Revised 10GBASE-T PHY Control with integrated link monitor (version 2)

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Abstract: This report describes a revised version of PHY Control in which the link-monitor function is part of PHY Control. A small change required in the state diagram of Auto Negotiation is shown in the Appendix. PHY Control differs from PHY Control as described in 10GBASE-10 Draft 2.3 in various ways. (1) InfoFields are reorganized and shortened to 8 octets. The 4-octet payload field thereof contains a state indicator and is state dependent. (2) The MASTER sends invitations to the SLAVE to start SLAVE transmission only at specified times rather than allowing the SLAVE to start transmission at any time during time windows of many PMA training frames. (3) Final transmit-power settings are achieved prior to coefficient exchange. (4) MASTER and SLAVE operations become fully symmetric shortly after the start of SLAVE transmission; each PHY can determine the minimum time spent in a particular state. (5) The link partners are not required to transition into states PMA_Fine_Adj, PCS_Test, PCS_Data nearly synchronously under MASTER control as in Draft 2.3.

55.xxx PHY Control function

PHY Control performs the control actions that are needed to bring a 10GBASE-T PHY into a mode of operation during which PCS frames are exchanged with the link partner. PHY Control shall comply with the state diagram description given in Figure 55-bb.

55.xxx.1 Interaction between PHY Control and Auto Negotiation

Auto Negotiation controls PHY Control through variable link_control ∈ {DISABLE, ENABLE}. PHY Control returns variable link_status ∈ {FAIL, OK} to Auto Negotiation. Assertion of link_control = DISABLE forces PHY Control unconditionally into state PHY_Disabled. In this state the PHY is silent, signals link_status = FAIL, and waits for being enabled by Auto Negotiation.

When Auto Negotiation sets link_control = ENABLE, it also starts the internal link_fail_inhibit_timer at a nominal value of 2 sec. PHY Control begins PMA training and is supposed to reach state PCS_Data before link_fail_inhibit_timer expires. If the link_fail_inhibit_timer times out before PHY Control signals link_status = OK in state PCS_Data, Auto Negotiation sets link_control = DISABLE and thus forces PHY Control into state PHY_Disabled.

If a failure situation is detected in states PCS_Test or PCS_Data, PHY Control returns to state PHY_Disabled and sets link_status = FAIL. When Auto Negotiation observes the transition of link_status from OK to FAIL while asserting link_control = ENABLE, it restarts the link_fail_inhibit_timer. PHY Control proceeds to PMA training and is again given the opportunity to reach state PCS_Data and set link_status = OK before link_fail_inhibit_timer expires.

[Restarting link_fail_inhibit_timer in case of PMA retraining requires a small change in the Aribitation state diagram of Clause 28, Figure 28-16. The change is shown in the Appendix at the end of this document]

55.xxx.2 InfoField

PMA training frames are transmitted in PHY Control states PMA_Train1_M, PMA_Train2_M, PMA_Train2_S, PMA_Coeff_Exch, and PMA_Fine_Adj. Each training frame conveys information to the link partner in an 8-octet InfoField (IF) that is inserted into the 64 last bit positions associated with pair A (see Figure 55-13 *[to be updated]*). The link partner is not required to decode every InfoField. However, InfoFields must be decoded frequently enough to ensure that PHY Control performs correct actions. The InfoField and its state dependent payloads are depicted in Figure 55-aa.

55.xxx.2.1 Start of InfoField delimiter

The 3-octet field start_of_InfoField_delimiter (Oct1:3) contains the hexadecimal value 0xBBA700, i.e., the binary sequence 1011 1011 1010 0111 0000 0000.

55.xxx.2.2 InfoField: payload

The 4-octet field payload (Oct4:7) is state dependent. Unused bit positions in the payload may be set in the transmitter to arbitrary values and are ignored upon reception.

55.xxx.2.3 InfoField: CRC-8

The 1-octet field CRC-8 (Oct8) checks the contents of the payload field. CRC-8 is computed by a circuit as depicted in Figure 55-11. Let $d(x) = d_{31}x^{31}+d_{30}x^{30}+ ... d_1x+d_0$ represent the 32 payload bits, where d_{31} = Oct4<7>, d_{30} = Oct4<6>, ... d_0 = Oct7<0>, and let $r(x) = r_7x^7+r_6x^6+ \dots r_1x+r_0$ represent the 8 check bits, where r_7 = Oct8<7>, r_6 = Oct8<6>, … r_0 = Oct8<0>. r(x) is the remainder of dividing $d(x)x^8$ by $g(x) = x^8+x^6+x^5+x+1$.

