

# T2-3 Analog-RoF mobile fronthaul networking testbed in Keio future photonic network open lab



Kojiro Nishimura (Speaker), Yoshihiko Uematsu,

Satoru Okamoto, and Naoaki Yamanaka

Graduate School of Science and Technology, Keio University

July 17-18, NICT Koganei, Japan

# Outline

---

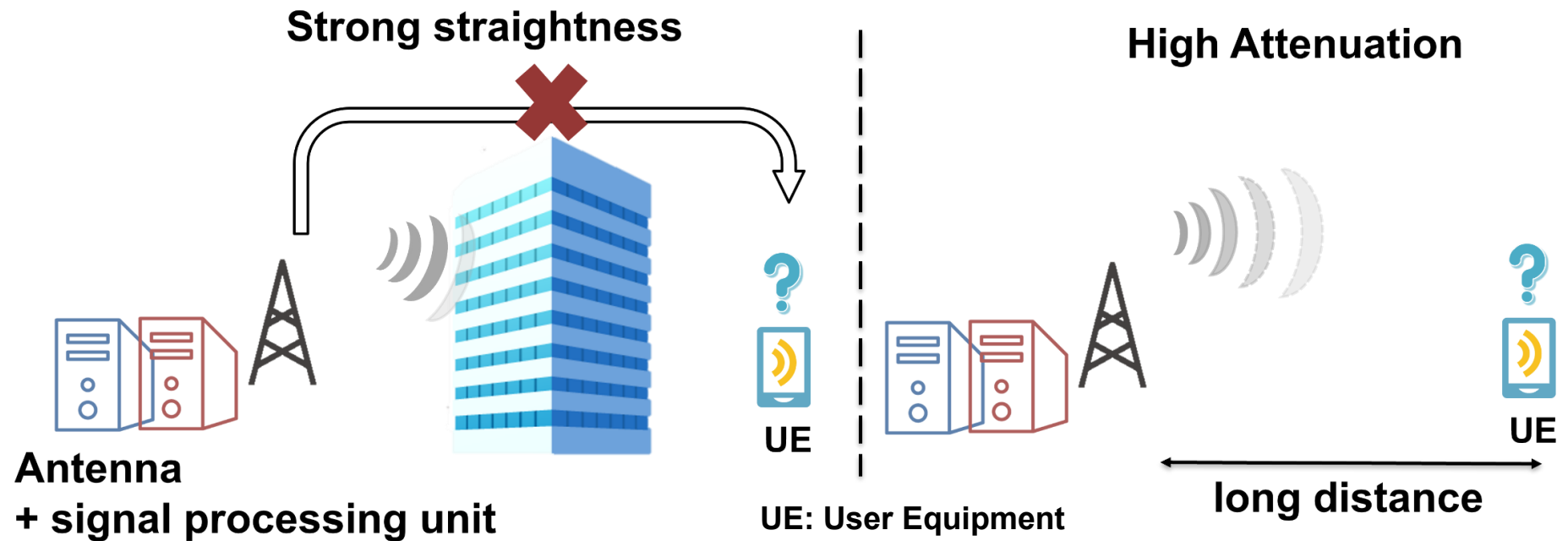
- Background
  - Why A-RoF, Why HCF, Networked A-RoF, Switched-RoF, Mult-spot RoF
- Campus Fiber Setup
- Local 5G A-RoF networking testbed
- Experimental scenario (Switching Experiment)
- Experimental result (Switching Experiment)
- Joint Transmission
  - Cyclic Prefix length
- Experimental setup (Joint-Transmission Experiment)
  - #1, #2
- Experimental results (Joint-Transmission Experiment)
  - DL, UL
- Summary

# Why Analog-Radio over Fiber (A-RoF)

Requirements in the beyond 5<sup>th</sup> generation (B5G) era

- high speed communication
- lower latency
- wide-area coverage

It is necessary to increase bandwidth using high frequencies (e.g.) millimeter waves, terahertz waves.

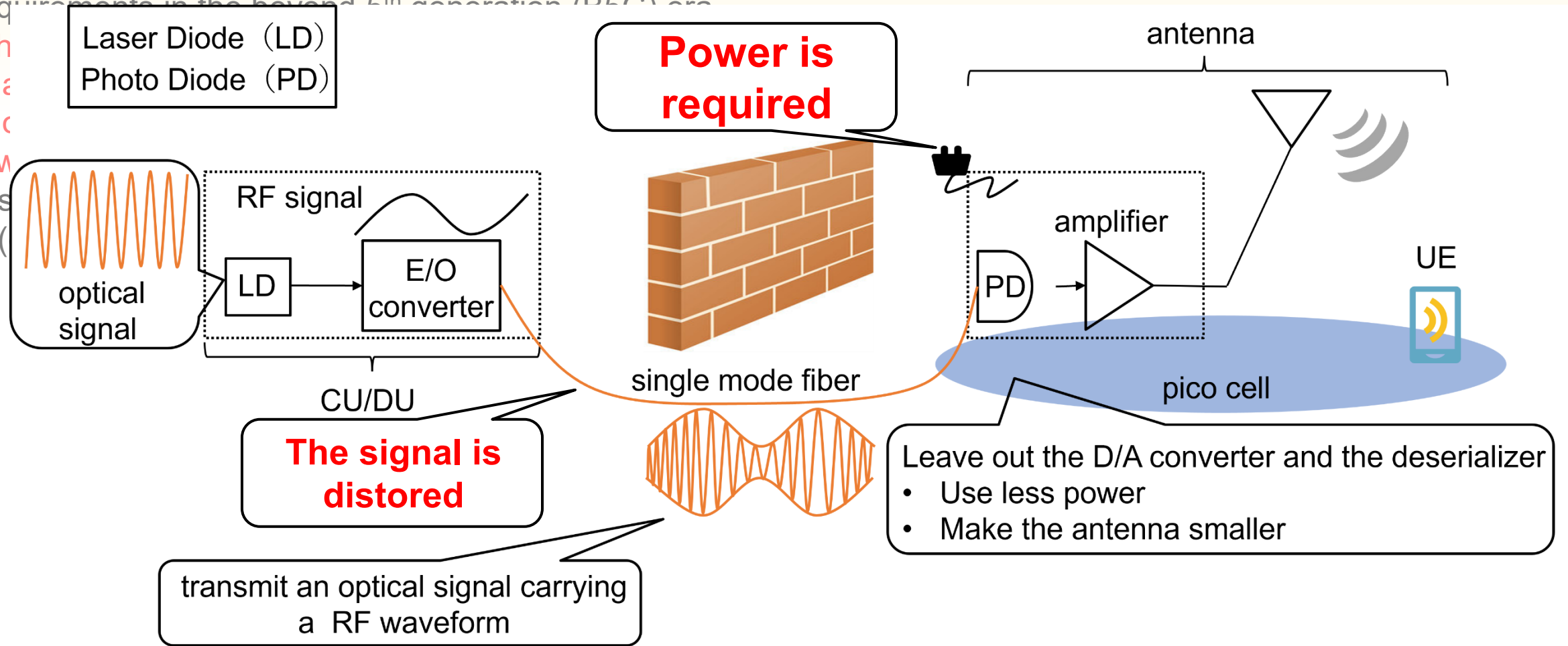


# Why Analog-Radio over Fiber (A-RoF)

Requirements in the beyond 5th generation (B5G) are

- h
- l<sub>2</sub>
- l<sub>3</sub>
- w

It is (

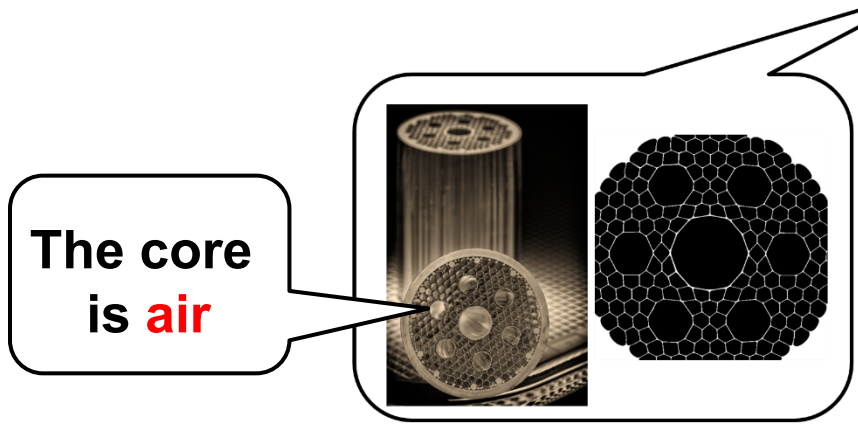
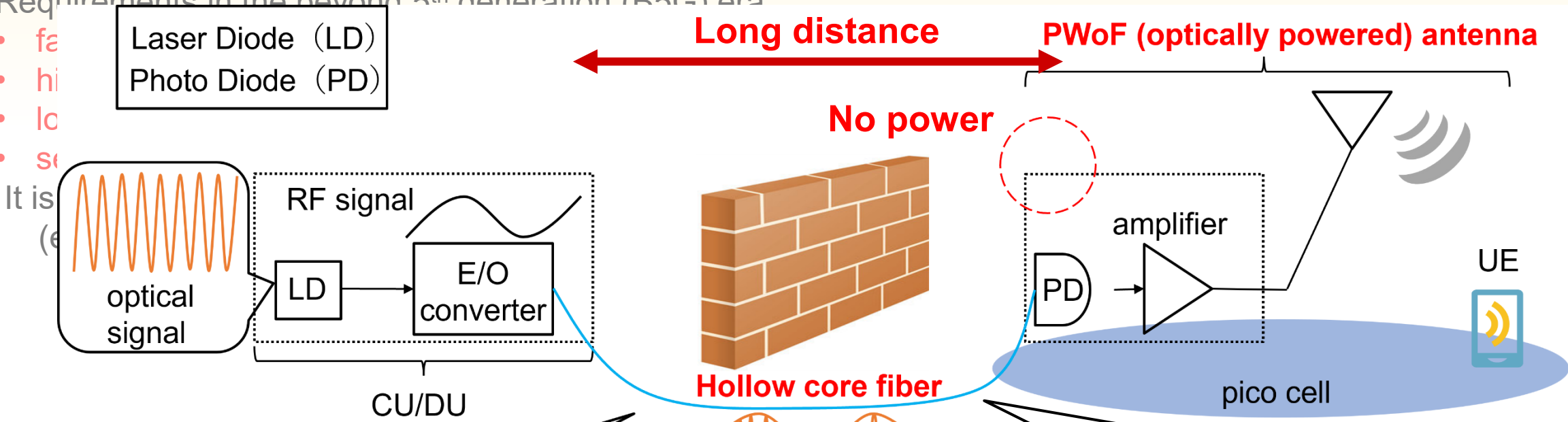


