Integration of wireless and optical technologies to meet the requirements of 5G networks and beyond

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Outline

- 5G overall technical goals
- Fronthaul concept in the C-RAN architecture:
  - Baseline technology (Digital RoF fronthaul)
  - Overview of new proposed technology (Analog RoF fronthaul)
- Elements of the all-analog fronthaul network
  - E/O conversion, Passive Optical Network, O/E conversion
- Challenges found in Downstream transmission

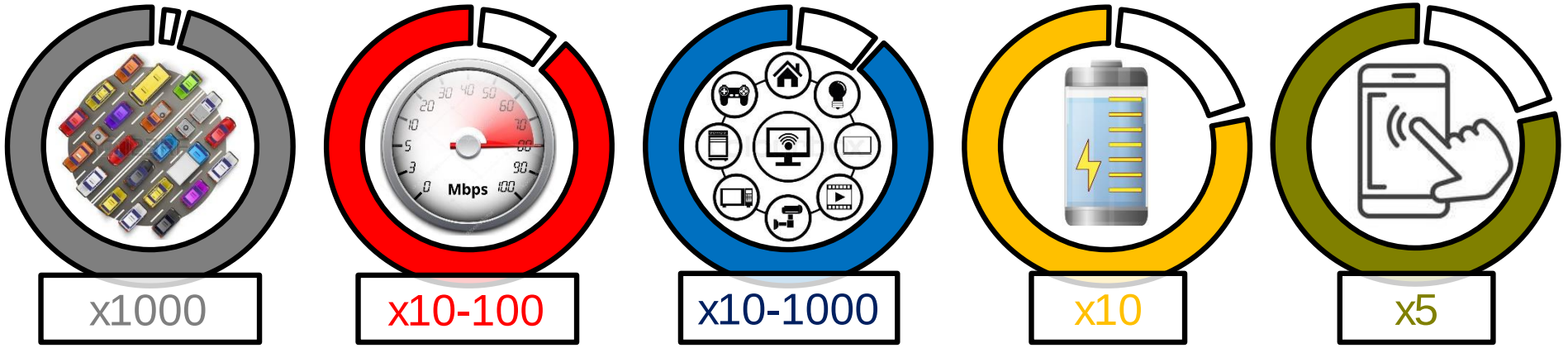
  (1) PAPR (2) Equivalent AF relay system (optical-wireless)
- Challenges found in Upstream transmission

  (1) Optical Beat Interference (OBI) (2) Near-far effect
- Proposed C-RAN architecture to fulfill 5G requirement

5G overall technical goals

Communication network and service environment of 2020 will be richer and more complex than the advertised for 4G:

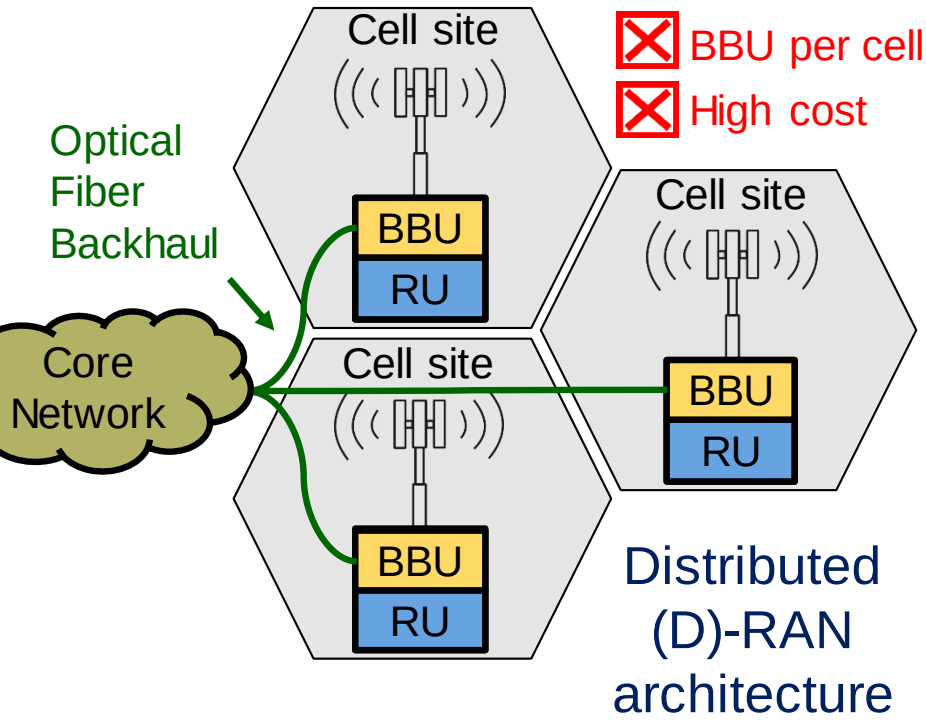
- 1000 times higher mobile data volume per area
- 10-100 times more traffic per end user
- 10-1000 times higher number of connected devices
- 10 times longer battery life for low power devices
- 5 times reduced End-to-End latency (sub-millisecond)

