Analysis Model and Verification of Optical Transmission Time Error for High Precision Time Synchronization

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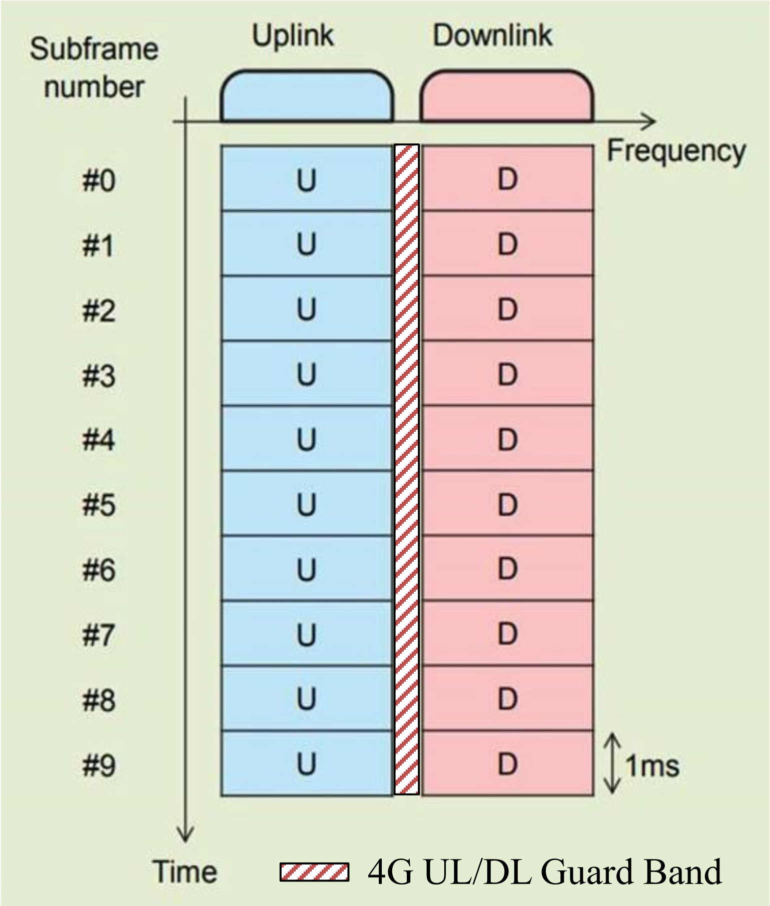
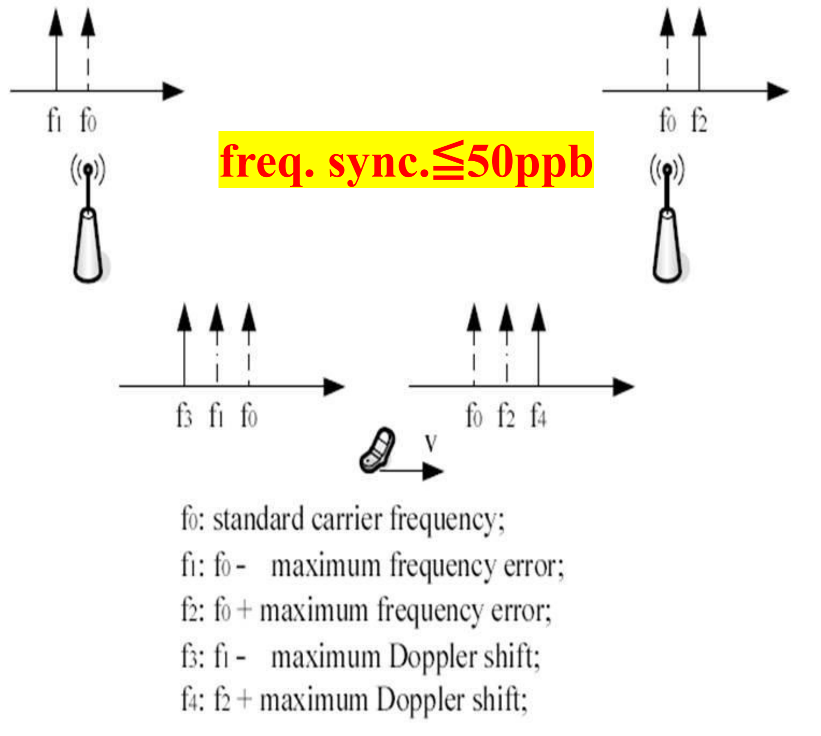
4G FDD only requires freq. sync.



