Innovative Navigation using new GNSS SIGnals with Hybridised Technologies

iNsight

Insights into GNSS Integrity Monitoring

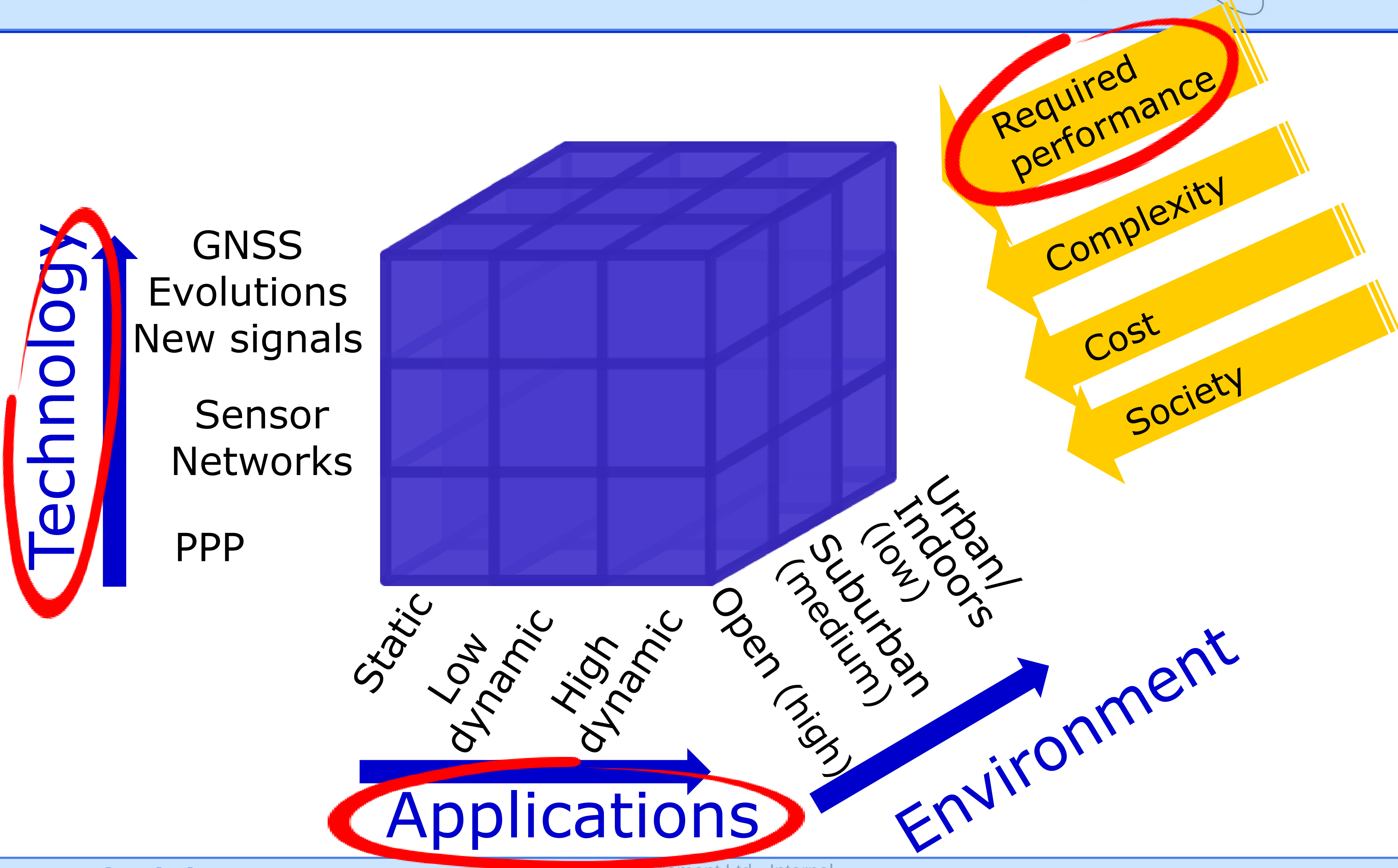
Imperial Contributors

- Prof. Washington Ochieng
- Dr. Shaojun Feng
- Dr. Carl Milner (Assist Prof. ENAC)
- Mr. Altti Jokinen

Outline

- Application scenarios
- RNP and need for integrity
- Challenges
- Solutions
- Impact and future work

Application Scenarios (1/2)



Application Scenarios (2/2)

- Applications and Environments
  - Identified potential applications
  - Quantified the Required Navigation Performance (RNP)

