High-Accuracy Optical Frequency Transfer over WDM Networks

Nov 4, 2021

Kaoru Arai

Agenda

1. Use Cases of High-Accuracy Frequency
2. Development of Optical Clock
3. IOWN Concept
4. All Optical Synchronization Network
5. Optical Frequency Transfer over WDM Networks
6. Experiments & Results
7. Consideration
8. Future Works

Use Cases of High-Accuracy Frequency

NTT

Mobile

Stable mobile communication thanks to long-term holdover

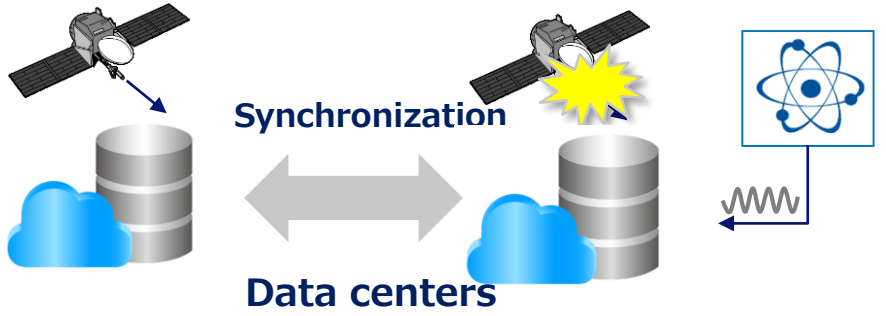
Accuracy

10^{-14}

10^{-16}

10^{-18}

Data Center

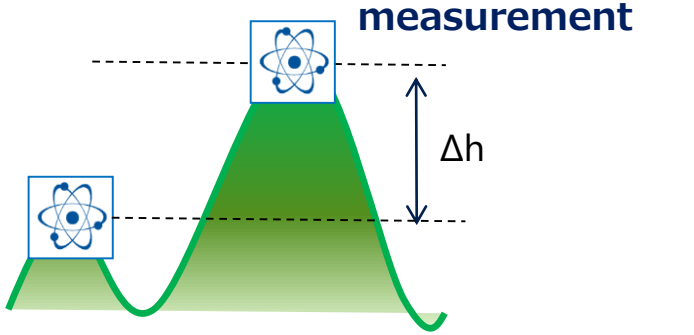


Stable calculation processing thanks to long-term holdover

Science

Synchronization for measurement

Sensing



Monitoring for disaster

Background 1

Development of Optical Clock

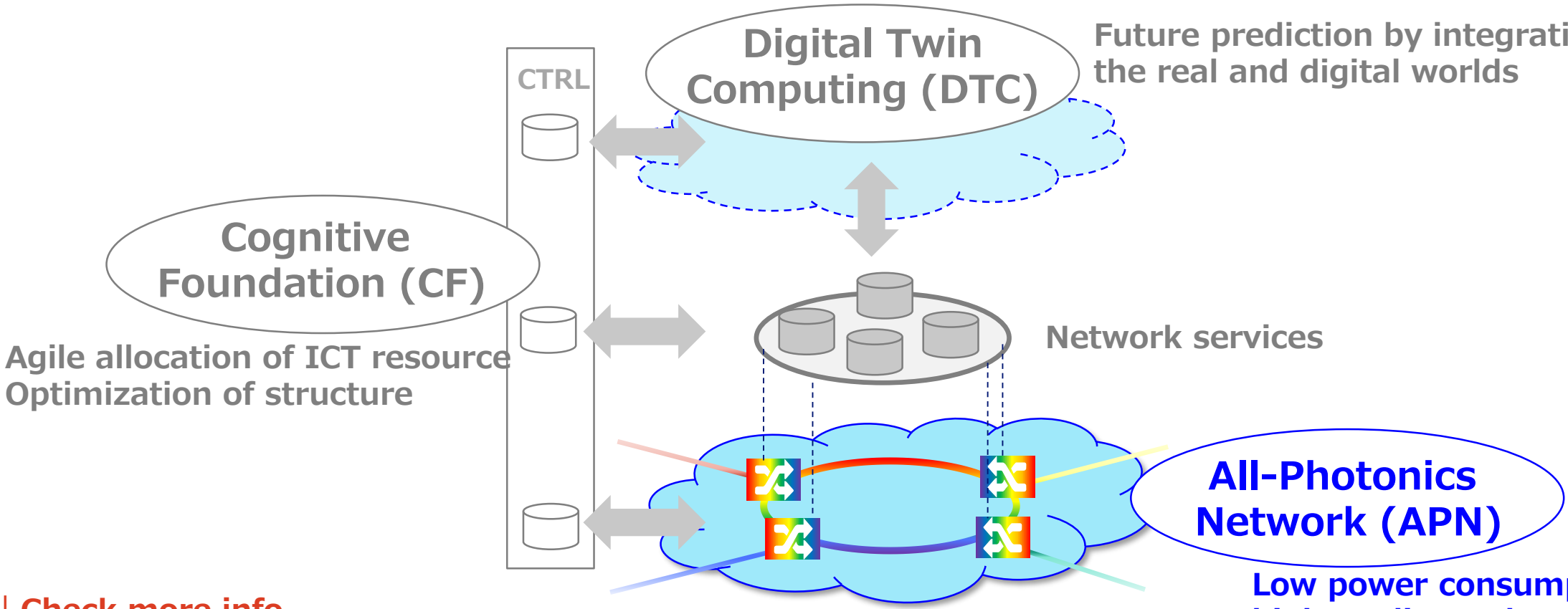
- We focus on optical clock as next-generation frequency source.
- Optical clock has potential as frequency standard.

