Future Synchronization Network Based on Next-Generation Atomic Clock

5th November, 2019

NTT

Kaoru Arai

Outline

1. Introduction
2. Background
3. Issues with Synchronization Networks
4. Concept of a Future Synchronization Network
5. Use cases of High Accuracy Synchronization
6. Study Points for Future Synchronization Networks
7. Summary

Introduction

- Time and frequency synchronization has various applications.

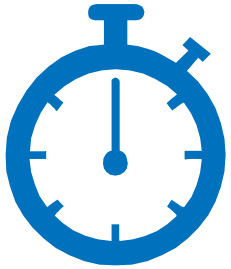
Mobile, Telecommunications

TDD, PSTN

Time sync accuracy 130ns

Frequency accuracy 10^{-12}

Metrology



Large-scale experiments (e.g. Accelerator)

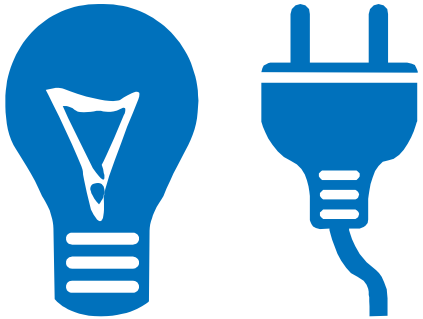
Assisted Cars, Traffic System

Synchronization between sub-systems in vehicles

Finance, Document Certification

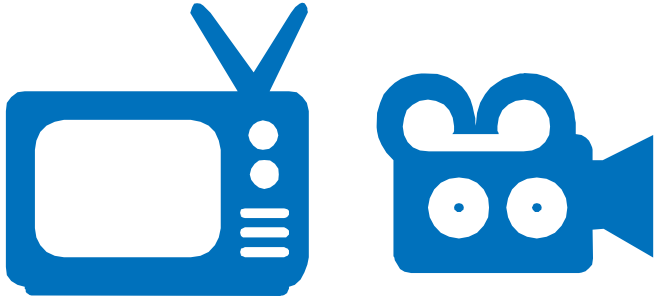
High Frequent Trades

Smart grid



High efficiency power supplies

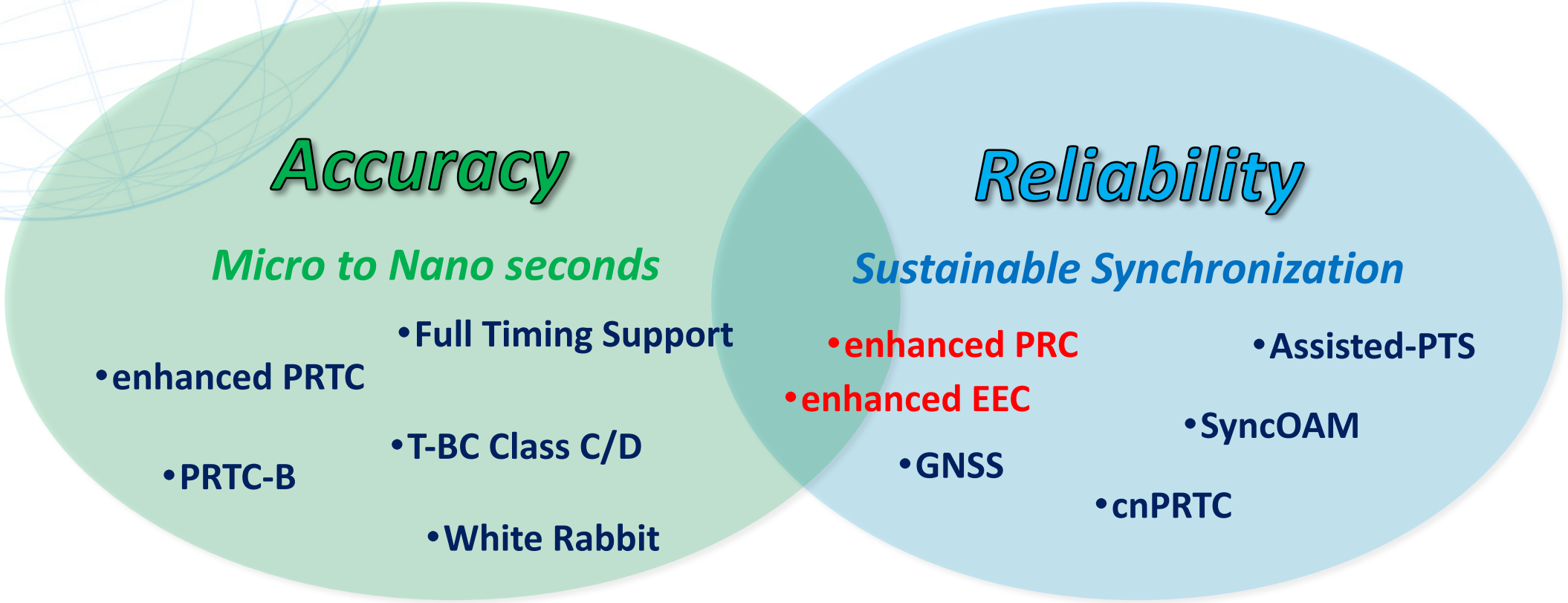
Broadcasting



Synchronization in studios

Synchronization Technology Trends

- There are two keywords in the current synchronization technology trends.
- Various technological developments and international standardization have progressed to meet the two requirements for advancement.