-> iNsight User Requirements Document

Required Navigation Performance

- Metrics to measure performance

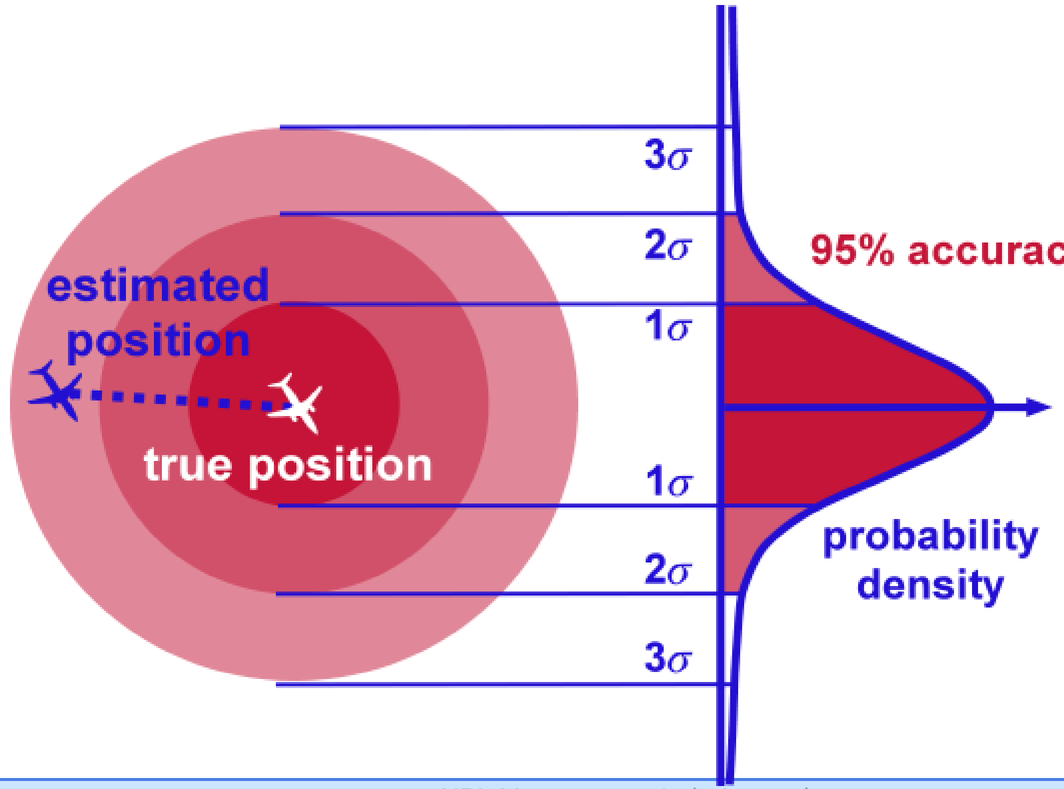
- Consider:
  - performance in the absence of failure
  - performance in the presence of failure
  - operational economy
  - standardisation

- RNP Parameters
  - Accuracy, Integrity, Continuity and Availability

- Quantification of metrics for a given application
  - $RNP_{model} = f\,(\text{operational factors, criticality \& efficiency})$

