HIGH ACCURACY GNSS IN 5G
RTK, PPP AND RTK-PPP

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Make ideas real

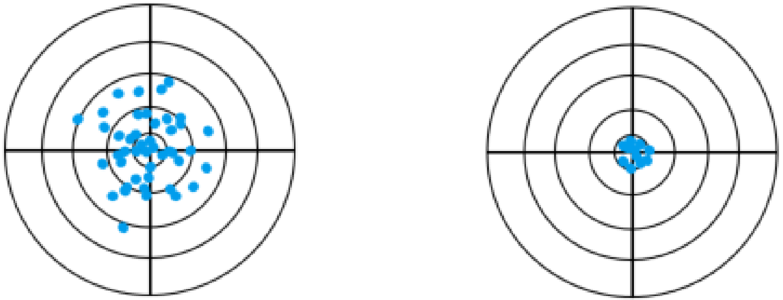
- ► **Part I: High-accuracy GNSS**
- ► **Part II: Market outlook for high-accuracy GNSS**
- ► **Part III: Antenna testing for high-accuracy GNSS**

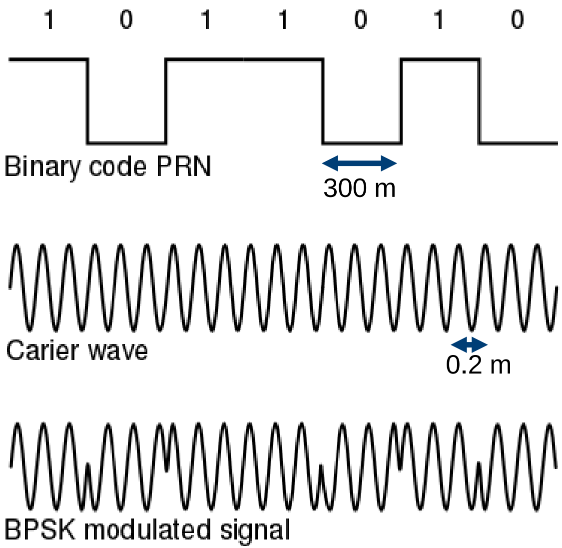
AGENDA

PART I: HIGH-ACCURACY GNSS

HIGH ACCURACY GNSS BASICS

- General concept
  - Start with „normal“ GNSS fix based on **code** phase*
  - Remove errors with
    double-differencing or error modelling
  - Resolve carrier phase ambiguity
    → major factor for convergence time
  - High-precision position based on **carrier** phase





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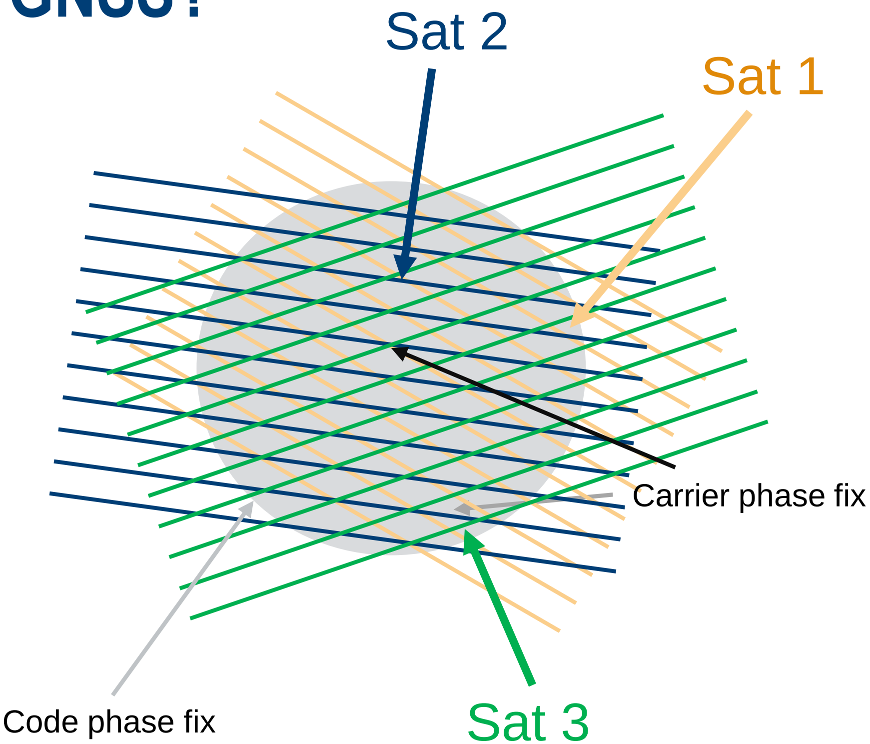
*) code phase is usually orders of magnitude less accurate than the carrier phase

STANDARD VS. HIGH-ACCURACY GNSS?

- For GPS L1 C/A:
  - Code: chip length: ~300 m
  - Carrier: cycle length: ~0.2 m
- High accuracy receivers measure the phase of the **carrier**
  - finer scale
  - less phase noise
  - higher accuracy (< 10 cm)
- Hurdle: ambiguity resolution
  - Code: ~300 km, carrier: 20 cm
- Since late 1990s used in high-end equipment



“High accuracy” == using a finer “scale”!

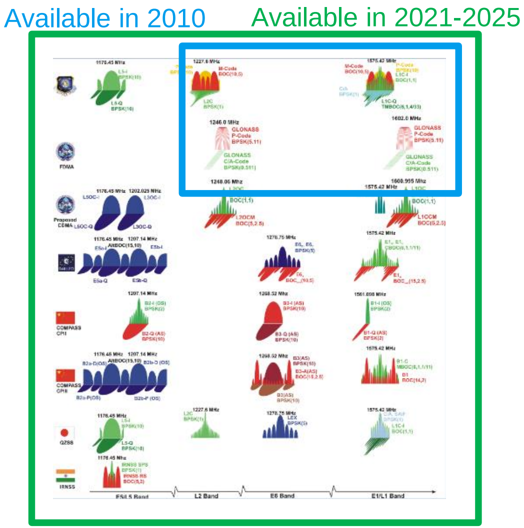
WHAT IS THE CATCH?

