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LINK RATE AUTO NEGOTIATION BETWEEN ECPRI IWFS IN 5G/ LTE-A FRONTHAUL/XHAUL PACKET NETWORK

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ABSTRACT

The enhanced Common Public Radio Interface (eCPRI) specification presents a probabilistic method for link rate negotiation in an eCPRI and Common Public Radio Interface (CPRI) interworking scenario which gets further complicated and more time consuming due to presence of two interim CPRI links and one fronthaul network path, generally resulting in multiple iterations of CPRI negotiations in the interim links. To address these types of challenges techniques are presented herein that support, among other things, bringing the eCPRI link rate negotiation on par with the rate negotiation which is employed in a direct point-to-point connected CPRI link so that, among other things, the multiple iterations may be reduced or eliminated. That is, a Radio Equipment Controller (REC) and the Radio Equipment (RE) start the link rate negotiation at the same time or the REC's transmit (Tx) cycle and RE's receive (Rx) cycles are phase aligned and start at the same time (similar to the direct point-to-point CPRI link).

DETAILED DESCRIPTION

The enhanced Common Public Radio Interface (eCPRI) is a successor to the Common Public Radio Interface (CPRI) protocol connecting a Radio Equipment Controller (REC) and the Radio Equipment (RE). In comparison to CPRI, eCPRI makes it possible to decrease the data rate demands between an eCPRI Radio Equipment Controller (eREC) and the eCPRI Radio Equipment (eRE) through a packet-based fronthaul/converged wireless/optical (often referred to as 'XHaul') transport network that leverages, for example, the Internet Protocol (IP) suite or Ethernet. During the migration towards a Third Generation Partnership Project (3GPP) Fifth Generation (5G) environment, it is important and necessary to enable re-use of the existing CPRI-based radio access network (RAN) equipment during the migration from point-to-point CPRI connectivity to an Ethernet-based fronthaul network. The eCPRI Interworking Function (IWF) Type 1 and IWF Type 2 functional configuration enables the needed interworking between CPRI and eCPRI to achieve the above.

Figure 1, below, illustrates the interworking view to enable end-to-end CPRI communication between the CPRI end points REC and RE through an eCPRI-based fronthaul transport.

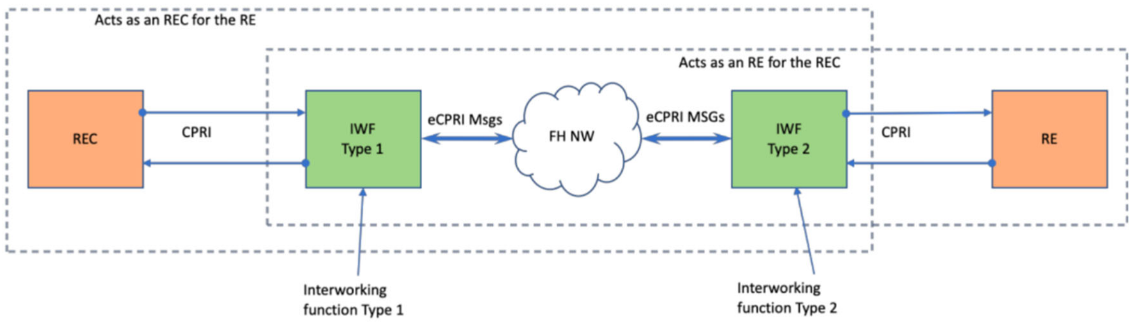

Figure 1: Illustrative eCPRI and CPRI Interworking View

As depicted in Figure 1, above, the IWF nodes have two separate types of ports – a CPRI port towards the CPRI end point and an eCPRI port towards the fronthaul network. The standard CPRI protocol is used for communication with the CPRI end points towards a REC and a RE. eCPRI messages are used to carry the CPRI traffic (e.g., quadrature (IQ) data, control information, synchronization data, etc.) across the Ethernet-based fronthaul network.

An important element in the above model is direct point-to-point CPRI link rate negotiation. In current deployments of a REC and a RE, the CPRI model is used as a directly-connected bi-directional point-to-point topology over fiber. The master port (REC) drives the link establishment with the slave port (RE). The link automatic negotiation, Layer 1 (L1) synchronization, and frame synchronization all happen together directly between the REC and the RE. The procedure that is presented below is used to arrive at a common matching link bit rate as described in the CPRI specification.