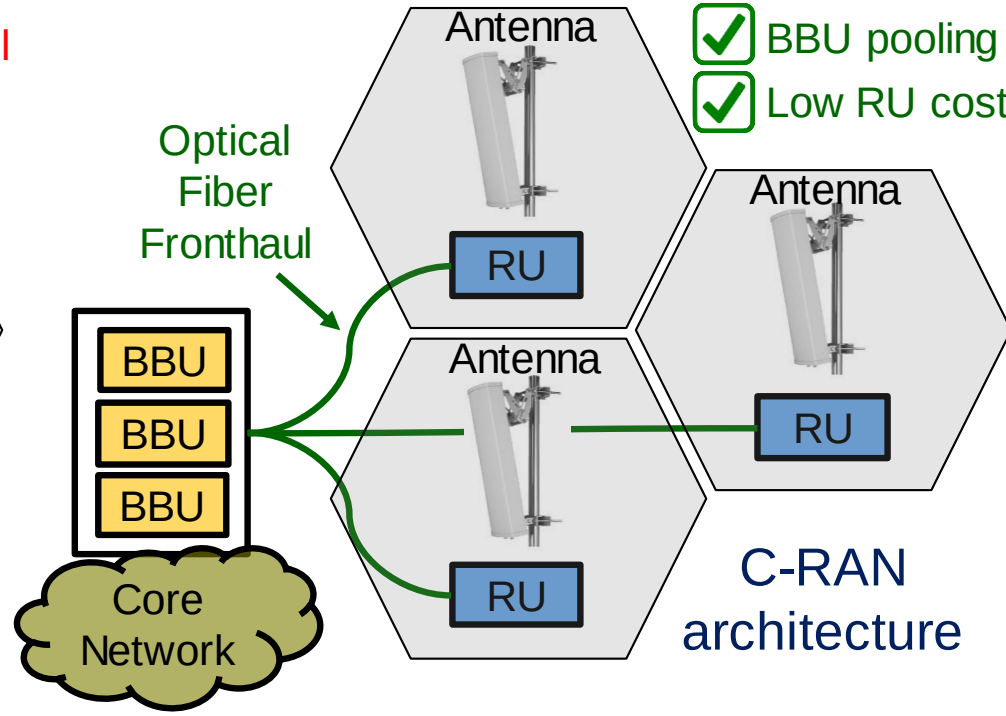


These requirements impact the fronthaul network directly!

Fronthaul in C-RAN architecture

- The **‘fronthaul”** is the network segment that appears in a C-RAN, where ‘C’ may mean “Centralized” or “Cloud”





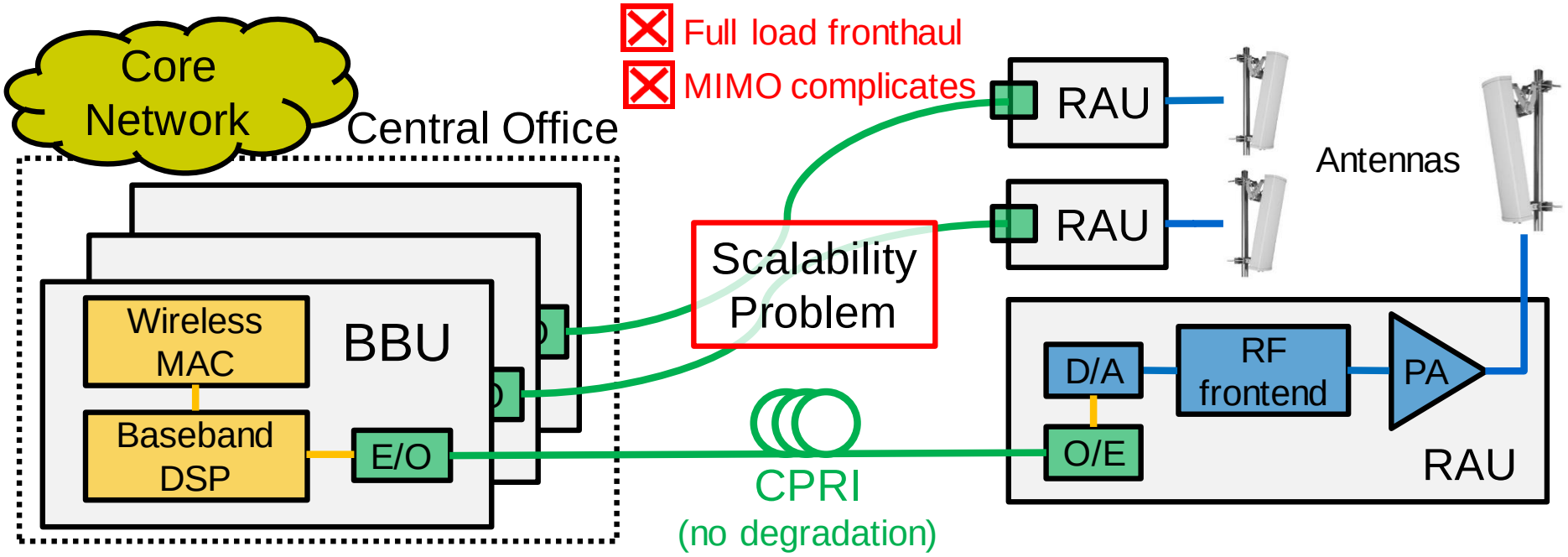
RU = Radio Unit (Analog signal processing)