Items \ Clocks	Conventional Atomic Clock	Optical Clock
Accuracy	10^{-12}-10^{-13}	10^{-15}-10^{-18}
Output signal	Microwave (e.g. 10 MHz)	Optical wave (e.g. 200 THz)
Definition	Standardized as second	Future candidate
Commercial Status	Available	In research

Background 2

What is IOWN?

- NTT is announcing the IOWN (Innovative Optical and Wireless Network) concept.
- APN is a fully meshed-optical network to reach high performance.



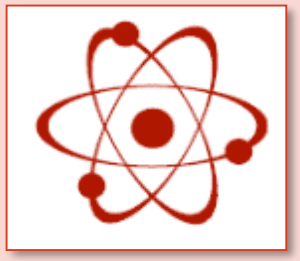
↓Check more info.

https://www.rd.ntt/e/iown/

Optical Clock x IOWN

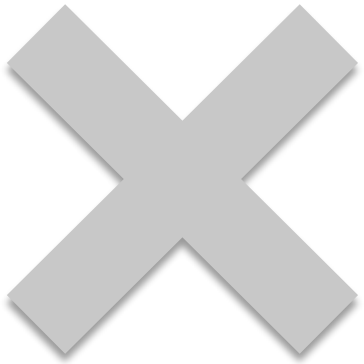
- We consider **all optical synchronization network** from two backgrounds

