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Synchronization Requirements of 5G and Corresponding Solutions

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Outline

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- Overview of China Mobile PTP network
- 5G Backhaul/Fronthaul architecture and Synchronization Requirements
- Time Synchronization network reference model and Potential solutions
- Conclusion

IEEE 1588 application in China Mobile

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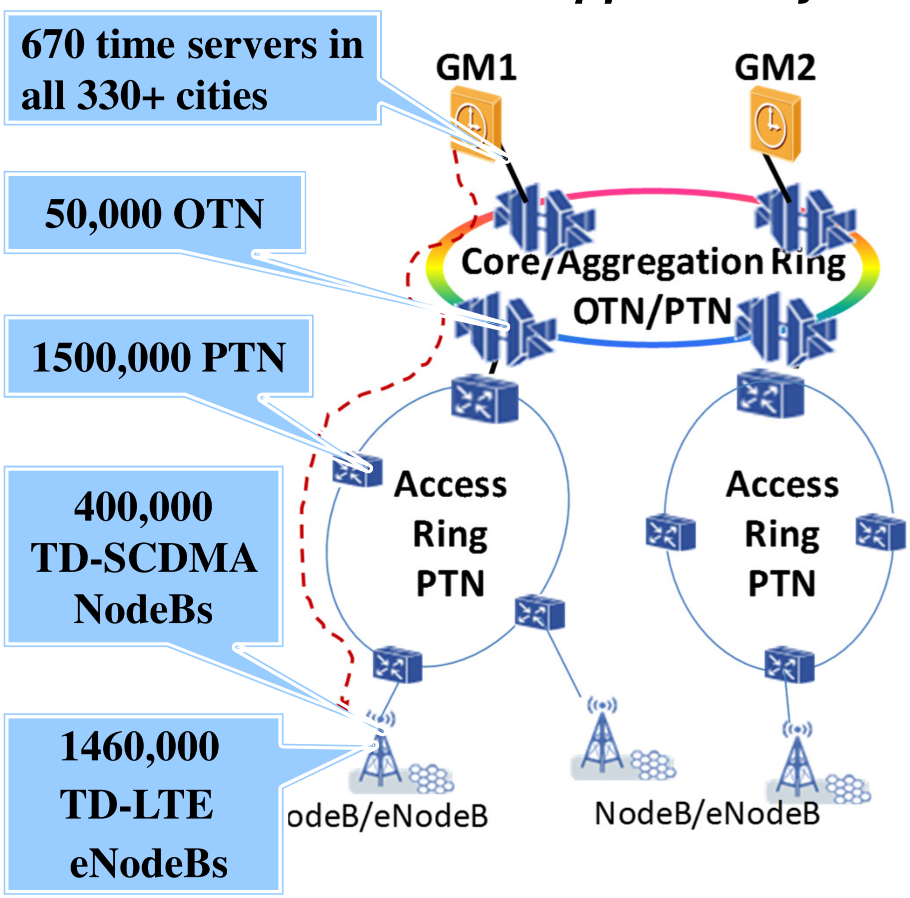
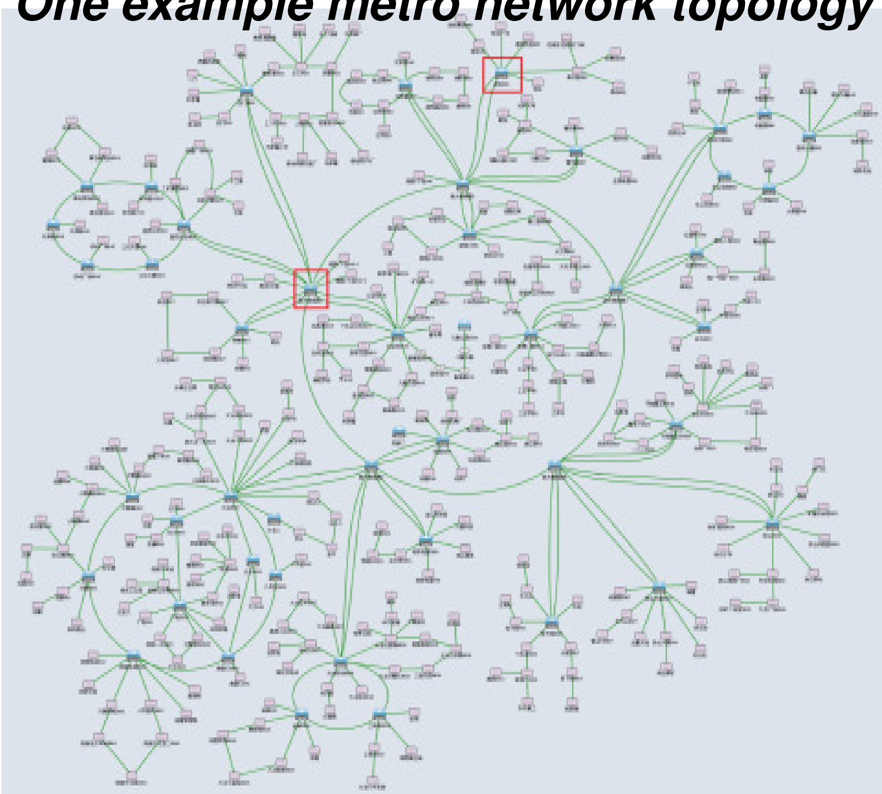
China Mobile has built the PTP networks for all the cities in China.
All the time servers, transport equipments and TD-SCDMA/TD-LTE stations have supported PTP.

The PTP functions are supported by:



One example metro network topology



- Mainly ring topology.
- 80% metro networks exceed 20 hops for PTP.

