White Paper

Anritsu envision : ensure

Improving Wireless Network Flexibility Using CPRI Technology

Introduction

The architecture of today's cell sites has evolved considerably since the early days of wireless networks.

Traditional cell sites consisted of a ground-based radio connected to tower-mounted antennas by a long run of coaxial cable which has high loss and is vulnerable to interference. This has negative impacts on maintenance costs as equipment ages and also on system performance.

To answer the need for more throughput at lower cost, wireless network providers have moved to using a remote radio head (RRH) where the radio equipment is connected to the baseband unit (BBU) by a fiber optic cable. This provides a new level of flexibility in how the cell site is deployed, including siting the RRH at the masthead (for low RF losses) or locating the BBU at a remote location (for improved operational efficiencies).

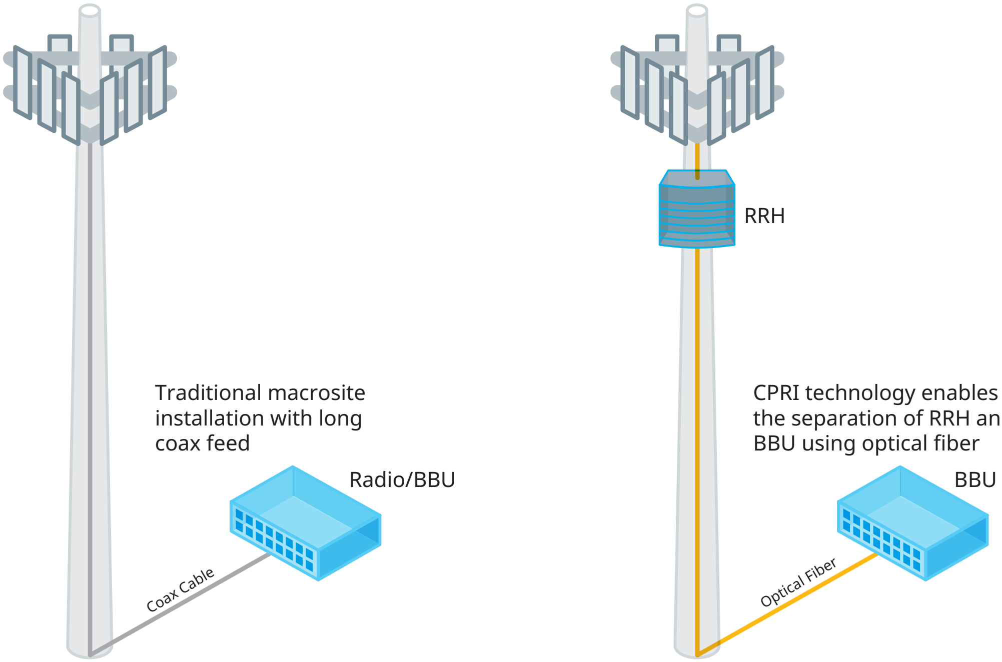


Figure 1. Evolution of Cell Sites

With this new flexible architecture came the necessity for an equally flexible interface between the BBU and RRH. Many high speed serial communication standards were available, but without modification none offered the high throughput, low latency and features required to support these cell site architectures. Therefore new interface standards were developed to support them.

The two interfaces that lead this charge are the Open Base Station Architecture Initiative (OBSAI) and Common Public Radio Interface (CPRI). OBSAI is the more complex of the two to implement and CPRI technology is now used in the majority of new installations. CPRI pushes the complexity into the higher layers of the system so a connection between the BBU and the RRH can be established with minimal configuration. CPRI has become the more common standard, allowing manufacturers to tailor the interface to their own requirements. Also, the high throughput potential of later CPRI releases enables providers to futureproof their rollouts.

While the RRH based configuration has alleviated common problems with the traditional cell site, it creates a new requirement for test and measurement of these sites. The final interface exists at radio frequencies (RF), but testing at RF requires a tower climb. However, it is possible to perform a wide range of performance tests on the site without a tower climb by analyzing the data on the CPRI link instead.

CPRI has support for many different topologies. For star configurations, a single BBU serves multiple RRHs and potentially multiple towers. This allows the operation of all the RRHs to be observed from that one BBU site. For chain and ring topologies, the operation of all the RRHs can be observed from a single CPRI link.