Problem domain	Limitations of high accuracy in the past (~2010)
Continuous correction data	Expensive data connections and correction data
Processing complexity for ambiguity resolutions	Slow convergence (tens of minutes)
Limited GNSS constellations and signals	Only GPS L1 C/A and codeless L2 was globally available
GNSS signal blockage caused re-convergence	Low-cost MEMS sensors for fix holdover were not available
Accurately calibrated antennas required	Expensive antennas, not suitable for mass market

- ▶ High accuracy GNSS in 2010
  - – High-end niche market applications (surveying, science)
  - – Expensive receivers and rather expensive annual subscription

THE GOLDEN AGE OF GNSS IS NOW

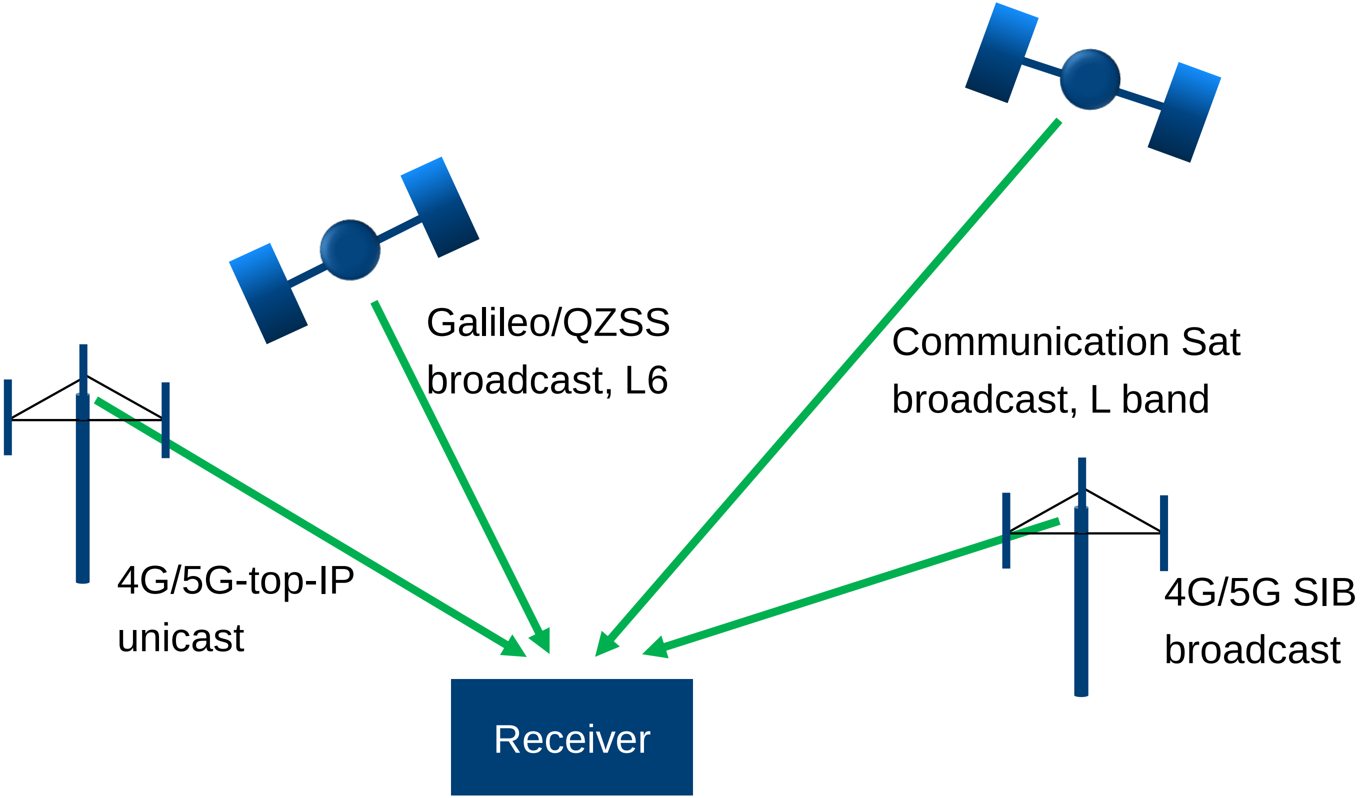
Problem domain	State of the art in 2021
Continuous correction data	Fast wireless connections / affordable correction services
Processing complexity for ambiguity resolutions	Improvement in algorithms and processing power
Limited GNSS constellations and signals	Approx. 4x more GNSS constellations and civil frequencies, Availability of multi-frequency mass market receivers
Fast convergence times in SSR mode	Advancements in error modelling
Robustness during GNSS signal blockage	MEMS integration, improvement of fusion algorithms
Accurately calibrated antennas required	Economies of scale for antennas



Source: Carlos.Lopez, Stefan Wallner / Navipedia

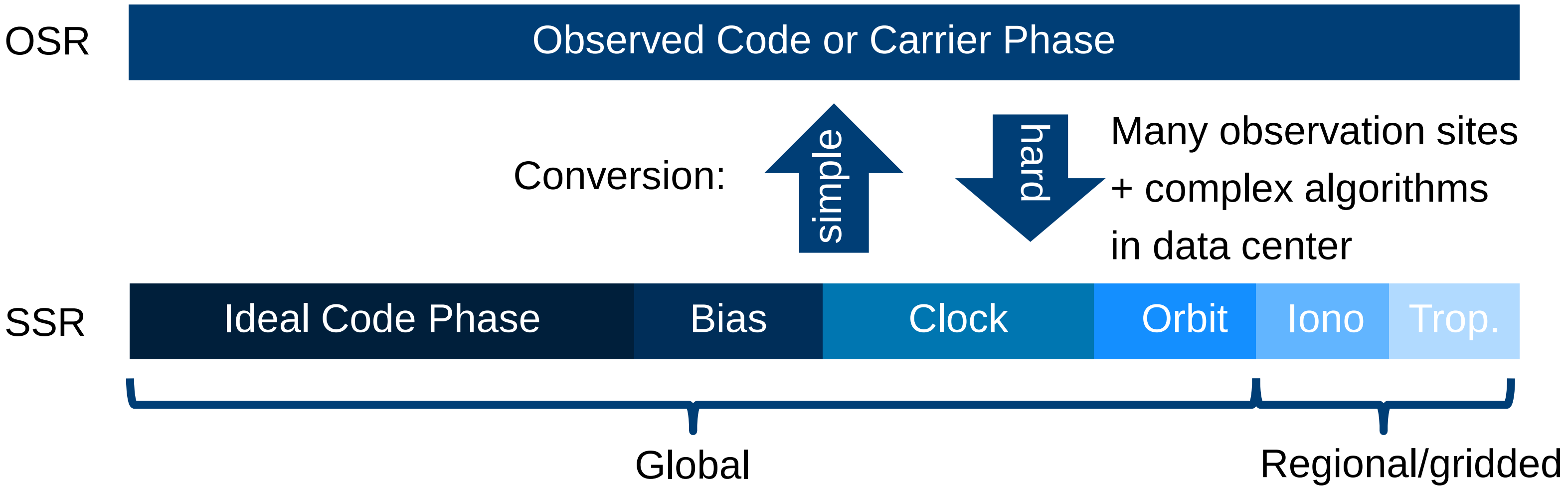
- Almost instantaneous fix
- Low cost
- High accuracy GNSS is arriving at mass market applications
- **A GNSS-revolution is happening right now**