PTP network performance and experience

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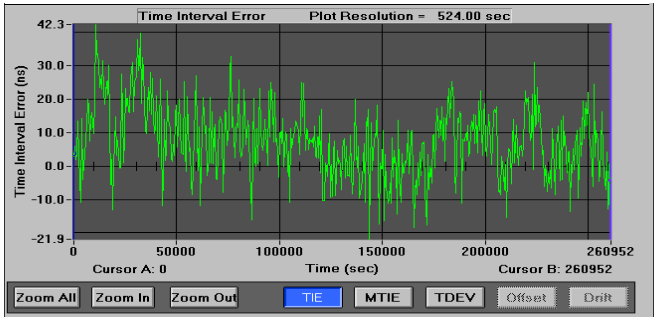
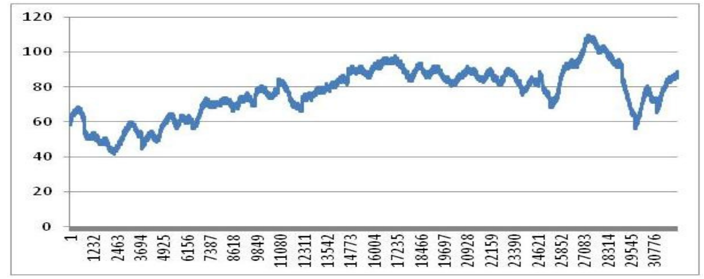
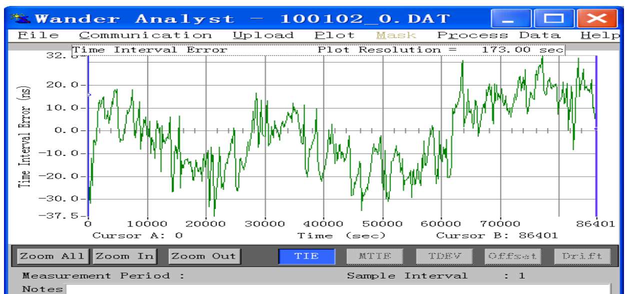
The PTP network under test are all within +/-500ns.



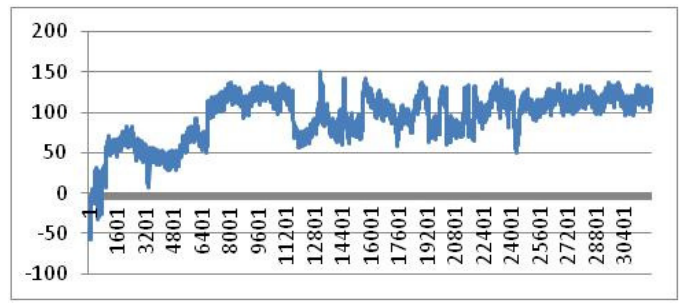
City: Hangzhou
-22ns to 43ns during 72 hours



City: Guangzhou
-46ns to 110ns during 27 hours



City: Yangzhou
-37.5ns to 32ns during 24 hours



City: Dongying
-254ns to 235ns during 27 hours

Valuable experience

- **Hop by hop BC+SyncE, full path sync support, limited time domain**
- **Frequency quality based clock class mechanism**
- **Asymmetry detecting in the ring topologies on PTP passive ports**
- **10% base stations with both PTP and GPS as monitoring points**

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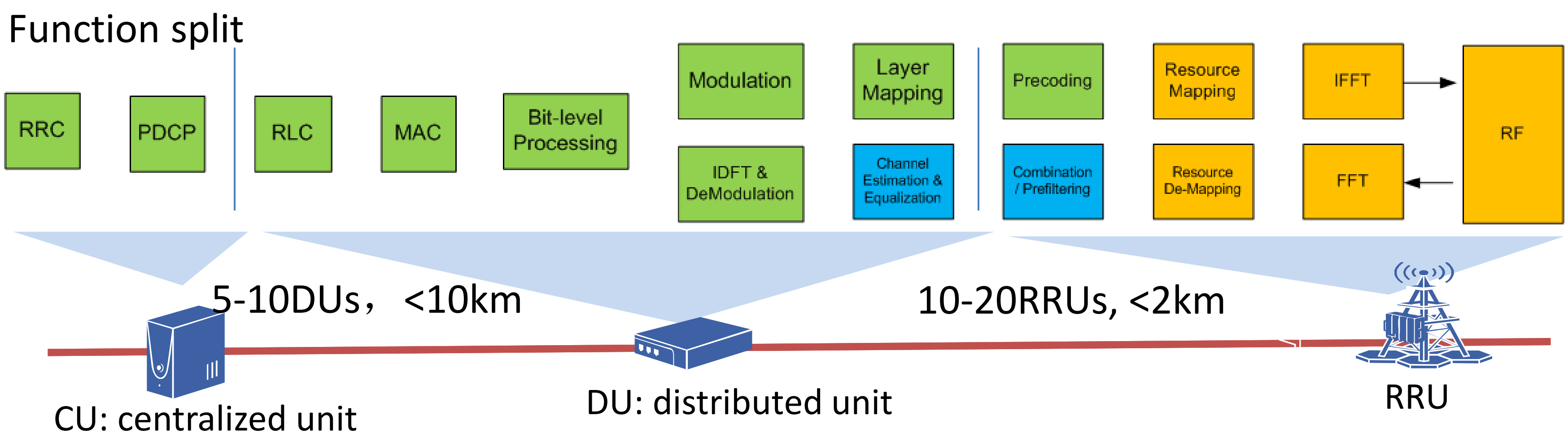
Two-stage CRAN Architecture for 5G

- **5G C-RAN BBU will be divided into the functional entities of CU and DU.**
- **Accordingly, the fronthual domain will include two stages (IEEE 1914 NGFI):**
  - **Domain I between RRU and DU**
  - **Domain II between DU and CU**



