A New Approach of Latency Error Compensation Using Compact RTK for GPS/GLONASS signals

SnuGL

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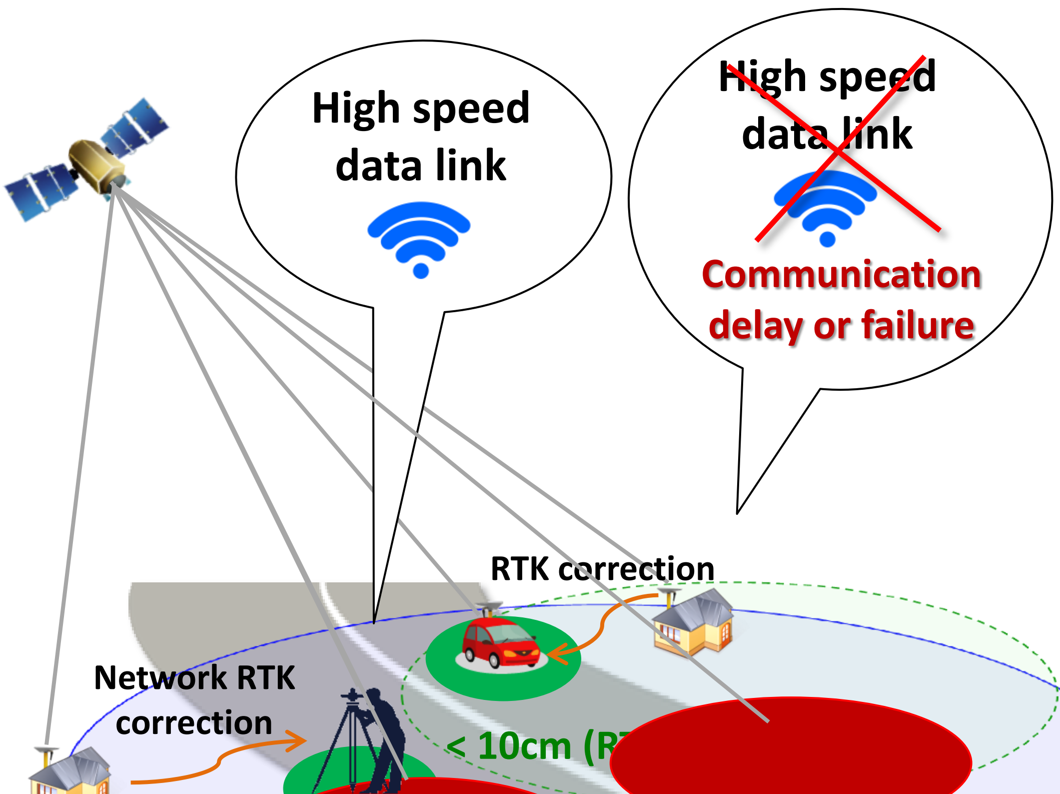
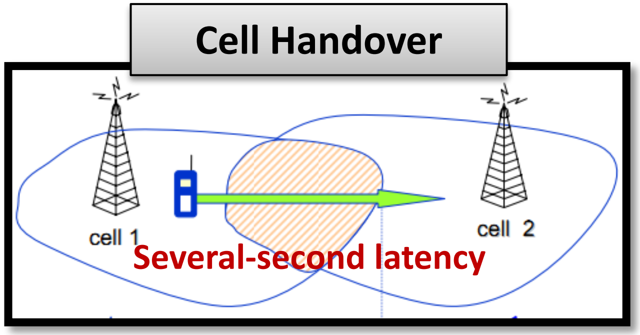
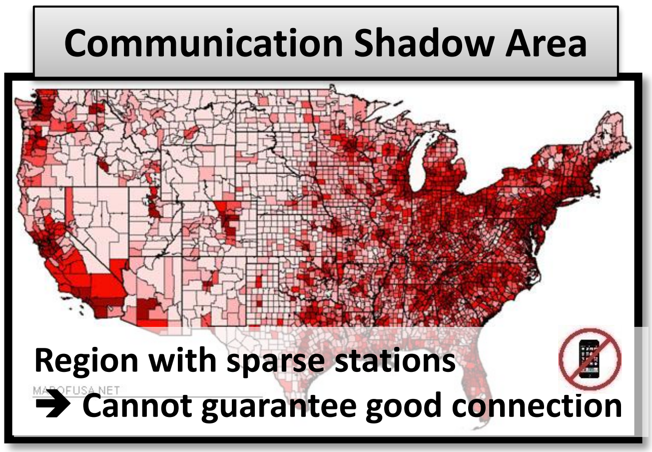
Motivation





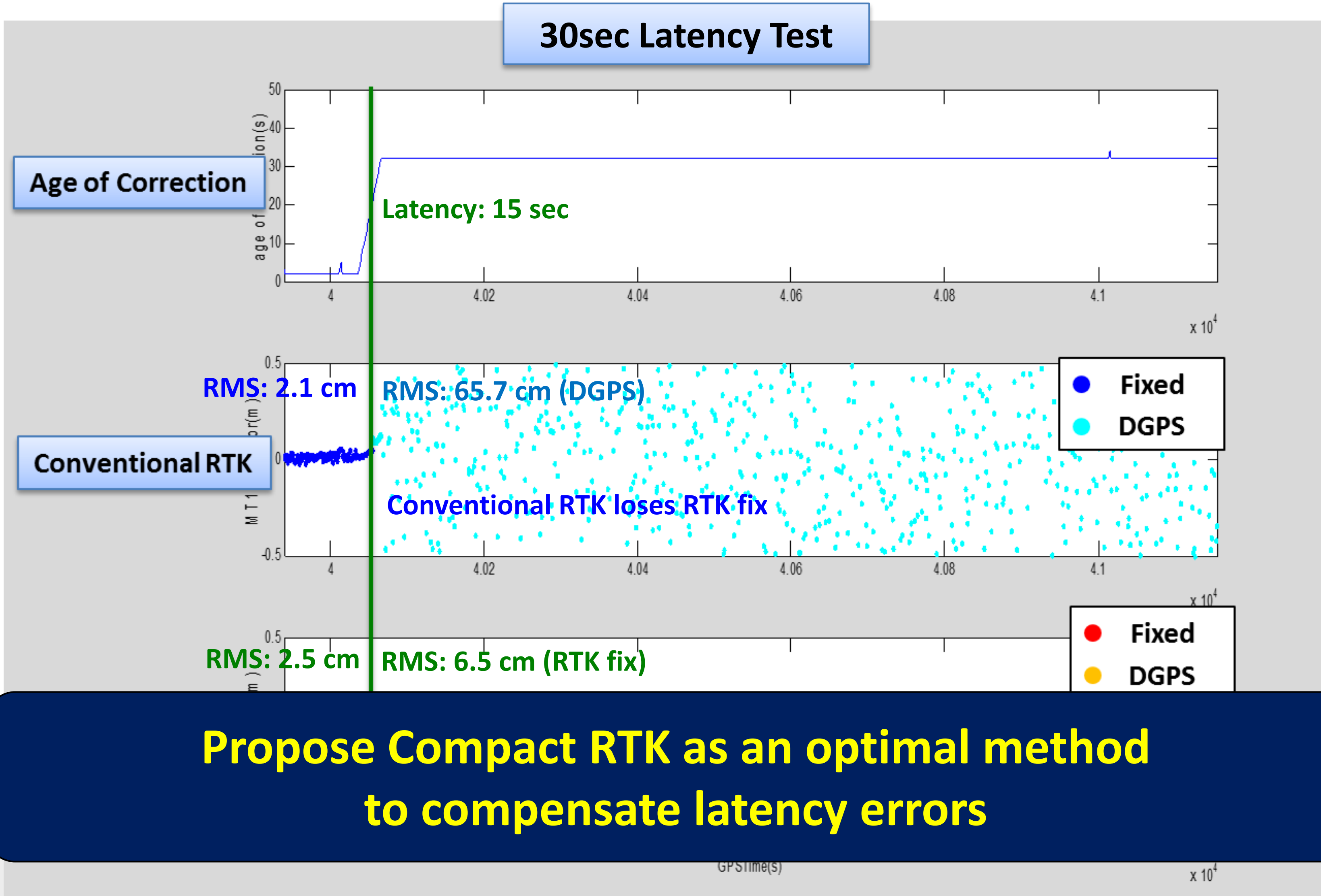


- Conventional RTK loses RTK position fix under communication delay or failure

➔ Need to deal with associated latency errors to maintain RTK position fix

Motivation – Latency occurred on a highway

- **Data communication: 3G**



Propose Compact RTK as an optimal method to compensate latency errors

Contents

Briefings on Compact RTK

- **Compact RTK**
  - Developed by Seoul National University (SNU) in 2002
  - Optimized to reduce temporal decorrelation errors
    - ✓ RTK service available in a low-rate data link (< 500 bps)

      cf. Conventional RTK requires approx. 1500 bps (RTCM v3.0 MT1004, 9 satellites)
  - Currently assigned as RTCM Message Type 4081 for Test

