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THOR

Wired and wireless seamless networks for beyond 5G

H2020 EU-Japan Project ThoR Final Workshop

Tetsuya Kawanishi, Braunschweig, 29-30 June 2022

Acknowledgement

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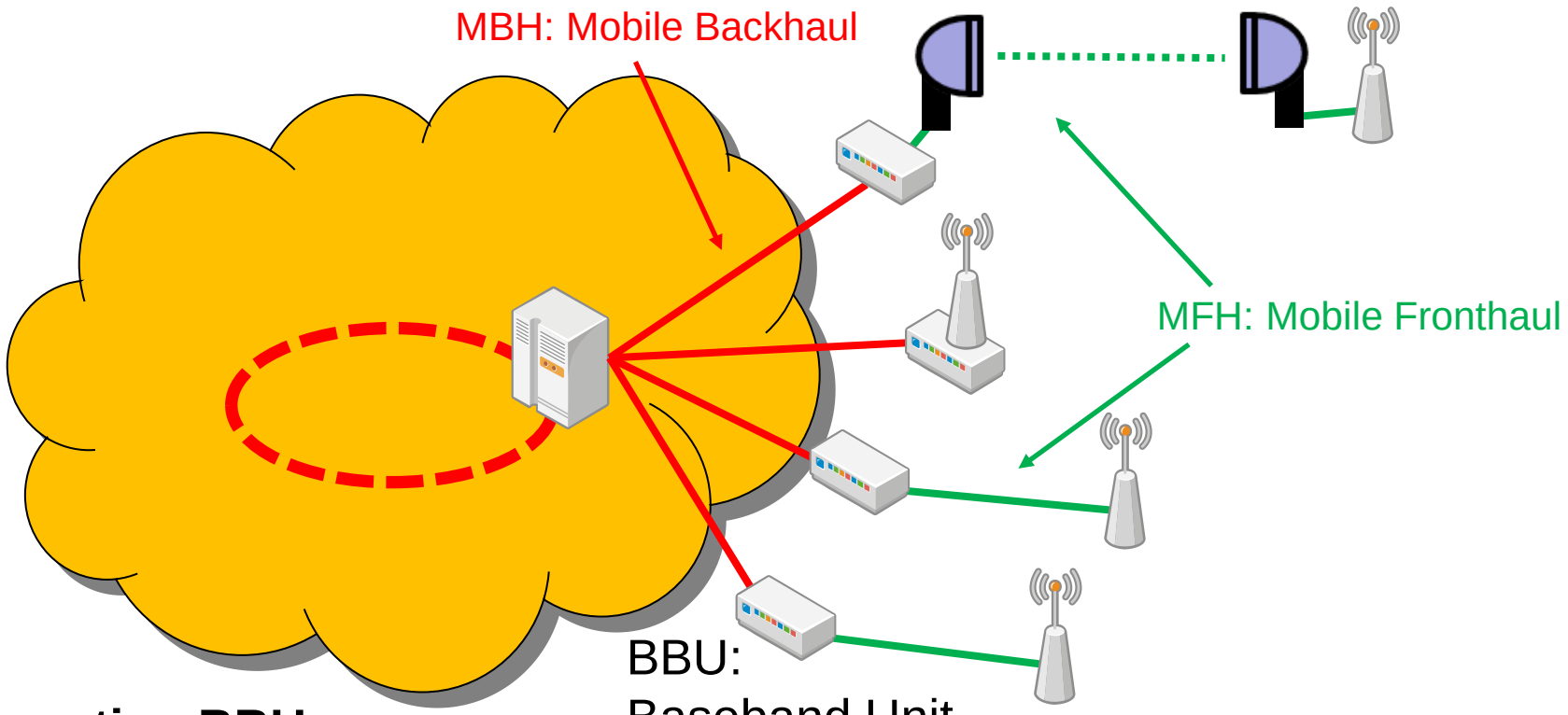
Agenda

1. Background
2. Trends in THz research
3. THz links for B5G
4. Digital and analog radio-over-fiber
5. Delta-sigma modulation
6. Photonics for THz links