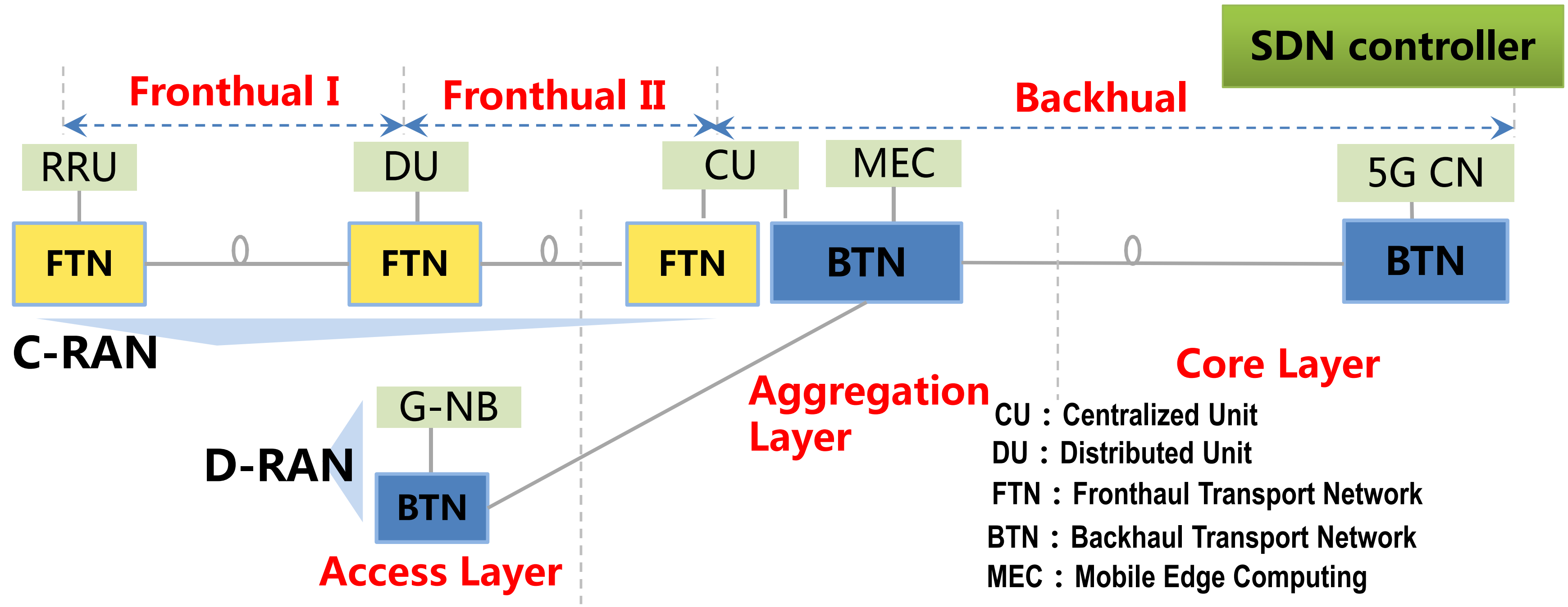
- Higher layer protocol stack
- Anchor point for DC/cell cooperation etc.
- platform/virtualization

- PHY layer and non-realtime layer 2 functions
- Collaboration among RRUs

- Partial physical functions moved to RRU

5G fronthaul and backhual Challenges

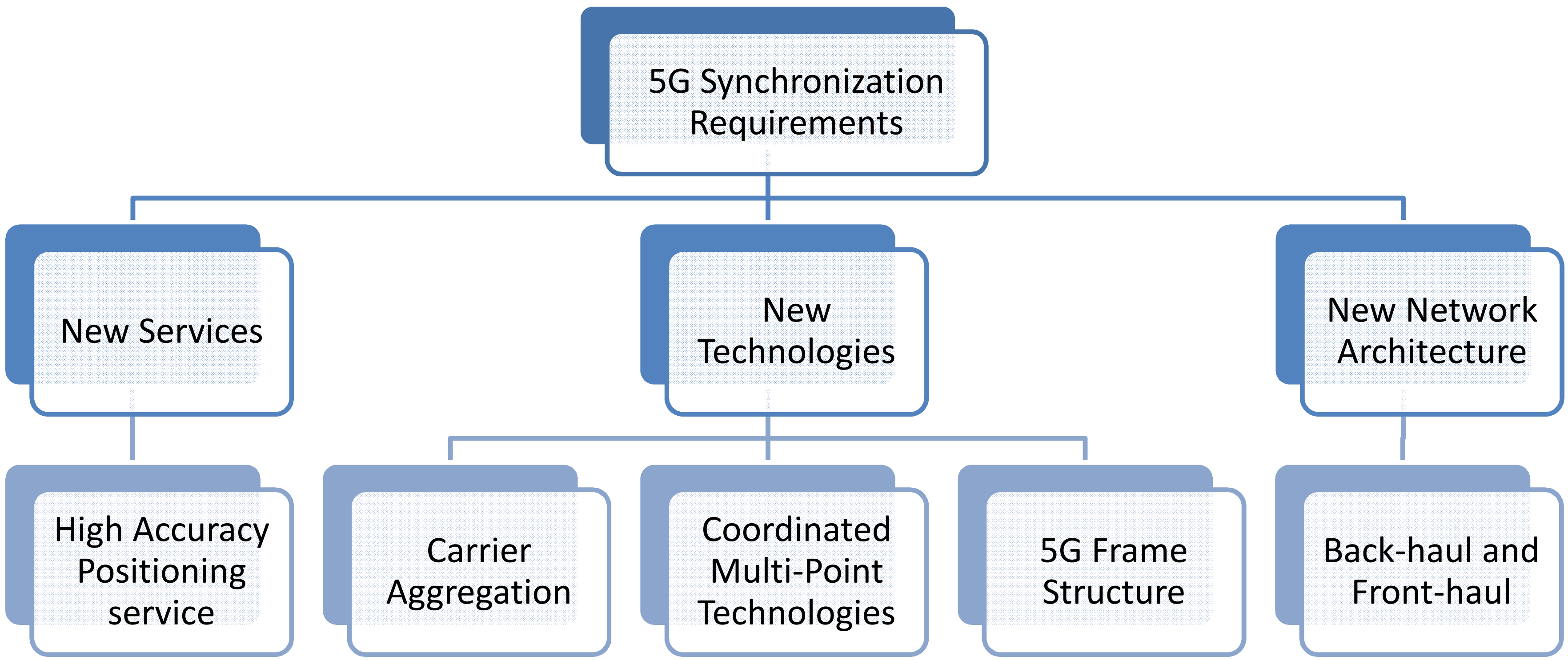
NGFI-I (RRU-DU) :~ 25Gbps as eCPRI 200MHz, 128 antennas, 16flows	NGFI-II (DU-CU) : ~ 8.4Gbps	BTN: >10.8T 7.8G/gNB, 2000 gNBs



2X of Transport nodes: extends to DU at least
10X of Bandwidth: 10.8T capacity, N*25G/50G/100G interfaces
100X of connections: L3 to the edge, SDN DCI for NFV/cloud
Ultra low latency: NGFI-I (~50us, pure optical), NGFI-II(~150us)

5G Synchronization Requirements

For 5G, higher accuracy time synchronization requirements are raised due to new services, technologies, and network architecture.