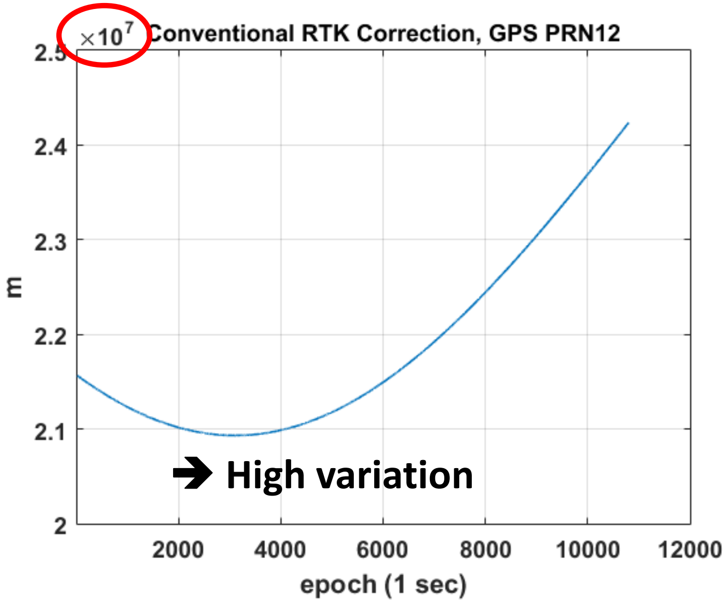
- **Participating National R&D Projects**
  - "Technical Research of the Land Application Infrastructure based on GNSS" (2009-2014)
    - ✓ funded by Ministry of Land, Infrastructure, and Transport (Budget: 16M$)
  - "Development of the Land Application Infrastructure based on GNSS" (2016-2018)
    - ✓ funded by Ministry of Land, Infrastructure, and Transport (Budget: 2M$)

- **Conventional RTK**
  - Correction representation

$$\phi \equiv d + \delta R + B - b - I + T + \delta N \lambda + \varepsilon$$

Terms w/ high variation

d	: range between a receiver and a satellite
$\delta R, b$	: satellite orbit and clock error
B	: receiver clock offset
I, T	: ionospheric and tropospheric delay
$\delta N, \lambda$	: integer ambiguity and wavelength
ε	: noise



  - RTCM Messages

Information	RTCM Message Type	No. of Bytes	Recommended update rate
Observations (GPS)	1004	8+15.625*Ns	0.5 – 2 Hz (low latency)
Observations (GLONASS)	1012	7.625+16.25*Ns	0.5 – 2 Hz (low latency)

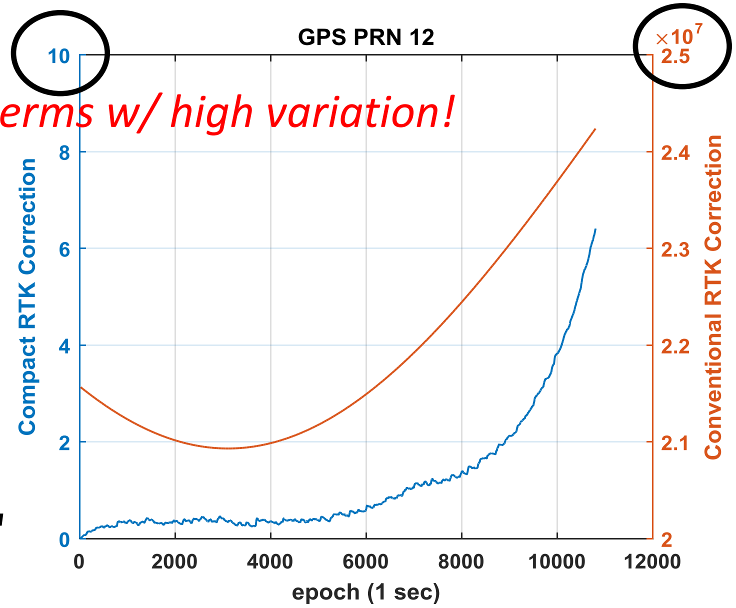
Compact RTK correction and protocol

- **Compact RTK (Kee and Kim, 2002)**
  - Correction representation → *Eliminate terms w/ high variation!*
    - ✓ Carrier Phase Correction (CPC)

$$\delta\phi \equiv \phi - \hat{d} - \hat{B} + \hat{b} - \hat{N}\lambda$$
$$= \delta R + \delta B - \delta b - I + T + \delta N\lambda + \varepsilon$$

    - ✓ CPC rate

$$\delta\dot{\phi} \equiv \frac{d\,\delta\phi}{dt} \approx -\dot{I} + \dot{T} + \delta\dot{R} + \delta\dot{B} - \delta\dot{b} + \varepsilon'$$



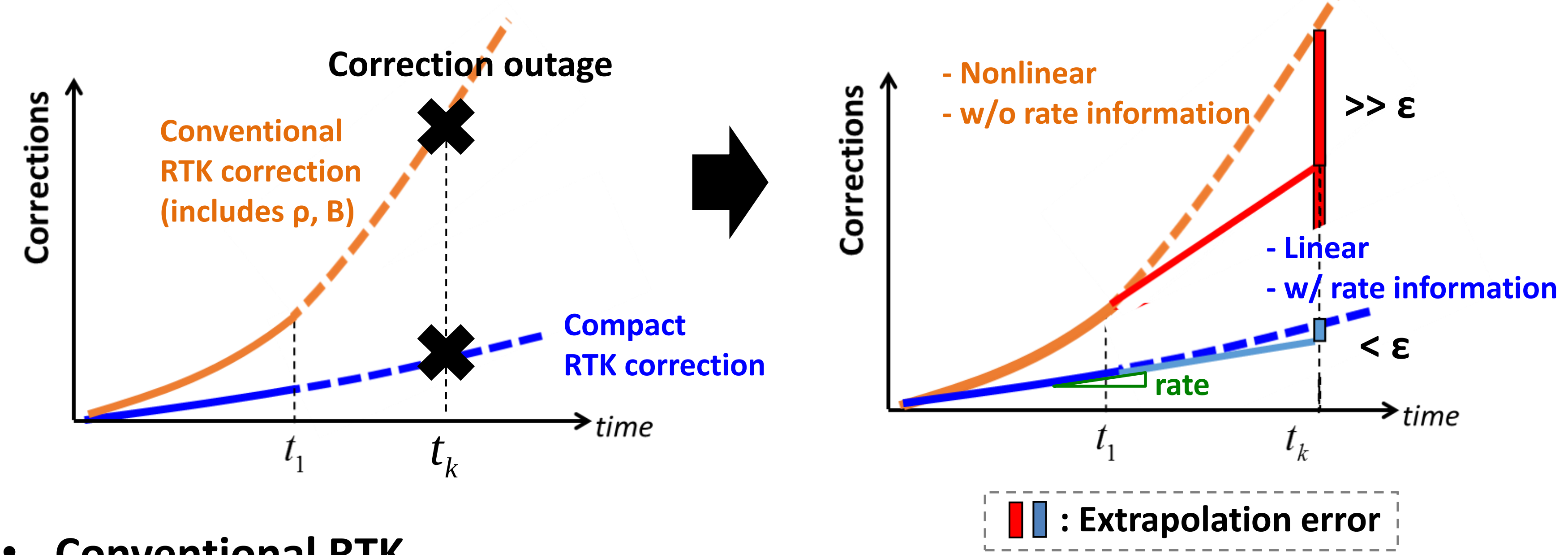
➔ **Low variation**
➔ **Can be extrapolated by low-order polynomial**