BBU = Baseband Unit (Digital signal processing)

C-RAN: Base station is split into two parts connected with a fronthaul interface

Baseline C-RAN configuration

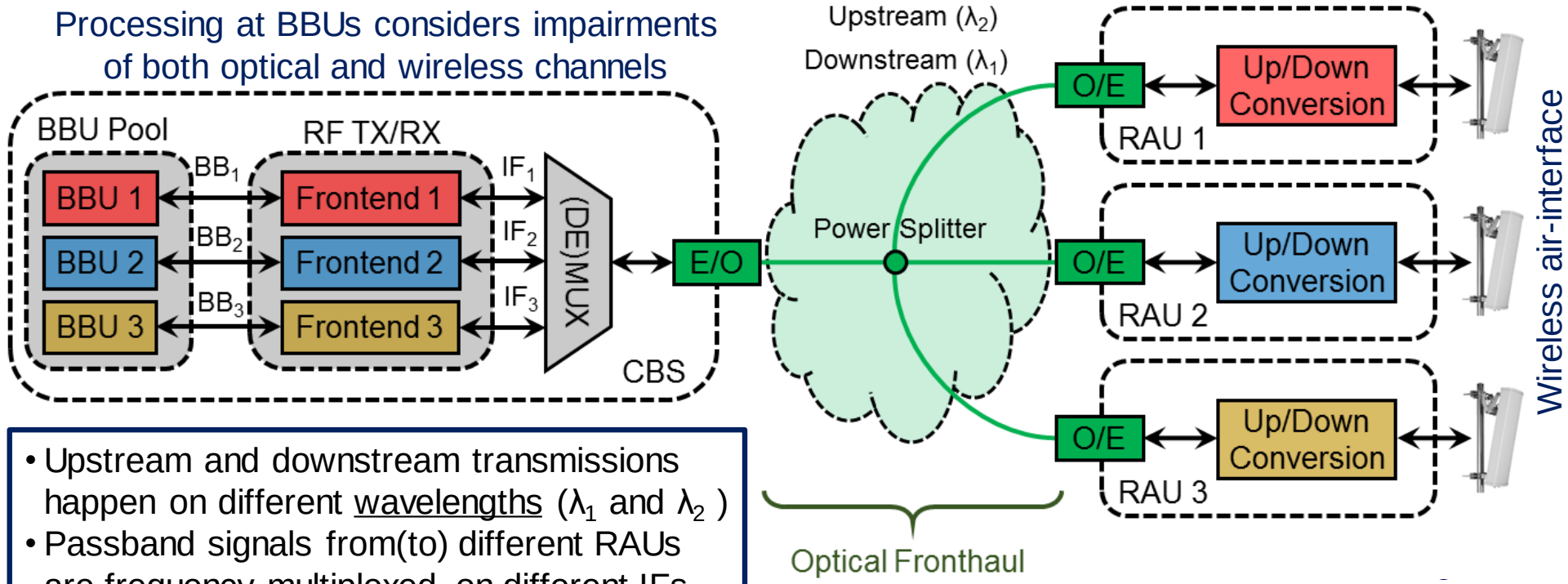
- Digital units of few cell sites co-located at Central Office (CO)
  - **Centralized-RAN:** One BBU per cell site (BBU hotel)
  - **Cloud-RAN:** BBU pool distributes common processing resources
- Common Public Radio Interface (CPRI) used in fronthaul



- CPRI transports digitalized I-Q samples (plus sync, control and management) that expand the data rate and introduce delay

New proposed C-RAN configuration

- RAU with low-cost analog hardware (ultra-dense deployments)
- Analog RoF fronthaul that introduces "*ideally*" only propagation delay and does not expand the wireless signal bandwidth over the fiber
- Fronthaul composed by single-fiber tree-like passive optical network architecture, which must be shared among all distributed RAUs



- Upstream and downstream transmissions happen on different wavelengths (λ_1 and λ_2)
- Passband signals from(to) different RAUs are frequency-multiplexed on different IFs

Electrical-to-Optical conversion

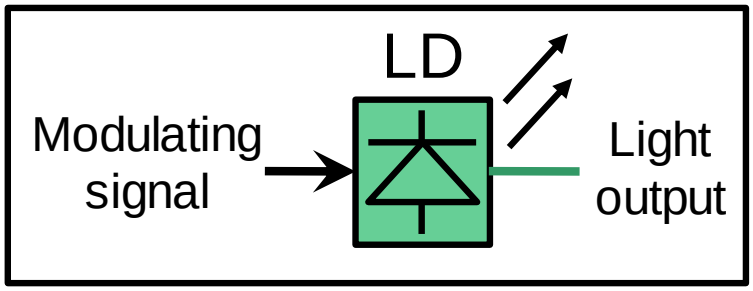
Direct modulation: Based on controlling the intensity of the light emitted by a Laser Diode (LD) varying its driving current:

- Pros: Simple to implement (low cost)
- Cons: Frequency chirp (phase modulation), modulation bandwidth

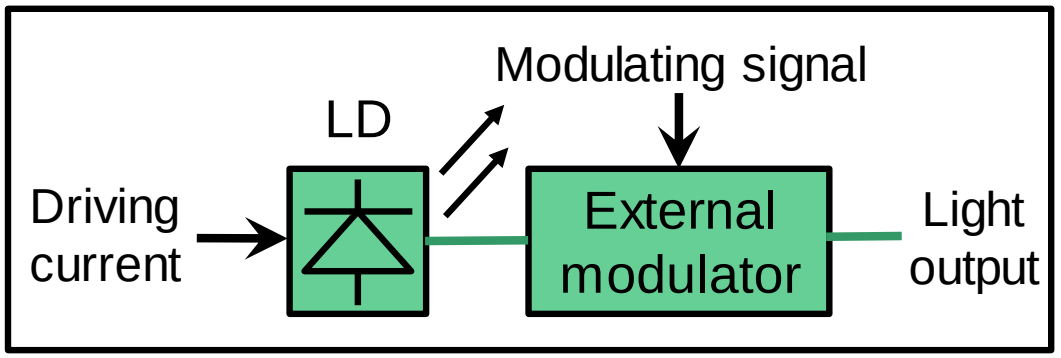
External modulation: External device changes the amount of optical power that goes through it according to applied voltage

- Electro-Absorption Modulator (EAM)
- Mach-Zehnder Modulator (MZM)

} Bias voltage (V_B) controls MZM transfer characteristic



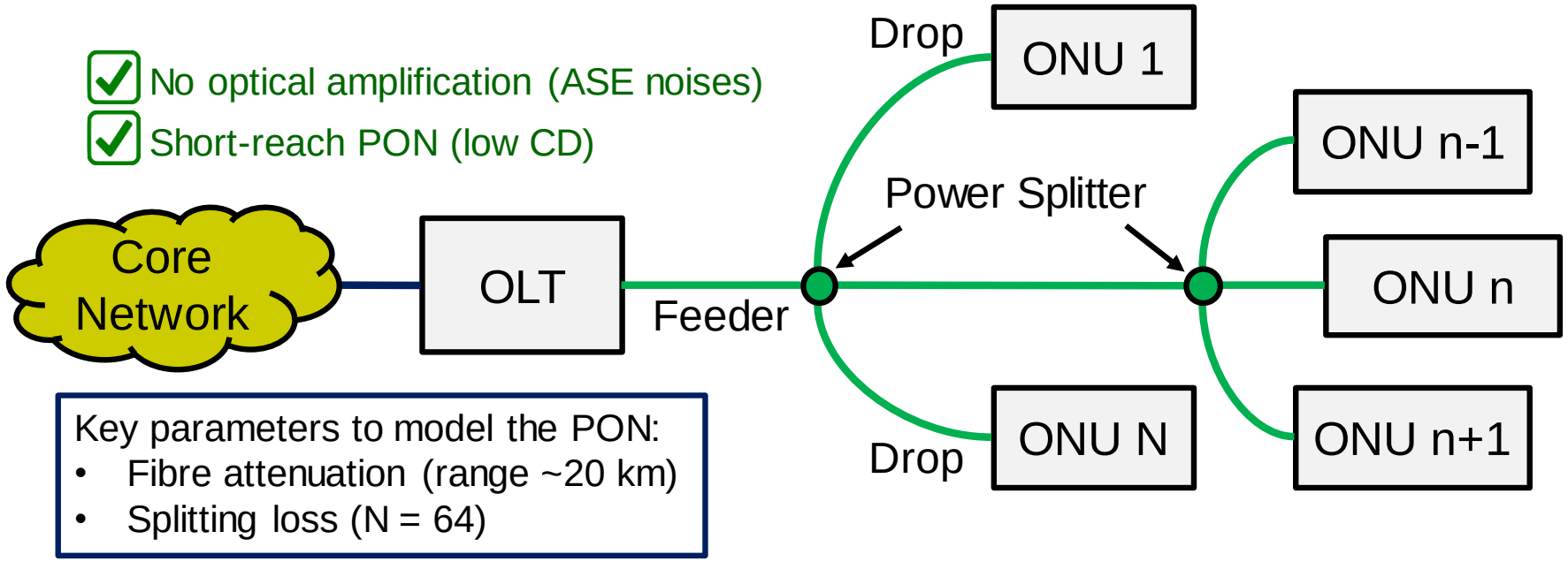
Direct modulation
(LD driving current)



External modulation

Passive Optical Network (PON)

- Widely deployed to provide low-cost, high-capacity, and high-flexibility last mile broadband access (FTTH)
- Point-to-multipoint architecture implemented with passive splitters that enable a tree-like topology using a single fibre



OLT = Optical Line Terminal; ONU = Optical Network Unit;
ASE = Amplified Spontaneous Emission; CD = Chromatic Dispersion