PATHS OF CORRECTION DATA



TYPES OF CORRECTION DATA: OSR / SSR (RTK / PPP)

- Observation Space Representation (OSR): observed code/carrier at a certain location
- State Space Representation (SSR): models to calculate expected code/carrier at ANY location

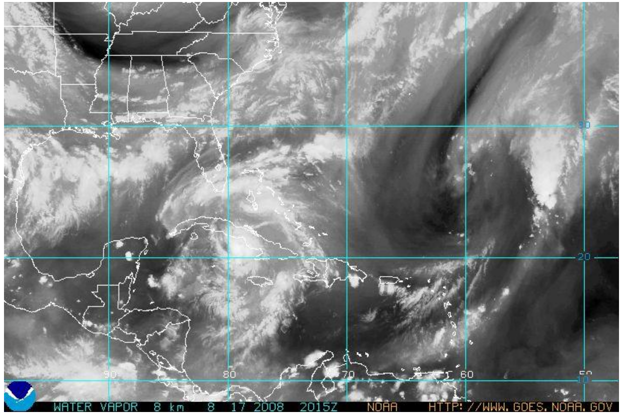


ACRONYMS DECIPHERED: RTK, PPP, OSR, SSR

RTK (OSR)	PPP (SSR)	RTK-PPP (SSR)
Differential positioning technique errors are removed by double-differencing: **reference station** and moving receiver (rover)	Satellite clock/orbit errors are calculated by a network of monitoring stations	Clock, orbit, bias, ionospheric and tropospheric errors are calculated by a network of monitoring stations, a superset/enhancement of PPP
► Convergence almost instantaneously ► Short baselines are required (<20 km) ► Regional coverage ► Handovers required for moving receivers	► No need for nearby reference stations – Works even in the middle of an ocean ► Longer convergence time for fixes (typ. several minutes)	► Promises to combine the strengths of RTK and PPP ► Regional monitoring networks necessary ► Fast convergence ► Large area coverage

WHY REGIONAL CORRECTIONS?

- ► For very fast (re-)convergence time
- ► Reason: natural, regional error sources:
  - – Troposphere: ~ water vapor
  - – Ionosphere: ~ space weather, solar activity
- ► Monitoring stations required in service area



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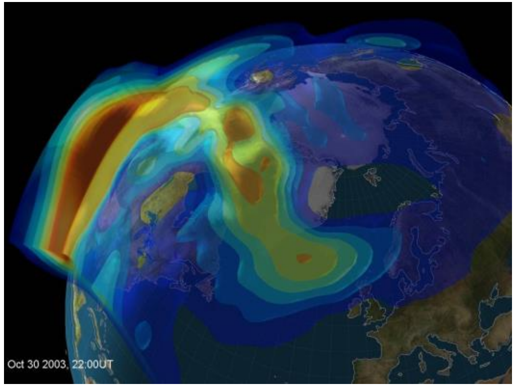
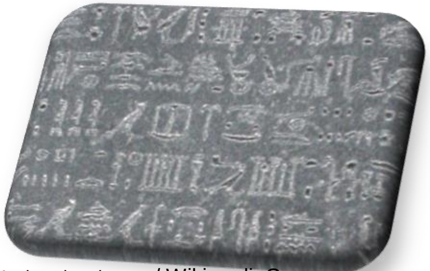


Source: https://www.esa.int/ESA_Multimedia/Images/2014/02/Stormy_ionosphere
University of Bath

MANY SSR STANDARDS

- Several SSR **“languages”**:
  - LPP, SPARTN, RTCM IGS, QZSS L6, Galileo E6 + proprietary formats
    - Similar content, different encoding
  - Will a high-accuracy receiver work world-wide?
- Each protocol has several options – **several “dialects”**
  - e.g. ionosphere low/high resolution
  - Will it work on the long run? For the lifetime of a car?
    - If the service provider is swapped?
    - If the correction service’s software is updated?
- Protocol conformance testing may help



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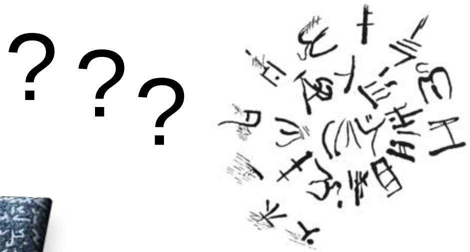