5G New Technologies - Carrier Aggregation

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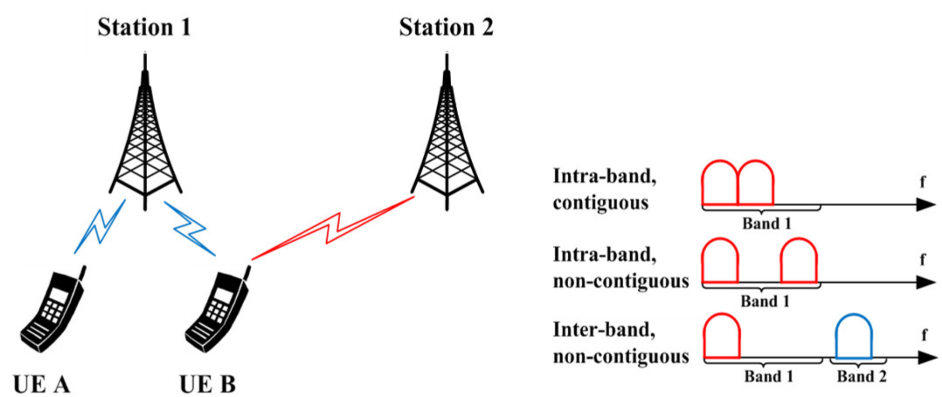
Carrier aggregation (CA) enables the use of multiple carriers in the same or different frequency bands, to increase mobile data throughput.

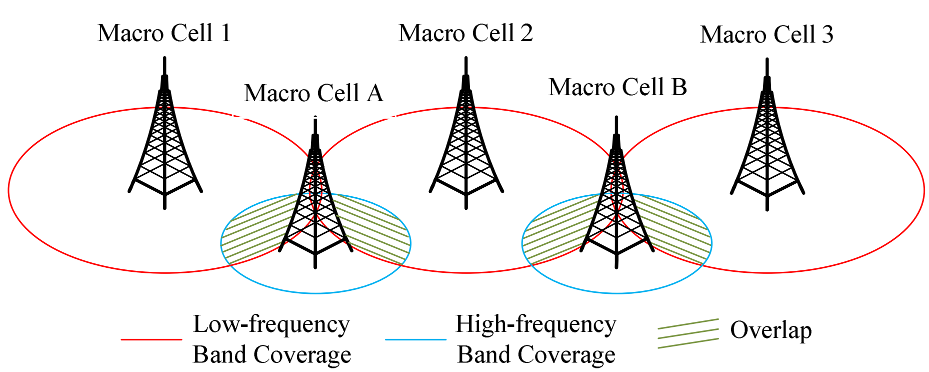


3GPP TAE requirement:

(1) Intra-band contiguous CA
TAE ≤ 130 ns

(2) Intra-band non-contiguous CA
TAE ≤ 260 ns

(3) Inter-band CA
TAE ≤ 260 ns

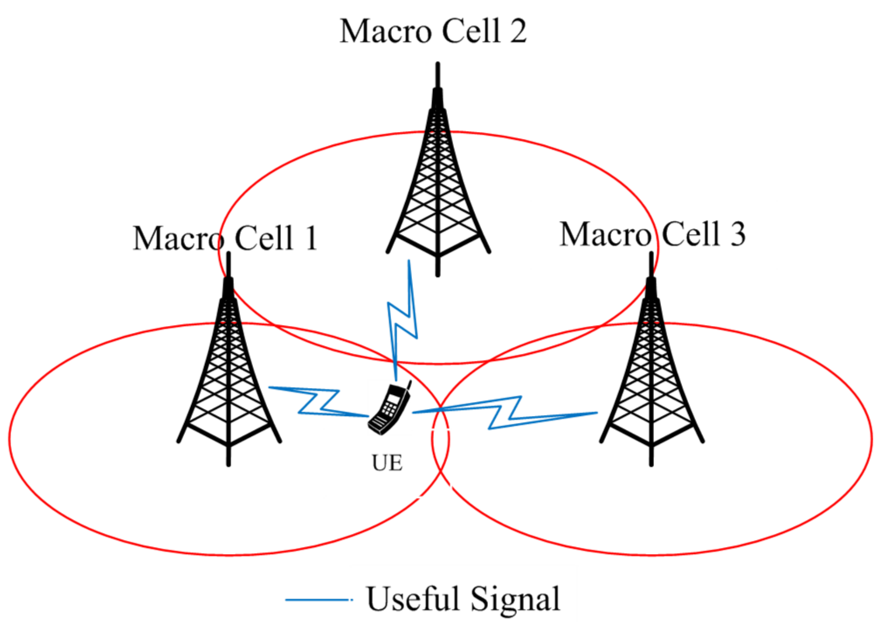


(1) Inter-band CA would be used for the inter-site scenario.

(2) 260ns between cell sites should be satisfied.

5G New Technologies – CoMP Technologies

Coordinated multi-point (CoMP): JT, JR and CS/CB
JT: simultaneous data transmission from multiple cells to a single UE
JR: Joint reception; CS/CB: Coordinated Scheduling/Beamforming



(1) In3GPP, JT UE performance requirements are defined by assuming a typical timing offset in the range [-0.5, 2] µs.

(2) This timing offset at the UE is composed of cell site TAE and the difference of propagation delays.