Optical Clock

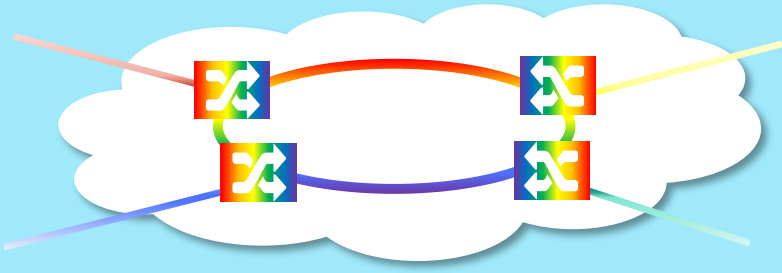


High-Accuracy Frequency in Optical Region

High affinity



IOWN



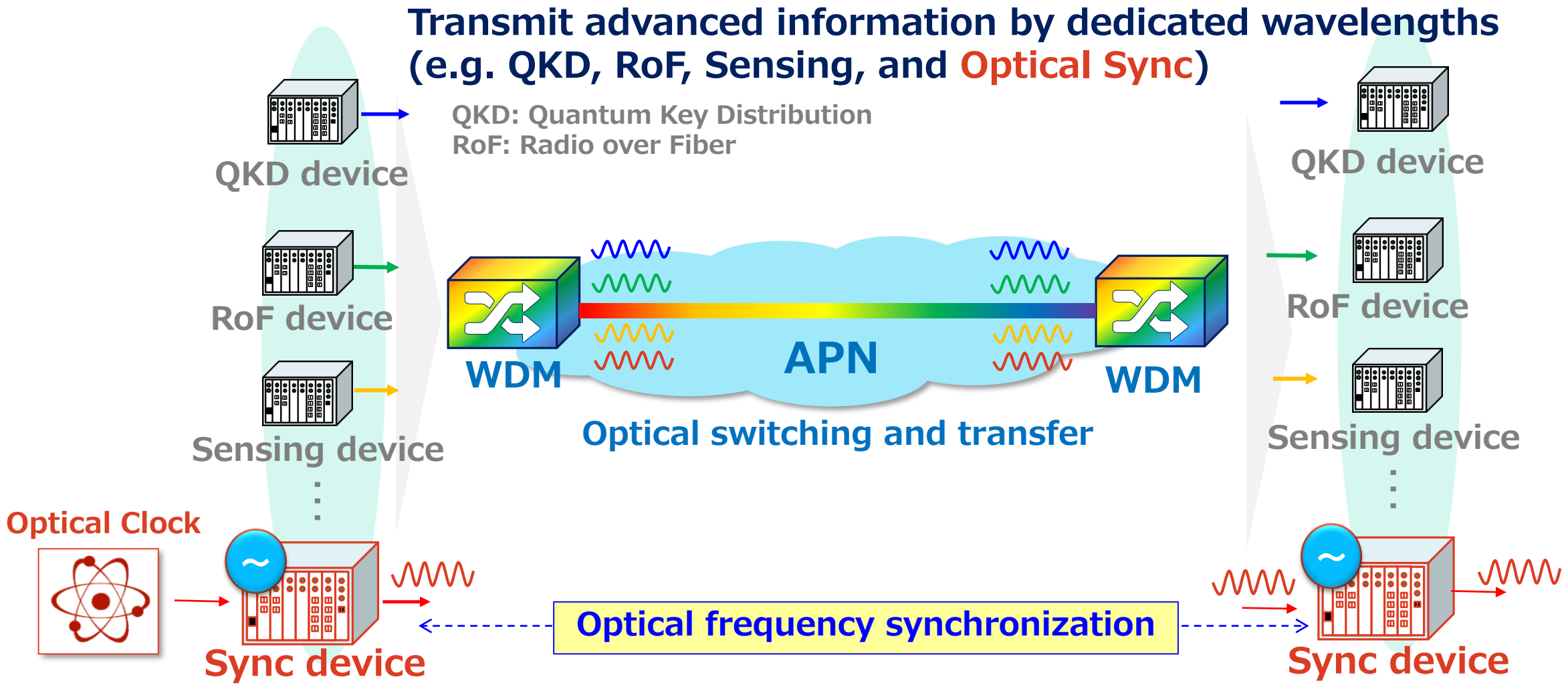
All Photonics Network

Combine

All Optical Synchronization Network

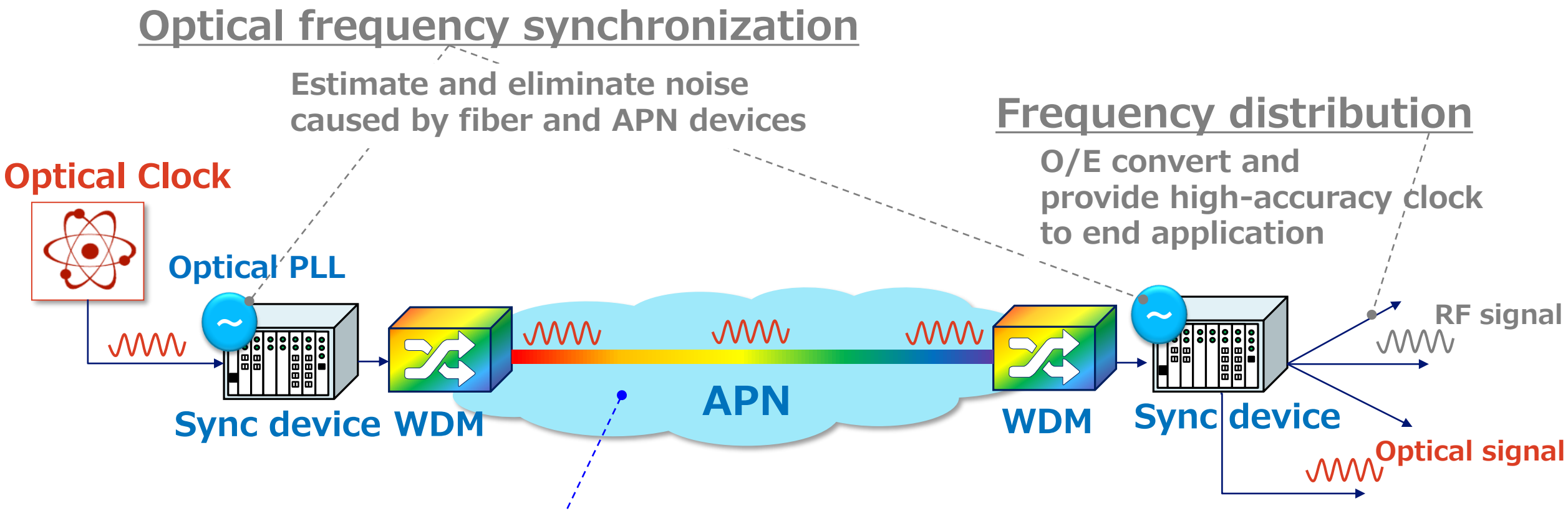
All Optical Synchronization Network

- **APN transfers information on advanced technologies** in addition to data traffic.
- Optical frequency is also transferred over APN as one signal.



Technical Points of All Optical Sync Network

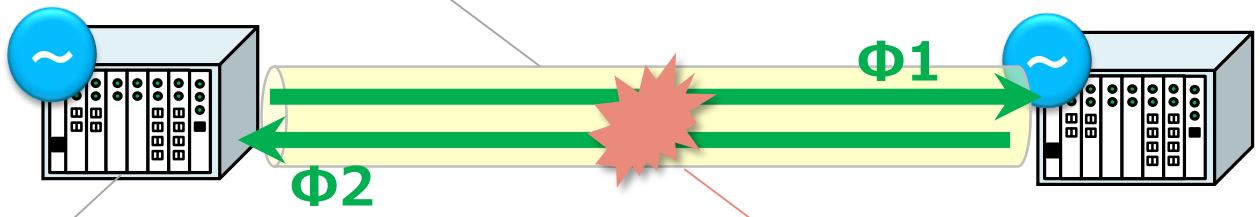
- We focus on optical frequency transfer over APN.



Challenging New Optical Frequency Transfer

- We are developing a frequency transfer method based on commercial networks.
- The big challenges are two-way transfer over different fibers and over WDM devices.