A master port may complete the following actions:

1. The master port starts to transmit CPRI traffic at the highest available line bit rate directly and also starts to attempt receiving CPRI traffic at the same line bit rate. If the frame alignment is not reached with slave port, the master port selects another line bit rate for transmission after time t (e.g., 0.9 to 1.1 seconds) if available.
2. At each following t interval, a new line bit rate is chosen for transmission and reception (if available).
3. The line bit rates are selected from the available set in a round robin fashion. That is, first the highest, then the second highest, on down to the slowest, and then restarting from the highest line bit rate.

A slave port may complete the following actions:

1. The slave port starts attempting to receive CPRI traffic at the highest available line bit rate directly. If the frame alignment is not reached with the master port, the slave port selects another line bit rate for CPRI reception after time t (e.g., 3.9 to 4.1 seconds) if available.
2. At each following t interval, a new reception line bit rate is chosen for reception (if available).
3. The line bit rates are selected from the available set in a round robin fashion. That is, first the highest, then the second highest, on down to the slowest, and then restarting from the highest line bit rate.
4. When the slave port reaches Hyper Frame Number (HFN) synchronization (i.e., consecutive successful detection of a synchronization (SYNC) byte in the received stream) it starts transmitting CPRI traffic at the same line bit rate. When the master port is able to receive and decode the slave port transmitted stream (since the master port is also tuned at the same rate) the link negotiation is considered complete as both nodes are now able to communicate with each other.

Note that HFN SYNC is considered to be achieved when the receiver node is able to properly decode the start of a frame marker at a correct position continuously (as described by the procedure in the CPRI specification V7 (CPRIv7)) in the received stream, which means that it has achieved the byte and frame alignment with the transmitting node. All of the master port and slave port steps that were described above are repeated until a common match is achieved.

For purposes of illustration, Figure 2, below, depicts aspects of an example where a master port is capable of {9.8, 4.9, 2.5 and 1.2} gigabits per second (Gbps) CPRI line rates and a slave port is capable of {2.5 and 1.2} Gbps CPRI line rates. In the instant example the following activities take place:

1. A master port changes bitrate every second.
2. A slave port changes bitrate every four seconds.
3. Both ports continue until a matching bit rate is found and HFN SYNC is achieved.

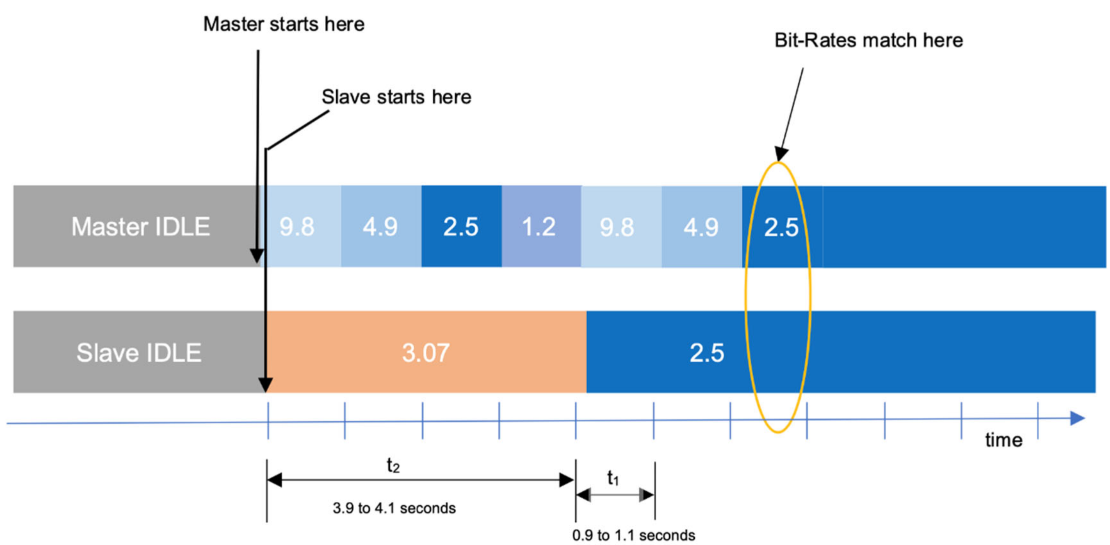

Figure 2: CPRI Link Bit Rate Negotiation

Important features of the end-to-end link negotiation that was described above include:

1. The HFN SYNC shall be achieved directly between a REC and a RE.
2. The current 'direct point-to-point' CPRI negotiation is a probabilistic method as the slave and master attempt different link rates at the same time. Rates are changed at both ends after different intervals – the master changes the link rate

for transmission every 0.9 to 1.1 seconds and the slave changes the link rate for reception every 3.9 to 4.1 seconds. Using this method, both ports tend to arrive at a common match. If the match does not happen in one iteration of 3.9 to 4.1 seconds, the procedure is repeated again.

As background to the eCPRI and CPRI interworking link rate negotiation process, Figure 3, which will be presented and discussed below, depicts the eCPRI and CPRI interworking view where there are two intermediate nodes between the two CPRI end points (i.e., a REC and a RE) that do not interact directly. Rather, they interact through the eCPRI IWF nodes.

First, it will be helpful to clarify certain eCPRI nomenclature. Figure 3, below, depicts more clearly the CPRI end point ports on the IWF nodes. In particular:

1. IWF Type 1 node's port communicating with the REC port is a slave port (S) as it acts as a proxy for the real CPRI slave node RE. In the narrative that follows it shall be referred to as an IWF-S node.
2. IWF Type 2 node's port communicating with the RE port is master port (M) as it acts as a proxy for the real CPRI master node REC. In the narrative that follows it shall be referred to as an IWF-M node.
3. The REC side CPRI port is a real CPRI master node. In the narrative that follows it will be referred to as a REC.
4. The RE side CPRI port is a real CPRI slave node. In the narrative that follows it will be referred to as a RE.

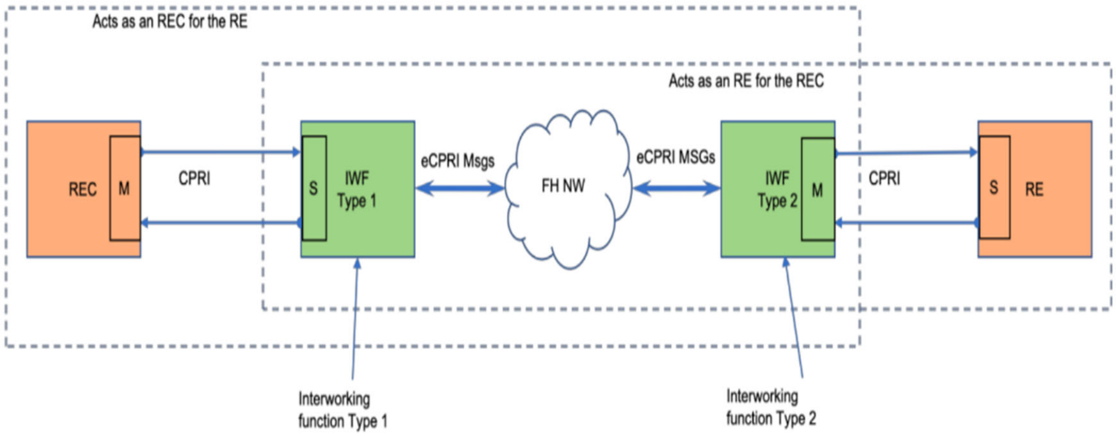

Figure 3: eCPRI Nomenclature

The eCPRI specification V2.0 (eCPRIv2) defines a method to achieve a common link rate between the REC and RE through the eCPRI based fronthaul network. Figure 4, below, illustrates aspects of that negotiation procedure.