  - RTCM Messages

Information	RTCM Message Type	No. of Bytes	Recommended update rate
Carrier Phase Correction (GPS)	4081 (proprietary)	6+11*Ns	According to rate and age of CPC

Latency compensation

- **Latency compensation for conventional & compact RTK**



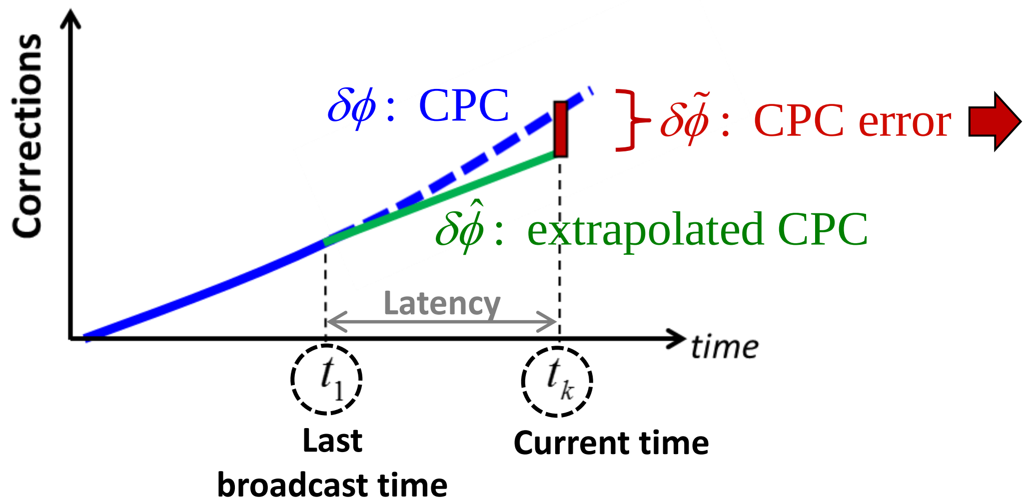
- **Conventional RTK**
  - ➢ **High nonlinearity, no rate information ➔ compensation error grows rapidly as latency increases ➔ Need high update rates**
- **Compact RTK**
  - ➢ **High linearity, rate information provided ➔ low-order polynomial extrapolation effectively compensates latency error**

➔ Allows low update rates
➔ Reduces required speed of data-link

Correction Scheduling Strategy for Compact RTK

- **Determination of Broadcast Priority**

Step 1: Monitoring CPC error at current time caused by latency



$$\delta\tilde{\phi}(t_k) \equiv \delta\phi(t_1) - (t_k - t_1)\cdot\delta\dot{\phi}(t_1)$$

Step 2: Determining transmission time of correction

- Transmission criteria

$$\left|\delta\tilde{\phi}(t_k)\right| > \delta\phi_{Threshold} \quad or \quad (t_k - t_1) > T_{\max}$$

$\delta\phi_{Threshold}$: Maximum allowable error

$T_{\max}$: Maximum allowable update interval

CPC: Carrier Phase Correction

Compact Network RTK

- **Compact RTK (RTCM 4081) can be combined with Network RTK**

Examples of RTCM correction messages for Network RTK realization

	Conventional	Proposed
MAC Network RTK	MT1004 MT1017	MT4081 MT1017
VRS Network RTK	MT1004	MT4081
FKP Network RTK	MT1004 MT1034	MT4081 MT1034

- **Network RTK corrections require low update rates**
  - MAC (MT1017) and VRS (MT1034)
- **Speed of data-link determined mostly by update rates of RTK corrections**
  - MT1004 and MT4081

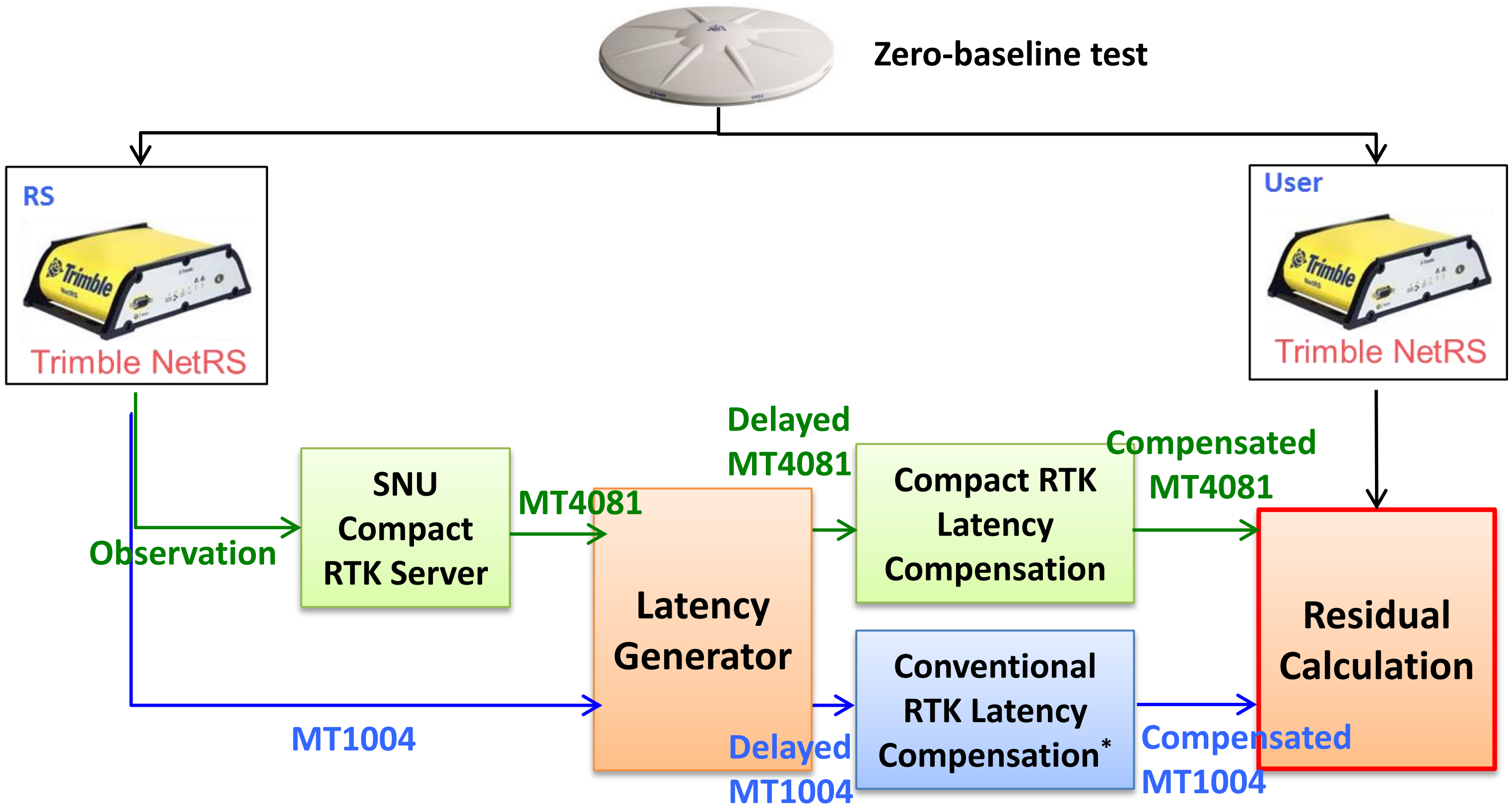
RTCM: Radio Technical Commission for Maritime Services
MT: Message Type
MAC: Master-Auxiliary Correction
VRS: Virtual Reference Station
FKP: Flächen Korrektur Parameter

