

Title

1. PHY Link.....	2
1.1. PHY Link Overview.....	2
1.2. PHY Link resource allocation.....	2
1.3. PHY Link Frame structure and protocol.....	2
1.3.1. DS Frame.....	4
1.3.1.1. DS Fixed Header.....	4
1.3.1.2. DS PHY Instructions.....	6
1.3.1.3. DS PHY Discovery window.....	7
1.3.1.4. DS PHY Link FEC.....	7
1.3.2. US Frame.....	7
1.3.2.1. US Fixed Header.....	7
1.3.2.2. US PHY Response.....	8
1.3.2.3. US PHY Discovery Response.....	9
1.3.2.4. US PHY Link FEC.....	9
1.4. PHY Discovery process.....	9

List of Tables

Table 1 PHY DA field values.....	5
Table 2 PHY Config ID bits.....	5
Table 3 Valid OPCODE command values.....	6
Table 4 OPCODE Acknowledgement values.....	8
Table 5 Required parameters for Discovery Response and Link-Up.....	11

List of Figures

Figure 1 PHY Link Frame.....	3
Figure 2 PHY Instruction response.....	4
Figure 3 Config ID bit usage.....	6

1. PHY Link

EDITORS NOTE: the paragraphs below are written (mostly) assuming there is no timestamp in the PHY frame. If such a time stamp exists additional text will need to be written.

1.1. PHY Link Overview

The PHY Link is a low level communications channel used between CLT PHY and its' subtended CNU PHYs. It is typically used to communicate PHY channel parameters and to negotiate initialization of CNU's that wish to join or rejoin the EPoC network. A small amount of RF spectrum is dedicated to the PHY Link at network set-up time for both the US and the DS directions. The PHY link uses a simple query response protocol to transfer information in MDIO registers between the CLT and it's subtended CNU's and vice versa. The PHY Link uses a fixed frame format, that is, once it is set-up the PHY Link frame length does not change dynamically based on the data being carried. When operating in TDD mode the PHY Link frame shall be aligned with the TDD Frame. When operating in FDD mode the PHY Frame shall be aligned with the staggered pilot pattern as described in *{ref}*. Each frame is composed of a fixed header, one or more PHY Instructions or PHY Responses, padding and FEC parity.

1.2. PHY Link resource allocation

During network setup a specific amount of RF spectrum is allocated for use by the PHY Link in both the US and the DS directions. The allocated spectrum shall reside within the required 24 MHz contiguous OFDM/OFDMA channel spectrum and have at least 3 MHz of contiguous spectrum above and below it.

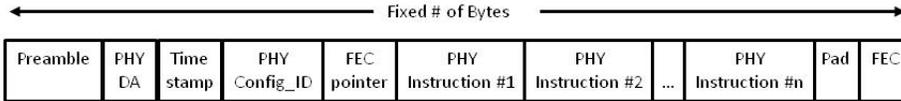
In the DS direction the PHY Link shall be allocated 400 kHz of spectrum for information and an additional eight sub-carriers for pilot tones placed symmetrically above and below the information sub-carriers.

In the US direction the PHY Link shall be allocated *TBD* kHz of spectrum for information and an additional *TBD* sub-carriers for pilot tones placed symmetrically above and below the information sub-carriers.

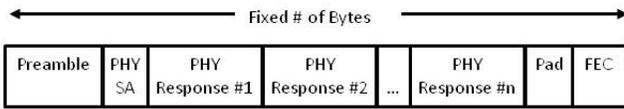
1.3. PHY Link Frame structure and protocol

The PHY Link frame is composed of a fixed header, one or more PHY Instructions, padding, and FEC parity as illustrated in **Figure 1**.