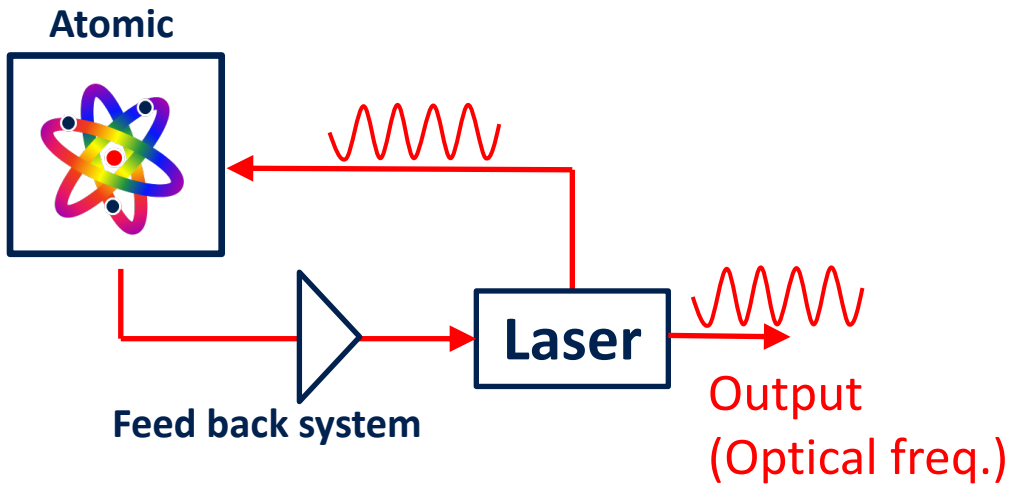


Next-Generation Atomic Clock Development

- In recent years, highly accurate atomic clocks have been developed to meet the needs of various synchronization services.
- We are focusing on the next generation atomic clock which is more accurate than the commercial cesium atomic clock.

Frequency Source	Accuracy
Next-Generation Atomic Clock (e.g. Optical Clock)	10^{-16}-10^{-18}
Hydrogen Maser	10^{-15}
Conventional Cesium Clock	10^{-11}-10^{-12}

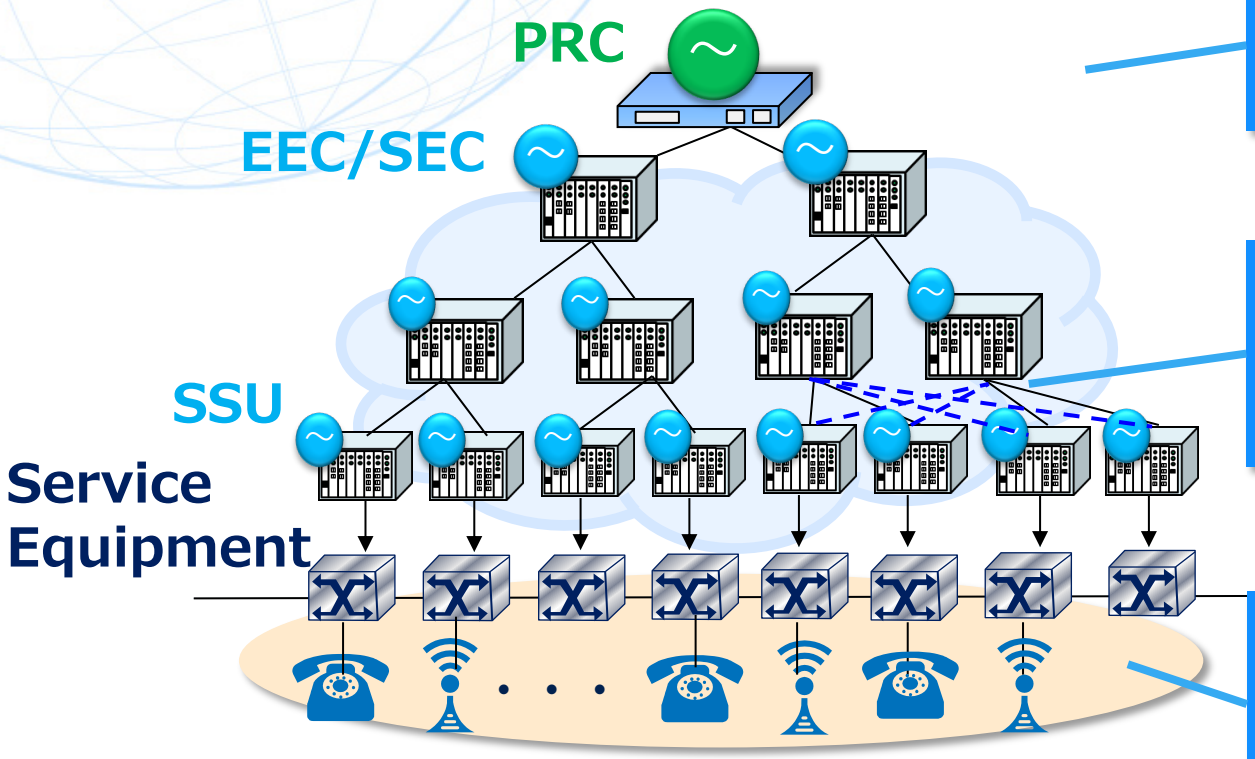
Example components of an optical clock



Issues with Frequency Synchronization

- Telecom operators have large-scale, nationwide synchronization networks.
- There may be issues from the following three viewpoints.