Test Results for Compact RTK

1. Performance Validation of Latency Compensation
2. 30-sec Latency Test Using Commercial Receiver
3. Static Positioning Performance under Low-Rate Data-Link

Performance Comparison of Latency Compensation using Conventional and Compact RTK – Test Configuration

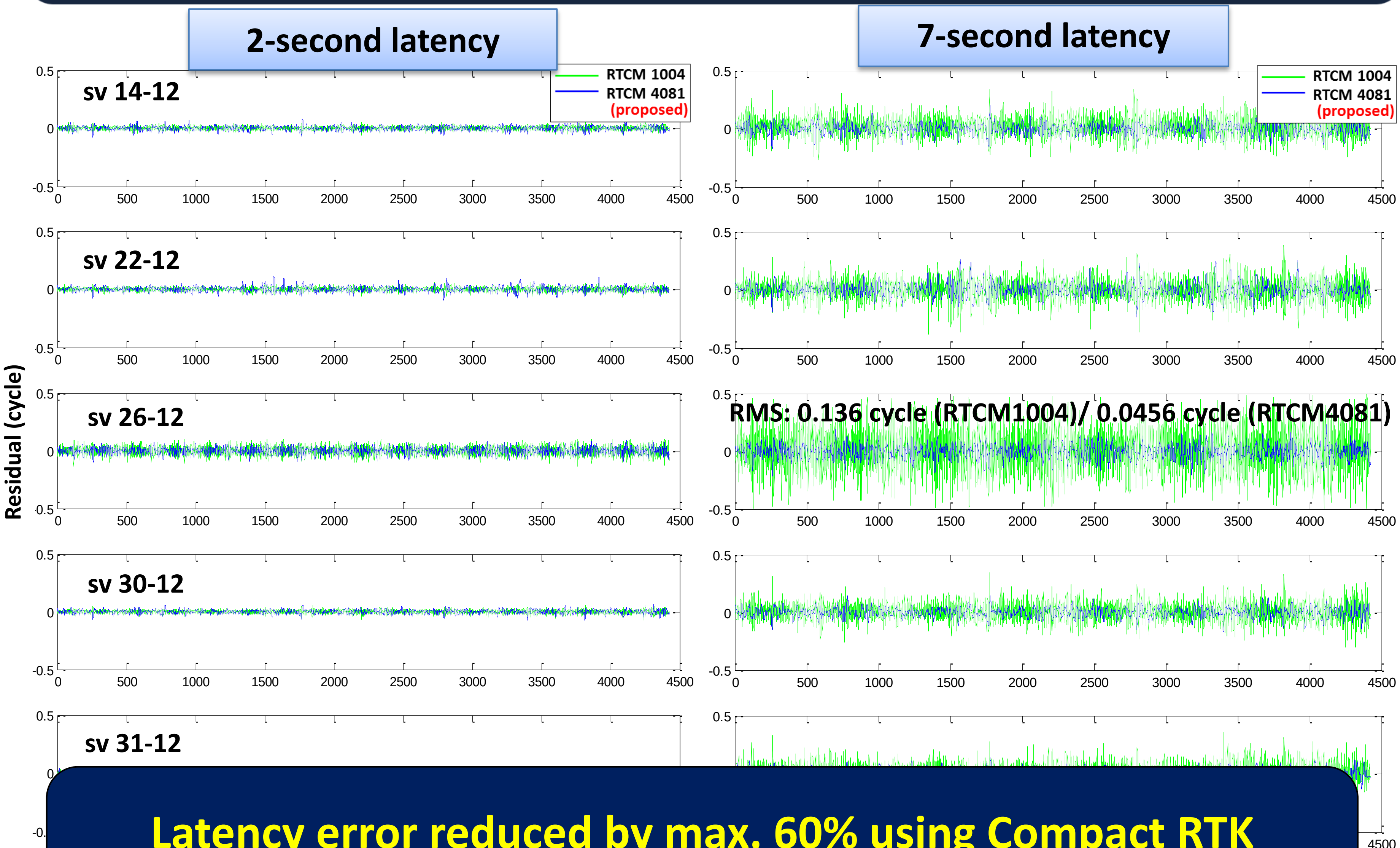
- **Test Configuration**



*Conventional RTK Latency Compensation (Neumann et al., 1996)

- 3-state Kalman Filter (Carrier phase observation, rate and acceleration)

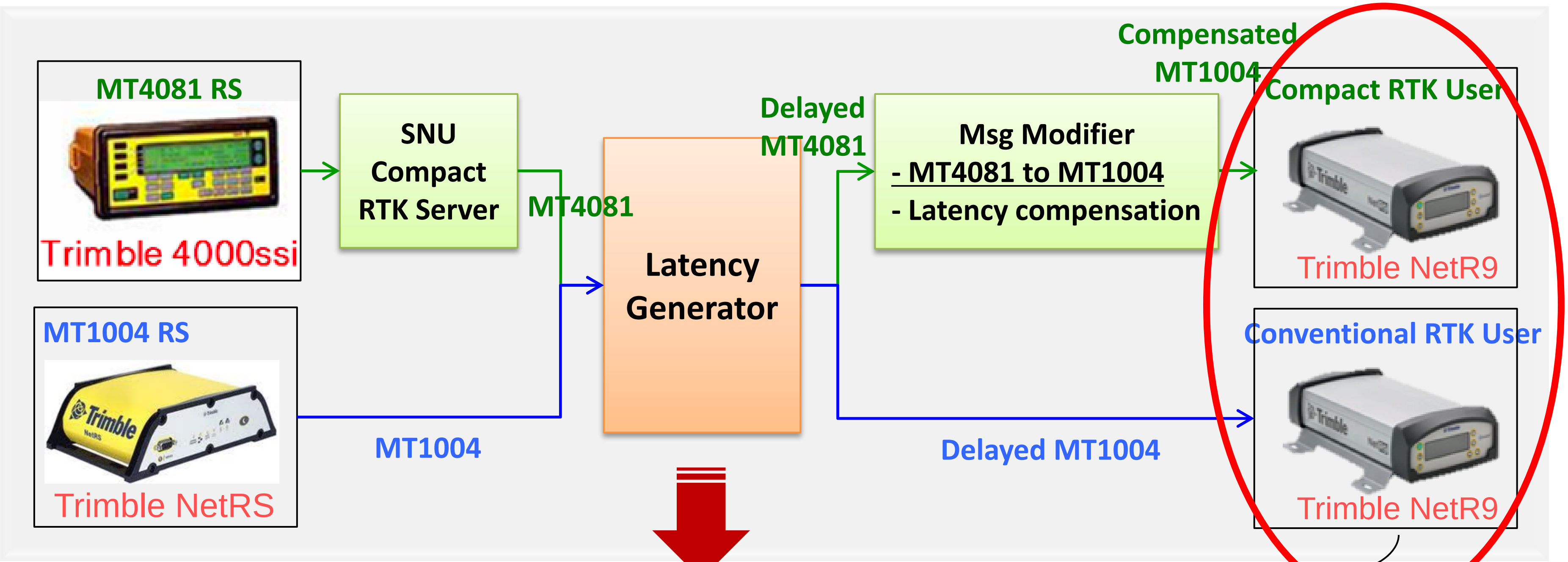
Residual after latency error compensation