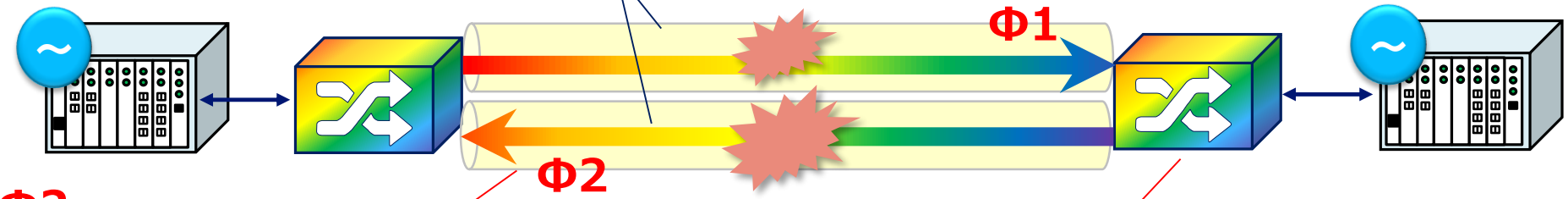
Two-way transfer over single fiber



Φ1=Φ2
Detect one-way phase shift Φ1 by round trip on single fiber

Phase shift caused by noise on fiber

Two-way transfer over different fibers by WDM

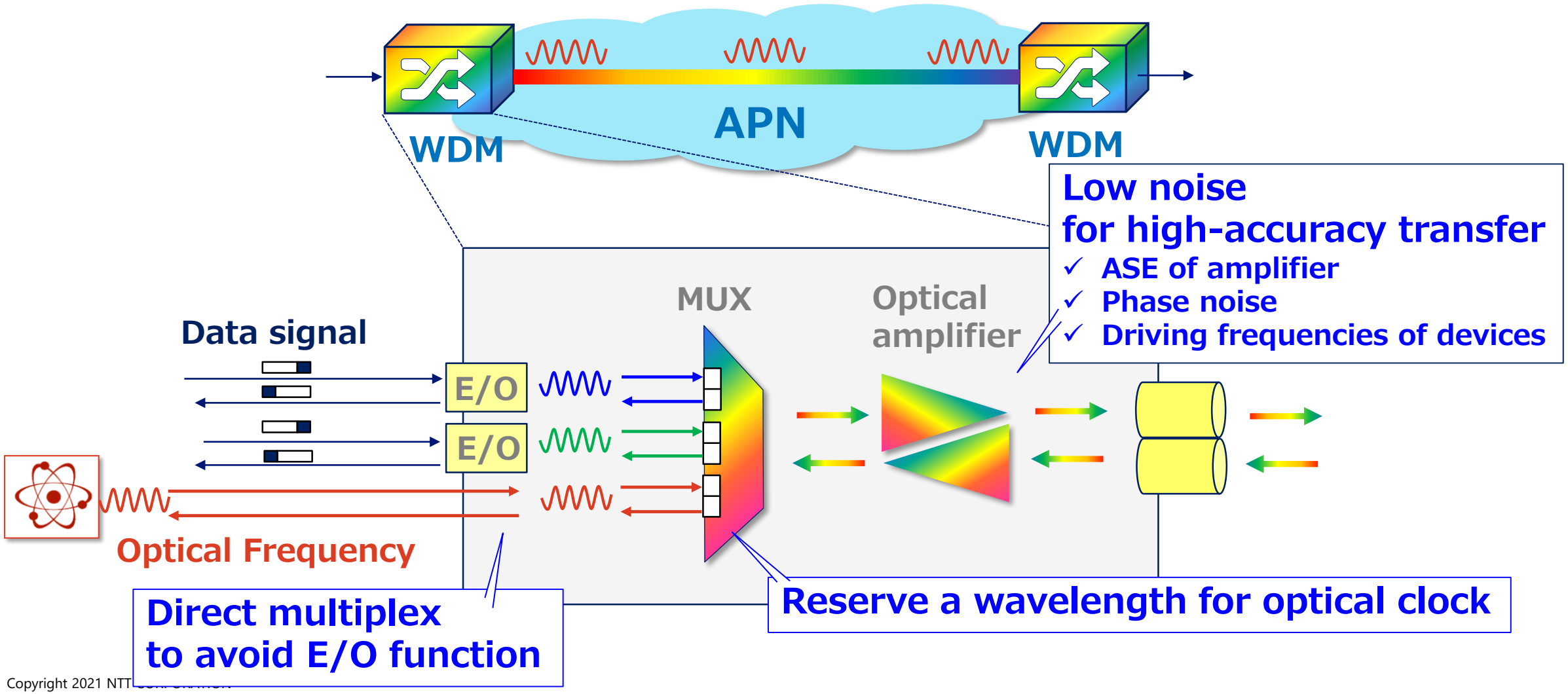


☹ Φ1≠Φ2
Difference in phase shifts caused by two fibers

☹ Additional noise generation and accumulation by WDM → Test

Optical Frequency Transfer Method over WDM

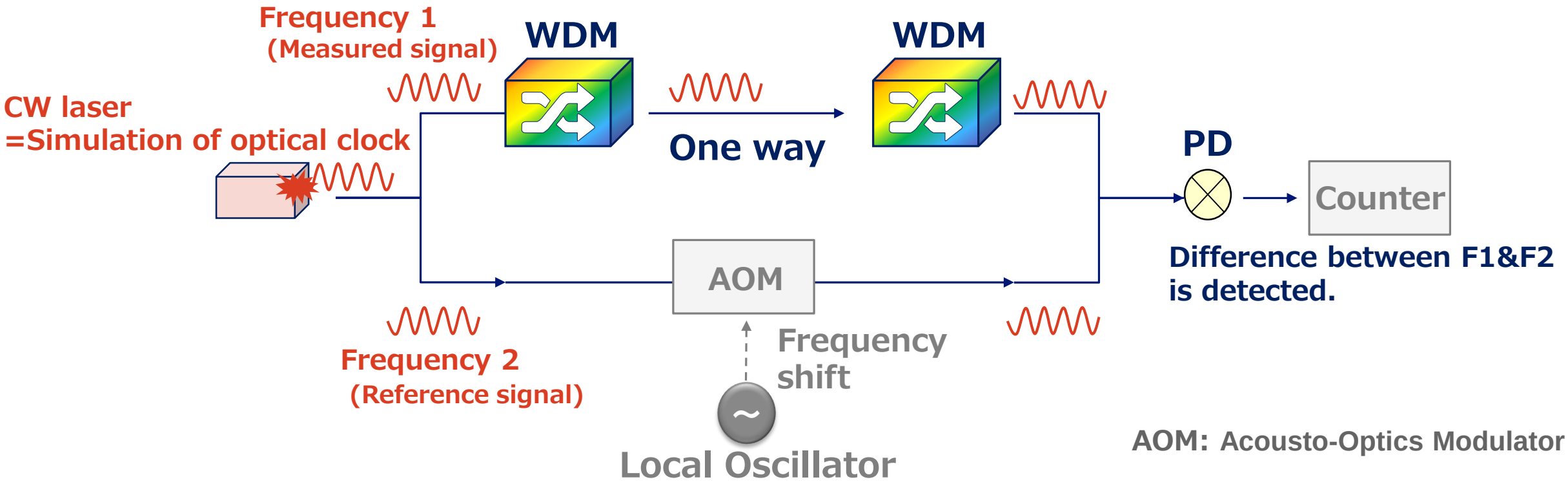
- We consider a transfer method using WDM and reserve a wavelength for clock.



Experiment

- We measured relative frequency accuracy and one-way WDM noise.
- Accurate frequency variation can be measured by heterodyne interference method.