JR and CS/CB have no special requirements;
For JT, the TAE is usually thought to be within 260ns based on simulations.

5G New Technologies – New Frame Structure

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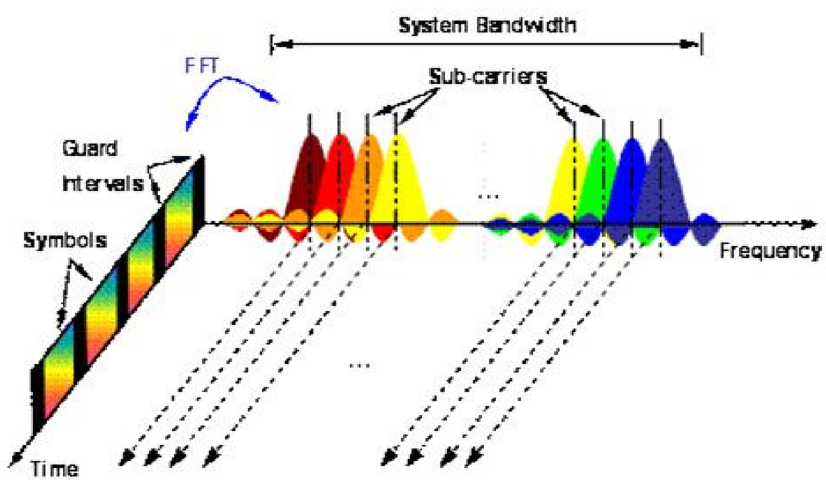
Six numerology options for 5G symbol length

Using same CP overhead regardless of numerologies						
Scaling factor (2^n)	-2	-1	0	1	2	3
Subcarrier spacing (kHz)	3.75	7.5	15	30	60	120
OFDM symbol duration (µs)	266.67	133.33	66.67	33.33	16.67	8.33
Normal CP length (µs)	(20.8,18.76)	(10.4, 9.38)	(5.2, 4.69)	(2.6, 2.34)	(1.3, 1.17)	(0.65,0.59)

4G 5G Candidate



3G/4G

(1) The accuracy requirement is +/-1.5µs by calculation based on the frame timeslot or the CP length.
(2) Existing LTE: 15kHz spacing, 4.69µs CP length

5G

The frame structure will be changed with shorter CP.
(1) 30kHz or 60kHz spacing
(2) 2.34µs or 1.17µs CP length
(3) +/-780ns or +/-390ns

5G New Services – High Accuracy Positioning

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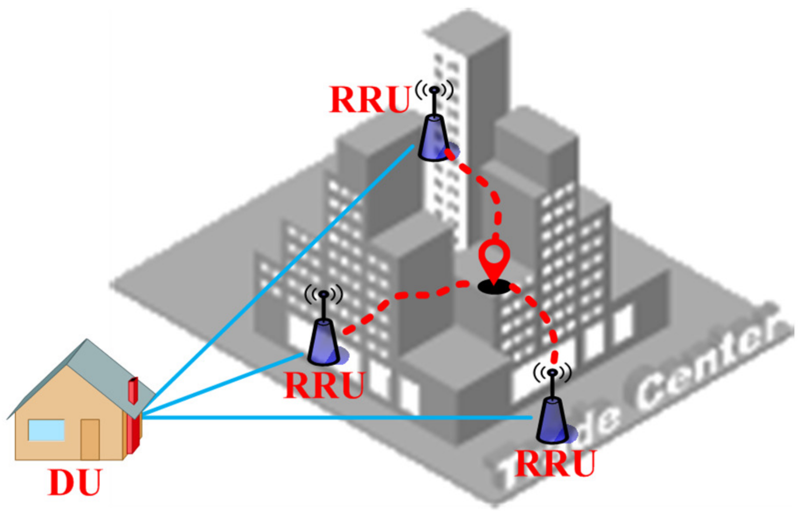
3GPP:
high accuracy location capability: less than [3 m] on [80 %] of occasions
in traffic roads and tunnels, underground car-parks, and indoor environments



High accuracy positioning service

$$RSTD_{i,1} = \sqrt{(x_t - x_i)^2 + (y_t - y_i)^2}/c - \sqrt{(x_t - x_1)^2 + (y_t - y_1)^2}/c - (T_i - T_1) + (n_i - n_1)$$

- $RSTD_{i,1}$ is the time difference between a base station i and the reference station 1 measured at the UE;
- $(T_i - T_1)$ is the transmit time offset between the two base stations;
- n_i, n_1 is the UE TOA (time of arrival) measurement error.

Time accuracy will affect the accuracy of calculating UE's position.
In the local area time offset among base stations should be less than 10ns.

Summary for 5G Synchronization Requirements

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- 5G inter-site CA and JT technologies require the time error between the base stations to be less than 260ns.
- 5G new frame structure under study may require as high as +/-390ns accuracy for the air interface to avoid interference.
- High accuracy positioning service in 5G proposes a 10ns ultra-high time synchronization requirement in the local area network providing the service.
- The 5G network would combine C-RAN and D-RAN. The time synchronization should be achieved in both the back-haul and front-haul transport network.