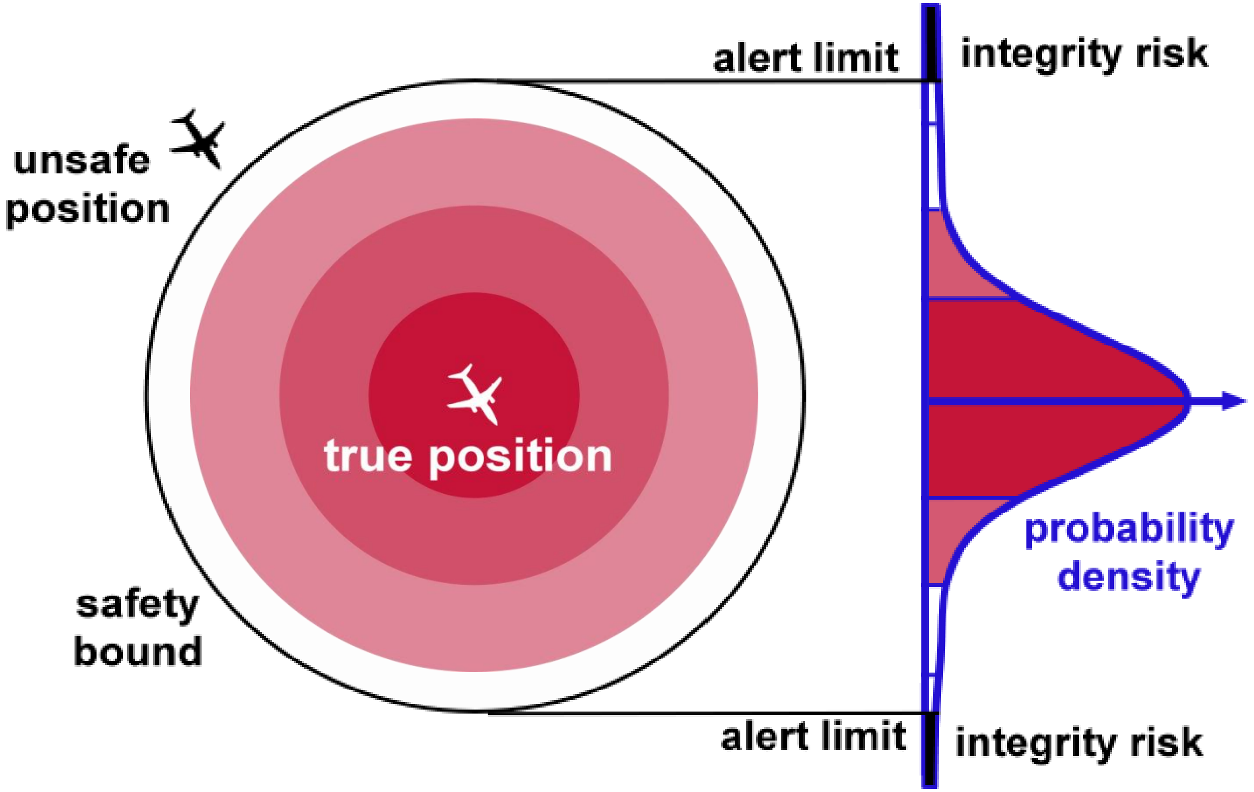
Performance in the absence of failure

- Accuracy
  - Conformance of the estimated position solution to the true position (95% level)



Performance in the presence of failure

- Providing safety – *integrity*
  - ability to inform users in the event of a failure (position error is unsafe) in sufficient time



Key factors:

1. Alert limit

2. Integrity risk

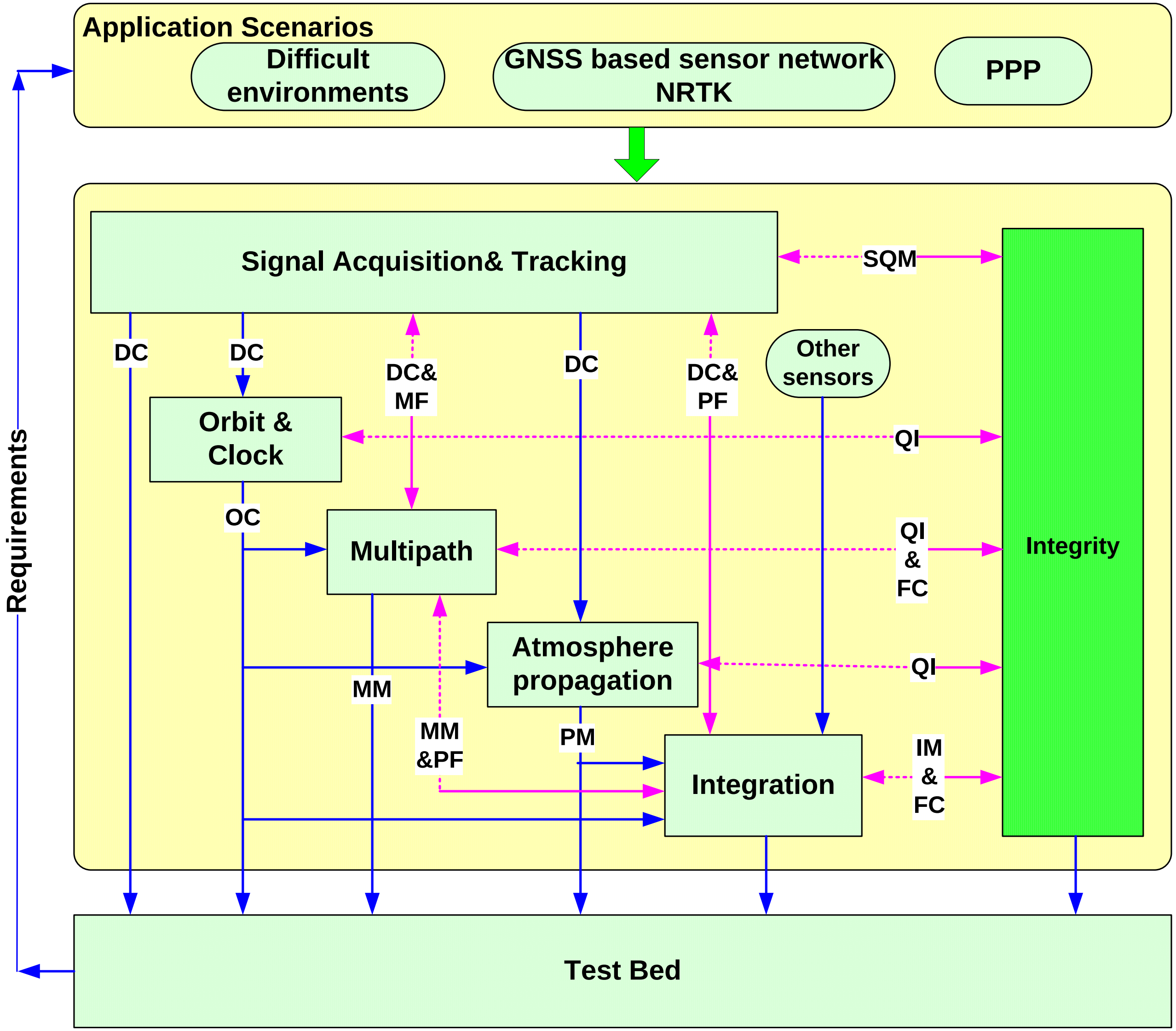
3. Time-to-alert

Integrity

- GNSS integrity monitoring
  - External (Built-in; SBAS, GBAS)
  - User level (RAIM and variations, e.g. ABAS)

- High accuracy positioning with GNSS
  - Carrier phase measurements
  - User level
  - Modes (e.g. PPP and Conventional RTK)

Integrity monitoring context



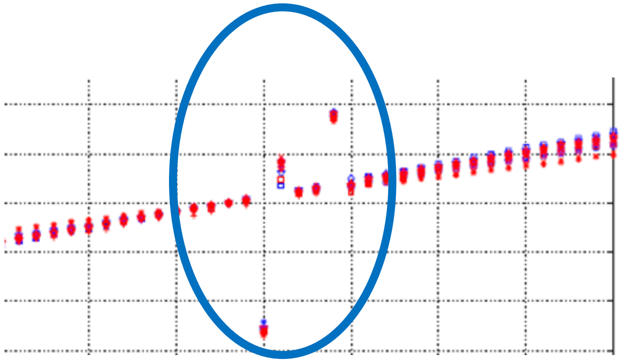
DC: DeCoded data
FC: Feedback Control
IM: Integrity Monitoring
MF: Measurement domain Feedback
MM: Multipath Mitigation
NRTK: Network RTK
OC: Orbit and Clock
PF: Position domain Feedback
PM: Propagation Mitigation
PPP: Precise Point Positioning
QI: Quality Indicator
RTK: Real Time Kinematic
SQM: Signal Quality Monitoring

Technical Challenges

- New signals and constellations
- New applications (e.g. collision avoidance) and scenarios
- Specification of integrity requirements
- Error distributions
- Failure modes identification & specification of failure models
- Carrier phase integer ambiguity resolution & validation
- Need for early detection & quality indication

Failure modes and models

- Previously identified various failure models
  - step, ramp, wander, oscillation, noise and their combinations
- New Failure modes identified, e.g.
  - anomalous behaviour on L1 carrier phase on SVN48
  - observed only on the L1 frequency - rules out on-board clock
  - likely cause is internal hardware multipath on the L1 signal
  - described as a bias-flicker failure model



