Meeting Jitter and Latency requirements in Mobile Fronthaul Network with Improved OTN Mapping and Multiplexing Schemes

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Abstract: Deployment of Cloud/Centralized Radio Access Network (C-RAN) architectures for LTE and LTE-A (Advanced) services is gaining momentum and is considered a key in enabling mobile operators to offer higher bandwidth to their customers while slashing the associated cost-per-bit. However, C-RAN has faced a number of challenges. Amongst them, a shortage of fiber optic capacity and a need to meet the stringent jitter and latency requirements of mobile fronthaul (MFH) networks connecting centralized Baseband Unit (BBU) controllers and Remote Radio Heads (RRH). This paper describes an approach and an implementation to address these challenges based on an improved Optical Transport Network (OTN) mapping and multiplexing scheme. IP Light has developed on Xilinx FPGAs a product family of IP cores under the brand name of Orion, demonstrating this novel technology.

1. Introduction

As mobile bandwidth offerings continue to rise, not only do mobile operators need to expand their network capacity but also to preserve profitability. This leads to an effort to reduce operational costs in order to cope with otherwise prohibitive capital expenditure increases. A significant contributor to mobile operators' expenditures is associated with the practice of deploying Base Station Controllers (BSC) adjacent to each antenna mast. In this traditional RAN architecture, the RF signal from each mast mounted antenna is processed by a corresponding radio unit and then is transmitted to a collocated Base-Band Unit (BBU) controller, usually over optical fiber, using a digital protocol called Common Public Radio Interface (CPRI). Typical CPRI signal rates for modern network deployments would range from CPRI Option 3 (2.5Gbps) to CPRI Option 9 (12.2Gbps). However, with the evolution of C-RAN and the deployment of cost effective Remote Radio Head (RRH) units, instead of processing these CPRI signals at an adjacent BSC, the CPRI signals would be transported to centralized sites via an optical mobile fronthaul (MFH) network. This would yield cost reductions through the elimination of countless BSCs, deploying BBU pools at a central location, as well as delivering increased capacity through the expansion of the MFH network.

However, in order to realize the benefits of CRAN, it is necessary for a MFH network to meet the stringent requirements of the associated CPRI signals, which are derived directly from BBU to RRH specifications. The following table illustrates the key requirements for a MFH network.

Table 1. MFH Network Requirements

Requirement	**Description**
Timing Transparency	Preserves end-to-end CPRI signal timing (RRH locked to BBU)
Jitter minimization	2ppb rms frequency offset for jitter/wander frequencies of up to 300Hz
Latency	Round Trip Time (RTT) of less than 5us (excluding fiber latency)
Delay Asymmetry	Uplink delay minus Downlink delay ≤ +/- 16 Nsec
Range	Support ranges of up to 40km*
BER	Ensure a bit-error-rate of less than 10^{-12}
OA&M	Support performance monitoring and fault isolation
Demarcation	Provide a physical boundary between infrastructure providers and mobile operators.
Scalability	Enable CPRI level scalability (i.e. from CPRI-3 to CPRI-9)
Standards based	Ensure multi-vendor interoperability and multi-source

*Range requirements may typically vary between 20km to 40km. A higher range offers higher economies of scale and improved coverage to the mobile operator.

2. Description of improved OTN mapping and multiplexing schemes for MFH network

The improved OTN mapping and multiplexing schemes described hereafter were original works of the authors listed here and have been adapted as a part of ITU-T Recommendation G Suppl. 56 Section 8 (07/2015).

G Suppl.56 section 7 describes methods for mapping CPRI client signals into G.709 payloads using techniques that are currently defined for use with other client signal mappings in G.709 (referred as "G.709 Traditional Mapping" scheme hereafter). For example, CPRI Option 3 signals are mapped into an ODU1 using Generic Mapping Procedure (GMP), while CPRI Options 4 and 5 signals are mapped into an ODUflex using Bit-synchronous Mapping Procedure (BMP) and then into 3 tributary slots (Option 4) or 4 tributary slots (Option 5) of an ODU2 using GMP. The figures below show block diagrams of the mappers and de-mappers implementing this scheme.

