



**Common Electrical I/O – Protocol (CEI-P)  
Implementation Agreement**

**IA # CEI-P-02.0**

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Implementation Agreement created and approved  
by the Optical Internetworking Forum  
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Working Group: Physical and Link Layer

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**TITLE: Common Electrical I/O – Protocol (CEI-P) Implementation Agreement**

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## 4 Document Revision History

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**DATE:** 2<sup>nd</sup> April 2008

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Revision 1.0 OIF-CEI-P-01.0 created out of oif2004.229.07 in March 2005

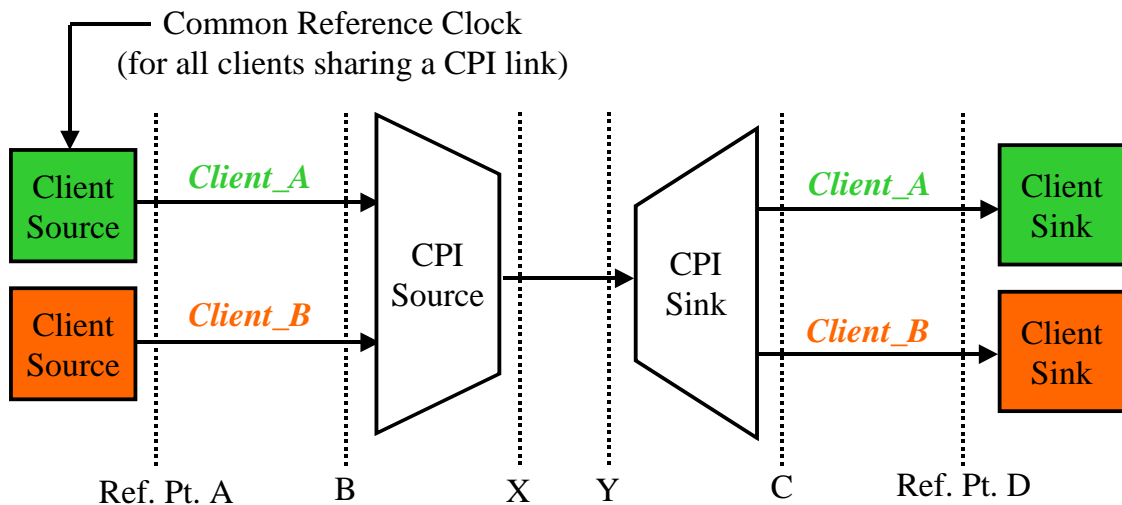
Revision 2.0 Added Clauses for TFI-5 and TDM-P client signals to CEI-P according to oif2007.225.02 as voted in principal member ballot #54 in March 2008



## 5 Introduction

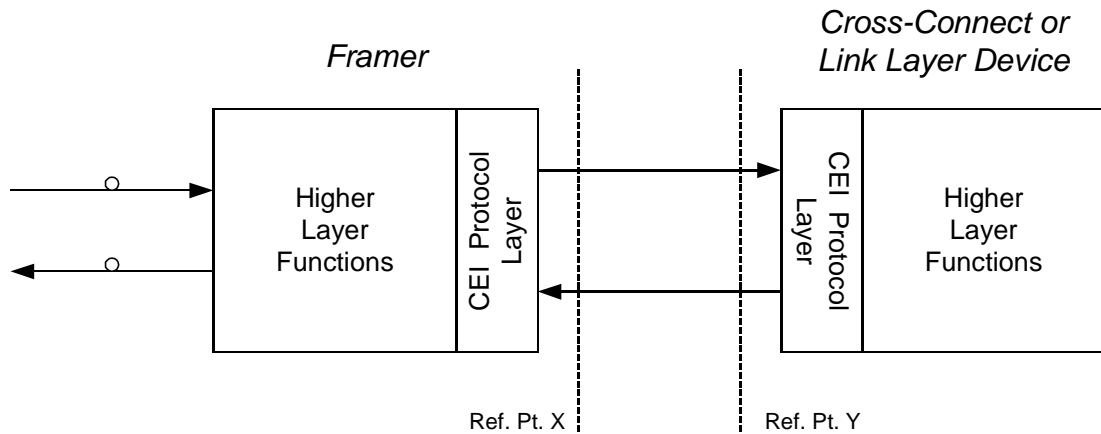
The CEI Protocol Implementation Agreement defines protocols that take advantage of faster electrical interfaces developed by the CEI project. The CEI Electrical Implementation Agreement and the CEI Protocol Implementation Agreement are peer documents. Adherence to one does not force adherence to the other. For example, a 10G SONET framer may connection directly to an optical module using CEI electricals with SONET scrambled data. In this case, CEI Protocol would be absent. It is also possible to use CEI Protocol without CEI Electricals. An example would be to encapsulate TFI-5 frames with CEI Protocol to provide forward error correction capability. The target applications of CEI Protocol are Lane Aggregation and Physical layer management of future OIF interfaces.

Lane Aggregation refers to the multiplexing of existing lower speed links onto a reduced number of high-speed links. A pair of devices would interface to existing lower speed client sources, transfer the client information over CEI Protocol links, and re-generate the client information onto the client sinks (See Figure 1).



**Figure 1 CEI Protocol Lane Aggregation Application**

Existing OIF interfaces have a wide variety of foundation protocols. For example, de-skew in SFI-5 differs markedly from that in SPI-5. Error monitoring in TFI-5 has little in common with SFI-5, despite mainly targeted at SONET/SDH traffic. As links speed rise, and error performance becomes more stringent, forward error correction may become necessary. The CEI Protocol Implementation Agreement will provide a common set of framing, de-skew, error correction and detection protocols for future OIF interfaces (See Figure 2).



**Figure 2 Foundation of Future OIF Interface Applications**

The CEI Protocol is based on the layered concept. Three layers are defined; Adaptation, Aggregation and Framing (See Figure 3). In general, the Adaptation layer performs client signal alignment, performance monitoring and mapping functions to convert from client protocol formats to CEI Protocol formats. The Aggregation layer is responsible for multiplexing and de-multiplexing clients onto CEI Protocol links. It performs link de-skew, where necessary. Optionally, it performs connectivity monitoring and supports a supervisory interface between the source and sink devices of CEI Protocol link. Finally, the Framing layer performs payload alignment, error detection and optional error correction of CEI Protocol links. In this document, functionality common to all applications for each layer is described first. Then, each application is assigned its own clause where the functions of each the three layers are further defined. The flow of data from the Client to CEI Protocol links is defined as the Transmit direction. The flow from CEI Protocol links to the Clients is defined as the Receive direction.

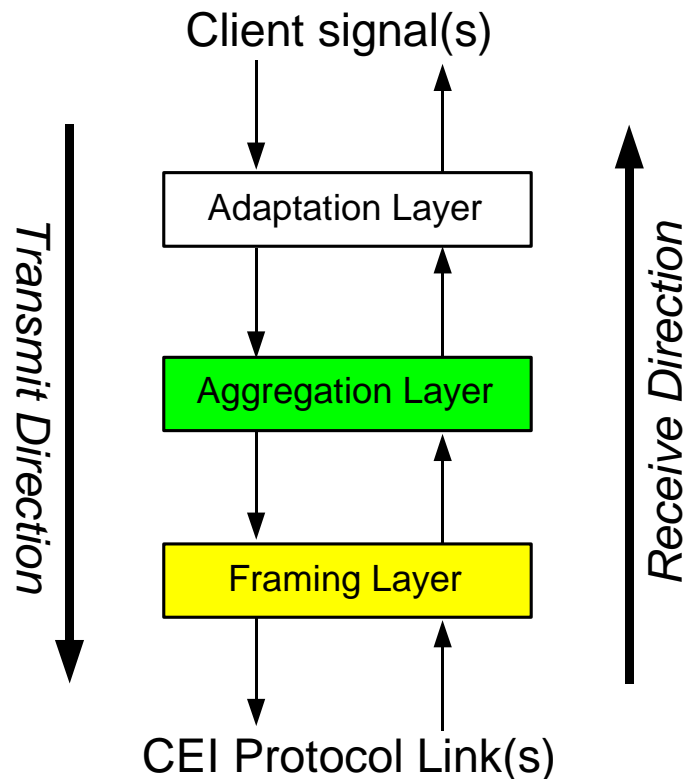


Figure 3 CEI Protocol Layers

## 6 Requirements

- The Implementation Agreement(s) shall allow single and multi-lane applications
- Shall conform to the data characteristics required by the CEI project (E.g., DC balance, Transition density, Max run-length)
- Support a wide range of client signals including SFI, SPI, TFI, 8b/10b Interfaces
- Protocol shall be the same within each CEI speed class (agnostic to SR or LR)
- Leverage layered protocol concepts developed for TFI-5
- In lane aggregation applications:
  - Ensure bit sequence integrity
  - Limit added client lane skew and wander
  - Provide mechanism to identify source client signals at de-mux point
  - Provide mechanism to de-skew CEI links

- In single lane applications :
  - Support SONET/SDH compliance at the optical carrier (OC) interface.

## **7 Objectives**

- Support a wide range of client signals including SFI, SPI, TFI, 8b/10b interfaces and be agnostic to the client link protocol.
- Provides similar EMI spectrum for a wide variety of clients.
- Protocol shall be the same for each CEI speed class (agnostic to reach)
- Achieve low BER
- Provides layer pass-through for light-weight implementations
- In lane aggregation applications:
  - Limit added client lane skew and wander
  - Limit added latency

## **8 Common Definitions**

### **8.1 Introduction**

This clause defines the common functions of the CEI Protocol for the Adaptation, Aggregation and Framing layers that will be used by all applications. The layers may have options and parameters. The clauses pertaining to specific applications will select appropriate options and assign values to parameters.

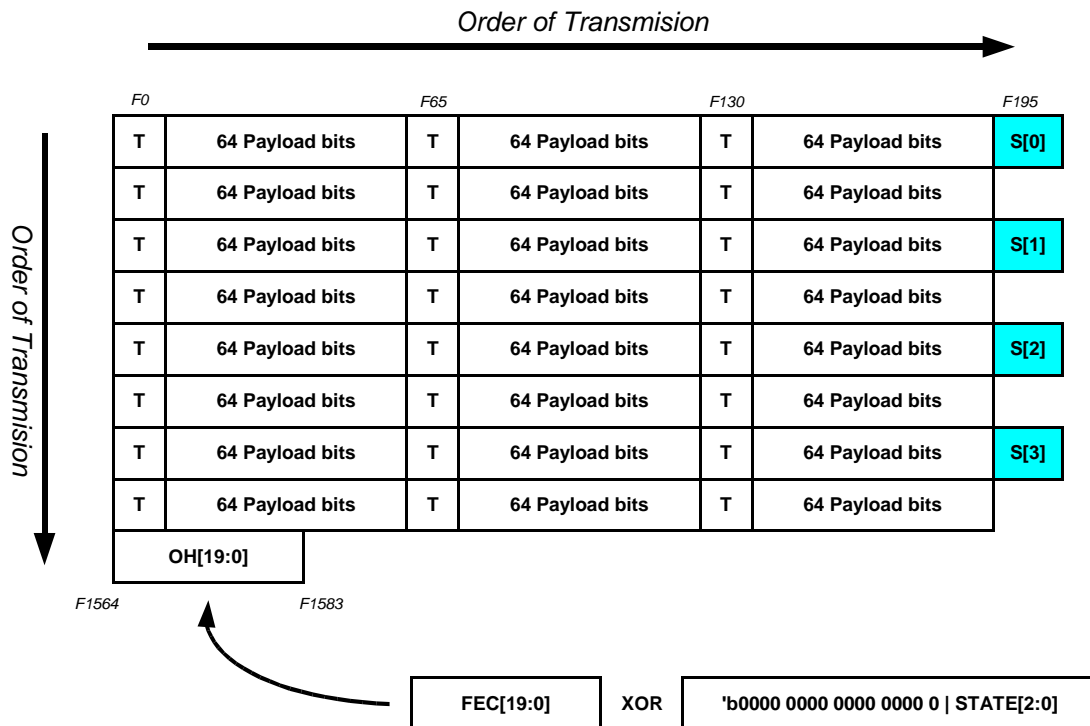
### **8.2 Frame Format Definition**

The CEI Protocol has a single frame format to address both low-latency and high-integrity applications. Parity check code from a Fire code generator polynomial is used for error checking and optionally, for forward error correction (FEC). The frame length of 1584 bits consists of 1560 bits of payload and 24 bits of overhead. Each frame is a Fire Code block.

#### **8.2.1 Frame Format**

Figure 4 shows a CEI Protocol frame. The length of the frame is 1584 bits. The frame has a regular structure. Each frame contains eight rows, and a Supervisory overhead bit is associated with each odd numbered row. At the end of each frame there is a 20-bit overhead field. Each row has three 65-bit payload fields (shown as T and 64 bits of payload in Figure 4). Transmission is from left to right within each row, and from top to bottom, between rows. The payload bits (1560 bits total) carry client payload originating from the Adaptation layer. The Adaptation layer of certain applications may insert stuff bits into the payload region for rate matching.

A number of existing protocols such as 1G Ethernet, 10G Ethernet (XAUI), InfiniBand, PCI-Express, Rapid I/O and Fibre Channel use 8b/10b encoding. It may be desirable for CEI Protocol links to be able to carry 8b/10b clients using a transcoding scheme that is similar to, but more efficient than, 64b/66b encoding. Twenty-four Transcoding overhead bits (T) are highlighted in Figure 4 to illustrate example locations where the Adaptation layer may place transcoding tags for non-multiplexed payloads. For multiplexed payloads, the locations of transcoding tags will depend on the multiplexing structure. The ratio of one transcoding bit for every 64 payload bits matches the overhead requirements of GFP-T format in ITU-T G.7041. For applications that do not use transcoding, all 65 payload bits (including T) are available for carrying client payload.



**Figure 4 CEI Protocol Frame Format**

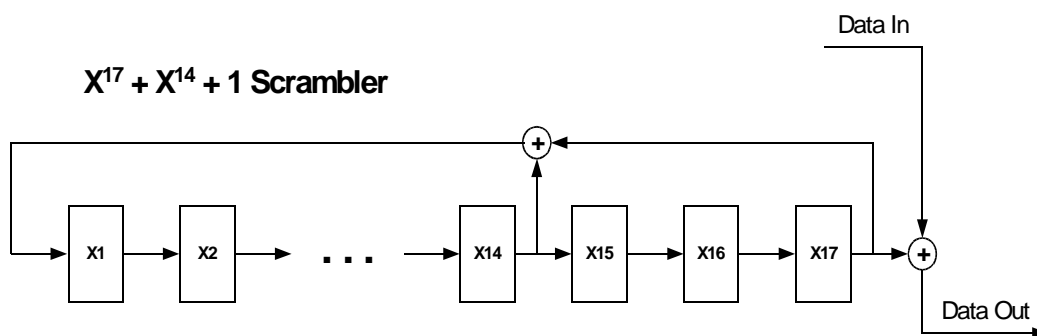
The twenty overhead bits (OH[19:0]) located at the end of the frame (F1564 to F1583) hold the XOR of the Fire code parity check bits (FEC[19:0]) with the fixed zero field and the STATE[2:0] bits. Bit F1564 carries FEC[19], while F1583 carries the XOR of FEC[0] with STATE[0]. All bits in the frame are scrambled. The Overhead bits are assigned to the Framing layer in accordance to Table 1.

Overhead	Location	Function
OH[19:3]	F1564 : F1580	Framing, Scrambler Synchronization, Error Detection, Forward Error Correction (Optional),
OH[2:0]	F1581 : F1583	Link State, Error Detection, Forward Error Correction (Optional)

**Table 1 Overhead Assignment in a Frame**

The optional Supervisory Interface is supported over the Supervisory overhead bits (S[0:3]) in Figure 4. The S[0:3] bits have not been assigned to any layer as the functions they serve tend to be management in nature and may cover both CEI Protocol link primitives and client primitives. When implemented, the Supervisory Interface is attached to the Aggregation layer. Examples of functions supportable by the Supervisory Interface include, but not limited to, inter-card data communications channel, per STS-1 status in TDM equipment, and flow-control flags/messages in packet-based equipment. The definition of the Supervisory Interface is application specific.

Frames are scrambled by a free running LFSR scrambler with a characteristic polynomial  $g(X) = X^{17} + X^{14} + 1$  (See Figure 5). The scrambler output is applied to all Payload bits (including T bits), to all Supervisory Interface bits, and to Overhead bits the frame. Since the scrambler bits are XOR'ed with FEC[19:3] at the CEI Protocol Transmitter, the state of the scrambler can be recovered, at the CEI Protocol Receiver, by subtracting the calculated parity from the received scrambled parity at bits F1564:F1580.