Conventional master-slave synchronization network



-Costs-
Increase maintenance costs

-Network Design-
Complicated
by redundancy and to prevent clock loop

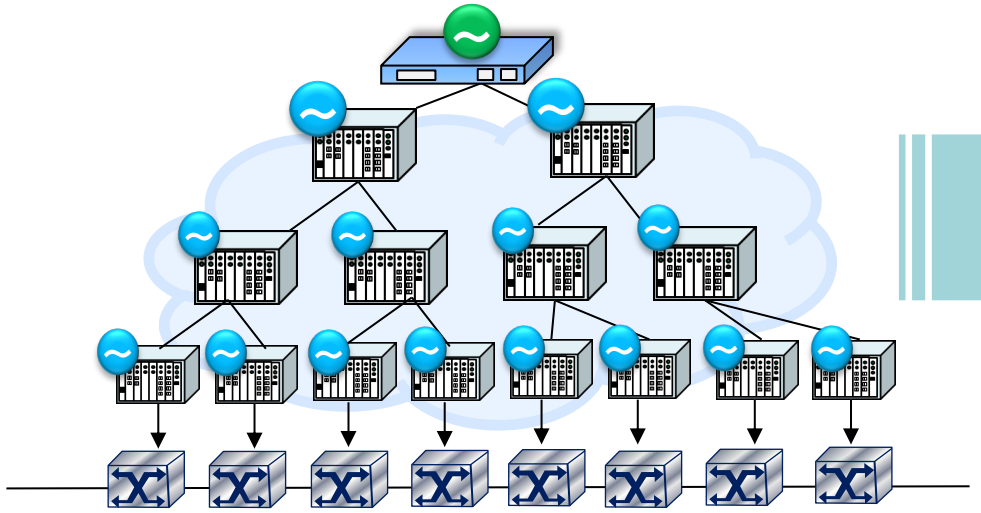
-Market-
Few use cases of synchronization
Limited to Telecommunication services

Changes to Synchronization Network Architecture

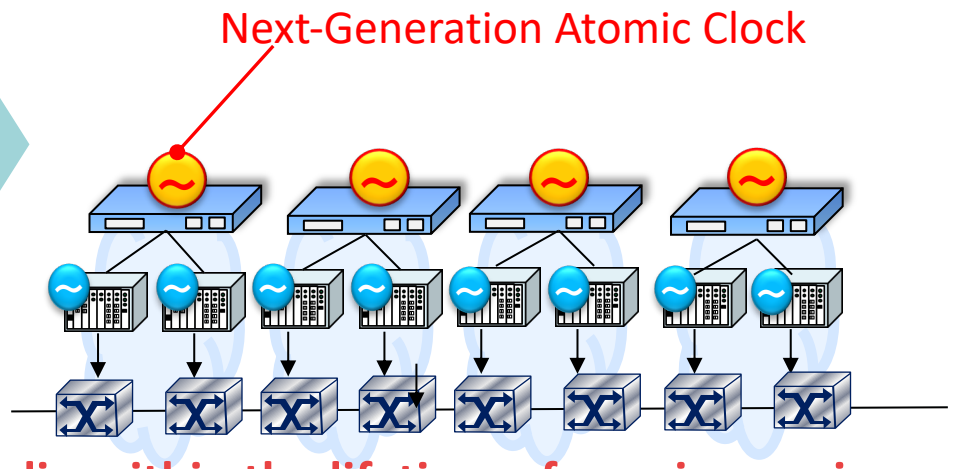
- The synchronization network can be changed from master-slave synchronization to independent synchronization with distributed next-generation atomic clocks.

Frequency Source	Accuracy	Slip time
Next-Generation Atomic Clock (e.g. Optical Clock)	10^{-16}-10^{-18}	20,000years -
Conventional Cesium Clock	10^{-11}	70 days

Now: Master-slave sync architecture



Future: Independent sync architecture (Distributed PRC)

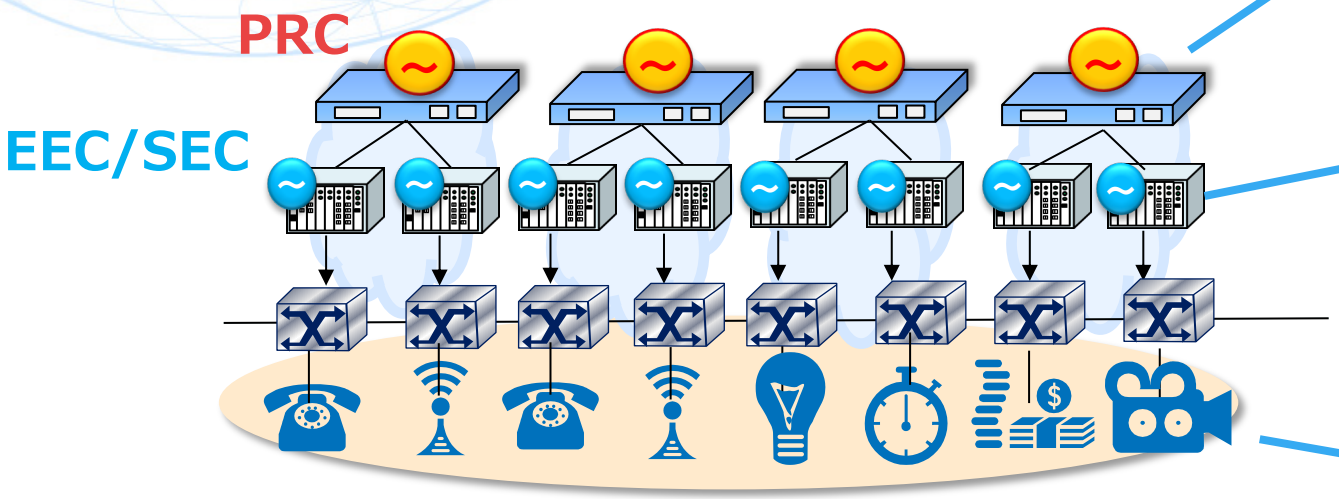


No slip within the lifetime of service equipment

Concept of a Future Synchronization Network

- The future synchronization network has advantages from cost, network design, and market perspectives.
- High accuracy frequency has two use cases: future mobile technologies and metrology.