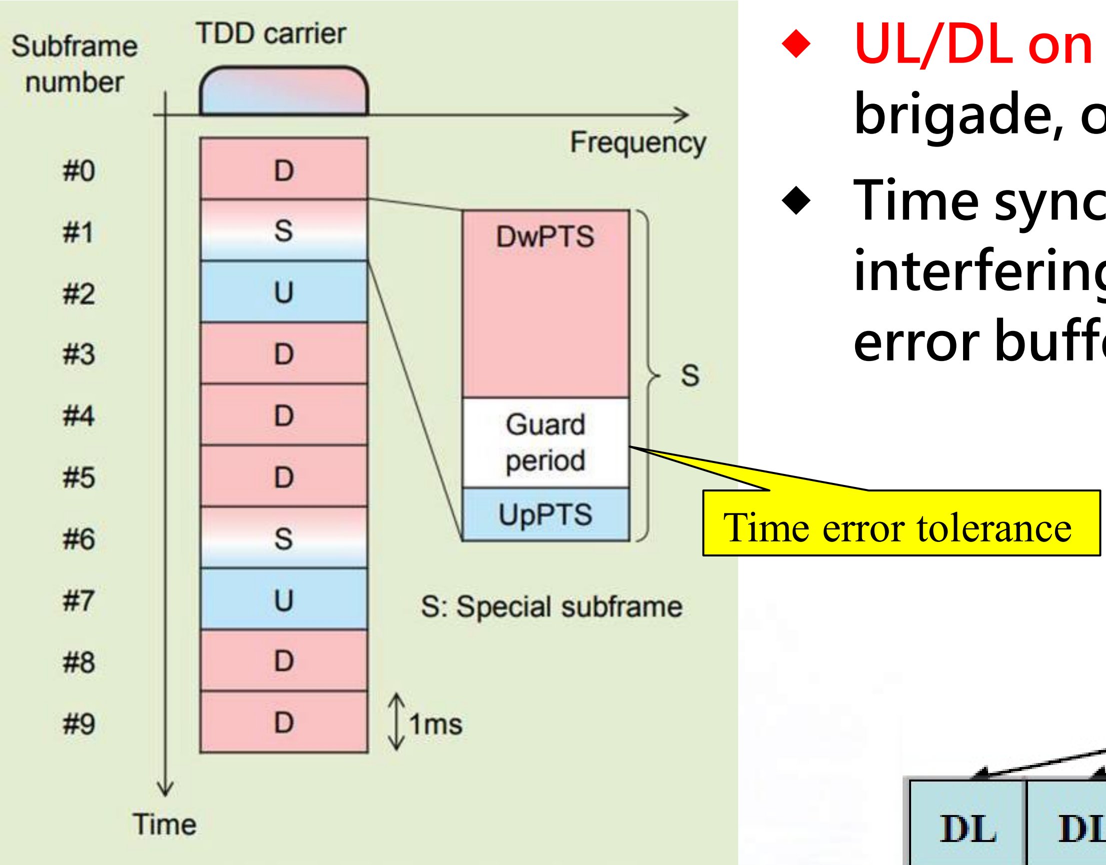
- Different runways for UL/DL, no need to wait.
- Guard band between UL and DL spectrum to ensure no interference.