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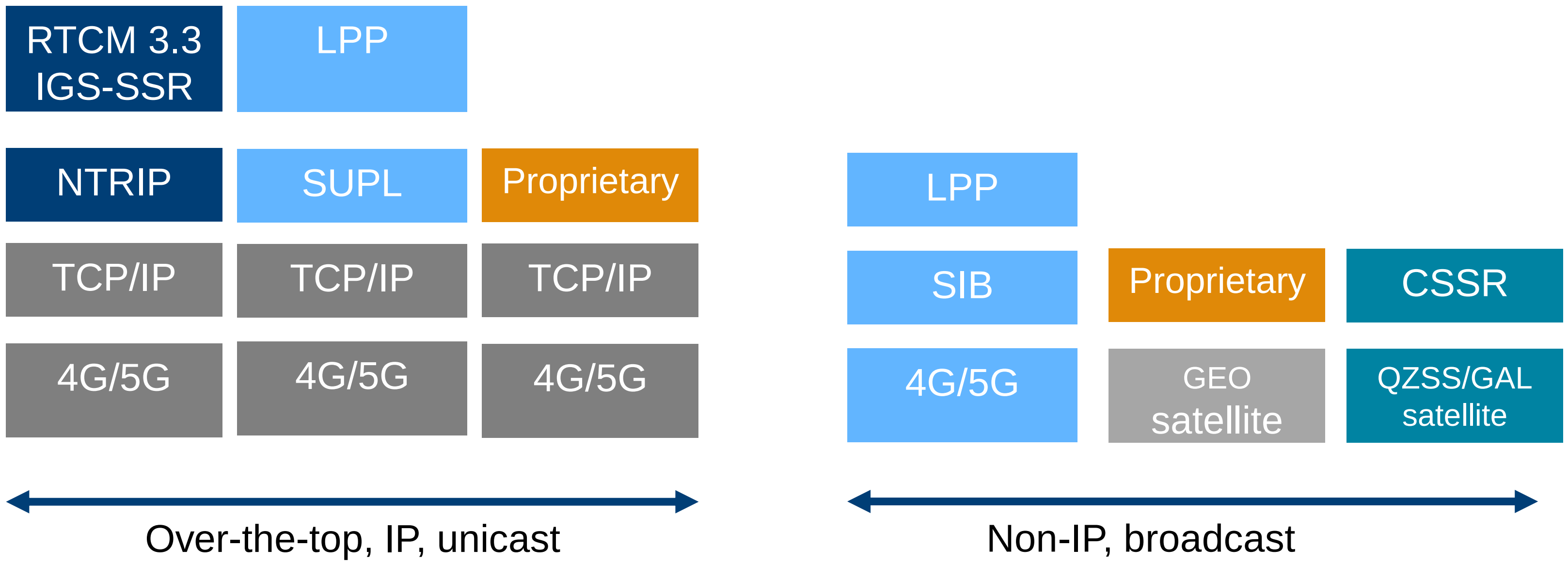
PROTOCOL STACKS FOR HIGH ACCURACY DATA PROVISION



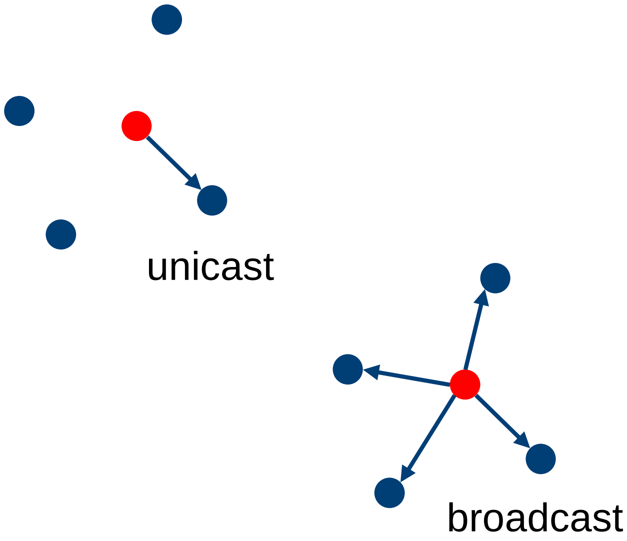
METHODS AND STANDARDS OVERVIEW

Feature	RTCM 3.3	IGS-SSR	LPP (CSSR-like)	Typical proprietary SSR	QZSS CLAS (CSSR) Japan-only	Galileo HAS (CSSR)
Method	OSR	SSR	OSR and SSR	SSR	SSR	
Convergence < 30 s	yes	planned	yes	yes	yes	no
Low data rate	no	yes	yes	yes	yes	
Top-IP	yes	yes	yes	yes	?	
Broadcast	no	no	yes (LTE/5G)	yes (SAT)	yes (SAT)	
Integrity	no	no	2022	yes	?	
SDO	RTCM	IGS	3GPP	Private companies	QZSS	Galileo

Today‘s presentation focus

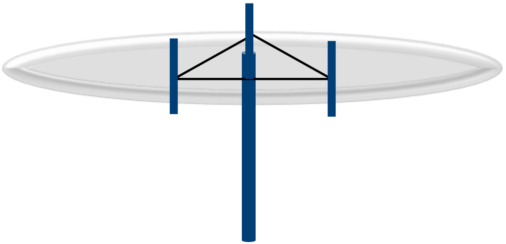
LPP UNICAST VS. BROADCAST?

- **Unicast** (Top-IP: e.g. Ntrip/RTCM, LPP-over-SUPL,)
  - Works on any 5G, 4G network worldwide, with any modem
  - Supports OSR and SSR
  - Data rate less than VoLTE call per user (few kbits/s)
  - Low cost at the beginning
  - Costs grow with number of active users
- **Broadcast** (via SIB)
  - Requires modem support and network upgrades (3GPP Rel. 15/16 network feature)
  - Supports SSR and OSR
  - Scales very well with many users



CELLULAR CORRECTION DATA BROADCASTING

CELLULAR BROADCASTING



- How does it work?
  - Every LTE/NR cell broadcasts basic information → SIBs
    - New in Rel. 15/16: SSR/OSR data in (pos)SIBs (36.331/38.331)
  - posSIB payload: LPP protocol (37.355)
  - Normal SIBs are unencrypted
    - posSIBs can be encrypted → subscription & spoofing protection
      - Different keys for the message types
        - Example:
          - High accuracy, slow convergence: *agriculture, construction*
          - High accuracy, fast convergence: *AR applications*
          - High accuracy, fast convergence + integrity (Rel. 17): *automotive applications*

HOW ARE THE KEYS DISTRIBUTED?