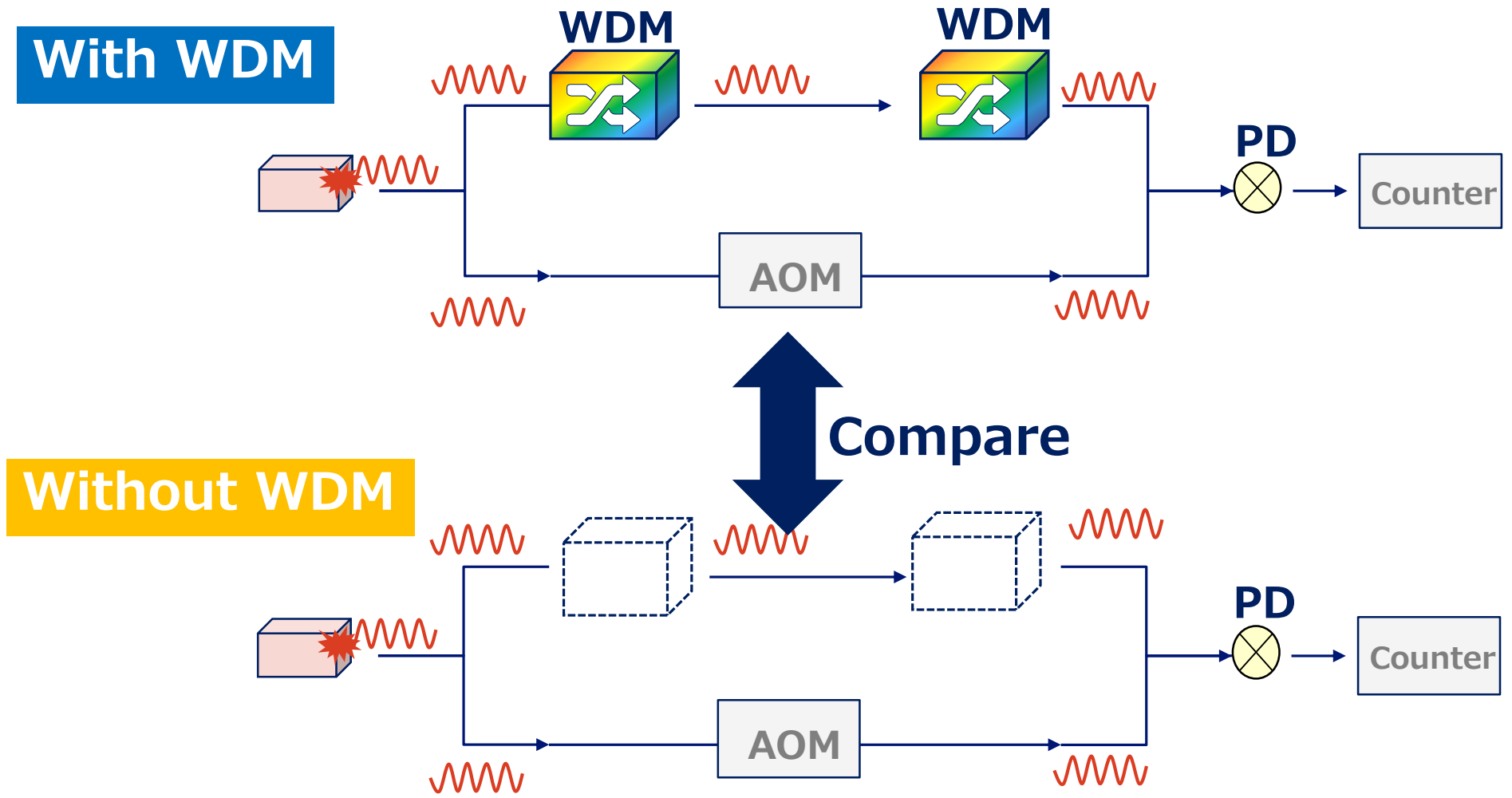
Heterodyne interferometer



Degradation by WDM can be measured.

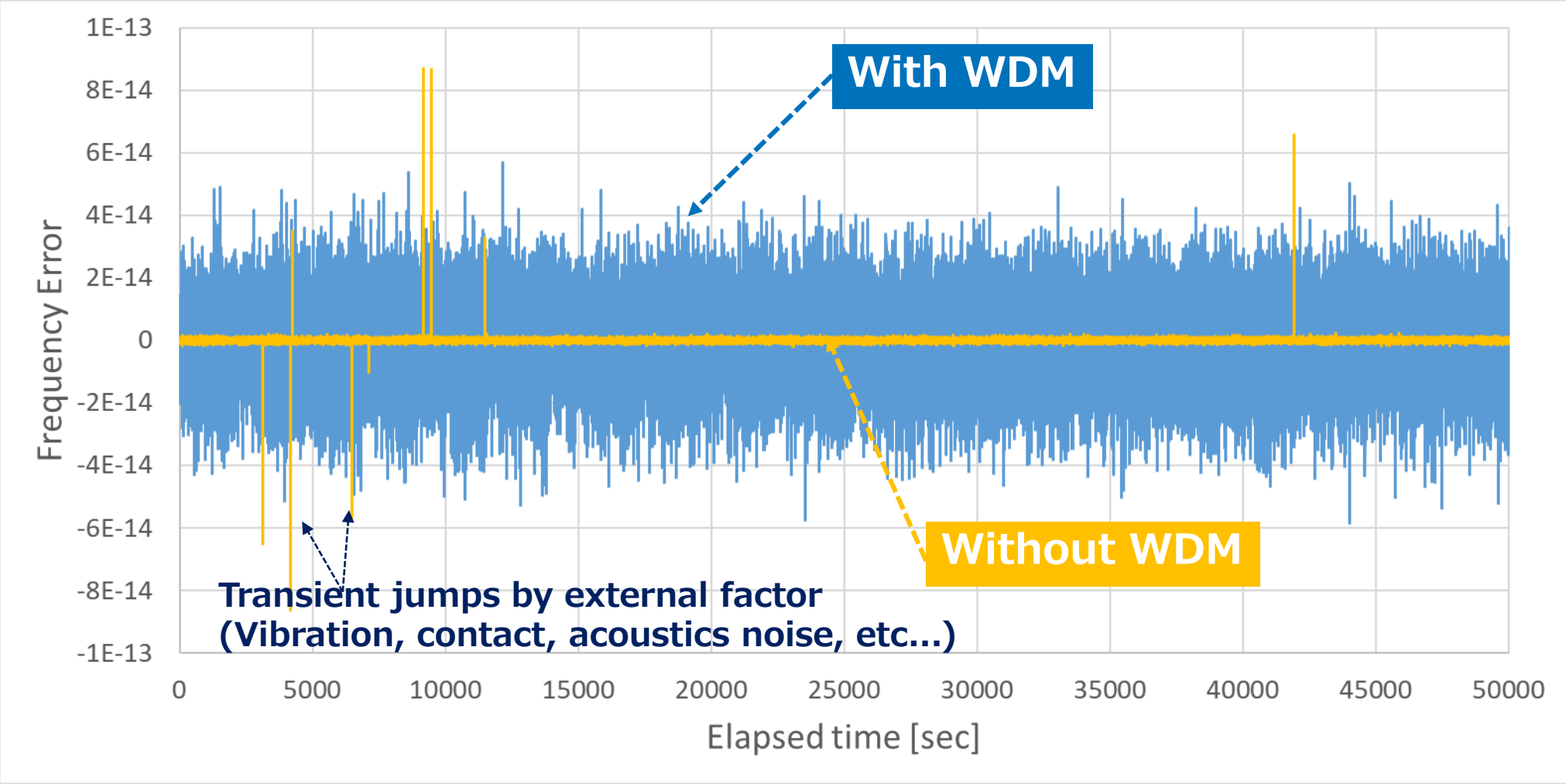
Experiment

- We compared two results to check the difference between with and without WDM.