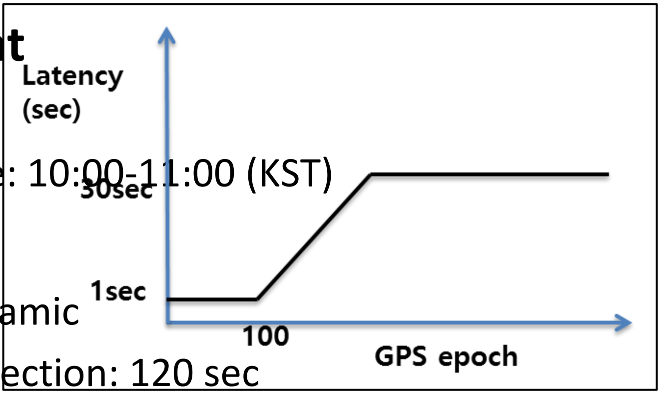
Latency error reduced by max. 60% using Compact RTK

➔ Compact RTK improves robustness to broadcast latency

30-sec Latency Test – Test Configuration

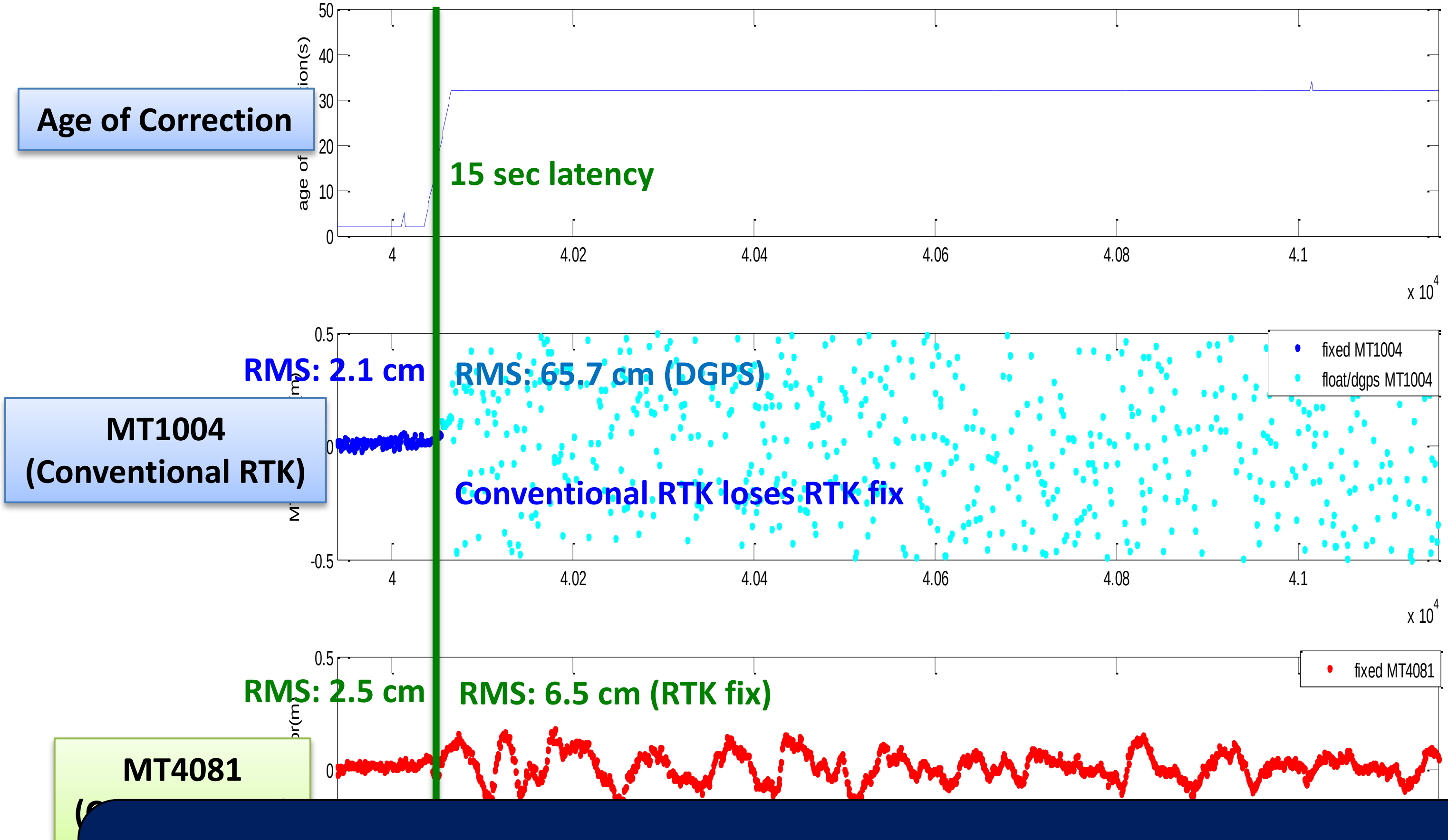


- **Test environment**
  - Baseline: 145 m
  - Experiment time: 10:00-11:00 (KST)
- **Rover setting**
  - Low latency dynamic
  - Max. age of correction: 120 sec



- **Latency error in MT1004: compensated by receiver manufacturer's own compensation scheme.**

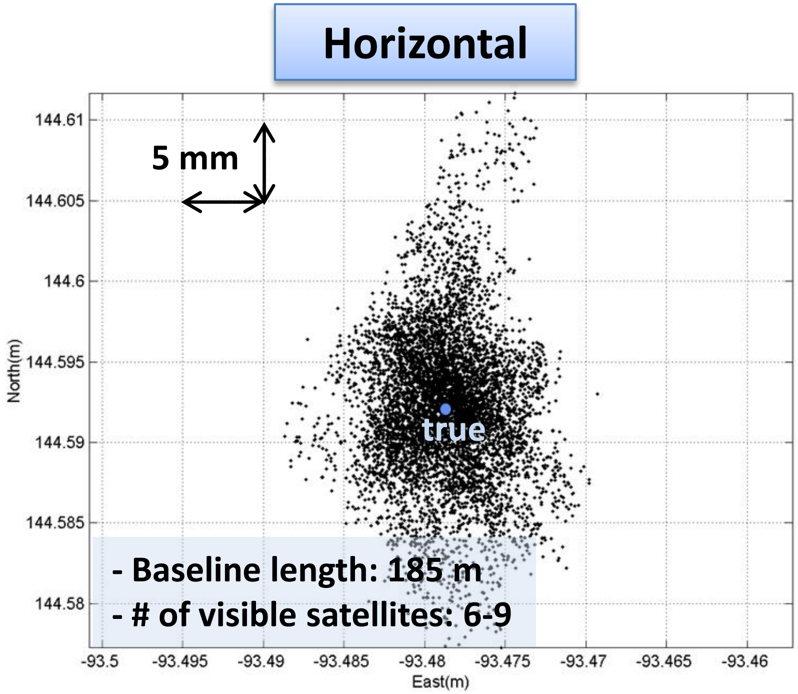
Time Series of Vertical Error for Max. 30sec Latency

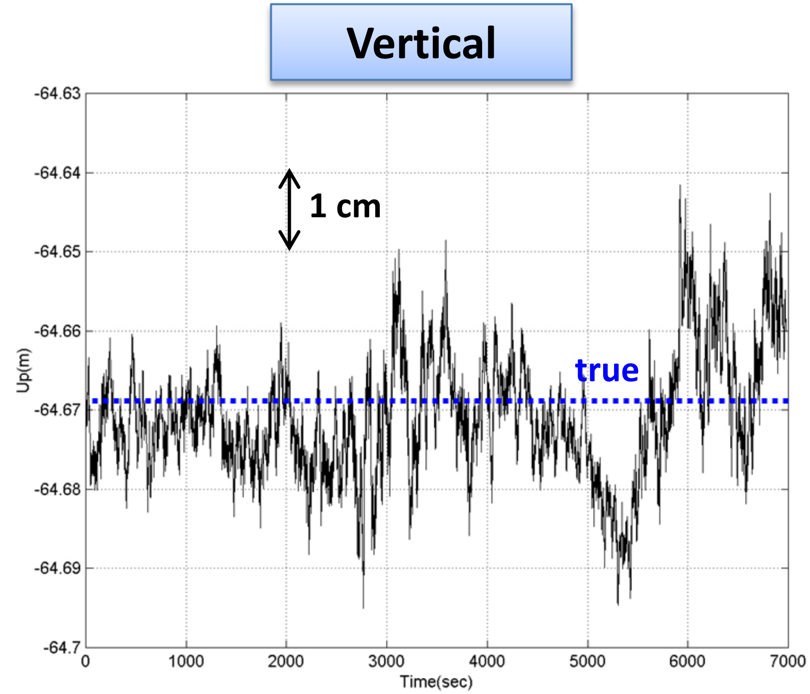


Compact RTK provides stable RTK-fix position even under 30sec latency unlike conventional RTK