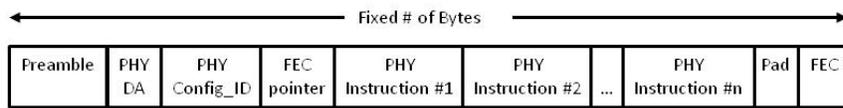
Downstream PHY Link frame



Upstream PHY Link frame



Downstream PHY Link frame



Upstream PHY Link frame

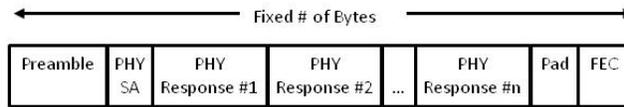


Figure 1 PHY Link Frame

The PHY Link protocol is a query and response protocol where the CLT transmits one or more instructions to a CNU or group of CNUs. Each instruction can perform a read, write or write/verify operation. PHY Instructions that require a response from the CNU (read & write/verify instructions) cannot be addressed to a group of CNU with the exception of a PHY Link Discovery (see below) **Insrtuction**. CNUs receiving PHY Instructions that require a response (read and write/verify operations) shall provide that response in the frame that starts following the end of the frame **including** the instruction **is received in**-(see Figure 2). When operating in FDD mode, the PHY Link frame shall be longer than the one way transit time, including all PHY delays, to the logically most distant CNU in the network.

EDITORS NOTE: if this frame length requirement is not met PHY Link frames cannot be aligned in a way allowing all CNUs to respond in the next US frame following the end of the DS frame including the instruction.

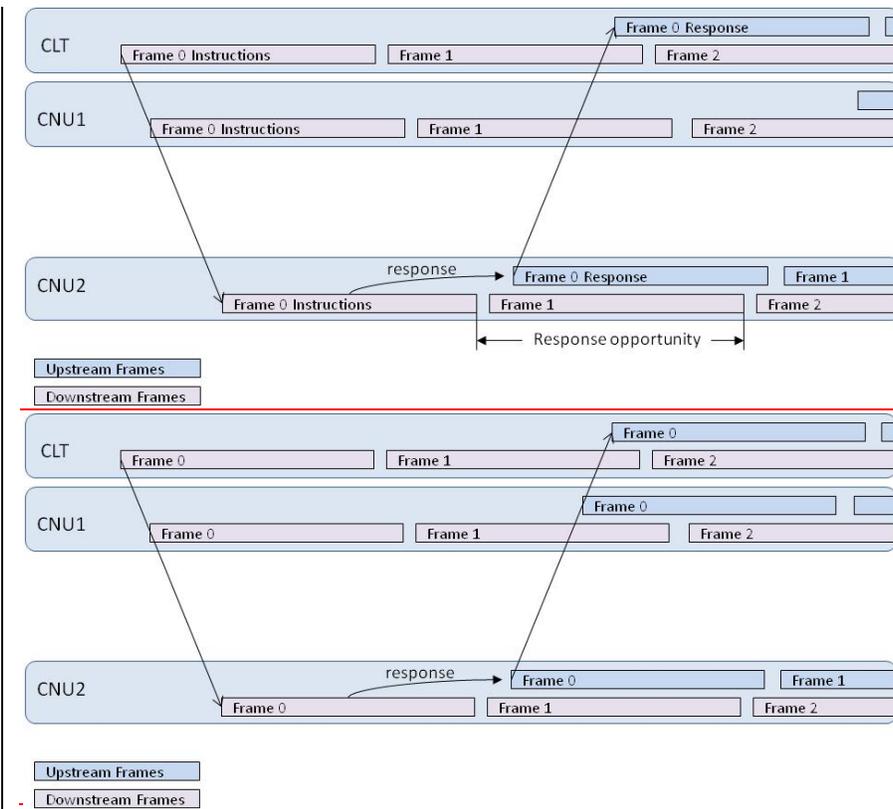


Figure 2 PHY Instruction response

1.3.1. DS Frame

The downstream PHY Link frame is composed of a fixed header, one or more PHY Instructions and an FEC. The fixed header includes a preamble, the PHY DA, a *TBD(16-32) bit Timestamp*, the PHY Config ID, an FEC Pointer and a pad *as illustrated in Figure 1*. Each PHY Instruction is composed of an OPCODE, a Data Count, an MDIO Address, and 0 to 31 *(1 to 32?)* Data fields. The PHY Link frame is protected with an FEC mechanism. These fields are described below.