- 3GPP 23.271 9.3a.5
- Location server informs AMF about keys
  - AMF provides keys to user in
    - Attach Accept
    - TAU Accept
  - Based on subscription
- If posSIBs are encrypted, UE has to be attached to cellular network
- Unencrypted posSIBs can be received without any uplink

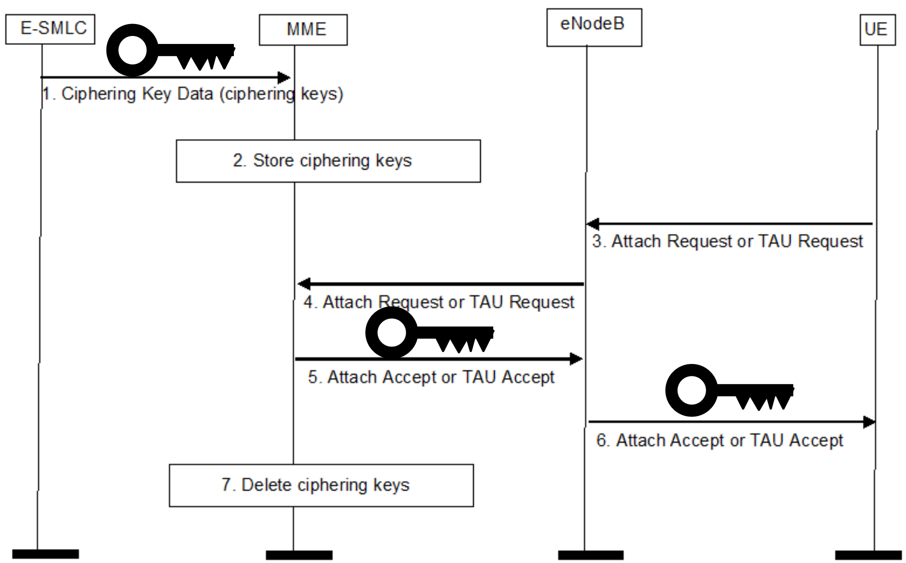
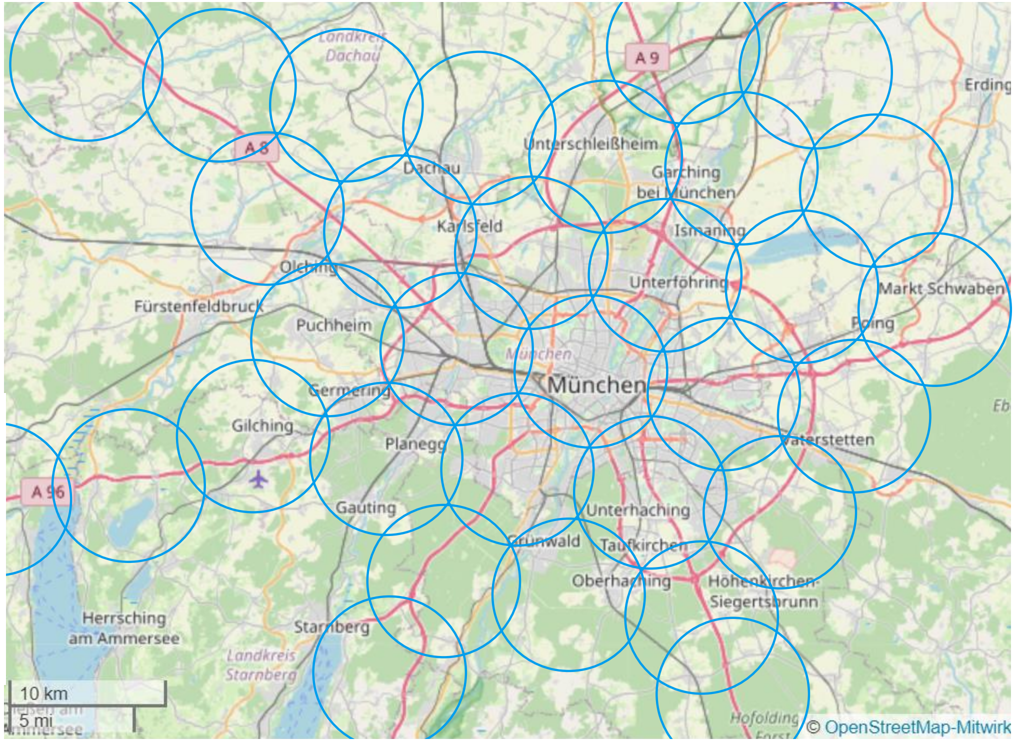


Figure 9.8i: Delivery of Ciphering Keys to UEs for Broadcast Assistance Data

IS OSR(RTK) POSSIBLE VIA BROADCAST?

- Possible, but requires planning
  - Configure cell groups within 10-50 km radius around station
  - Each circle broadcasts different data



PART II: MARKET OUTLOOK FOR HIGH-ACCURACY GNSS

3GPP POSITIONING ACCURACY REQUIREMENTS

3GPP Release 15	Commercial						E2E Latency
	Indoor			Outdoor			
	Hor.	Vert.	% UEs	Hor.	Ver.	% UEs	
	<3 m	<3 m	80%	<10 m	<3 m	80%	1 s

3GPP Release 17	Commercial			IIoT			E2E Latency
	Hor.	Vert.	% UEs	Hor.	Ver.	% UEs	
	<1 m	<3 m	90%	<0.2 m	<3 m	90%	100 ms