# Why Hollow-Core Fiber (HCF)

Requirements in the beyond 5th generation (B5G) era

- fa
- hi
- lo
- se

It is (e



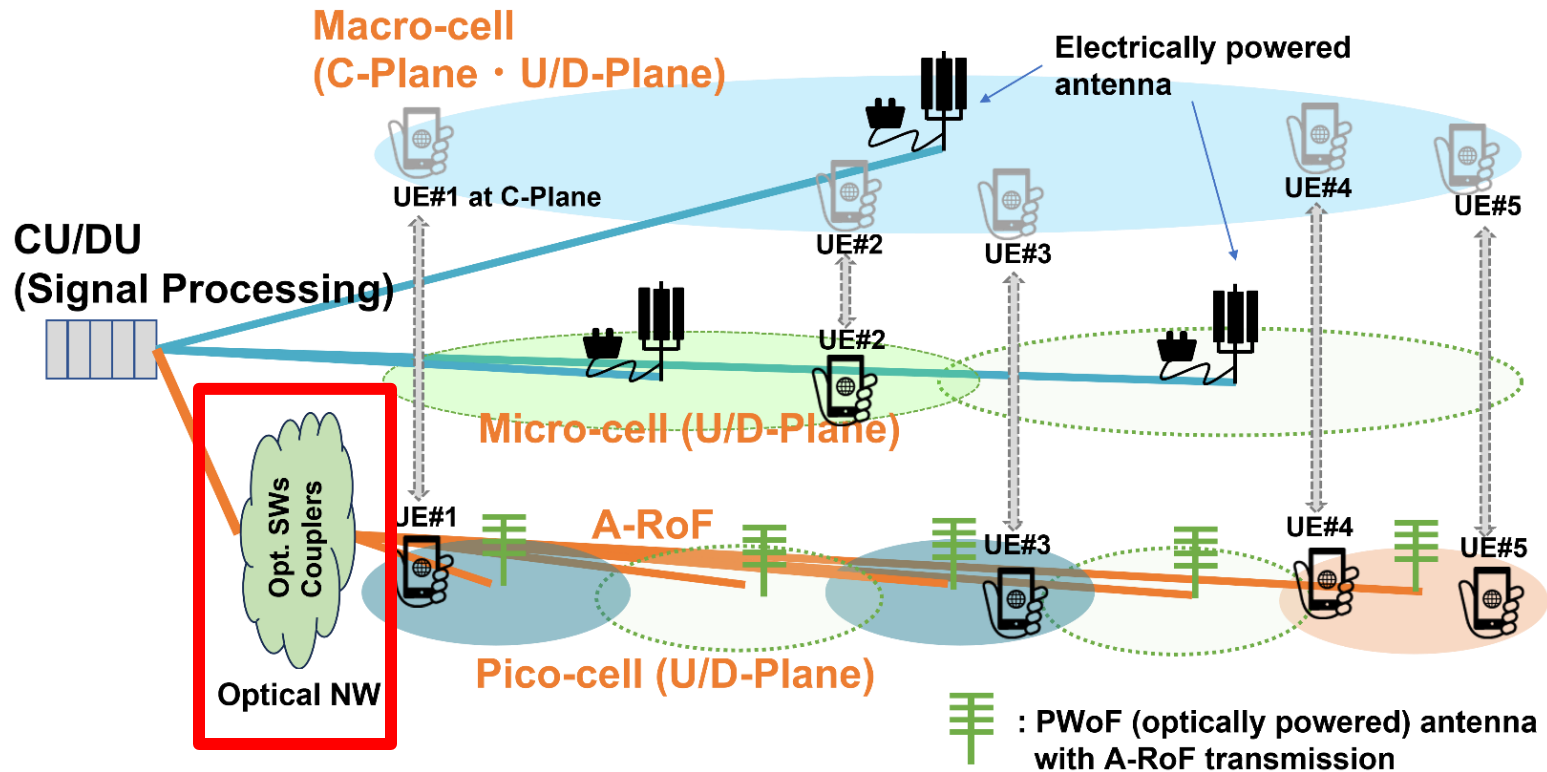
- Key advantages of Hollow-core fiber (vs. standard single-mode fiber)
1. **Ultra-low non-linearity** – only about  $\frac{1}{1000}$  of SMF's
  2. **Very high damage limit** – can handle roughly  $1000 \times$  more optical power
  3. **Lower delay** – light takes only  $\frac{2}{3}$  of the time to travel the same length

# Networked A-RoF

We have proposed the smart mobile fronthaul (SMFH) concept using A-RoF technologies with HCFs.

Build an **optical-layer network** by adding **optical switches and optical couplers**

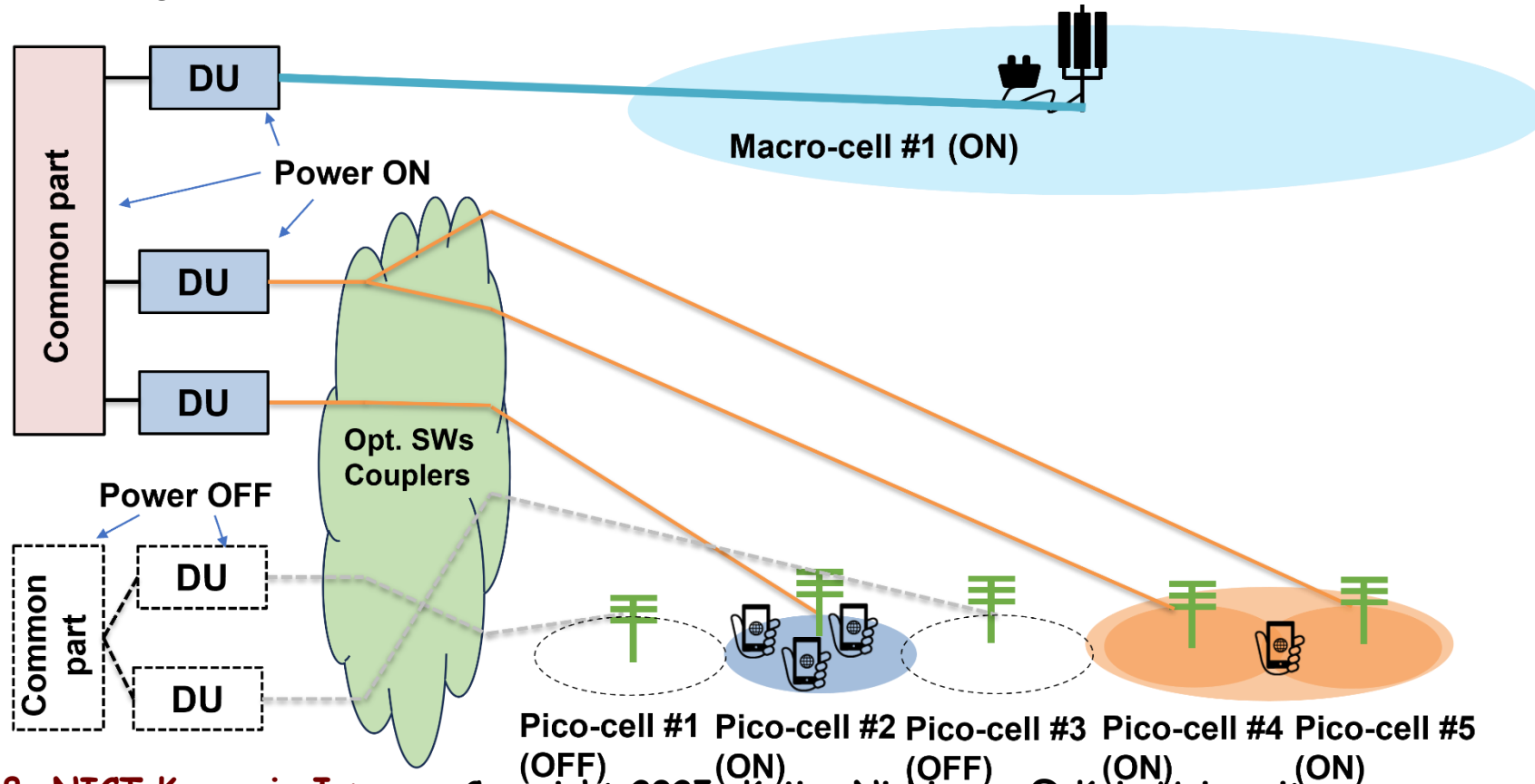
→ Saves power and uses RF resources more efficiently.