1.3.1.1. DS Fixed Header

The downstream Preamble is a fixed pattern of *TBD* bits that fill the first eight symbols of the PHY Link frame. The pattern is selected to enable the CNU to easily ascertain the PHY Link sub-carriers without prior knowledge of the PHY Link's precise location in the RF spectrum range of an EPoC network. Detection of the PHY Link is the first action a CNU must take to join an EPoC network.

EDITORS NOTE: insert additional preamble descriptive text on here based on Motion #10 Geneva July 2013, see montreuil_3bn_01_0713.pdf slides 2, 3, 12, and 13. Leo is encouraged to provide this text.

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The PHY Link DA is an address field that identifies the CNU the PHY frame is targeted for. This field is *TBD {48, 11, 10, 9}* bits and may be a unicast address or a broadcast address. *{if we decide to use MAC Address for this field state so here, if not include and reference a table of Unicast/Broadcast values as illustrated below }.*

Table 1 PHY DA field values

Filed Value	Use
0x 3 48 .. 0x 3 4F	Broadcast addresses
0x01 .. 0x 2 47	Unicast addresses
0x00	CLT PHY DA address

The PHY Timestamp is a TBD {16-32} bit field which the EPoC PHY uses to synchronize the US PHY Link frame and OFDMA symbols. The counter is clocked from the {204.8 MHz} OFDM clock. When the CNU PHY receives a PHY Frame addressed to it or to the broadcast address it shall reset it's local clock to the value in the Timestamp plus the value in it's Offset register (see *ref.*). For additional information on the use of the Timestamp see *ref.*.

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The PHY Config ID is a two bit field used to inform a CNU or group of CNUs to switch from one modulation profile to another. Each CNU contains two profiles, copy "A" and copy "B"; only one of which is active at any one time. The CLT updates the unused profile then, using the PHY Config ID bits, switches the CNU or a group of CNUs to the updated profile. Once the CLT begins the switchover, as indicated by PHY Config ID values 0b01 or 0b10 it shall complete the switchover. During a switchover the value of the PHY Config ID field is either incremented or decremented by one in each successive frame; thus a switchover takes three PHY Link frames and the new profile is activated at the conclusion of the third frame. Table 2 summarizes the use and meaning of the PHY Config ID bits and their operation is illustrated in {Figure 3}.

Table 2 PHY Config ID bits

PHY Config ID		Meaning
bit 0	bit 1	
0	0	Copy 0 in use
0	1	prepare for switchover
1	0	
1	1	Copy 3 in use

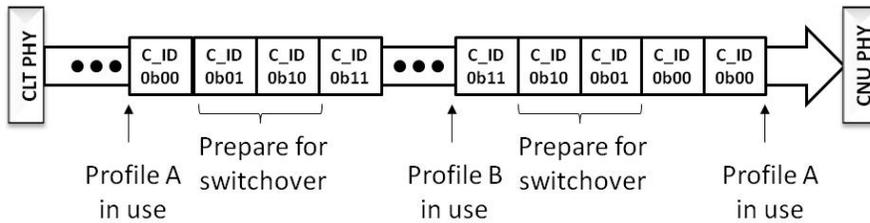


Figure 3 Config ID bit usage

EDITORS NOTE: see boyd_3bn_02a_0313.pdf for slides originally describing the PHY Config ID bits.

The FEC Pointer is a 16 bit field used to identify the start of the first FEC codeword in the next PHY Link frame.

EDITORS NOTE: see boyd_3bn_02_0513.pdf for slides originally describing the FEC Pointer.

The Pad field is used to fill the PHY frame in the event there are unused bits after the fixed overhead, PHY Instructions and FEC fields have been populated.

1.3.1.2. DS PHY Instructions

The CLT can perform read and write operations on the MDIO register space of subtended CNU's via PHY Instructions. Each instruction contains an OPCODE, an MDIO Address and up to 31 ~~(32)~~ data fields.