User Level Quality Assurance

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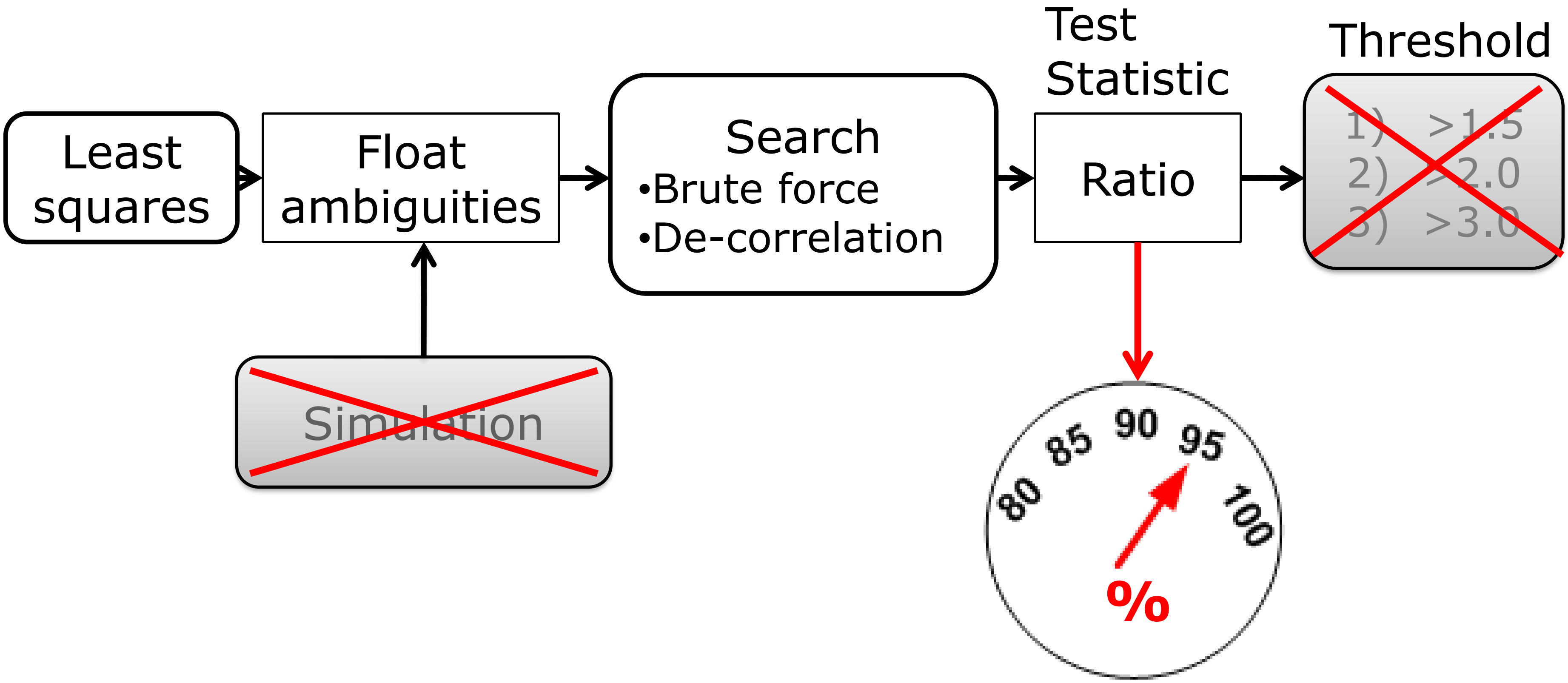
Signal reception → **Acquisition and tracking** → **Data Pre-processing** → **Ambiguity resolution** → **Positioning**

- Signal reception ↑ Antenna e.g. Choke Ring, Pattern Gain Control, RHCP/LHCP
- Acquisition and tracking ↑ Signal Quality Monitoring
- Data Pre-processing ↑ Products Screening Models Cycle slip detection and repair Mes. combination
- Ambiguity resolution ↑ Ambiguity validation ?
- Positioning ↑ Carrier phase RAIM

Holistic two-stage integrity monitoring (1 → Ambiguity validation; 2 → Carrier phase RAIM)

Novel Ambiguity Validation Algorithm (1/3)



Doubly Non-Central F distribution (DNCF)

Novel Ambiguity Validation Algorithm (2/3)

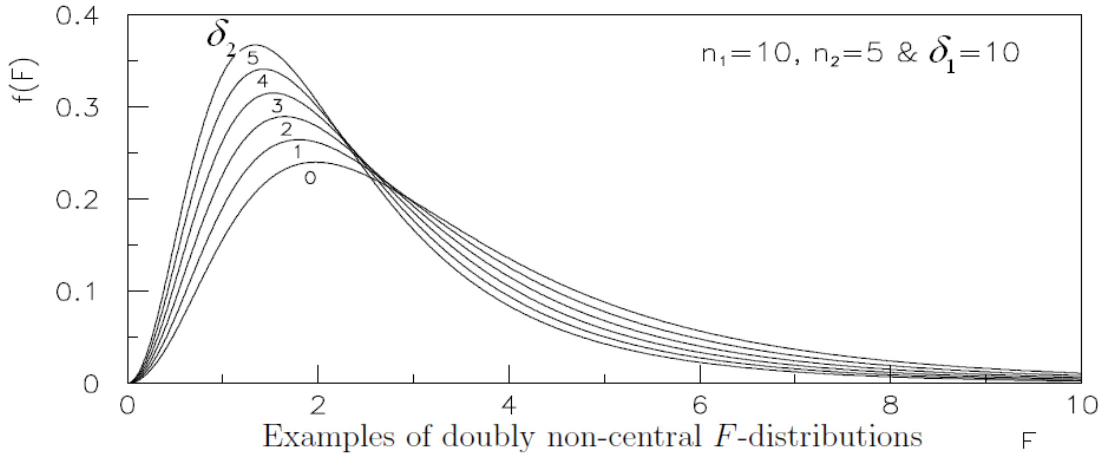
- Doubly Non-Central F distribution (DNCF)