Source: 3GPP TS 36.104 (2018/07) Section B.4

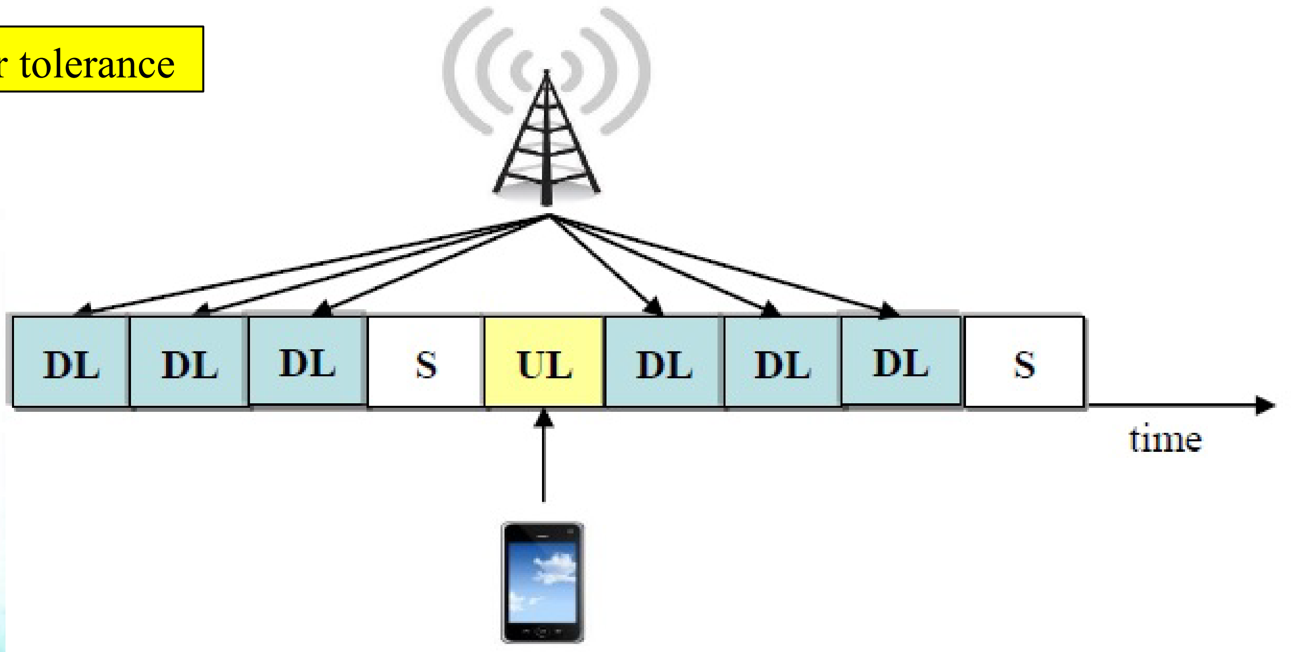
FDD: Frequency-Division Duplexing

5G TDD needs time and freq. sync.



(b) TDD (UL/DL configuration #2)

- UL/DL on the same runway, like relay race in a brigade, only transmit when taking over the baton
- Time sync. confirms UL/DL takeover without interfering with each other, guard period is time error buffer.



Source: 3GPP TS 36.104 (2018/07) Section B.4

TDD: Time-Division Duplexing

5G Synchronization Requirements

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中華電信 Chunghwa Telecom

■ Frequency requirements for 5G BS

BS class	Accuracy
Wide Area BS	±0.05 ppm
Medium Range BS	±0.1 ppm
Local Area BS	±0.1 ppm

±50ppb

Source: 3GPP TS 38.104 (2020/04) Table 6.5.1.2-1

Time Division Duplex

■ Time requirements for 5G BS

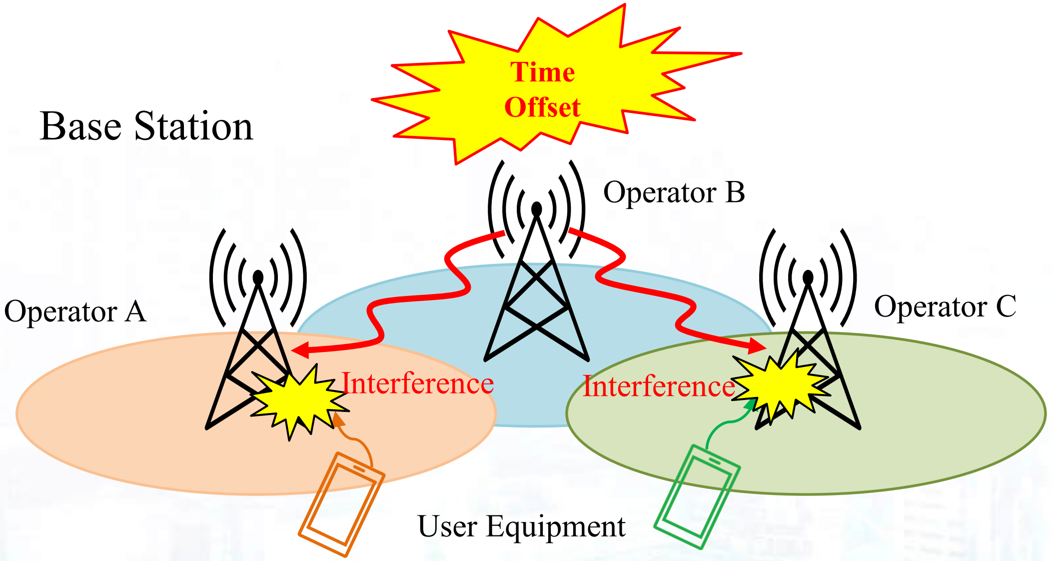
±1.5μs

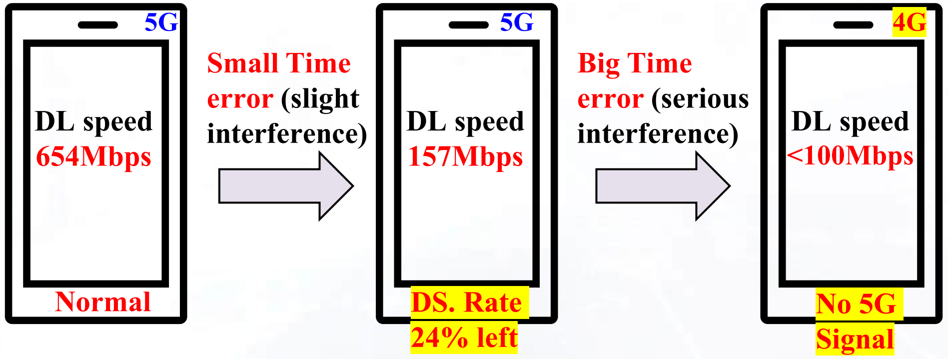
The cell phase synchronization accuracy measured at BS antenna connectors shall be better than 3μs. (each BS < ±1.5μs)

Source: 3GPP TS 38.133 (2020/02) Section 7.4.2

Time Synchronization and 5GS

- 5G TDD system needs Time Synchronization.
- Three conditions are met, interference occurs:
  1. **Between adjacent spectrum operators.**
  2. **Neighboring base stations.**
  3. **Time between two operators is not synchronized (greater than 3000ns).**