The PHY Link OPCODE is an 8 bit field separated into two sub-fields; the Command sub-field and the Data Count sub-field. The command sub-field is a 3 bit value that conveys the operation of the PHY Instruction in which it resides. The CLT shall only transmit the valid values of the command sub-field as given in Table 3.

Table 3 Valid OPCODE command values

Value	Operation	Description
0b000	NOP	no operation, the CNU acknowledges this instruction only
0b001	read	The CNU responds with the contents of MDIO registers starting at the address specified by the MDIO Address field and subsequent registers as specified by the Data Count field
0b010	write	the CNU stores the values given in the data field starting at the register given in the MDIO Address field and subsequent register as specified by the Data Count field
0b011	write/verify	the CNU first writes the MDIO registers as specified by MDIO Address and Data Count field and then responds with the values contained in those same registers
0b1xx	reserved	no operation, the CNU ignores these instructions

The Data Count sub-field specifies the number of 16 bit data words contained in a write or write/verify PHY Instruction or the number of 16 bit MDIO registers that are to be returned in a

read or write/verify PHY Instruction. The Data Count sub-field can have a value of 0 to 31 ~~(1 to 322)~~.

The 16 bit MDIO Address field specifies the MDIO register address at which the CNU is to begin the read, write or write/verify operation.

The 16 bit Data fields contains the data values to be written in consecutive MDIO registers starting with the register indicated by the MDIO Address field and continuing for the number of registers indicated by Data Count of the target CNU. The Data fields are valid only for a write or write/verify PHY Instructions. In the event there is a discrepancy between the Data Count field and the number of 16 bit Data fields the CNU shall write no data to its MDIO register and returns a Nack indication (see Table 4 OPCODE Acknowledgement values).

1.3.1.3. DS PHY Discovery window

The CLT opens a PHY Discovery window by sending a specific sequence of broadcast instructions addressed to the broadcast DA in a single PHY frame. This sequence includes:

- Write Discovery Preamble
- ~~Read~~ Random back-off value (see ref)
- Read CNU MAC address
- Write/Verify Discovery Window duration

EDITORS NOTE: at this point the above list is merely a suggestion by the author to be included in the draft, additional suggestions are solicited from the TF

Once the PHY Discovery window is open the CLT should *{shall?}* refrain from sending read or write/verify instructions over the DS PHY Link ~~for the~~ to allow sufficient time for joining CNUs to respond to the PHY Discovery window; the exact time period depends on the length of the PHY Discovery window and the maximum RTT for the EPoC network.

1.3.1.4. DS PHY Link FEC

The downstream PHY Link uses a (384,288) binary punctured LDPC code.

EDITORS NOTE: see shen_3bn_01_0713.pdf for original slides describing DS PHY Link FEC. FEC experts, such as BZ Shen, are requested to submit an adequate description of this FEC.

1.3.2. US Frame

The upstream PHY Link frame is composed of a fixed header, one or more PHY Responses and an FEC. The fixed header includes a preamble, the PHY SA, and a pad. Each PHY Response is composed of an OPCODE, a Data Count, an MDIO Address, and 0 to 31 ~~(1 to 322)~~ Data fields. The PHY Link frame is protected with an FEC mechanism. These fields are described below.

1.3.2.1. US Fixed Header

The upstream Preamble is a fixed pattern of *TBD* bits that fills the first ~~TBD~~ symbols of the PHY Link frame. The pattern is selected to enable the CLT to easily detect the CNU PHY Link transmission.

EDITORS NOTE: insert additional descriptive text here based on final agreed US PHY Link Preamble.

The PHY SA is an address field that identifies the CNU the PHY frame is transmitted from. This field is TBD (48, 11, 10, 9) bits and is always the unicast address associated with the CNU transmitting in the PHY Link. *{if we decide to use MAC Address for this field state so here, if not refer to table above}.*

The Pad field is used to fill the PHY frame in the event there are unused bits after the fixed overhead, PHY Response and FEC fields have been populated.