**Figure 5 Free Running Scrambler**

The state of a CEI Protocol link, is communicated between the Transmitter and Receiver pair by the STATE[2:0] bits. For robust communications, STATE[2:0] is

transmitted in every frame. (Note that STATE[2:0] is XOR'ed with FEC[2:0].)  
Table 2 shows the overhead locations where each bit in STATE[2:0] is transmitted.

State	Overhead	Location
STATE[2:0]	OH[2:0]	F1581:F1583

**Table 2 Overhead location of STATE[2:0]**

The encoding of the State bits is shown in Table 3 below. When the associated receiver in the local device is in need of training, the transmitter will enter the Training Request state (TRequest). The transition to the TRequest state has precedence over all other transitions. The STATE[2:0] bits are set to 'b111 to indicate training is requested. The payload field (including T bits) will carry the training pattern defined by the CEI Implementation Agreement to train the remote receiver. The transmitter will stay in this state until the local receiver has completed training. At this point, the transmitter will transition to the TPresent state if the remote receiver continues to require training. The STATE[2:0] bits are set to 'b110 to indicate that the local receiver has completed training. Training pattern continues to be sent in order to train the remote receiver. When the remote receiver reports training completion (via STATE[2:0] != 'b111), the transmitter enters the Idle state. The transmitter will transition directly from the TRequest state to the Idle state, if the remote receiver has already completed training when the local receiver completes its training. In the Idle state, the Framing layer is capable of transferring data. However data may not be available to/from higher layers. The payload bits are set to all zeros and payload scrambling is enabled. The link is fully operational in the PScramble state.

The State bit STATE[0] (assigned to OH[0]) may be used to convey a multiframe alignment signal (MF) in the Idle and PScrambled states. The length of the multiframe is application specific and is static. The first frame in the multiframe is indicated by setting STATE[0] to logical one, and the remaining frames are indicated by setting STATE[0] to logical zero.

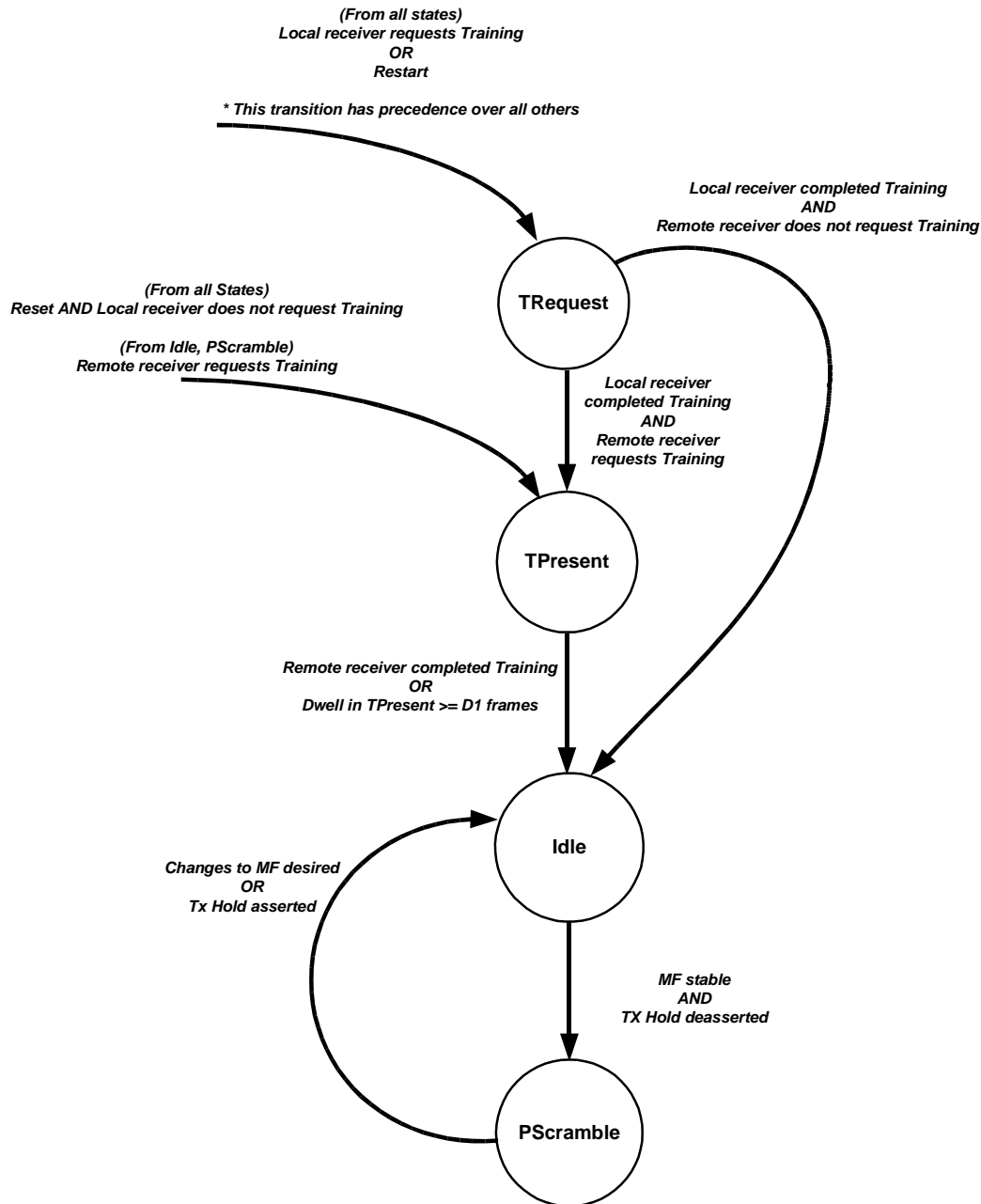
The TX Hold signal in Figure 6 is a software controlled signal. It is optional and may be used by software to synchronize the start of normal payload activity when multiple CEI-P links are aggregated to carry a single high-bandwidth client. In a simplex application, the remote receiver never requests training as it has no path to signal a need for training. The transmitter will dwell in the TPresent state for D1 frames to allow time for the remote receiver to complete training.

State Name	STATE[2:0] Encoding	Description
TRequest	'b111	Training pattern present. Training Requested. Payload scrambler disabled.
TPresent	'b110	Training pattern present. Local receiver trained. Payload scrambler disabled.
Idle	'b011	Local and Remote receivers trained. Payload scrambler enabled. First frame of a multiframe. MFAS marker frame.
Idle	'b010	Local and Remote receivers trained. Payload scrambler enabled. Second and subsequent frames of a multiframe.
PScramble	'b001	Link fully operational. Payload scrambler enabled. First frame of a multiframe. MFAS marker framer.
PScramble	'b000	Link fully operational. Payload scrambler enabled. Second and subsequent frames of a multiframe.
Reserved	Others	Reserved for future definition.

**Table 3 Transmitter Link State Reporting**

The transition diagram of the state reporting mechanism at a CEI-P transmitter for duplex applications is shown in Figure 6.

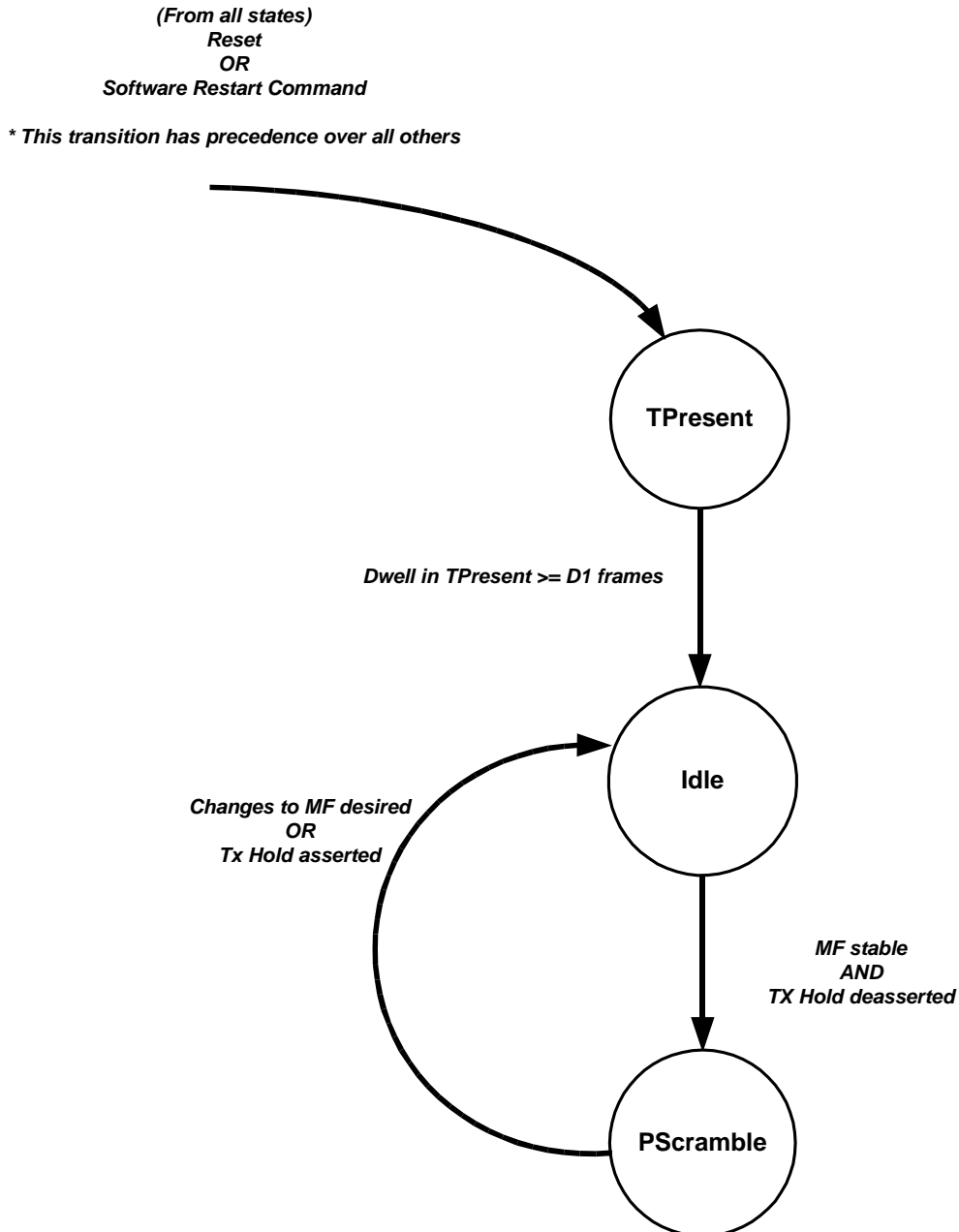




**Figure 6 Transmitter Link State State Machine Diagram – Duplex**

The transition diagram of the state reporting mechanism at a CEI-P transmitter for simplex applications is shown in Figure 7. In a simplex application, the CEI-P transmitter in the local device and the CEI-P receiver in the remote device are connected by a link. No return path from the remote device to the local device is associated with this CEI-P transmitter / receiver pair. Consequently, STATE[2:0] communications is unidirectional. The CEI-P Receiver is not able to request Training Pattern nor indicate training completion. Thus the TRequest state is not

present in Figure 7. An external means is needed to trigger Training Pattern insertion in the CEI-P transmitter.



**Figure 7 Transmitter Link State State Machine Diagram – Simplex**

The Duplex Receiver link state machine (Figure 8) can be used in simplex or duplex CEI-P applications. It tracks the state of the remote transmitter (STATE[2:0]) of a CEI-P link. STATE[2:0] values are accepted when they are

received with a constant value for R1 consecutive presentations. The receiver link state machine enters the Seek state upon reset and when it is not able to track the state of the remote transmitter. The receiver transitions from the any state to the TRequest or the TPresent state when the accepted state from the transmitter is in those respective states. The receiver waits in the Idle state until the optional software controlled signal RX Hold is negated. It will transition to the Idle state when the RX Hold signal is asserted. As with the TX Hold counterpart, RX Hold is an optional software controlled signal. It is useful in synchronizing multiple CEI-P links that are aggregated to service a single high bandwidth client.

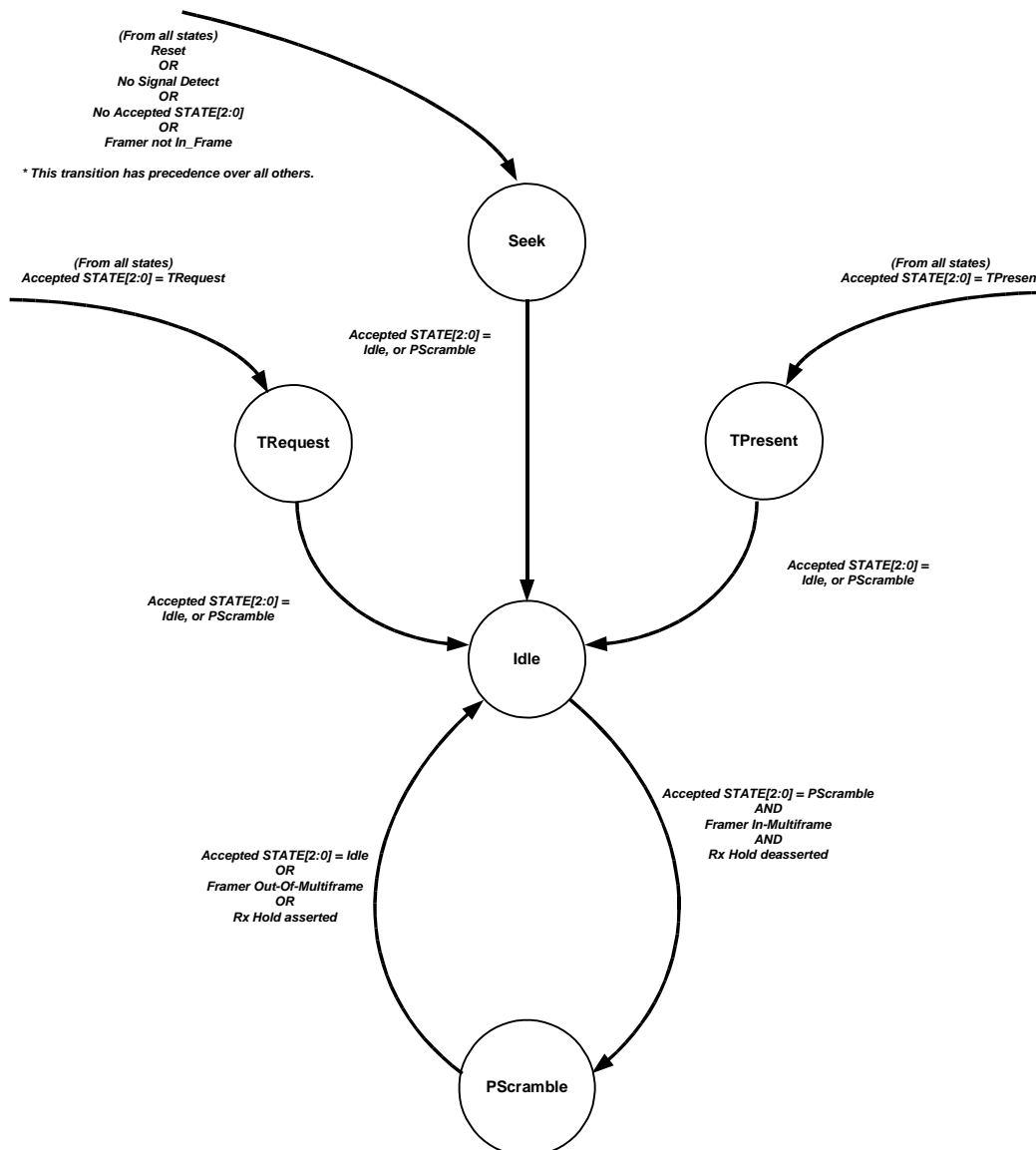
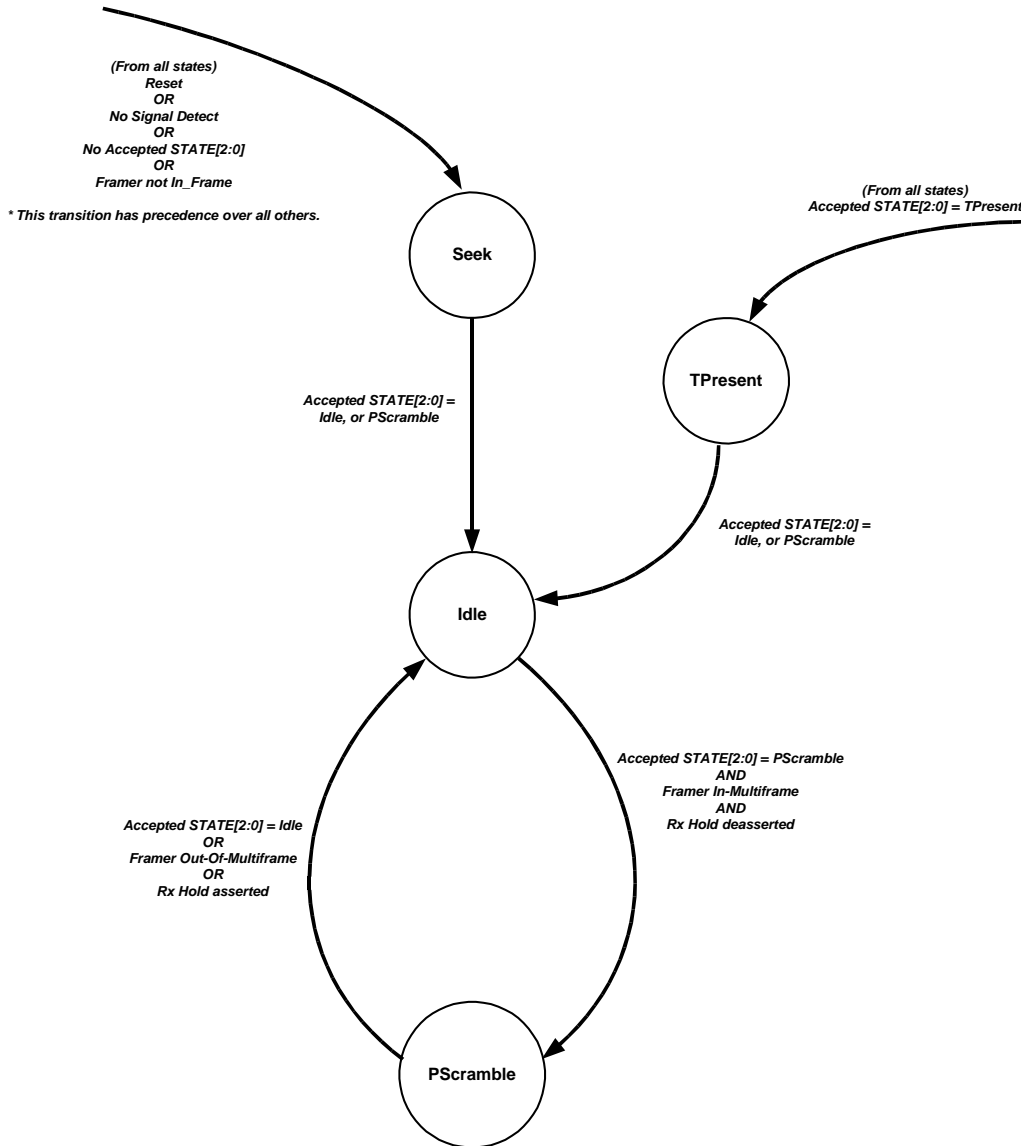