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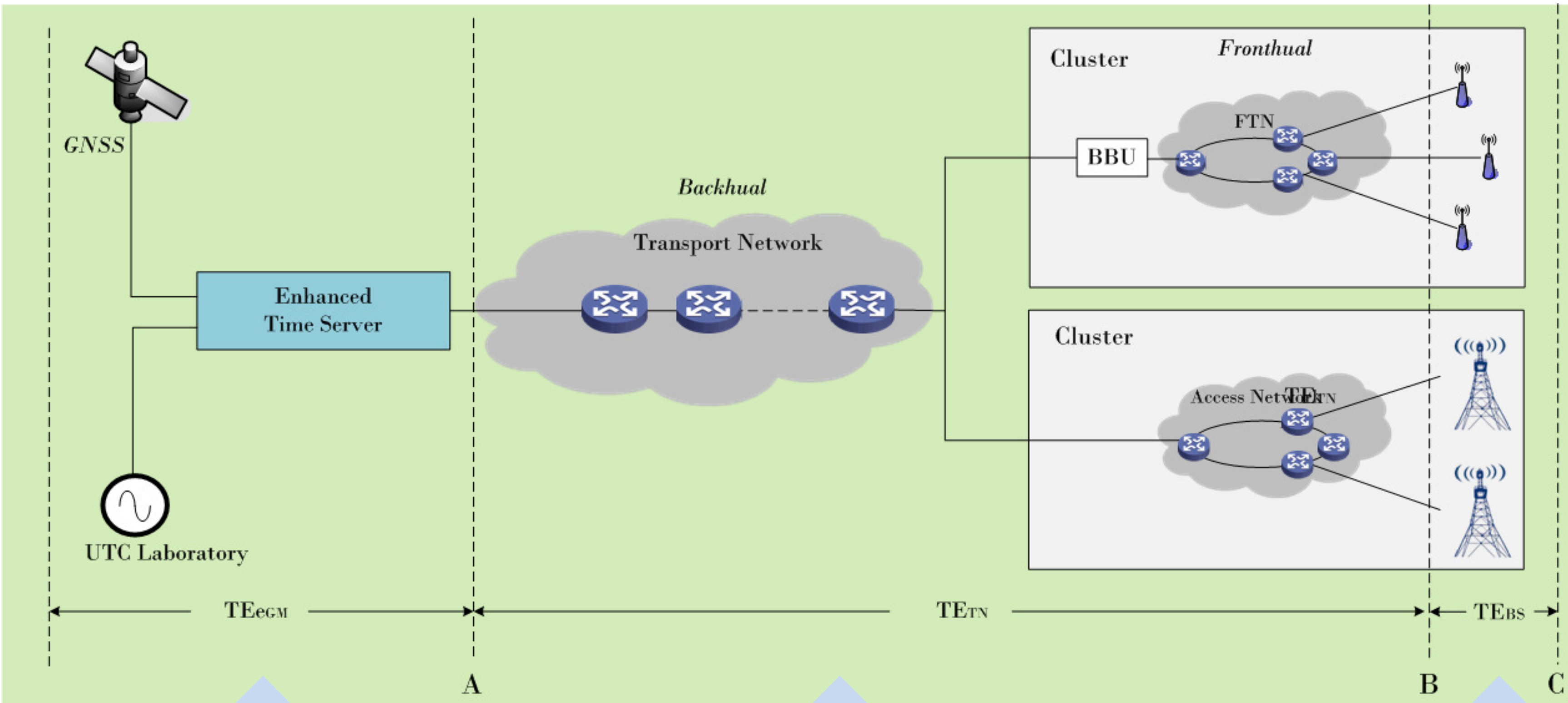
Time network reference model suggestion

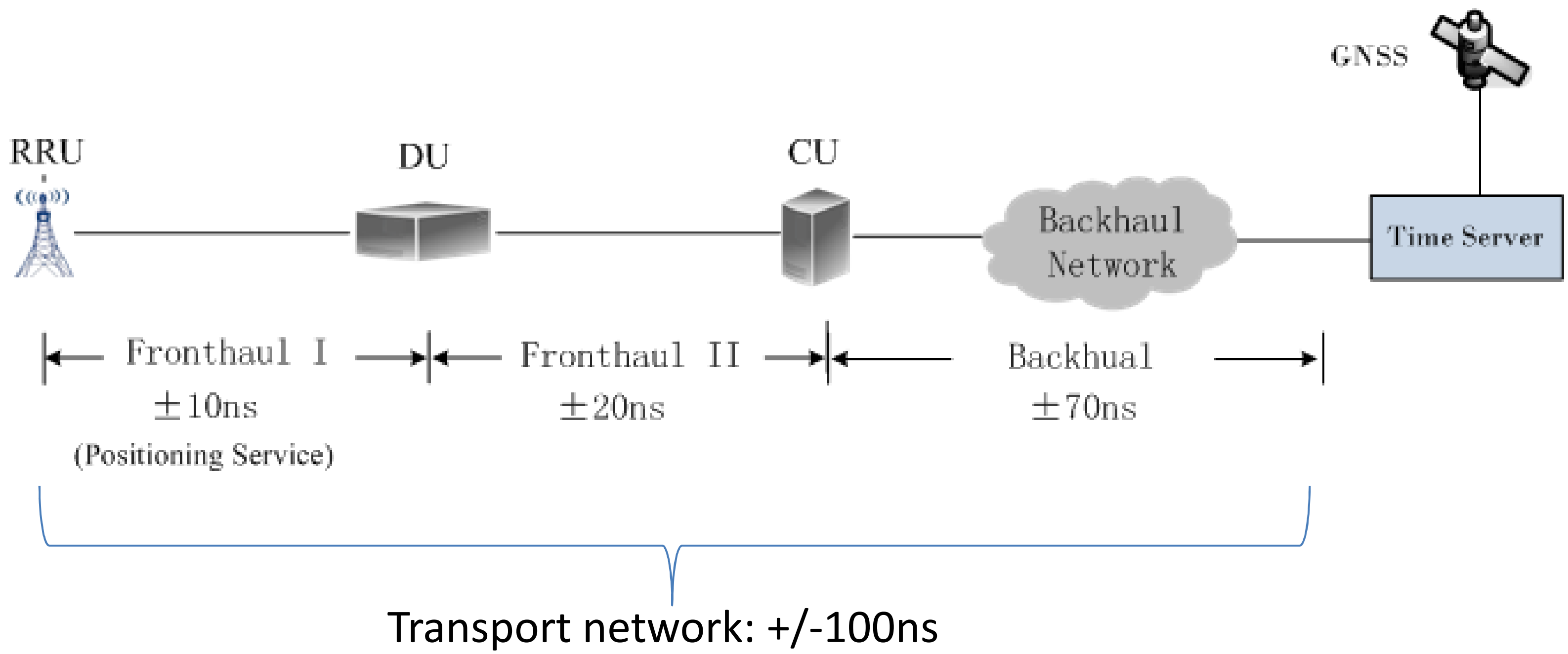
End-to-end time accuracy for 5G: +/- 130ns



- Time server (grandmaster): +/-20ns
  10ns for holdover or not needed
- Time error of the transport network: +/-100ns, 20hops
- Each node: +/-5ns
- Base station: +/-10ns

Fronthual and backhual synchronization

The +/-100ns of time transport should consider both the time budget of the front-haul and the back-haul network.



