A Business Case for Employing Direct RF Transmission over Optical Fiber In Place of CPRI for 4G and 5G Fronthaul

Presented by

APIC Corporation

5800 Uplander Way

Culver City, CA 90230

www.APICHIP.com

sales@apichip.com

Revised 10/15/2017

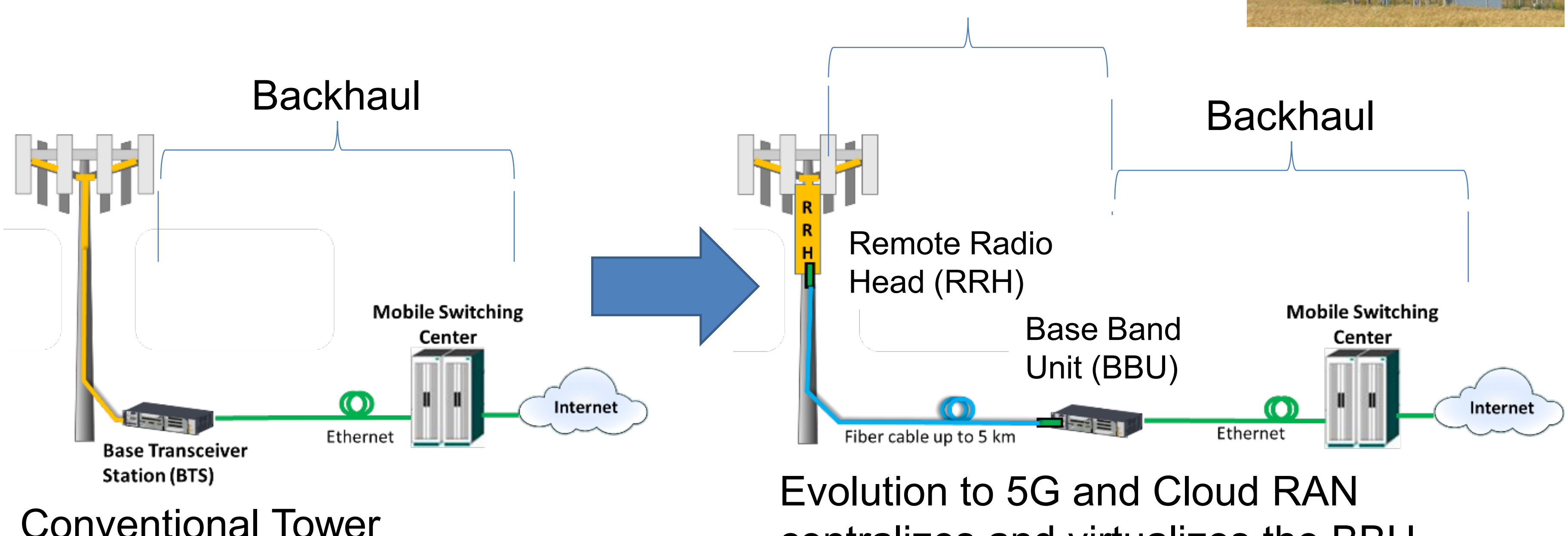
Overview

- In the last 20 years mainstream opto-electronics was driven by 2 goals:
  - Increase transmission data rate based on 2 level modulation (recently PAM4 is being considered, 4 levels)
  - Reduce cost of transmitters
- The above objectives were achieved at the expense of:
  - Optical links noise floor - Typical digital links operate at > 30dB above the electronics shot noise limit.
  - Linearity - In order to achieve lower cost modulation for two level states, linearity was not a priority, because it was compensated with limiting amplifiers.
- In contrast, wireless transmissions have taken the approach to use the spectrum as efficiently as possible and apply high order modulation, lower data rates and densely spaced carriers. This requires low noise and high linearity from the link components.
- Therefore, in order to carry wireless signals in fiber the options are:
  - High linearity, low noise optical components (APIC's solution)
  - Convert to digital using oversampling, inefficient data rate payload, added latency and back conversion to RF as implemented by CPRI
- Legacy optical components are not the optimal solution for future 5G

What is “Fronthaul?”

Fronthaul: In a classic cell tower there is a <u>base transceiver station (BTS)</u> adjacent to the tower. The BTS is contained in an enclosure which requires significant power for radio amplifiers and environmental conditioning. To improve system efficiency the BTS has been split between the remote radio head (RRH) at the antenna and the baseband unit (BBU) which is located further away from the antenna.
The RRH and the BBU communicate through a “fronthaul” link using Common Public Radio Interface (CPRI) or Open Base Station Architecture Initiative (OBSAI) standards.