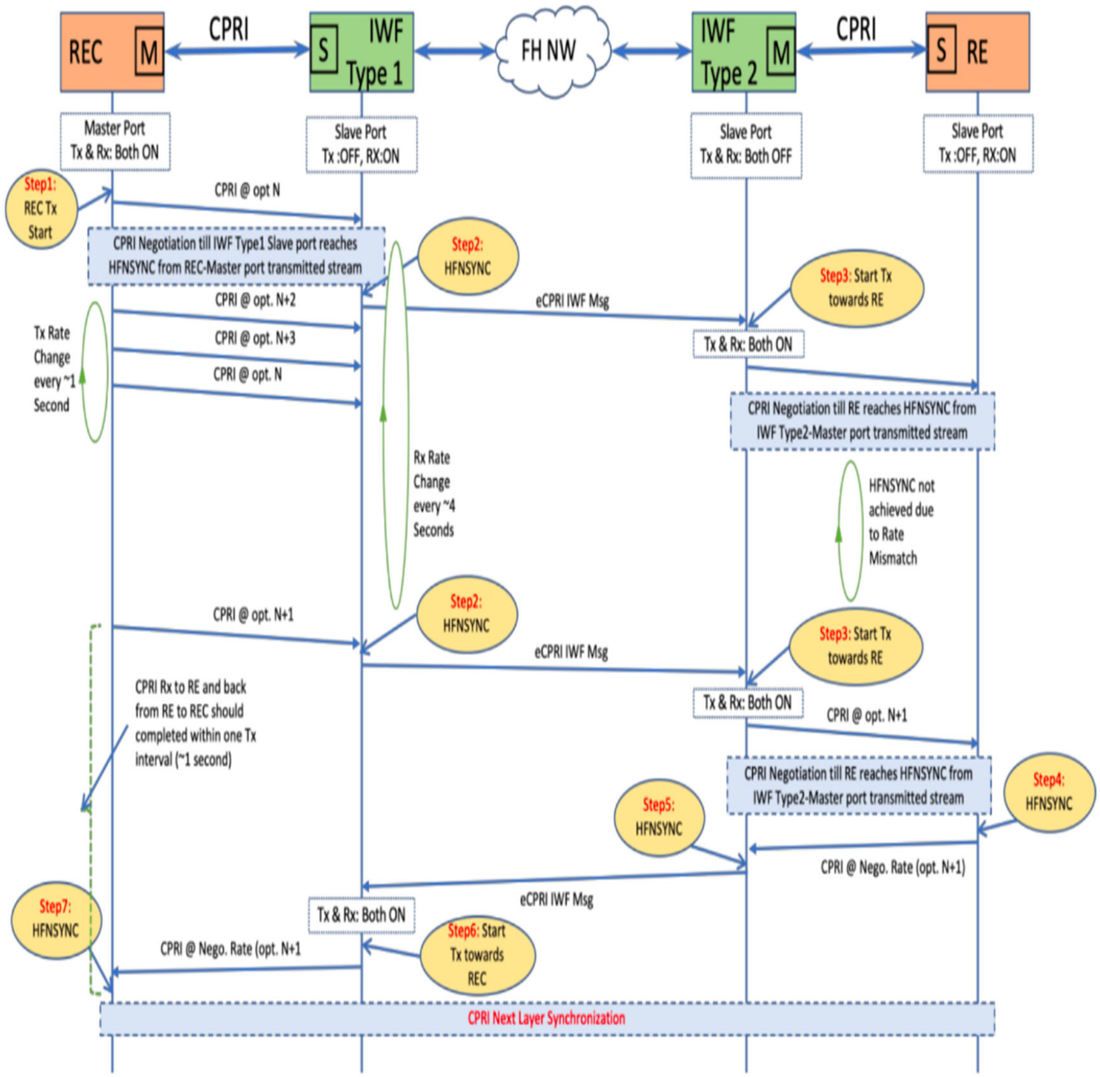

Figure 4: Link Bit Rate Negotiation Procedure According to eCPRI Specification

The end-to-end link rate negotiation process spans multiple stages which, as will be described below, may be repeated. The negotiation process stages include:

1. An IWF-S attempts to decode the CPRI transmission that is received from a REC. The standard CPRI link rate negotiation process that was described in connection with Figure 2, above, is followed as per the CPRIv7 specification. It continues until the IWF-S port reaches HFN SYNC from the REC-Master port transmitted stream.

