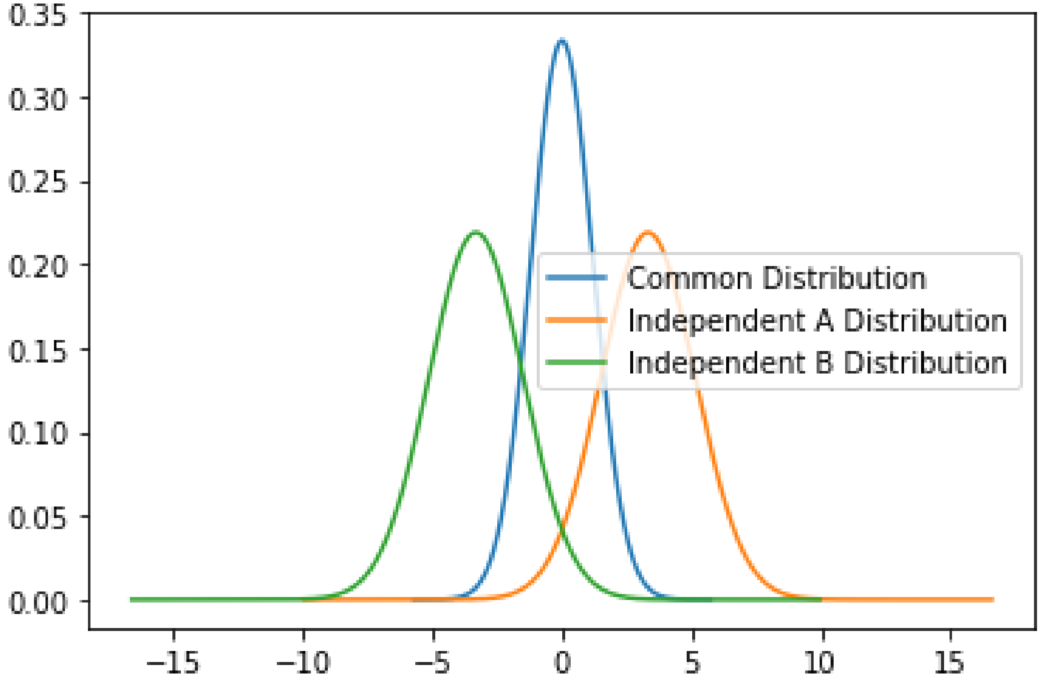
$$\Psi(C_c) = (\mu_{a\backslash c} - \mu_{b\backslash c})^\top (C_{a\backslash c} + C_{b\backslash c})^{-1} (\mu_{a\backslash c} - \mu_{b\backslash c})$$

Input Distribution Covariances Equal

- Input Distributions: (1, 1) | (-1, 1)
  - EI computed: $\Psi = 100.5$
  - Fused EI covariance: 1
  - PC constrained: $\Psi = 6.6348$
  - Fused PC covariance: 0.77