Independent Synchronization Architecture (Distributed PRC)



-Costs-
Decrease number of equipment in network

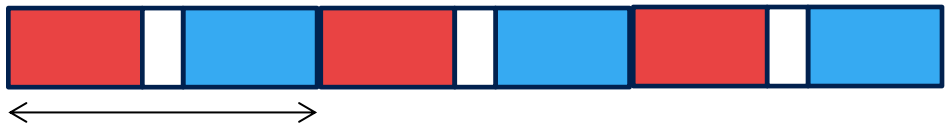
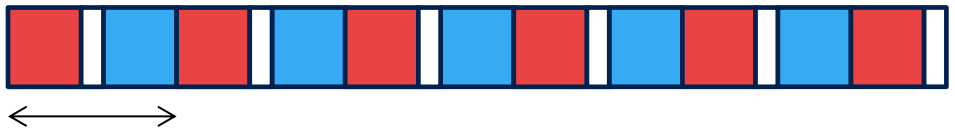
-Network Design-
Simple: Short hops, divided by small domain

-Markets-
Exploit new markets by high accuracy synchronization

- Use cases
  1. Time sync for 5G/5G+
  2. Metrology/Sensing Network

Requirements for Future Time Synchronization

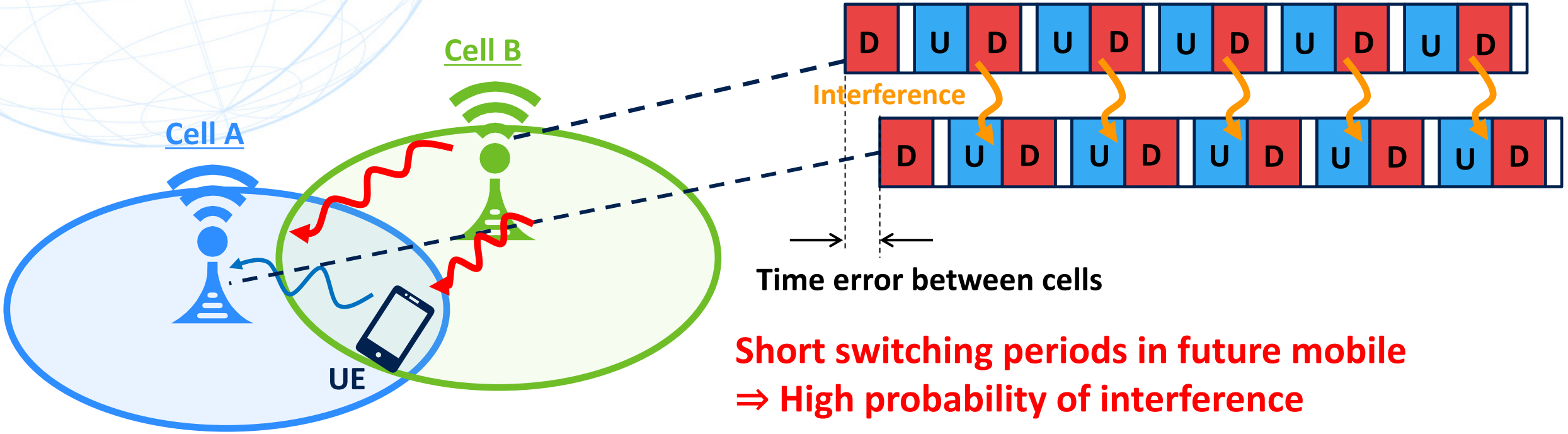
- In 4G, the time synchronization mainly requires high accuracy such as 130ns relative time error.
- In addition to accuracy, 5G and future mobile technologies will require stability because the number of UL/DL switching will be more frequent and the frame period of TDD will become shorter than 4G.

G	Image of TDD frame structure	UL/DL Switching Period	Service requirements	Time sync requirements
4G		Long ↕ Short	● High frequency efficiency	● High Accuracy
5G 5G+			● High frequency efficiency ● URLLC	● High Accuracy ● Sustainability/ Continuity (Long term stability)

Up Link　Down Link　GP

Interference Between TDD Frames

- In TDD mobile, radio wave interference intra-operator or inter-operators is an issue[1]. The probability of interference increases as the UL/DL switching timing increases.
- For example, strong down link signals from adjacent cells can interfere with weak signals from UE.



Short switching periods in future mobile
⇒ High probability of interference

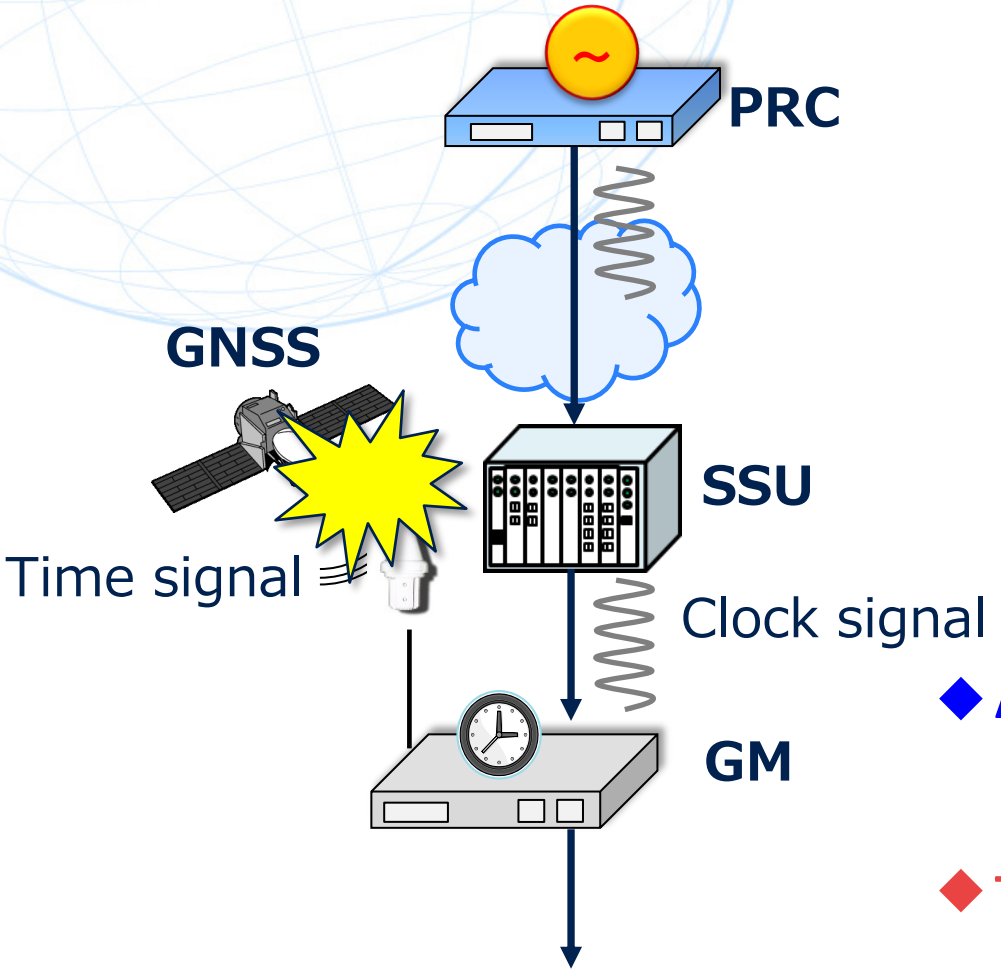
Long term time sync stability is required