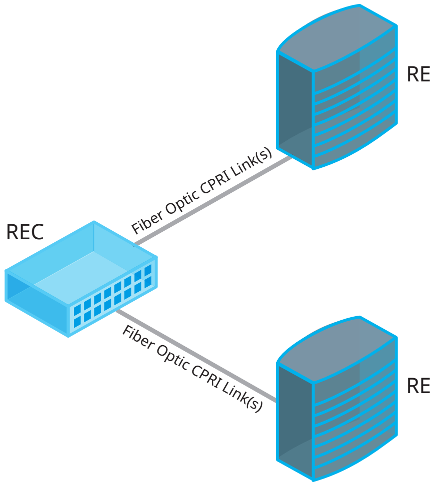


Figure 2. Star Topology

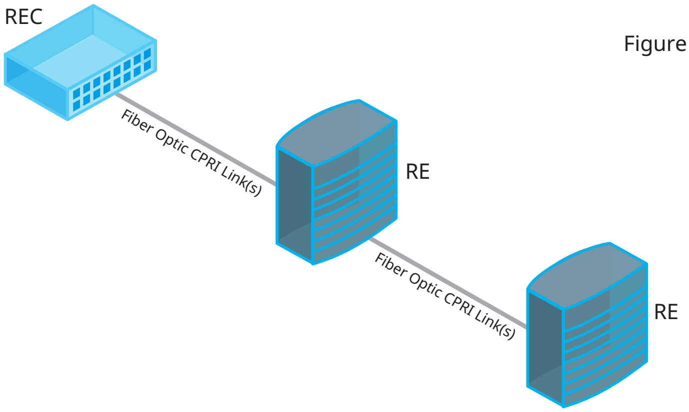


Figure 3. Chain Topology

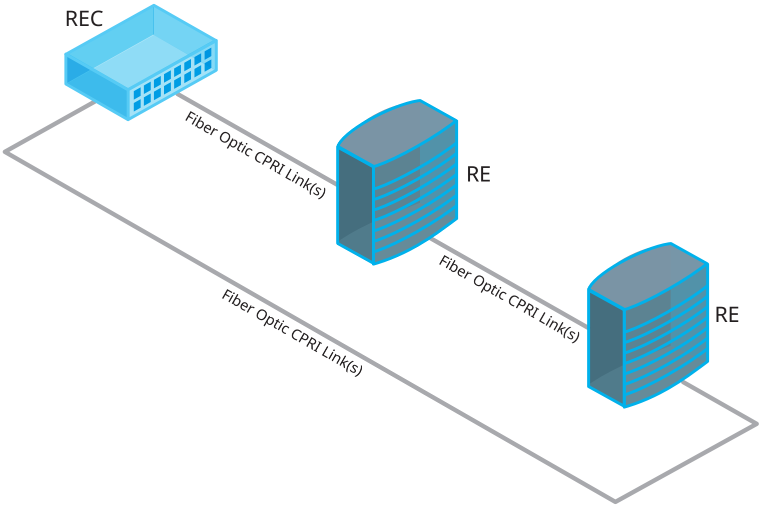


Figure 4. Ring Topology

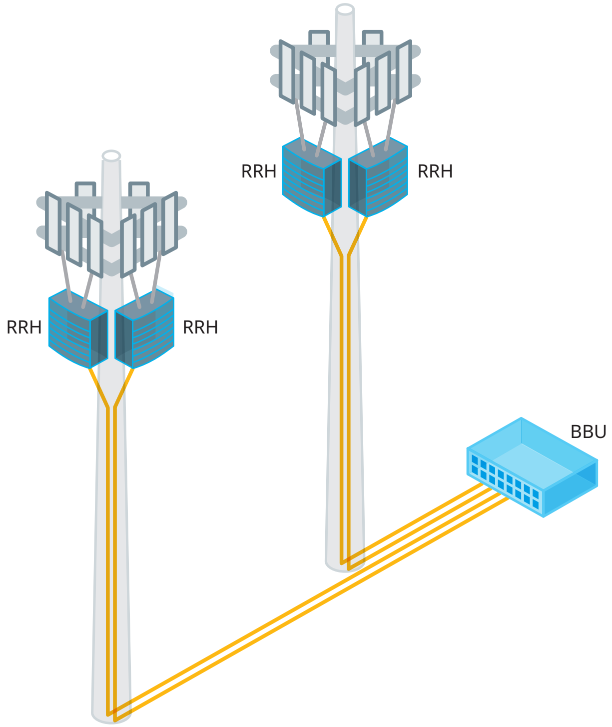


Figure 5. Star Cell Site

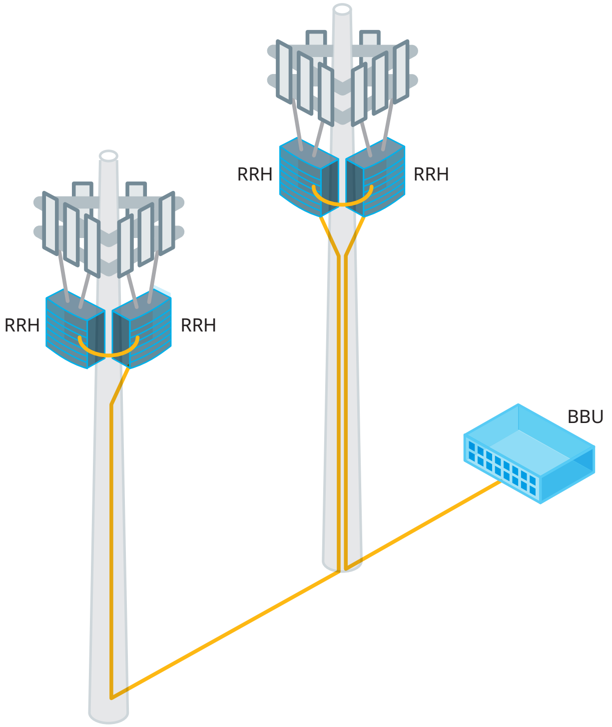


Figure 6. Chain Cell Site

The move to RRH based cell sites has delivered flexibility, performance improvements and cost savings. However the increased number and density of wireless networks combined with increasing congestion of spectrum has greatly increased the vulnerability of such networks to RF interference and Passive Intermodulation (PIM). Being able to perform RF measurements through the CPRI link provides a powerful tool for hunting down interference and PIM without tower climbs and even without visiting the cell site where the BBU is sited remotely.

Overview of the CPRI Protocol Setup

A CPRI link consists of at least one radio equipment controller (REC) node and one radio equipment (RE) node. In a cell site, the BBU acts as the REC and the RRH is an RE.

There are two main information flows:

1. Digitized downlink (DL) and uplink (UL) RF signals known as “antenna carriers”, which constitute the main CPRI payload. These are represented as streams of in-phase and quadrature (IQ) signal samples on the CPRI link. The primary task of the RRH is to convert these digital antenna carriers to and from the RF air interface.
2. Control and Management (C&M) flows. These are used to configure, control and monitor the RRHs and associated equipment. The CPRI specification concerns itself only with transport aspects for C&M, messaging protocols and syntax are vendor-specific,

All information flows are multiplexed onto a digital serial communication line using appropriate layer 1 and layer 2 protocols. Layer 1 handles the physical connection between the REC and RE. Once the link is established at layer 1, the different information flows then have access to layer 2 via appropriate service access points (SAP). These include the control and management (C&M), synchronization, and in-phase and quadrature data (IQ) SAPs.