Optical networks connecting antennas: mobile backhaul/fronthaul



MBH：Networks connecting BBUs

→ **Network for digital data**

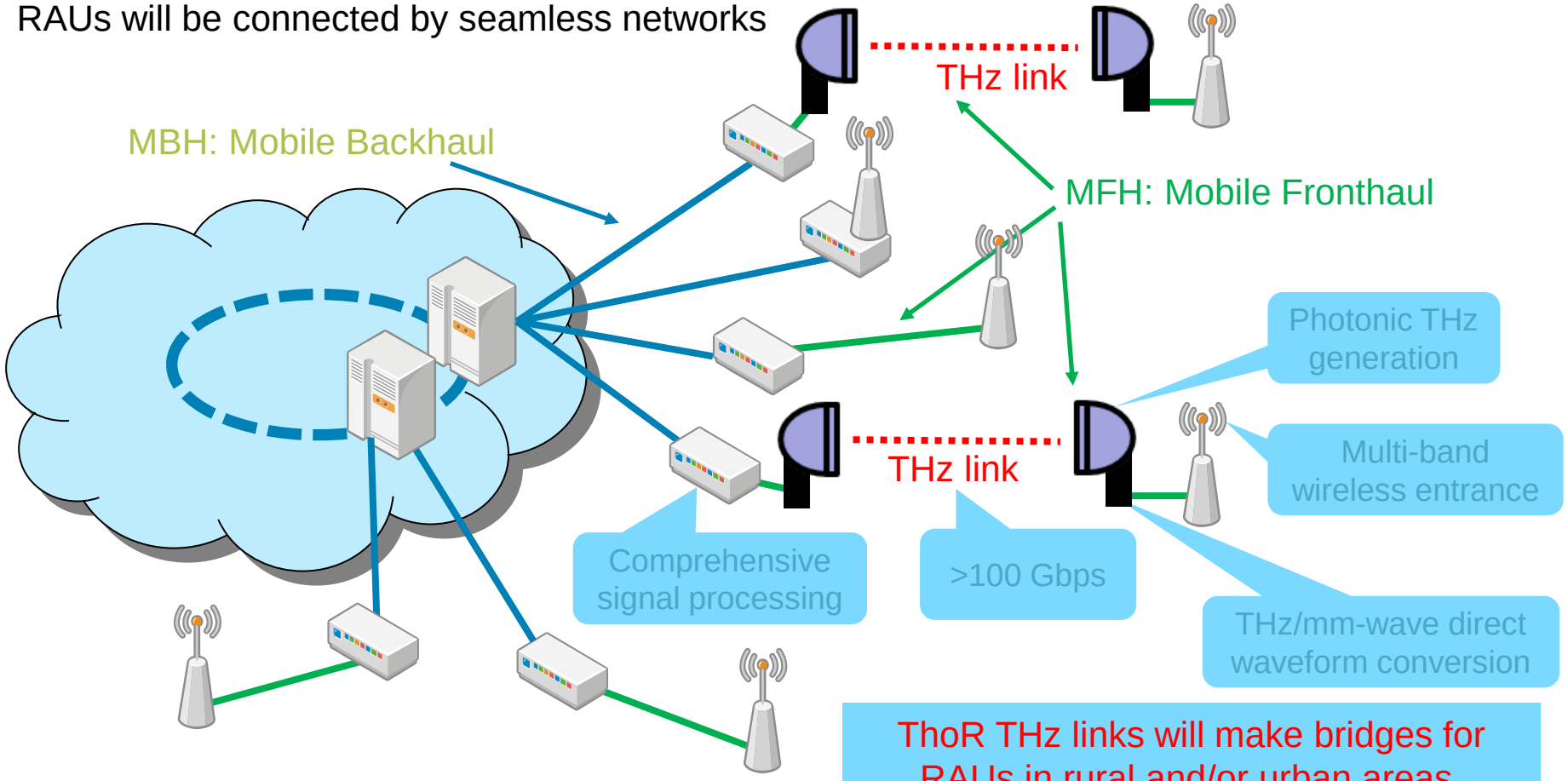
MFH：Links connecting BBUs and RAUs

→ **Networks for waveform transfer**

No. of base-stations will be greater than population

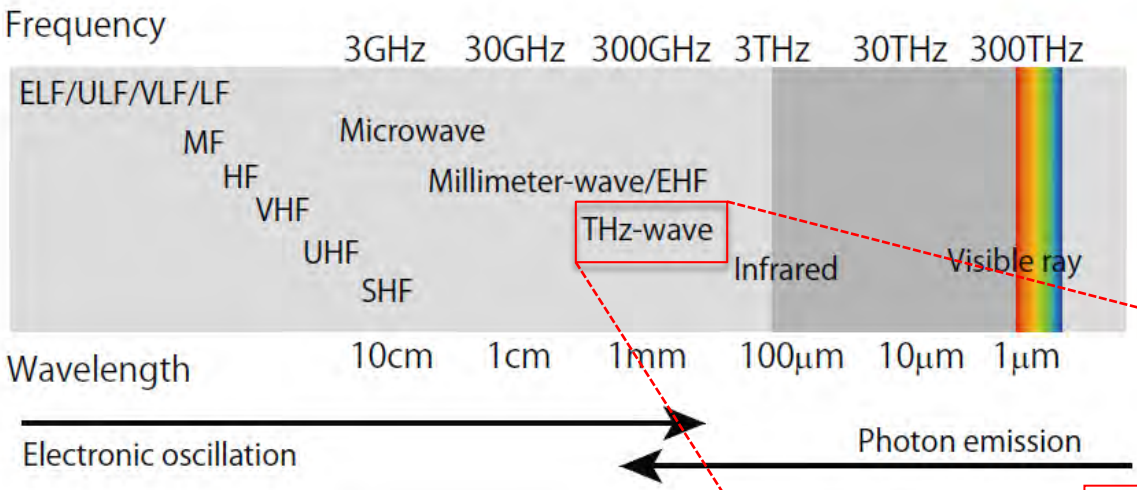
Concept of THz-optical seamless networks

- Beyond 5G systems will have huge numbers of Remote Antenna Units (RAUs)
- Number of RAUs may be larger than number of users
- RAUs will be connected by seamless networks