Figure 8 Receiver Link State State Machine Diagram –Duplex

The Simplex Receiver link state machine (Figure 9) is restricted to simplex CEI-P applications. It tracks the state of the remote transmitter (STATE[2:0]) of a CEI-P link. STATE[2:0] values are accepted when they are received with a constant value for R1 consecutive presentations. The receiver link state machine enters the Seek state upon reset and when it is not able to track the state of the remote transmitter. The receiver transitions from the any state to the TPresent state when the accepted state from the transmitter is in that state. The receiver waits in the Idle state until the optional software controlled signal RX Hold is negated. It will transition to the Idle state when the RX Hold signal is asserted. As with the TX Hold counterpart, RX Hold is an optional software controlled signal. It is useful in synchronizing multiple CEI-P links that are aggregated to service a single high bandwidth client.



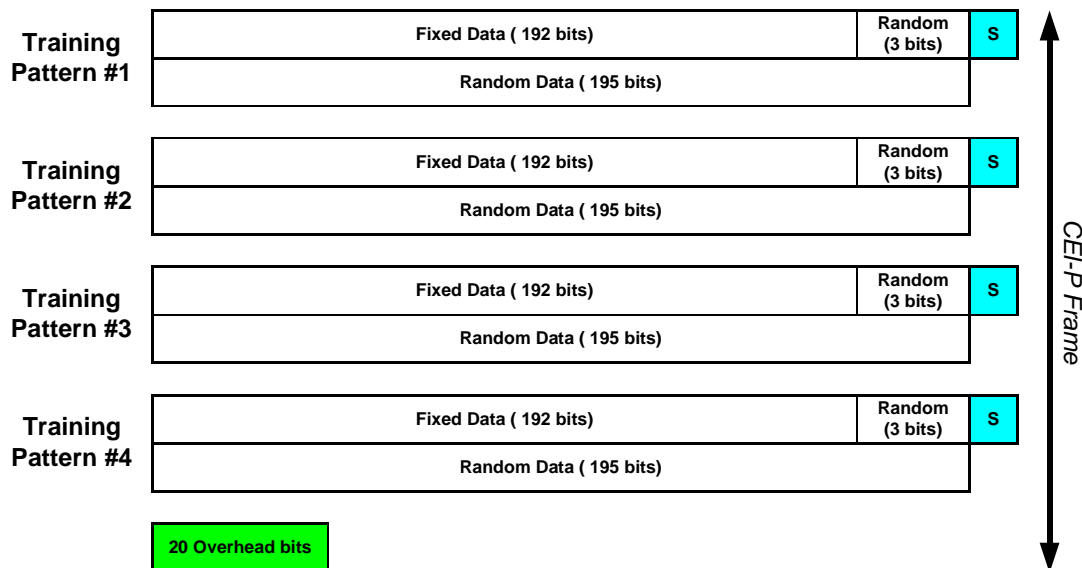
**Figure 9 Receiver Link State State Machine Diagram - Simplex**

The CEI Implementation Agreement has defined a Training Pattern for calibrating CEI electrical components. (Table 5-6 of the CEI IA is replicated here as Table 4 for reference only.) When sending the CEI Training Pattern, the sequence will be 391 bits long, consisting of a 192-bit fixed data field, followed by a 199-bit pseudo-random data field. The Supervisory Channel bits (S) are scrambled and form part of the pseudo-random data field. The first bit of the fixed data field is aligned to the first bit of the CEI Protocol frame. Each CEI Protocol frame carries four CEI Training Patterns. Table 4 shows the alignment

of the patterns. Implementations may support additional training patterns. The definition of these patterns is outside the scope of this IA.

Pattern (Hex)	Purpose
00 FF 00 FF 00 FF	48 bits - f/16 square wave
00 08 00	24 bits - positive impulse with 12 leading and trailing zeros
55 55 55 55 55 55	48 bits - f/2 square wave
FF FE FF	24 bits - negative impulse with 12 leading and trailing ones
00 FF 00 FF 00 FF	48 bits - f/16 square wave
At least 192 random or pseudo-random bits	Approximation of normal randomized data patterns

**Table 4 Training Pattern (from CEI Electrical IA)**



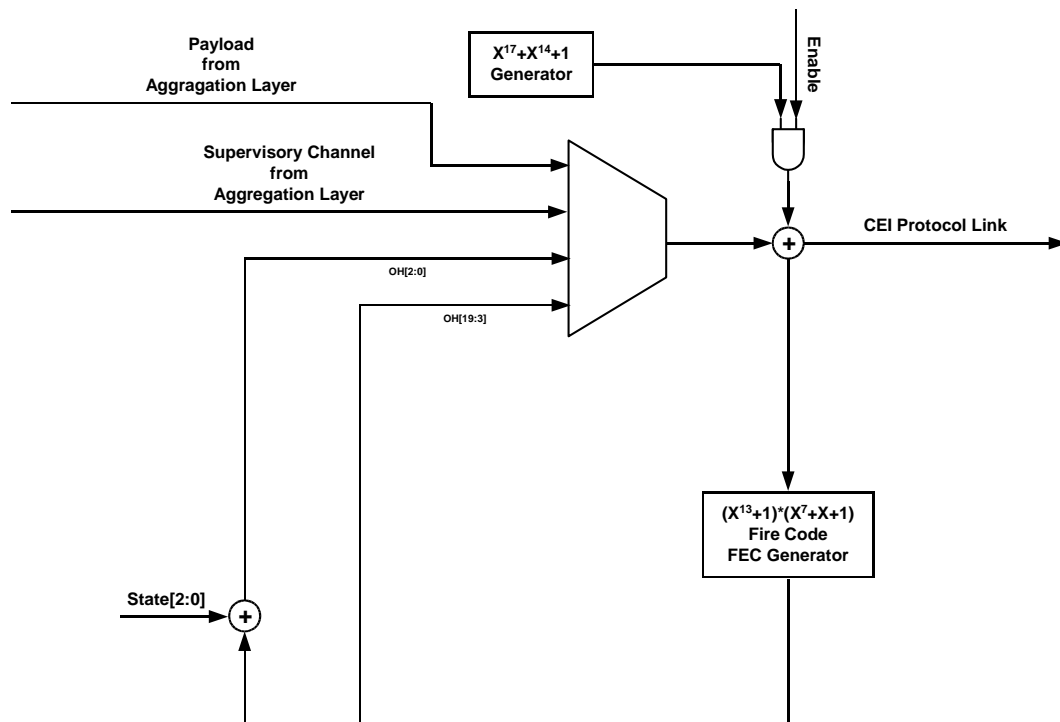
**Figure 10 Alignment of CEI Training Pattern to CEI Protocol Frames**

Figure 11 shows a logical block diagram of the frame generation process. Actual implementation may differ.

The generation of Forward Error Correction parity check code bits is mandatory and is appended to the end of the block in each frame. The FEC code is Fire

code with a generator polynomial of  $g(X) = (X^{13} + 1)(X^7 + X + 1)$ , and is capable of correcting a single error burst of up to 7 bits, per frame. The parity check code is computed over all the Payload (including T bits) and Supervisory bits in the current frame, after scrambling. The Fire Code parity check code is XOR'ed with the associated STATE[2:0] bits, scrambled and inserted to the end of the frame.

The STATE[2:0] bits share some of the bit positions as the Fire Code parity bits. A single bit error in the payload will typically cause several parity bits, and the corresponding STATE[2:0] bits, to invert. Using the Fire code to correct errors in the STATE[2:0] bits, at a CEI Protocol Receiver, is therefore complex. Since the transmitted values of the STATE[2:0] bits are not permitted to change during normal operation, they should be protected from transmission errors using de-bouncing over multiple frames, rather than Forward Error Correction.



**Figure 11 Frame Generation Process – Logical Block Diagram**

### 8.3 Framing Layer Definition

The Framing layer is responsible for frame boundary delineation, error detection and maintaining rich transition density. Fire Code parity check code is defined to mark frame boundaries and to detect transmission errors. Transition density is provided by a free-running LFSR scrambler. Optionally, the Framing layer at the

receiver provides Forward Error Correction capability. The following requirements apply to the frame formats of the CEI Protocol frame.

<b>Req. No.</b>	<b>Description</b>
R1.1	The frame format of a CEI Protocol link shall be as shown in Figure 4. The first bit the frame is labeled F0 and the last bit F1583. F0 is aligned to the first payload bit (a.k.a., the first T bit), while F1583 is aligned to FEC[0], the least significant bit of the Fire code parity check code.
R1.2	Transmission of a CEI Protocol frame shall be sequential from bit F0 to bit F1583.
R1.3	In the Idle state, all payload bits (Including T bits) shall be set to zero (before scrambling) by a CEI-P transmitter, and shall be ignored by a CEI-P Receiver.
R1.4	A free-running stream cipher, with a polynomial of $g(X) = X^{17} + X^{14} + 1$ , shall be used for scrambling. (See Figure 5.) The stream cipher state shall advance at every bit time, without regard to whether the bit is scrambled.
R1.5	The Overhead bits (OH[19:3]) shall be set to 'h00000 XOR FEC[19:3].
R1.6	When multiframe alignment is implemented, STATE[0] in the Idle and PScramble states shall be set high at the first frame of the multiframe and set low at all other frames.
R1.7	The FEC parity check code shall be computed using the Fire code polynomial $g(X) = (X^{13} + 1)(X^7 + X + 1)$ . The parity check code shall cover the Payload bits (including T bits) and the Supervisory bits in the current Frame, after scrambling.
R1.8	The FEC parity check codes FEC[19:3] bits shall be inserted into frame locations F1564 : F1580, before scrambling.  The FEC parity check codes FEC[2:0] bits shall be XOR'ed with the state code STATE[2:0] bits and inserted into frame locations F1581 to F1583, before scrambling.
R1.9	Payload scrambling shall be enabled in the PScramble and Idle states. The payload scrambler shall be disabled in the TRequest and TPresent states.

**Table 5 CEI Protocol Frame Format Requirements**



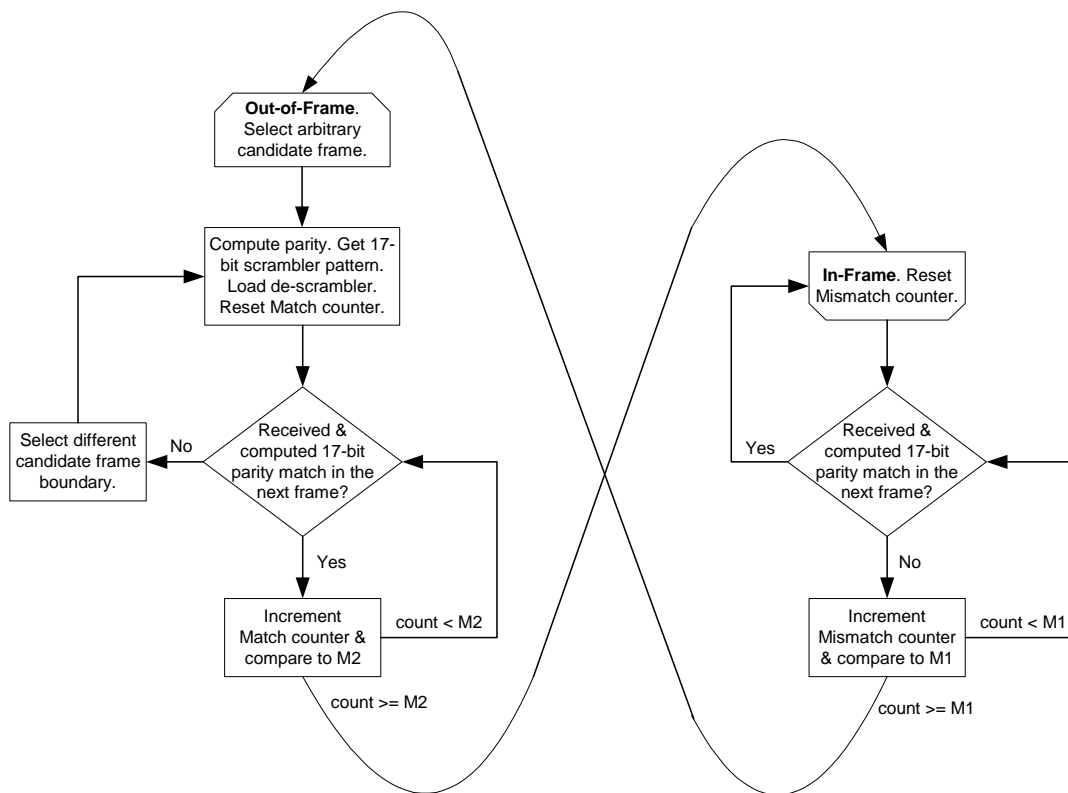
A CEI Protocol Receiver uses the Fire Code parity check code in the received data stream to delineate frame boundaries (See Table 6 for sample framing algorithm). When the receiver is in the In-Frame state, Fire Code parity check code errors in  $M_1$  consecutive frames will cause a transition to the Out-Of-Frame state. When the receiver is in the Out-Of-Frame state, it will sequentially search the received stream for candidate frame boundaries. A potential frame boundary is found if the associated 1584-bit block has correct Fire Code parity check code, after descrambling. The potential frame boundary is verified, for correct Fire Code parity check code over  $M_2$  consecutive frames. At which point, the framer transitions to the In-Frame state. Implementations may use a only subset of the Fire Code parity check bits in the frame delineation process. The speed of frame delineation is proportional to the number of candidates ( $N_1$ ) being searched simultaneously. It is outside the scope of this Implementation Agreement to specify  $N_1$ .

An example of a framing algorithm is shown in Table 6 and below. It is provided here for illustrative purposes only. Alternative compliant implementations exist.

