Superior CPRI over OTN Front-Haul Solutions

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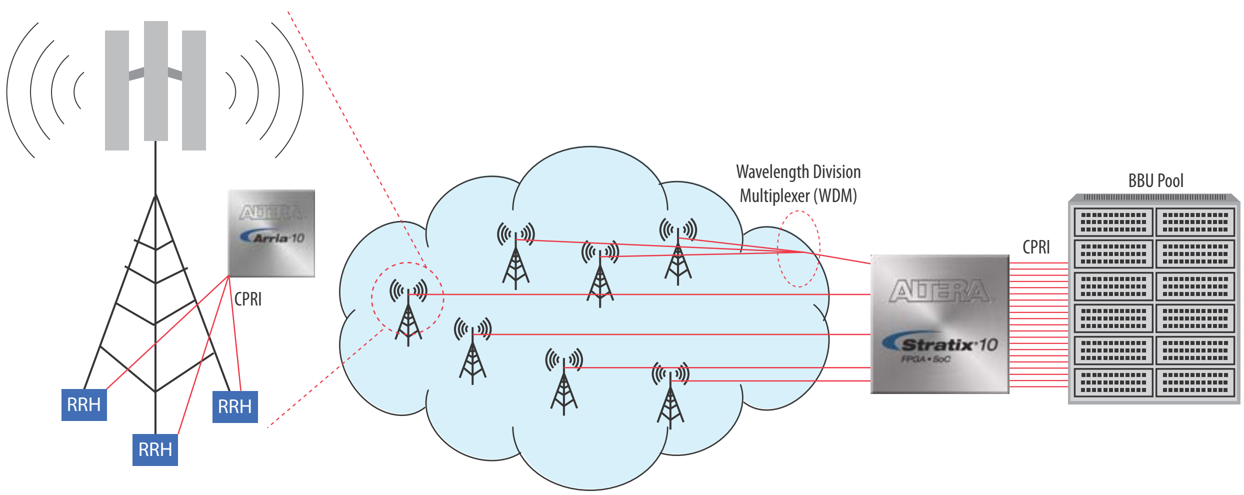
WP-01263-1.0 White Paper

The number of smart mobile devices is steadily growing and the usage pattern is shifting towards more video streaming in higher quality. There seems to be no limit to the growth of demand for capacity in the mobile network. To optimize the efficiency of the mobile access network, operators are implementing centralized radio access networks (CRAN). These network architectures separate into simple remote radio heads (RRH) at the antenna sites and centralized pools of base band units (BBU). The signal transferred between the two sites is the Common Public Radio Interface (CPRI). It is the digitized components of the baseband IQ signal of the RF signal of the antenna. [(1)]

The CPRI signal is high bandwidth (today up to 10 Gbit/s). With typically three sectors per antenna tower, the front-haul network becomes very high capacity. The CPRI signals must be transported with high attention to jitter/wander or frequency/latency stability because these parameters directly affect the quality of the mobile service. Fortunately, transmission schemes like CPRI over OTN combine cost-efficient, high-capacity transport with high signal integrity.

Figure 1. Example CPRI over OTN Application



Altera, now part of Intel, offers FPGA technology and IP to implement integrated and re-programmable front-haul solutions. Altera conducted tests to compare two alternative CPRI over OTN solutions.

- *Traditional OTN multiplexing*—The first solution offers traditional OTN multiplexing of multiple CPRI clients. [(2)] This solution allows mixing of CPRI clients with other types of clients, such as Ethernet.

- *CPRIm based multiplexing*—The second solution is based on multiplexing several CPRI signals into a CPRIm aggregate signal before mapping to OTN. (3) This method allows up to 50% higher effective CPRI capacity on a wavelength.

Both solutions are fully integrated in a single device which includes recovery and generation of CPRI timing. With the 20 nm Arria® 10 FPGA family it is possible to track and filter multiple independent signals with only a single fixed XO as common reference. The test results show superior performance for both solutions.