# Switched-RoF

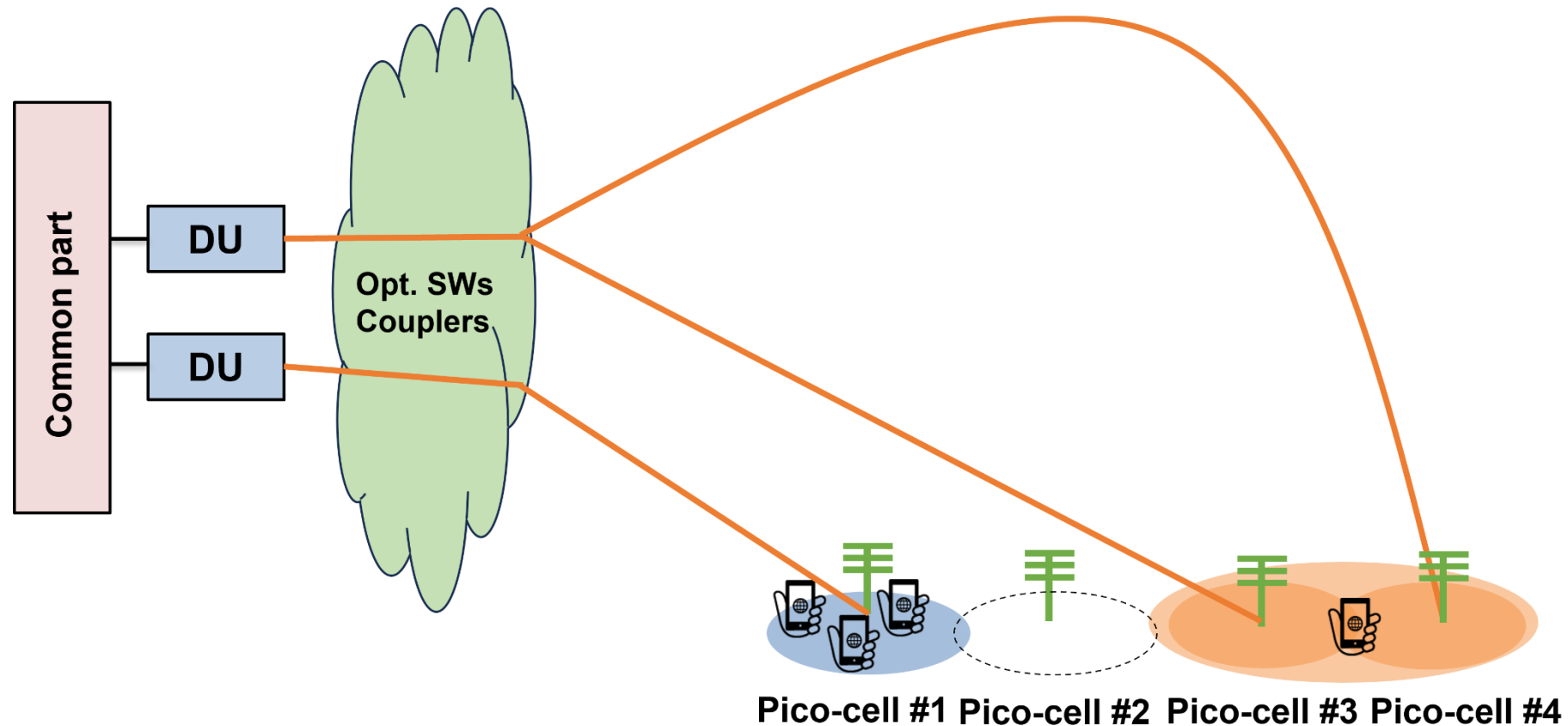
- Switched-RoF

- An optical switch makes a one-to-one fiber link.
- If no user is inside a cell, we keep its Pico-cell asleep and its DU powered down.
- When a user walks in, we wake that Pico-cell ; the DU stays in a shared pool.
  - big power savings.



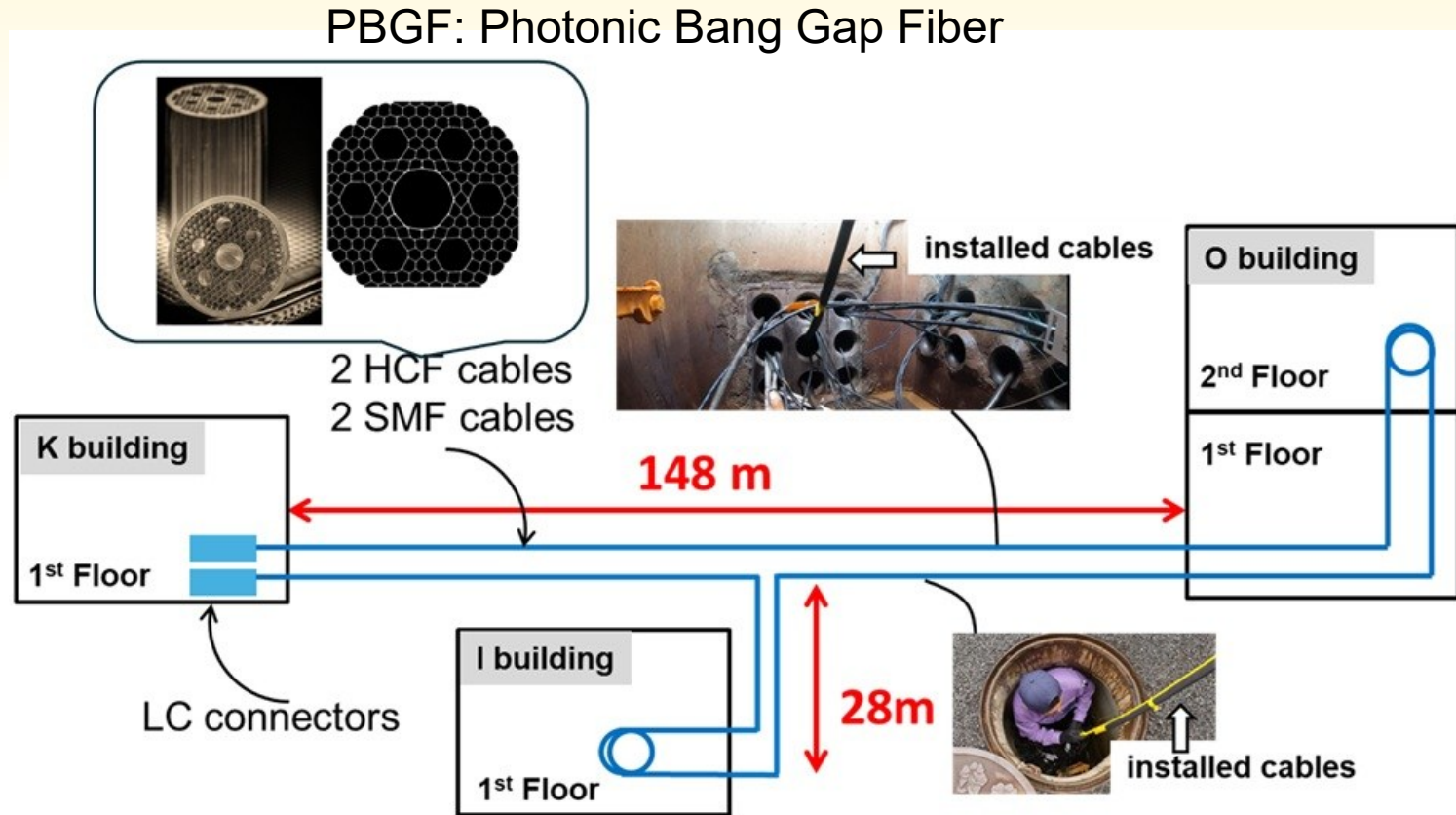
# Mult-spot RoF

- Multispot-RoF
  - One DU sends the same RF signals over a P-to-MP optical path to several nearby cells.
  - A single DU can drive many antennas, so we use RF resources and hardware better.



# Campus Fiber Setup

## - 500 m PBGF-HCF cables -



### Cable makeup

- **Two PBGF-HCF cables in the installed cable.**
  - Provided by Lightera
- **Standard LC connector is attached to PBGF-HCF.**
  - Few cm SMF is spliced to the PBGF-HCF.
  - < 1 dB loss penalty for each HCF termination point.



### Optical loss

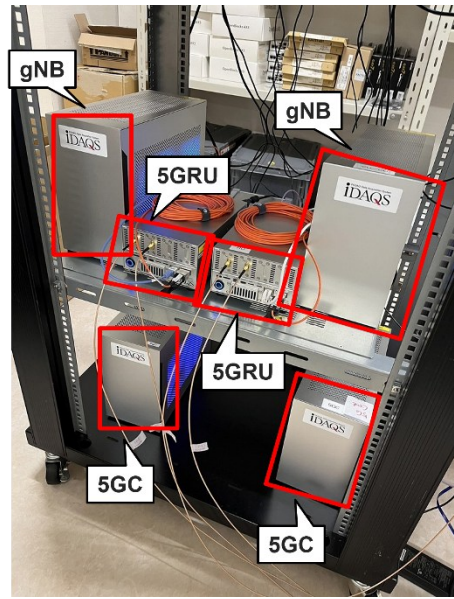
- **Splice + connector loss is under 1 dB per end.**
- Total loss of **the 500 m HCF line is about 3.2 dB**

# Local 5G A-RoF networking testbed

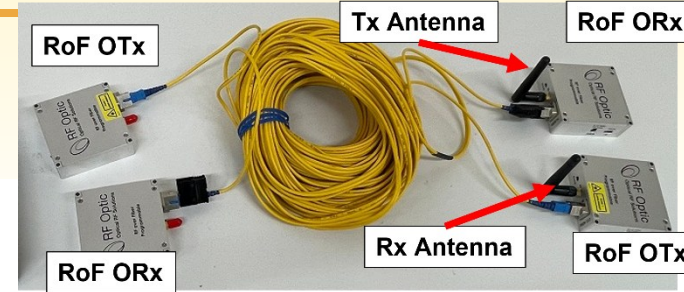
## What we built

1. Sub6 (4.9 GHz) Local 5 G base station
2. A-RoF link
3. Optical network with one MEMS switch and two 1 : 2 couplers
4. Local 5 G UE.