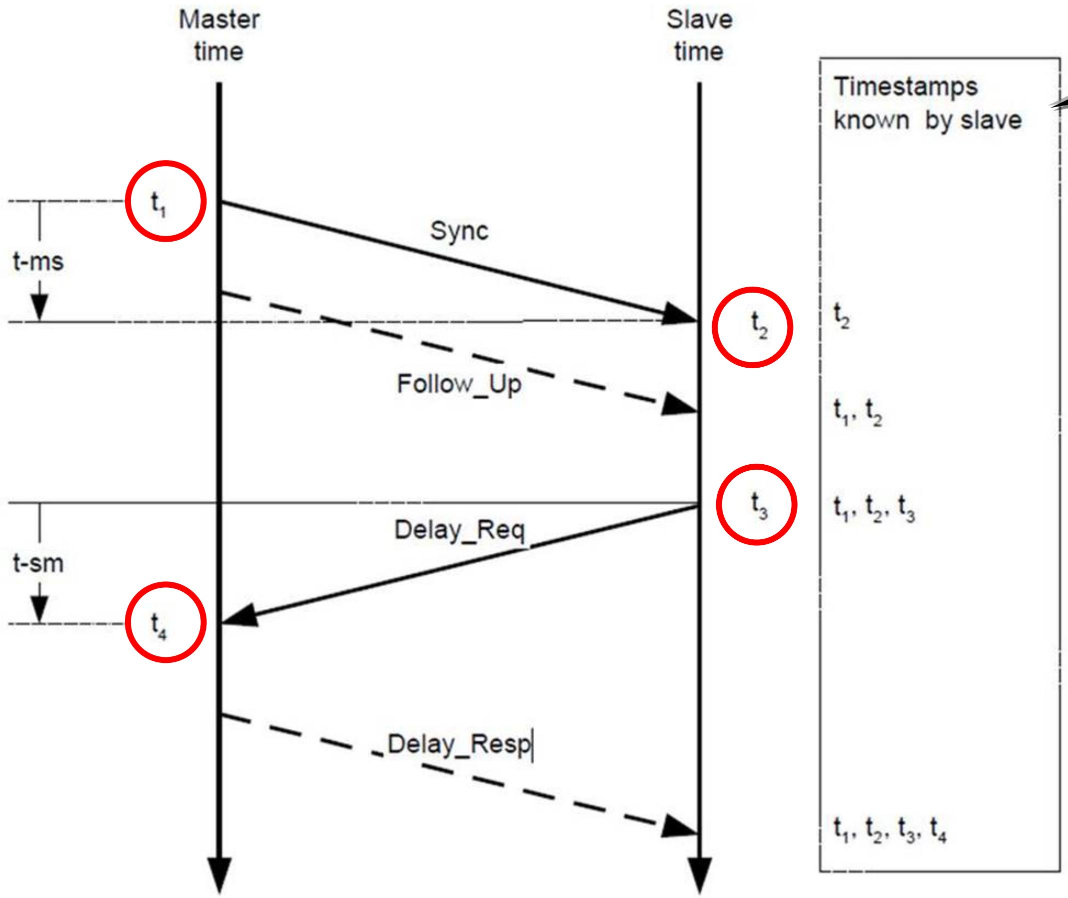




Lab test at CHTTL

Precision Time Protocol (PTP)

- IEEE 1588-2008/2019 Precision clock synchronization protocol for network measurement and control systems.



Delay request-response mechanism

Master to slave delay
t-ms = $t_2 - t_1$

Slave to master delay
t-sm = $t_4 - t_3$

round trip delay
t-ms + t-sm =
$(t_2 - t_1) + (t_4 - t_3)$

symmetry assumption

one way delay
round trip delay / 2 =
$[(t_2 - t_1) + (t_4 - t_3)] / 2$

estimated time offset =
$t_2 - (t_1 + \text{one way delay})$ =
$[(t_2 - t_1) - (t_4 - t_3)] / 2$

Source: IEEE 1588-2008 Figure 12

Methodology- Delay asymmetry model

- A delay asymmetry model proposed to analyze time errors caused by
  (1) asymmetric bidirectional transmission cable lengths.
  (2) unequal laser wavelengths in transceivers.

$$A = \frac{1}{2}\left(\frac{\boldsymbol{L_{ms}}}{c} \times \left(n_o + \frac{cS_0}{8}\boldsymbol{\lambda_{ms}}^2\left(1 - \frac{\lambda_0{}^2}{\boldsymbol{\lambda_{ms}}^2}\right)^2\right)\right.$$

$$\left. - \frac{\boldsymbol{L_{sm}}}{c} \times \left(n_o + \frac{cS_0}{8}\boldsymbol{\lambda_{sm}}^2\left(1 - \frac{\lambda_0{}^2}{\boldsymbol{\lambda_{sm}}^2}\right)^2\right)\right)$$