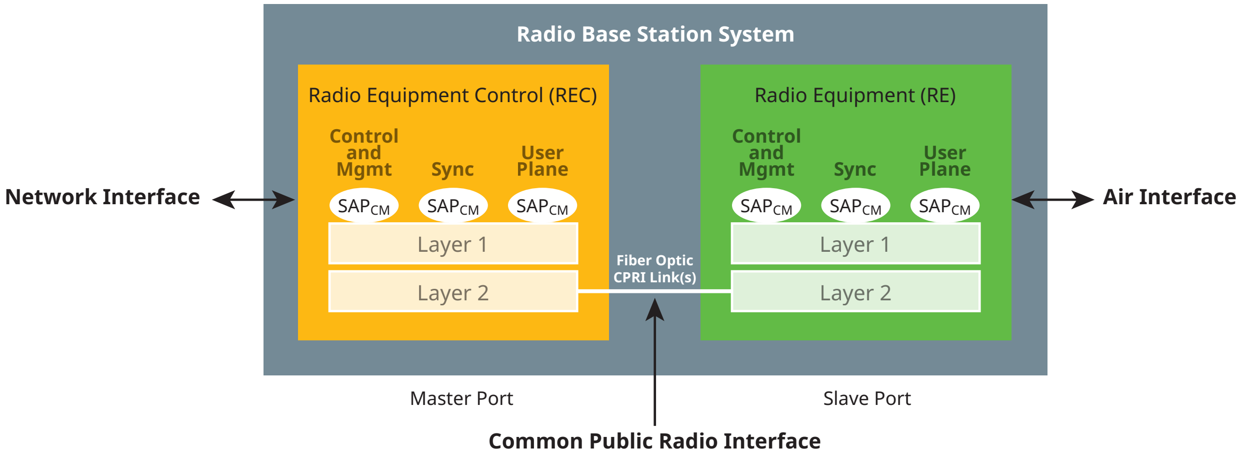


Figure 7. System Architecture

Layer 1

CPRI uses a digital serial communication link that can run at eight different line rates over an optical or electrical connection.

The type of connection is controlled by the type of small form-factor pluggable (SFP) transceiver that is used. CPRI has support for SFP, SFP+, and QSFP, allowing transceivers from standards such as Gigabit Ethernet to be used.

The first seven line rates (614.4 mbps through 9830.4 mbps) use 8B/10B encoding, which is a line code that maps 8-bit symbols to 10-bit symbols to achieve DC-balance and bounded disparity, and yet provide enough state changes to allow reasonable clock recovery. 8B/10B encoding also provides a way of gauging the quality of the link by detecting errors in the disparity calculations and illegal line codes.

Rate 8 (10137.6 mbps) in contrast uses 64B/66B encoding, which has less encoding overhead. In many cases, the same transceivers and optical fibers used for 9830.4M bps can be used for 10137.6 mbps CPRI, which results in a 25% higher throughput for the same equipment.

CPRI Line Rate Option	Line Rate (Mbps)	Word Width
1	614.4	8
2	1228.8	16
3	2457.6	32
4	3072.0	40
5	4915.2	64
6	6144.0	80
7	9830.4	128
8	10137.6	160

Table 1. CPRI Line Rates

The serial data is broken down into structured frames. The main CPRI frame is 10ms long and it consists of 150 smaller frames called hyperframes. Those are divided into 256 basic frames. The basic frame rate (chip rate) is 3.84 MHz (period of 260.416667ns) and consists of 16 words where the width of the word increases with line rate. So for example, figure 8 shows the basic frame for 614.4 mbps with 8 bits per word, whilst figure 9 shows how this expands for higher bit rates by increasing the number of bits per word. The first word of each basic frame is assigned as the control word. Each of the 256 control words in a hyperframe has a specific use and contains C&M, synchronization, and link maintenance information. That pattern repeats every hyperframe.