Courtesy: Dr. Byungwoon Park

Static Positioning Results for various speeds of data-link





Broadcast bandwidth (bps)	Horizontal Error (2DRMS, cm)	Vertical Error (2RMS, cm)
Unlimited	1.10	1.56
500 bps	+ 0.05	+ 0.10

RTK service available with Compact RTK in 250-500 bps data-link (c.f. Conventional RTK requires approx. 1500 bps)

Test Results for Compact Network RTK

1. Compact Network RTK Positioning Results and Assessment of Required Bandwidth for GPS only signal
2. Test Feasibility of GPS/GLONASS Compact Network RTK and Assessment of Required Bandwidth

Test Environment for Compact Network RTK Validation

GPS only

Network configuration (CORS RS in North Carolina State)

Test environment	
Date of test	July 12th, 2007
Time	17:00 ~ 18:00 KST (local time)
Reference stations	1 Master station (PITT) 5 Auxiliary stations (NCAS, HILB, NCFA, NCLI, RALR)
User	SNFD (27km away from Master station)

Post-processing Field Test

- CORS rinex data (logged in 1 sec)
- Intentional 1sec Time Delay
- Correction Scheduling

➔ No Difference from the Real Time Process

Network RTK Algorithms

- Corrections are generated by SNU-developed software

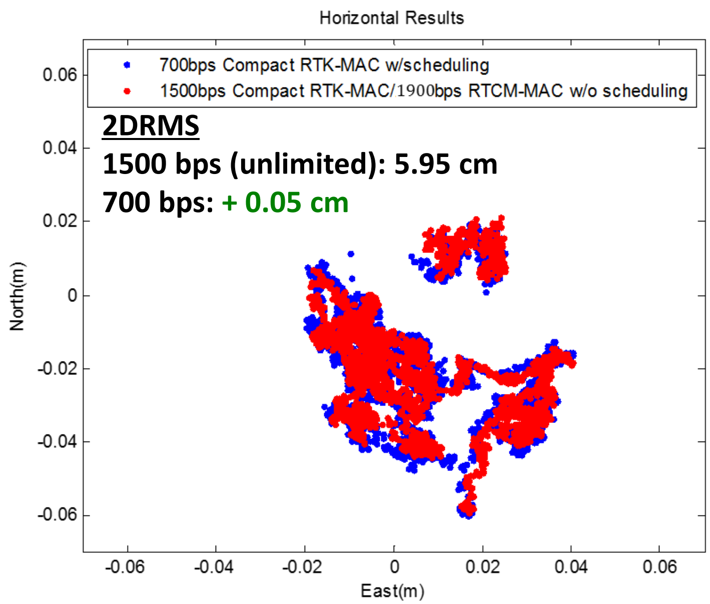
Correction format

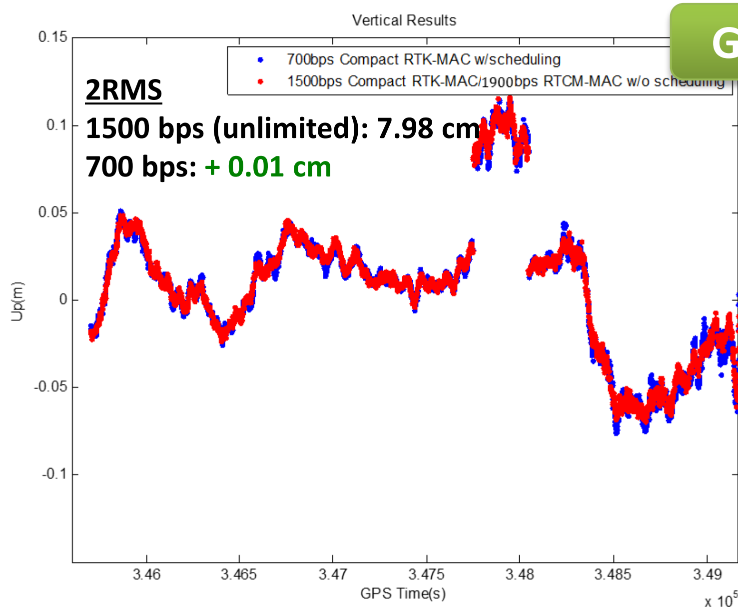
- Compact RTK + Conventional Network RTK Solutions (RTCM 4081 + RTCM v3 1015, 1016, 1034)

➔ **Test Compact Network RTK for various speeds of data-link**

Compact RTK + MAC Test Results & Bandwidth Gain Attribution

GPS only





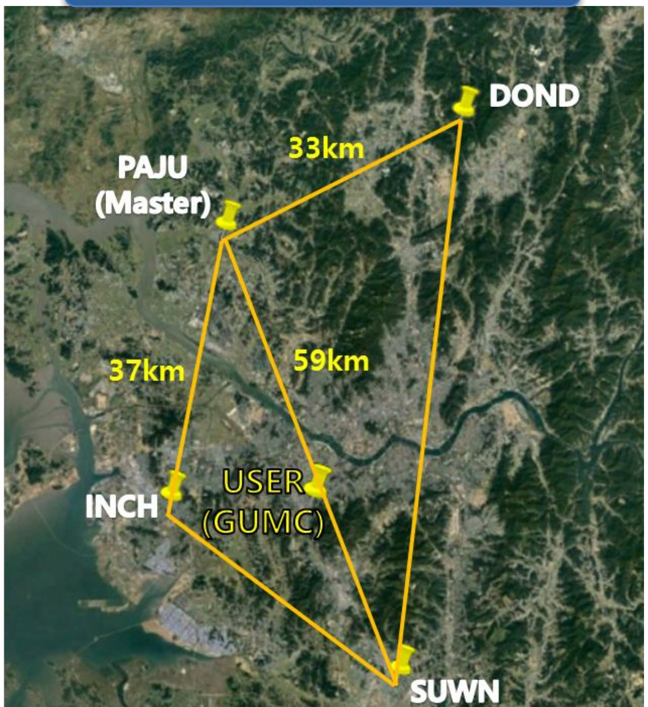
Conventional		Proposed		Performance Assessment	
System Protocol	Bandwidth (MT 1004, 9SVs)	System Protocol	Bandwidth Achieved	Bandwidth Gain	Accuracy Degradation
	>2000 bps		600 bps	70%	

Compact Network RTK Solution reduces the data link rate by approx. 63~70% w/o Accuracy Degradation

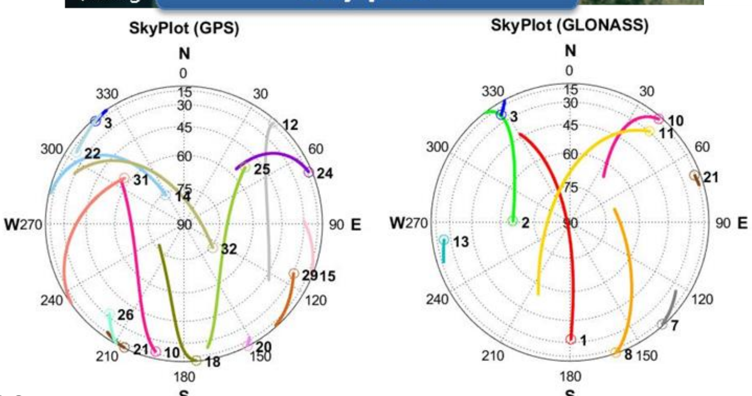
Next step: Use GPS/GLONASS signals for improved visibility