## Local 5G system



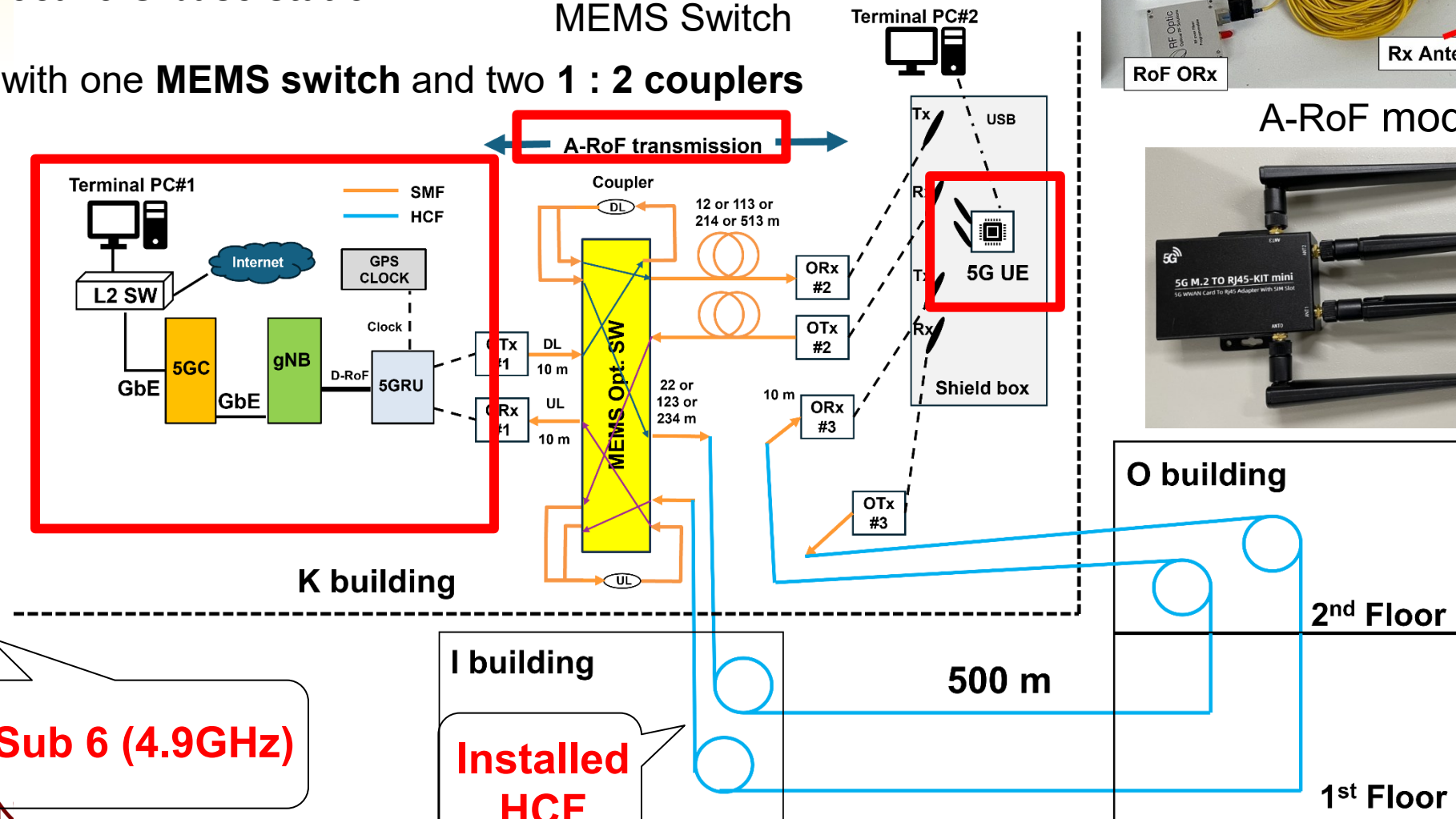
MEMS Switch



A-RoF modules



5G UE



Sub 6 (4.9GHz)