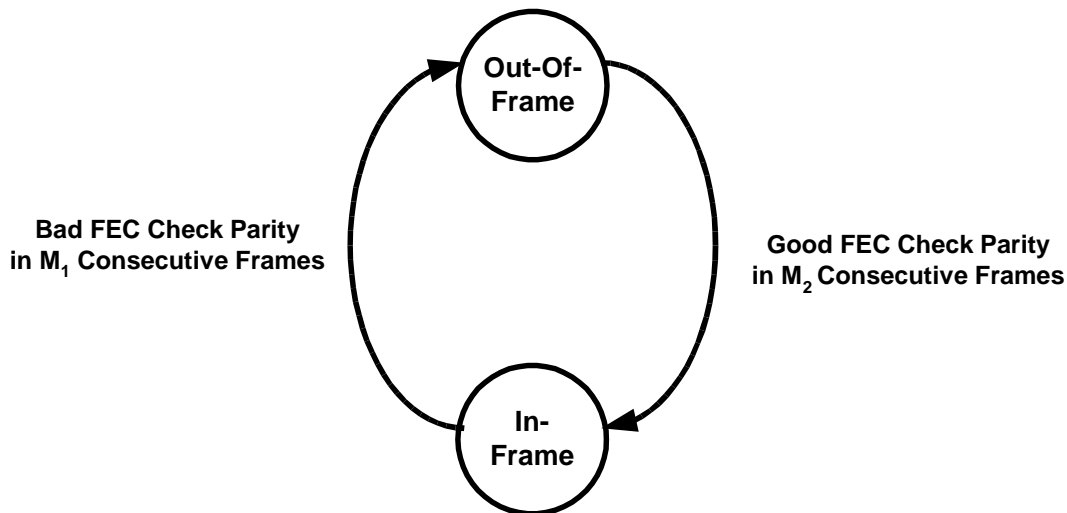
Step #	Description
1	Select an arbitrary bit as the candidate CEI-P frame boundary.
2	Compute a candidate Fire Code checksum from a candidate block of 1564 bits starting at the candidate frame boundary.  Note : In the absences of transmission errors, if the candidate frame boundary matches the actual CEI-P frame boundary, the candidate Fire Code checksum would match the Fire Code checksum at the transmitter, before scrambling.
3	Generate a candidate scrambler state by XOR'ing the candidate Fire Code checksum with the next 17 bits received following the 1564-bit candidate block.
4	Load the de-scrambler with the candidate scrambler state and release it to advance normally.
5	Compute candidate Fire Code checksum #2 for candidate block #2. The first bit of block #2 is 1584 bits after block #1.
6	De-scrambled the next 17 received bits after candidate block #2 and compare with candidate Fire Code checksum #2.  Note : In the absence of transmission errors, the 17 received bits, after de-scrambling should match the candidate checksum.
7	If the comparison in Step 6 yielded a match, a potential frame boundary is found. This frame is deemed the first frame in the search for consecutive matches. The Fire Code checksum is checked in subsequent frames until $M_2$ consecutive matches are found. At this point the framer can declare In-Frame. The steps above naturally synchronize the de-scrambler in the receiver with the

scrambler in the transmitter.  
 If the comparison in Step 6 yielded a mismatch, the candidate frame boundary is assumed to be not aligned with the actual CEI-P frame boundary. An alternate candidate start of CEI-P frame bit is selected.

**Table 6 Sample Framing Algorithm**



**Figure 12 Sample Framing Algorithm**



**Figure 13 Framing State Machine Diagram**

When the multiframe structure is enabled, the CEI Protocol Receiver uses the Multiframe Alignment Signal (MFAS) marker bit carried in STATE[2:0] of the received data stream to delineate multiframe boundaries. When the receiver is in the In-MultiFrame state, Multiframe Alignment Signal (MFAS) pattern errors in  $M_3$  consecutive multiframe boundaries will cause a transition to the Out-Of-MultiFrame state. When the receiver is in the Out-Of-MultiFrame state, it will sequentially search the received STATE[2:0] for candidate multiframe boundaries. A potential multiframe boundary is found if a sequence of frames carried the MFAS marker in one frame, followed by  $N-1$  frames without the MFAS marker; where  $N$  is the number of frames in a multiframe. The potential multiframe boundary is confirmed, and the receiver transitions to the In-MultiFrame state, when correct MFAS sequences (1 frame with MFAS,  $N-1$  without) are detected for  $M_4$  consecutive multiframe boundaries. A CEI Protocol Receiver is not required to automatically detect the length of the multiframe ( $N$ ).

The following requirements apply to the frame and multiframe delineation process of a CEI Protocol Receiver.

Req. No.	Description
R2.1	A CEI Protocol Receiver shall follow Figure 12 in framing to a CEI Protocol link.
R2.2	A CEI Protocol Receiver shall monitor Fire Code parity check code. It shall transition from the In-Frame state to the Out-Of-

	Frame state when incorrect Fire Code parity check code is received in $M_1$ consecutive frames. It is acceptable to monitor a subset of the parity check bits.
R2.3	When a CEI Protocol Receiver is in the Out-Of-Frame state, it shall search for candidate frame boundaries. It shall transition to the In-Frame state when the current candidate frame boundary yields correct Fire Code parity check code for $M_2$ consecutive frames. It is acceptable to monitor a subset of the parity check bits.
R2.4	Consequential actions, such as data squelching, as a result of the CEI Protocol Receiver being in the Out-Of-Frame state, shall be defined by the each specific application.
CR2.5	For applications that define a multiframe, the MFAS marker (carried in STATE[2:0]) shall be set to 'b011 or 'b001, to indicate the first frame of the multiframe. The STATE[2:0] shall be set to values other than 'b011 or 'b001. For applications that do not define a multiframe, STATE[2:0] does not indicate MFAS markers.
CR2.6	For applications that define a multiframe, the CEI Protocol Receiver shall monitor STATE[2:0] for the MFAS marker. A CEI Protocol Receiver shall transition from the In-MultiFrame state to the Out-Of-MultiFrame state when the received STATE[2:0] does not follow the expected sequence of one frame with MFAS marker and N-1 frames without, for $M_3$ consecutive multiframe.
CR2.7	For applications that define a multiframe, the CEI Protocol Receiver shall transition from the Out-Of-MultiFrame state to the In-MultiFrame state when the received STATE[2:0] follows the expected sequence of one frame with MFAS marker and N-1 frames without, for $M_4$ consecutive multiframe.
R2.8	When the frame delineation process of a CEI Protocol Receiver is in the Out-Of-Frame state, the multiframe alignment process shall be locked in the Out-Of-MultiFrame state.
R2.9	Consequential actions, such as data squelching, as a result of the CEI Protocol Receiver being in the Out-Of-MultiFrame, shall be defined by the each specific application.

**Table 7 CEI Protocol Receiver Frame and Multiframe Requirements**

The Forward Error Correction parity check code bits (FEC[19:3]) are scrambled and placed in frame location F1564:F1580 by the CEI Protocol Transmitter. A CEI Protocol Receiver can recover the scrambler sequence by computing an

FEC parity check code locally and XOR'ing it with the received, scrambled OH[19:3].

The following requirements and options apply to the scrambler synchronization process of a CEI Protocol Receiver.

Req. No.	Description
R3.1	When a CEI Protocol Receiver is in the Out-Of-Frame state and has selected a new candidate CEI-P frame boundary, it shall compute a candidate state of the de-scrambler using bits F1564 to F1580 of the candidate frame. Comparison of Fire Code parity check code match/mismatch shall begin at the next frame.
R3.2	The candidate state of the scrambler shall be derived by subtracting the computed FEC parity of the candidate frame from the received value at OH[19:3] (bits F1564:F1580) of the candidate frame.
R3.3	Further consequential actions for the Out-Of-Frame state shall be defined by the each specific application.

**Table 8 CEI Protocol Receiver Scrambler Synchronization Requirements**

The training of a link is reported via the STATE[2:0] bits.

Req. No.	Description
R4.1	The state of a bi-directional CEI Protocol link shall be reported in the STATE[2:0] bits according to Table 3.
R4.2	State transitions shall follow Figure 6 and Figure 8.

**Table 9 CEI Protocol Bi-directional Link Requirements**

The Forward Error Correction process is a FEC block that is aligned to the CEI Protocol frame boundary. Each FEC block is assigned 1560 bits of payload (including T), and four Supervisory overhead bit (S), and is protected by a 20-bit Fire Code parity check code. This code is capable of correcting a single burst of up to 7 bits in each frame. The generator polynomial is  $g(X) = (X^{13} + 1)(X^7 + X + 1)$ . The FEC parity check code is computed over the scrambled payload of each CEI Protocol frame. The parity check codes in each frame is then scrambled.

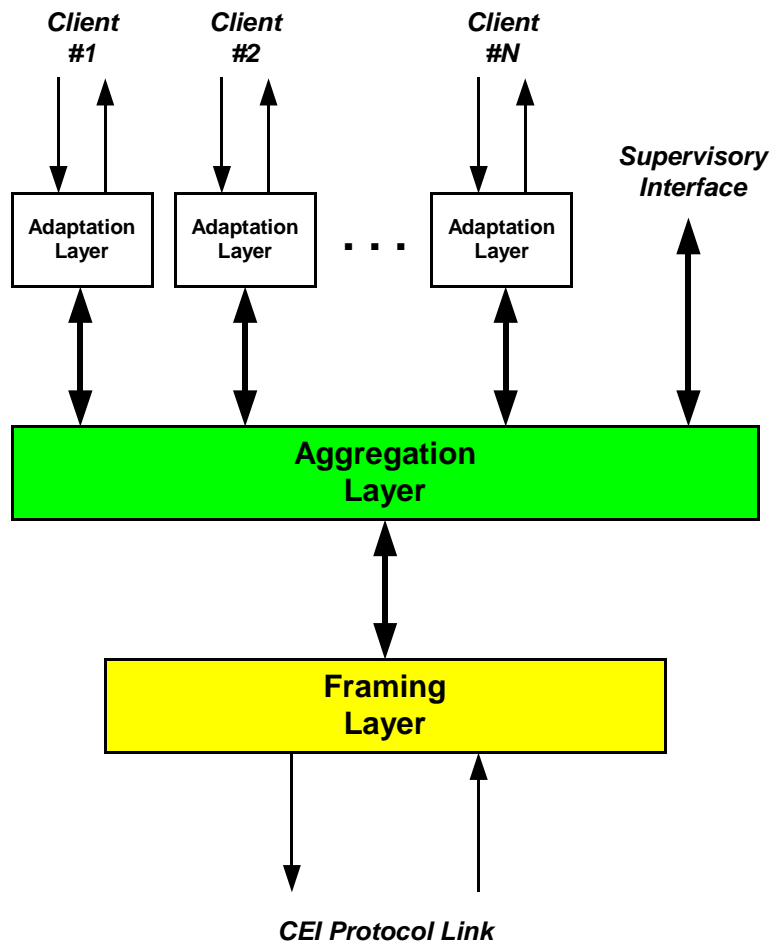
<b>Req. No.</b>	<b>Description</b>
R5.1	A CEI Protocol frame shall consist of one FEC block covering the entire frame.
R5.2	The FEC parity check code shall be generated by the polynomial $g(X) = (X^{13} + 1)(X^7 + X + 1)$ over the scrambled payload (including T) bits, and the Supervisory overhead bits. At the start of each frame, the FEC parity check code generator shall be initialized to an all-zeros pattern.
R5.3	The 20-bit FEC parity check code of each FEC block shall be inserted into the FEC[19:0] Overhead bits, by the CEI Protocol Transmitter.
O5.4	When Forward Error Correction is enabled, a CEI Protocol Receiver should be able to correct a single burst of up to N (N = 7) errors within each FEC block.
CR5.5	When Forward Error Correction is implemented at a CEI Protocol Receiver, the function shall be configurable as being enabled or disabled.
O5.6	Implementation of Forward Error Correction at a CEI Protocol Receiver is optional.

**Table 10 CEI Protocol Forward Error Correction Requirements**

#### 8.4 Aggregation Layer Definition

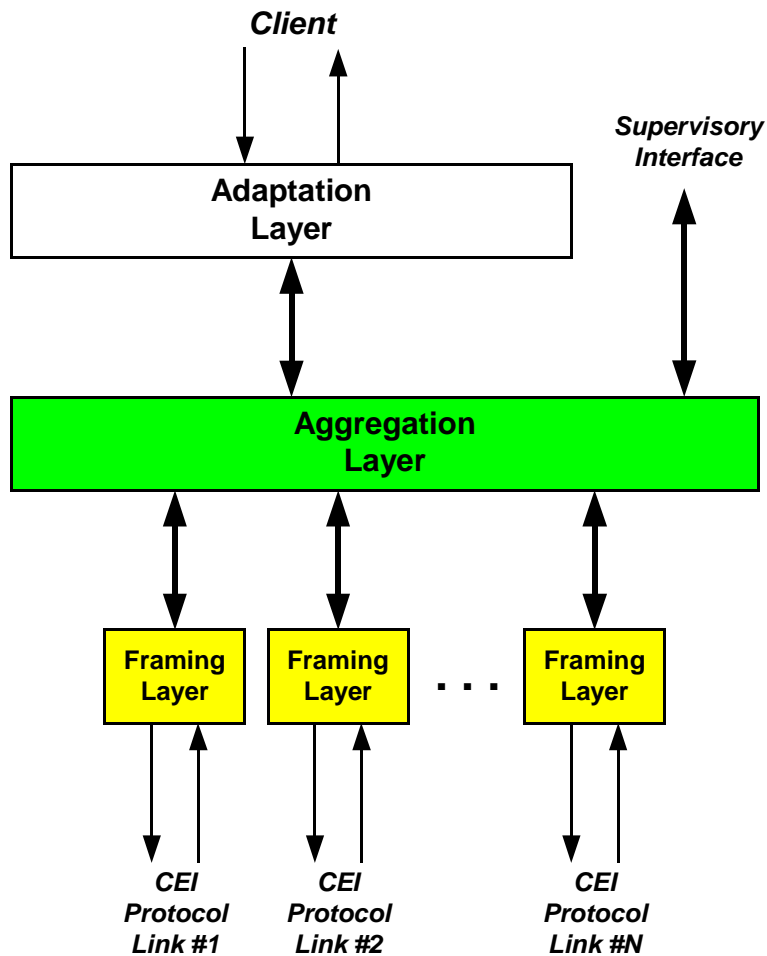
The Aggregation Layer is responsible for placing client data from the Adaptation Layer onto CEI Protocol links. Its function covers both multiplexing and inverse-multiplexing. Rate adaptation from the client signal rate to the CEI Protocol link rate is handled by the Adaptation layer. Thus, the interface between the Aggregation Layer and the Adaptation Layer can be timed by the CEI Protocol link(s). The Supervisory Interface is supported by the Aggregation layer.

In cases where clients have lower bandwidth than the CEI Protocol link, the Aggregation Layer can multiplex several clients onto a single link (See Figure 14). Logically, the Aggregation Layer process would have interfaces to multiple Adaptation Layer processes, one for each client, and a single interface to the Framing Layer process. The case where a client is a bus containing multiple physical links (E.g., 10GE over XAUI, SPI-4, SPI-5) is viewed as having only one Adaptation layer serving that client. De-skew of signals within the client bus, if necessary, is the responsibility of the Adaptation layer. The assignment of client data bits to CEI Protocol frame bits is defined in the clauses of the specific application.



**Figure 14 Logical Aggregation Layer Interfaces – Multiplexing**

In cases where a client has higher bandwidth than a CEI Protocol link, the Aggregation Layer distributes the client data over multiple links (See Figure 15). Logically, the Aggregation Layer process would have a single interface to the Adaptation Layer process, and multiple interfaces to the Framing Layer processes, one for each link. The Aggregation Layer at a CEI Protocol Receiver is responsible for de-skewing the data from the multiple CEI Protocol links. The theoretical range that the frame format is capable of de-skewing is  $\pm 792$  bits. Individual applications will set the de-skew limits to appropriate values. If multiframe is implemented, the Aggregation layer in the CEI Protocol Transmitter will ensure that the multiframe boundaries in all N Framing layer processes are aligned. The assignment of client data bits to CEI Protocol links and to bits within the CEI Protocol frames is defined in the clause of the specific application.



**Figure 15 Logical Aggregation Layer Interfaces – Inverse-Multiplexing**

Req. No.	Description
R6.1	For applications that multiplex multiple clients onto a single CEI Protocol link, the CEI Protocol Transmitter shall interleave the output of each Adaptation layer onto the Payload field of each CEI Protocol frame, in a round-robin fashion. The mapping and alignment of client data to the CEI Protocol frame (including grain size) shall be defined in the clauses of the specific application.