By Luděk Hrušák, CC BY-SA 3.0

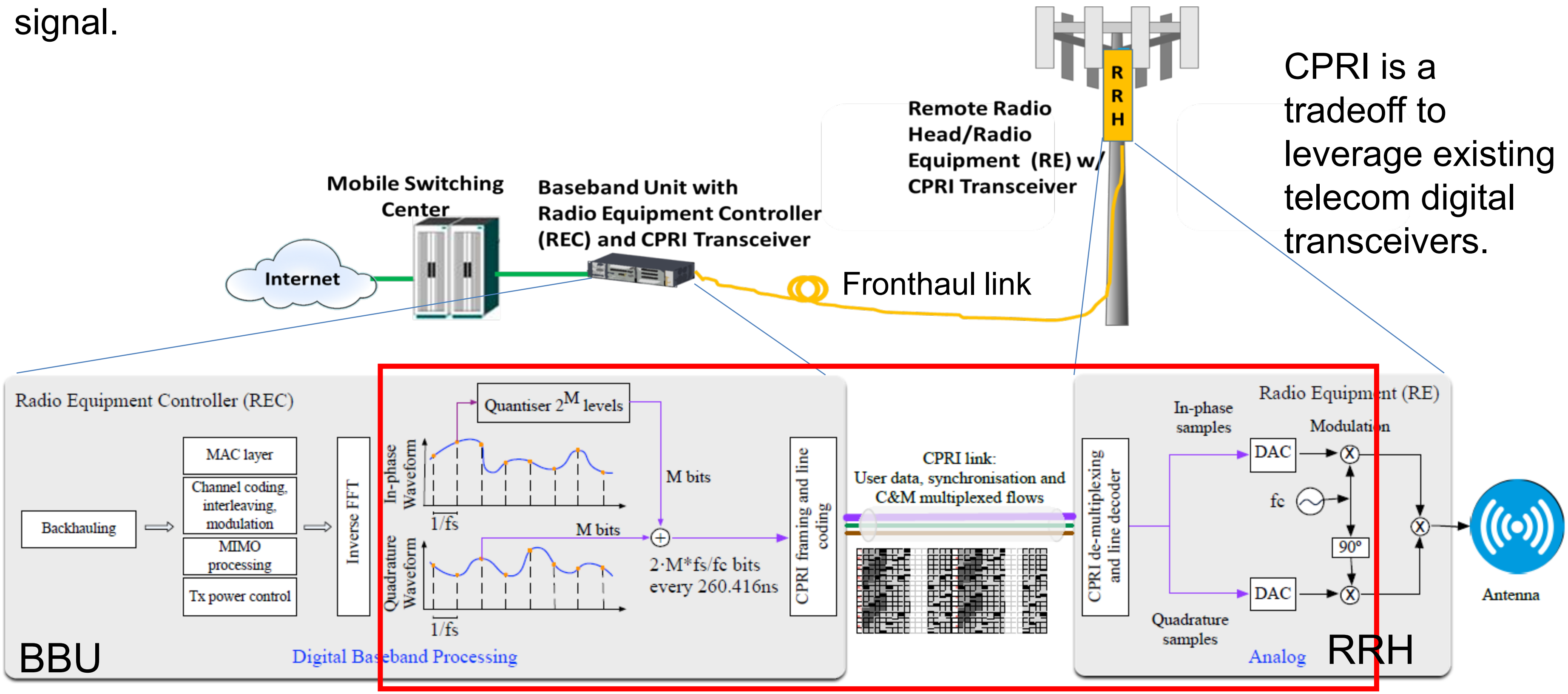


Evolution to 5G and Cloud RAN centralizes and virtualizes the BBU

The Fronthaul Link with CPRI

Very efficient spectrally efficient high bandwidth OFDM radio signals with high-order modulation are digitized with low-order modulation (QPSK) and serially streamed using CPRI between the BBU and RRH and then demodulated to reconstruct the original OFDM radio signal.

CPRI is a tradeoff to leverage existing telecom digital transceivers.

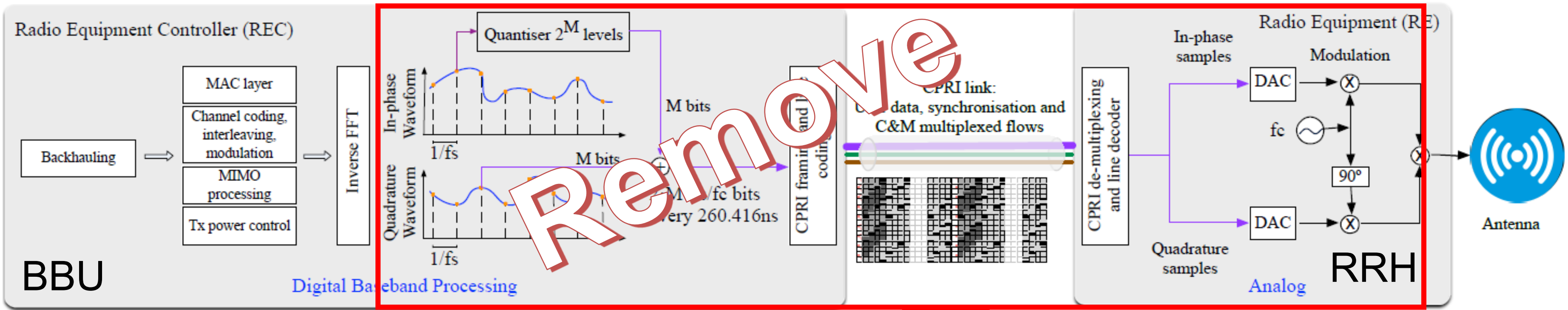


Conceptual explanation of REC/RE functional split[1]