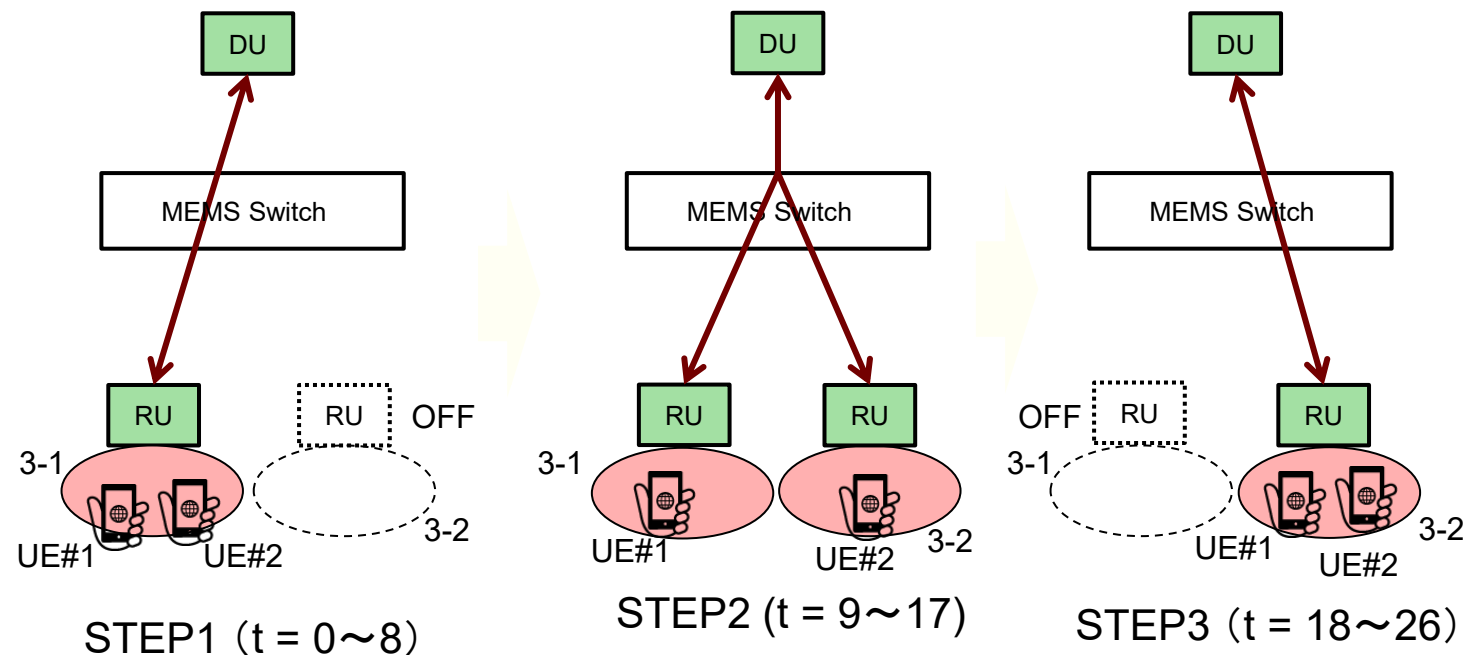
Installed HCF

July 17-18, 2020

# Experimental scenario (Switching Experiment)

## Physical Switching Test During UE Mobility (Simulation)

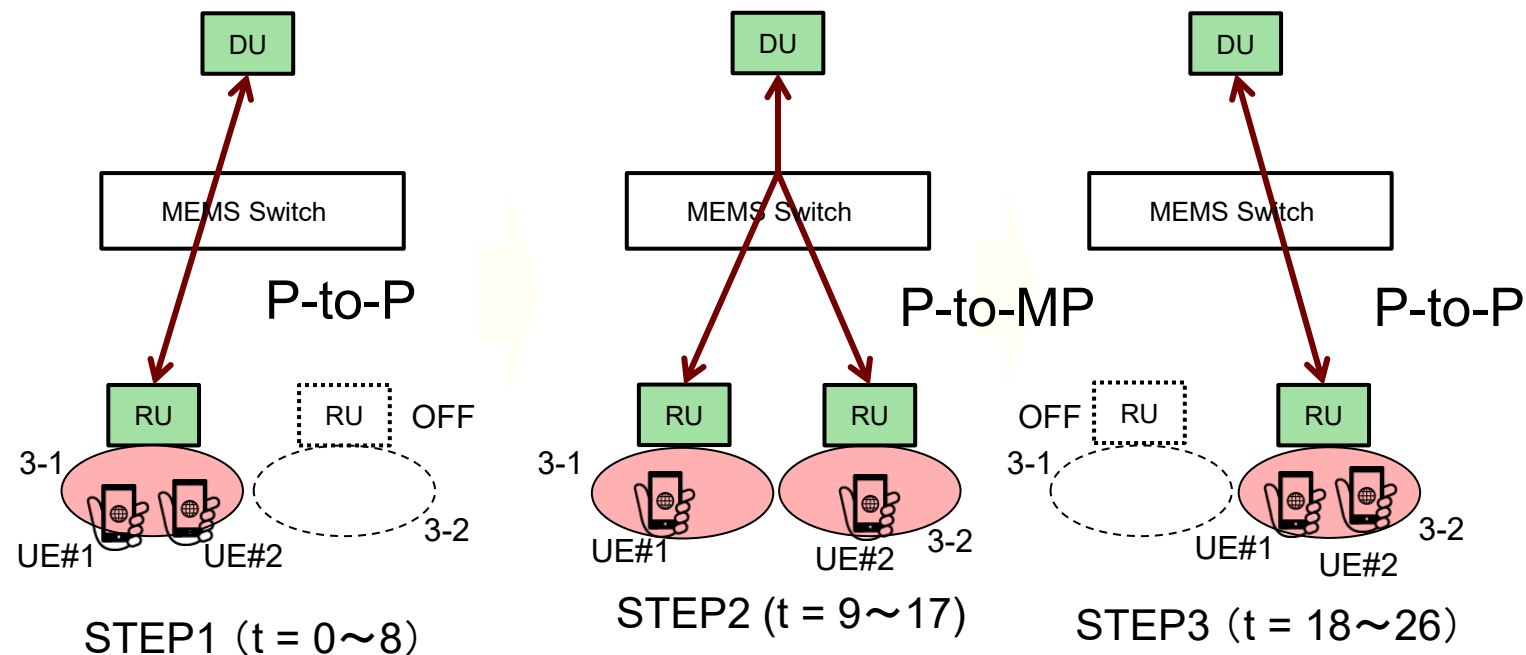
- **Step 1 (t = 0 – 8 s)** Both **UE#1** and **UE#2** stay in **Small Cell 3-1**; **Small Cell 3-2 = OFF**
- **Step 2 (t = 9 – 17 s)** **UE#1** remains in **Small Cell 3-1**; **UE#2** moves to **Small Cell 3-2** → **Small Cell 3-2 = ON**
- **Step 3 (t = 18 – 26 s)** **UE#1** also moves to **Small Cell 3-2**; **Small Cell 3-1 = OFF**



# Experimental scenario (Switching Experiment)

## Physical Switching Test During UE Mobility (Simulation)

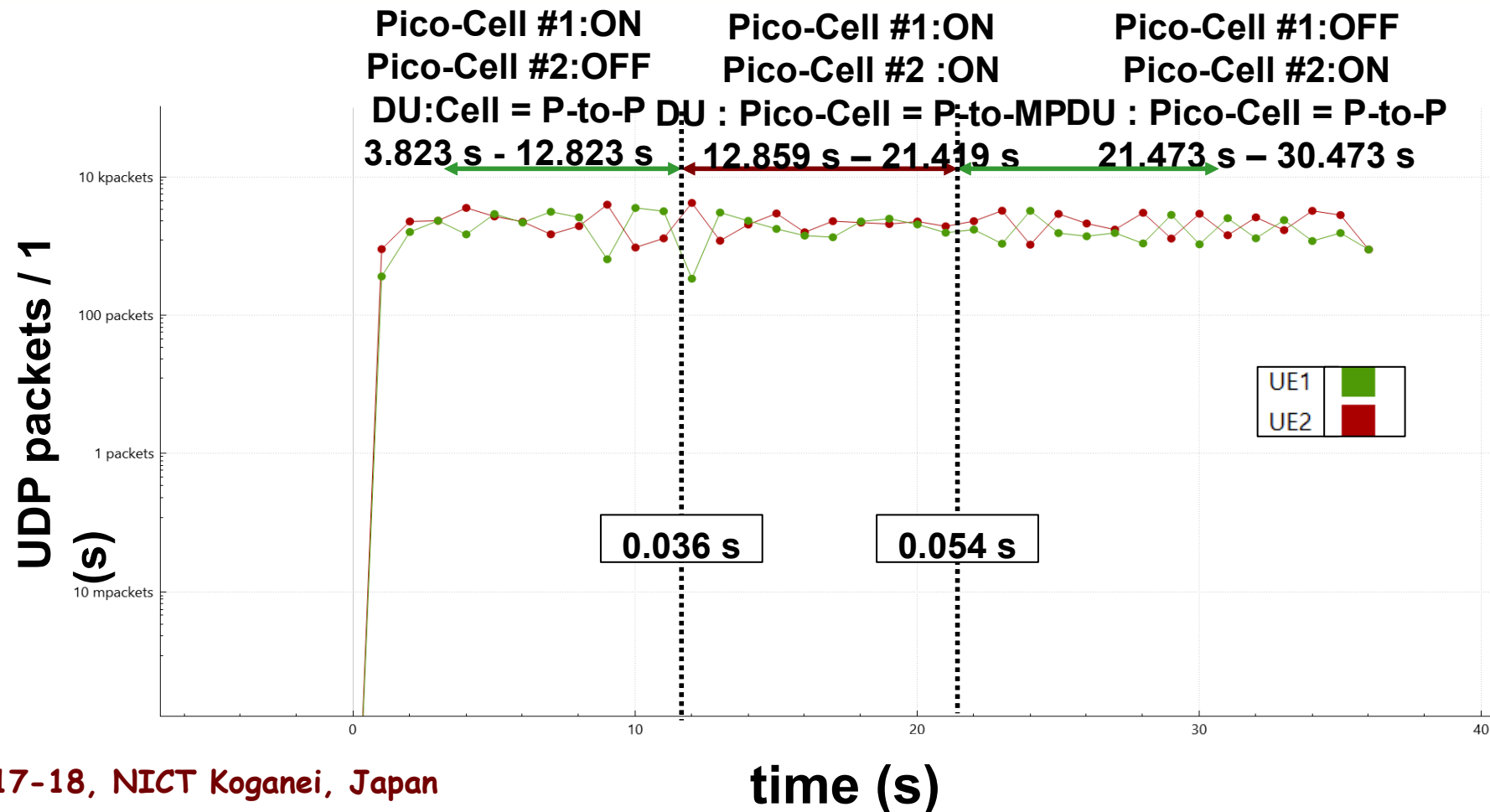
- **Step 1 (t = 0 – 8 s)** Both **UE#1** and **UE#2** stay in **Small Cell 3-1**; **Small Cell 3-2 = OFF**
- **Step 2 (t = 9 – 17 s)** **UE#1** remains in **Small Cell 3-1**; **UE#2** moves to **Small Cell 3-2** → **Small Cell 3-2 = ON**
- **Step 3 (t = 18 – 26 s)** **UE#1** also moves to **Small Cell 3-2**; **Small Cell 3-1 = OFF**



# Experimental result (Switching Experiment)

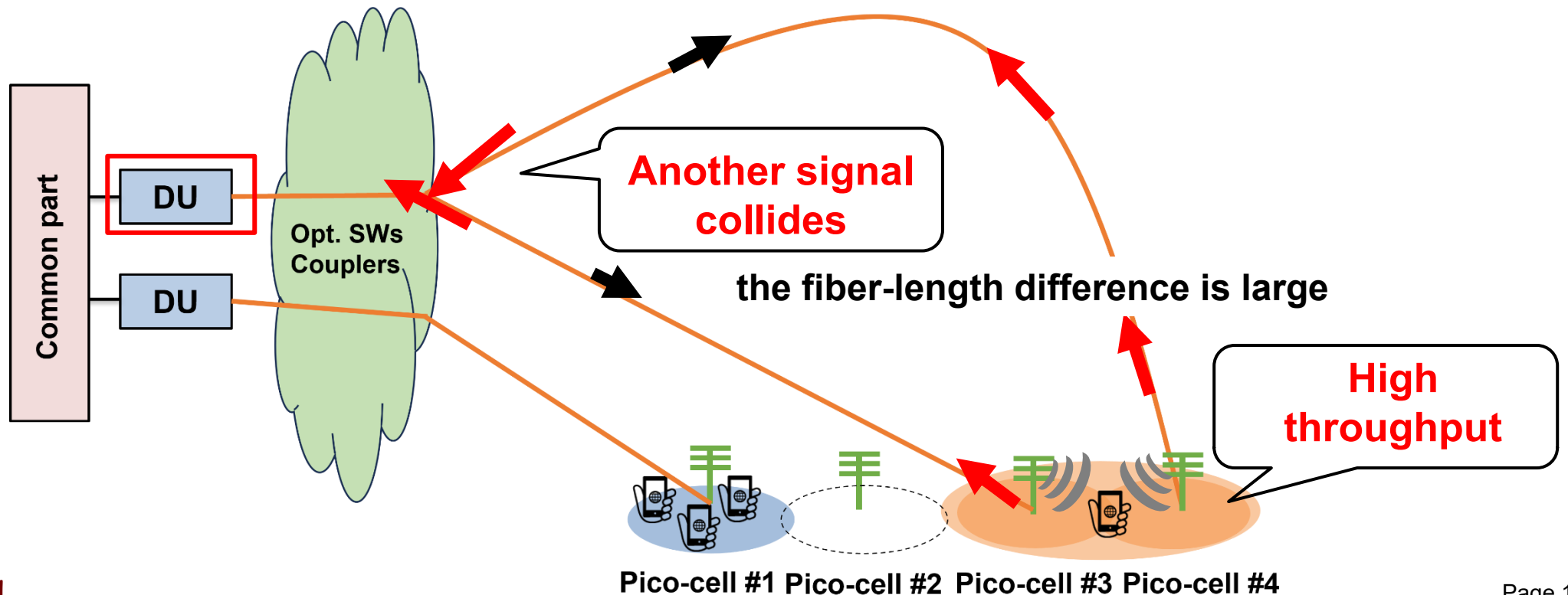
## UDP Performance Summary (35 s average)

- **Bit rate:** UE#1 11.2 Mb/s | UE#2 13.1 Mb/s
- **Packet loss:** UE#1 0.74 % | UE#2 0.48 %



# Joint-Transmission

- Multi-spot RoF has another feature: Joint-Transmission
  - Downlink: the UE can achieve **high throughput**.
  - Uplink: The UE's signal reaches both antennas and is mixed on the fibers. If the difference of fiber lengths are big , **the speed advantage disappears**.