$$\frac{R_2}{R_1} \sim F(n_2, n_1, \delta_2, \delta_1)$$

Numerator: non-central Chi Squared distribution

Denominator: non-central Chi Squared distribution

– P_{FA} and P_{MD} -> non-central parameters δ_1, δ_2

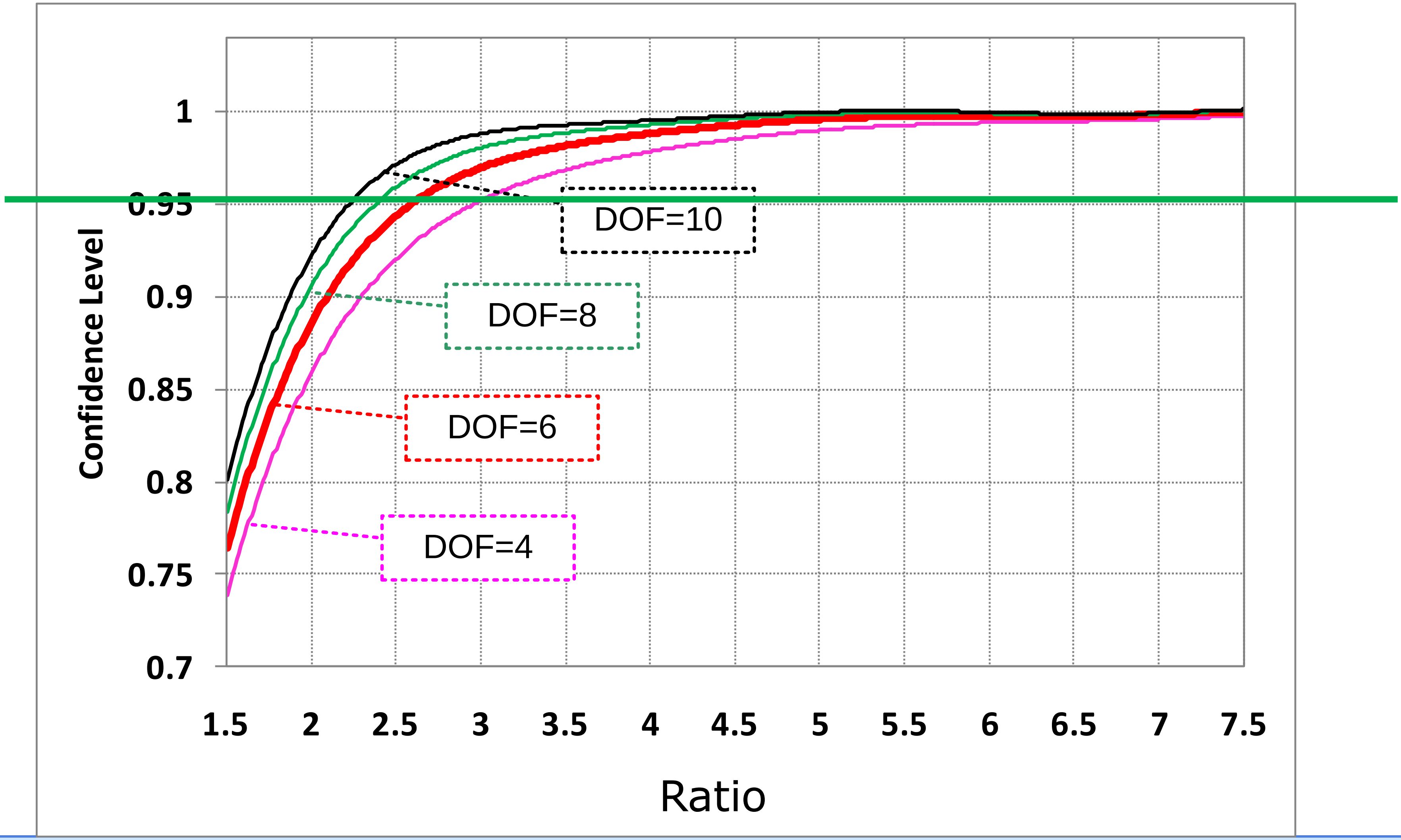


Examples of doubly non-central F-distributions

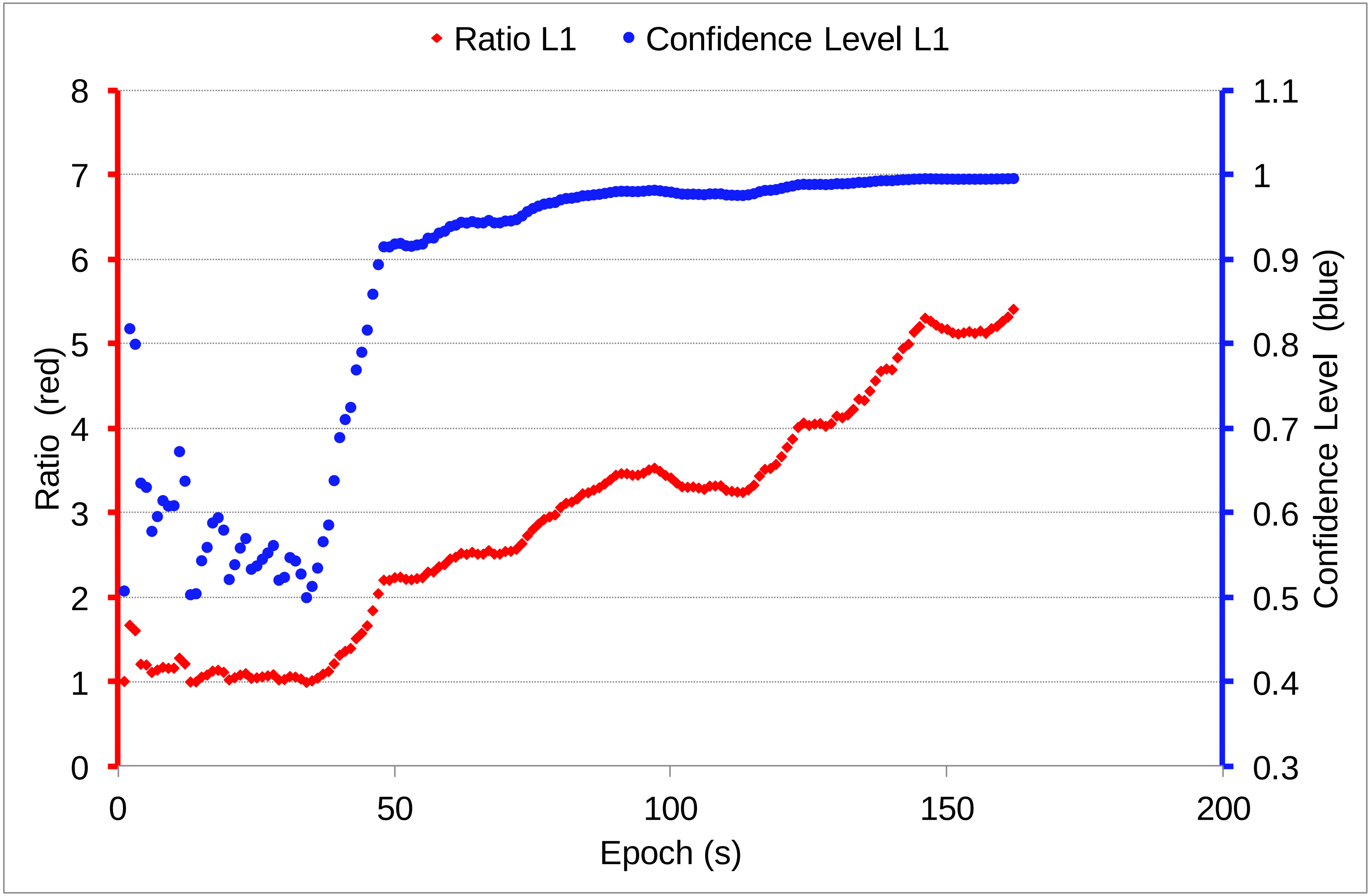
http://www.stat.rice.edu/~dobelman/textfiles/DistributionsHandbook.pdf

Novel Ambiguity validation algorithm (3/3)

- DNCF based Confidence level, Ratio and DOF



Example Results
Ambiguity validation in Conventional RTK



ICRAIM

- Test statistics
  - Full set
  - Subsets e.g. L1, Widelane
- Thresholds
  - Probability of false alert
  - Standard deviation of observations
  - Degrees of freedom
  - Distribution
- Protection levels: *the upper bound of position error*
  - Maximum slope based
  - Kσ