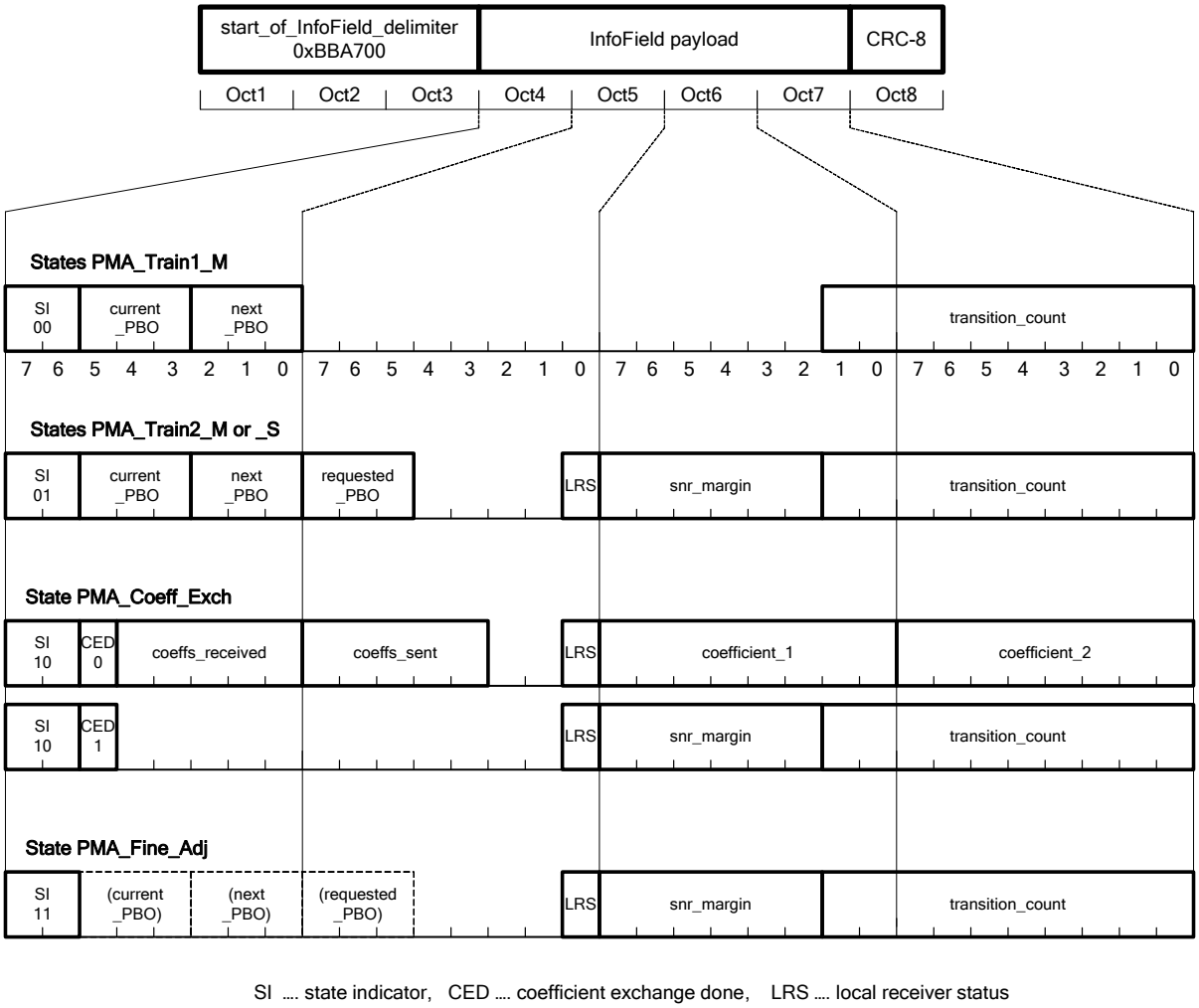


Figure 55-aa—InfoField format and payloads

55.xxx.2.4 InfoField payload: state indicator (SI)

The 2-bit field SI (Oct 4<7:6>, state indicator) reflects the PHY Control state of the transmitting PHY: SI = 00 for PMA_Train1_M, 01 for PMA_Train2_M or PMA_Train2_S, 10 for PMA_Coeff_Exch, and 11 for PMA_Fine_Adj.