Table 1. Arria 10 Front-Haul Solution Performance

Measurements	Traditional OTN Multiplexing	CPRIm Based Multiplexing
Small latency variation	✓	✓
Good latency repeatability	✓	✓
Good RF performance	✓	✓
Most CPRI signals per wavelength		✓
Mix of client types on one wavelength	✓	

Introduction

The program studied two different implementation schemes. Both schemes are based on optical transport using OTN as the underlying transport protocol. Using OTN brings some fundamental advantages:

- A well standardized scheme for performing operations, administration, and maintenance on optical links
- An option for forward error correction (FEC) to mitigate performance degradation in the optical network
- A demarcation point between a mobile service and a transport provider

Another advantage is that OTN allows time multiplexing of several CPRI signals on the same optical signal. The two studied schemes implement this time multiplexing differently.

With traditional OTN multiplexing, all CPRI signals are mapped into individual ODU containers. These containers are subsequently multiplexed and mapped into an OTN signal (OTU2). Because the standard rates and granularities of OTN do not match well with the CPRI rates, some bandwidth is lost in this process.

With CPRIm based multiplexing, the 8b/10b encoding of the CPRI signals terminates before the CPRI signals are multiplexed in groups of 3, 6, 9... into one CPRIm signal. The signal then maps into a special OTN signal (OTU2r). The signal's rate is selected to match with the CPRIm signal. Because of this dedicated handling of the CPRI signals, there is a gain of multiplexing efficiency.

Table 2 illustrates the gain in efficiency from using CPRIm across a number of CPRI line rates. The standard 10 Gbit/s OTN signal is the OTU2 at a line rate of 10.709 Gbit/s. The corresponding signal for CPRIm based transport is the OTU2r at a rate of 12.63909 Gbit/s. Table 3 illustrates the potential use of an OTN line signal, OTU25G, at a line rate corresponding with the 25GE line rate. This rate is not a standardized OTN rate. However, there is nothing in the definition of OTN that prevents applying all the usual OTN functions at that rate. The tables show how many cases have an efficiency gain of 50% or more by using CPRIm based multiplexing instead of traditional OTN.

Table 2. Number of CPRI Signals per OTN Signal OTU2

CPRI Signal	CPRI Rate (Gbit/s)	Traditional OTN Multiplexing Line Signal OTU2 at 10.709 Gbit/s	CPRIm Based Multiplexing Line Signal OTU2r at 12.639 Gbit/s (1)	CPRIm Gain
CPRI-2	1.22880	8	12	50%
CPRI-3	2.45760	4	6	50%
CPRI-4	3.07200	2	3	50%
CPRI-5	4.91520	2	3	50%
CPRI-6	6.14400	1	2	100%
CPRI-7	9.83040	1	1	0%

Note:

(1) 11.85 Gbit/s without FEC, 12.63909 Gbit/s with FEC.

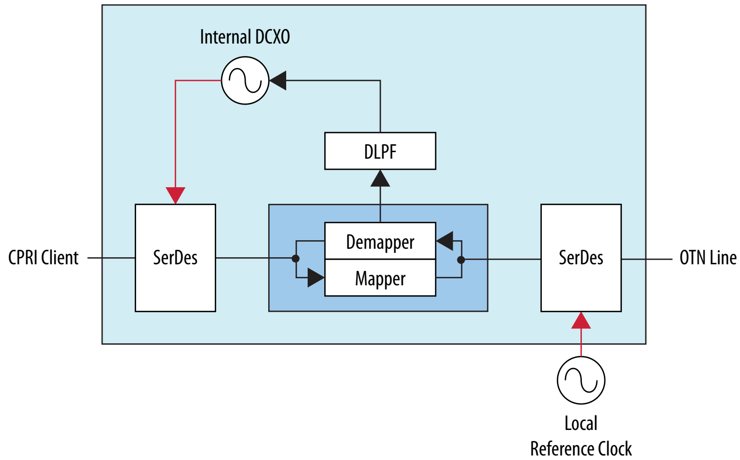
Table 3. Number of CPRI Signals per OTN Signal OTU25G