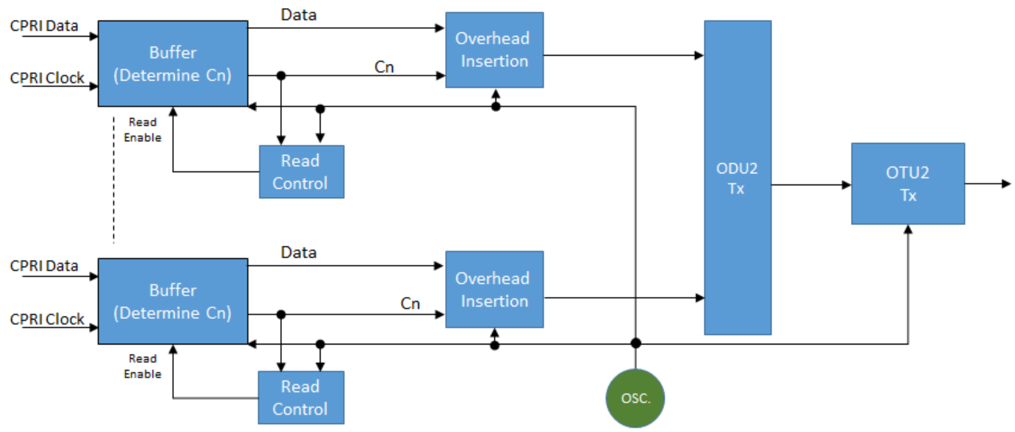

Figure 1: Traditional G.709 mapper; Mapping of CPRI signals to an OTU2 bearer

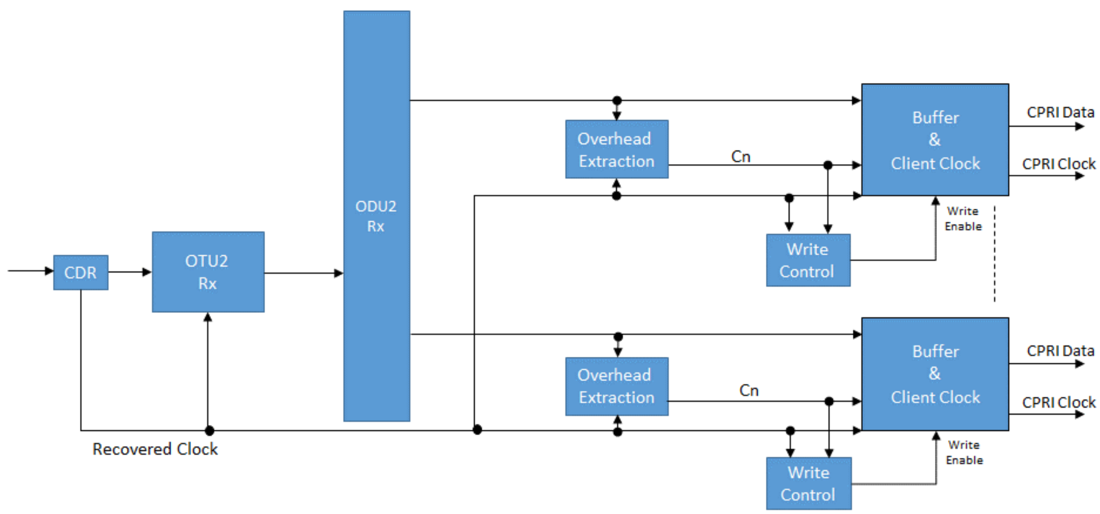

Figure 3: Traditional G.709 de-mapper; De-mapping of CPRI signals from an OTU2 bearer