2. After the IWF-S port achieves HFN SYNC it starts forwarding the received CPRI basic frames, by means of eCPRI messages, to the remote IWF (i.e., IWF Type 2).
3. The IWF Type 2, upon receipt of an eCPRI start-up message from the remote end (i.e., IWF Type 1), starts transmitting CPRI traffic, at the line bit rate of the received eCPRI start-up message, to the RE. It also starts attempting to receive CPRI traffic at the same line bit rate.
4. At this stage, when the RE also starts receiving the traffic on the line from IWF-M it starts attempting to decode the received traffic according to its configured rate. It will attempt to do so for 3.9 to 4.1 seconds (i.e., a t interval) before moving to the second rate, in a round robin fashion, until it achieves HFN SYNC. On achieving HFN SYNC the RE starts transmitting back at the same rate in the direction towards the REC.
5. The IWF Type 2 node's master port (i.e., IWF-M) is already using the same link bit rate for receiving from the RE. So, when the IWF-M also receives this RE transmitted stream and achieves HFN SYNC with the same, the link negotiation is considered complete between the IWF-M and the RE as both nodes are now able to communicate with each other. At this stage, the IWF Type 2 node starts forwarding the received CPRI basic frames by means of eCPRI messages to the remote IWF (i.e., IWF Type 1).
6. The IWF Type 1 node, upon receipt of an eCPRI start-up message from the remote end (i.e., IWF Type 2), enables transmission towards the REC and starts transmitting CPRI traffic at the line bit rate of the received eCPRI start-up message to the REC.
7. At this stage, if the REC is still operating at the same rate (that was used in the above stages 1 to 6) it shall also try to decode the receiving CPRI stream and once it achieves HFN SYNC with the received stream it will stop changing its transmit rates (which is done at every t interval of 0.9 to 1.1 seconds) and continue with the CPRI higher layer negotiations with the RE.

   a. Note that the IWF nodes do not have any active role in the CPRI higher layer negotiations. They just enable the end-to-end communication transparently having achieved a common link rate on all four nodes.

8. As described in stage 4, above, if the RE is at a different rate than the one transmitted by the IWF-M (hence indirectly by the REC) a common rate may not be achieved in the same t time window which will mean that the REC will move to the next configured rate after the expiration of the t time window and the entire sequence will be repeated.
9. Similar to Stage 7, above, if the REC has moved to a new rate or if it is not able to achieve HFN SYNC with the received stream before the t time window expires, it would move to a new rate and the entire sequence will be repeated.

The above process sequence makes it very clear that the link rate communication in an eCPRI and CPRI interworking deployment is also probabilistic and can require multiple iterations of the above sequence.

An eCPRI/CPRI interworking architecture has two interim CPRI links or paths – a first one between a REC and the IWF-S port and a second one between the IWF-M and a RE port. The end-to-end CPRI link is a cross product of the protocol procedures of these two CPRI links along with the packet-based transport between the IWF Type 1 and Type 2 nodes. These two separate intermediate CPRI links often result in multiple repeat iterations (as described in stages 8 and 9 in the above procedure) of the CPRI link negotiations between the two CPRI paths until both the IWF-S and the RE are aligned to the same rate which will enable an end-to-end match concluding the overall link rate negotiation. As a result, the overall link rate negotiations either consume too much time or under some circumstances do not yield a converging procedure for some CPRI rate configuration combinations on these nodes.

To address the various challenges that were described above, techniques are presented herein that support, among other things, bringing the eCPRI/CPRI link rate negotiation to par with the direct point-to-point CPRI link between the REC and the RE according to the CPRIv7 specification so that the multiple iterations can be reduced or eliminated (i.e., to achieve link rate negotiation between the REC and RE in an eCPRI and CPRI interworking on par with the point-to-point CPRI link).

It is important to note that in practical deployments:

1. The CPRI link rates that are usable at the RE must be supported on the fronthaul transport (i.e., the IWF Type 1 and Type 2 nodes). That is, the RE's CPRI link rates will be a subset of the rates that are supported on the IWF-S and IWF-M ports.
2. The REC has the ability to use a link rate based on the RAN configuration for the link rate negotiation. Additionally, the REC can decide to reconfigure the link rate (e.g., a better rate) based on RAN dynamics such as, for example, a reconfiguration on the spectrum or carrier bandwidth supported for the radio site, link quality experience, etc.

Considering the above, aspects of the techniques presented herein may be explicated with the help of an illustrative example which highlights the challenges and the problems with the link bit rate negotiation procedure as specified in the eCPRIv2 specification. In the example:

1. The rates R1, R3, and R4 (in descending order) are configured on a REC.
2. The rates R2, R3, and R4 are configured on a RE.
3. IWF-S and IWF-M are configured with the rates R2, R3, and R4. The IWF-S shall drive the IWF-M for the rate selection hence the IWF-M does not introduce extra combinations in the overall negotiation procedure.