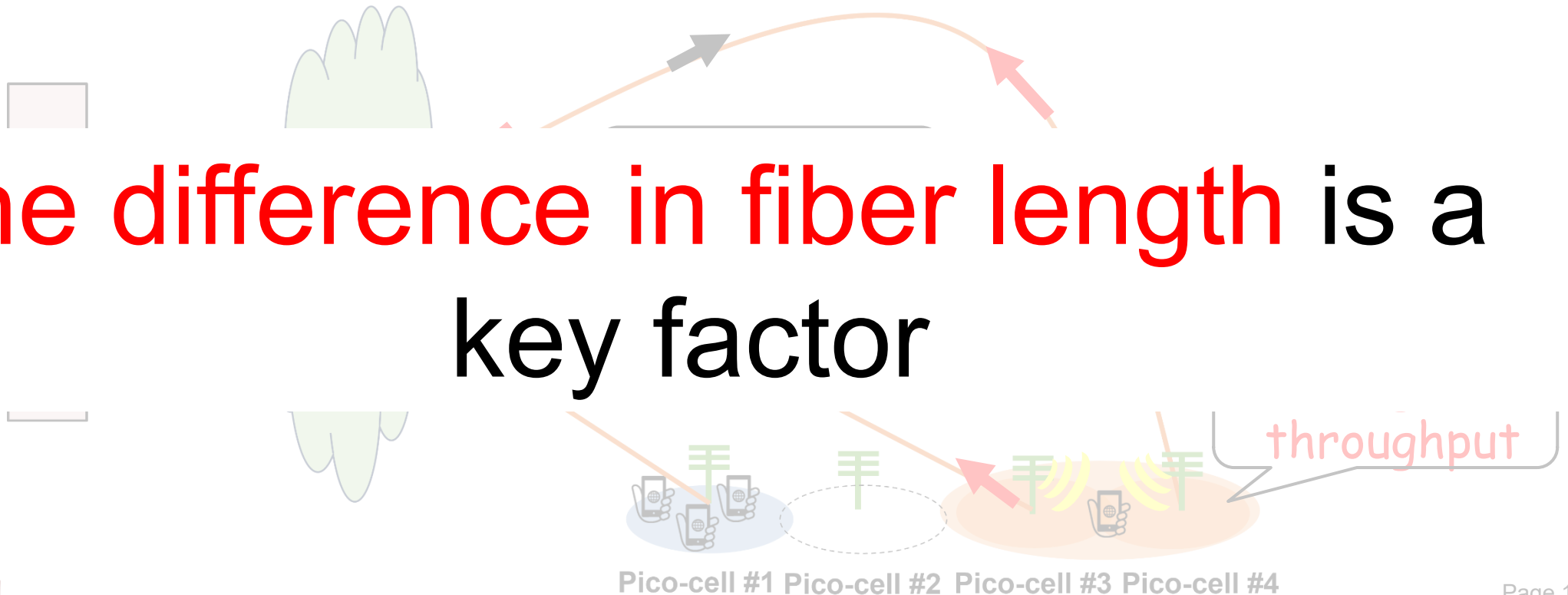


# Joint-Transmission

- Multi-spot RoF has another feature: Joint-Transmission
  - Downlink, the UE can achieve high throughput

➤ We measured **these effects of JT**

**The difference in fiber length is a key factor**



# Cyclic Prefix (CP) length

How much fiber length difference can be accepted ?

- Every OFDM symbol has a **cyclic prefix (CP)**
  - CP length: a short guard time

- **30 kHz** sub-carrier spacing : the CP is **2.34 μs**.

- **If the path-length difference is shorter than this distance,**
  - the receiver can combine them and keep throughput high.

- **If the difference is longer,**

- the second copy slips into the next symbol and acts as interference, so throughput drops.

The smaller the sub-carrier spacing, the longer the time.

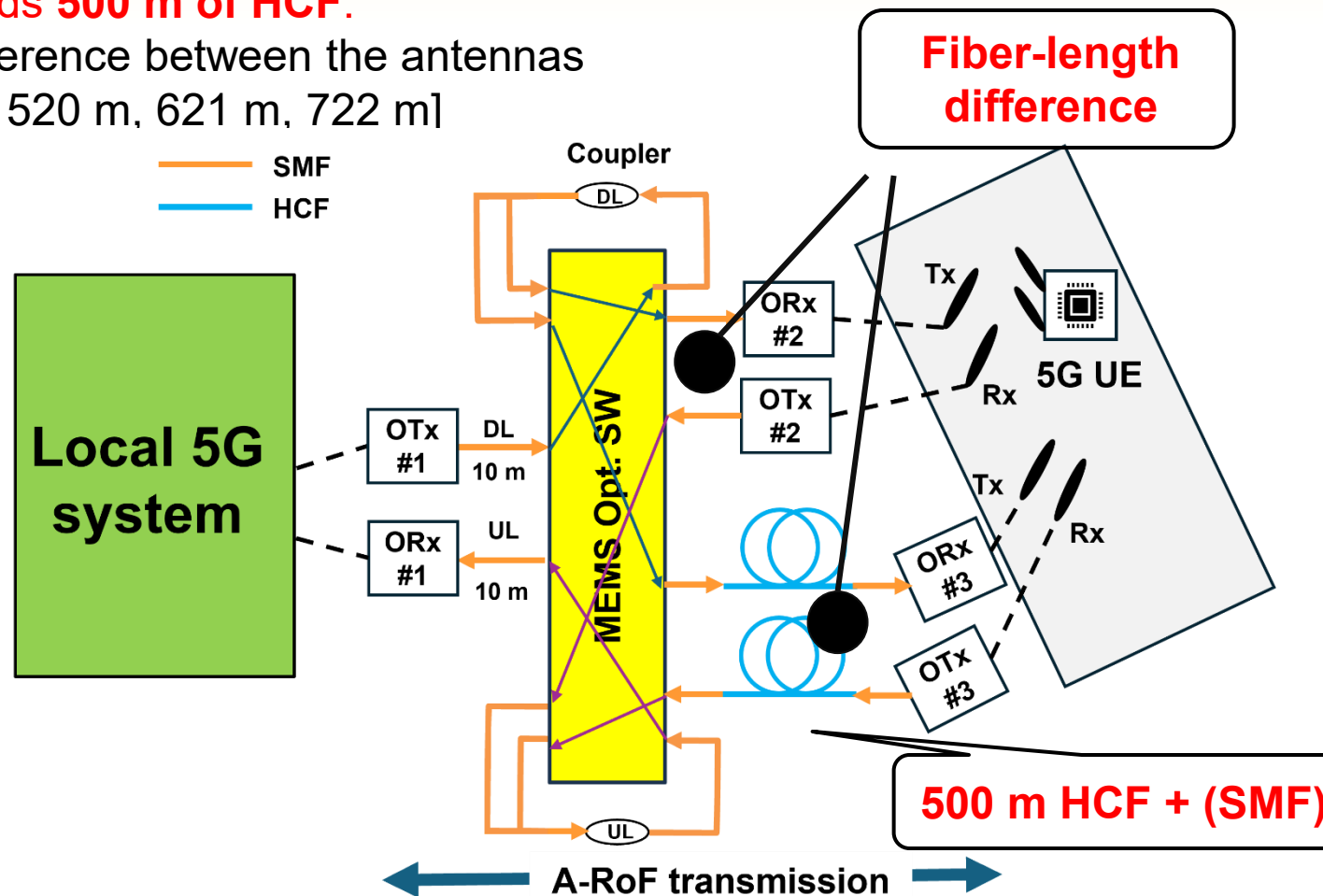
At 15 kHz, the time is 4.7 microseconds. (3GPP)

Fiber type	Refractive index $n$	Distance light travel in 2.34 μs
HCF	≈ 1.00	≈ <b>701 m</b>
SMF	≈ 1.44	≈ <b>487 m</b>