CPRI Signal	CPRI Rate (Gbit/s)	Traditional OTN Multiplexing Line Signal OTU25G at 25.781 Gbit/s	CPRIm Based Multiplexing Line Signal OTU25G at 25.781 Gbit/s	CPRIm Gain
CPRI-2	1.22880	16	24	50%
CPRI-3	2.45760	8	12	50%
CPRI-4	3.07200	5	9	80%
CPRI-5	4.91520	4	6	50%
CPRI-6	6.14400	3	4	33%
CPRI-7	9.83040	2	3	50%

Traditional CPRI to OTU2 Mapping and Multiplexing

In this scheme, the CPRI client is first transparently bit- and timing-mapped into an ODU container. The container is then asynchronously multiplexed into N timeslots of an ODU2. Timing reconstruction involves extracting the timing information from the GMP justification information.

Figure 2. Traditional Mapping

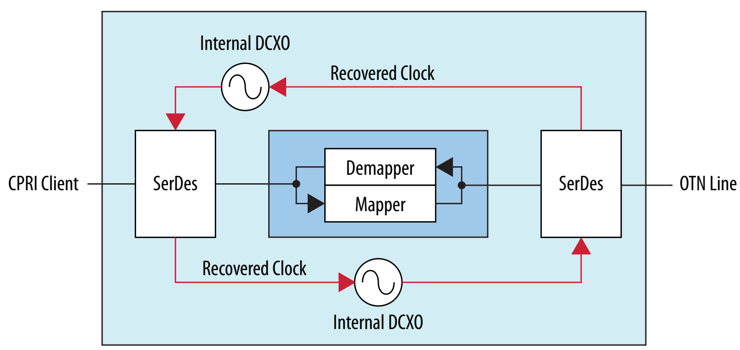


This timing information is low-pass filtered and then used to control the internal Arria 10 device DCXO. It provides the transmit reference clock for the CPRI client SerDes, effectively controlling the CPRI signal rate.

CPRIm Based Mapping and Multiplexing

In this scheme, a fixed set of CPRI clients are multiplexed together synchronously and then synchronously (BMP) mapped as payload in an ODU2r container. Because all signals are synchronous, timing reconstruction involves locking the CPRI client transmit clock to the received OTU2r signal. This method can be performed digitally or with a standard analog PLL. This test used digital reconstruction.

Figure 3. CPRIm Based Mapping



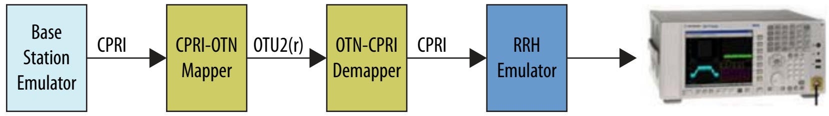
In this case, the transmit reference clocks for both CPRI and OTN signals were derived using the internal DCXO of the Arria 10 device.

Network

To simulate a realistic network, two CPRI-OTN nodes were used. These nodes were connected by OTU2(r) on an optical fiber. Each node had an independent local reference clock.

All reference clocks for the various devices in the system – test sets, signal generators, and the CPRI-OTN nodes—were derived from high-stability OCXO or Rubidium sources. The only exception was the base station emulator. The reference clocks for the various nodes were not phase locked to each other.