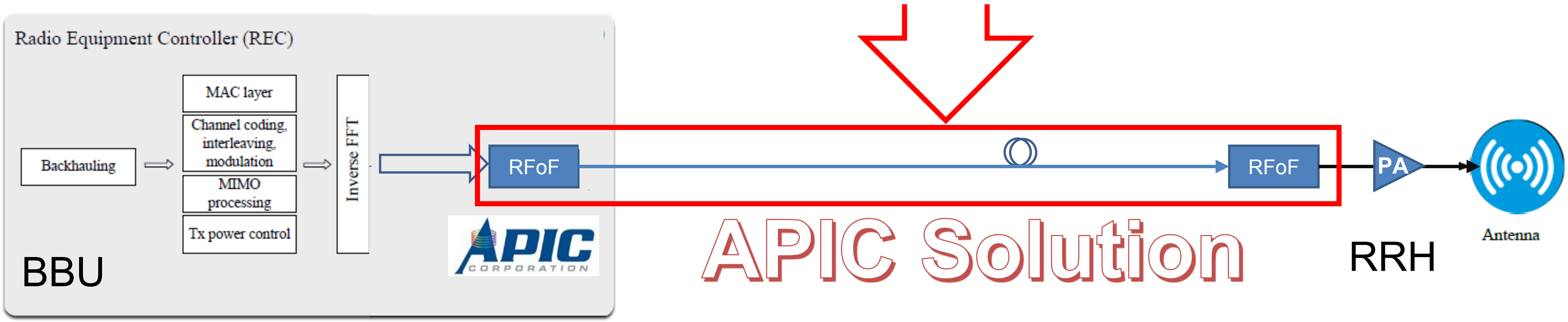
1. Graphic is from Antonio de la Oliva, et. al., “An overview of the CPRI specification and its application to C-RAN based LTE scenarios,” IEEE Communications Magazine • February 2016

APIC Solution:
Directly Transmitted RF over Fiber

Instead of digitizing the RF signal (as in CPRI or OBSAI) transport the RF signal in its native form via light through fiber – Direct Transmission of RF over Fiber (RFoF)



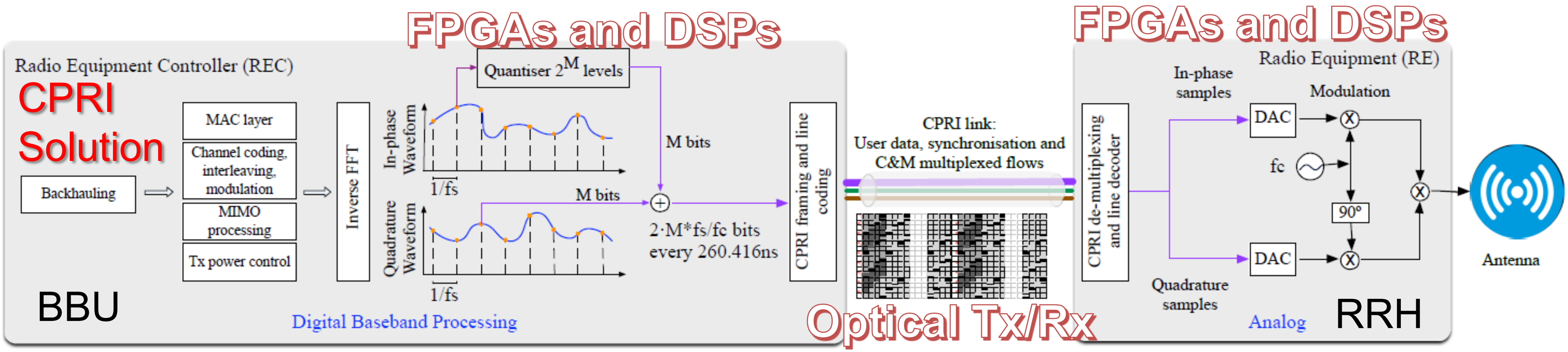
APIC solution: direct transmission of high order modulation RF signals over fiber



Issues with CPRI/Digitized RF for Fronthaul

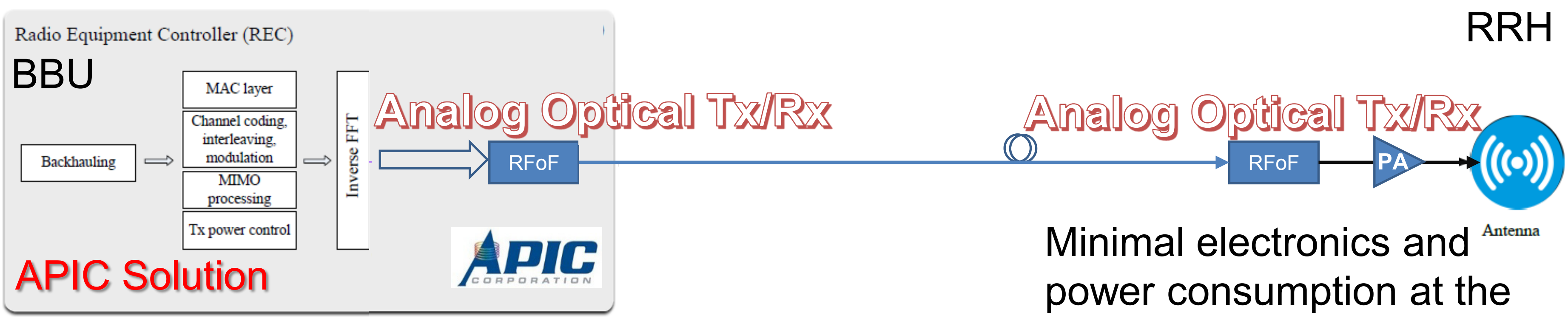
- Bandwidth Efficiency:
  - High order modulation OFDM spread spectrum radio waveform vs CPRI encapsulated serial data
  - Channel data rate vs payload throughput
  - Bandwidth inefficiency impacts capacity and OPEX
- Latency
  - Time required for CPRI processing vs processor speed
  - Impact of increased bandwidths on CPRI latency
  - Higher performance processors to improve latency impacts CAPEX
- OPEX
  - Complexity of RRH and reliability in harsh environment increases CAPEX & OPEX
  - Power Consumption of CPRI processors
  - Life expectancy of CPRI Transceivers with 100% duty Cycle
- CAPEX
  - Complexity & Cost of RRH with CPRI
  - Successive upgrades to match future bandwidth requirements