Ellipsoidal Intersection

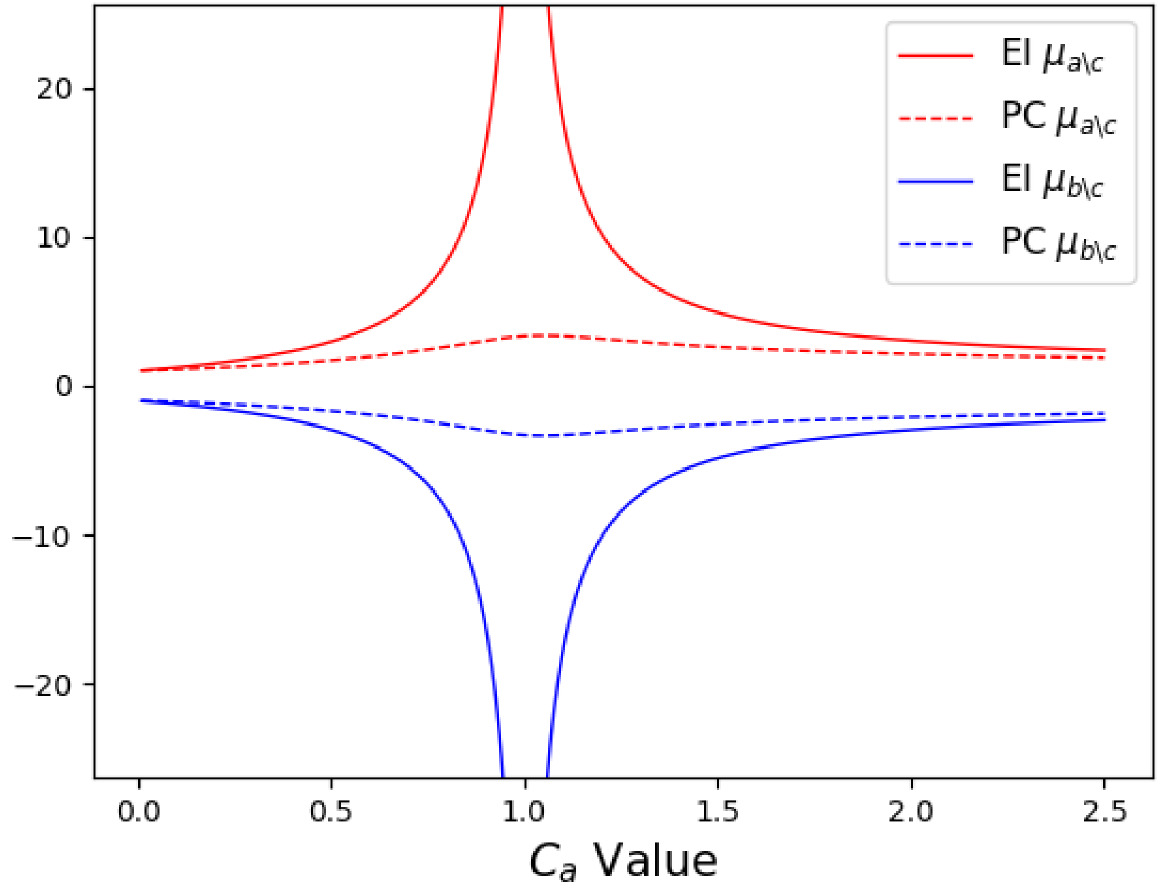


Probabilisticly Conservative

Effects of Probabilistic Constraint, cont.

Case Study: Varying Covariances

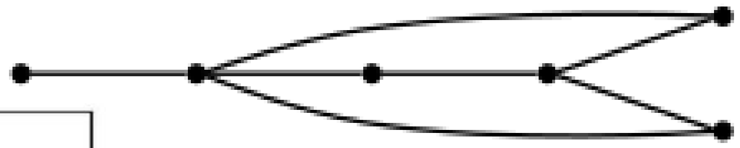
- Input 1 (1,1)
- Input 2 (1,C_a)