<b>Req. No.</b>	<b>Description</b>
R6.2	For applications that inverse-multiplex a client onto a set of CEI Protocol links, the CEI Protocol Transmitter shall distribute the client data onto the Payload field of the set of CEI Protocol frames, in a round-robin fashion. The mapping and alignment of client data to the CEI Protocol frames (including grain size), in the set of links, shall be defined in the clauses of the specific application.
R6.3	For applications that multiplex multiple clients onto a single CEI Protocol link, the CEI Protocol Transmitter/Receiver pair shall deliver data from each client source to the corresponding client sink.
R6.4	For applications that inverse-multiplex a client onto a set of CEI Protocol links, the CEI Protocol Receiver shall de-skew the set of CEI Protocol links. The range of skew to be tolerated shall be defined in the specific application.
R6.5	For applications that inverse-multiplex client onto a set of CEI Protocol links, the multiframe boundaries, if any, on the CEI Protocol links shall be aligned.

**Table 11 CEI Protocol Multiplexing Requirements**

Requirements R6.1 to R6.5 does not preclude applications where M clients share N CEI Protocol links. The M clients are expected to be frequency locked to each other. Such an application can be viewed logically as the serial instantiation of a Multiplexing Aggregation Layer followed by a Inverse Multiplexing Aggregation Layer. The M clients would first be concentrated onto a single Aggregation Layer Payload stream by a Multiplexing Aggregation Layer, and is then fed to a Inverse Multiplexing Aggregation Layer, where it is distributed to N Framing Layer functions.

#### **8.4.1 Supervisory Channel**

Optionally, the Aggregation layer provides a socket to support the Supervisory Interface. The use of this interface is application dependent. When implemented, data written to the Supervisory Interface are inserted into the Supervisory overhead bits (S[0:3]). The Supervisory overhead bits may be ganged into buses, or treated as individual signals. Data recovered from the Supervisory overhead bits are readable via the Supervisory Interface. The actual implementation of the Supervisory Interface and the mapping of Supervisory data onto S[0:3] is application specific. Examples uses of the Supervisory Interface include, data communications channel between cards, client status monitoring, and flow control messaging.

It is expected that a number of applications of the Supervisory channel can be supported by an HDLC data link. For those applications, a common HDLC frame

format is shown in Figure 16. Bit oriented HDLC in ISO-3309 [2] is used. Packets are delimited by flags ('b01111110) and protected by a CRC-16 parity check code. The Type field identifies the type and format of the message.

Flag (01111110)	TYPE (8 bits)	Application Specific Message (Variable length)	CRC-16	Flag (01111110)
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**Figure 16 Generic HDLC Frame of Supervisory Channel**

Type	Application	Description
00		Reserved
01	Lane Aggregation	Client Status
02	All	Parameter Read/Write
03-FC		Reserved
FD	Inter-chassis communications	System Vendor Specific
FE	Inter-card communications	Card Vendor Specific
FF	Inter-device communications	Device Vendor Specific

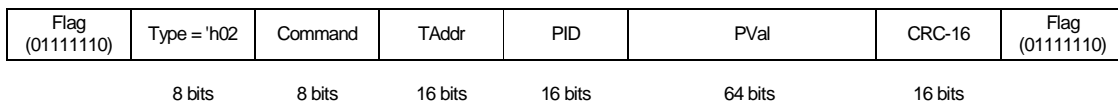
**Table 12 Assignment of Type field in Supervisory Channel Packets**

Req. No.	Description
O8.1	When implemented, the Aggregation layer should support a Supervisory Interface.
O8.2	When implemented, the Supervisory Interface in the Transmitter communicates with its peer in the Receiver via the Supervisory Overhead bits (S[0:3]). The organization of and the protocol carried over S[0:3] are application specific.
O.8.3	When an HDLC based Supervisory channel is implemented, the channel should use Supervisory Overhead bit S[0]. The organization of and the protocol carried over S[1:3] are application specific.
O8.3	When an HDLC based Supervisory channel is implemented, the CEI Protocol Transmitter should provide one or more software writable buffers to store transmit packets. Each buffer should be at least 64 bytes in size.
O8.4	When an HDLC based Supervisory channel is implemented, the CEI Protocol Transmitter should insert flags to delineate packets and insert zero stuff bits per reference [2]. The ability to compute and insert the CRC-16 parity check code automatically, in hardware, by the CEI Protocol Transmitter is not required.

O8.5	When an HDLC based Supervisory channel is implemented, the CEI Protocol Receiver should provide one or more software readable buffers to store received packets. Each buffer should be at least 64 bytes in size.
O8.6	When an HDLC based Supervisory channel is implemented, the CEI Protocol Receiver should delineate packets with flags and zero stuff bits per reference [2]. The ability to compute and verify CRC parity check code automatically, in hardware, by the CEI Protocol Receiver is not required.
O8.7	The contents of the TYPE field should be one listed in Table 12.
O8.8	When the Connection Identification option is disabled, the CID[16:0] code should be held at all-zeros.
O8.9	When Mode reporting is disabled, the APM[7:0], AGM[3:0] and FRM[1:0] codes should be held at all zeros.  Mode reporting is for further study and shall default to disabled in this revision of the IA.
O8.10	Implementation of the Supervisory Interface is optional.

**Table 13 CEI Protocol Supervisory Interface Requirements**

The Parameter Read/Write messages (Type=2) facilitate remote query and setting of parameters of devices at either end of a CEI Protocol link. The packet is fixed length and its format is shown in Figure 17 below. Figure 17 describes the individual fields within the frame.



**Figure 17 Parameter Read/Write Frame of Supervisory Channel**

Field	Description
Type	Set to 'h02 to identify packet as a Parameter Read/Write packet
Command	Action requests and responses
TAddr	Target entity of packet. A target is the set of CEI Protocol Transmitter, Receiver and the channel connecting them.
PID	Identity of parameter to be written or read
PVal	Value written to / read from specified parameter

**Table 14 Fields of Parameter Read/Write Packets**

The Command field defines the action taken by the Parameter Read/Write packet. Valid Command codes are listed in Table 15 below.

<b>Command</b>	<b>Name</b>	<b>Description</b>
00	NOP	
01	Read	Read specified parameter from target
02	ACK-Read	Response to Read. Value in PVal field.
03	Write	Write specified parameter with value in PVal field. Result of write reported in a ACK-Write packet.
04	Write-Incr	Increment specified parameter. Step size of increment defined by the sink device. Result of increment reported in a ACK-Write packet.
05	Write-Decr	Decrement specified parameter. Step size of increment defined by the sink device. Result of decrement reported in a ACK-Write packet.
06	ACK-Write	Reports result of Write, Write-Ince and Write-Decr commands
07	NACK-Error	Error detected in a Read, Write, Write-Ince and Write-Decr command.
08	NACK-NoParam	Specified parameter of Read, Write, Write-Ince and Write-Decr command is not supported by the targeted link.
09-FF	Reserved	

**Table 15 Command field of Parameter Read/Write Packets**

The Target Address (TAddr) field specifies the target entity of a Parameter Read/Write packet. The encodings of TAddr are listed in Table 16 below. The TAddr of ACK-Read, ACK-Write, NACK-Error, and NACK-NoParam response packets carry the TAddr value of the corresponding Read, Write, Write-Incr, and Write-Decr request packets.

TAddr	Description
0000	Specifies the link carrying the current Parameter Read/Write packet.
0001	Specifies the link carrying the response to the current Parameter Read/Write packet.
0002-0FFF	Reserved
1000-FFFF	Vendor specific

**Table 16 Target Address (TAddr) field of Parameter Read/Write Packets**

The Parameter Identifier (PID) field specifies the parameter to be accessed by a Parameter Read/Write packet. The encodings of TAddr are listed in Table 17 below. The PID of ACK-Read, ACK-Write, NACK-Error, and NACK-NoParam response packets carry the PID value of the corresponding Read, Write, Write-Incr, and Write-Decr request packets.

The PID code of “Announced Connection ID” is sent by the CEI Protocol Transmitter to identify the CID of the local link. It should only be sent as part of a Write packet and with a Target Address of 0x000 to specify the local link. The PID code of “Expected Connection ID” is used to set or query the expected CID of CEI Protocol Receivers at a remote device. PID codes “Announced MODE” and “Expected MODE” behaves similarly to their CID counterparts for announcing transmitter mode and setting receiver expectations.

PID	Description
0000 – 00FF	Receiver equalizer parameter number.
0100 – 01FF	Transmitter equalizer parameter number.
0200	Training Pattern
0201	Multiframe Length
0202	Announced Connection ID (CID)
0203	Announced MODE
0204	STATE
205	Expected Connection ID (CID)
206	Expected Mode
0207 – 0FFF	Reserved
1000 – FFF0	Vendor Specific
FFF1	CEI Clause (Read only)
FFF2	CEI Version (Read only)
FFF3	CEI-Protocol Version (Read only)

FFF4 – FFFE	Reserved
FFFF	JTAG IDCODE (Read only)

**Table 17 Parameter Identifier (PID) field of Parameter Read/Write Packets**

The Parameter Value (PVal) field is 64 bits wide. In cases where the parameter to be accessed is narrower, the value is left justified to PVal[63:63-(W-1)], where W is the width of the parameter. It is acceptable for the source to a Write packet to send a PVal with more bits of precision than the sink. In responses to such a Write command, the PVal field of the ACK-Write packet would echo the bits that are successfully captured and the complement of the bits that are not captured. For example, a source can compute equalizer tap settings to 7 bits of precision and sends the result on PVal[63:57]. The sink has only 6 bits of precision and captures PVal[63:58]. The ACK-Write response packet echoes PVal[63:58] and sets PVal[57:0] to the complement of what was in the Write command.

Optionally, the Aggregation Layer may insert a Connection Identification code (CID) into the Supervisory Channel of each CEI Protocol link. The CID may be monitored for correct connection between source and sink ports in systems with a large number of CEI Protocol links.

Req. No.	Description
O7.1	When implemented, the software configurable Connection Identification code should be reported over the Supervisory Channel at the CEI Protocol Transmitter.
O7.2	When implemented, the CEI Protocol Receiver should allow software access to the received Connection Identification code.
O7.3	Implementation of Connection Identification is optional.

**Table 18 CEI Protocol Connection Identifier Requirements**

The Connection ID bits are allocated to the Aggregation layer and are communicated using the facilities of the Supervisory Channel. CID is an optional feature. When implemented, Connection ID allows each CEI Protocol link within a system to be uniquely identified. The Connection Identifier is a software configurable field for labeling CEI Protocol links in a system. When CID is not enabled, CID bits default to all zeros. The Connection Identifier bits are expected to remain constant for the duration of a connection.

The Modes bits are allocated to the report the status of all three layers in CEI Protocol and are communicated using the facilities of the Supervisory Channel. Mode is an optional feature. When implemented, Mode bits provide overhead

bits for each layer in a CEI Protocol link to report status information. The definition of the Mode bits is shown in Table 19. The Mode bits are expected to remain constant for the duration of a connection.

Bit Assignment	Description
MODE[16:9] = APM[7:0]	Application Layer Mode, Reserved
MODE[8:4] = AGM[4:0]	Aggregation Layer Mode, Reserved
MODE[3:0] = FRM[3:0]	Framing Layer Mode, Reserved

**Table 19 Mode Code Assignment**

## 8.5 Adaptation Layer Definition

Definition of Adaptation Layer is application specific.

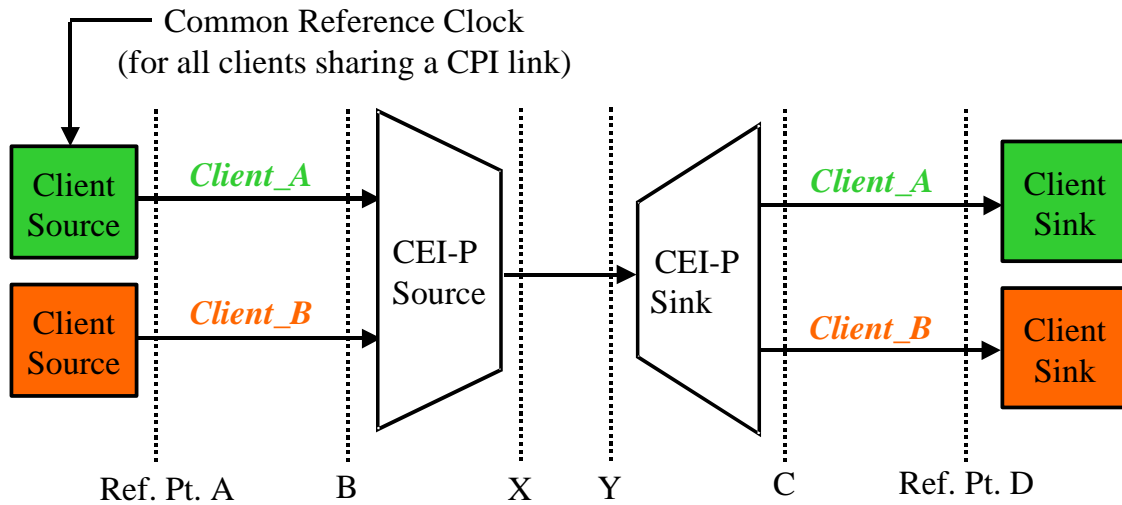
# 9 Lane Aggregation Application - no transcoding

## 9.1 Introduction

This clause addresses the application of aggregating multiple lower rate clients onto a single CEI Protocol link without the use of transcoding. Minimal impact on the client signals is desired. Thus, additional skew and latency are minimized. The number of clients that can be multiplexed is limited to powers of two, up to 128. The clients must be frequency locked to each other and have bounded relative wander. Although the Lane Aggregation Application is itself protocol agnostic, devices may be protocol specific and still be compliant to this clause.

Figure 1 shows an example of multiplexing two clients onto a single CEI Protocol link (this figure is reproduced below as Figure 18). Client\_A and Client\_B must be frequency locked to each other and have bounded wander. It is not necessary to further define the requirements and parameters of the client interfaces as they are already specified in standards relevant to the clients. For example, if the clients are two XAUI links, their characteristics are specified in IEEE 802.3. The CEI Protocol link has a data rate that is twice the client rate, multiplied by 1.03125, to accommodate the CEI Protocol Overhead bits. This factor of 1.03125 is identical to the factor used in 64b/66b based protocols such as 10G Ethernet LAN PHY and OIF SFI-4, Phase 2 [7].





**Figure 18 CEI Protocol Lane Aggregation Application**

## 9.2 Adaptation Layer Definition

The Adaptation Layer process performs data recovery on the client signals and maps the bits directly into the Payload region of a CEI Protocol frame. Rate adaptation is unnecessary, as the CEI Protocol link is frequency locked to the clients.

In the transmit direction, performance monitoring of client signals may be performed, but it is not a requirement. Consequential actions due to client signal failures are defined in the relevant standard of the client. They will be different for each client protocol. It is neither necessary nor possible to define them here. In the receive direction, failures on the CEI Protocol link may trigger alarm indications on the client signal. The exact mechanism of the alarm indication is defined in the relevant standard of the client. They will be different for each client protocol. It is neither necessary nor possible to define them here.

The following requirements apply to the Adaptation Layer process.

Req. No.	Description
R9.1	The Adaptation Layer shall conform to the electrical requirements of the standards relevant to the client interface. However, it is acceptable for a device compliant to this Implementation Agreement to place a further requirement that the clients are frequency locked.
R9.2	At a CEI Protocol Transmitter, the Adaptation Layer process shall be able to tolerate relative wander of at least <i>TBD</i> UI between clients.
R9.3	In the transmit direction, consequential actions, due to failures

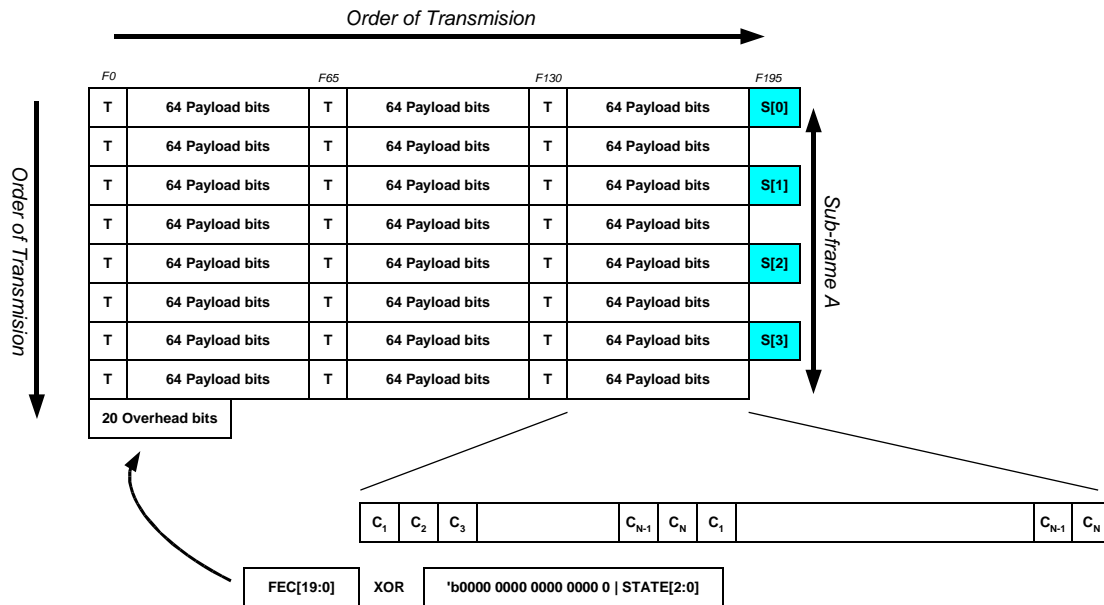


	in the client signal, shall not be defined in this IA.
R9.4	In the receive direction, consequential actions, due to failures in the CEI Protocol link, shall not be defined in this IA.