Complexity: CPRI vs. Directly Transmitted RF over Fiber



Conceptual explanation of REC/RE functional split[1] with CPRI

APIC solution: replace high performance processors and algorithms with high-linearity link



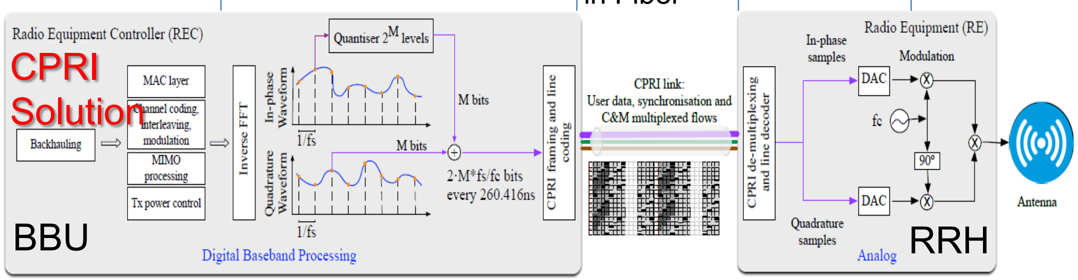
With RFoF, Radio is consolidated in the BBU

Minimal electronics and power consumption at the antenna

Latency: CPRI Processing vs. Directly Transmitted RF over Fiber

4G HARQ round trip time is 3 ms. 5G may decrease the round trip time

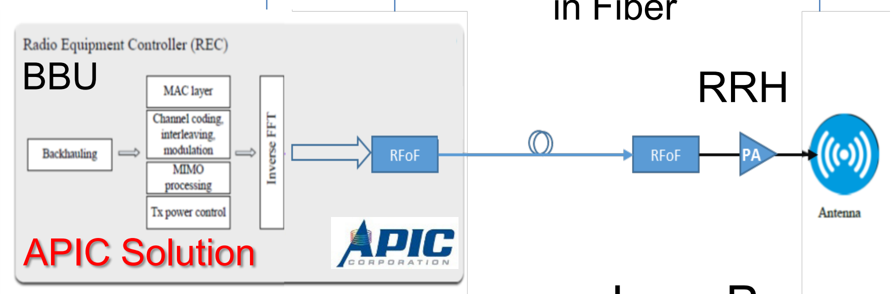
a) CPRI Processing in BBU | b) Signal Propagation in Fiber | c) CPRI Processing in RRH



Total time = a + b + c

APIC solution: no time needed for processing; direct transmission of the RF signal

a' = 0 | b') Signal Propagation in Fiber | c' = 0

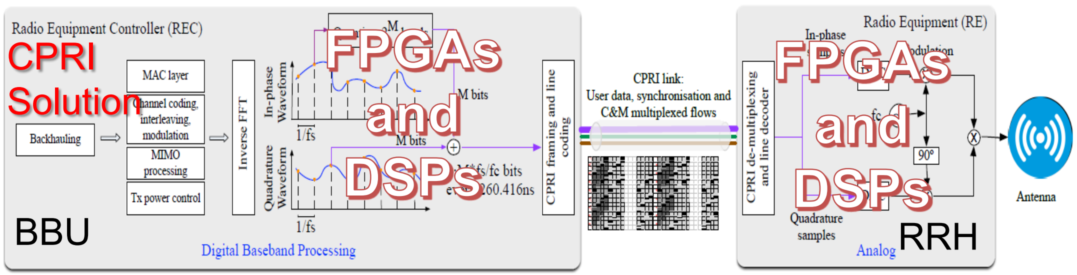


Total time = b'
Time saved (a + c) can be reallocated to extend the reach of the link; 10 μs = 1 km

<u>Less Processing Time = Longer Fronthaul Reach</u>

CAPEX: CPRI vs. Directly Transmitted RF over Fiber

CPRI digital sampling of high order modulation RF signals requires expensive processors such as FPGAs and DSPs



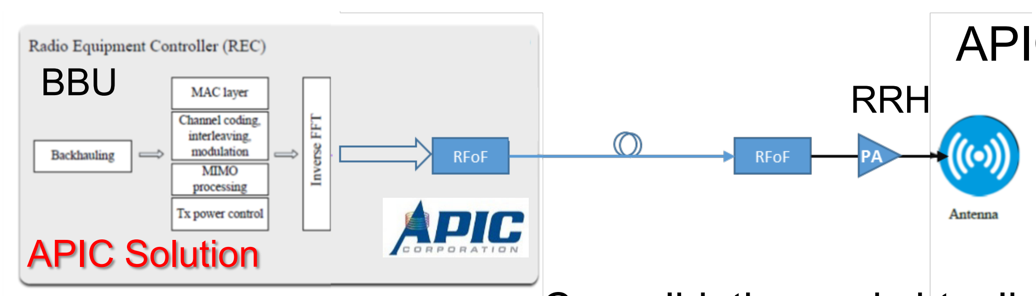
Example FPGAs:

- Altera Stratix IV GX = $2,610
- Altera Stratix V = $5,700
- Altera Arria V[1] = $1,6352

SFP Optical Transceiver ~ $150

Complex and expensive!