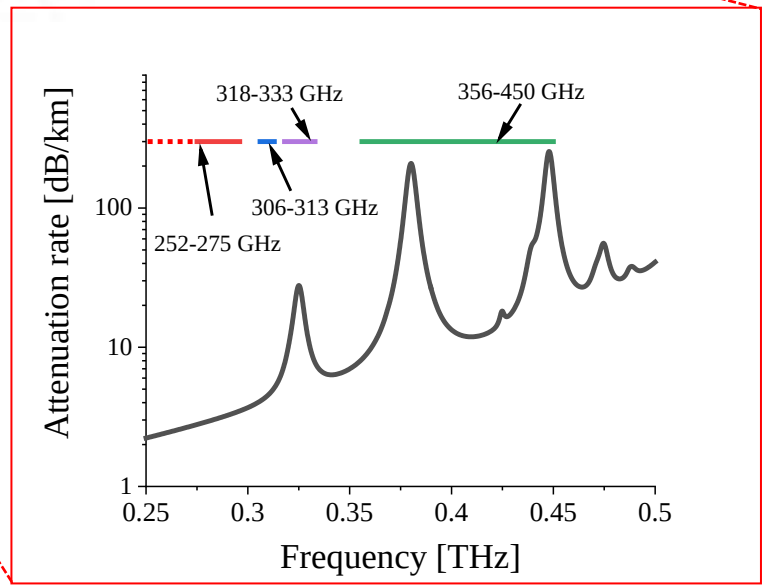
ThoR THz links will make bridges for RAUs in rural and/or urban areas.

THz-wave bands

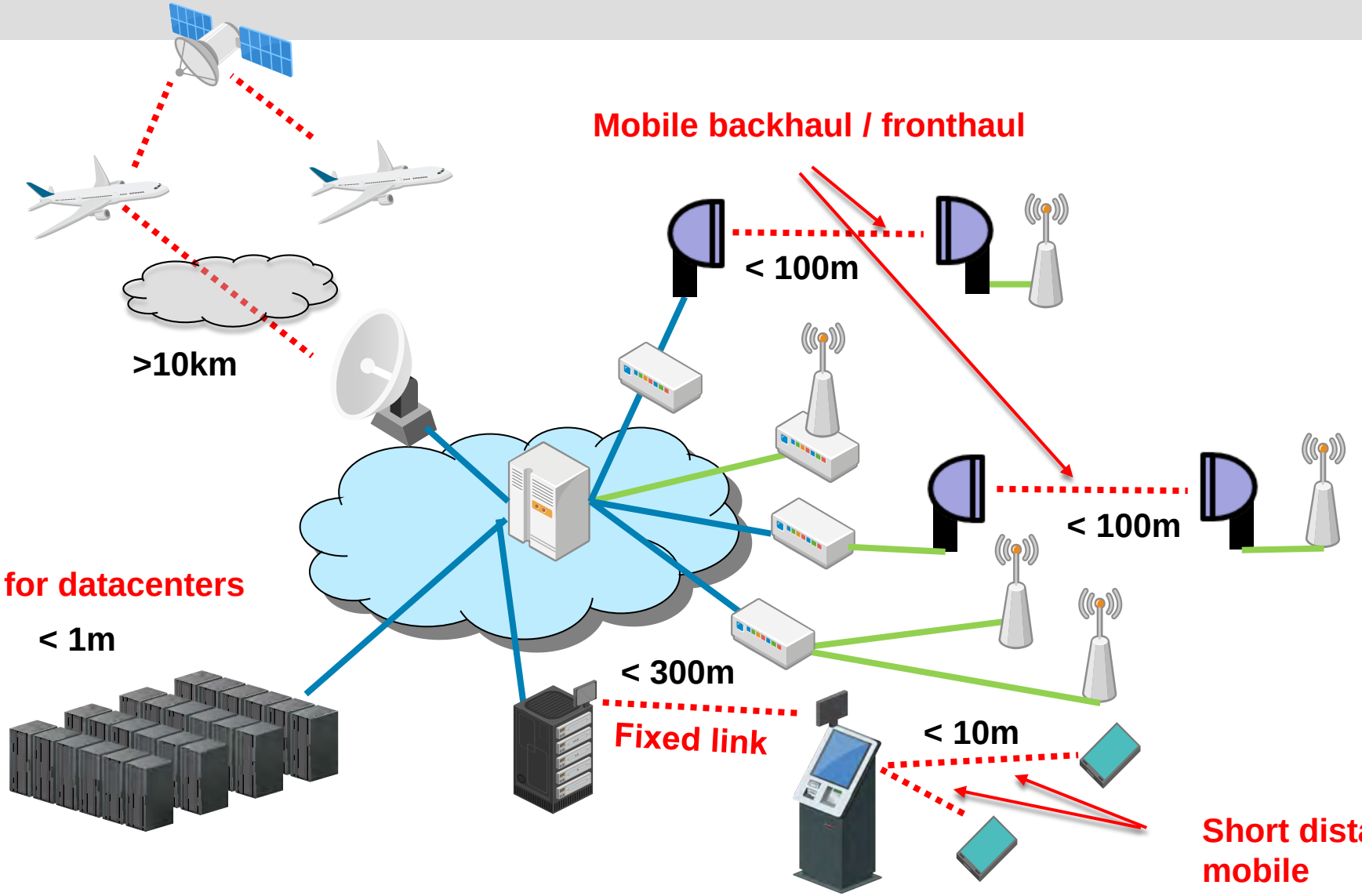


Newly identified THz bands for telecommunications
275-296 GHz 306-313 GHz
318-333 GHz 356-450 GHz