Figure 5, below, depicts aspects of the illustrative example, where one set of iterations of trying all four of the rates by the REC is referred to as one meta-cycle of CPRI transmission.

Rates	(R1,R3,R4).	(R2,R3,R4)	(R2,R3,R4)	(R2,R3,R4)	
	REC	**IWF-S**	**IWF-M**	**RE**	**Match**
	Tx: ON	Tx:OFF	Tx:OFF	Tx:OFF	
	Rx: ON	Rx:ON	Rx:OFF	Rx:OFF	
Meta Cycle 1					
t0	R1	R2	R2	-	X
t1	R3	R2	R2	-	X
t2	R4	R2	R2	-	X
t3	R1	R2	R2	-	X
Meta Cycle 2					
t0	R3	R3	R3	R2 *(Rx Turned ON)*	X
t1	R4	R3	R3	R2	X
t2	R1	R3	R3	R2	X
t3	R3	R3	R3	R2	X
Meta Cycle 3					
t0	R4	R4	R4	R3	X
t1	R1	R4	R4	R3	X
t2	R3	R4	R4	R3	X
t3	R4	R4	R4	R3	X
Meta Cycle 4					
t0	R1	R2	R2	R4	X
t1	R3	R2	R2	R4	X
t2	R4	R2	R2	R4	X
t3	R1	R2	R2	R4	X
Meta Cycle 5					
t0	R3	R3	R3	R2	X
t1	R4	R3	R3	R2	X
t2	R1	R3	R3	R2	X
t3	R3	R3	R3	R2	X
Meta Cycle 6					
t0	R4	R4	R4	R3	X
t1	R1	R4	R4	R3	X
t2	R3	R4	R4	R3	X
t3	R4	R4	R4	R3	X
Meta Cycle 7					
t0	R1	R2	R2	R4	X
t1	R3	R2	R2	R4	X
t2	R4	R2	R2	R4	X
t3	R1	R2	R2	R4	X
Meta Cycle 8					
t0	R3	R3	R3	R2	X
t1	R4	R3	R3	R2	X
t2	R1	R3	R3	R2	X
t3	R3	R3	R3	R2	X
Meta Cycle 9					
t0	R4	R4	R4	R3	X
t1	R1	R4	R4	R3	X
t2	R3	R4	R4	R3	X
t3	R4	R4	R4	R3	X
Meta Cycle 10					
t0	R1	R2	R2	R4	X
t1	R3	R2	R2	R4	X
t2	R4	R2	R2	R4	X
t3	R1	R2	R2	R4	X
...					
Never converging					

Figure 5 Non-Converging eCPRI/CPRI Link Bit Rate Negotiation Procedure

The example that was described and illustrated above clearly explains the challenge in the eCPRI/CPRI interworking rate negotiation. Similar to the above configuration combination, the configuration of additional rates containing a fewer number of common rates will require many such iterations making it very non-deterministic as well as raising non-converging situations in some combinations.

Thus, there are various key challenges to the eCPRI/CPRI link rate negotiations. A first challenge involves the entire probabilistic CPRI negotiation process for achieving HFN SYNC at an IWF-S may need to be repeated multiple times due to phase differences (e.g., a difference in the starting time for a RE as compared to the IWF-S). Subsequent to that, the entire REC to RE CPRI negotiation covering all of the nodes may also need to be repeated if the complete loop of REC to RE and back from RE to REC using the same rate is not completed before the REC moves to the next transmit rate.

A second challenge is that the entire loop of REC to IWF-S to IWF-M to RE and back from RE to IWF-M to IWF-S and to RE should be completed for the 'same rate' during one CPRI transmit (Tx) interval (e.g., a t interval of 0.9 to 1.1 seconds). That is, at the very least, the rate match between REC and IWF-S and between the IWF-M and RE shall happen within the same CPRI Tx interval.

Aspects of the techniques presented herein support a solution which removes the shortcomings in eCPRIv2 and provide a distinguished advantage without disturbing the RE and REC CPRI implementation or changing anything in the CPRIv7 specification. Within this context, some of the benefits in connection with the techniques presented herein include, for example, providing link auto negotiation that is at par with a point-to-point CPRI link as described in the CPRIv7 specification; facilitating the completion and convergence of auto negotiation to avoid landing in a non-converged situation; facilitating auto negotiation that converges faster than the eCPRIv2 specification. Further, the techniques presented herein may not break any interworking functions.