Test environment for GPS/GLONASS Compact Network RTK

Network configuration



Sky plot



Test environment	
Date of test	February 2nd, 2017
Time	13:00 ~ 16:00 KST (local time)
Reference stations	PAJU, DOND, INCH, SUWN (equipped with Trimble receivers)
User	GUMC (35km way from Master station)

Post-processing Field Test

- CORS rinex data (logged in 1 sec)
- Intentional 1sec Time Delay
- Correction Scheduling

➔ **No Difference** from the **Real Time Process**

Network RTK Algorithms

- Apply generated MAC from SNU-developed Compact Network RTK Software

Consideration for GLONASS Feasibility Test

- Consider only homogeneous receivers
- Estimate Single-difference ambiguity to maintain integer characteristics

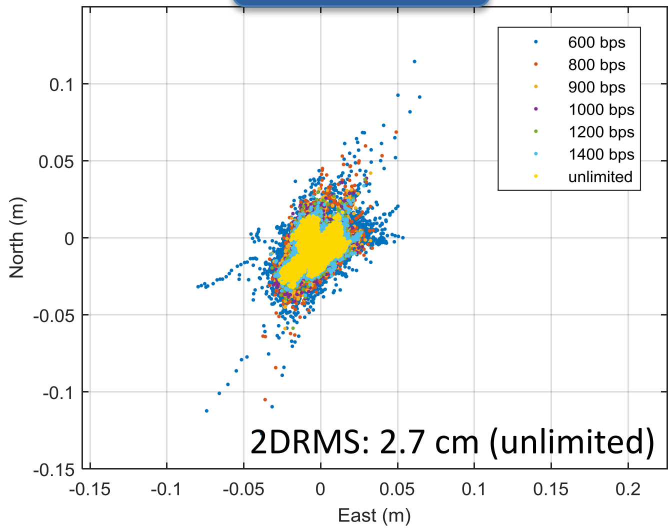
➔ **Test GPS/GLONASS Compact Network RTK for various speeds of data-link**

➔ Required data-link compared with conventional RTCM

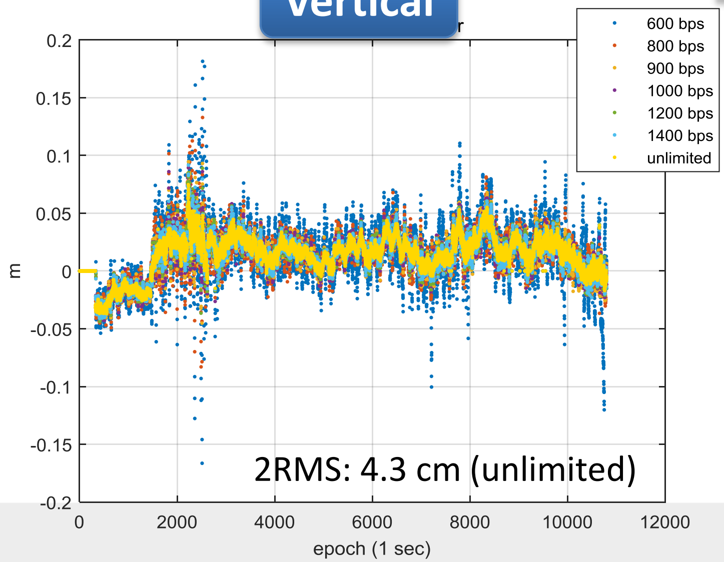
Positioning Error for Various Broadcast Bandwidths

GPS/GLONASS

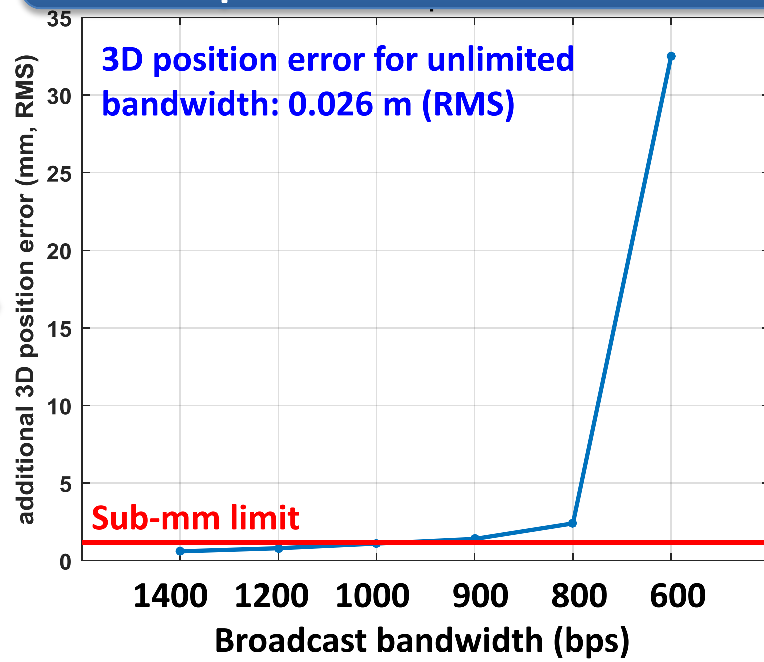
Horizontal



Vertical



Additional 3D position error with respect to unlimited bandwidth



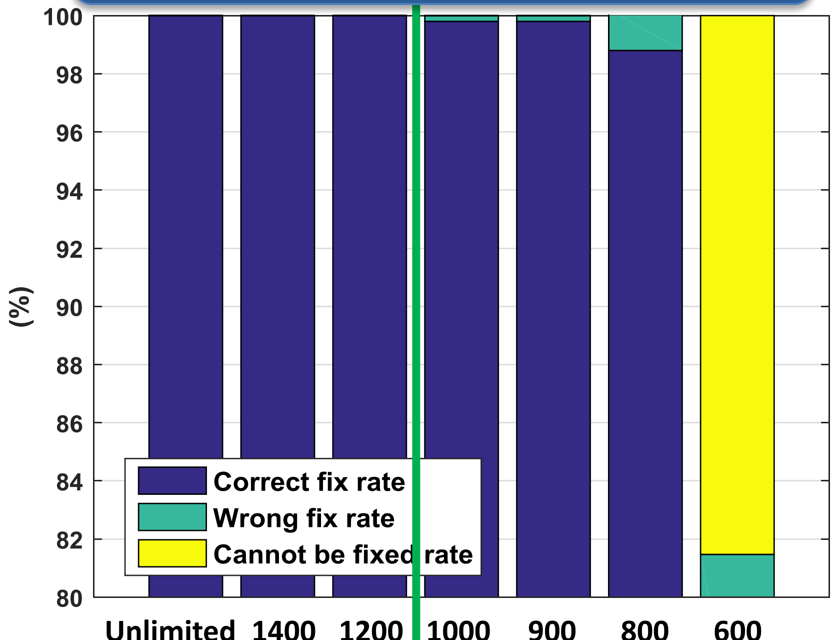
➔ Additional positioning error less than 1 mm for bandwidths larger than 1200 bps (GPS/GLONASS)