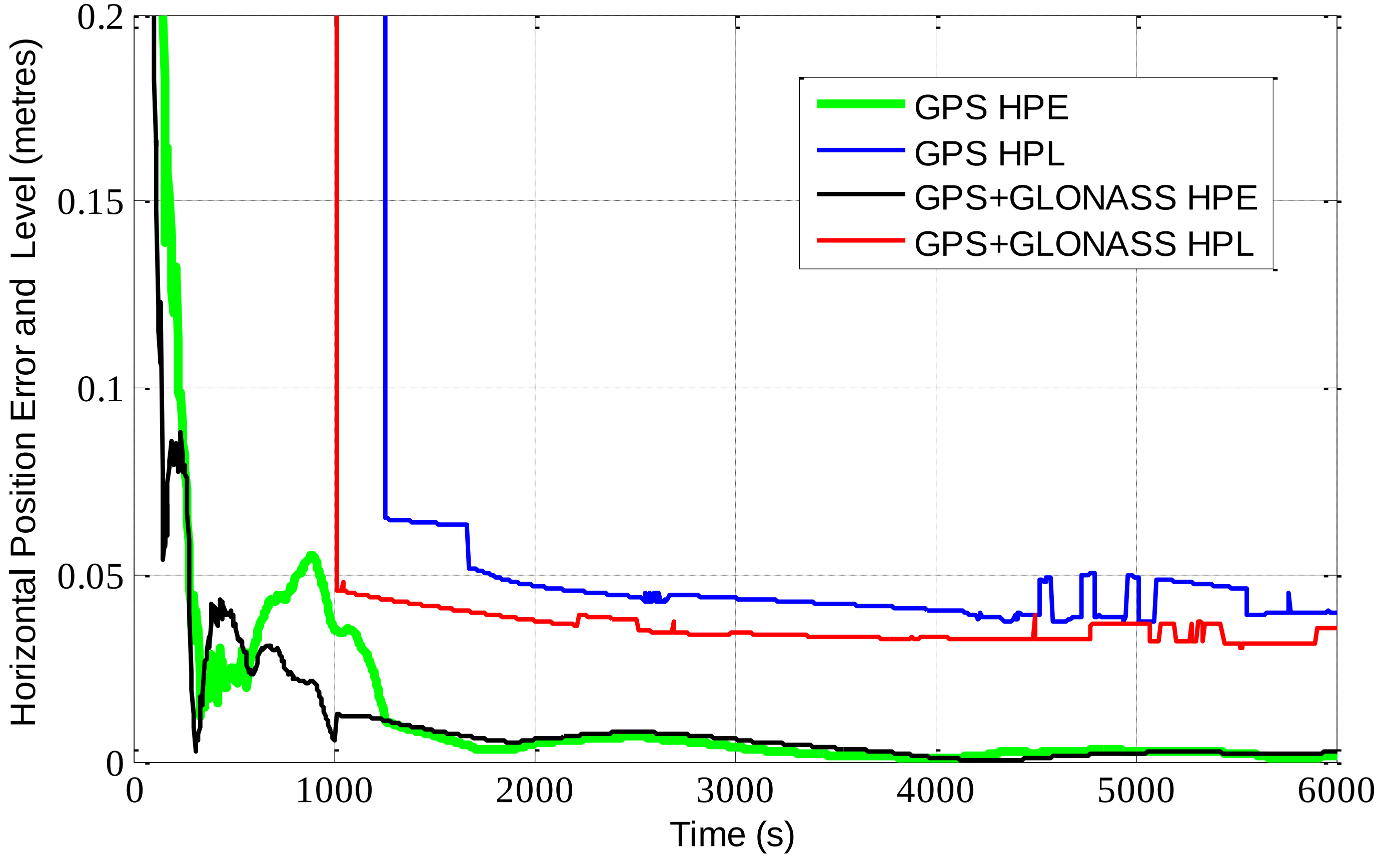
Novel PPP algorithm and integrity(1/2)

- PPP algorithms
  - Single receiver using carrier phase with information support
  - Challenges
    - Difficult to resolve integer ambiguity
    - Long convergence time
  - Innovations
    - Using both GPS and GLONASS
    - Minimum Constellation method
    - Fixing GPS carrier-phase ambiguities to integers

Novel PPP algorithm and integrity (2/2)

- Integrity Monitoring for PPP
  - Failure detection and exclusion
  - Ambiguity validation
  - Adaptation of ICRAIM to PPP
    - During converging process
    - After integer ambiguities are fixed

Example Results-PPP accuracy and Protection level



Impacts and Future Research

Impacts

- Proposed methods are superior to conventional methods
- The algorithms developed provide double protection for users
- Extension of GNSS to more stringent applications
- Saving on cost of building infrastructure in remote areas (PPP)

Future Research

- Comprehensive testing of algorithms
- Application of methods to include more constellations and signals
- Identification of new applications

Thank you!

Questions?