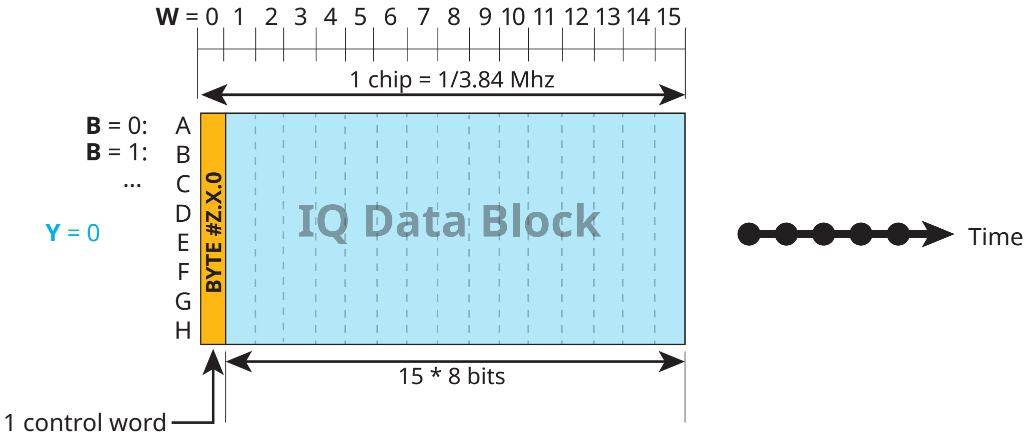


Figure 8. Basic Frame Structure for 614.4Mbps Line Rate

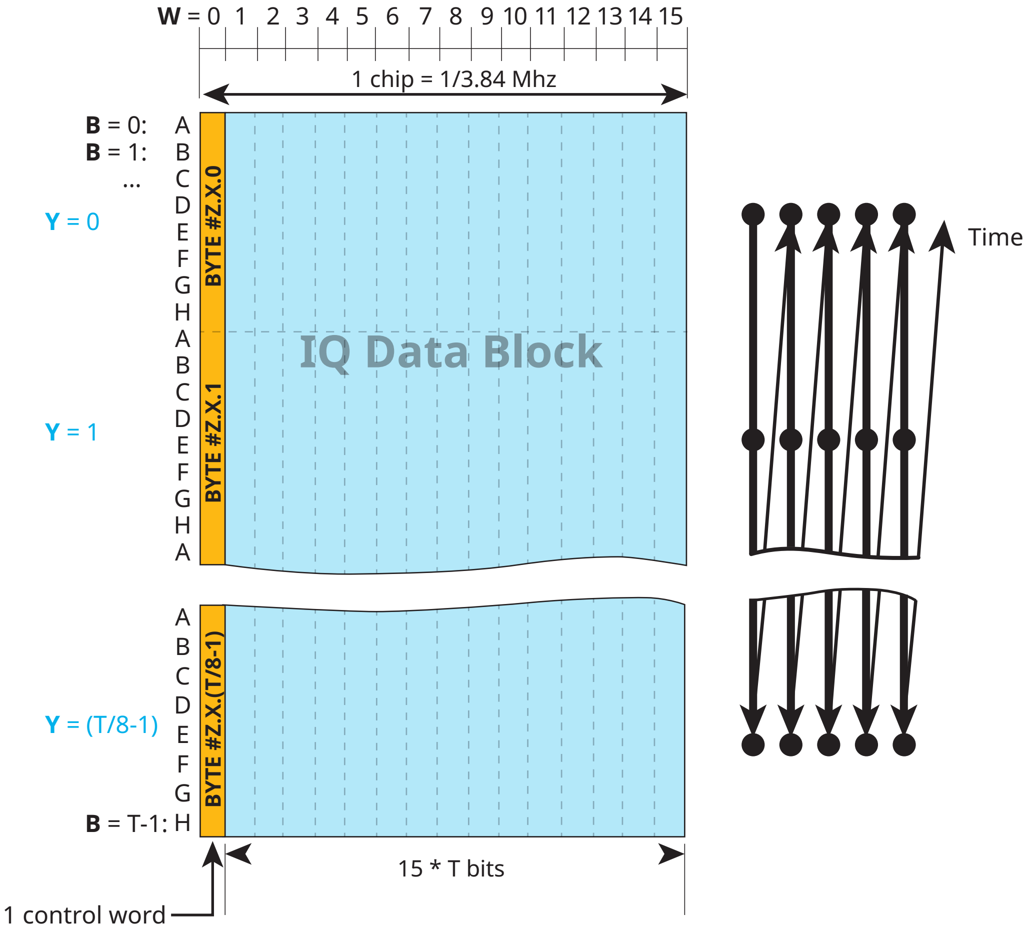


Figure 9. Generic Basic Frame Structure

There are four major alarms that are generated and are used to control the state of the layer 1 link negotiation:

1. Loss of signal (LOS) indicates an issue with the physical link. It is raised if there is low signal power indicated by the SFP or too many 8B/10B or 64B/66B encoding errors.
2. Loss of frame (LOF) is asserted if the node has lost hyperframe alignment, which is required if control words can be properly decoded.
3. The remote alarm indication (RAI) is asserted in either the LOS or LOF cases.
4. The SAP defect indication (SDI) is used to indicate an error with one of the SAP information flows where they should be ignored. The criteria for indicating a defect are defined by the vendor.

The layer 1 alarms map to specific bits in a control word and are used to communicate near end link status to the far end.

Layer 2

All of the user information flows are combined together in layer 2 of the protocol.

Once layer 1 synchronization has been achieved the protocol version and C&M rates are negotiated. If both the REC and RE support protocol version 2 and the line rate is above 4915.2 mbps, then scrambling can be enabled. Scrambling ensures a more random signal that increases the performance of the link at higher line rates.

With the protocol version negotiated the layer 2 C&M startup state is entered. There are two C&M channels supported: the slow channel using HDLC and the fast channel using Ethernet. Both have flexible throughputs that are selected as part of the layer 2 setup.

The last section of the control words that can be used directly by the user is the vendor specific subchannel (VSS). Sixteen control words are reserved for the VSS for additional messaging that is predetermined by the manufacturer. If the full throughput of the fast C&M channel is not utilized, then they can be allocated for additional VSS space. The VSS is the last portion of link negotiation before it is considered operational.

Control & Management

The slow C&M channel uses the HDLC standard, which is a low rate serial connection. The bit rate is selectable between 240kbps and 7.68 mbps.

The Ethernet or fast C&M channel in CPRI can populate up to 68% of the control words. The throughput can be controlled by changing the Ethernet pointer, which selects the number of control words to be populated with Ethernet data. Setting the pointer to zero disables the channel. The valid pointer range of 20 to 63 configures the bit rate between 384 kbps and 270.336 mbps depending on the line rate.

The CPRI specification recommends using either the HDLC or Ethernet C&M channels. If neither is used, the link will not enter the operational state. Instead, the CPRI is considered passive. The VSS is then the only subchannel where control messages can be sent.

Synchronization Plane

Most air interface standards have guidelines for time alignment. Whether the interface uses FDD or TDD, the system needs to be synchronized. The CPRI specification includes the necessary measurements and delay compensation to meet these requirements.

The 10 ms CPRI frame is sent from the REC aligned with the airframe, which in most cases is the 1 pps GPS tick. CPRI requires both the REC and RE to provide their internal delay values so that the delay over the fiber can be compensated. Any processing delays in the RE are provided to the REC so that alignment of the IQ data at the airframe can be done within the required specification for that air standard. In chain or ring topologies, the process is repeated for each hop.

CPRI IQ Bit Mapping

A CPRI link transports digitized RF signals (antenna-carriers) in a complex baseband format. Each sample has an in-phase (I) and quadrature (Q) component. The CPRI specification was specifically created to handle the signal data in this format. The I and Q samples are interleaved together to create a single word. Those words are put together in a pattern to satisfy the target sampling rate and bit width of the signal.