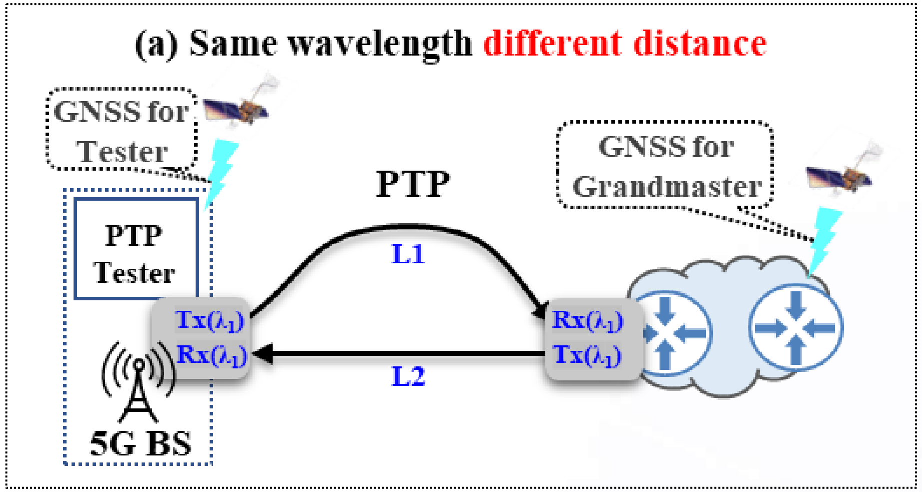
- L_{ms} and L_{sm} are the downlink (master to slave) and uplink (slave to master) path lengths respectively
- λ_{ms} and λ_{sm} are the laser wavelengths used in the downlink and uplink respectively
- S_0 is the dispersion slope (0.092 ps/nm^2/Km)
- c is the speed of light (3x10^5 Km/s)
- n_0 is the refractive index of the fiber
- λ_0 is the zero dispersion wavelength (1310nm).

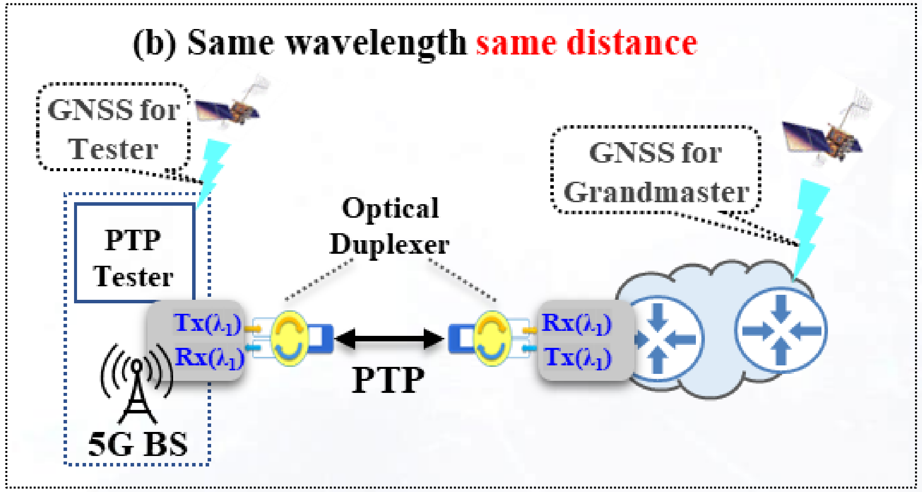
Use Case 1. different distance

- Time errors caused by (1) asymmetric bidirectional transmission cable lengths.
- Using Optical Duplexer to enable the same optical cable for UL/DL transmission, and to eliminate the asymmetric time errors.

	Variation	1st Line		2nd Line	
		w/o Dupl.	w/Dupl.	w/o Dupl.	w/ Dupl.
DL Length	L_{ms}	13,414(m)	13,414(m)	13,841(m)	2,519(m)
UL Length	L_{sm}	5,131(m)	13,414(m)	2,519(m)	2,519(m)
	ΔL*	8,283(m)	0(m)	11,322(m)	0(m)
	|Theoretical|	20,434(ns)	**0(ns)**	27,701(ns)	**0(ns)**
	|Measured|**	**19,000(ns)** →	451(ns)	**29,000(ns)** →	471(ns)