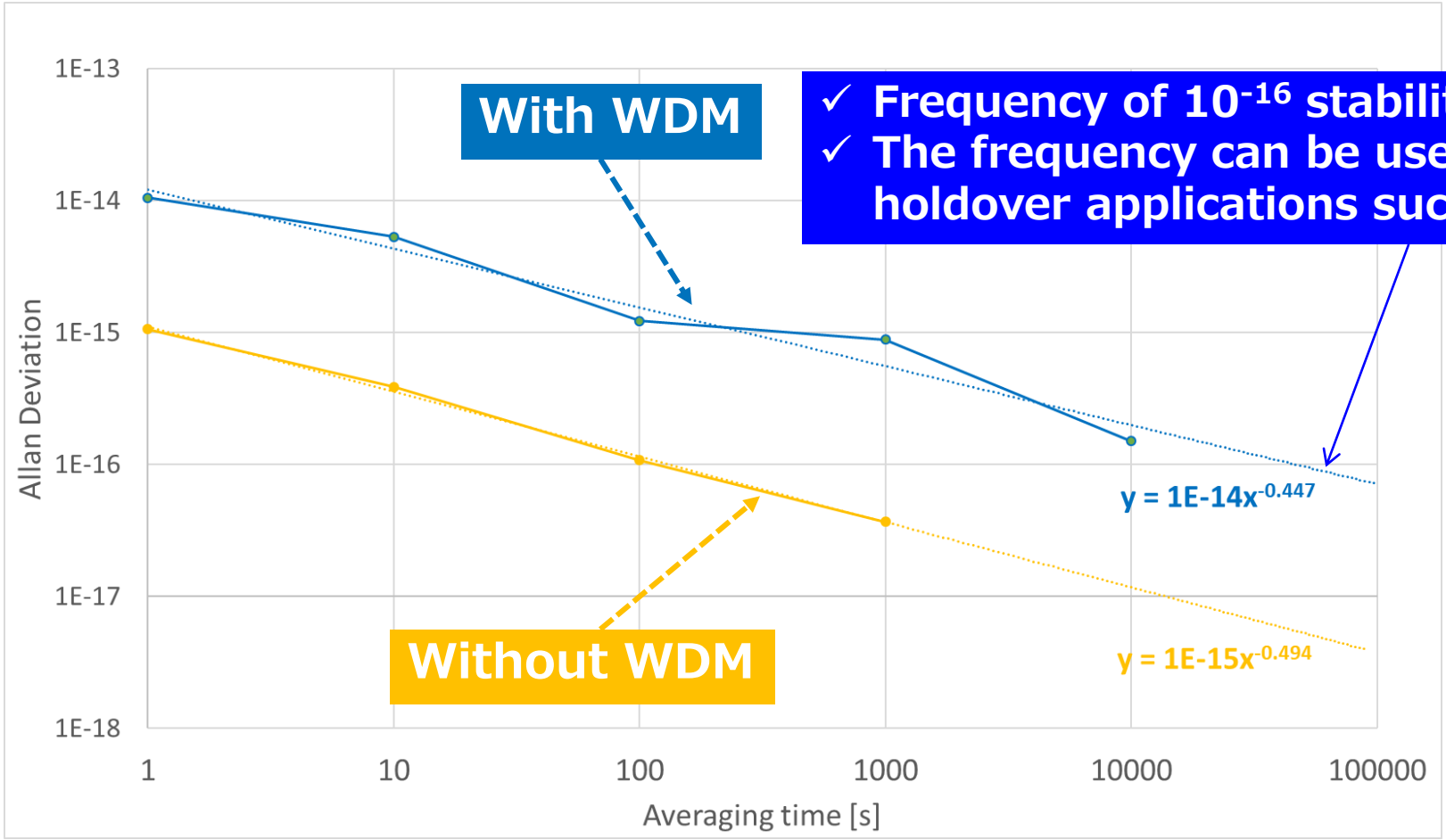
Result –Frequency Error-

- One-way frequency error becomes worse with WDM than without it.