TR 38.857

USE CASES FOR HIGH-ACCURACY POSITIONING

Rel. 15

Augmented Reality

Assisted Driving

UAV

Bike Sharing

eHealth

Waste Management

Wearables

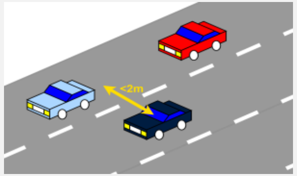
Asset Tracking

Advertisement Push

Traffic monitoring and control

Rel. 17

Automotive

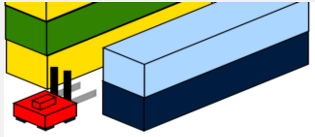


- Assisted and automated driving
- Collision avoidance systems

Rail

- Absolute positioning
- Track identification
- Train warning systems

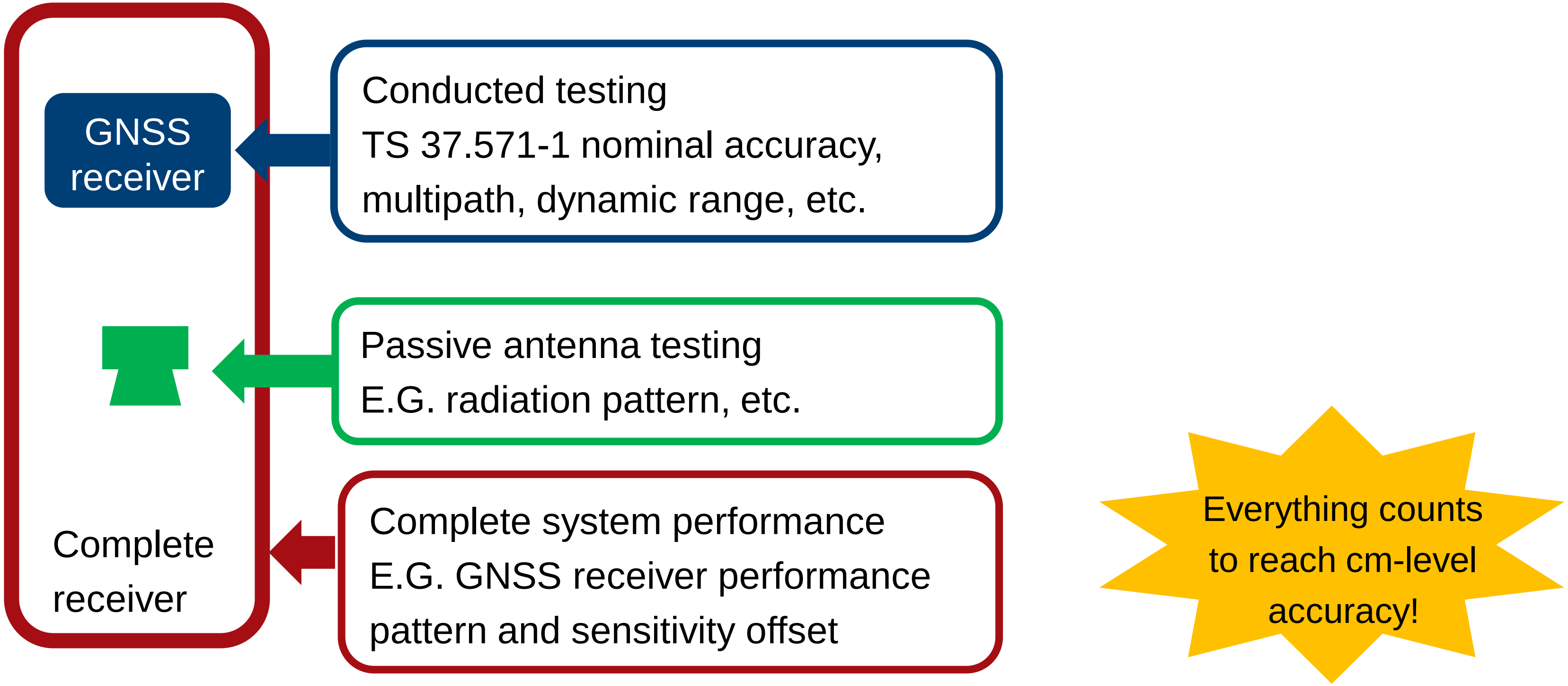
IIoT



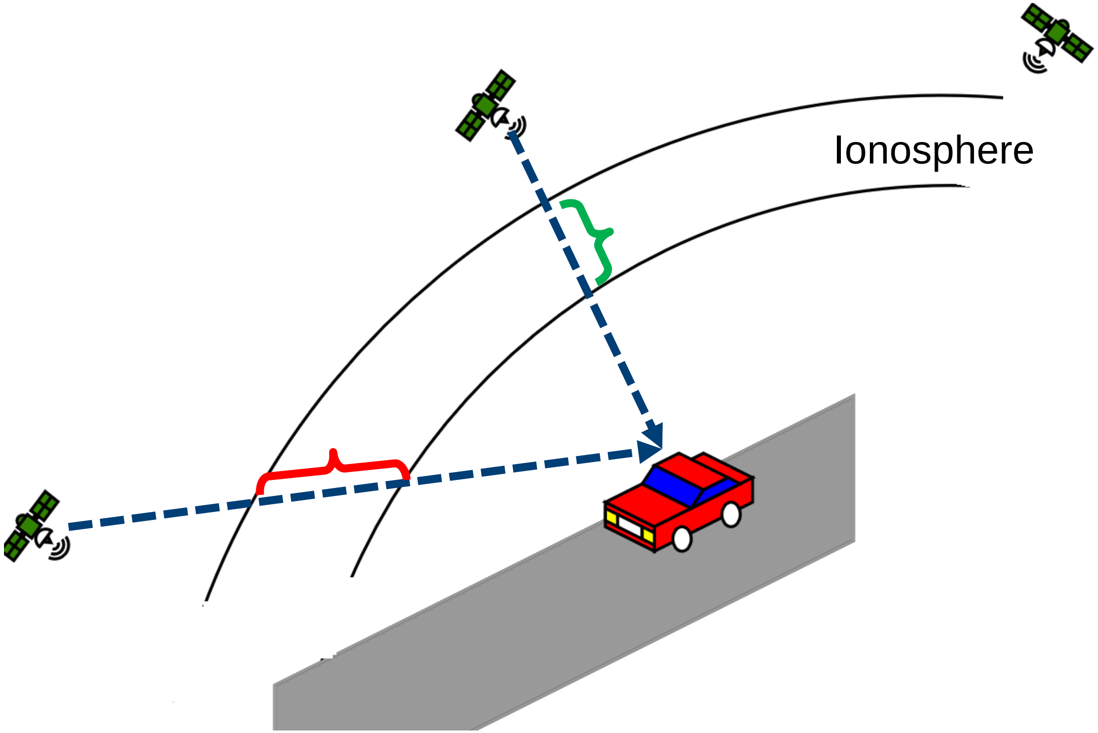
- AGV (Automated Guided Vehicles)