[1]SG15-C1281, "Proposal of new Appendix draft on time synchronization of TDD systems in G.8271"
Contribution of ITU-T SG15 from NTT, July, 2019

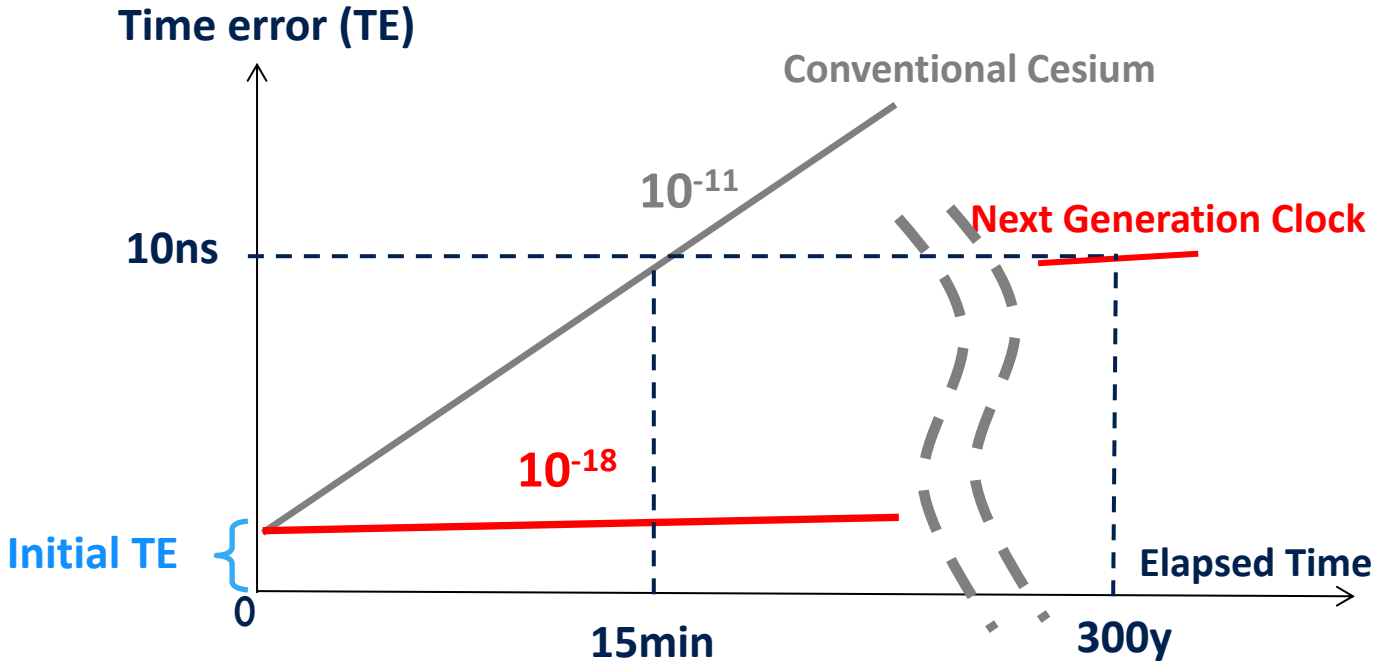
Stable Time Sync with High-Accuracy Frequency

- To realize long-term continuity of time synchronization, it is possible to back up the time synchronization using the high-accuracy frequency of the next generation atomic clock.