CPRI allows different bit widths to be used depending on the requirements of the air interface and whether the signal is in the uplink or downlink. In the downlink, the number of bits can range from 8 to 20. To allow for higher sampling rates in the uplink, it can use between 4 and 20 bits. Also, smaller width IQ samples can be sign- extended or padded with reserve bits to fill the space of larger bit widths. This is useful if the IQ sample processing in the downlink and uplink have different widths, but the user prefers to have the same size for both when mapping the samples onto the CPRI link.

When dividing spectrum, RF carriers are given a specific frequency band in which to operate. Similarly, on the CPRI link, a carrier is given a specific block in each basic frame, called an antenna container or AxC, to populate with its IQ sample data. The size of the antenna container (NAxC) is based on the bit width and sample rate of the IQ data. The size and structure of the AxCs is defined by the mapping method.

Mapping Methods

The CPRI specification outlines three different methods to map IQ samples into the user plane: (1) IQ sample based, (2) WiMAX symbol based, and (3) Backward compatible. Methods 1 and 3 are the most widely used for RRH based cell sites. The purpose of the different methods is to allow various combinations of IQ sample rates and bit widths from different RRHs to be multiplexed into a single link.

The basic frame rate of CPRI is 3.84 MHz. For air standards that are integer multiples of that 3.84 MHz rate (LTE and UMTS), the mappings are simple. In the case of WiMAX and GSM, stuffing bits are used for alignment of the sample frequencies to the basic frame frequency. The equations for determining the number of stuffing bits/samples and their placement are defined in [1]. The scope of this document will mostly cover the common LTE and UMTS mappings. But the difference between the mapping methods is most clearly seen if there are stuffing bits.

Mapping method 1 is intended for dense packing of IQ data and is optimized for low latency. One AxC container can contain more than one IQ sample and the container size required NAxC is set by the equation:

$$\mathrm{N}_{\mathrm{AxC}} = 2 \cdot ceil\left(\frac{M \cdot f_s}{f_c}\right) \text{ bits}$$

where M is the number of bits per I or Q sample, f_s is the sample frequency, and f_c is the basic frame rate of 3.84 MHz.

If any stuffing bits are required for rate matching, they are sent as a single block first, followed by the IQ sample data. In the case of UMTS and LTE (except for 1.4 MHz channel bandwidth), there are no stuffing bits so each basic frame has a block of $\mathrm{N}_{\mathrm{AxC}}$ samples reserved for each carrier. For 1.4 MHz LTE, every other basic frame contains sample data.

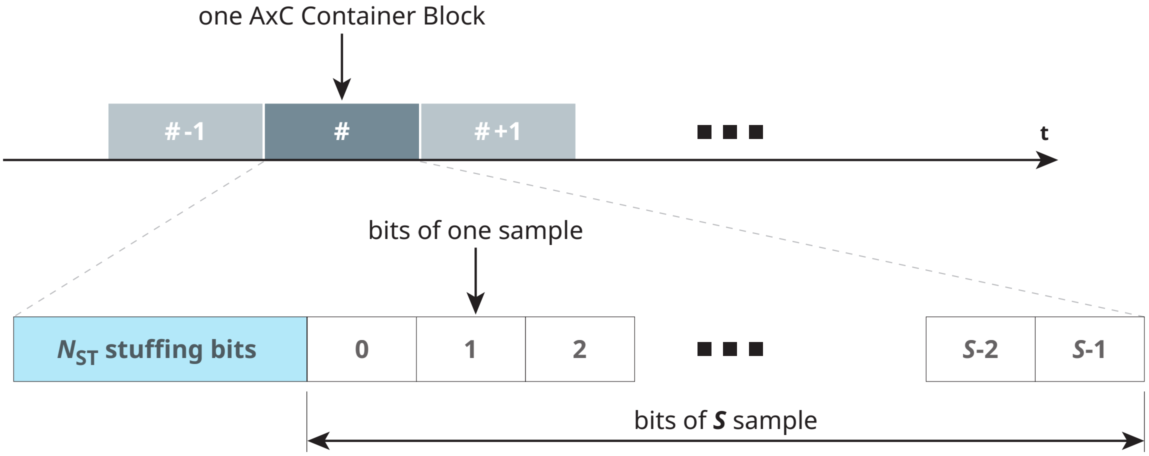


Figure 10. Mapping Method 1 Diagram

Mapping method 3 (backward compatible) uses the definition from previous releases of the CPRI specification where one AxC Container always contains one sample, so NAxC is 2·M where M is the number of bits per I or Q sample. Each antenna container is repeated within the basic frame to achieve the target sample rate. The containers for one carrier can be sent as a single block, or if more than one carrier is used it is possible for the containers to be interleaved.

In the case of WiMAX, GSM and LTE1.4 where the sampling rate is not a multiple of the basic frame rate, stuffing bits are needed. Instead of having one block of stuffing bits like in mapping method 1, stuffing samples of length NAxC are placed throughout the carrier's IQ sample stream to achieve the desired sample rate.

Common Uses

Since both LTE (above 1.4 MHz) and UMTS do not require any stuffing bits, there are only two scenarios regardless of the mapping method: each carrier uses a single block of IQ samples with no space in between, or the IQ samples for the carriers are interleaved together. Therefore, when configuring the user plane for LTE or UMTS, one needs to know the bit width, the channel bandwidth, if IQ sample interleaving is used, the starting antenna container position for each carrier, and any reserve bits that can be ignored.

Carrier	Sampling Frequency (f_s)	Samples Per Basic Frame
UMTS Downlink	3.84 MHz	1
UMTS Uplink	7.68 MHz	2
LTE 3 MHz	3.84 MHz	1
LTE 5 MHz	7.68 MHz	2
LTE 10 MHz	15.36 MHz	4
LTE 15 MHz	23.04 MHz	6
LTE 20 MHz	30.72 MHz	8

Table 2. LTE and UMTS Sample Parameters

The payload portion of a basic frame that contains the IQ data consists of 15 words. Note that in most cases both the number of LTE/UMTS samples per frame and the CPRI basic frame width are powers of two. This means that using 15-bit IQ data usually makes the most efficient use of the space in the payload. Most equipment vendors take advantage of this and use 15-bit IQ data. If smaller bit widths are used, usually reserve bits are included to match the space taken by 15-bit IQ data.