PART III: ANTENNA TESTING FOR HIGH-ACCURACY GNSS

GNSS RECEIVER VS. ANTENNA TESTING



LOW-ELEVATION SATELLITES

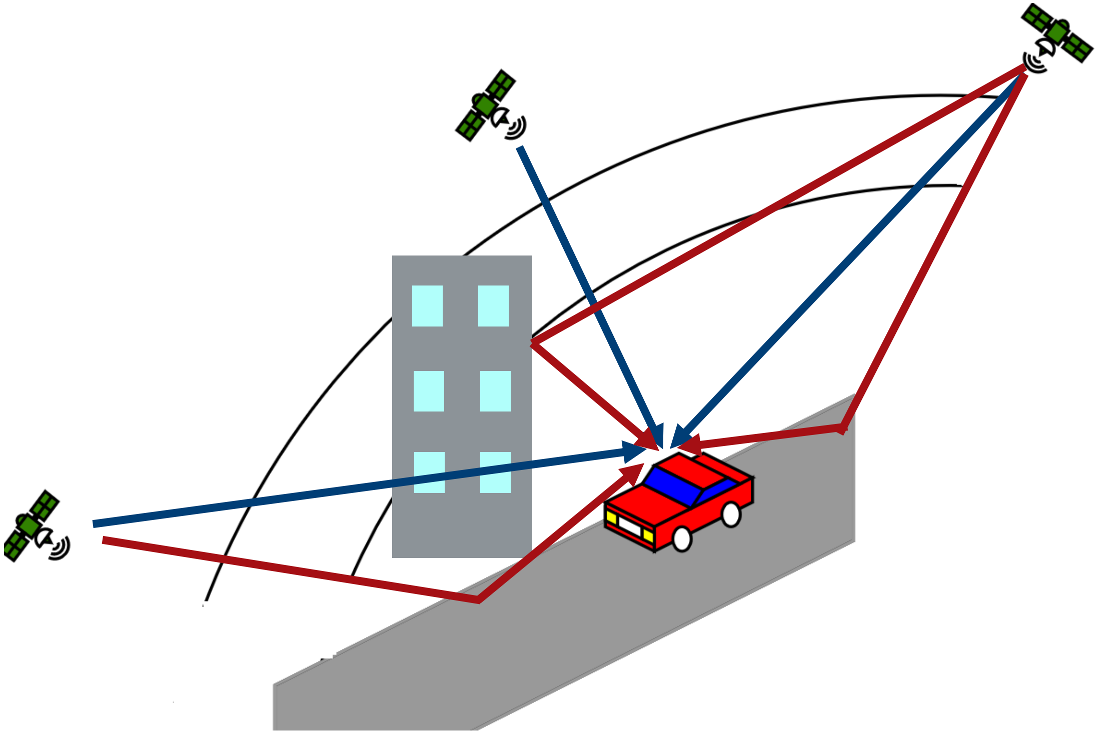


The signal from high elevation satellites crosses the atmosphere perpendicularly.

The signal from low elevation satellites crosses the atmosphere transversally.

Low elevation satellites are affected by larger atmospheric perturbances and result in larger positioning errors. Low elevation satellites can be automatically filtered by commercial receivers.

MULTIPATH

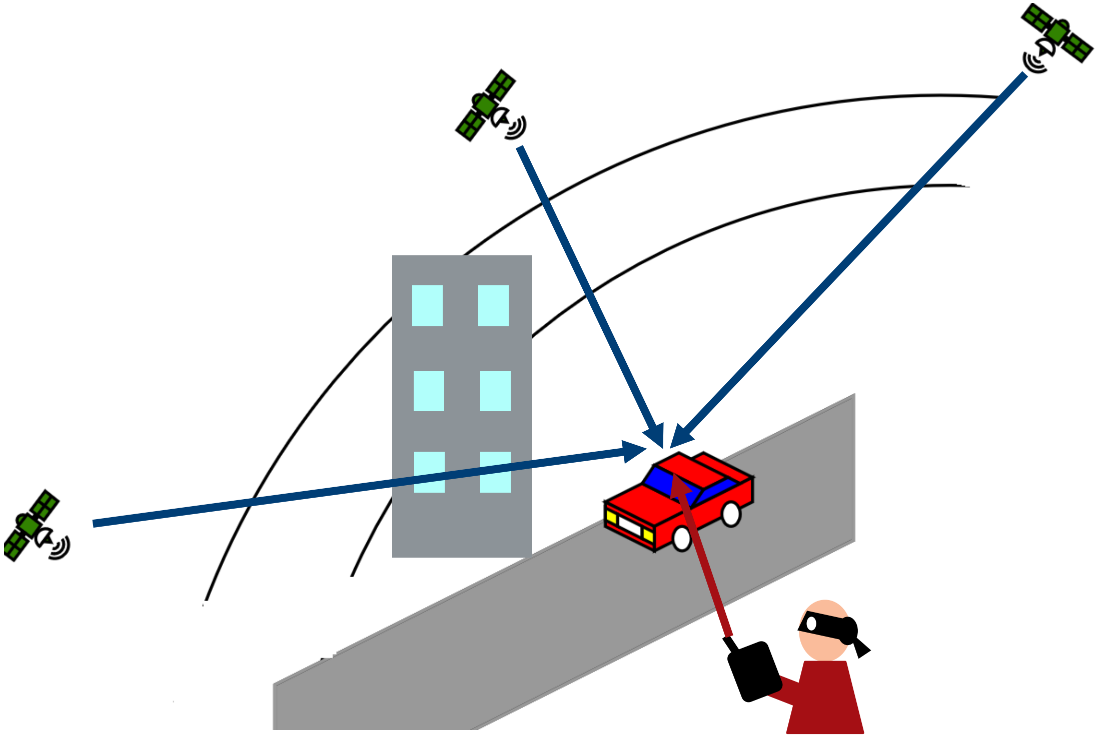


The GNSS receiver receives not only the LoS components, but also multipath components.

A large portion of the multipath components originate from reflections on the ground level and come with low elevation angle.

Low elevation satellites are typically more affected by multipath.