	Frequency range	Wavelength	Bandwidth
ELF (Extremely Low Frequency)	0 Hz-300 Hz	> 1000 km	300 Hz
ULF (Ultra Low Frequency)	300Hz-3 kHz	100 km-1000 km	2.7 kHz
VLF (Very Low Frequency)	3 kHz-30 kHz	10 km-100 km	27 kHz
LF (Low Frequency)	30 kHz-300 kHz	1 km-10 km	270 kHz
MF (Medium Frequency)	300 kHz-3 MHz	100 m-1 km	2.7 MHz
HF (High Frequency)	3 MHz-30 MHz	10 m-100 m	27 MHz
VHF (Very High Frequency)	30 MHz-300 MHz	1 m-10 m	270 MHz
UHF (Ultra High Frequency)	300 MHz-3 GHz	10 cm-1 m	2.7 GHz
SHF (Super High Frequency)	3 GHz-30 GHz	1 cm-10 cm	27 GHz
EHF (Extremely High Frequency)	30 GHz-300 GHz	1 mm-1 cm	270 GHz
Microwave	0.3 GHz-30 GHz	1 cm-1 m	29.7 GHz
Millimeter-wave	30 GHz-300 GHz	1 mm-1 cm	270 GHz
THz-wave	0.1 THz-10 THz	3 mm-30 μm	9.9 THz

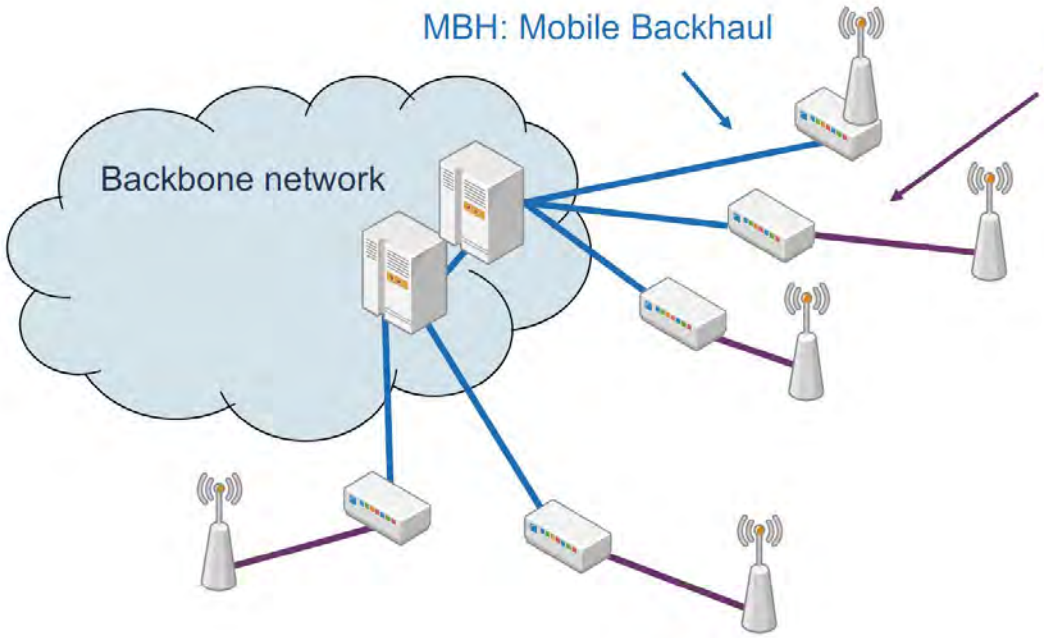


THz links for B5G



Need for Seamless Networks

The functions of the BSs can be categorized into the following two parts:
(1) baseband units (BBUs) which convert baseband digital signals and radio waveforms into one another
(2) antenna units, which radiate and receive radio waves in the air.



BBUs are connected to core networks through MBH links that transfer digital data streams in the same way as conventional digital optical fiber communication systems. On the other hand, MFH links, which connect BBUs and RAUs, transfer waveforms for radio services.

Waveform transfer can be offered by analog or digital radio-over-fiber (RoF)

Tetsuya Kawanishi, Wired and Wireless Seamless Access Systems for Public Infrastructure , Artech, 2020.