Line Rate (Mbps)	Number of 15-Bit IQ Samples
614.4	4
1228.8	8
2457.6	16
3072.0	20
4915.2	32
6144.0	40
9830.4	64
10137.6	80

Table 3. Number of 15-Bit IQ Samples

Examples

Figure 11 shows two LTE20 carriers with 15-bit IQ samples mapped onto a Rate 3 (2457.6 mbps, 32 bit words) basic frame with no interleaving. For this scheme mapping methods 1 and 3 are in fact identical in their result.

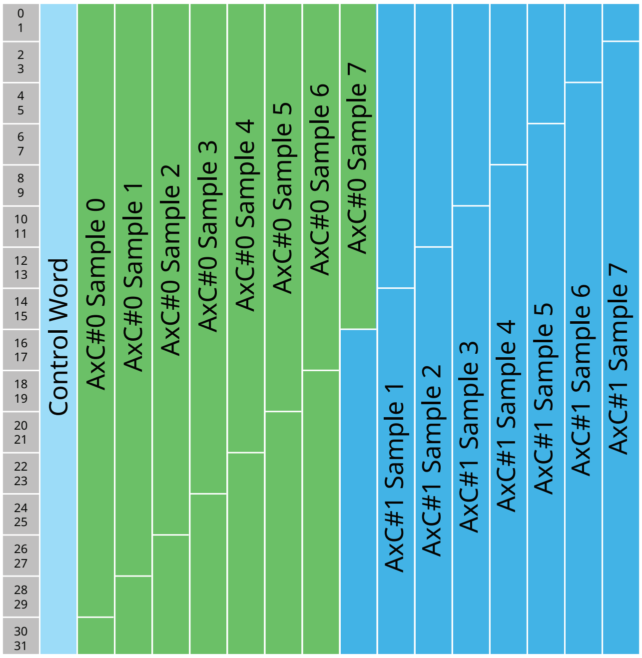


Figure 11. 20 MHz LTE, 2 Carriers, 15 Bit Data, Mapping Method 1 or Mapping Method 3 with No Interleaving

Figure 12 shows the same configuration with samples interleaved according to Method 3. Again, the two LTE20 15 bit antenna carriers exactly fit the 15 word x 32 bit capacity of the Rate 3 basic frame but the ordering of the samples is different.

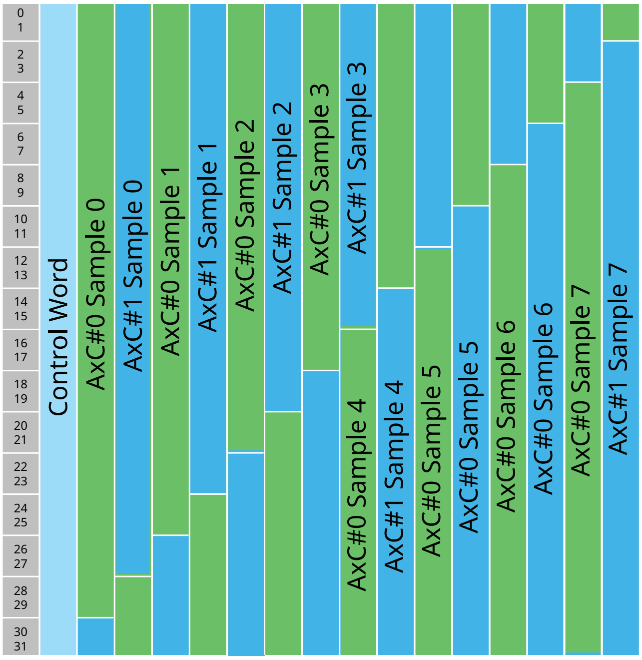


Figure 12. 20 MHz LTE, 2 Carriers, 15 Bit Data, Mapping Method 3 with Interleaving

Figure 13 shows a different example. This is also a Rate 3 (2457.6 mbps link) but with 2 off LTE10 antenna carriers mapped onto it using mapping Method 1. Another difference is that in this case the data is only 12 bits but there are 6 reserved bits configured so the position of the samples within the frame is identical to if it were 15 bit data.

At 4 samples per basic frame each LTE10 gets 15.36 Msps throughput, which is exactly the required number. In this case we can also see that the frame has spare capacity for two further LTE10 antenna carriers of the same format.

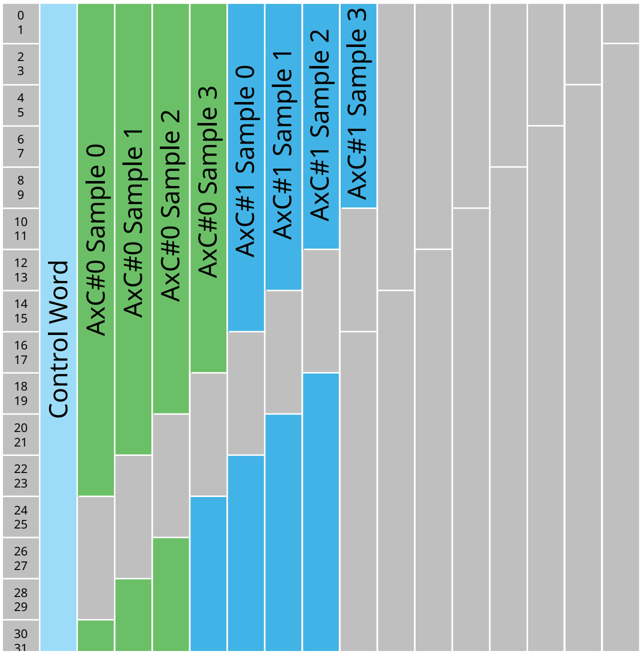


Figure 13. 10 MHz LTE, 2 Carriers, 12-Bit IQ data, 6 Reserved Bits

Analyzing Uplink RF Interference over CPRI

Once the IQ data is extracted from the link, signal and interference analysis can be performed using the digital data as one would do with RF data. Modulation testing can be performed in the downlink direction to verify correct BBU operation, CPRI levels and compliance of the digital signal with the RRH capability.