Performance of Ambiguity Resolution for Various Broadcast Bandwidths

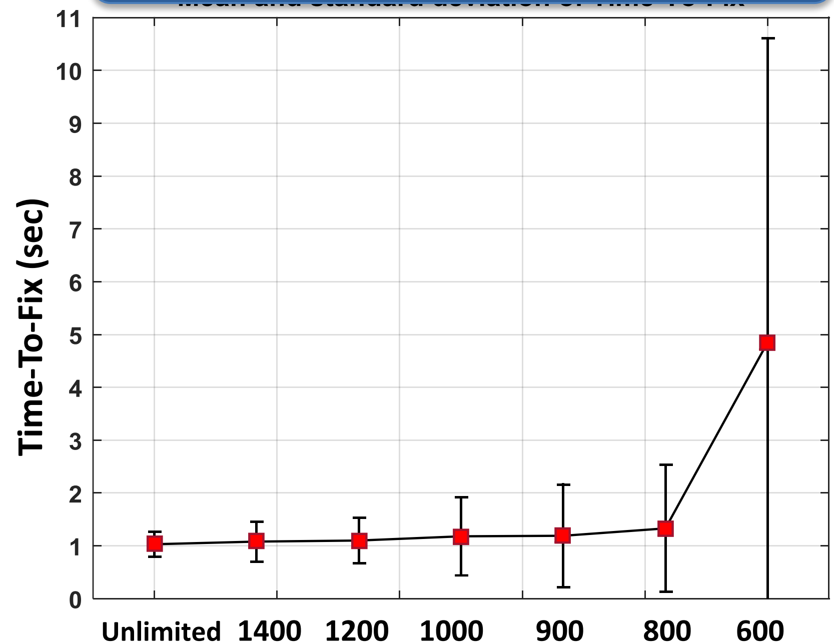
GPS/GLONASS

- **Assessment of ambiguity resolution performance out of 1500 trials**

Ambiguity resolution performance



Mean and standard deviation of Time-To-Fix



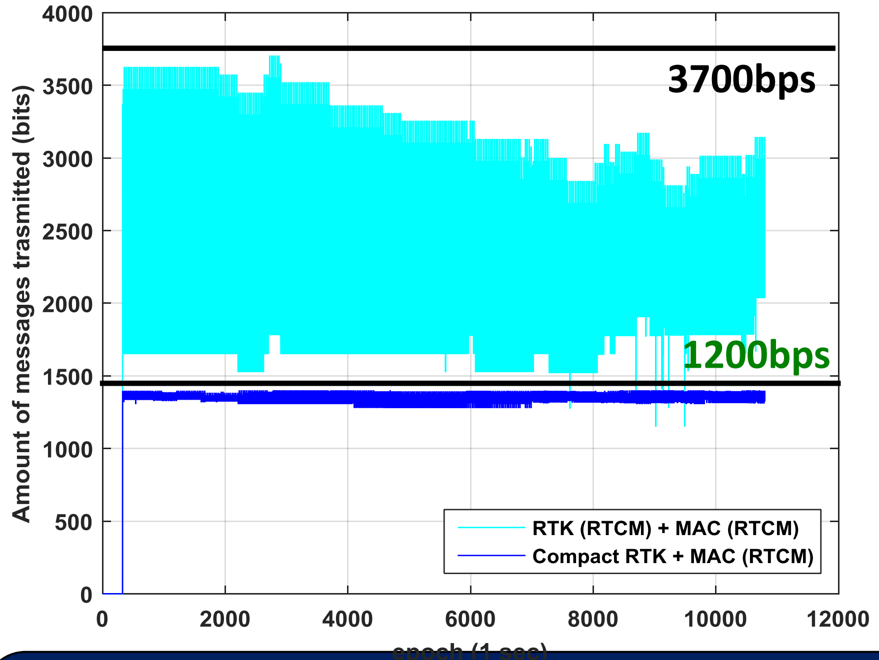
GPS/GLONASS Network RTK service available for 1200 bps data-link using Compact RTK without performance degradation

- Ambiguities can be correctly fixed in 2 seconds

Required bandwidth for GPS/GLONASS Network RTK

GPS/GLONASS

- **Amount of messages transmitted for conventional & Compact Network RTK for the test data set**



Method of Network RTK	Required bandwidth
Conventional MAC Network RTK (calculated according to RTCM recommendation)	3700 bps
MAC Compact Network RTK (proposed)	**1200 bps**

Compact Network RTK can reduce bandwidth by 65% compared to conventional Network RTK for GPS/GLONASS

Conclusions

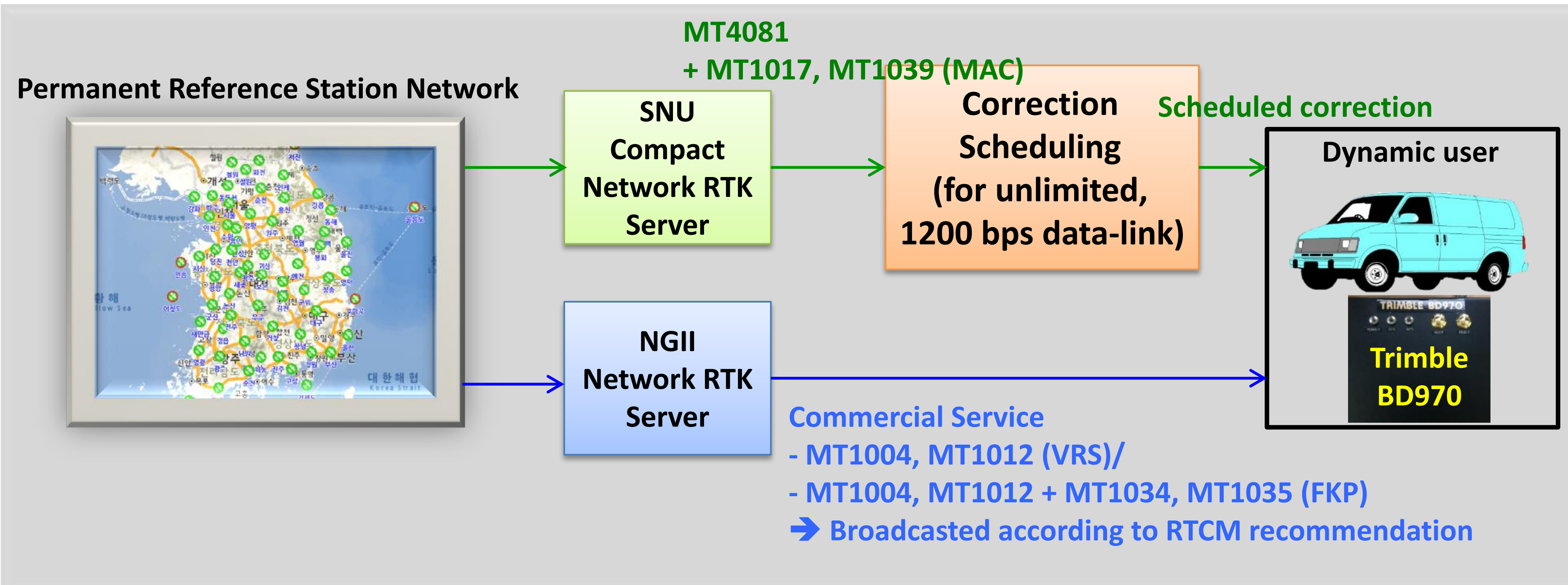
- **Compact RTK (RTCM4081) effectively reduces latency errors caused by broadcast delay or failure**
  - Reduces latency error by 60% compared to conventional RTK (RTCM1004)
  - Maintains RTK position fix for 30-second latency unlike conventional RTK
    - ✓ Conventional RTK switched to DGPS when time of latency reaches 15 sec
- **Compact RTK (GPS only) provides RTK fixed position with 500 bps or even slower data-link without performance degradation (Conventional RTK needs at least 1500 bps)**
- **Compact Network RTK reduces speed of data-link by max. 60% compared to conventional method**

	Required bandwidth (bps)	
	Conventional (MAC)	Compact Network RTK (MAC)
GPS only	1900	700
GPS/GLONASS	3700	1200

- **Target data-link: satellite communication link**

Future Works

- **Real-Time Dynamic User Test for GPS/GLONASS Compact Network RTK**
  - Performance validation of Compact Network RTK for various data-link condition
  - Comparison of performance with conventional Network RTK



Acknowledgement

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Thank you for your attention!