**Table 20 CEI Protocol Adaptation Layer Requirements**

### 9.3 Aggregation Layer Definition

The Aggregation Layer function is responsible for multiplexing of client data onto a CEI Protocol link. Client data is bit-interleaved onto the Payload region, avoiding the T bits, in a round-robin fashion. Data from the first client ( $C_1$ ) is always placed in the second bit of the CEI Protocol frame. Due to the limitation that the number of clients is a power of two, data from the last client ( $C_N$ ) naturally lands in the last bit of the last Payload region in each frame. Figure 19 shows the assignment of data from clients  $C_1$  to  $C_N$  onto a CEI Protocol frame. Processing of the Connection Identification code Overhead is defined in Clause 8.



**Figure 19 Client Assignment to CEI Protocol Frame**

Since the CEI Protocol links are independent in the Lane Aggregation applications, there is no requirement for the Aggregation Layer process to de-skew. In addition to those defined in Clause 6, the following requirements apply to the Aggregation Layer process.

Req. No.	Description
R10.1	At a CEI Protocol Transmitter, the Aggregation Layer process shall insert client data into the Payload region of a CEI Protocol

	frame in the order the data bits are received. Client data shall be aligned to the CEI Protocol frame and inserted in a bit-interleaved fashion. Data from the first client shall be in the second bit (F1) of the frame. The T bits shall be set to logical zeros.
R10.2	At a CEI Protocol Receiver, the AggregationAdaptation Layer process shall retrieve client data bits from the Payload region of a CEI Protocol frame and assign the bits to clients in the order the bits are received. Received data shall be distributed to clients in a bit de-interleaved fashion. Data from the first client shall be taken from the second bit (F1) of the frame. The T bits shall be ignored.

**Table 21 CEI Protocol Aggregation Layer Requirements**

The Lane Aggregation Source and Sink devices are optionally connected by a bi-directional data link using the Supervisory Interface. The data link uses the bit oriented HDLC protocol of ISO 3309 [2] and is expected to have very low bandwidth requirements. At the CEI Protocol Transmitter, system software constructs an HDLC packet and loads it into the buffer provided. The Transmitter inserts the delimiting flags and the necessary zero stuff bits and transmits the packet serially over Supervisory overhead bit S[0]. The remaining Supervisory overhead bits (S[3:1]) are reserved for future use and are set to logical zeros. The CEI Protocol Receiver monitors S[0] for packet arrivals. The received packet is recovered and the zero stuff bits are removed. The packet is then loaded into a buffer for reading by system software. It is acceptable for the CRC generation and verification to be performed by hardware or by software. As state in [2], the CRC generator polynomial is  $X^{16} + X^{12} + X^5 + 1$  and is initialized to all-ones.

Currently, one message type is defined to report the status of the client signals. The format of the client status packet is shown in Figure 20. The TYPE field is set to 'h01 to indicate that the packet is a Lane Aggregation, Client Status message. The status of each client is encoded in a two-bit code (CS[1:0]) and are listed sequentially in the message body of the HDLC packet (See Figure 20). Client #1 is listed first, and Client #N is listed last. The encoding of the client status is shown in Table 22.



**Figure 20 Client Status Message Format**

<b>CS[1:0]</b>	<b>Description</b>
00	No Alarm
01	Alarm
10	Alarm - Reserved
11	Alarm - Reserved

**Table 22 Client Status Codes**

<b>Req. No.</b>	<b>Description</b>
O11.1	When implemented, the data link between the CEI Protocol Transmitter and Receiver should be carried over Supervisory Overhead bit S[0] and use bit oriented HDLC protocol. S[3:1] are reserved and should be set to all zeros by the Transmitter. The Receiver should ignore S[3:1]. When the data link is not implemented, S[0] should be set to zero.
O11.2	When Client Status message is implemented, the status of each client should be encoded in the CS[1:0] field according to Table 22.
O11.3	When Client Status message is implemented, the packet should conform to  Figure 20. Client status codes (CS[1:0]) are listed sequentially beginning with Client #1 and ending with Client #N.
O11.4	Implementation of Client Status messaging is optional.

**Table 23 CEI Protocol Client Status Requirements**

#### 9.4 Framing Layer Definition

The CEI Protocol links are frequency locked to the Client links. Thus, in the transmit direction the CEI Protocol link rate is equal to client link rate multiplied by the number of clients and further multiplied by a factor of 1.03125 to account for the Overhead bits. In the receive direction, the client link rate is equal to the CEI Protocol link rate divided by the number of clients and by the overhead factor of 1.03125. It is outside the scope of this Implementation Agreement to define how the client and CEI Protocol link rates are maintained in frequency lock. Examples of acceptable methods include referencing the client and the CEI Protocol to a common reference and using clock recovery techniques on one signal (client or CEI Protocol) to generate reference for the other (CEI Protocol or client).

The Lane Aggregation application may be required to support a multiframe in the Framing layer if required by the intended clients. The length of the multiframe is

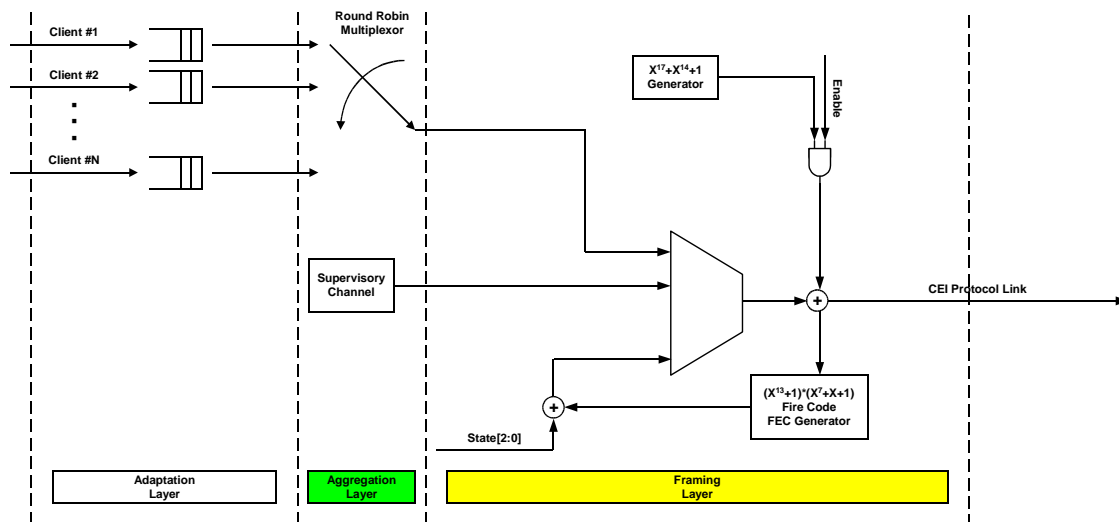
dependent on the client protocol. It is acceptable for a CEI Protocol Transmitter and receiver to support only the multiframe lengths necessary for their intended clients. A CEI Protocol Receiver is not required to automatically detect multiframe length from the MFAS markers in STATE[2:0].

In addition to those defined in Clause 6, the following requirements apply to the Framing Layer process.

Req. No.	Description
R12.1	Client links shall meet the electrical characteristics as defined in the relevant standards.
R12.2	The CEI Protocol transmit link rate shall be given by :  Client_Link_Rate * Number_of_Clients * 1.03125.
R12.3	The Client link rate at a CEI Protocol Receiver shall be given by :  CEI_Protocol_Link_Rate / (Number_of_Clients * 1.03125)
CR12.4	A CEI Protocol Transmitter and receiver shall support multiframe in overhead bits STATE[2:0] if required by the client signal.

**Table 24 CEI Protocol Framing Layer Requirements**

The construction of a CEI Protocol frame is shown logically in Figure 21. Other implementations are possible.



**Figure 21 Logical Frame Construction in Lane Aggregation Application**

## 10 TFI-5 Aggregation Application

### 10.1 Introduction

This clause addresses the application of aggregating multiple TFI-5 clients at 2.48832 Gb/s onto a single CEI Protocol link without the use of transcoding. Minimal impact on the client signals is desired. The number of TFI-5 clients at 2.48832 Gb/s, that can be multiplexed, is limited to even numbers, by the frequency range of available electrical layers defined by CEI [3], which results in 2 and 4. Nevertheless the defined mapping scheme is written in a generic way, which would also allow supporting higher aggregation levels for future electrical standards.

The clients must be frequency locked to each other and have bounded relative wander. Although the Lane Aggregation Application is itself protocol agnostic, devices may be protocol specific and still be compliant to this clause.

Figure 22 shows an example of multiplexing two TFI-5 clients onto a single CEI Protocol link. Client\_A and Client\_B must be frequency locked to each other and have bounded wander. Requirements and parameters of the TFI-5 client interfaces shall comply with OIF-TFI5-01.0 [5]. The CEI Protocol link has a data rate that is twice the client rate, multiplied by 1.03125, to accommodate the CEI Protocol Overhead bits. This factor of 1.03125 is identical to the factor used in 64b/66b based protocols such as 10G Ethernet LAN PHY and OIF SFI-4, Phase 2 [7].

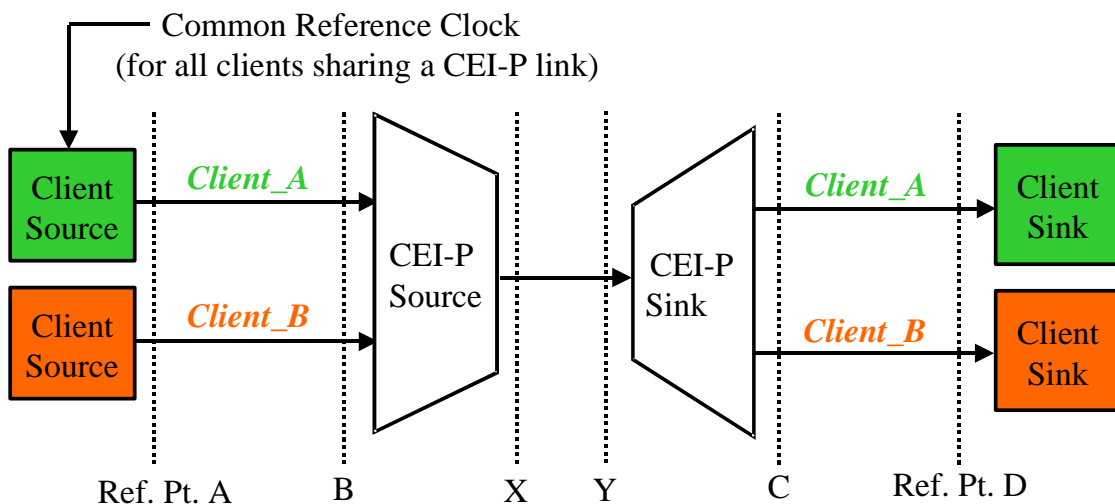


Figure 22: CEI Protocol TFI-5 Aggregation Application

## 10.2 TFI-5 Client Adaptation Layer Definition

The Adaptation Layer process performs data recovery on the client signals and maps the bytes directly into the Payload region of a CEI Protocol frame. Rate adaptation is unnecessary, as the CEI Protocol link is frequency locked to the clients.

In the transmit direction, performance monitoring of client signals may be performed, but it is not a requirement. Consequential actions due to client signal failures are specified in OIF-TFI5-01.0 [5]. In the receive direction, failures on the CEI Protocol link may trigger alarm indications on the TFI-5 signal. The exact mechanism of the alarm indication is specified in OIF-TFI5-01.0 [5].

The following requirements apply to the Adaptation Layer process.

Req. No.	Description
R_TFI-5_1	The Adaptation Layer shall conform to the electrical requirements of the standards relevant to the TFI-5 client interface. However, it is acceptable for a device compliant to this Implementation Agreement to place a further requirement that the clients are frequency locked.
R_TFI-5_2	At a CEI Protocol Transmitter, the Adaptation Layer process shall be able to tolerate relative wander of at least <i>TBD</i> UI between TFI-5 clients.

**Table 25: TFI-5 CEI Protocol Adaptation Layer Requirements**

In the transmit direction, consequential actions, due to failures in the TFI-5 client signal, are not defined in this IA. In the receive direction, consequential actions, due to failures in the CEI Protocol link, are not specified in this IA.

## 10.3 TFI-5 Client Aggregation Layer Definition

The Aggregation Layer function is responsible for multiplexing of TFI-5 client (2.48832 Gb/s) data onto a CEI Protocol link. TFI-5 client data is byte-interleaved onto the Payload region, without using the T bit positions, in a round-robin fashion. For details please refer to Figure 23 and Figure 24. The frame start of the TFI-5 client signals is aligned with the start of the first CEI-P multiframe. The first A1 byte of client A is placed in F1 – F8, the first A1 of client B in F9 – F16 of the CEI-P frame and so forth. The bits of the bytes are inserted MSB first: F1 carries the MSB of A1 and F8 the LSB. Due to the limitation that the number of clients is an even number, the first A1 byte of client A always lands again at position F1 – F8 at the beginning of the next CEI-P multiframe. The first frame of the CEI-P multiframe will be marked MFAS, as described in OIF-CEI-P-01.0 in Clause 8.2.1, Table 3 with STATE[2:0] = ‘b011 or ‘b001.

Since the CEI Protocol links are independent in the Lane Aggregation applications, there is no requirement for the Aggregation Layer process to de-skew. In addition to those defined in OIF-CEI-P-01.0, Clause 6, the following requirements apply to the TFI-5 Client Aggregation Layer process.

<b>Req. No.</b>	<b>Description</b>
R_TFI-5_10	At a CEI Protocol Transmitter, the Aggregation Layer process shall insert TFI-5 client data into the Payload region of a CEI Protocol frame in the order the data bytes are received. TFI-5 Client data shall be inserted frame aligned to the CEI Protocol frame and inserted in a byte-interleaved fashion. The first data byte from the first client shall be inserted in the bits F1 – F8 of the frame; the first byte from the second client gets inserted into bits F9 – F16 and so forth. The bits of a byte are inserted MSB first, e.g. F1 carries the MSB and F8 the LSB of the byte. The T bits shall be set to logical zeros.
R_TFI-5_11	The frame aligned insertion of the TFI-5 client signals (2.48832 Gb/s) into the CEI Protocol multiframe shall work in such a way that the first A1 byte of the first client is inserted in F1 – F8 of the first frame of the CEI-P multiframe, the first A1 byte of the next TFI-5 client in F9 – F16 and so forth. The insertion is continued byte wise in a round robin fashion. As one TFI-5 client requires a payload area of 202.5 CEI-P frames, aggregating an even number of TFI-5 clients always results in the A1 bytes being placed at the same position of the first frame of the CEI-P multiframe.
R_TFI-5_12	At a CEI Protocol Receiver, the Aggregation Layer process shall retrieve client data bytes from the Payload region of a CEI Protocol frame and assign the bytes to clients in the order the bytes are received. Received data shall be distributed to clients in a byte de-interleaved fashion. Data for the first client shall be taken from the byte on F1 – F8 of the frame, data for the second client shall be taken from the byte on F9 – F16 of the frame and so forth. The T bits shall be ignored.

**Table 26: TFI-5 Client CEI Protocol Aggregation Layer Requirements**

### 10.3.1 Aggregation of 2 TFI-5 Client Signals into a CEI-P frame

Mapping two TFI-5 Client Signals with a rate of 2.48832 Gb/s into CEI-P results in a CEI-P rate of 5.13216 Gb/s. The two complete TFI-5 frames require a CEI-P multiframe, which consists of 405 single CEI-P frames. Figure 23 shows the assignment of data from Clients A and B into a CEI Protocol frame.