CPRI based RF testing is especially powerful in the uplink. Since user equipment (UE) has much lower transmit power compared to an RRH, interference has the biggest system impact in the uplink, figure 16 shows actual Spectrum of the Uplink via the CPRI link. The uplink is also susceptible to interference from passive intermodulation (PIM), figure 18 shows an actual PIM problem captured over CPRI. PIM detection and distance to PIM source can all be readily analyzed in the digital domain using CPRI IQ data. It is even possible under many circumstances to cancel PIM on the uplink using digital techniques.

Interference hunting using CPRI has also been aided by the installation of optical taps at cell sites. An optical tap couples a percentage of the optical signal so an external device can monitor both the uplink and downlink CPRI link with no disruption of the link itself. RF interference can then be analyzed on a live system without locking or disabling the network. In chain or ring configurations, multiple RRHs can be investigated simultaneously. PIM detection can be performed by connecting one fiber containing the affected uplink data and another to potential PIM sources.

Combined with fewer tower climbs, reduced maintenance time, and lower operating expenses, uplink testing over CPRI becomes an even more powerful tool.

Anritsu MT8220T BTS Master CPRI RF measurement option

The Anritsu BTS Master has an option to enable CPRI RF measurements to be made at ground level. Specifically, the uplink LTE spectrum can be viewed in real-time on a live network to monitor for interferers. This provides a powerful test capability without the need to call a tower climbing crew. Many common causes of poor KPI indicators can be diagnosed, especially those resulting from accidental or illegal transmitters interfering with the uplink.

Figure 14. Cellular tower showing typical Remote Radio Head installation behind antennas at the tower top

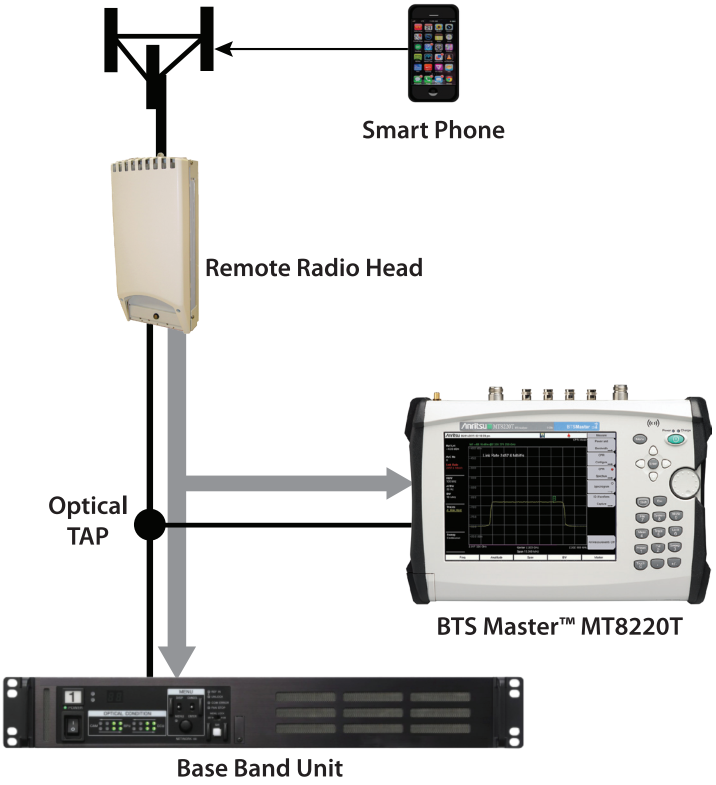
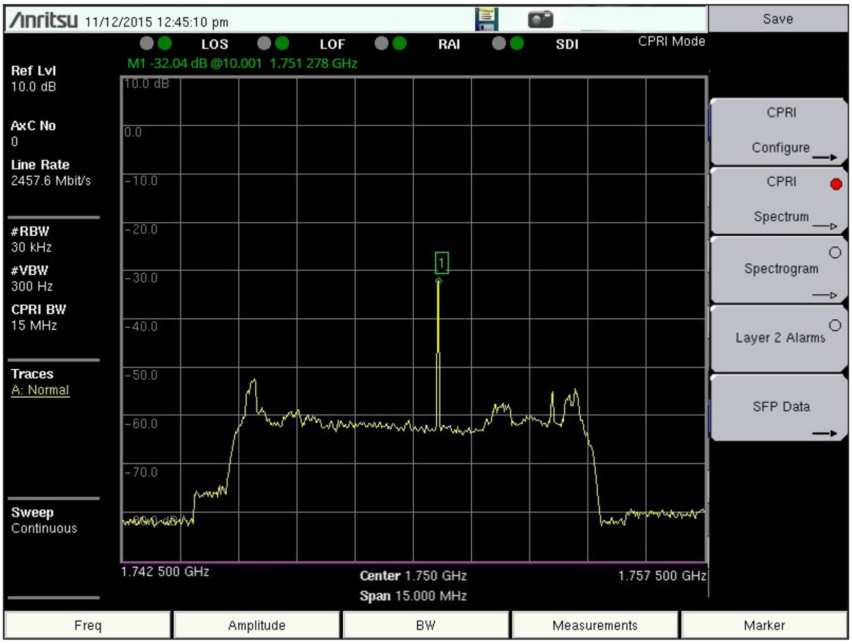


Figure 15. Typical test configuration for uplink monitoring

The uplink spectrum is displayed and in this case, a CW interferer is clearly visible.