APIC solution: Less than half the cost of CPRI link, interfaces and processors

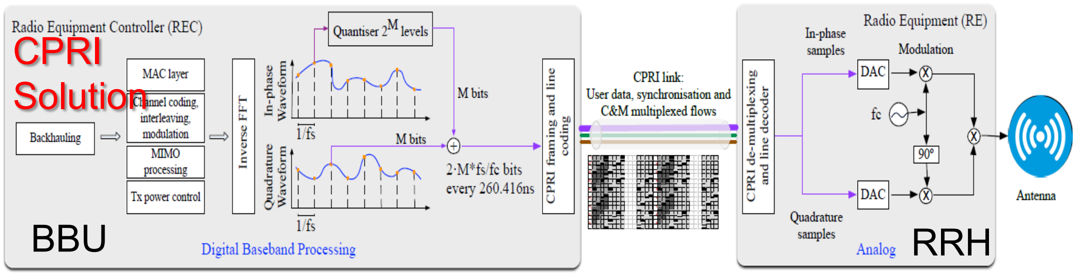


APIC Optical Transceiver < $500 (ROM)

Simple, low power, wide bandwidth and modulation independent – future proof

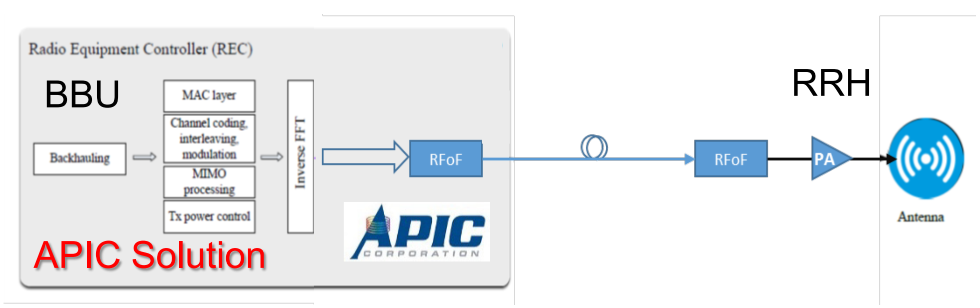
Consolidation and virtualization (i.e. SDR) of all radio functionality in the BBU reduces the complexity and cost of the electronics

OPEX: CPRI vs.
Directly Transmitted RF over Fiber



- More electronics and power required at the RRH for CPRI processing and signal conditioning
- Transceivers operate at 100% duty cycle; impacts power consumption and lifespan
- Greater complexity for reliability, diagnostics and repair
- Need to future bandwidth upgrades

APIC solution: Radio and most all electronics consolidated in the BBU



- Less electronics and power required at the antenna.
- Transceivers only operate when RF signal is present; energy efficient
- Simpler, more robust, easier to diagnose and repair
- Same transceiver works with 1.25 MHz and 2 GHz signal bandwidths

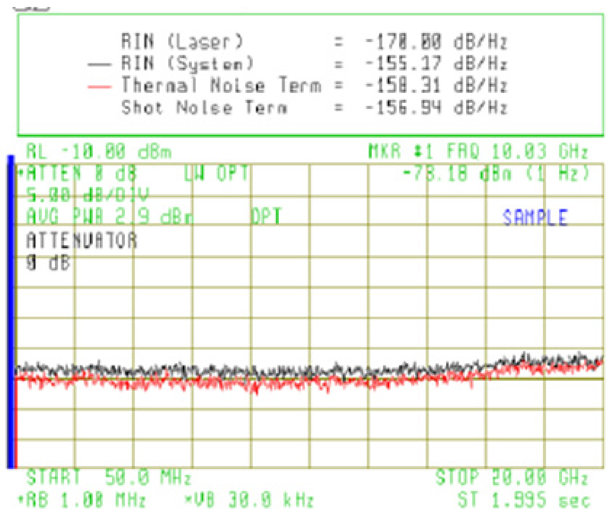
Consolidation and virtualization of all radio functionality in the BBU conserves power and improves overall reliability and maintainability

APIC's Technology

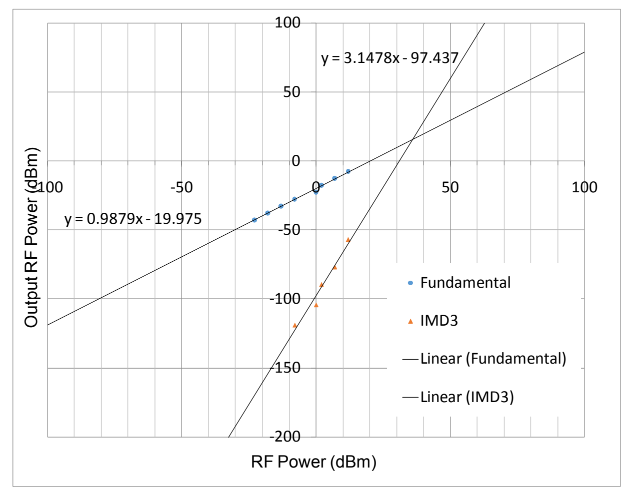
Is a commercial application of high performance analog transceivers developed over a period of 10 years for the Department of Defense.

- Ultra low noise lasers operate at shot noise levels, below -160 dB
- Highly linear and responsive photo detectors, above 0.9 responsivity
- Links have a high dynamic range, above 112 $dBHz^{-2/3}$
- Links have a high IIP3 of 36 dBm

APIC 4 GHz Direct Mod transmitter developed for the US Navy, used for testing.