# Experimental setup #1 (Joint-Transmission Experiment)

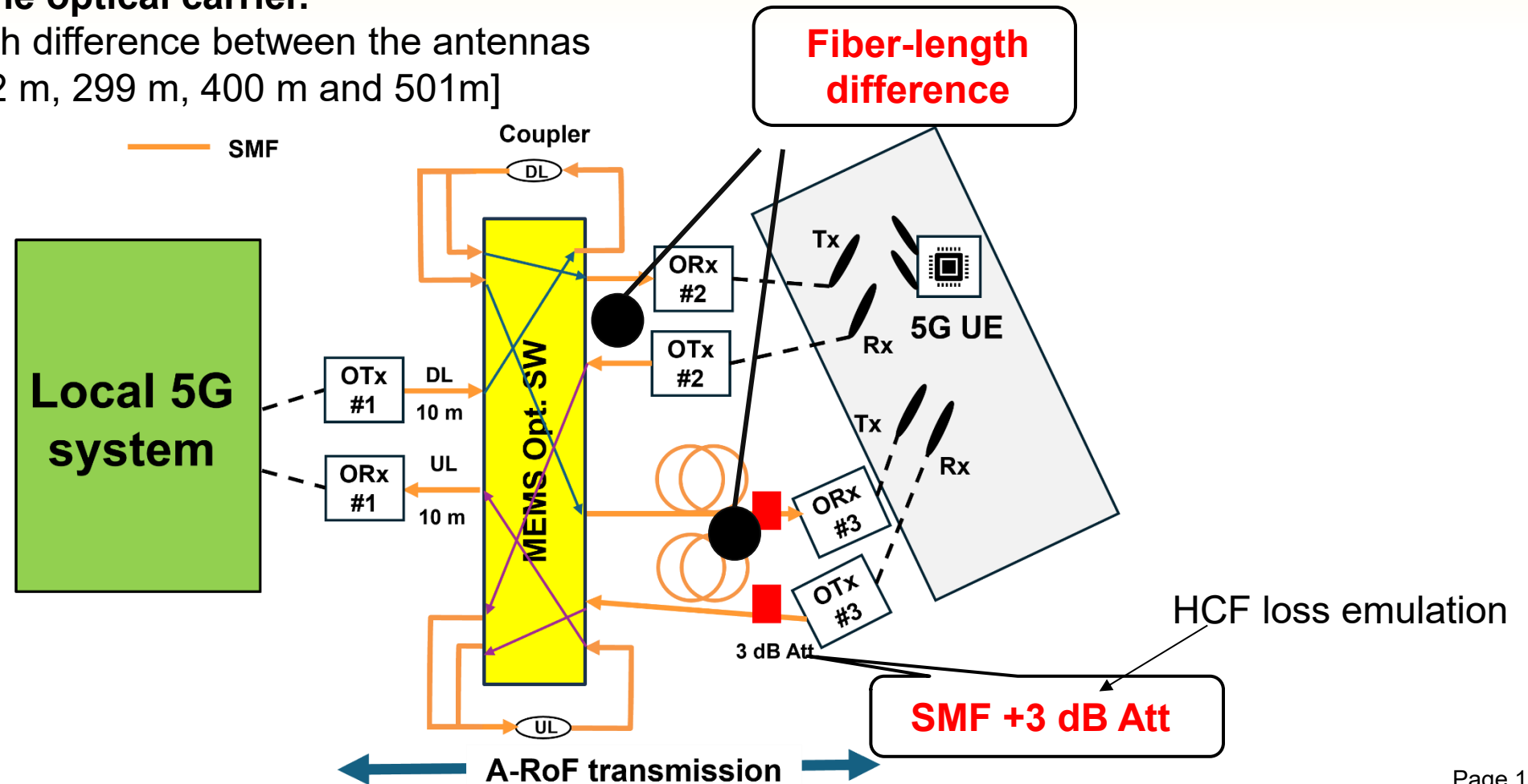
## “Config #1” setup

- Path A still uses only SMF.
- **Path B, however, now adds 500 m of HCF.**
- We set six fiber-length difference between the antennas
  - [19 m, 318 m, 419 m, 520 m, 621 m, 722 m]



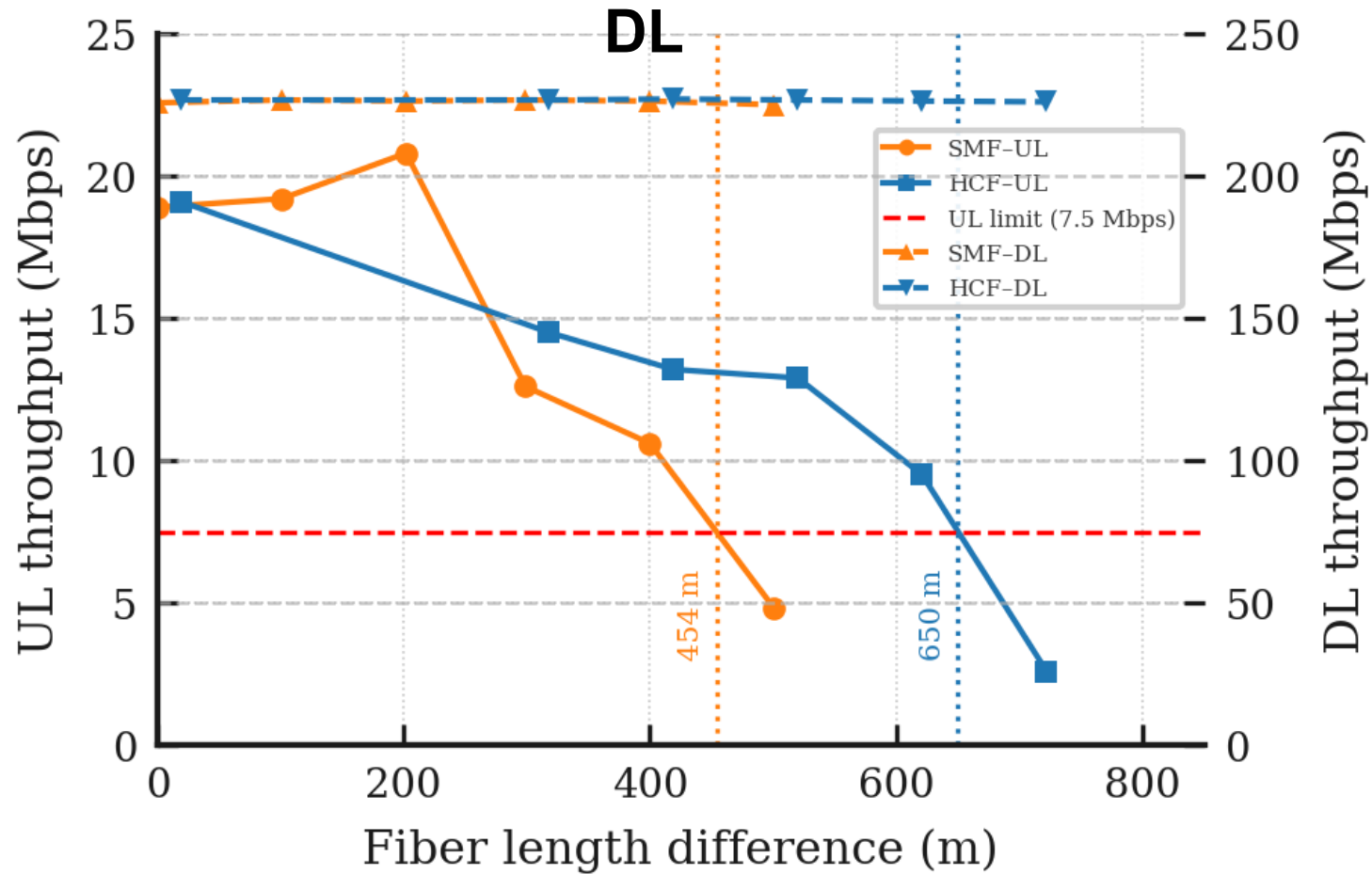
# Experimental setup #2 (Joint-Transmission Experiment)

- **Both A-RoF paths use only SMF**
- **To force joint transmission, we put the two antennas in one shield box, so the UE hears two RF signals from the same optical carrier.**
- We set six fiber-length difference between the antennas
  - [0 m, 101 m, 202 m, 299 m, 400 m and 501m]



# DL Experimental results (Joint-Transmission Experiment)

DL: even a large fiber-length difference caused no drop in throughput in either setup