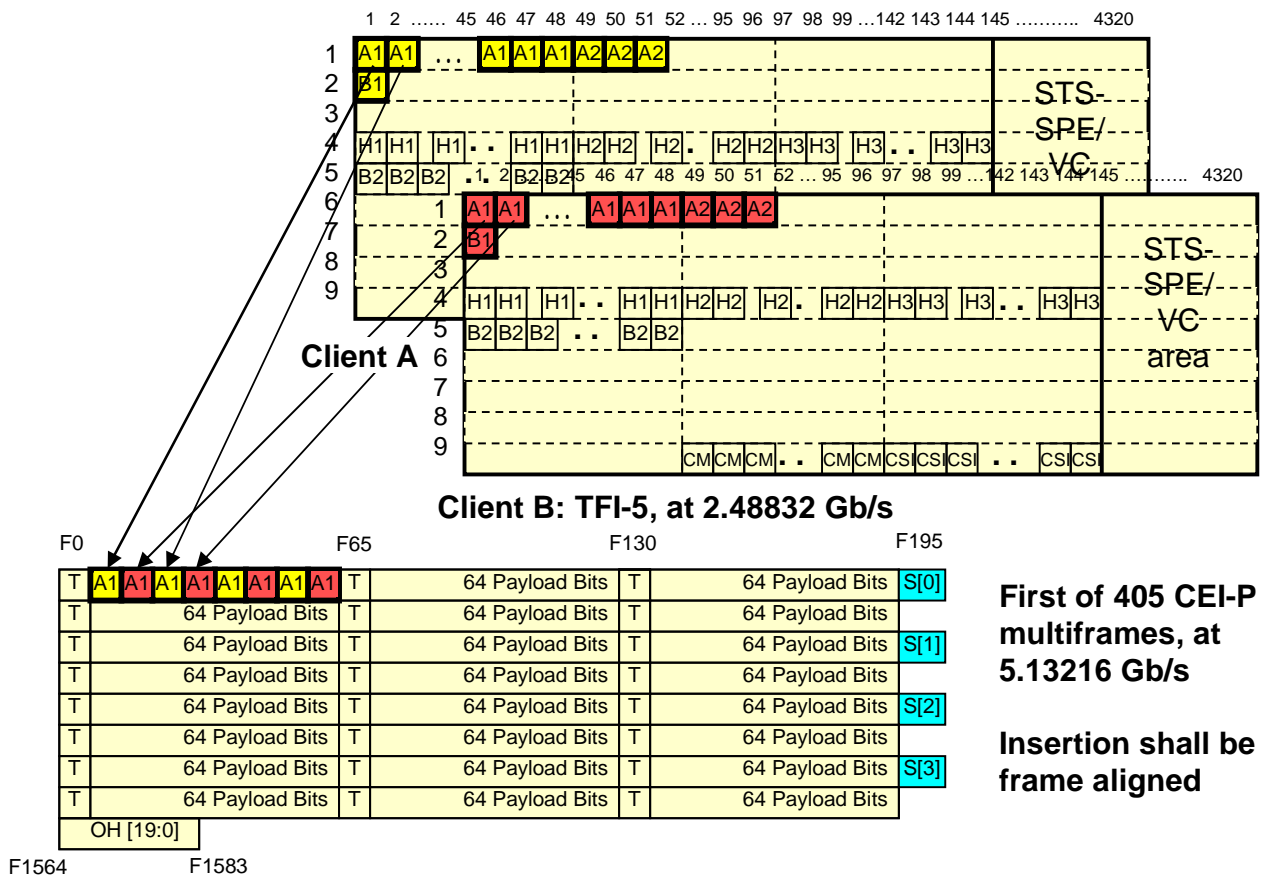
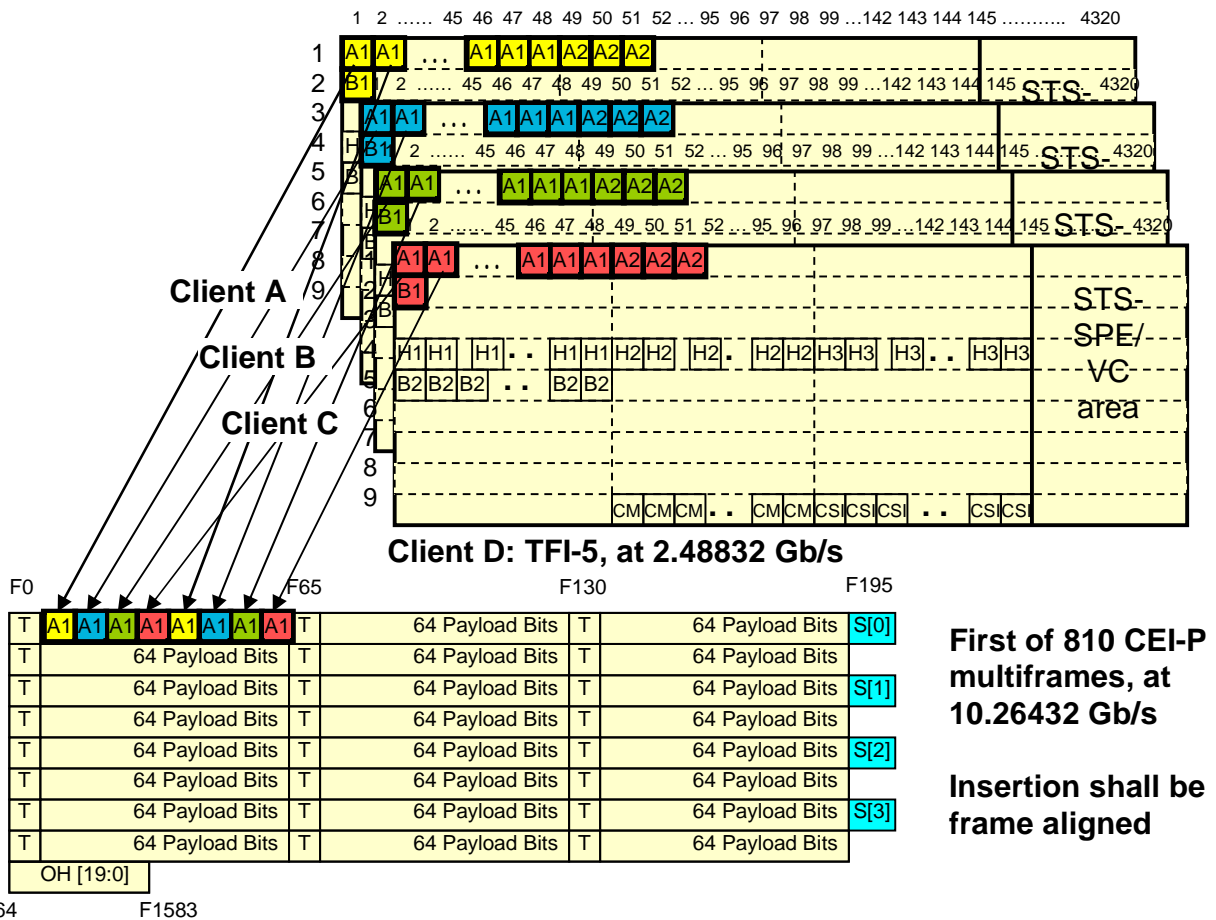


Figure 23: Aggregation of 2 TFI-5 Client Signals into CEI Protocol Frame



**10.3.2 Aggregation of 4 TFI-5 Client Signals into a CEI-P frame**

Mapping four TFI-5 Client Signals with a rate of 2.48832 Gb/s into CEI-P results in a CEI-P rate of 10.26432 Gb/s. The four complete TFI-5 frames require a CEI-P multiframe, which consists of 810 single CEI-P frames. Figure 24 shows the assignment of data from Clients A, B, C and D into a CEI Protocol frame.



**Figure 24: Aggregation of 4 TFI-5 Client Signals into CEI Protocol Frame**

### 10.4 TFI-5 Client Framing Layer Definition

The CEI Protocol links are frequency locked to the TFI-5 Client links. Thus, in the transmit direction the CEI Protocol link rate is equal to the TFI-5 client link rate multiplied by the number of clients and further multiplied by a factor of 1.03125 to account for the Overhead bits. In the receive direction, the client link rate is equal to the CEI Protocol link rate divided by the number of clients and by the overhead factor of 1.03125. Methods for maintaining frequency lock of clients and CEI protocol link rates are not specified. Examples of acceptable methods include referencing the client and the CEI Protocol to a common reference and using clock recovery techniques on one signal (client or CEI Protocol) to generate reference for the other (CEI Protocol or client).

The TFI-5 Client Lane Aggregation application requires supporting a multiframe in the Framing Layer. The length of the multiframe is dependent on the TFI-5 client protocol. As one TFI-5 frame at 2.48832 Gb/s fits into the payload area of 202.5 CEI-P frames, the length of the required multiframe is 202.5 times the number of aggregated TFI-5 clients. It is acceptable for a CEI Protocol Transmitter and receiver to support only the multiframe lengths necessary for their intended clients. A CEI Protocol Receiver is not required to automatically detect multiframe length from the MFAS markers in STATE[2:0].

In addition to those defined in OIF-CEI-P-01.0, Clause 6, the following requirements apply to the Framing Layer process.

Req. No.	Description
R_TFI-5_21	The CEI Protocol transmit link rate shall be given by :  $\text{TFI-5\_Client\_Link\_Rate} * \text{Number\_of\_TFI-5\_Clients} * 1.03125.$
R_TFI-5_22	The TFI-5 Client link rate at a CEI Protocol Receiver shall be given by :  $\text{CEI\_Protocol\_Link\_Rate} / (\text{Number\_of\_TFI-5\_Clients} * 1.03125)$
R_TFI-5_23	The first frame of a CEI-P multiframe carrying TFI-5 client signals shall be marked with MFAS on the STATE[2:0] bits as described in OIF-CEI-P-01.0 in Clause 8.2.1 , Table 3. This additional information can be used to simplify the TFI-5 framer implementation required after the CEI-P Receiver.  The length of the multiframe for TFI-5 clients at 2.48832 Gb/s is given by:  $\text{Number\_of\_TFI-5\_Clients} * 202.5$

**Table 27: TFI-5 Client CEI Protocol Framing Layer Requirements**

## 11 TDM-P Aggregation Application

### 11.1 Introduction

This clause addresses the application of aggregating multiple TDM-P clients at speeds of multiples of 2.48832 Gb/s onto a single CEI Protocol link without the use of transcoding. Minimal impact on the client signals is desired. The number of TDM-P clients described in this clause, that can be multiplexed, is limited by the frequency range of available electrical layers defined by CEI [3], which results in 1 and 2. Nevertheless the defined mapping scheme is written in a generic way, which would also allow supporting higher aggregation levels for future electrical standards.

The clients must be frequency locked to each other and have bounded relative wander. Although the Lane Aggregation Application is itself protocol agnostic, devices may be protocol specific and still be compliant to this clause.

Figure 25 shows an example of multiplexing two TDM-P clients onto a single CEI Protocol link. Client\_A and Client\_B must be frequency locked to each other and have bounded wander. Requirements and parameters of the TDM-P client interfaces shall comply with OIF-TDM-P-01.0 [6]. The CEI Protocol link has a data rate that is twice the client rate, multiplied by 1.03125, to accommodate the CEI Protocol Overhead bits. This factor of 1.03125 is identical to the factor used in 64b/66b based protocols such as 10G Ethernet LAN PHY and OIF SFI-4, Phase 2 [7].

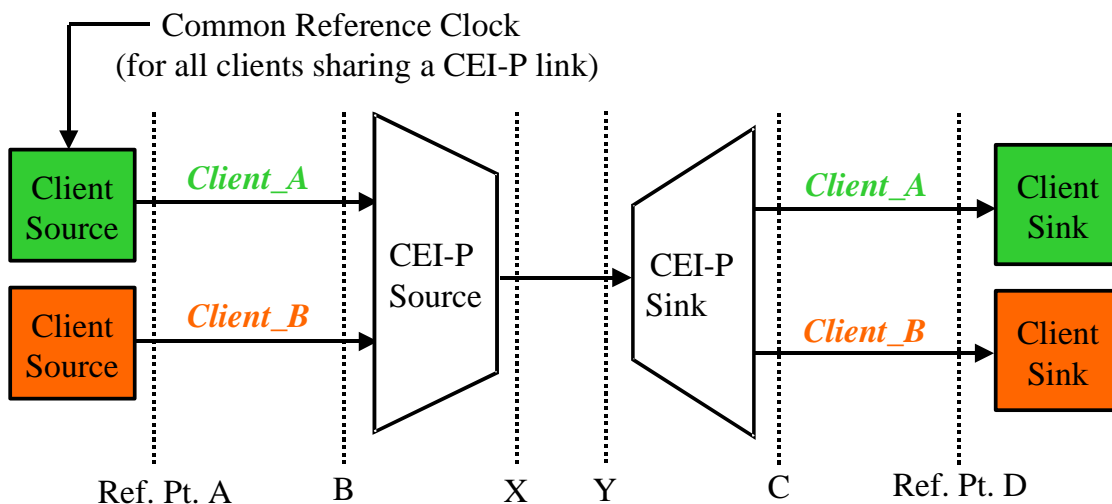


Figure 25: CEI Protocol TDM-P Aggregation Application

## 11.2 TDM-P Client Adaptation Layer Definition

The Adaptation Layer process performs data recovery on the client signals and maps the bytes directly into the Payload region of a CEI Protocol frame. Rate adaptation is unnecessary, as the CEI Protocol link is frequency locked to the clients.

In the transmit direction, performance monitoring of client signals may be performed, but it is not a requirement. Consequential actions due to client signal failures are specified in OIF-TDM-P-01.0 [6]. In the receive direction, failures on the CEI Protocol link may trigger alarm indications on the TDM-P signal. The exact mechanism of the alarm indication is specified in OIF-TDM-P-01.0 [6].

The following requirements apply to the Adaptation Layer process.

Req. No.	Description
R_TDM-P_1	The Adaptation Layer shall conform to the electrical requirements of the standards relevant to the TDM-P client interface. However, it is acceptable for a device compliant to this Implementation Agreement to place a further requirement that the clients are frequency locked.
R_TDM-P_2	At a CEI Protocol Transmitter, the Adaptation Layer process shall be able to tolerate relative wander of at least <i>TBD</i> UI between TDM-P clients.

**Table 28: TDM-P CEI Protocol Adaptation Layer Requirements**

In the transmit direction, consequential actions, due to failures in the TDM-P client signal, are not defined in this IA. In the receive direction, consequential actions, due to failures in the CEI Protocol link, are not specified in this IA.

## 11.3 TDM-P Client Aggregation Layer Definition

The Aggregation Layer function is responsible for multiplexing of TDM-P client (multiples of 2.48832 Gb/s) data onto a CEI Protocol link. TDM-P client data is byte-interleaved onto the Payload region, without using the T bit positions, in a round-robin fashion. For details please refer to Figure 26 and Figure 27. The frame start of the TDM-P client signals is aligned with the start of the first CEI-P multiframe. The first A1 byte of client A is placed in F1 – F8, the first A1 of client B in F9 – F16 of the CEI-P frame and so forth. The bits of the bytes are inserted MSB first: F1 carries the MSB of A1 and F8 the LSB. Due to the limitation to TDM-P clients at a rate of multiples of 2.48832 Gb/s, the first A1 byte of client A always lands again at position F1 – F8 at the beginning of the next CEI-P multiframe. The first frame of the CEI-P multiframe will be marked MFAS, as described in OIF-CEI-P-01.0 in Clause 8.2.1, Table 3 with STATE[2:0] = 'b011 or 'b001.

Since the CEI Protocol links are independent in the Lane Aggregation applications, there is no requirement for the Aggregation Layer process to de-skew. In addition to those defined in OIF-CEI-P-01.0, Clause 6, the following requirements apply to the TDM-P Client Aggregation Layer process.

Req. No.	Description
R_TDM-P_10	At a CEI Protocol Transmitter, the Aggregation Layer process shall insert TDM-P client data into the Payload region of a CEI Protocol frame in the order the data bytes are received. TDM-P Client data shall be inserted frame aligned to the CEI Protocol frame and inserted in a byte-interleaved fashion. The first data byte from the first client shall be inserted in the bits F1 – F8 of the frame; the first byte from the second client gets inserted into bits F9 – F16 and so forth. The bits of a byte are inserted MSB first, e.g. F1 carries the MSB and F8 the LSB of the byte. The T bits shall be set to logical zeros.
R_TDM-P_11	The frame aligned insertion of the TDM-P client signals into the CEI Protocol multiframe shall work in such a way that the first A1 byte of the first client is inserted in F1 – F8 of the first frame of the CEI-P multiframe, the first A1 byte of the next TDM-P client in F9 – F16 and so forth. The insertion is continued byte wise in a round robin fashion. As one TDM-P client at 4.97664 Gb/s requires a payload area of 405 and at 9.95328 Gb/s of 810 CEI-P frames, aggregating TDM-P clients always results in the A1 bytes being placed at the same position of the first frame of the CEI-P multiframe.
R_TDM-P_12	At a CEI Protocol Receiver, the Aggregation Layer process shall retrieve client data bytes from the Payload region of a CEI Protocol frame and assign the bytes to clients in the order the bytes are received. Received data shall be distributed to clients in a byte de-interleaved fashion. Data for the first client shall be taken from the byte on F1 – F8 of the frame, data for the second client shall be taken from the byte on F9 – F16 of the frame and so forth. The T bits shall be ignored.