Simulations have been done in order to analyze the incurred jitter and latency of such a mapping and de-mapping scheme when operating with commonly used jitter filters. The results indicate that, for a CPRI client side de-synchronizer bandwidth in the range of 100-300 Hz, the peak-to-peak jitter ranges from approximately 6.7-14.1 UIpp for the transport of CPRI Option 3 signals, and 0.76-7.2 UIpp for CPRI Option 4 signals. The reason for these large values of jitter is that a GMP mapping mechanism contributes to the accumulation of the frequency offset while in contrast, a BMP mapping does not contribute to the accumulation of the frequency offset since timing is transparently passed from the CPRI domain to the OTU domain.
The resultant associated latency is also relatively large due to the buffering required by the fixed overhead field dedicated to FEC mapping and de-mapping processes. The resultant round trip delay is in the range of 1 OTU2 frame. Furthermore, the number of CPRI Option 5 signals that can be multiplexed to an OTU2 bearer is 2, while typically cellular directional antennae operate in multiples of 3 sectors (i.e. 3 CPRI signals per antenna need to be transported), and therefore this mapping and multiplexing scheme is not optimized capacity wise for an MFH application.

To overcome these problems, G Suppl.56 section 8 describes a method that uses a combination of transcoding and multiplexing/interleaving of multiple CPRI clients into an over-clocked ODU2, called an ODU2r, in order to optimize the transport bandwidth efficiency in some important CPRI applications. It creates 2 new types of OTN signals dedicated to C-RAN applications: OTU2r and ODU2r (OTU2r without FEC appended), operating at rates of 12.6Gbps and 11.8Gbps respectively. OTU2r/ODU2r signals carrying CPRI services avoid in its entirety the classical OTN justification mechanism, reduce CPRI level latency to a bare minimum and provide an effective synchronization scheme optimized for MFH networks. All of this is achieved while preserving the option for future scaling of the CPRI signals bit rates. The figures below, which have been implemented as actual functional blocks in Orion IP cores, show block diagrams of an improved mapper and de-mapper implementing this scheme.

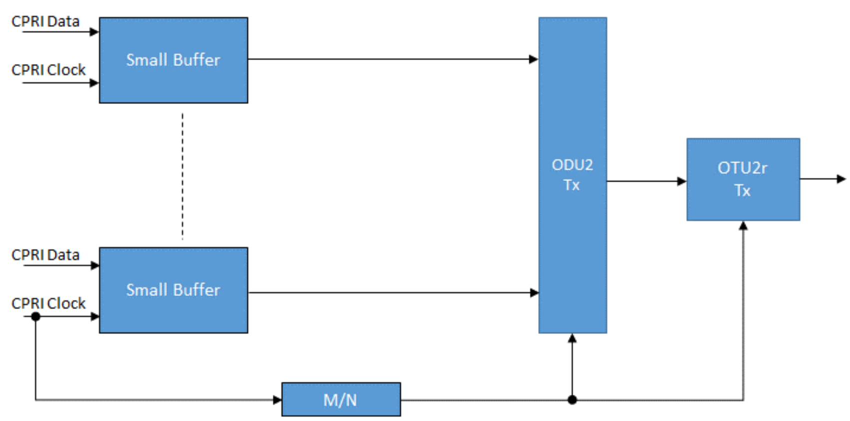

Figure 3: Improved mapper; Mapping of CPRI signals to OTU2r/ODU2r bearers

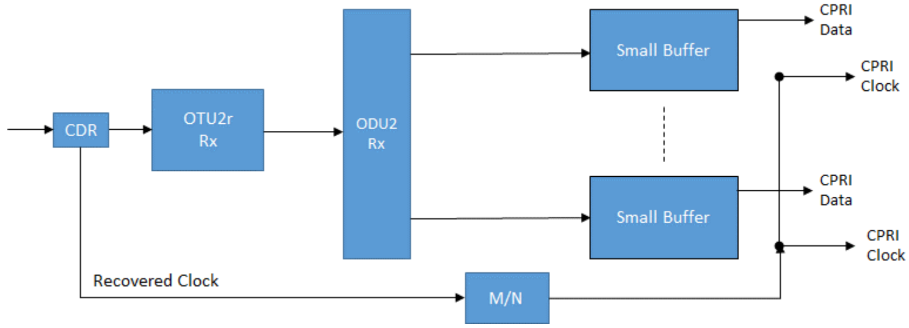

Figure 4: Improved de-mapper; De-mapping of CPRI signals from OTU2r/ODU2r bearers