Radio-over-Fiber

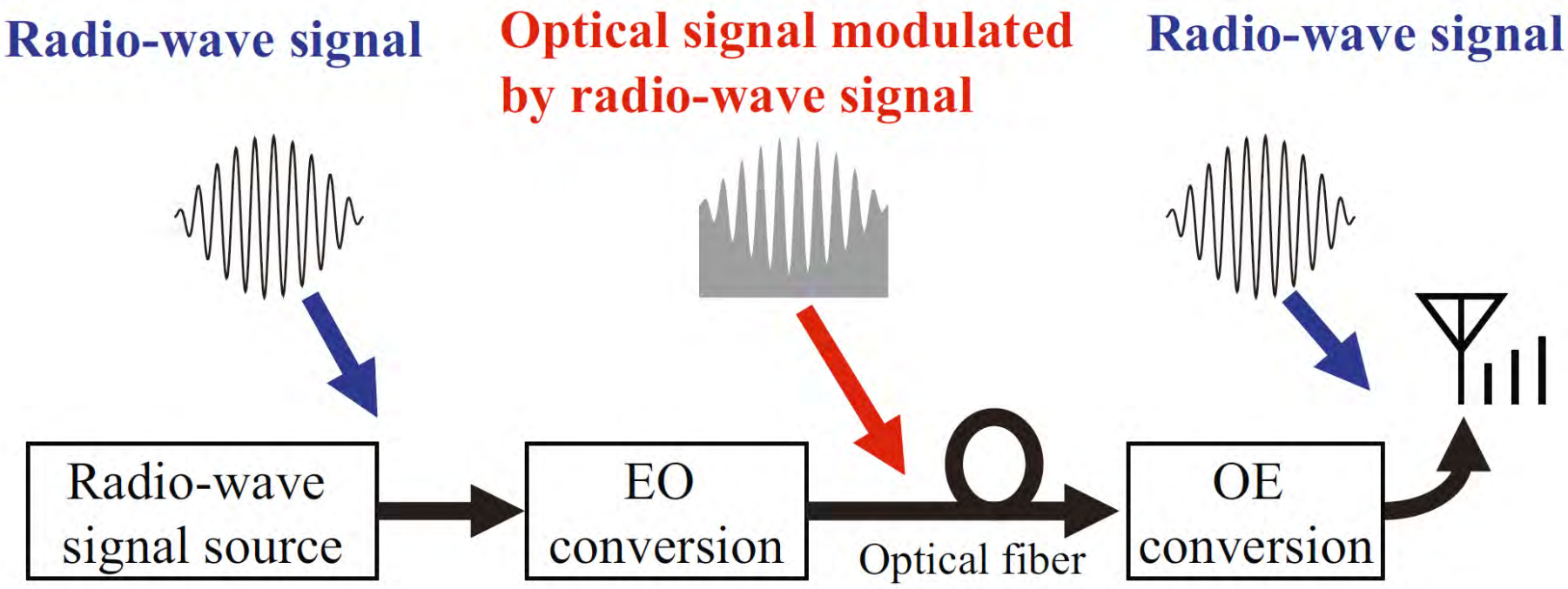


Figure 4.4 Configuration of analog radio-over-fiber.

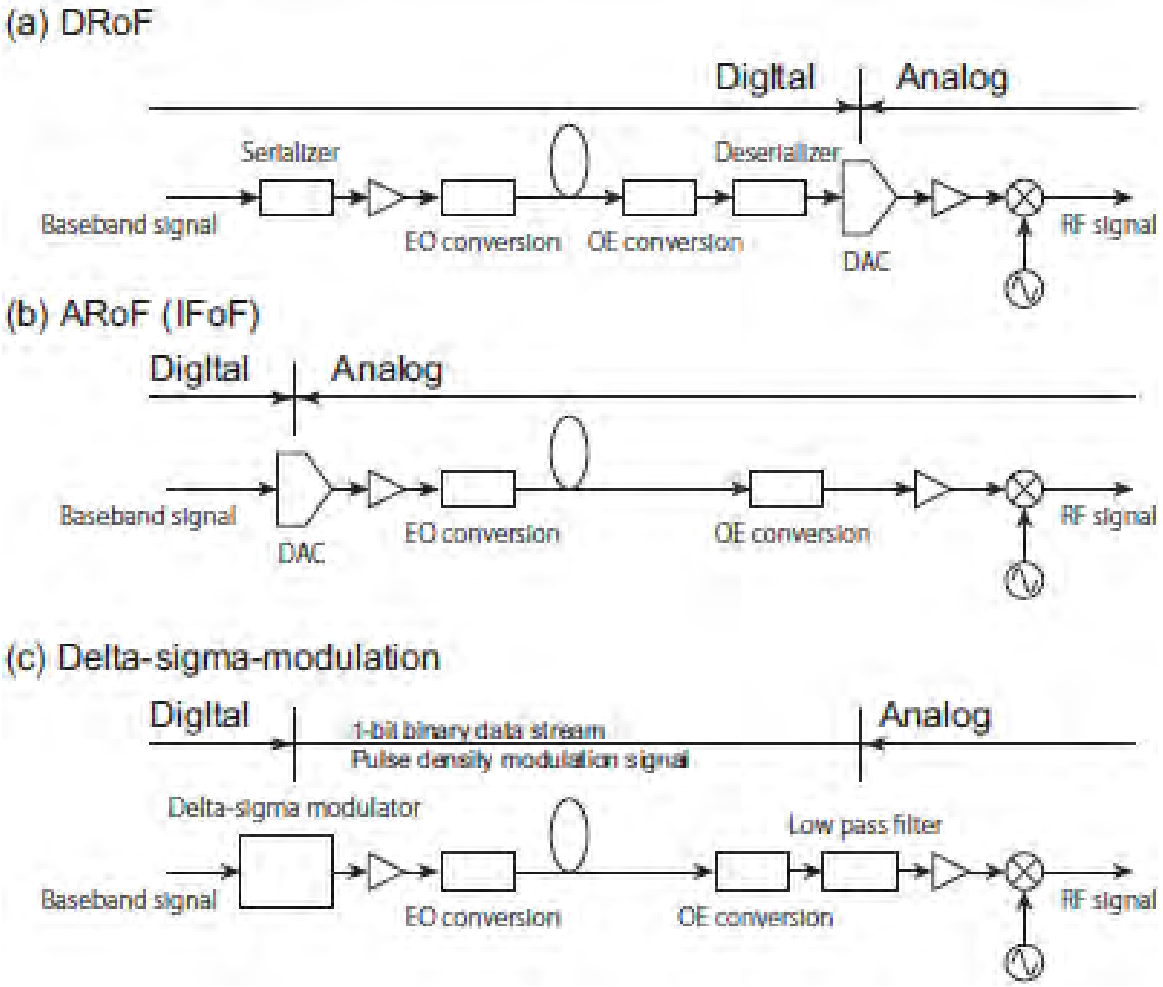
Simple configuration, low-latency,
low-loss and broadband signal transmission

Digital RoF interface (CPRI)

MFH systems are defined
by the Common Public Radio Interface (CPRI) defines DRoF interface.
For 3G and 4G systems, required bitrate is smaller than 10 Gb/s.
For 5G, required bitrate is larger than 100 Gb/s.