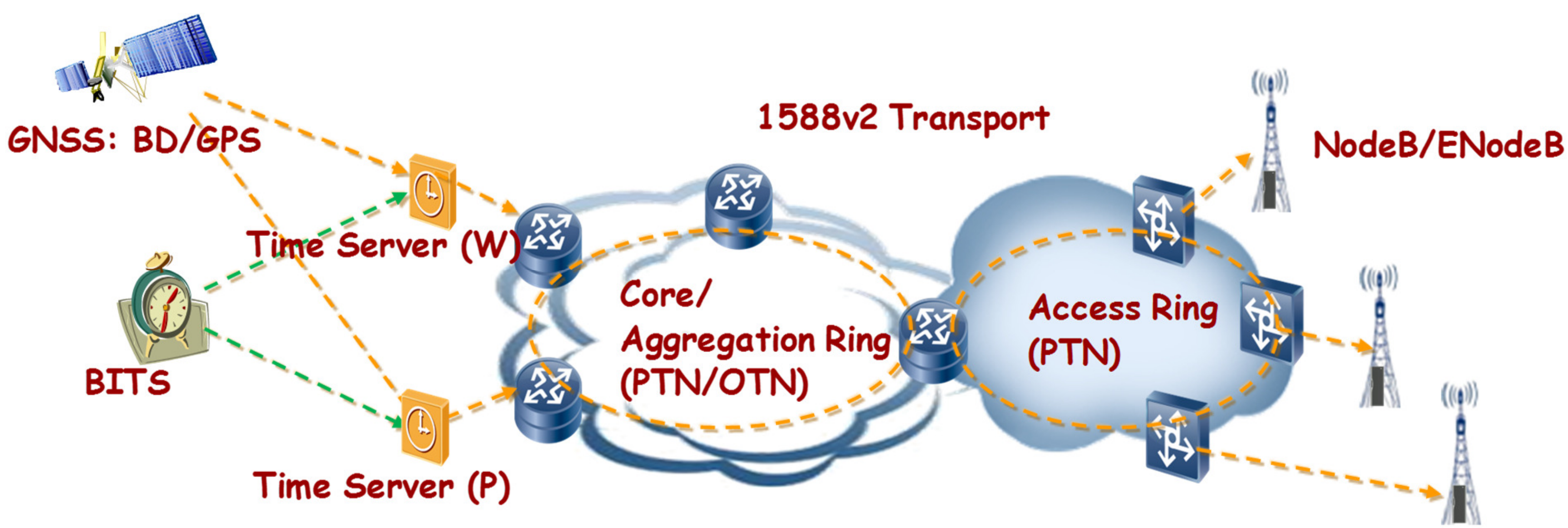
- According to the time error allocation on the whole time distribution chain, it is proposed that:
  - The fronthual domain I: ± 10ns (to support positioning service)
  - The fronthual domain II: ± 20ns (related to the synchronization hops)

Considerations on the holdover budget

Holdover budget is not critical when have good redundancy
10ns holdover: ePRC, 1 time domain?

Time network Redundant protection

- **Time Server**
  - Two GMs for protection
  - Redundant GNSS cards
  - GPS/Beidou dual mode receiver
- **Transport network**
  - Ring or mesh topology for redundant PTP paths

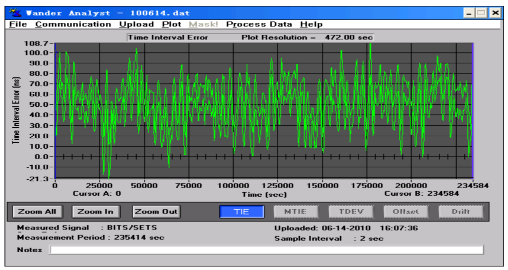


Considerations on the holdover budget

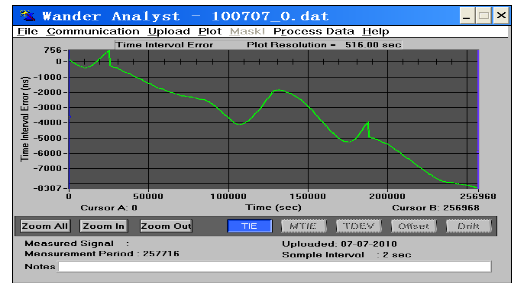
When the GM enters holdover, if all the base stations are traced to this GM, the relative phase synchronization still can be guaranteed.

GM holdover based on Cesium (>60hr.) | GM holdover based on Rubidium(>60hr.)