Figure 4. Simulated Network

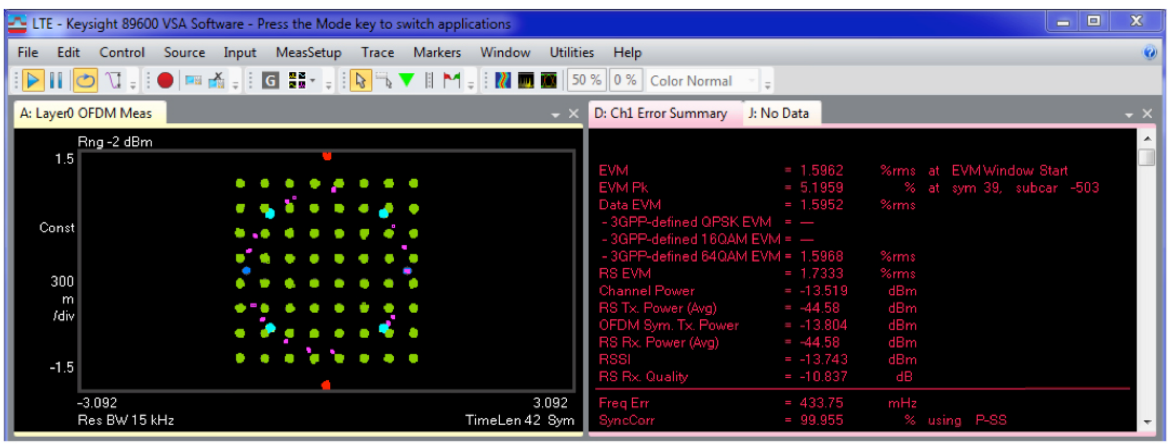


Measurements

RF Measurements

The goal of any CPRI transport system is to ensure that the final resulting radio signal is not compromised by the method used. These measurements are performed by generating a CPRI signal from a BBU emulators, passing it through the test network, and generating an electrical RF signal in a RRH emulator. The resulting signal can be measured using an RF signal analyzer.

Figure 5. RF Signal Analyzer



The two main performance parameters are:

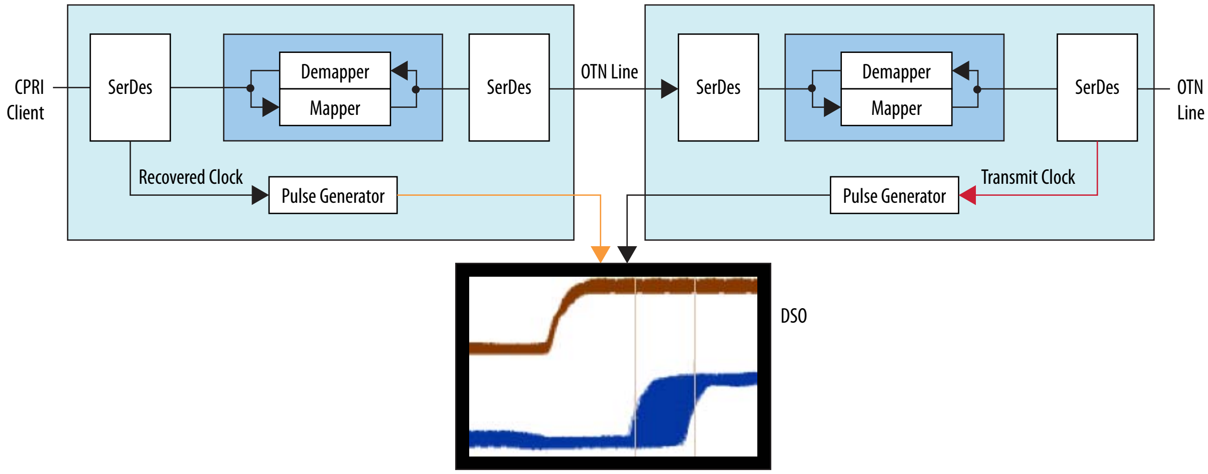
- *EVM%*—Measures the noise added related to how a demodulator is affected.
- *FreqErr*—Carrier frequency deviation. Affected by any very low frequency noise (or wander).

Comparisons can be made against a reference system where the CPRI connection is a direct fiber link.

Latency Variation Measurements

Any low frequency jitter (wander) and long term drift causes variation in the network latency. This variation is measured by taking an input frame pulse signal output from the CPRI signal as it enters the network and an output frame pulse as it leaves the network.