Key elements that are of interest and note in the techniques presented herein include, among other things:

1. As will be explained below, the REC (Master) automatic negotiation process with a RE or RRH (Slave) is phase aligned (with some delay) with a few milliseconds (msecs) lag.
2. As described in the CPRIv7 specification, in an idle state an optical transceiver Tx is OFF and a transceiver receive (Rx) is ON.
3. As described in the CPRIv7 specification, before automatic negotiation starts a master port switch on the transceiver will switch on the laser and this is an event for a slave to start its automatic negotiation process. Of course, here a slave process will start a little later than a master due to propagation delay, etc. but that is not an issue.

4. Trying to align the auto negotiation process at a REC and a RE or RRH to bring it on par with a CPRI point-to-point link, which is a shortcoming in the eCPRIv2 specification as explained above.
5. An IWF-2 or IWF-M will not send comma character (i.e., K28.5 in an 8b/10b encoding) or link delineation information (i.e., 64b/66b encoding) unless there is HFN SYNC at an IWF-1 or IWF-S and notified to an IWF-2 or IWF-S.

In accordance with techniques of this proposal, during the first step of the existing eCPRI link rate negotiation procedure as described above, when the IWF-S port receives the CPRI stream from a REC the first time at the beginning of the link negotiation, despite not achieving HFN SYNC on the received stream, it shall immediately send an IWF startup message (optional version 2 as described in the eCPRI specification) to the IWF Type 2 node.

Thereafter, the IWF Type 2 node, on receiving the above IWF startup message, can immediately enable the transmitter on the IWF-M port towards the RE node. This enabling of the transmitter at the IWF-M will act as a trigger (i.e., the RE will start receiving light on the port, triggering the Serializer/Deserializer (SerDes) lock start) on the RE to immediately start the link rate negotiation. On receiving the signal on the port, the RE will immediately choose the highest rate for receive sampling. However, as mentioned earlier, at this stage it will not send any link delineation information (such as K28.5 in an 8b/10b encoding) towards the RE or RRH and hence the RE or RRH will not be able to lock in. The IWF-2 or IWF-M will start sending a CPRI frame for link synchronization only when it receives the command from an IWF-1 or IWF-S once it gets into HFN SYNC.

This will immediately align the RE receive cycle to the REC Tx cycle within a few msecs, considering the SerDes level locks in between will take some time. (Empirical testing has shown that the SerDes lock can be completed comfortably within 50 msecs). Or it can be said that the RE link rate negotiation cycle will be immediately phase aligned with the REC link rate negotiation cycle. However, in this stage an IWF Type 2 node shall not send any CPRI hyper frame marker SYNC bytes towards the RE.

This will bring the eCPRI link rate negotiation on par with the rate negotiation which is employed in direct point-to-point connected CPRI link. That is, a REC and a RE are starting the link rate negotiation at the same time. Since the CPRIv7 specification mandates that both ends shall start with the highest rate for transmit and receive (as per their role) and switch to other configured rates in a round robin fashion, from the highest rate to a second highest rate and so on, both the ends eventually converge at a common match. Also, the probability to achieve link rate negotiation between the REC and the RE comes at par with the point-to-point CPRI link.

In Figure 6, below, the red colored rows from IWF Type 1 to IWF Type 2 and IWF-M to RE at the beginning of the diagram illustrate aspects of the techniques presented herein in an enhanced eCPRI and CPRI interworking link rate negotiation procedure.