Optical-to-Electrical conversion

Direct-detection: The electrical current at the output of a Photodetector (PD) follows the square-law detection principle

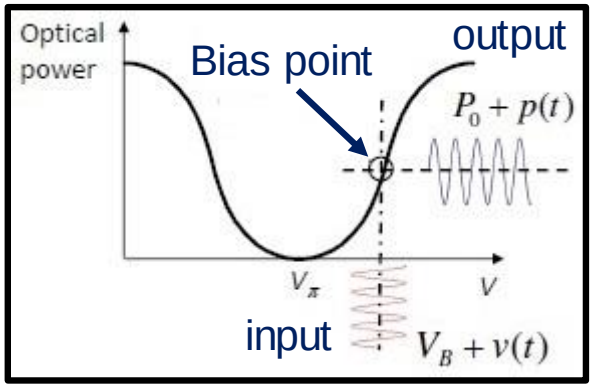
$$I_{pd}(t) = \mu \left| E_{pd}(t) \right|^2 = \mu \, E_{pd}(t) E_{pd}(t)^*,$$

where μ [A/W] is the responsivity of the PD and $E_{pd}(t)$ is the amplitude of the electrical field at the input of the PD

When MZM bias voltage is set to obtain an IM of the LD, then

$$I_{pd}(t) = \mu \, A_{pd}{}^2 \left[1 + \alpha \, v_m(t)\right]^2 \approx \mu \left[A_{pd}{}^2 + 2 A_{pd}{}^2 \alpha \, v_m(t) \right],$$

where the latter approximation results when the MZM operates in the linear response region $\alpha \, v_m(t) \ll 1$

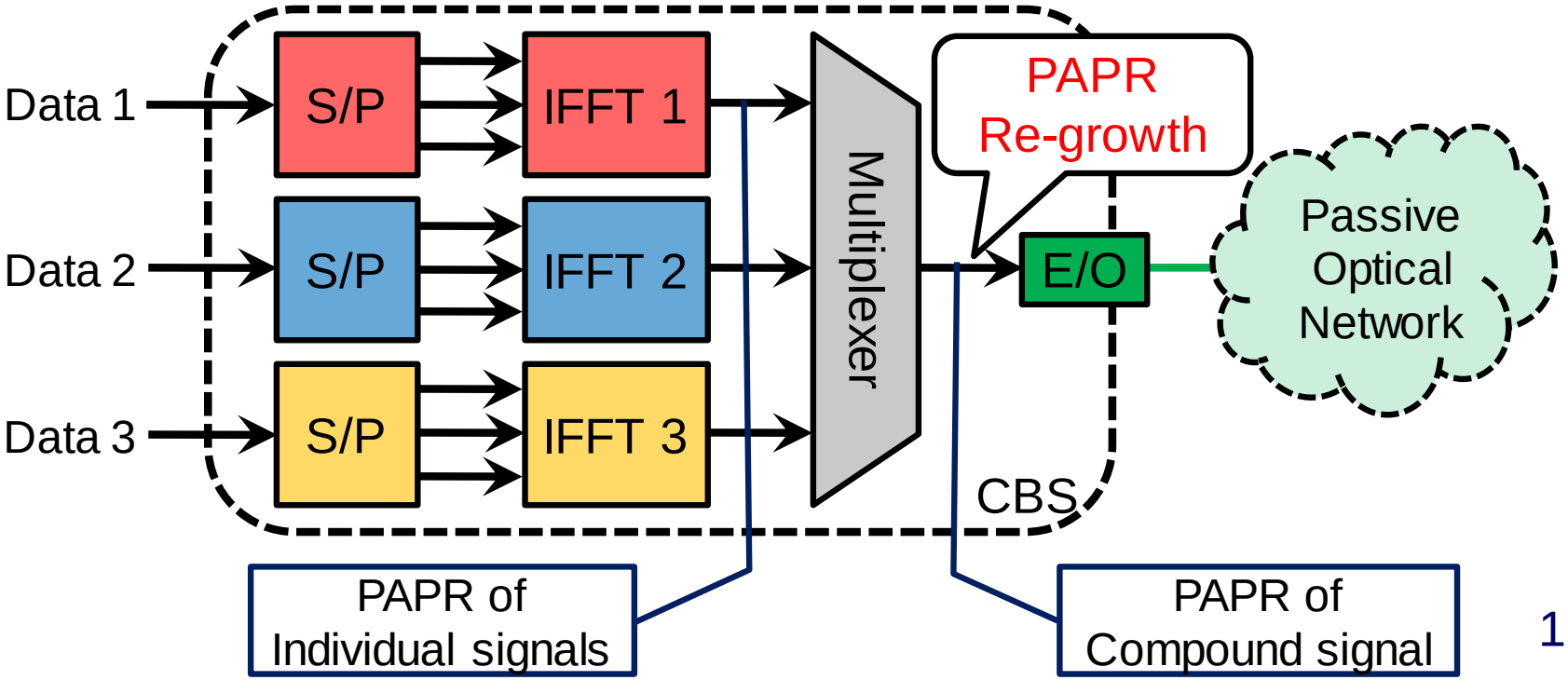


MZM response

Note: The bandwidth of the PD is typically larger than the bandwidth of a MZM one