Backup of time synchronization by network



Keeping the term of time after GNSS signal loss

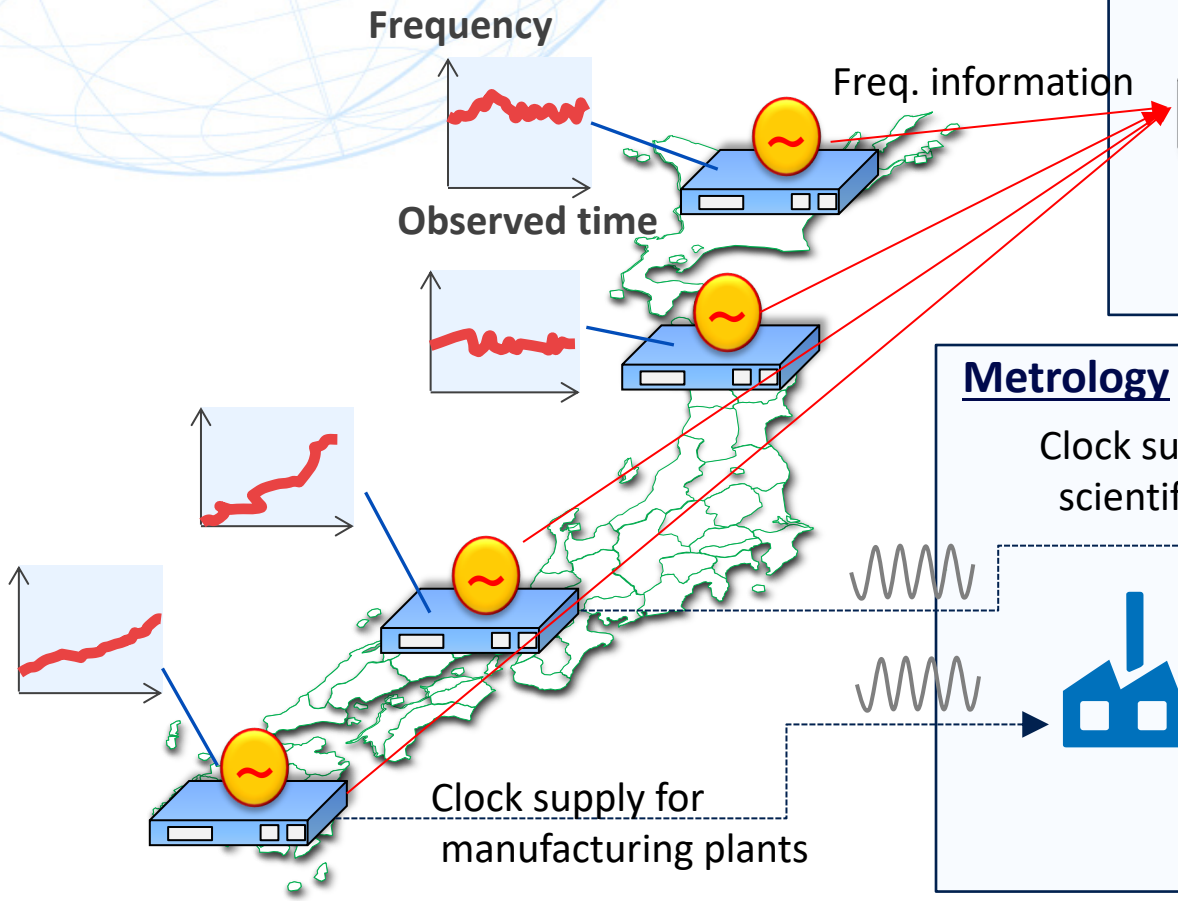


- ◆ Advantages
  - ✓ Don't need frequent time error correction
  - ✓ Long-term time keeping by frequency
- ◆ Technical issues
  - ✓ High-accuracy frequency transfer and distribution
  - ✓ To supply initial time error with high accuracy

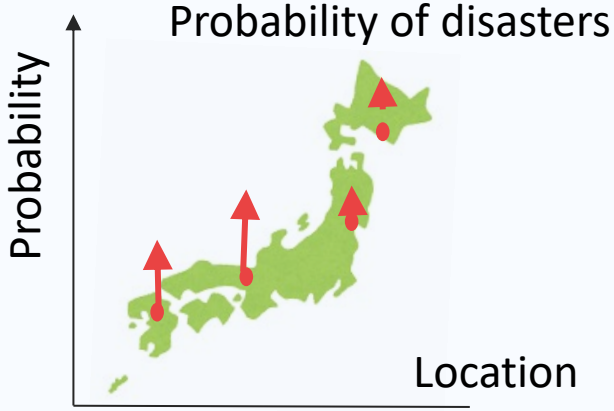
Sync Network for Sensing/Metrology

- Sensing using frequency/time information
  - ✓ Crustal movements
  - ✓ Tide levels
- Metrology
  - ✓ Calibration of timing devices
  - ✓ Large scale experiments (e.g. Accelerator)