1.3.2.2. US PHY Response

The CNU must respond to PHY Link read and write/verify instructions using the PHY Response. Each Response contains an OPCODE, an MDIO Address and up to 31 ~~(32)~~ data fields.

The PHY Response OPCODE is an 8 bit field separated into two sub-fields; the Acknowledgement sub-field and the Data Count sub-field. The Acknowledgement sub-field is a 3 bit value that conveys the type of PHY Instruction to which the CNU is responding and the success or failure of the PHY Instruction Command. CNU's shall use the valid values of the Acknowledgement sub-field are given in Table 4.

Table 4 OPCODE Acknowledgement values

Value	Operation	Description
0b000	NOP Ack	NOP Instruction acknowledge returned in response to a successfully received NOP Instruction
0b001	read Ack	read Instruction acknowledge returned in response to a successfully received read Instruction along with the requested MDIO registers as specified in the MDIO Address and Data Count fields of the PHY Instruction
0b010	write Ack	write Instruction acknowledge returned in response to a successfully received write Instruction
0b011	write/verify Ack	write/verify Instruction acknowledge returned in response to a successfully received write/verify Instruction along with the requested MDIO registers as specified in the MDIO Address and Data Count fields of the PHY Instruction
0b100	NOP Nack	NOP Instruction negative acknowledge returned in response to a successfully received NOP Instruction <i>{might just want to keep this as a reserved value}</i>
0b101	read Nack	read Instruction negative acknowledge returned in response to an unsuccessfully received NOP Instruction
0b110	write Nack	write Instruction negative acknowledge returned in response to an unsuccessfully received NOP Instruction
0b111	write/verify Nack	write/verify Instruction negative acknowledge returned in response to an un successfully received NOP Instruction

The Data Count field specifies the number of 16 bit MDIO registers that are being returned in response to a read or write/verify PHY Instruction. In the event the CNU is returning a Nack response (Acknowledgement values 0b100 through 0b0111) the Data Count field should *{shall?}* be set to zero and is ignored at the CLT.

The 16 bit MDIO Address field specifies the first register address for which the CNU is returning data due to a read or write/verify operation or the first register address of the corresponding write Instruction.

The 16 bit Data fields contain the data values read from the MDIO registers due to a read or write/verify PHY Instruction. In the event the CNU is responding to a write instruction this field is omitted. The Data field should {shall?} be omitted in Nack Responses (Acknowledgement values 0b100 to 0v111) and, if included, shall be ignored at the CLT.

1.3.2.3. US PHY Discovery Response

The CNU Discovery Response is only allowed after a CNU has completed the Discovery prerequisites (see ref.). In the Discovery Response message:

- the preamble used is the special PHY Discovery Preamble {ref CL 45 registers}
- the SA field is set to 0xb900 {if we decide to use the MAC address instead of an ONU ID can set this to MAC address}
- the random back-off TDB {16-32} bit local clock of the CNU used by the CNU in the Discovery Response {assuming no timestamp or frame ID field}
If timestamp field is used then it is part of the c_{min} on h_{ea} der
If Frame ID field is used then need both Frame ID and Random back off value
- the CNU MAC address is carried in the MDIO Data fields. {assumes using CNU_ID, if not combine 2nd & 4th bullets to read "the SA field is set to the CNUs MAC address}

{Optional description and list of parameters in Discovery Response, in actuality the required response is determined by the PHY Discovery Window, again input is solicited on the precise definition for this message}

1.3.2.4. US PHY Link FEC

TDB

1.4. PHY Discovery process

When a CNU first joins the EPoC network it has no prior knowledge of the upstream OFDMA frame and timing necessary to produce transmissions that are orthogonal to the rest of the EPoC network when viewed from the perspective of the CLT receiver. PHY Discovery is the process whereby newly connected or off-line CNUs are provided timing and operating parameters necessary to function properly in the EPoC network.

When a CNU joins an EPoC network it must first locate the downstream PHY Link. This is typically done via a vendor specific correlation algorithm. Prior to any transmission in an EPoC network the CNU shall locate the downstream PHY Link, gather the required Discovery operating parameters listed in Table 5 and synchronize its local clock to the downstream OFDM clock. Once the CNU has completed the prerequisites for transmission it waits for the CLT to issue a PHY Discovery window.