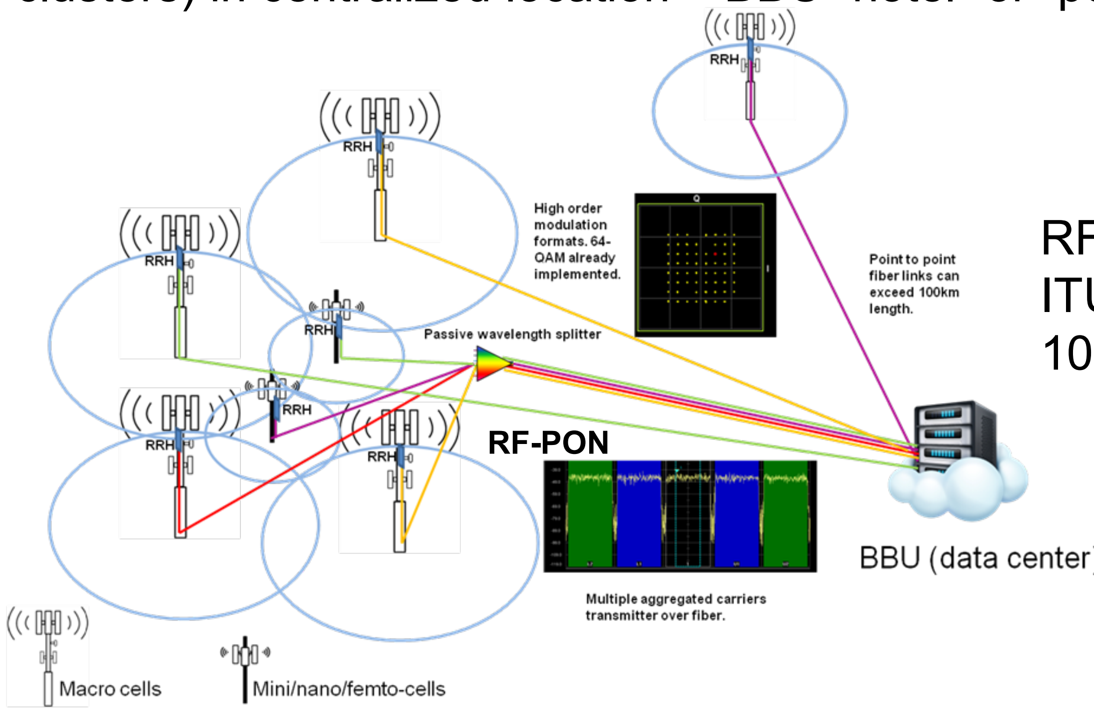
Laser RIN (noise) of -170 dB measured from 0.5 to 20 GHz



IIP3 measurement for the RFoF link at 1 GHz. Similar results were measured at 3 GHz.

APIC Solution: Direct Transmission of OFDM Signals on **RF-PON**

Consolidate the Baseband Units (BBUs) for multiple towers (macro-, micro-, pico-cell clusters) in centralized location – BBU “hotel” or “pool”

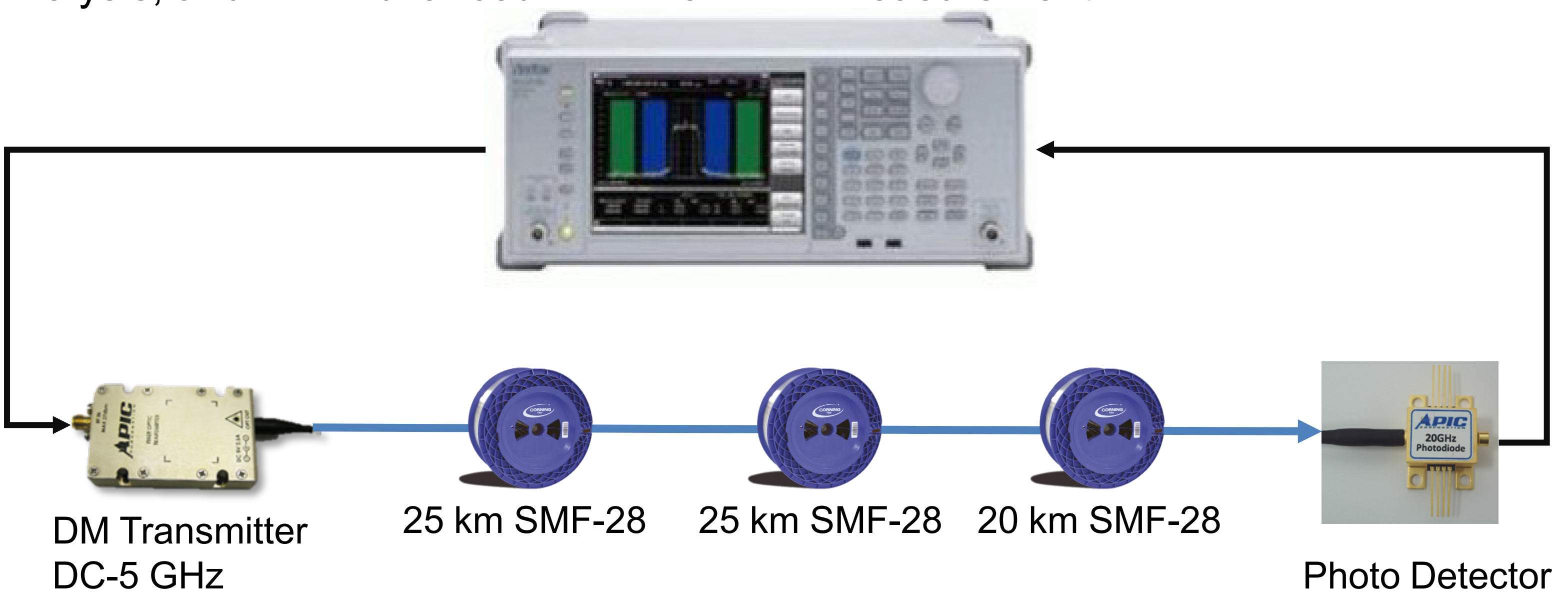


RF-PON based on ITU grid of 50 or 100GHz separation

- Improve network efficiency, timing and synchronization
- Significantly lower CAPEX & OPEX costs
- Reduce number and locations for maintenance calls
- Prepare network for emerging 5G and Cloud-RAN deployments