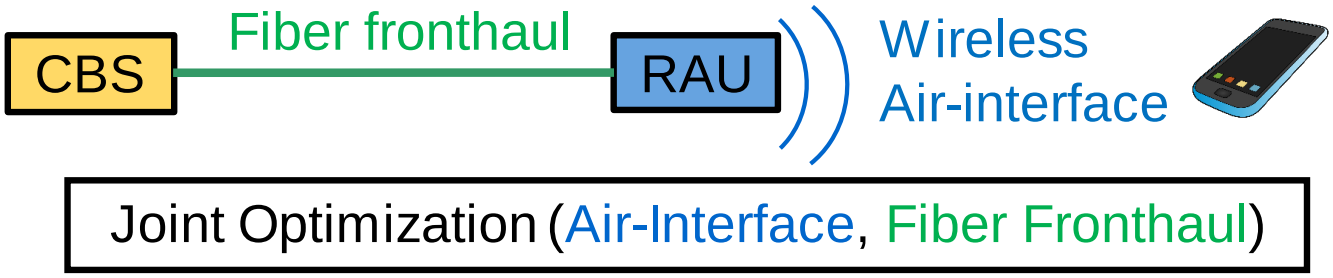
Challenges in Downstream (1)

- Optical OFDM schemes provide an unipolar output signals
  - Two well-known schemes: DCO-OFDM and ACO-OFDM
- High **Peak-to-Average Power Ratio (PAPR)** happens when phase of different subcarriers combine constructively at IFFT output
- Clipping reduce PAPR but introduce in- and out-of-band distortion

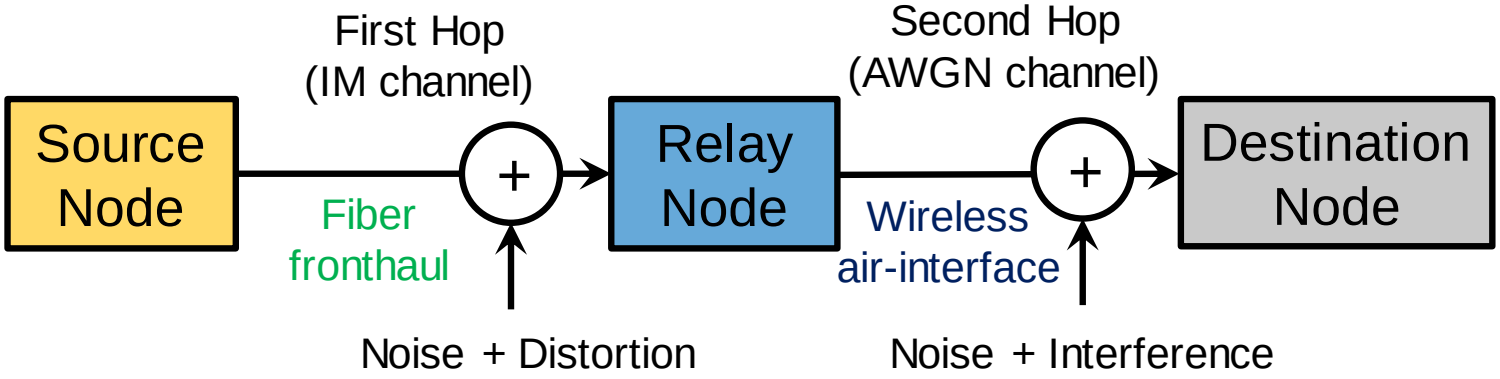


Challenges in Downstream (2)

- Traditionally, the modulation and coding scheme of a wireless system is selected based on the channel gain of radio channel



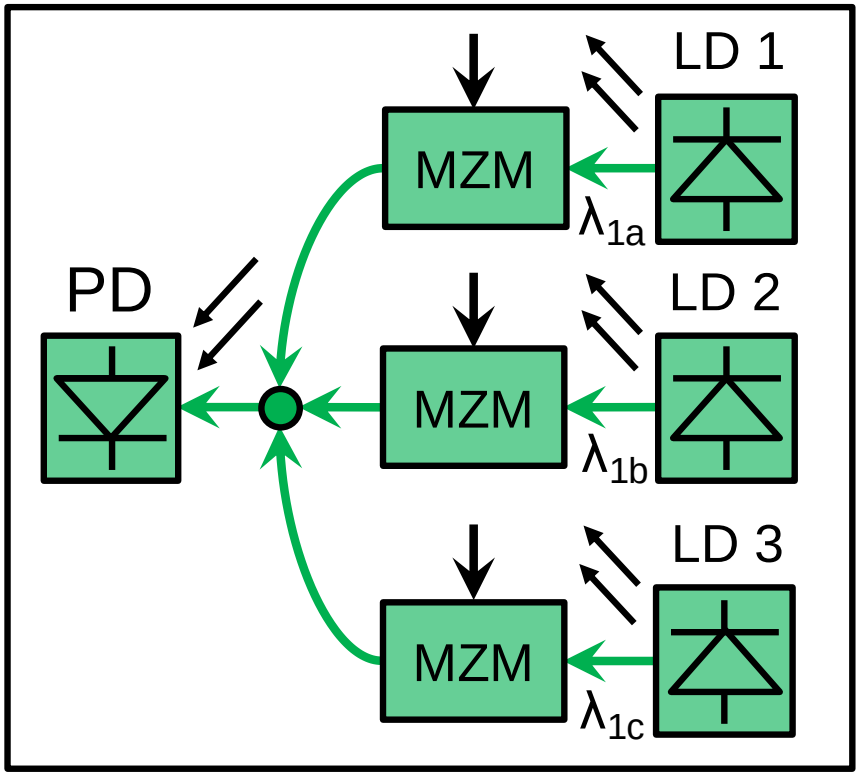
- The hybrid optical-wireless link that is configured when cascading the fibre fronthaul and air interface becomes and Amplify-and-Forward (AF) relaying system