55.xxx.2.5 InfoField payload: transmit power backoff fields

The 3-bit field current_PBO (Oct4<5:3>) reflects the current PBO_tx setting of the transmitting PHY.

The 3-bit field next_PBO (Oct4<2:0>) is employed to announce with a non-zero value of transition_count a change in the PBO_tx setting of the transmitting PHY. When transition_count = 0, the link partner ignores next_PBO.

The 3-bit field requested_PBO (Oct5<7:5>) is used to request that the link partner sets its PBO_tx setting to the requested value.

The 8 possible PBO values are defined in 55.xxx.4.1.

55.xxx.2.6 InfoField payload: transition counter

Insertion of a non-zero value into the 10-bit field transition_count (Oct6<1:0>,Oct7<7:0>) announces to the link partner a transition in the characteristics of the transmitted signal. The following transitions are announced: changes in the PBO_tx setting; state transition from state PMA_Coeff_Exch to state PMA_Fine_Adj (activation of TH precoding); and state transition from state PMA_Fine_Adj to state PCS_Test (sending PCS frames instead of PMA training frames). Transition_count may be set to a value between min_transition_count (defined in 5.xxx.4.1) and 1023. In state PMA_Train1_M, the MASTER is allowed to announce a "zero power change" with next_PBO = current_PBO. The SLAVE operating in state PMA_Train1_S interprets this as an invitation to start transmission.

In every subsequently transmitted InfoField, transition_count will automatically be decremented by one until transition_count becomes zero and then stays zero until another transition is announced. The transition takes effect immediately after the InfoField, in which the transition_count becomes zero. For the link partner it suffices to decode a single InfoField with a non-zero transition_count to know when the transition will occur. Announced transitions must not be revoked.

55.xxx.2.7 InfoField payload: local receiver status (LRS)

The 1-bit field LRS (Oct5<0>) reflects the current value of variable loc_rcvr_status: 0 for loc_rcvr_status = NOT_OK, 1 for loc_rcvr_status = OK, as defined in 55.xxx.4.1.

55.xxx.2.8 InfoField payload: SNR margin

The 6-bit field snr_margin (Oct6<7:2>) expresses the anticipated SNR margin for reliable decoding of LDPC-coded 128DSQ signals (decoding of PCS frames) with the current PBO_tx setting of the link partner and the current canceller and receiver adjustments of the local PHY. The field is included for monitoring and diagnostic purposes. The snr_margin values 000000, 000001, … 111110, 111111 shall indicate decision-point SNR margins of ≤-8.00, -7.75, … 7.50, ≥7.75 dB, respectively.

55.xxx.2.9 InfoField payload: fields used for coefficient exchange

In state PMA_Coeff_Exch the InfoField payload depends on the value of the 1-bit field CED (Oct4<5>, coefficient exchange done). With CED = 0, two coefficients are transmitted and reception of the two last received coefficients is acknowledged.

Coefficients are transmitted in the order A/1:2; A/3:4; … A/15:16; B/1:2; … B/15:16, C/1:2, … D/15:16, where A,B,C,D stands for pair A,B,C,D, respectively, and the numbers represent the indices of the coefficients transmitted in the 8-bit fields coefficient_1 (Oct6) and coefficient_2 (Oct7). Each pair of coefficients is repetitively sent until the link partner acknowledges successful reception.

The 8-bit coefficients are represented in two's complement format sx.xxxxxx and can take values in the range -2.0 to 1.984375 in steps of 0.015625 (=1/64).

The 5-bit field coeffs_received (Oct4<4:0>) indicates the coefficient pair that has last been received: 00000, 00001, …. 11111 designates coefficients A/1:2, A/3:4, … D/15:16, respectively. When no coefficients have yet been received, coeff_received = 11111 is sent. The remote PHY cannot mistake this as an acknowledgement of local reception of the last pair of coefficients, because it must first receive an acknowledgement of reception of the first pair of coefficients.