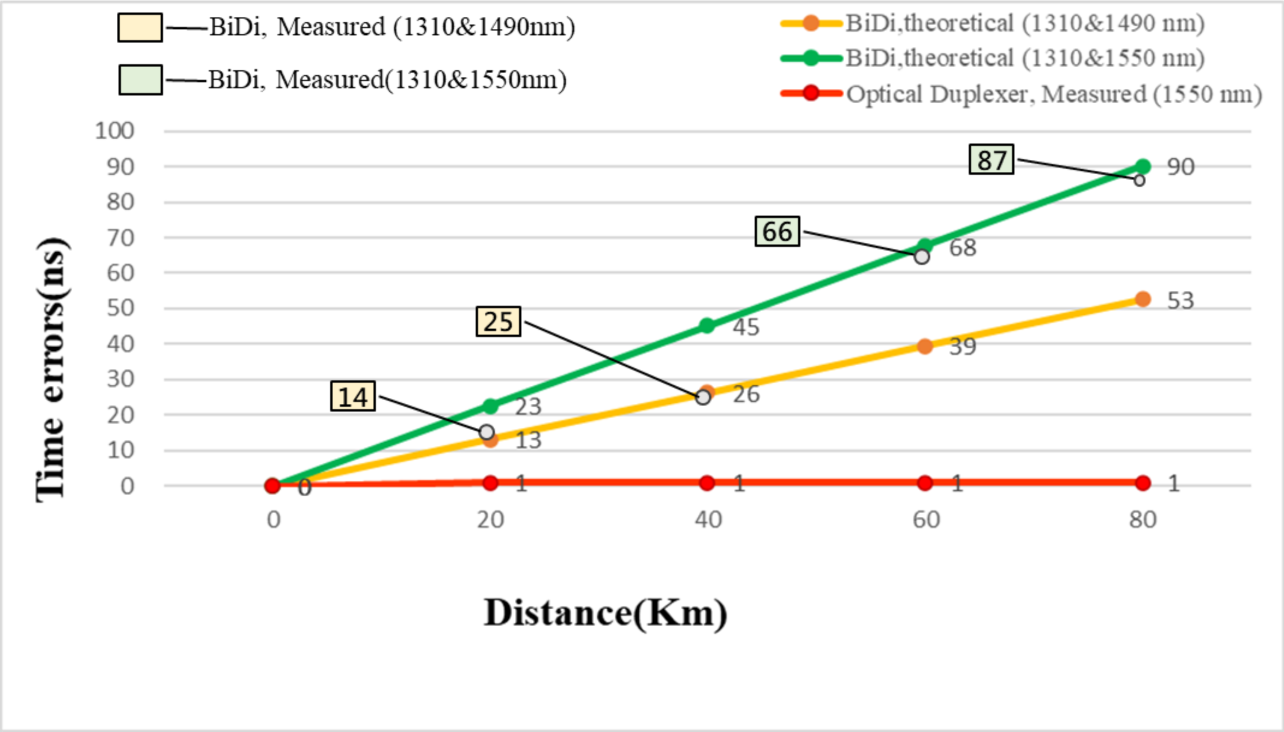
Note:*$\Delta L = L_{ms} - L_{sm}$
**Including time errors caused by GNSS reception and equipment

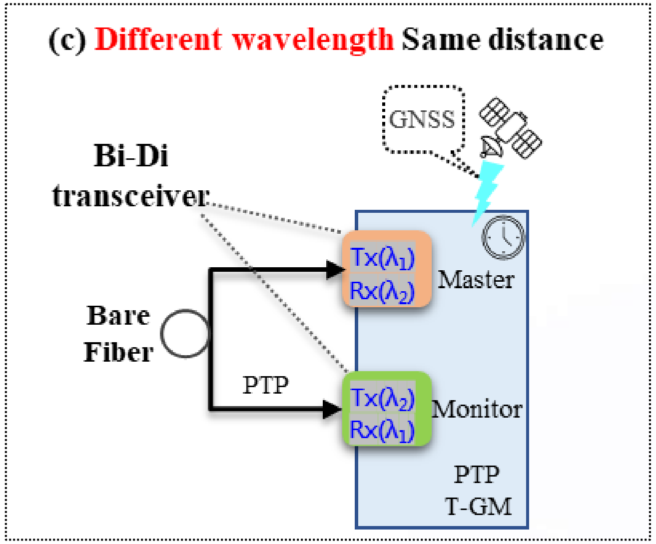


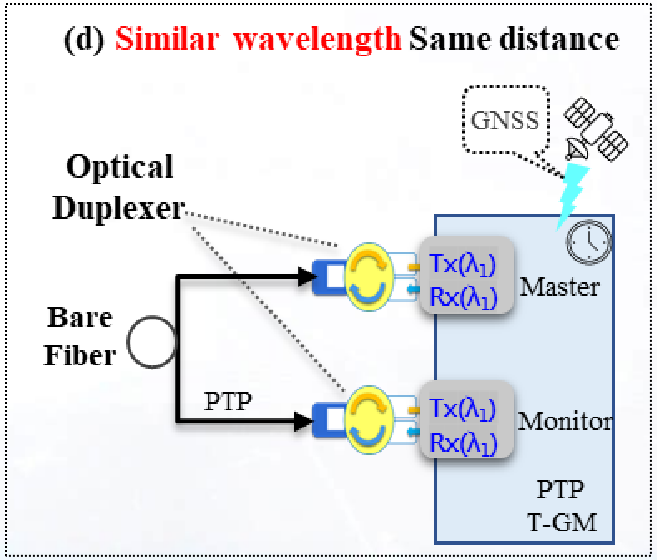


Use Case 2. different wavelength

- Time errors caused by (2) unequal laser wavelengths in transceivers.
- Using Optical Duplexer to enable the similar wavelengths for UL/DL transmission, and to eliminate the time errors.