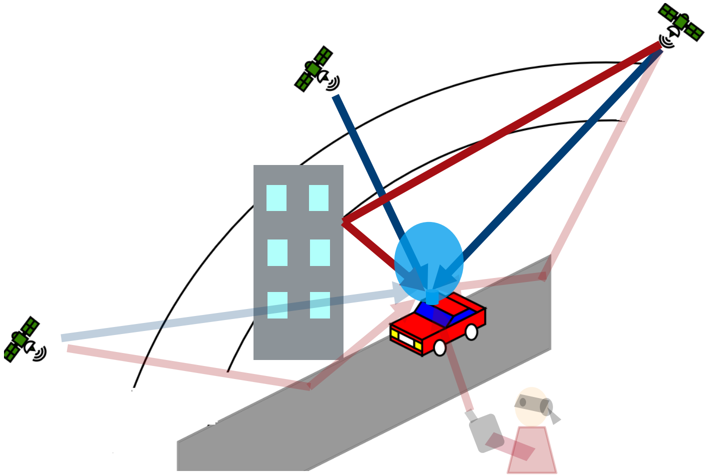
INTERFERENCE, JAMMING, SPOOFING

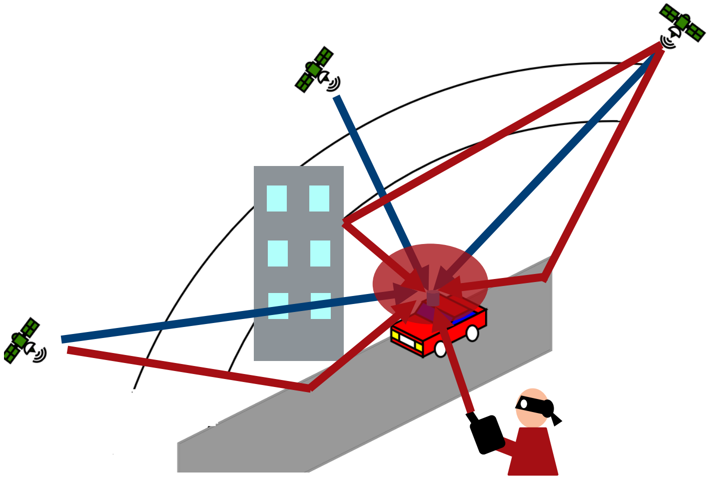


Another source of error for GNSS positioning is interference, either malicious (e.g. jamming, spoofing) or not.

These interferences and attacks are also likely to originate at ground level.

ANTENNA INFLUENCE

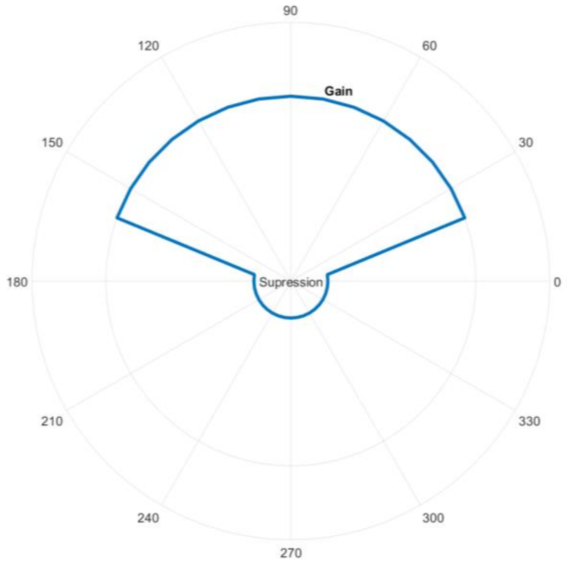




A good antenna can help reduce GNSS errors by mitigating or filtering some of the error sources

A bad antenna on the other hand may even amplify the error sources, decreasing the overall system performance

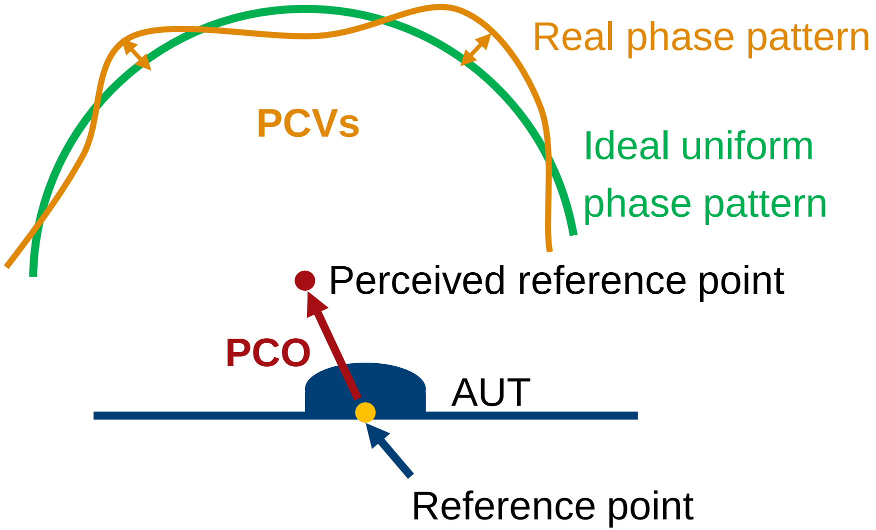
ANTENNA REQUIREMENTS



- Typical antenna pattern for high-accuracy GNSS
- The area around the Zenith is designed for maximum gain, in order to amplify the desired signals
- The area around and below the horizon is designed for suppression, in order to filter out undesired interference, low elevation satellites, multipath, etc.
- Similar patterns are often recommended, e.g. in the 5GAA “Vehicular Antenna Test Methodology”

PCV / PCO

- The phase pattern has a direct impact in high-precision GNSS
- The phase center offset is the difference between the reference point of the antenna and the perceived reference point (center of phases)
- The phase center variation is the difference between the ideal and the real phase pattern at a specific variation



COMPLETE RECEIVER TESTS

- GNSS pattern measurement
  - Collect C/N0 measurement reports in a 3D scan
  - This results in a 3D C/N0 pattern for the GNSS receiver + antenna
- Sensitivity offset
  - Select the beam peak from the GNSS pattern
  - Run a sensitivity search procedure to determine the sensitivity level of the system at the beam peak
  - Use the results to offset the GNSS pattern

Ref: https://5gaa.org/news/vehicular-antenna-test-methodology/

R&S TEST SOLUTIONS FOR HIGH ACCURACY GNSS

R&S®SMBV100B
vector signal generator

- 1 RF
- Simultaneous L1, L2, L5
- NTRIP/RTCM support

R&S®SMW200A
vector signal generator

- 2 RF (further extendable)
- Simultaneous L1, L2, L5
- Interference emulation
- Multiple antenna emulation
- NTRIP/RTCM support

R&S®CMW500
R&S®CMX500
Radio communication testers

- 2G, 3G, 4G, 5G

WPTC shielded room

- PCV/PCO

HIGH ACCURACY GNSS IN 5G
RTK, PPP AND RTK-PPP

Thank you

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Make ideas real