To overcome this difficulty, function split options are proposed, where some of the functions in the BBUs are moved to the remote units. The required bandwidth for the MFH would be smaller than in the CPRI, but the configuration of the remote units would be complicated.

Comparison between RoF architectures for mobile fronthaul



pros / cons

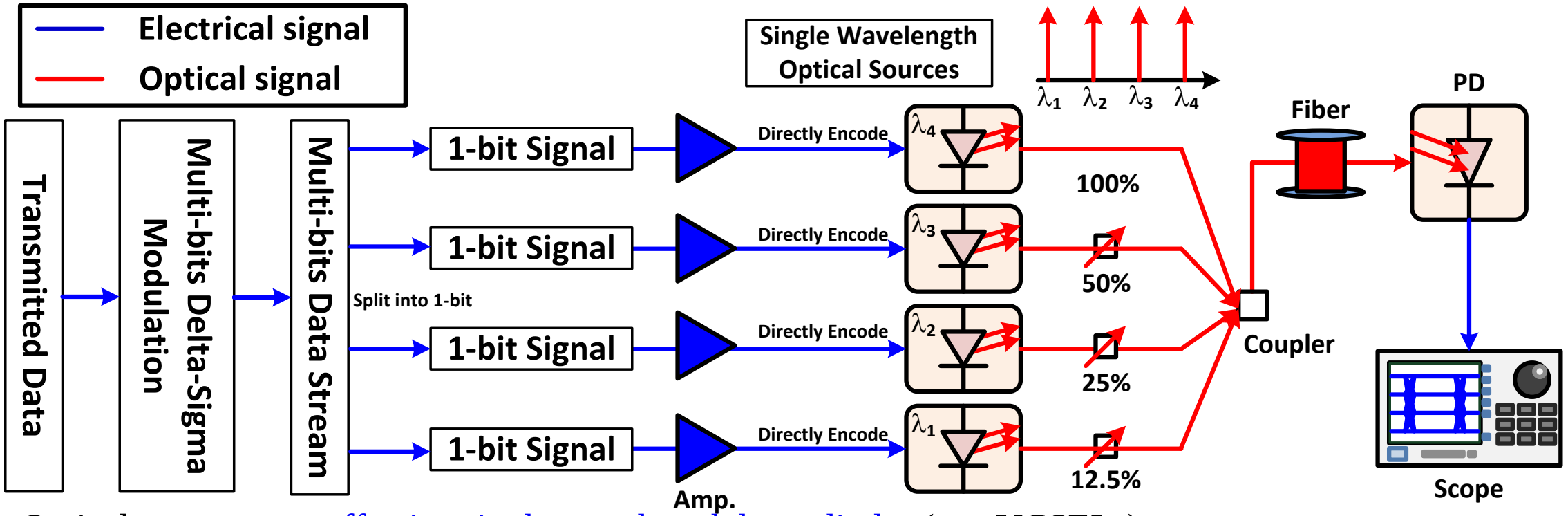
- (a) **digital radio-over-fiber (DRoF)**
  - conventional mobile network
  - large bandwidth required for 5G
- (b) **analog radio-over-fiber (ARoF)**
  - intermediate-frequency (IF) over fiber
  - high spectral efficiency
  - fragile anti-nonlinearity
- (c) **delta-sigma modulation**
  - oversampling / high sampling rate
  - high SNR waveform transfer
  - smaller bit rate than DRoF
  - simple
- **best approach for beyond 5G/6G network?**

Tetsuya Kawanishi, Wired and Wireless Seamless Access Systems for Public Infrastructure , Artech, 2020.

Mobile fronthaul interface candidates

Interface	Analog RoF	Common Public Radio Interface (CPRI)	Delta-Sigma Modulation based RoF	Multi-leveled Delta-sigma Modulation
Analog or Digital	analog	digital	digital	digital
Type of ADC	N/A	Nyquist ADC	oversampling	oversampling
Type of DAC	N/A	Nyquist DAC	digital low-pass filter	digital low-pass filter
Sampling Rate	N/A	30.72 MSa/s	10 GSa/s	6 GSa/s, 12 GSa/s
Quantization bits	N/A	15	1	2
Pros	simple low cost	simple	low quantization bits quantization noise minimization robust anti-nonlinearity	combination of the pros of CPRI and original delta-sigma modulation cost effective
Cons	sensitive to nonlinearity	high quantization bits expensive	high sampling rate expensive	