**Table 29: TDM-P Client CEI Protocol Aggregation Layer Requirements**

### 11.3.1 Aggregation of 2 TDM-P Client Signals into a CEI-P frame

Mapping two TDM-P Client Signals with a rate of 4.97664 Gb/s into CEI-P results in a CEI-P rate of 10.26432 Gb/s. The two complete TDM-P frames require a CEI-P multiframe, which consists of 810 single CEI-P frames. Figure 26 shows the assignment of data from Clients A and B into a CEI Protocol frame.

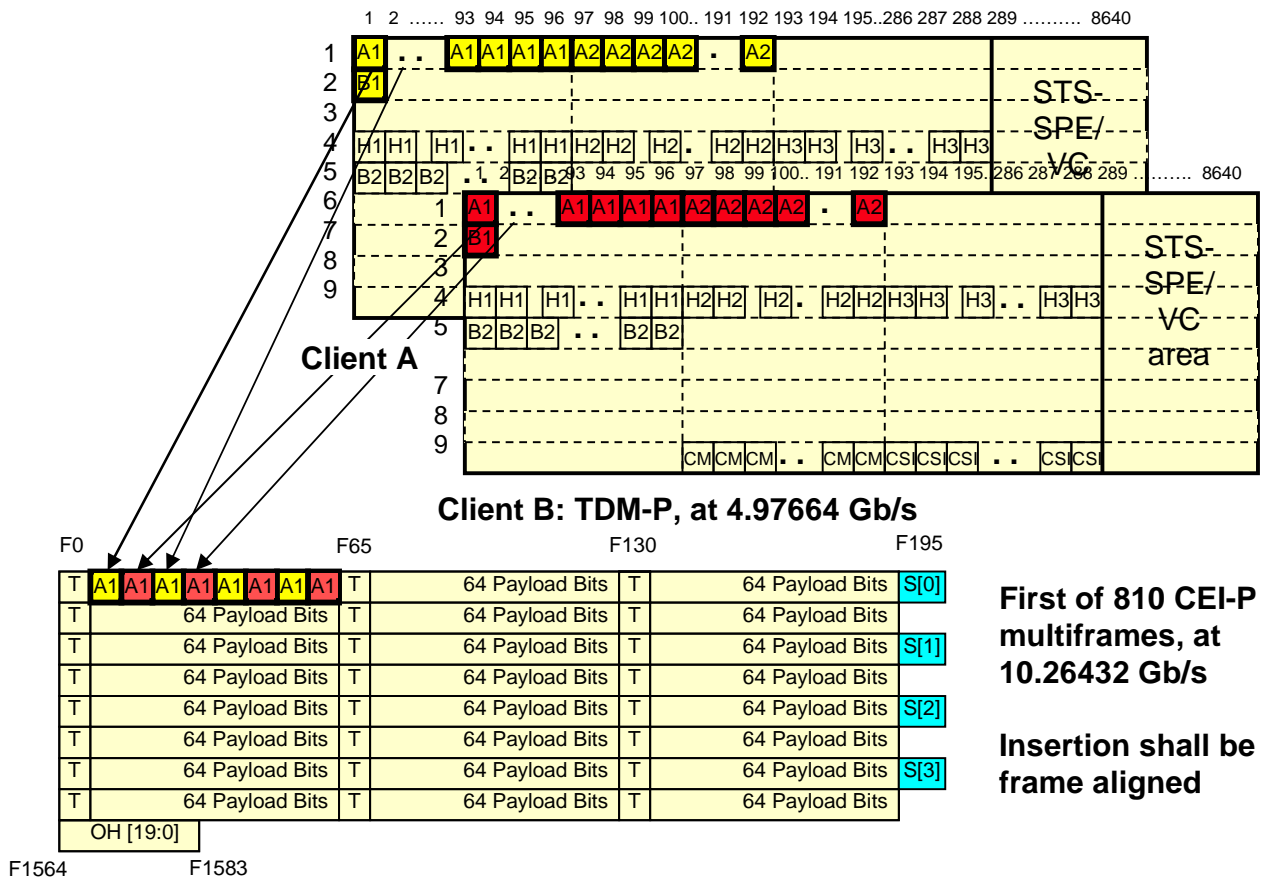


Figure 26: Aggregation of 2 TDM-P Client Signals (4.97664 Gb/s) into CEI Protocol Frame





#### 11.4 TDM-P Client Framing Layer Definition

The CEI Protocol links are frequency locked to the TDM-P Client links. Thus, in the transmit direction the CEI Protocol link rate is equal to the TDM-P client link rate multiplied by the number of clients and further multiplied by a factor of 1.03125 to account for the Overhead bits. In the receive direction, the client link rate is equal to the CEI Protocol link rate divided by the number of clients and by the overhead factor of 1.03125. Methods for maintaining frequency lock of clients and CEI protocol link rates are not specified. Examples of acceptable methods include referencing the client and the CEI Protocol to a common reference and using clock recovery techniques on one signal (client or CEI Protocol) to generate reference for the other (CEI Protocol or client).

The TDM-P Client Lane Aggregation application requires supporting a multiframe in the Framing Layer. The length of the multiframe is dependent on the TDM-P client protocol. As one TDM-P frame at 4.97664 Gb/s fits into the payload area of 405 CEI-P frames, the length of the required multiframe is 405 times the number of aggregated 4.97664 Gb/s TDM-P clients. As one TDM-P frame at 9.95328 Gb/s fits into the payload area of 810 CEI-P frames, the length of the required multiframe is 810 times the number of aggregated 9.95328 Gb/s TDM-P clients.

It is acceptable for a CEI Protocol Transmitter and receiver to support only the multiframe lengths necessary for their intended clients. A CEI Protocol Receiver is not required to automatically detect multiframe length from the MFAS markers in STATE[2:0].

In addition to those defined in OIF-CEI-P-01.0, Clause 6, the following requirements apply to the Framing Layer process.

Req. No.	Description
R_TDM-P_21	The CEI Protocol transmit link rate shall be given by:  $\text{TDM-P\_Client\_Link\_Rate} * \text{Number\_of\_TDM-P\_Clients} * 1.03125.$
R_TDM-P_22	The TDM-P Client link rate at a CEI Protocol Receiver shall be given by:  $\text{CEI\_Protocol\_Link\_Rate} / (\text{Number\_of\_TDM-P\_Clients} * 1.03125)$
R_TDM-P_23	The first frame of a CEI-P multiframe carrying TDM-P client signals shall be marked with MFAS on the STATE[2:0] bits as described in OIF-CEI-P-01.0 in Clause 8.2.1, Table 3. This additional information can be used to simplify the TDM-P framer implementation required after the CEI-P Receiver.



	<p>The length of the multiframe for TDM-P clients at 4.97664 Gb/s is given by:</p> $\text{Number\_of\_TDM-P\_Clients} * 405$ <p>The length of the multiframe for TDM-P clients at 9.95328 Gb/s is given by:</p> $\text{Number\_of\_TDM-P\_Clients} * 810$
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**Table 30: TDM-P Client CEI Protocol Framing Layer Requirements**

## **12 Future OIF Interface Application**

### **12.1 Introduction**

### **12.2 Adaptation Layer Definition**

### **12.3 Aggregation Layer Definition**

### **12.4 Framing Layer Definition**

## **13 Summary**

## **14 Glossary**

CEI	Common Electrical I/O
CEI-P	Common Electrical I/O Protocol
FEC	Forward Error Correction
LAN	Local Area Network
LSB	Least Significant Bit
MFAS	Multiframe Alignment Signal
MSB	Most Significant Bit
PHY	Physical Interface
SFI-4	SERDES Framer Interface Level 4
TFI-5	TDM Fabric to Framer Interface
TDM-P	TDM System Interface Protocol

## 15 References

### 15.1 Normative references

- [1] S. Lin and D. Costello, *Error Control Coding: Fundamentals and Applications*, Prentice Hall, Englewood Cliffs, New Jersey, 1983
- [2] International Organization for Standards, ISO Standard 3309-1993, “Information Technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures – Frame structure”, December 1993.
- [3] Optical Internetworking Forum OIF-CEI-02.0, “ Common Electrical I/O (CEI) – Electrical and Jitter Interoperability agreement for 6G+ bps and 11G+ bps I/O”
- [4] International Telecommunication Union, ITU-T G.7041/Y.1303, “Generic framing procedure (GFP)”, December 2001.
- [5] Optical Internetworking Forum OIF-TFI5-01.0, “TDM Fabric to Framer Interface (TFI-5)”
- [6] Optical Internetworking Forum OIF-TDM-P-01.0, “TDM System Interface Protocol”

### 15.2 Informative references

- [7] Optical Internetworking Forum OIF-SFI4-02.0, “SERDES Framer Interface Level 4 (SFI-4) Phase 2: Implementation Agreement for 10 Gb/s Interface for Physical Layer Devices”

## **16 Appendix A: Default Values of Variables**

This normative annex lists the default values of variables used in this Implementation Agreement.

<b>Variable</b>	<b>Description</b>	<b>Value</b>
N1	Frame boundary candidate searched	N/A
M1	Number of consecutive frames with Fire Code check parity errors to go Out-Of-Frame	15
M2	Number of consecutive frames with good Fire Code check parity to go In-Frame	4
M3	Bad MFAS patterns to go OOM	3
M4	Good MFAS to go IM	1
D1	Time-out for CEI Protocol Receiver Training	TBD
R1	Number of consecutive frame of consistent STATE[2:0] to accept received value	TBD

**Table 31 Default values of variables**

## **17 Appendix B: Framing Process in a CEI Protocol Receiver**

This informative appendix describes the framing process in a CEI Protocol receiver.

The framing process (E.g., from power-up) involves locating the CEI Protocol frame boundaries and simultaneously synchronizing the stream cipher de-scrambler. A CEI Protocol receiver first searches for the frame boundaries by selecting a potential frame boundary and then computing the corresponding Fire Code Parity bits from the received data. The difference between the computed Fire Code Parity and the Overhead bits in the candidate frame is assumed to be due to scrambling. The scrambler state is initialized by the difference vector and allowed to free-run. The potential frame boundary becomes the candidate frame boundary if the computed Fire Code Parity bits matches the received bits, after de-scrambling, at the next frame. If the parity bits do not match, a new frame boundary is examined. Once a candidate framing boundary is found, the framer examines multiple Fire Codes Parities in a sequence of frames to build confidence in the candidate frame boundary.

Figure 28 below shows a logical model of a CEI Protocol receiver. Actual implementation may differ.

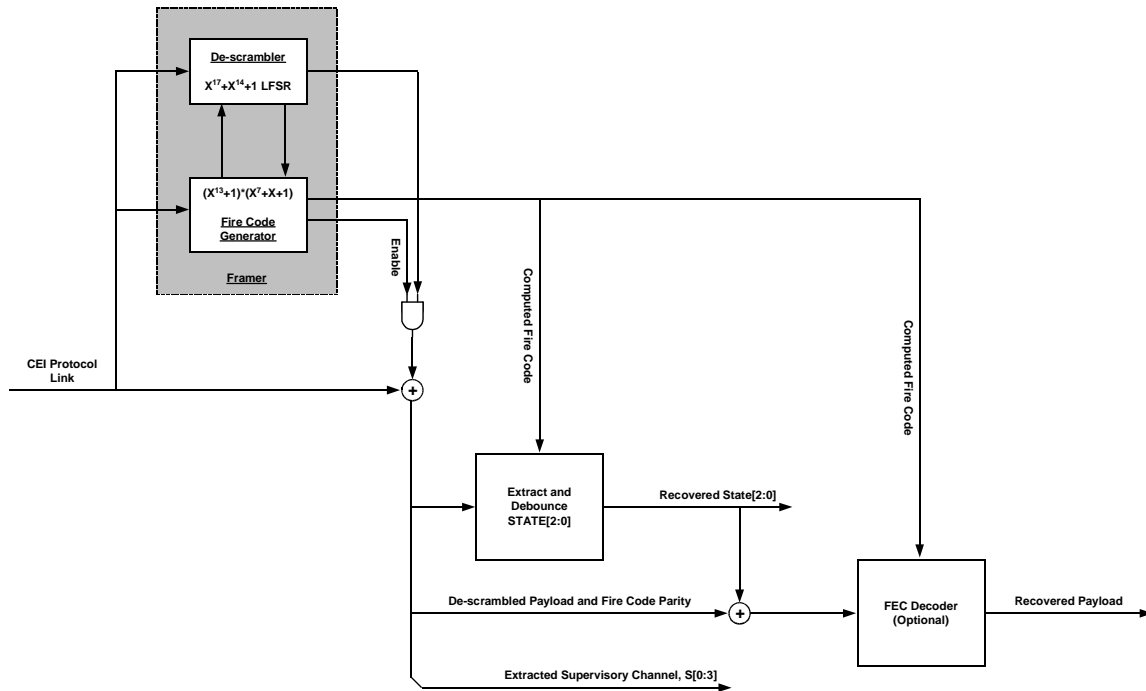


Figure 28 Frame Receiver Process – Logical Block Diagram

## 18 Appendix C: Sample CEI Protocol Frame

This informative appendix shows a sample CEI Protocol frame.

Figure 29 below shows a sample CEI Protocol Frame. In this frame, all Payload, Transcoding (T), Supervisory (S[0:3]) and State (STATE[2:0]) bits are set to zero prior to scrambling. Contents of the frame after scrambling, is shown below. At the first bit of the frame (F0), the scrambler is assumed to have an initial state of all-ones. The unscrambled Fire Code parity (FEC[19:0]) for this frame is 'h278B4 and the scrambler sequence used to scramble it is 'h430B2. After scrambling the Fire Code parity is 'h64806.

1	FFFF0003800FC038	1	C1FFE7006F8189C6	1	C7F1FC3F0EE3BCFF	0
0	B60C83344D4B1389	1	8FC7F8FC1F8E71FE	1	FE0907209F1233C1	
1	ADCF61DA3785C5D5	1	EB7A58544D7B1351	1	89DFE3907F89C1E3	1
1	9DF9B91A38E5FFE5	0	00CD03528CE375FC	0	DA1F057397779665	
1	254907809DC239E9	1	F6A621CB97CB94CB	1	32975316E5D0E5AB	1
1	91E98F52FAE296FB	0	2123941F9A71A4FE	0	830C4DB71007C81C	
1	88FAE796ED90C08B	0	C4D07129FC330ED5	1	78785DDD599BCAA2	1
1	3F696211394C7997	1	B5290E30BFDAA087	1	A4B940B9A2BA5BB4	
278B4 XOR 430B2 =						
64806						

**Figure 29 Sample CEI Protocol Frame**

## 19 Appendix D: List of companies belonging to OIF when document is approved

ADVA Optical Networking	Flextronics	Nokia Siemens Networks
Agilent Technologies	Force 10 Networks	Nortel Networks
Alcatel-Lucent	Foxconn	NTT Corporation
Altera	France Telecom	Opnext
AMCC	Freescale Semiconductor	PMC Sierra
Analog Devices	Fujitsu	Sandia National Laboratories
Anritsu	Furukawa Electric Japan	Santur
AT&T	Huawei Technologies	Sierra Monolithics
Avago Technologies Inc.	IBM Corporation	Silicon Logic Engineering
Avalon Microelectronics	IDT	Soapstone Networks
Avanex Corporation	Infinera	Sycamore Networks
Bookham	Intel	Syntune
Booz-Allen & Hamilton	IP Infusion	Tektronix
Broadcom	JDSU	Telcordia Technologies
BT	KDDI R&D Laboratories	Telecom Italia Lab
China Telecom	Level 3 Communications	Tellabs
Ciena Corporation	LSI Logic	Texas Instruments
Cisco Systems	Marben Products	Time Warner Cable
ClariPhy Communications	MergeOptics GmbH	Transwitch
CoreOptics	Mintera	Tyco Electronics
Cortina Systems	MITRE Corporation	Verizon
Data Connection	Mitsubishi Electric Corporation	Vitesse Semiconductor
Department of Defense	Molex	Yokogawa Electric Corporation
Deutsche Telekom	Music Semiconductors	ZTE Corporation
Ericsson	NEC	
Finisar Corporation	NeoPhotonics	