Result -Stability-

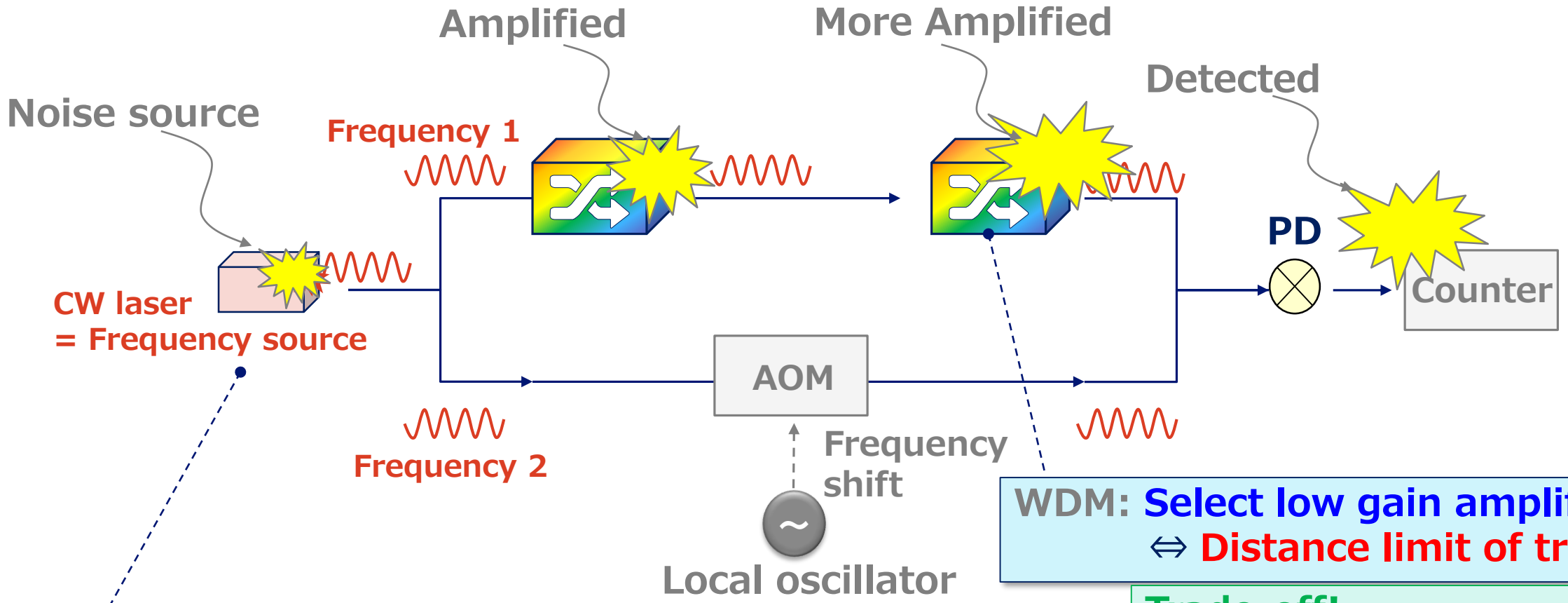
- The frequency stability with WDM is 10^{-16}, 10 times worse than without WDM.
- 10^{-16} stability can meet the requirements of long-term time holdover by frequency.



✓ Frequency of 10^{-16} stability can be transferred.
✓ The frequency can be used for long-term time holdover applications such as mobile.

Consideration: Toward Higher Accuracy

- Common noises on both frequencies are canceled by detection of difference.
- Amplified noise by WDM is detected as non-common noise.



WDM: Select low gain amplifier
⇔ Distance limit of transfer

Source: Select low noise laser and
setting parameters of PLL ⇔ Bandwidth of laser

Trade-off!
→Search for better solution

Future Works

- We will test further aspects to achieve more stable frequency transfer (10^{-16}-10^{-18}).

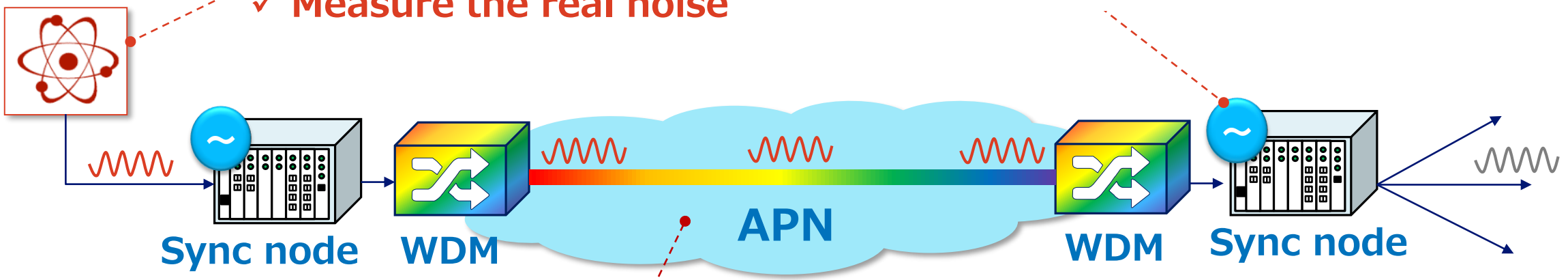
Connect to optical clock

Optical Clock

- ✓ Synchronize with an optical clock
- ✓ Measure the real noise

Can be noise compensated?

- ✓ Connect to optical sync node
- ✓ Determine network limits



How much additional noise from other factors?

- ✓ Long distance fiber cable
- ✓ Other traffic signals on WDM (Optical crosstalk)

Summary

[Concept]
- Optical clocks are under development worldwide.
- APN is an essential technology in IOWN.
- Optical clock x IOWN = All Optical Synchronization Network

[Test]
- Optical frequency transfer over WDM is difficult.
- We evaluated frequency stability by using a dedicated wavelength of WDM.
- 10^{-16} stability with WDM can be transferred without degradation.
- The system can be used for applications such as time holdover in these conditions

[Future works]
- Additional tests are needed to measure total amount of noise.