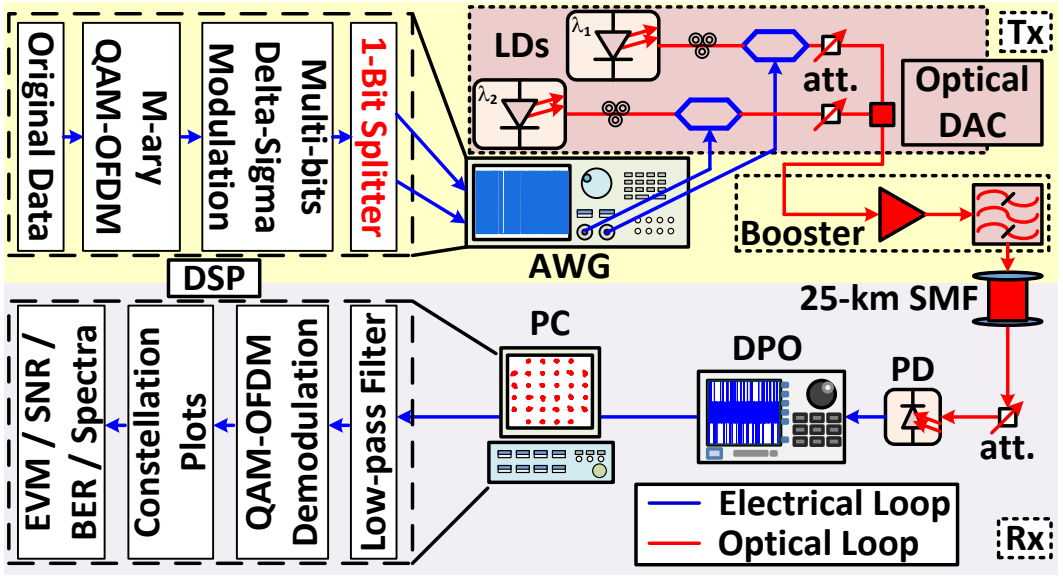
Proposed system scheme

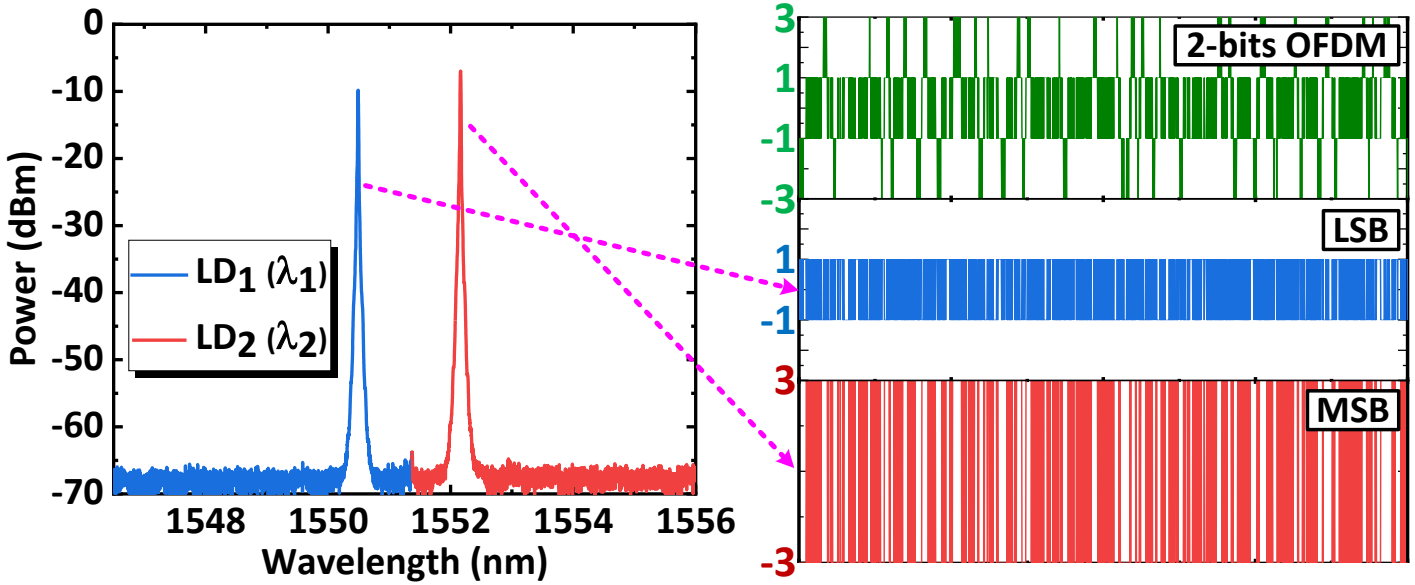


- Optical source: cost-effective single wavelength laser diodes (e.g. VCSELs)
- Each optical carrier carries 1-bit data
  - Robust anti-nonlinearity
  - Simple and compact receiver for ubiquitous wireless network

Z. -K. Weng, A. Kanno and T. Kawanishi, "2-bit Delta-sigma Modulated 32-QAM OFDM based Dual-wavelength Digital RoF Link," *2021 Optical Fiber Communications Conference and Exhibition (OFC)*, 2021, pp. 1-3.