Figure 6. Measuring Variations in Network Latency

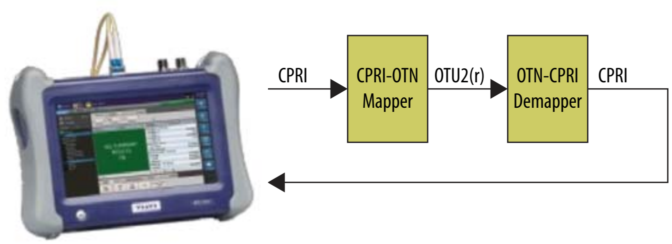


A DSO monitored the maximum variation in the delay between input and output over a given time period (e.g., 12 hours).

Latency Repeatability

A test set that measures the delay in a CPRI signal determines the repeatability of the system latency.

Figure 7. Measuring CPRI Signal Delay



To initiate a complete restart of the system, the optical signals at both the CPRI and OTN sides are interrupted and then traffic is re-established. We then measured the latency. The test process repeated this sequence a number of times and we recorded the worst-case deviation from the average.

Results

RF Measurements

The Keysight 89600 VSA software running on an MXA N9020A analyzer recorded the test measurements. The carrier frequency was 1.97 GHz. In all instances, the values reported are the worst case taken from a sequence of at least 500 samples.

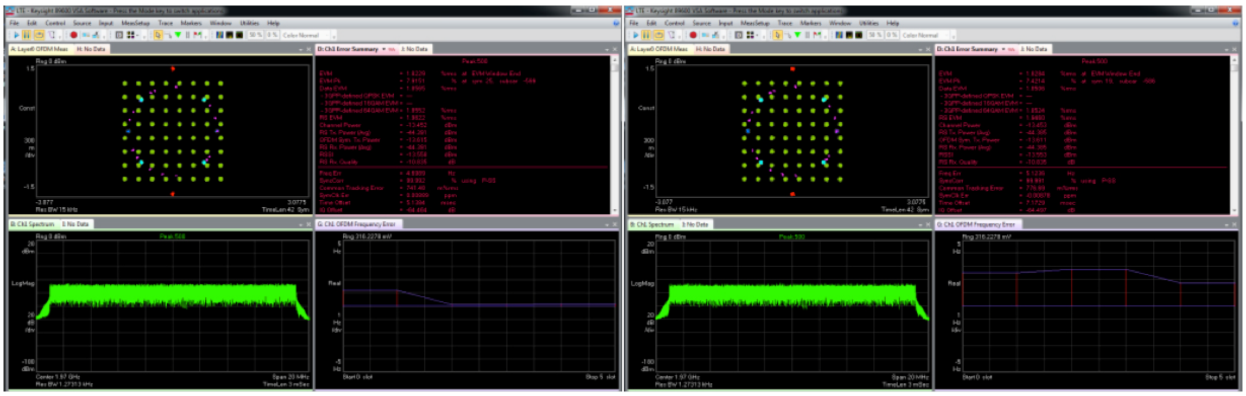
The CPRI test signal was generated and analyzed by means of a BBU emulator board and an RRH emulator board. Both boards were implemented using Altera FPGAs.

Reference measurements were taken using a direct CPRI fiber connection between the BBU and RRH. Then, the fiber was replaced by a connection routing the CPRI via OTN as previously described.

Table 4. RF Measurement Results

	Fiber (Reference)	Traditional OTN Multiplexing	CPRIm Based Multiplexing
EVM (% RMS)	1.83	1.85	1.83
FreqErr (Hz)	3.59	7.1	6.52
FreqErr increase (Hz)	-	3.51	2.93
FreqErr increase (ppb)	-	1.78	1.49

Figure 8. Sample Screenshots of Fiber and OTN(ITU)



Latency

Latency variation testing used a custom latency testing unit with a resolution of 0.4 ns.