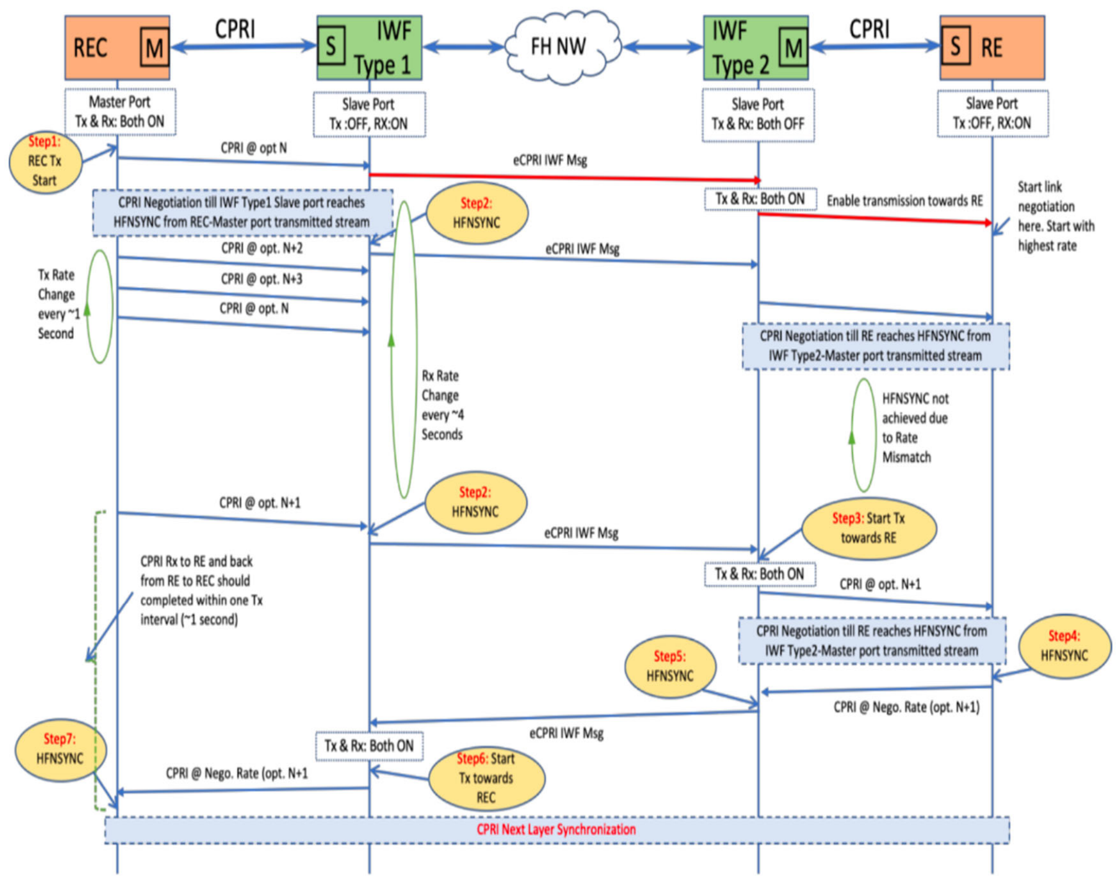

Figure 6: Enhanced eCPRI / CPRI Interworking Link Bit Rate Negotiation Procedure

Referring back to the illustrative example that was depicted in Figure 5, above, Figure 7, below illustrates how aspects of the techniques presented herein enable a faster convergence of the link bit rate negotiation procedure.

Rates	(R1,R3,R4). **REC** Tx: ON Rx: ON	(R2,R3,R4) **IWF-S** Tx:OFF Rx:ON	(R2,R3,R4) **IWF-M** Tx:OFF Rx:OFF	(R2,R3,R4) **RE** Tx:OFF Rx:OFF	**Match**
Meta Cycle 1					
t0	R1	R2	R2	R2 *(Rx Turned ON)*	X
t1	R3	R2	R2	R2	X
t2	R4	R2	R2	R2	X
t3	R1	R2	R2	R2	X
Meta Cycle 2					
t0	R3	R3	R3	R3	√
t1	R3	R3	R3	R3	
t2	R3	R3	R3	R3	
t3	R3	R3	R3	R3	

Figure 7: Rapid Alignment of RE Rx Cycle with REC Tx Cycle

As depicted in Figure 7, above, in meta-cycle 1 during the t0 interval itself the RE's receive cycle is kick started as opposed to the meta-cycle 2 t0 interval according to the procedure that is described in the eCPRI specification. The RE's Rx cycle and REC's Tx cycle are on par with the point-to-point CPRI negotiation procedure cycle in this case.

In summary, techniques have been presented herein that support bringing the eCPRI link rate negotiation on par with the rate negotiation which is employed in a direct point-to-point connected CPRI link. That is, a REC and the RE start the link rate negotiation at the same time or the REC's Tx cycle and RE's Rx cycles are phase aligned and start at the same time (similar to the direct point-to-point CPRI link).