Anritsu 11/12/2015 12:45:10 pm

CPRI Mode

M1 -32.04 dB @10.001 1.751 278 GHz

Ref Lvl
10.0 dB

AxC No
0

Line Rate
2457.6 Mbit/s

#RBW
30 kHz

#VBW
300 Hz

CPRI BW
15 MHz

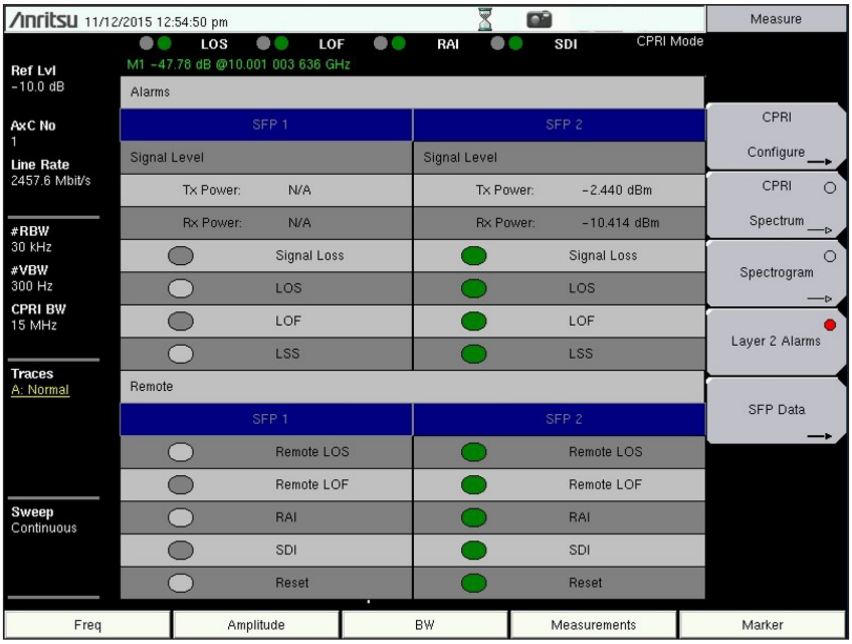
Traces
A: Normal

Sweep
Continuous

Center 1.750 GHz
Span 15.000 MHz

Figure 16. CPRI LTE uplink spectrum with CW interferer

The BTS Master is also able to display the Layer 2 alarms. This is a diagnostic aide used to confirm the existence of a CPRI link to the passive link status when no spectrum is displayed.



11/12/2015 12:54:50 pm

LOS LOF RAI SDI

CPRI Mode

M1 -47.78 dB @10.001 003 636 GHz

Ref Lvl
-10.0 dB

AxC No
1

Line Rate
2457.6 Mbit/s

#RBW
30 kHz

#VBW
300 Hz

CPRI BW
15 MHz

Traces
A: Normal

Sweep
Continuous

Alarms

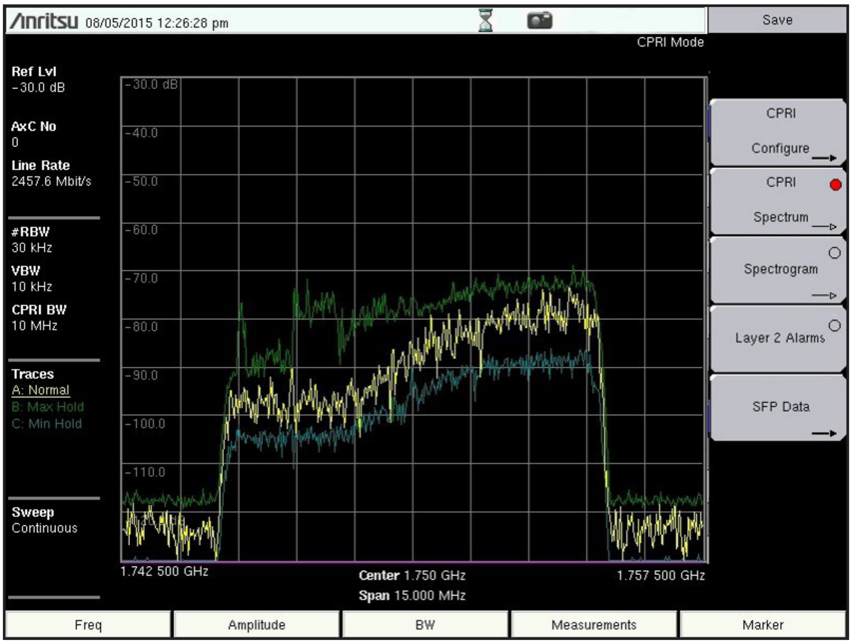
SFP 1		SFP 2	
Signal Level		Signal Level	
Tx Power:	N/A	Tx Power:	-2.440 dBm
Rx Power:	N/A	Rx Power:	-10.414 dBm
○	Signal Loss	●	Signal Loss
○	LOS	●	LOS
○	LOF	●	LOF
○	LSS	●	LSS

Remote

SFP 1		SFP 2	
○	Remote LOS	●	Remote LOS
○	Remote LOF	●	Remote LOF
○	RAI	●	RAI
○	SDI	●	SDI
○	Reset	●	Reset

Figure 17. Display for Layer 2 alarm status

PIM in LTE systems appears as wideband noise in the uplink band. A sloping increase in noise across the uplink band is a strong indication of PIM. The noise level increases as you get closer to the LTE downlink frequency that is generating the PIM. PIM can be caused by connectors, antennas or even external sources which can act as a diode beyond the antenna. Full PIM analysis requires a PIM analyzer such as Anritsu PIM Master.



08/05/2015 12:26:28 pm

CPRI Mode

Ref Lvl
-30.0 dB

AxC No
0

Line Rate
2457.6 Mbit/s

#RBW
30 kHz

VBW
10 kHz

CPRI BW
10 MHz

Traces
A: Normal
B: Max Hold
C: Min Hold

Sweep
Continuous

Figure 18: Typical spectrum of an uplink with PIM.

References

[1] CPRI Interface Specification V6.1 (2014-07-01), Common Public Radio Interface (CPRI).

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