Table 5. Latency Results

	Fiber (Reference)	Traditional OTN Multiplexing	CPRIm Based Multiplexing
12 hour latency variation (ns)	0	+/- 2.5	+/- 2.2

Product Implementation

The above sections focus on the signal integrity aspects of CPRI over OTN transmission. For product implementation, the Altera FPGAs offer additional advantages:

- Many devices allow for efficient implementation both of small nodes at the RRH and of centralized, larger nodes.
- Can integrate vendor specific functions along with the CPRI over OTN transmission.
- Can be changed and updated if standards change. For example, if capacity must be upgraded or to adapt to specific end-user needs.

- On a longer time-scale, adaptability to changing standards may include being upgradeable with potential future Radio over Ethernet functions [4] and being able to mix OTN and Ethernet front-haul and back-haul transport.

The Arria 10 and Stratix® 10 families are both applicable for efficient implementation of CPRI transport. Arria 10 devices are available in very small sizes. Therefore, they are good targets for small to medium size products, particularly those products close to the RRH. Stratix 10 devices are available in very large sizes with many transceivers, making it a good target for medium to large products. Additionally, these devices can integrate other functions.

Table 6. Altera Devices for Implementing CPRI Solutions

FPGA Family	Process	Maximum Logic Size	Number of Transceivers for CPRI and OTN Interfaces
Arria 10	20nm	1.15M LE	6 – 96
Stratix 10	14nm	5.5M LE	24 - 144

The following table illustrates some possible products. Naturally there are many other options.

Table 7. Devices Applicable for Various Applications

Application	FPGA family	Scheme	# CPRI	# OTN
RRH site	Arria 10	Traditional	6 x CPRI-5	3 x OTU2
			12 x CPRI-7	6 x OTU25G
BBU site	Stratix 10		48 x CPRI-5	24 x OTU2
			36 x CPRI-7	18 x OTU25G
RRH site	Arria 10	CPRIm	3 x CPRI-5	1 x OTU2r
			18 x CPRI-7	6 x OTU25Gr
BBU site	Stratix 10		54 x CPRI-5	18 x OTU2r
			48 x CPRI-7	16 x OTU25Gr

Conclusion

General-purpose devices for OTN transport cannot properly address all CPRI requirements at the same time, i.e., capacity, efficiency, and high signal integrity. Altera has FPGA silicon and IP that achieves all of these goals.

Our tests have shown how traditional OTN multiplexing and CPRIm based multiplexing can perform equally well in terms of signal integrity. The combination of FPGAs and IP for OTN protocol handling and digital filtration, and the FPGAs' fractional PLL technology provides excellent frequency stability and latency variation results. Frequency degradation can be kept below 2 ppb and latency variation below 2.5 ns for a point-to-point connection.

Inherently, the CPRIm multiplexing scheme provides 50% better networking efficiency than the traditional OTN multiplexing scheme. By combining CPRIm multiplexing and 16 channel CWDM, 48 CPRI-5 signals are taken over a single fiber with a line rate of 12.64 Gbit/s. This number can be doubled by increasing the line rate to 25.7 Gbit/s. This rate is equal to the upcoming 25GE line rate.

Because of the broad range of FPGA sizes available, it is possible to build everything from very small and efficient nodes serving an antenna site with 3 x CPRI-5 signals to large aggregation nodes handling 48 (=16 x 3) CPRI-5 signals or even up to 96 CPRI-5 or 48 CPRI-7 signals with a single FPGA.

It may be complemented with other schemes such as radio over Ethernet later on. An additional benefit of implementations based upon FPGA is that it is possible to design products that can adapt to new features and protocols simply by downloading new IP to existing platforms. CPRI over OTN appears to be the technology of choice for the next coming years.

References

1. Common Public Radio Interface (CPRI); Interface Specification; V7.0 (2015-10-09)
2. G.709/Y.1331 (02/12), Interfaces for the optical transport network
3. G.Sup56 (07/15), OTN Transport of CPRI signals
4. IEEE 1904.3 - Standard for Radio Over Ethernet Encapsulations and Mappings

Document Revision History

Table 8 shows the revision history for this document.

Table 8. Document Revision History

Date	Version	Changes
March 2016	1.0	Initial release.