Experimental setup and working principle





Devices

AWG: Tektronix AWG 7122B

DPO: Tektronix DPO 73304D

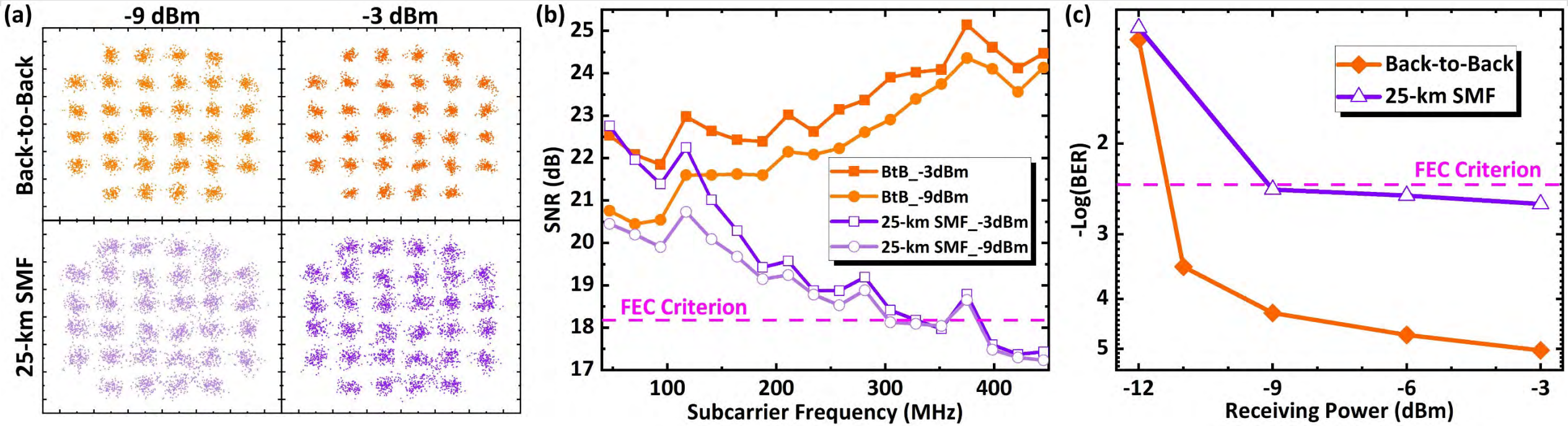
LD: santec ECL-200

MZM: Fujitsu FTM7937EZ

Optical Carriers	LD1 (**LSB**)	LD2 (**MSB**)
Wavelength	1550.49 nm	1552.16 nm
Peak Power	-9.99 dBm	-6.97 dBm

Z. -K. Weng, A. Kanno and T. Kawanishi, "2-bit Delta-sigma Modulated 32-QAM OFDM based Dual-wavelength Digital RoF Link," *2021 Optical Fiber Communications Conference and Exhibition (OFC)*, 2021, pp. 1-3.

Delta-sigma modulated 32-QAM OFDM at 2 Gbit/s



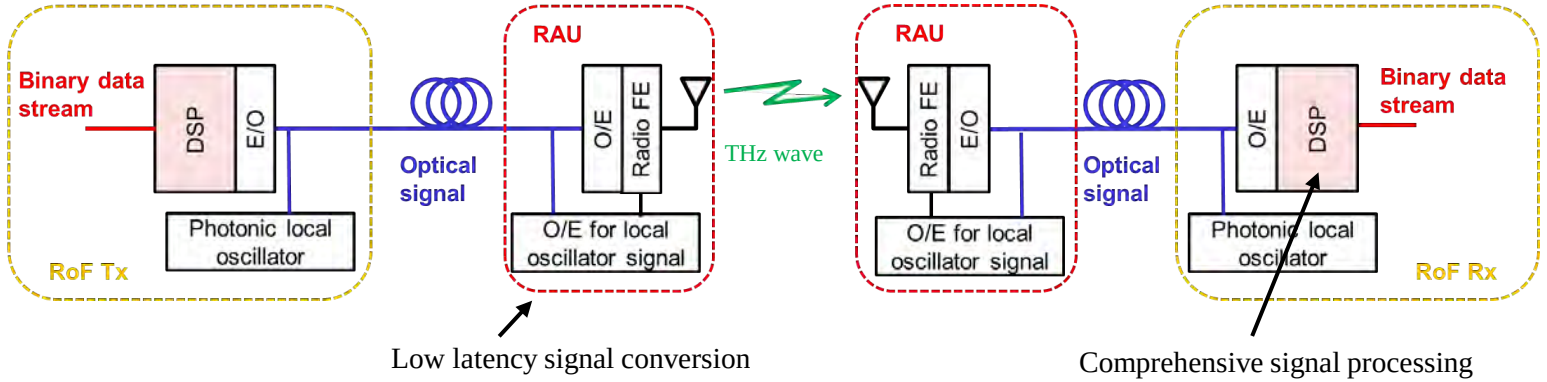
testing signal: 32-QAM OFDM
signal bandwidth: 400 MHz
oversampling ratio: 15
raw data rate: 2 Gbit/s
receiving power: -3 dBm

Receiving power sensitivity : -9.0 dBm to meet FEC criterion
Power penalty : 2.4 dB

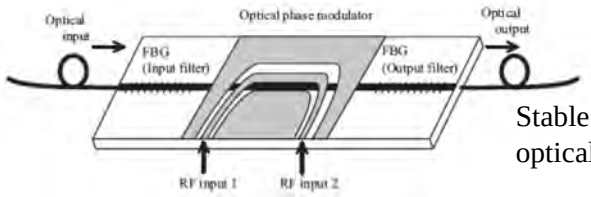
Z. -K. Weng, A. Kanno and T. Kawanishi, "2-bit Delta-sigma Modulated 32-QAM OFDM based Dual-wavelength Digital RoF Link," *2021 Optical Fiber Communications Conference and Exhibition (OFC)*, 2021, pp. 1-3.

Photonics for THz links

Waveform transfer over fiber (Radio-over-fiber / IF-over fiber)

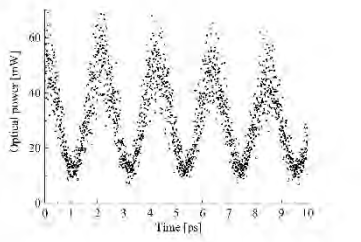


Photonic Local Oscillator (photonic THz generation)



External modulator for harmonic generation

Stable 470GHz optical signal



Photonics developed for high-speed fiber communications can be used for THz links.

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Thank you for your attention!

ご清聴ありがとうございました

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