The accumulated jitter and wander (i.e., rms frequency offset) for the G Suppl.56 section 8 mapping, as verified on Xilinx demonstration boards carrying Orion IP cores is very small since the only source of frequency offset introduced by the OTN transport in this case will be the noise generation of the mapper and de-mapper phase-lock loops (PLLs). The OTN de-synchronizer (ODCp) wander generation is described in A.5.2 of ITU-T G.8251, where it is indicated that the intrinsic wander generation of the ODCp is negligible compared to the wander generated by the de-mapping process (i.e., by the justifications). In conclusion, and as demonstrated by IP Light and Xilinx on actual Orion demonstration boards, it is possible to meet the 2 ppb rms frequency offset requirement for the case of the transport of CPRI options 3, 4, or 5 signals while using this mapping scheme.

Latency is also very low, since relatively very small buffers are required only in order to overcome the waiting time during OTN overheads. The round trip delay (Round Trip Time, RTT), as measured on Orion demonstration boards, is of less than 1.0 µsec. Furthermore, by removing the CPRI line coding before mapping it into ODU2r containers, the number of CPRI Option 4 or 5 signals that can be carried by an OTU2 is increased to 3, which matches the typical number of sectors deployed by mobile carriers per each cellular operating frequency.

3. Optical transport technology alternatives for MFH networks

The main technologies being considered for MFH networks are either based on pure optical domain technologies such as dedicated fiber connections or Wavelength Division Multiplexing (WDM) or a combination of optical technologies and digital processing with electronics. The following drawing illustrates two typical alternatives, while the ensuing table provides a more comprehensive review of the various MFH technological transport alternatives and their key advantages vs. disadvantages.