Preliminary Testing Validates Directly Transmitted RF over Fiber Technology

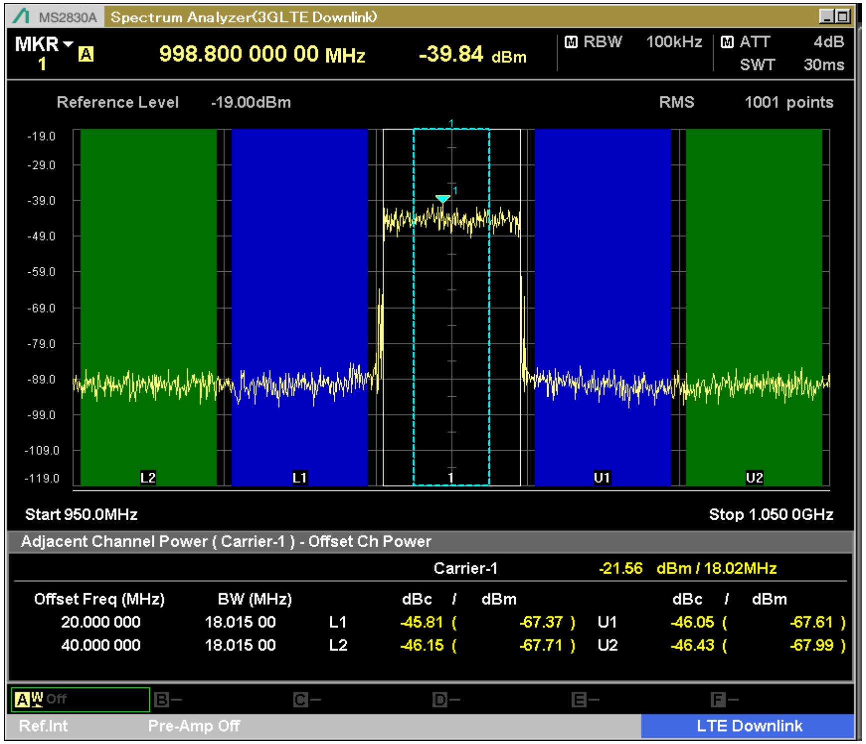
Anritsu MS2830A 6GHz Signal analyzer with: 6GHz Vector Signal Generator; bandwidth extension to 125MHz; software modules for LTE-Advanced IQ Producer; Vector Modulation Analysis; and LTE-Advanced FDD Downlink Measurement.



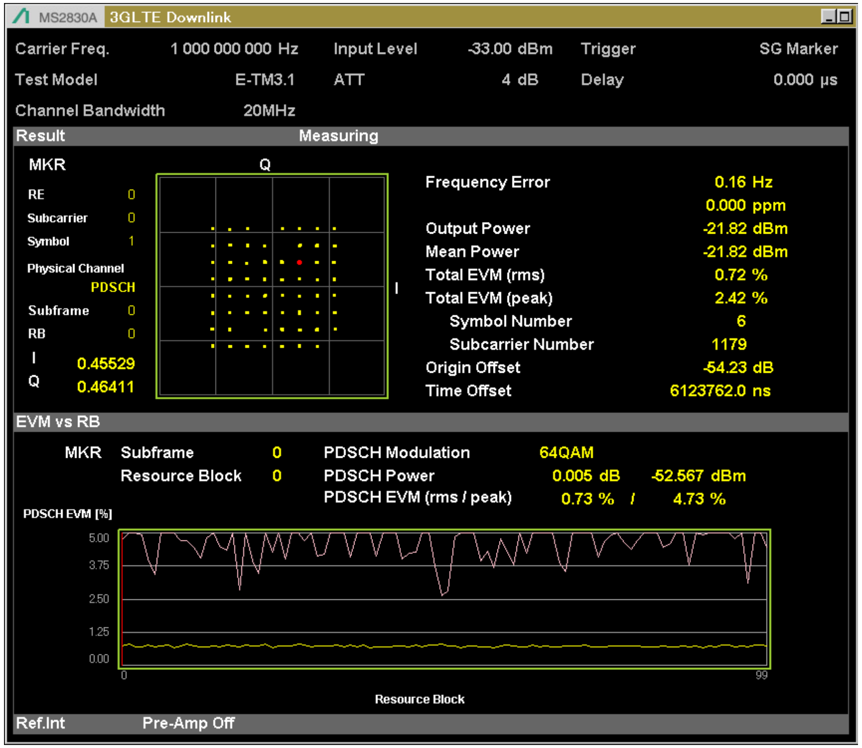
- For all testing we use E-UTRA Downlink Test Model 3.1 (E-TM3.1) with 64QAM modulation, initially with a single 20 MHz carrier and then with 5 aggregated 20MHz carriers for 100MHz transmission bandwidth.
- Performance metrics:
  - Total EVM (rms) ≦ 8%
  - ACP (ACLR) ≦ -44.2 dBm.