EDITORS NOTE: the TF needs to determine precisely how accurately the CNU must be synchronized to the OFDM clock before US transmission is allowed.

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The CLT periodically makes available PHY Discovery Windows during which off-line CNU are given the opportunity to make themselves known to the CLT. The periodicity of these windows is unspecified and left up to the ~~implementer~~**implementer**. The CLT signifies that a PHY Discovery period is occurring by broadcasting a PHY Discovery Instruction, which includes the length of the PHY Discovery window *{optionally list other elements of this instruction}* as defined in *{ref}*.

Off-line CNU, upon receiving a PHY Discovery Instruction, wait for the beginning of the next upstream frame and then transmit a PHY Discovery Response to the CLT. PHY Discovery windows are unique in that they are the only times when multiple CNU can access the CDN using the same RF spectrum simultaneously, and transmission overlap can occur in both time and frequency. *In order to reduce transmission overlaps, a contention algorithm is used by all off-line CNU. Measures are taken to reduce the probability for overlaps by artificially simulating a random distribution of distances from the CLT. Each CNU waits a random amount of time before transmitting the PHY Discovery Response that is shorter than the length of the discovery window. It should be noted that multiple valid PHY Discovery Responses can be received by the CLT during a single discovery window.* Included in the PHY Discovery Response is the CNU's MAC address and *{list of other parameters}*.

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EDITORS NOTE: the above statements regarding multiple responses to a PHY Discovery window may or may not be true depending on the size of the window and collision mitigation method finally selected by the TF. If we cannot get multiple CNU responses in a discovery window due to frame length constraints (for example in TDD where the frame length may be short then additional means of limiting participation in a PHY Discovery window may be warranted

EDITORS NOTE: the following text is in Cl 102.3.3 but may be more appropriate here.

In order to assure maximum utilization of the upstream channel and to decrease the required size of the guard band between individual data bursts, the registering CNU notifies the CLT of the RF on/off times, by setting appropriate values in the RF On Time and RF Off Time fields, where both values are expressed in the units of time_{quanta}.

EDITORS NOTE: the following text is written assuming we adopt the CNU_ID concept, if this is not the case the Editor should remove references to CNU_ID.

Upon receipt of a valid PHY Discovery Response, the CLT updates the CNU by allocating and assigning a new port identity (CNU_ID) and bonding a corresponding MAC to the CNU_ID. The CLT also calculates an OFDMA Timing Offset and adjusts the CNU's amplitude. The CLT also sets the target value of RF on time and RF off time, which may be different than RF on time and RF off time delivered by the CNU in the PHY Discovery Response. These parameters are transmitted to the CNU via the appropriate PHY Instructions.

The next step in the process is for the CLT to perform an upstream channel estimate of the newly discovered CNU using probing or fine ranging as described in *{ref}*. The CLT may further adjust the US amplitude and timing of the CNU as needed. The CLT also ascertains the CNU's capabilities via the appropriate read instructions. Before declaring a CNU is in the link-up state the CLT must ensure that a CNU joining the EPoC network is properly aligned to the US OFDMA timing and is

cognizant of all necessary provisioning parameters needed to properly operate in the OFDMA network without adverse impact to the EPoC network or other services operating in RF spectrum unused by the EPoC network. A list of required parameters is given in Table 5 .

Once the CLT ~~now~~ has enough information to declare the CNU has attained a link-up status. The CNU first informs the CNU and verifies the CNU has transitioned to link-up status. After verifying the CNU's link-up status the CLT informs the upper layers that a new CNU has joined the EPoC network and is ready to be registered by the MAC Control layer. The PHY Discovery message exchange is illustrated in Figure 4.

There may exist situations when the CLT requires that a CNU go through the PHY Discovery sequence again. Similarly, there may be situations where a CNU needs to inform the CLT of its desire to leave the EPoC network. The CNU can then go through the PHY Discovery sequence again.