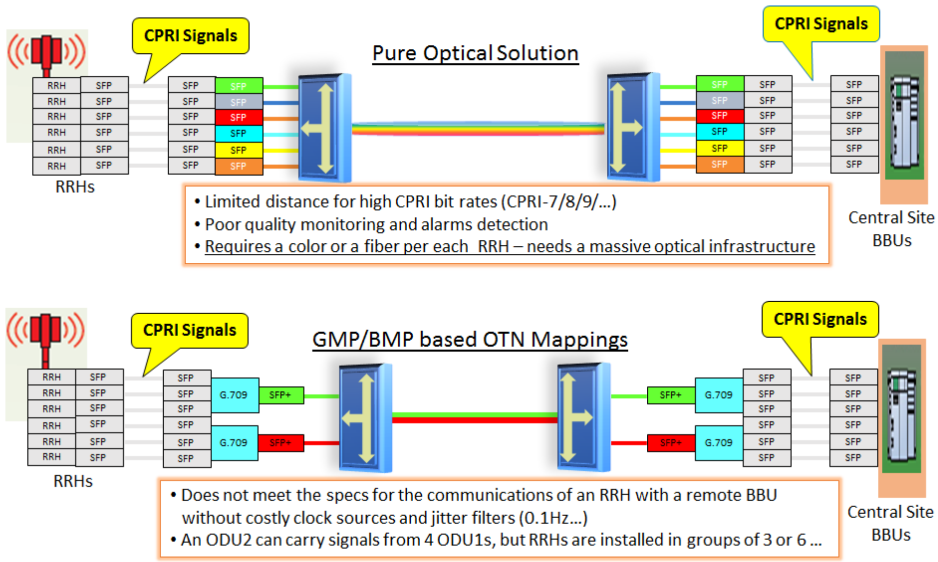

Figure 5: Optical transport technologies for Mobile Fronthaul networks

	Optical Solutions			G Suppl. 56 Sec 7		Ethernet (2019 Target)	G Suppl.56 Sec 8
	Passive	Semi passive	Digital Wrapper	Transparent	GFP-T		
Distance from BBU to RRH	Limited for high bit rates		Up to 40 Km	Up to 35 Km		10 Km (Not less than)	Up to 40 Km
Jitter/Wander: Less than 2ppb	√			Up to 317 ppb rms	√	Could be met. (Under study)	√
Round Trip Time (5µSec)	√			26 µSec	7µSec	Could be met. (Under study)	√ (Less than 1.0 µSec)
Delay Accuracy (+/-8.138 ns)	√			High Variation		Could be met. (Under study)	√
Real-Time OA&M	No	Out of Band	√	√ (OTN)		√	√ (OTN)
Optical Infrastructure	A color per each CPRI signal (Requires a massive optical infrastructure)			Multiplexing (CPRI-3: saves 4X CPRI-5: saves 2X)		Multiplexing	Multiplexing (CPRI-3: saves 6X CPRI-5: saves 3X)
				ODUx	GFP-T to ODU2		
Standardization	√	No	No	√	√	In process	√

Table 2. Advantages and Disadvantages of optical transport technologies for a Mobile Fronthaul network

As summarized in Table 2 above, the enhanced mapping and multiplexing scheme specified in G Series Suppl.56 section 8 meets CPRI specifications. It offers improved jitter performance, minimal end-to-end latency, meets latency asymmetry requirements, offers OTN real-time monitoring of the CPRI signals and provides a path forward for scalability and for a longer range optical transmission with an optional Forward Error Correction (FEC) capability. These performance parameters have been successfully tested on Xilinx FPGAs incorporating IP Light's Orion IP cores.

In addition, G Series Suppl. 56 Sec. 8 specifications can be adapted to support also OBSAI and Ethernet signals.

3. Summary

The transport of CPRI signals over mobile fronthaul networks, a new fiber optic infrastructure, poses technical challenges not adequately addressed by the traditional G.709 OTN mapping and multiplexing schemes. The improved schemes described herein have been verified to meet the stringent CPRI jitter and latency requirements while enabling an efficient, scalable and standards based deployment of a mobile fronthaul network. The verification has been jointly carried out by IP Light Ltd. and Xilinx Inc. with a field proven implementation done on Xilinx FPGA demonstration boards incorporating Orion IP cores.
For additional information please browse to www.iplight.com.

4. References

[1] ITU-T G Suppl. 56, OTN transport of CPRI signals, July 2015.

[2] Geoffrey M. Garner, Frequency Synchronization Considerations for the Transport of CPRI Signals over OTN using the CPRIm Mapping, February 25, 2015.

[2] ITU-T G.709/Y.1331: Proposed appendix – Mapping of multiple CPRI signals over OPU2r, ITU-T SG 15, Q11, Geneva, 24 November – 5 December 2014, TD 289 (WP 3/15).

[3] Leon Bruckman, Jean-Michel Caia, and Frank Melinn, Efficient mapping of CPRI signals over OTN draft text, IP Light Ltd., Inphi Corporation, and Xilinx Inc. contribution to ITU-T SG 15, Q13, Geneva, November 2014, COM 15 – C 824 – E.

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[5] Geoffrey M. Garner and Wei Jianying, Additional Simulation Results for Peak-to-Peak Phase and RMS Frequency Offset for Transport of a CPRI Client over OTN, Huawei contribution to ITU-T SG 15, Q13, Geneva, May 2010, COM 15 – C 967 – E.

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[7] ITU-T G.8251, The control of jitter and wander within the optical transport network (OTN), ITU-T, Geneva, September 2010, Amendment 1, April 2011, Amendment 2, February 2012, Corrigendum 1, February 2012, Amendment 3, October 2012.

[8] CPRI PICS V1.0, Protocol Implementation Conformance Statement (PICS); Interface Conformance Specification, April 1, 2014, available at http://www.cpri.info/spec.html.