Base station 1 Absolute time

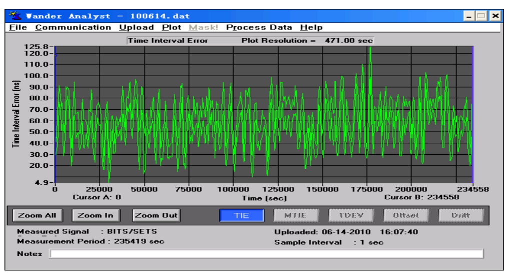


130ns

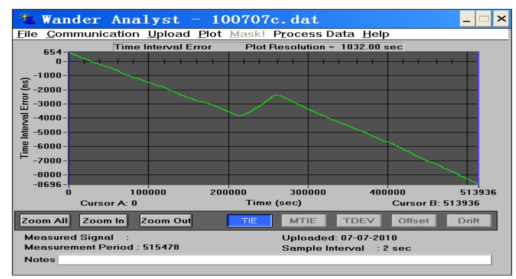


9.0us

Base station 2 Absolute time

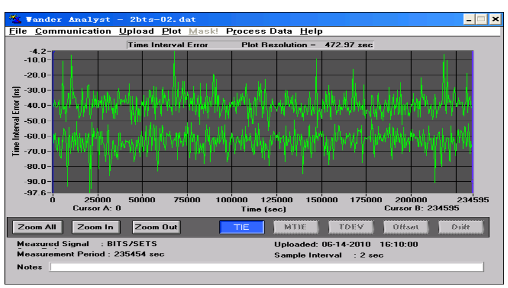


121ns

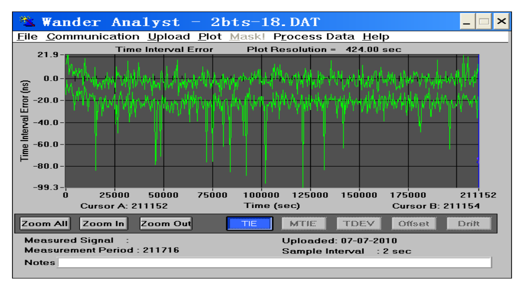


9.3us

Relative error between BS1 and BS2



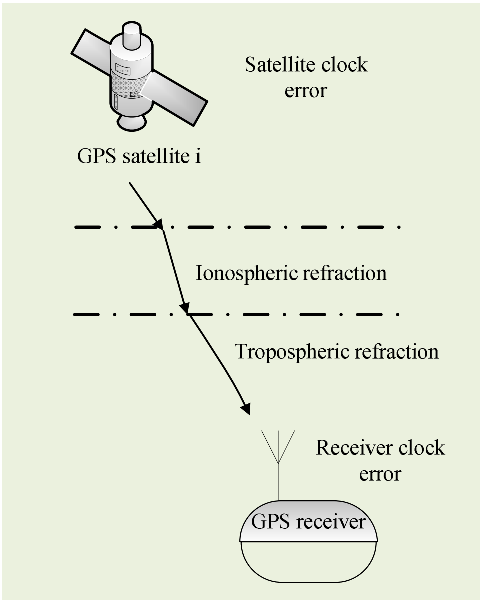
93ns



121ns

Evolution of time reference source

How to reduce the time error of reference source?

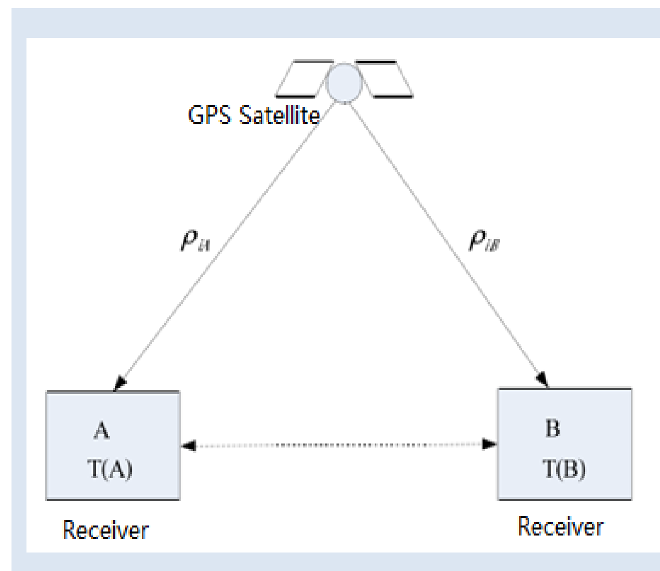


Tradition one-way GNSS receiver: +/-50ns

- ephemeris errors,
- ionospheric and tropospheric delays,
- measurement error,
- noise induced in the receivers

Common-view GNSS receiver: +/-10ns

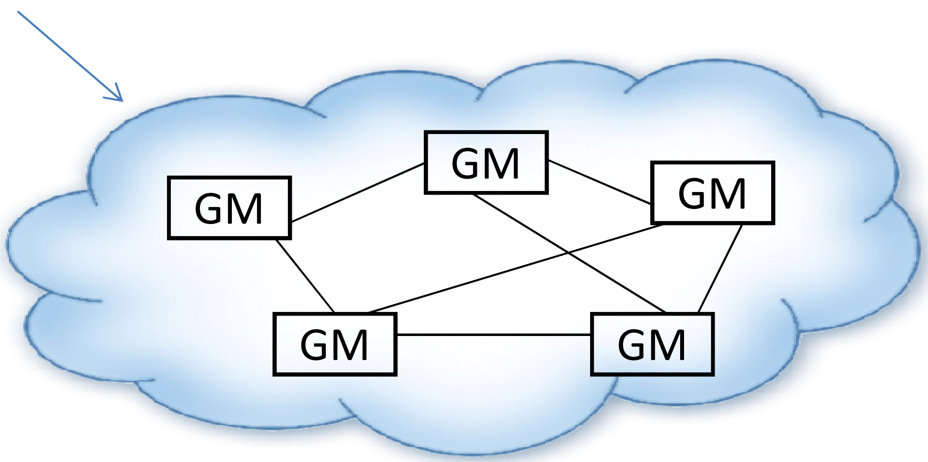
- To exchange data between stations A and B via a communication network.
- Time error caused by different satellites in view can be fully ignored
- ephemeris errors: reduced by a factor of 10.
- ionospheric and tropospheric delays : only the difference of the two receivers left.



Evolution of time reference source

Another potential solution is to get the time reference from transport network, not GNSS.

The GM group solution



- Each GM is connected to other GMs, and get time information from them.
- Each GM processes the obtained time information.
- The frequency and time output performance of the GM group may be better than each single one of the several clocks.

Summary

- Time Synchronization is more important for 5G. It's time to develop and provide 260ns accuracy end-to-end.
- POTN transport needs to achieve +/- 5ns time accuracy per node.
- Enhanced time source will be needed to achieve +/-20ns budget for the time server. Potential solutions include GNSS common-view technique, clock group technique, etc.
- The synchronization measurement with ultra-high precision and resolution will be a key factor to support the 5G synchronization development.

Thank you!