Table 5 Required parameters for Discovery Response and Link-Up

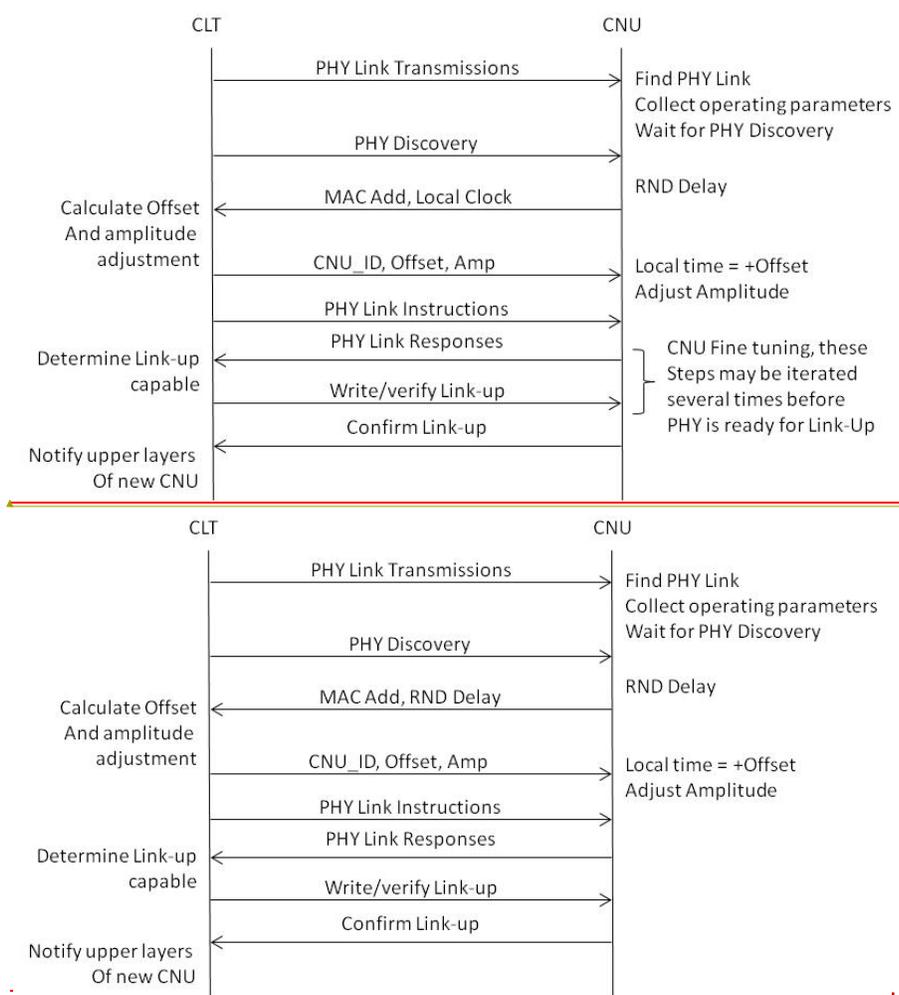
Parameter	MDIO Reg.	Required for	
		Discovery	Link-Up ⁽¹⁾
US Preamble	TBD	Y	
DS Preamble	TBD	Y	
TDD/FDD Mode	TBD	Y	
DS OFDM Descriptor	TBD		Y
DS RF Channel Descriptor	TBD		Y
DS PHY Link Descriptor	TBD	Y	
DS Profile	TBD		Y
US OFDMA Descriptor	TBD		Y
US RF Channel Descriptor	TBD		Y
US PHY Link Descriptor	TBD	Y	
US Profile	TBD		Y

Notes:

1) Parameters required for Discovery are also required for Link-Up.

EDITORS NOTE: The above table is an example only, this will need to be rationalized_and cross referenced with CL 45 MDIO Registers at some point. Depending on how detailed we need to get this table may be fairly large

Figure 4 PHY Discovery message exchange



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{ Fine ranging to be described elsewhere as this is also a part of ongoing channel maintenance }