Sync networks as social infrastructure

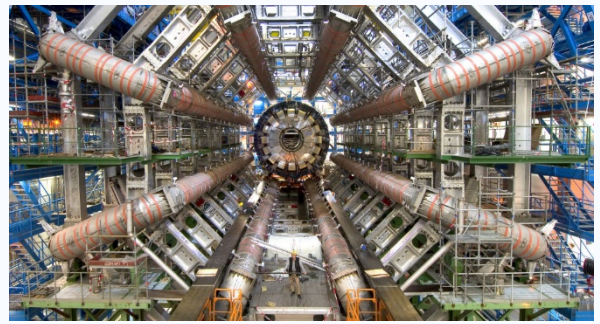


Sensing

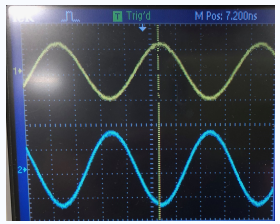


Metrology

Clock supply for scientific facilities



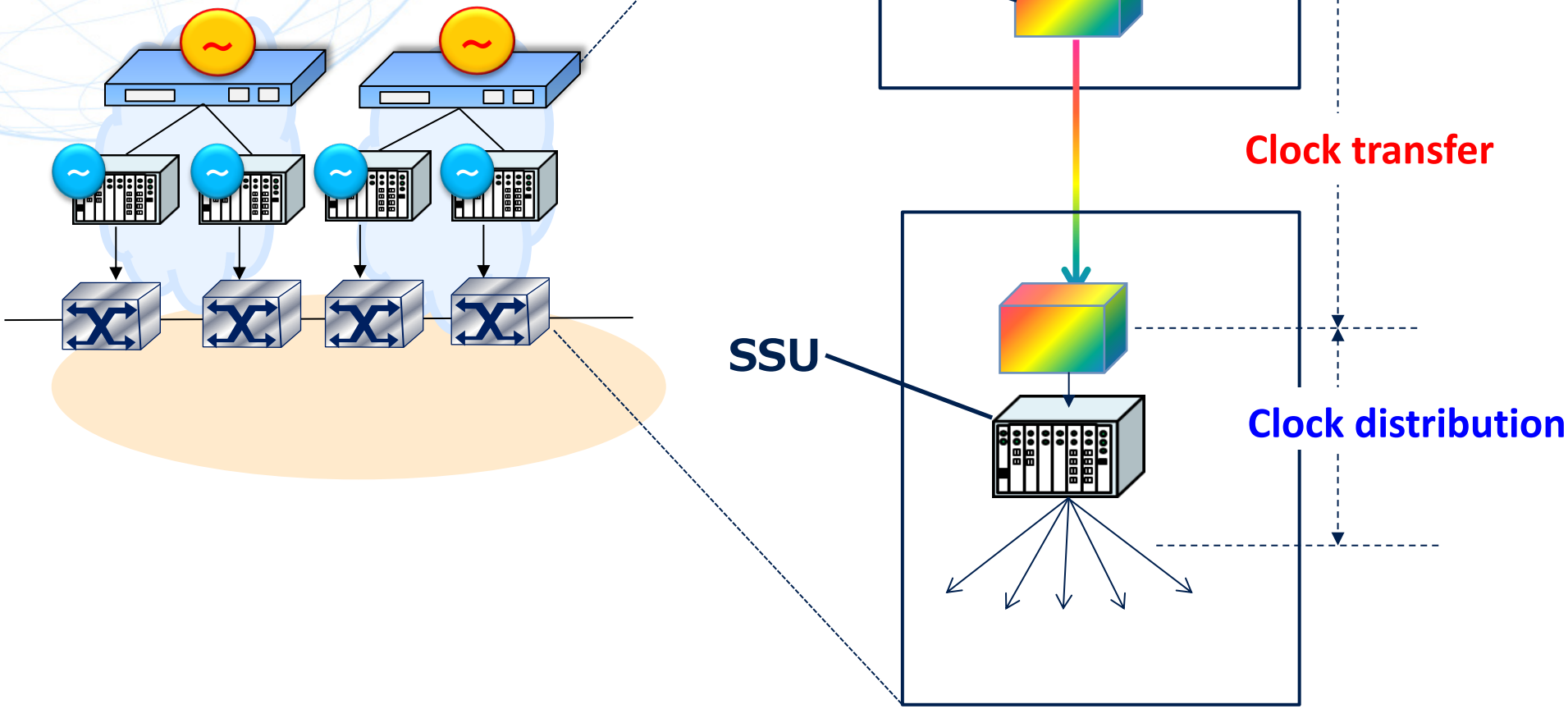
Copyright :Image editor CERN



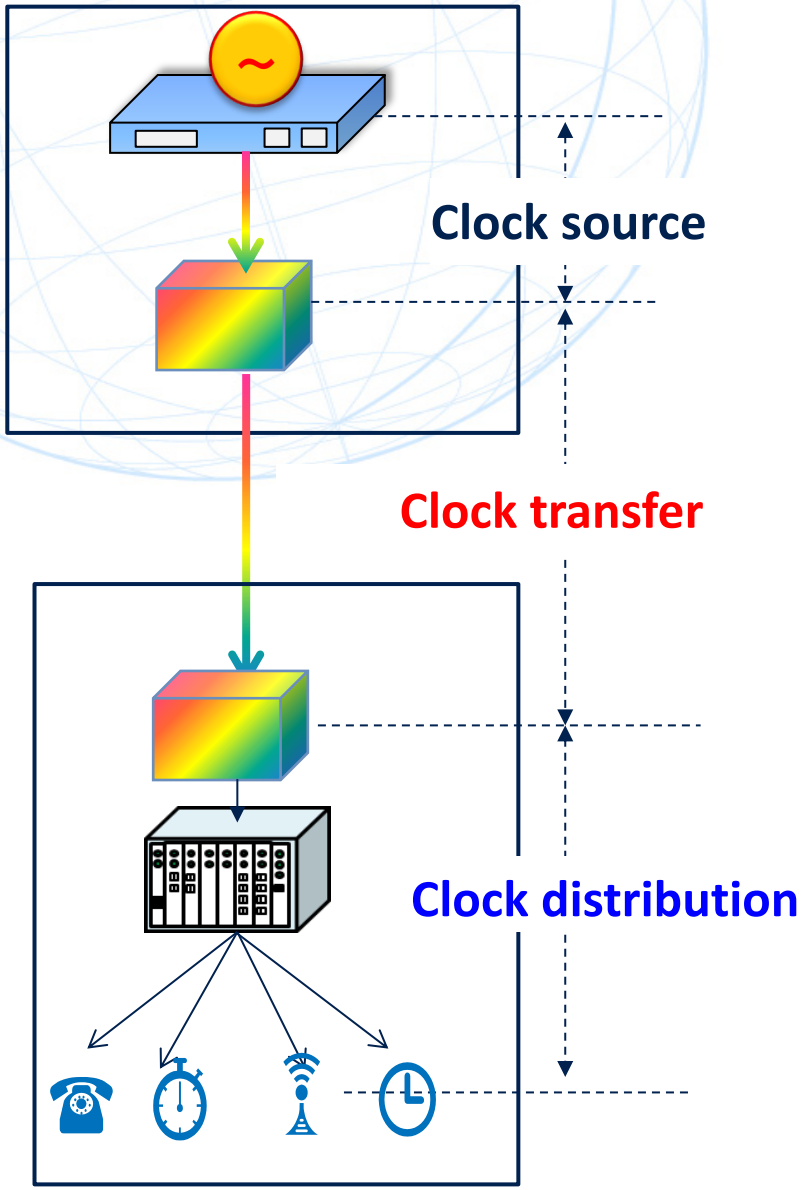
Calibration of devices

Study Points for Future Synchronization Networks

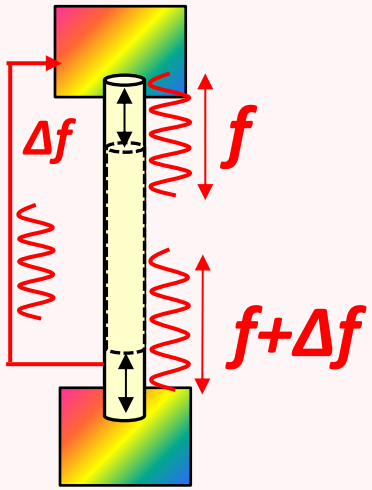
Overview of study points



Study Points - Clock Transfer and Distribution -

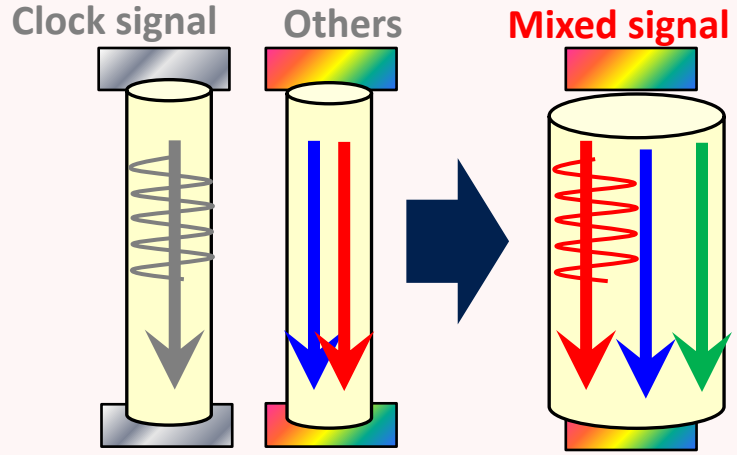


Noise compensation



Feed back wander info.

WDM technology for distributed PRC networks

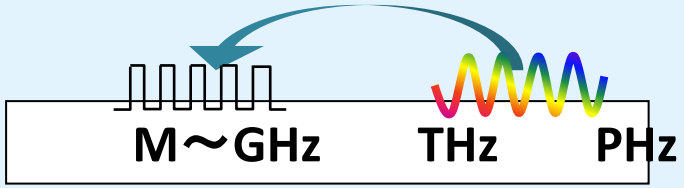


Dedicated Fiber for clock transfer

WDM

High quality synthesizer technology for various services

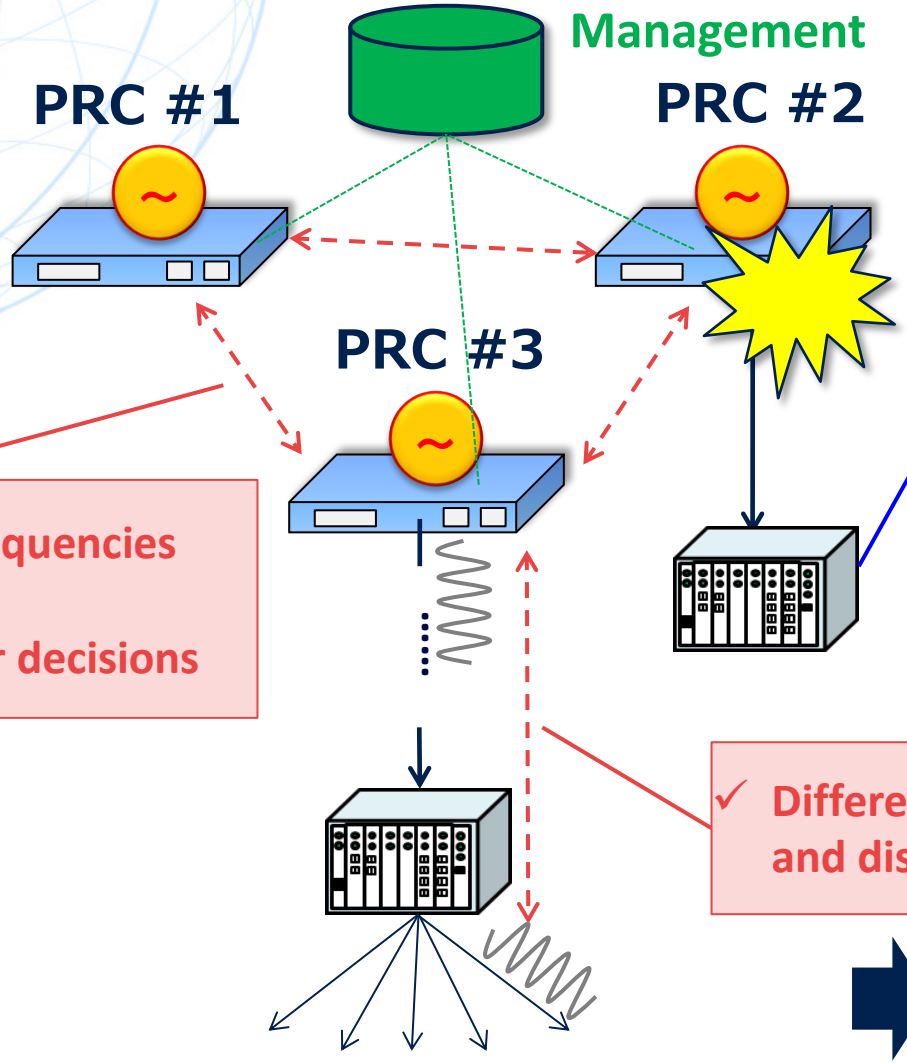
10^{-16}-10^{-18}



- Photoelectric conversion with high-accuracy
- Radio to Radio conversion with low noise

Study Points - Network Management -

- Quality monitoring and decision on the correct frequency of the next-generation atomic clock
- Functions to maintain high-accuracy frequencies to respond to failures



✓ Reliability of synchronization network
-High-accuracy holdover

Development of optical domain devices (e.g. High-stability laser cavity in free run mode)

✓ Compare relative frequencies between PRCs
✓ Three or more major decisions

✓ Difference between PRC output clock and distributed clock

Development of measurement mechanisms (e.g. Frequency comparison functions)

Summary

The concept of a future synchronous network using a high-accuracy atomic clock

Architecture:

From master-slave synchronization to independent synchronization by distributed PRC

- Reduced cost of sync equipment
- Short and simple networks
- Creation of new markets

Use cases for high accuracy frequencies:

- Future TDD technology : Long-term, stable time synchronization

  ⇒To prevent interference of TDD frames, countermeasures for GNSS vulnerability
- Metrology and sensing

  ⇒To add new value with sync networks as social infrastructure

Study points:

- High-accuracy clock transfer and distribution/conversion
- Network management -quality measurement and reliability-