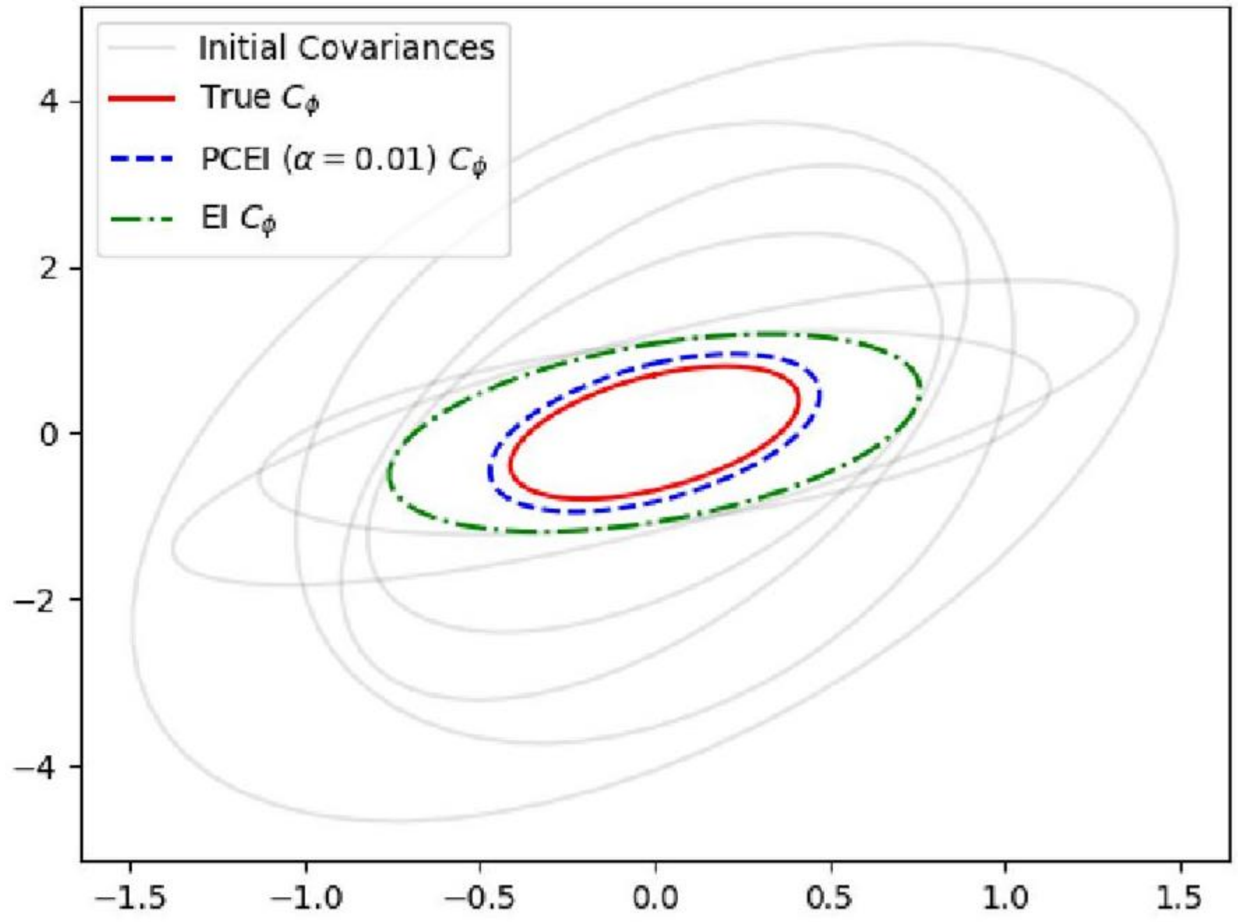


Notice that as C_a approaches 1 EI's independent means asymptotically approach infinity.