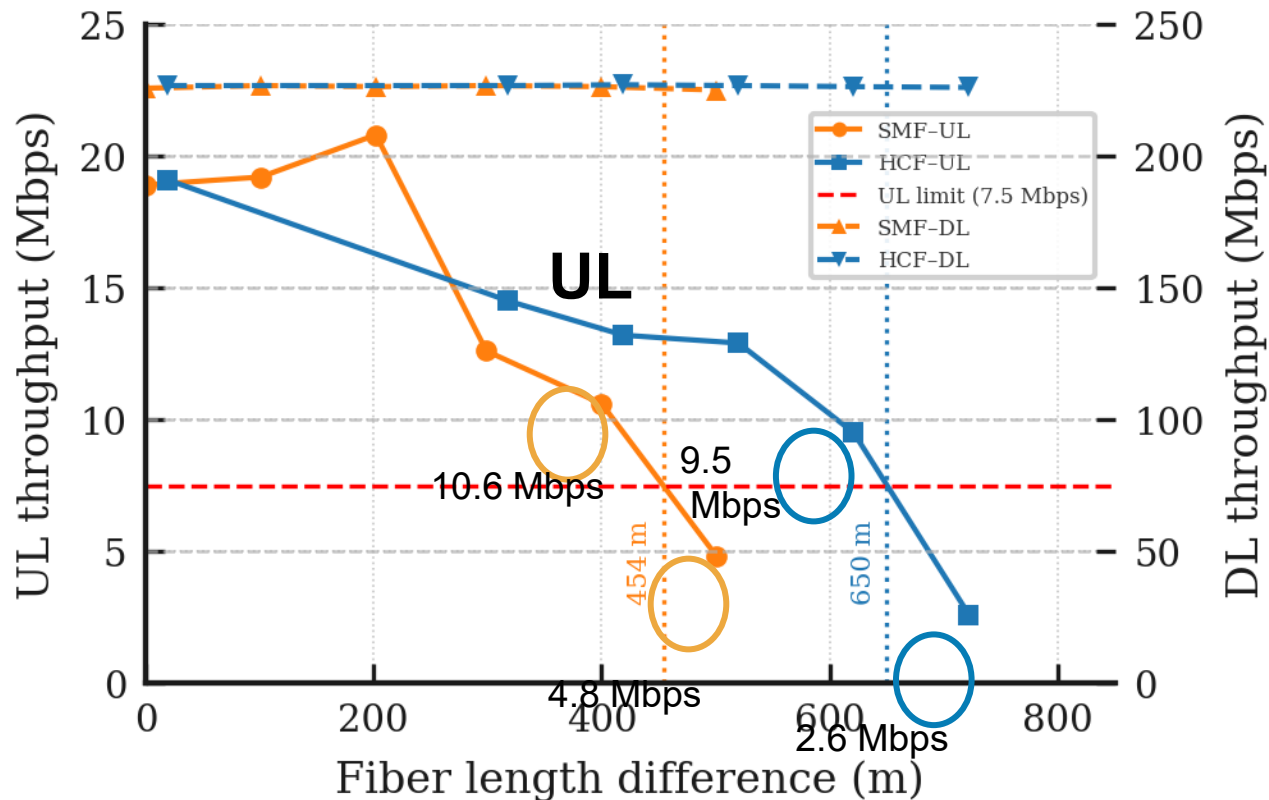


# UL Experimental results (Joint-Transmission Experiment)

UL: when the fiber-length difference grows, throughput falls in both setups

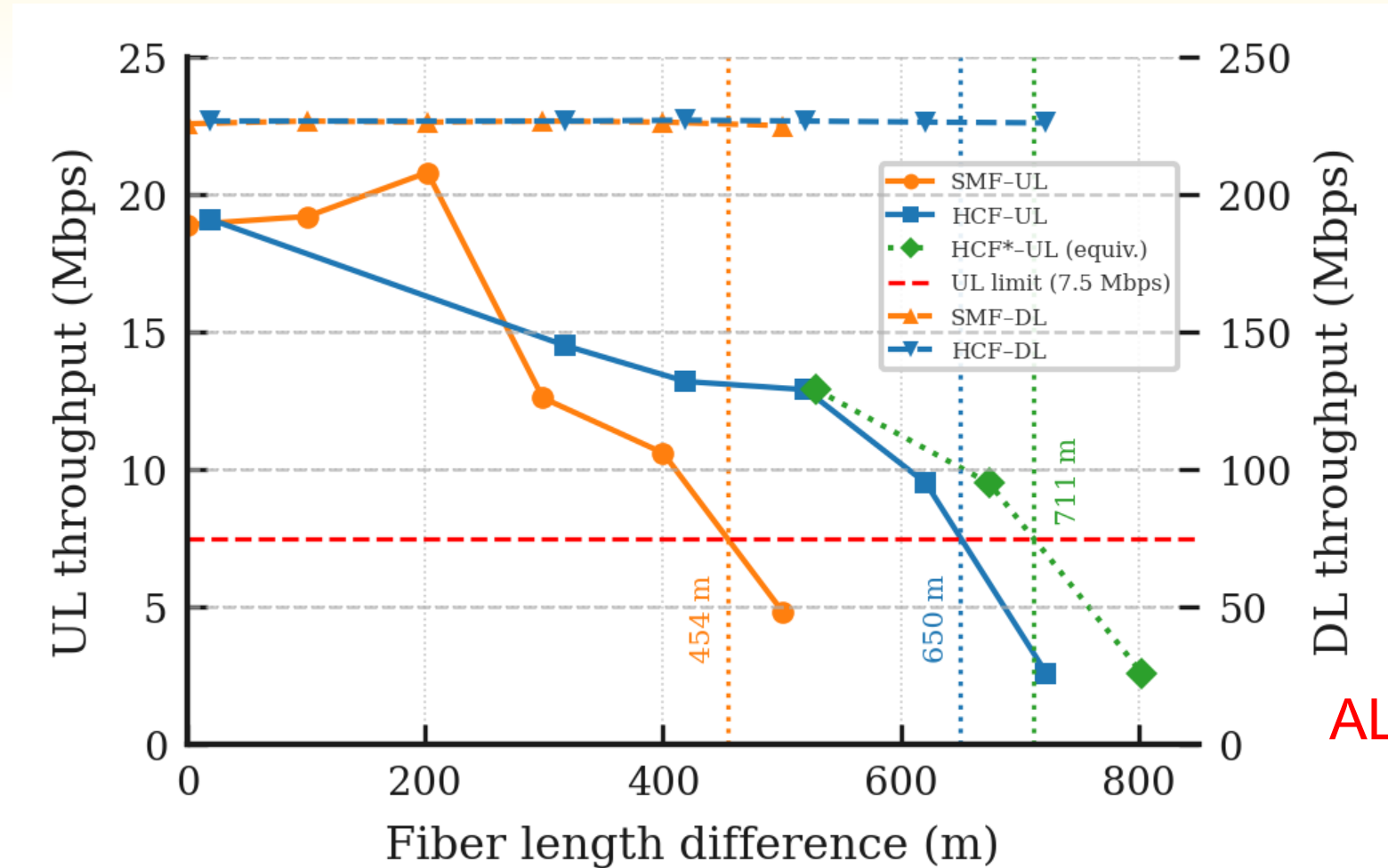
**SMF-only setup:** 400 m difference : **10.6 Mb/s**, 501 m difference : **4.8 Mb/s**

**HCF + SMF setup:** 621 m difference : 9.5 Mb/s, 722 m difference : 2.6 Mb/s.



# UL Experimental results (Joint-Transmission Experiment)

If the entire path were HCF, the throughput would be maintained up to **711 meters**.



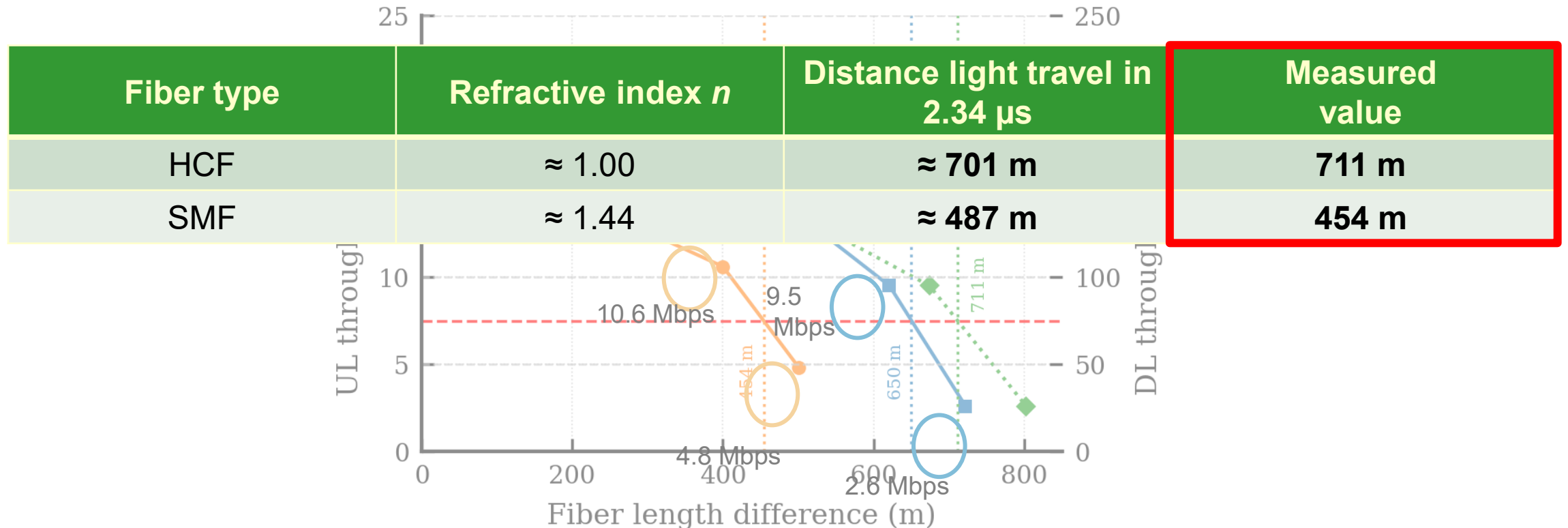
# Experimental results (Joint-Transmission Experiment)

UL: when the fiber-length difference grows, throughput falls in both setups

**SMF-only setup:** 400 m difference : **10.6 Mb/s**, 501 m difference : **4.8 Mb/s**

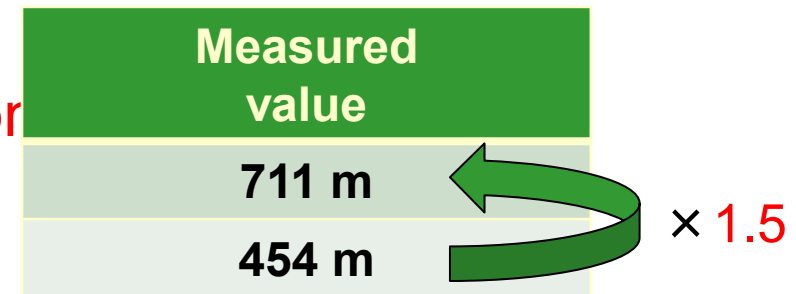
HCF + SMF setup: 621 m difference : 9.5 Mb/s, 722 m difference : 2.6 Mb/s.

All HCF :green line



# Summary

- We have proposed the smart mobile fronthaul (SMFH) concept using **A-RoF** technologies with HCFs.
  - **A large fiber length difference** causes a decline in communication quality
- In experiment (Switching Experiment)
  - Optical channel reconfiguration (P2P ↔ P2MP) tracks UE mobility with no throughput drop; switching completes < 50 ms
- In experiment (Joint transmission)
  - We can see that with HCF, throughput stays high even when the fiber difference is larger, while the SMF-only link starts to fall earlier.
  - **HCF contributes to the expansion of Joint-Transmission**



---

# Thank you!

## Acknowledgements:

This work was supported in part by the R&D of innovative optical network technologies for a green society project (JPMI00316) of the Ministry of Internal Affairs and Communications (MIC) of Japan and the National Institute of Information and Communications Technology (NICT) (JPJ012368C07101). The authors are grateful to KEIO future photonic network Open Lab for providing experimental facilities.

The author appreciate the members in Lightera Japan Co, Ltd. for their technical supports and discussions of HCF cables.