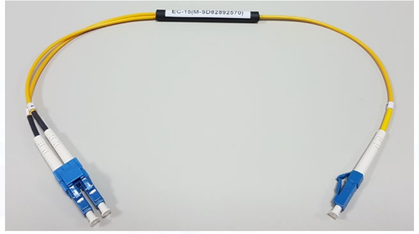






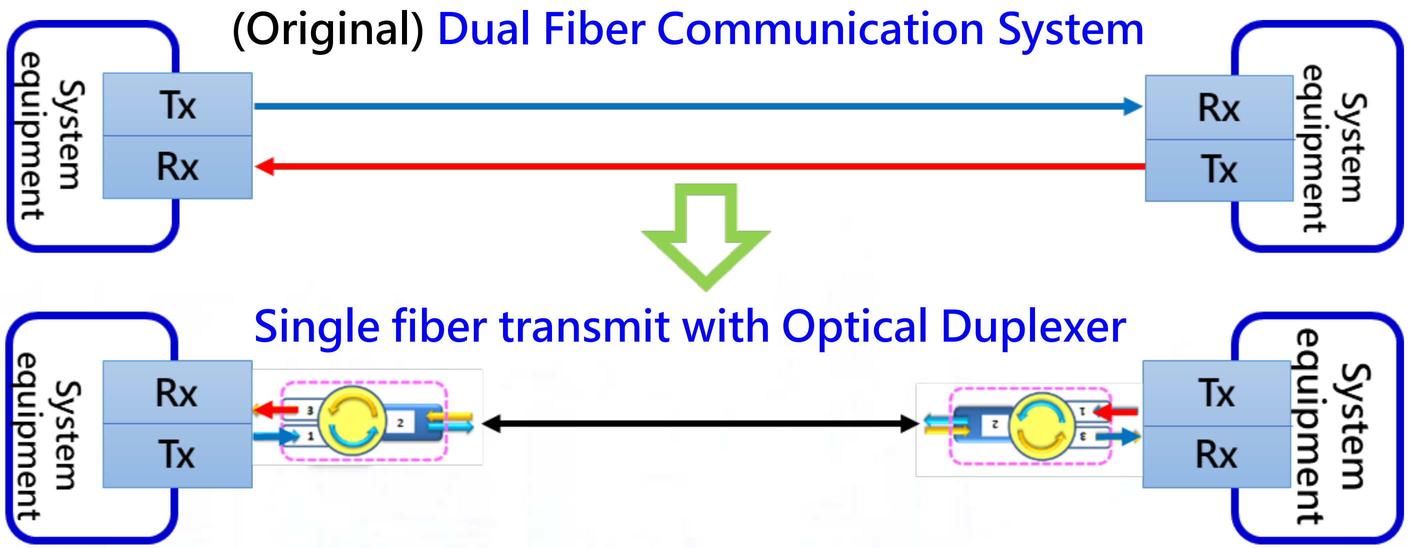
Optical Duplexer (1/2)

- Suitable for optical wavelength transmission range from 1260 to 1625nm. (O、E、S、C、L bands)
- Patterns
  - Optical Duplexer and Optical Transceiving System (R.O.C. Patent: M574365, 2019-02-11)
  - Optical Forwarding Device (R.O.C. Patent: I716265, 2021-01-11)
  - Optical Forwarding Device (U.S. Patent: US 11,303,378 B2, 2022-04-12)
  - System and Method of Bidirectional Transmission Delay Equalization for Time Synchronization Network Using Optical Duplexer(R.O.C. and Japan Patent Applying)



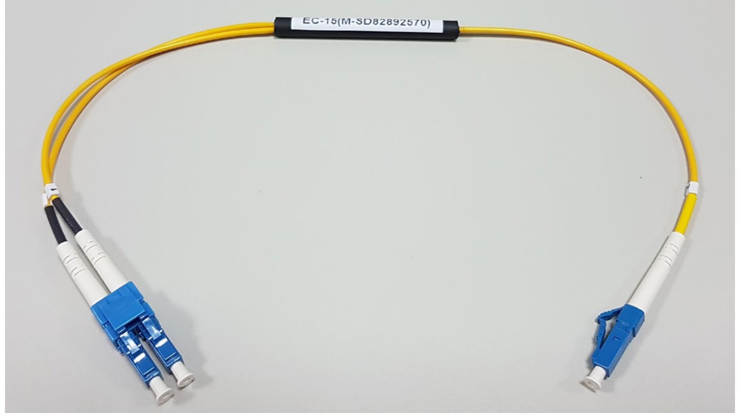
Optical Duplexer (2/2)

- **Using an Optical Duplexer in existing communication systems enables the conversion of dual-fiber transmission into single-fiber transmission.**