Results: Decentralized Network Convergence

- The randomly generated sensor topology is as follows…





- Probablistic Constraint → less conservative fused covariances

PC fusion applied to RF velocity estimation

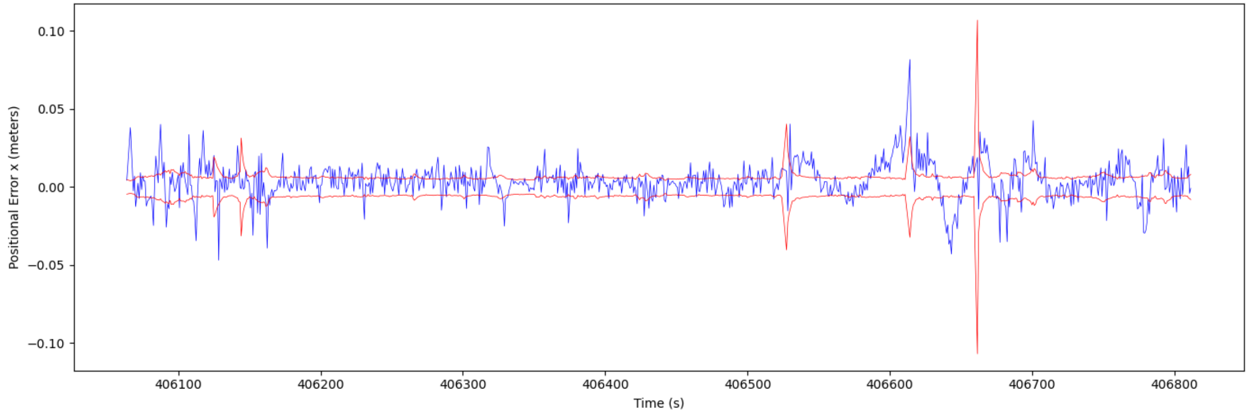
- Test using multi-GNSS velocity estimation
- Differences in clocks between systems lead to unknown correlations
- Accuracy of covariance can be evaluated using ANEES (should be dimension of state)

$$\lambda_i = e_i^\top C_i^{-1} e_i$$

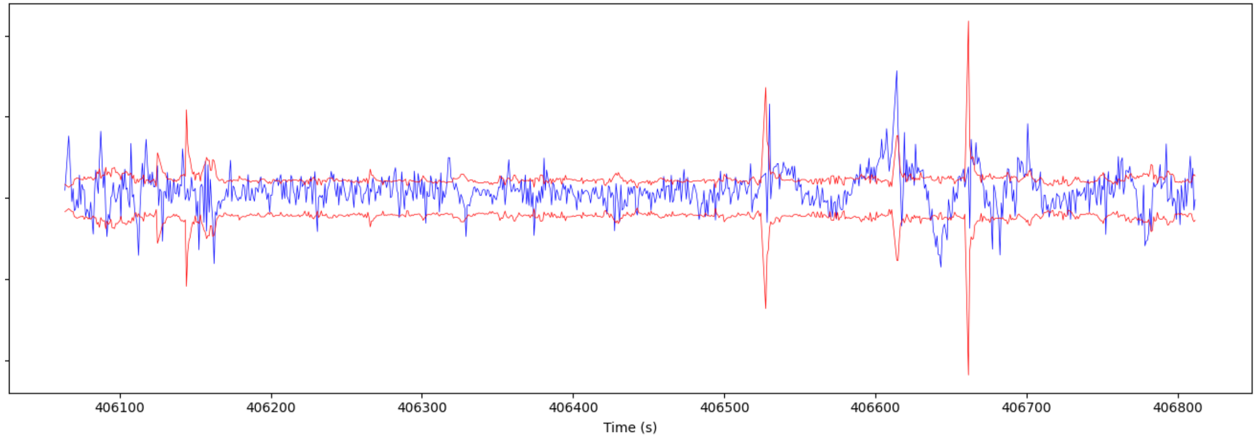
$$ANEES = \frac{1}{N}\sum_{i=1}^{N}\lambda_i$$

Results with GNSS-based velocity estimation

	$MSE(*10^{-4})$	$ANEES$
Bayesian (naive)	5.97	9.578
Ellipsoidal Intersection	149.13	2.888
Covariance Intersection	6.64	1.817
Probablistic Conservative ($\alpha = 0.05$)	6.45	3.088



Bayesian fusion errors (with 1-sigma lines), x velocity



PC fusion errors (with 1-sigma lines), x velocity

Conclusions / Future Work

- Novel correlation-agnostic fusion technique was proposed (probabilisticly constrained)
- Demonstrated improved performance in simulated network data and real GNSS velocity data

- Future Work:
  - Apply to real-world distributed network estimates
  - Apply to ground-based signals of opportunity