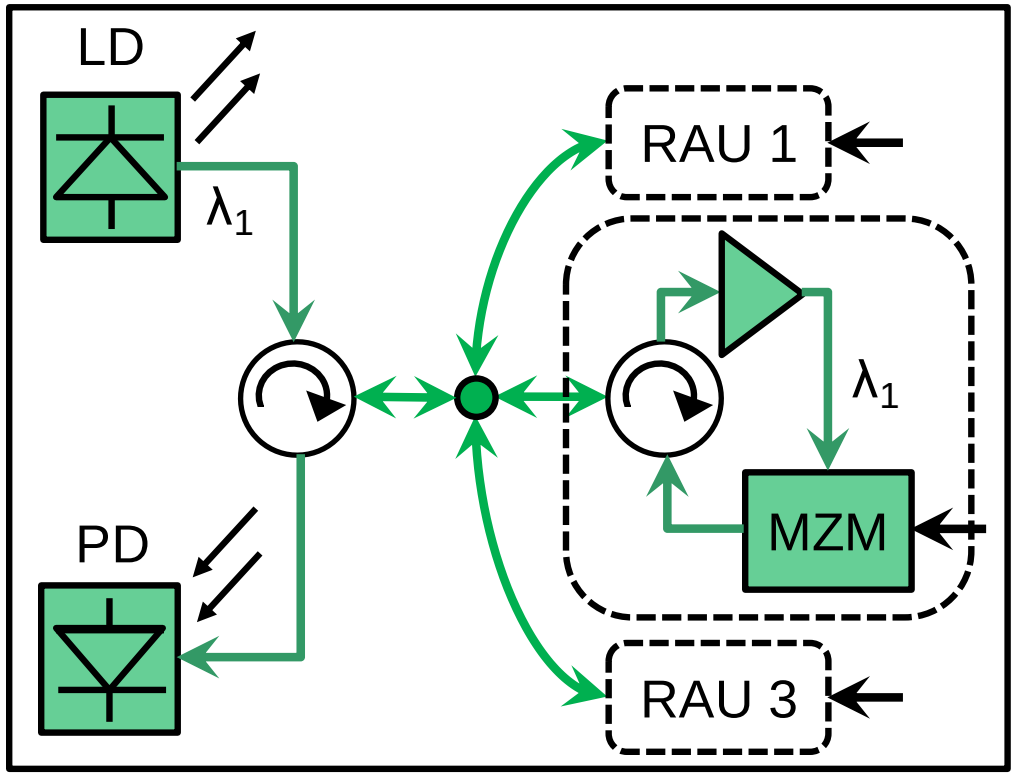
Challenges in Upstream (1)

Optical Inter-Modulation Distortion:

- Originated due to the superposition of incoherent sources of light that are independently modulated in intensity



Distributed LDs (Δω and Δϕ)

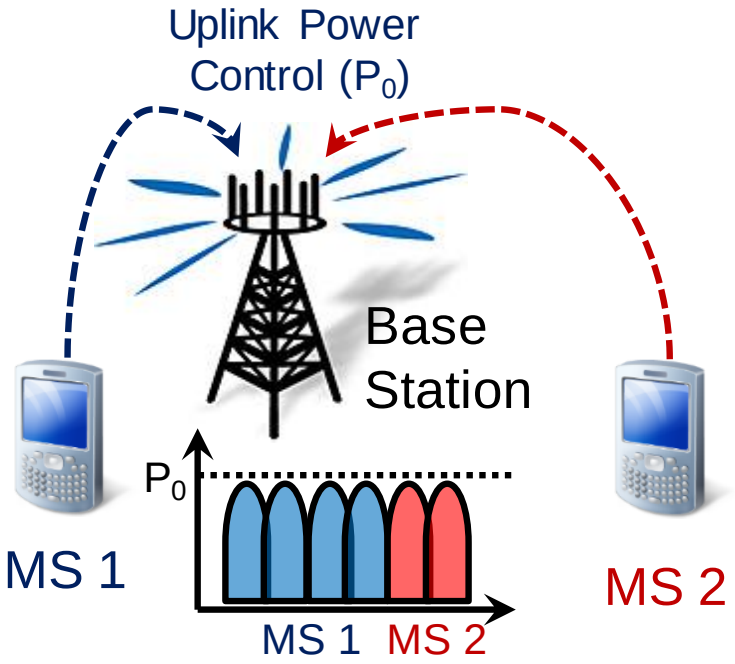


Centralized LD (Δω = 0 and Δϕ)