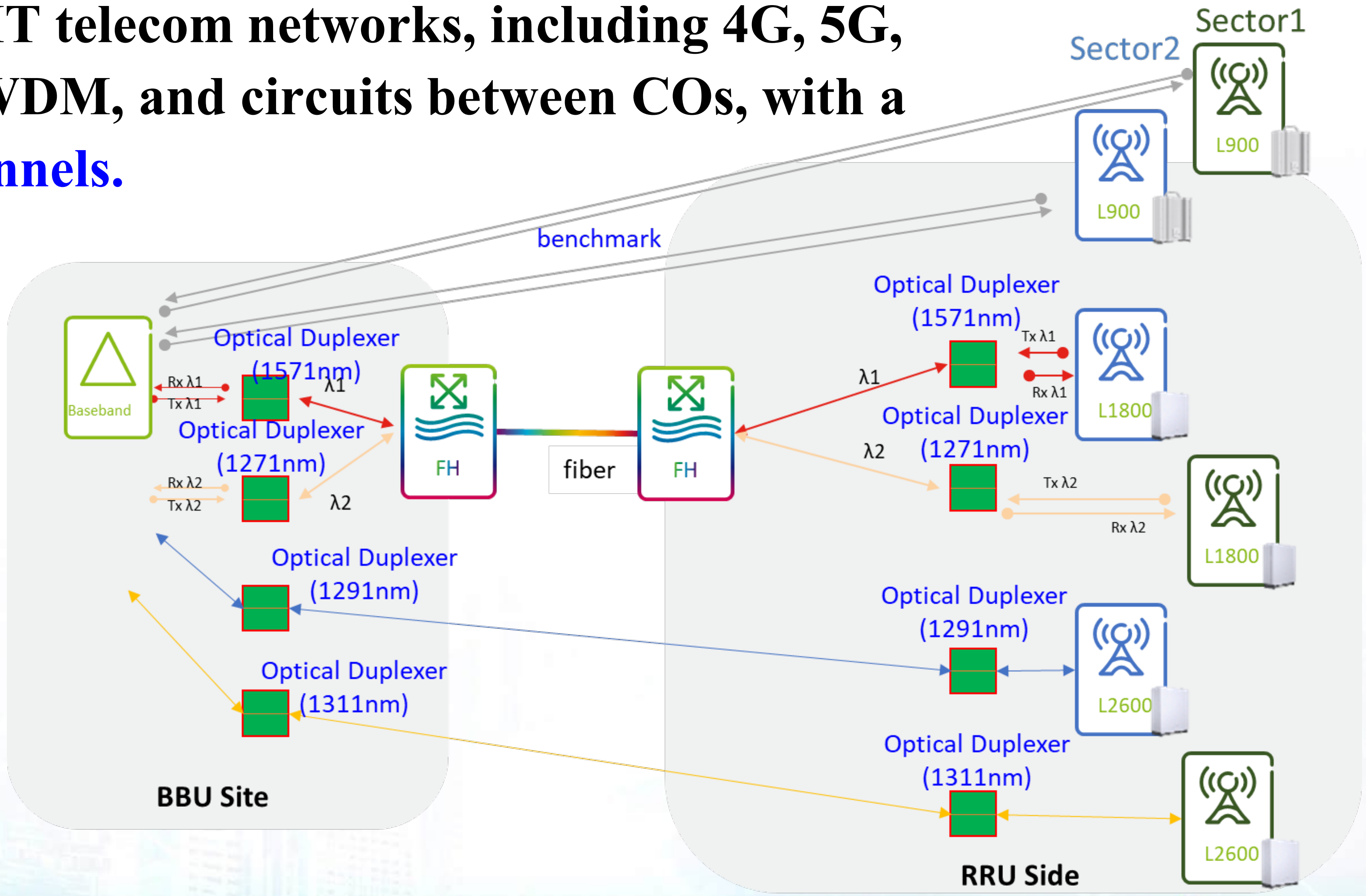
Optical Duplexer Spec.

- Operating wavelength range from 1260 to 1625nm, divided into three Optical Duplexer bands.
  - Insertion Loss with connector: ≦ 3 dB
  - Adjacent Channel Loss: ≦ 0.2 dB
  - Return Loss: ≧ 45 dB
  - Directivity @CWL: ≧ 50 dB
  - Max. Power Handling: ≧ 500 mW



Optical Duplexer Use Case

- Already applied in CHT telecom networks, including 4G, 5G, Fronthaul CWDM/DWDM, and circuits between COs, with a total of **over 1,000 channels.**
  - Observing the main 4G KPI quality, there is **approximately a 0.1% difference before and after.**
  - The CWDM wavelengths from 1271~1611nm, 18 channels spaced@ 20nm.



Conclusion

- 5G and future mobile networks require high-precision time synchronization and compliance with international standards for normal operation.
- The Optical Duplexer we proposed can effectively solve the time error problem caused by different distances, and there will be no additional time error problem caused by using BiDi transceivers at long distances.

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