Preliminary Test Summary: Single 20 MHz Channel

- One 20 MHz, 64QAM OFDM signal transmitted over 25 km of fiber
- 3GPP LTE ACLR Spec: ≤ -44.2 dBm
- 3GPP LTE EVM Spec: ≤ 8%



Measured ACLR is -45.81 dBc

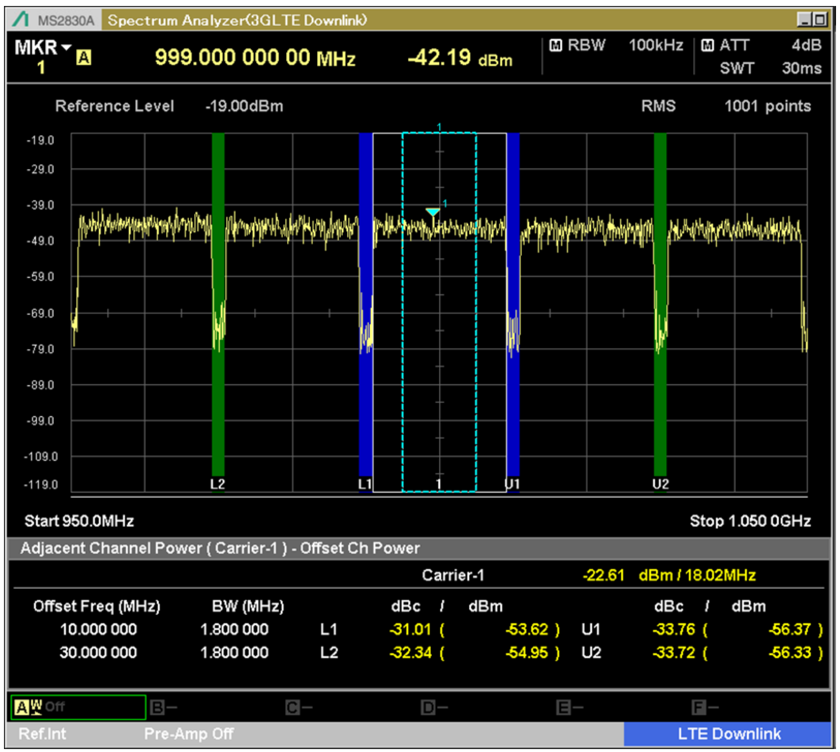


Measured EVM is 0.72%

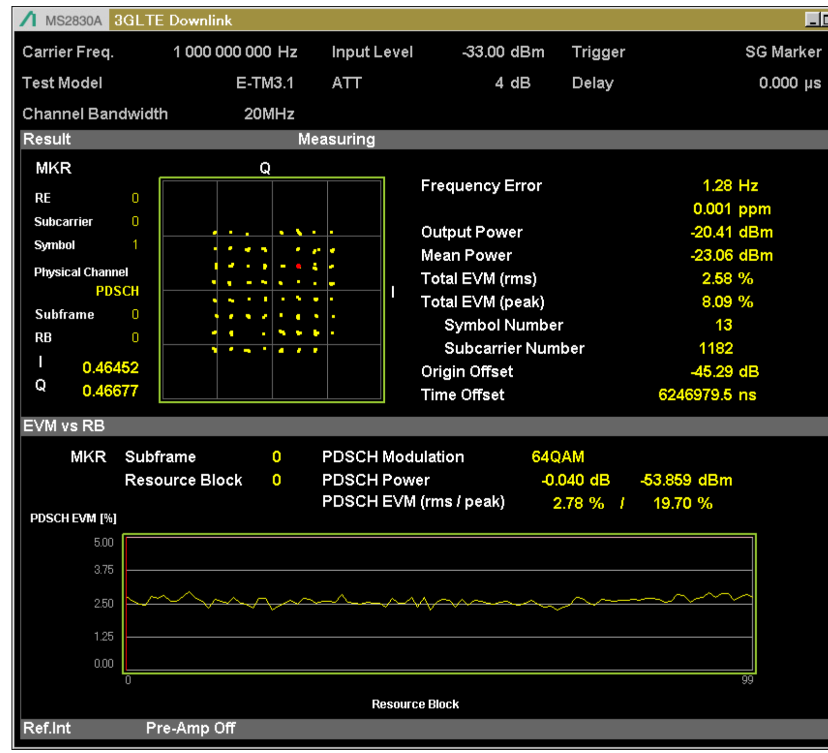
Full report is available at http://www.apichip.com/rfof-5-lte-advanced-carriers-70km/

Preliminary Test Summary: Five aggregated 20 MHz Channels

- 5 x 20 MHz, 64QAM OFDM signals transmitted over 50 km of fiber
- 3GPP LTE ACLR Spec: ≤ -44.2 dBm
- 3GPP LTE EVM Spec: ≤ 8%



5 Adjacent 20 MHz Channels



Measured EVM is 2.58%

Full report is available at http://www.apichip.com/rfof-5-lte-advanced-carriers-70km/

For More Information

- Refer to the APIC website: www.apichip.com
- Additional information on the direct transport of 4&5G Radio signals over fiber: http://www.apichip.com/5g-c-ran-fronthaul/
- Follow APIC on Linkedin:
- For Business and sales contact Bob Walter directly at: walter@apichip.com
- For technical questions contact Anguel Nikolov at: Nikolov@apichip.com