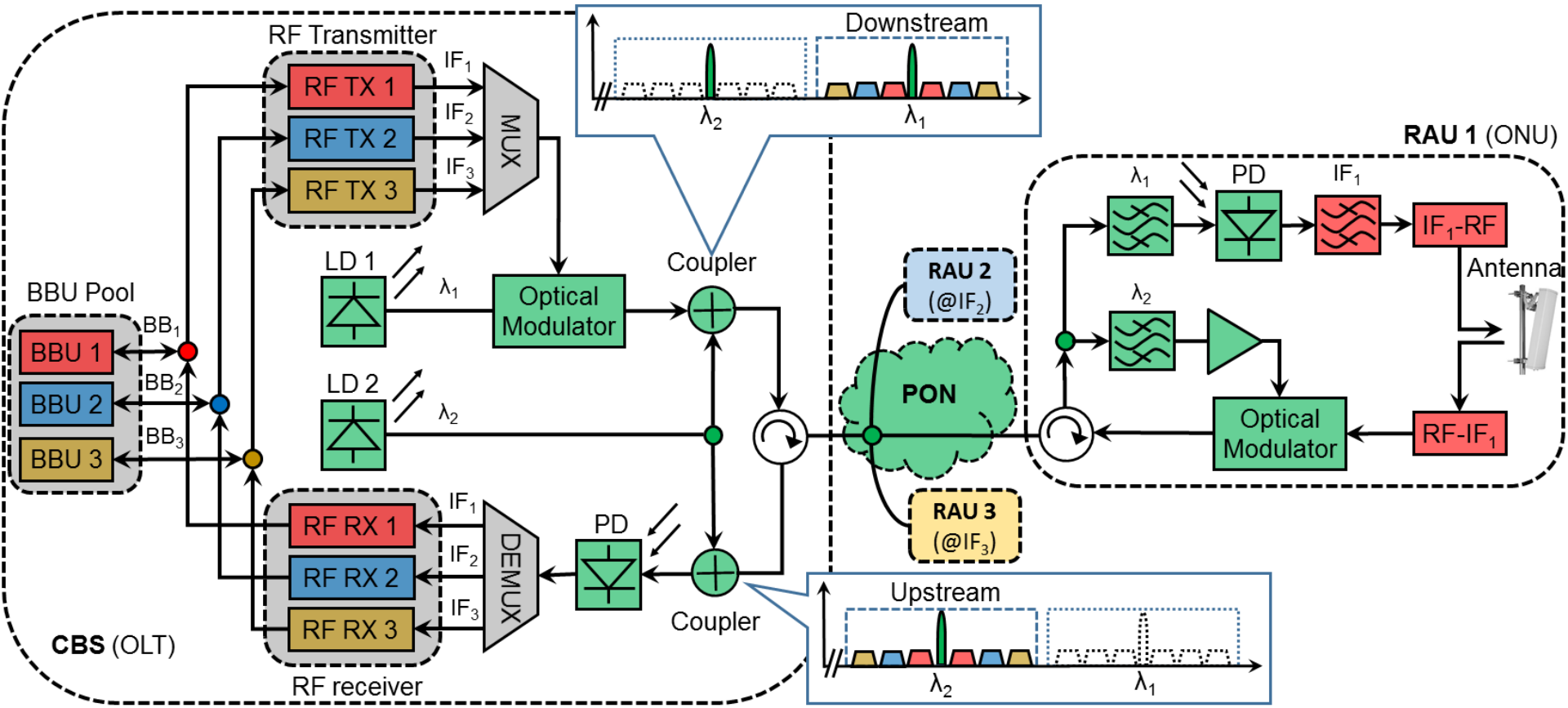
Challenges in Upstream (2)

Near-far effect:

- Data streams generated by the different Mobile Stations (MSs) in the upstream direction are not synchronized
- Intra-cell interference occurs when different MSs are scheduled on adjacent portions of the RF band
- In proposed C-RAN architecture, the uplink transmission power of each MS should take into account the combined effect of the optical-wireless link that is configured (mean path loss attenuation)



Proposed C-RAN for 5G



- **Downstream:** Intensity modulation (IM) of composite IF-mux signal
- **Upstream:** Electrical-field modulation with carrier supresssion

Summary

- In C-RAN architecture, the joint design of the radio (wireless) air interface and optical (wired) fronthaul technologies has not been considered in detail so far
- The use of analog RoF technologies to transport wireless signals over fiber fronthaul has several advantages:
  - Only analog signal processing at RAU needed (low-cost HW)
  - No bandwidth expansion is experienced (suitable for ultra-dense networks with tree-like optical transport network)
  - No processing delay in fronthaul (tactile Internet)
- Different challenges that appear when implementing upstream and downstream transmissions have been identified, along with possible approaches to tackle them

Thanks for your kind attention!

Questions and/or comments?

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