The 5-bit field coeffs_sent (Oct5<7:3>) indicates the coefficient pair that is currently transmitted in the fields coefficient_1 and coefficient_2: 00000, 00001, …. 11111 designates coefficients A/1:2, A/3:4, … D/15:16, respectively.

When the local PHY has acknowledged reception of all coefficients from the remote PHY and observes that the remote PHY has acknowledged reception of all coefficients from the local PHY, the local PHY sends CED = 1. The InfoField format with CED = 1 now permits to announce a transition to state PMA_Fine_Adj by setting transition_count to a non-zero value.

55.xxx.3 Startup sequence

55.xxx.3.1 State PHY_Disabled

In state PHY_Disabled, PHY Control starts wait_timer at 1 ms, sets link_status = FAIL, and remains silent. If after the 1 ms period Auto Negotiation presents link_control = ENABLE, PHY Control proceeds to PMA training. If config = MASTER, PHY Control enters state PMA_Train1_M. Otherwise, config = SLAVE and PHY Control enters state PMA_Train1_S.

55.xxx.3.2 State PMA_Train1_M

In state PMA_Train1_M, the MASTER sets tx_mode = SEND_T(THP_off) for transmission of PMA training frames without TH precoding. Every PMA training frame will include an InfoField.

Initially, the MASTER sends PMA training frames at minimum transmit power by using PBO_tx = 7 and starts wait_timer at 168±5 ms *[≈ 8200 PMA training frames]*. After having sufficiently adjusted its echo and next cancellers, the MASTER sends invitations to the SLAVE to start transmission at specified times. If the beginning of SLAVE transmission is detected, the MASTER advances to state PMA_Train2_M. Otherwise, when no SLAVE signal is detected and wait_timer expires, the MASTER announces a change of its PBO setting to PBO_tx = 5. When the transition has occurred, the MASTER restarts wait_timer at 100±5 ms *[≈ 4880 PMA training frames]* and ensures that sufficient echo and next cancellation is achieved. The MASTER then sends again invitations to the SLAVE to start transmission at specified times. If the beginning of SLAVE transmission is detected, the MASTER advances to state PMA_Train2_M. Otherwise, when no SLAVE signal is detected and wait_timer expires again, the MASTER announces a change to PBO_tx = 3. Operations continue as described above, however, without further time limit set for sending invitations to the SLAVE and detecting SLAVE transmission. PHY Con-

trol will be forced to return to state PHY_Disabled only when link_fail_inhibit_timer in Auto Negotiation expires.

In the InfoFields, the MASTER sends current_PBO = PBO_tx.

As explained in 55.xxx.2.6, the MASTER sends invitations to the SLAVE to start transmission at specified times. These invitations are expressed by announcing "zero power changes", i.e., sending in the InfoFields next_PBO = current_PBO together with a non-zero transition_count indicating the time, when the SLAVE may start transmission. In contrast, real changes in the PBO_tx setting are announced by sending next_PBO ≠ current_PBO together with a non-zero transition_count.

The transition from state PMA_Train1_M to state PMA_Train2_M is not announced, because no change in the characteristics of the transmitted signal occurs. The SLAVE recognizes the state transition by receiving InfoFields with SI = 01, which indicates that the MASTER is operating in state PMA_Train2_M.

[Sending invitations to start transmission at specified times by announcing "zero power changes" provides for a simple separation of times at which SLAVE transmission may start and times at which the MASTER increases transmit power. Permitting the SLAVE to start transmission only at well defined times minimizes the probability of false alarms and for certain implementations minimizes the signal processing resources required to detect the beginning of SLAVE transmission. In addition, it enables measuring link round-trip delay and hence cable length by the MASTER, which may be useful in some implementations.]

55.xxx.3.3 State PMA_Train2_M

In state PMA_Train2_M, the MASTER continues to send PMA training frames without TH precoding. In addition to maintaining adequate echo and next cancellation, the MASTER trains its receiver section. When the MASTER is able to decode InfoFields, it determines the transmit power level for the SLAVE such that the decision-point SNR margin of the MASTER will be sufficient for eventually decoding PCS frames. In the unlikely situation, where the MASTER detects the SLAVE signal, but cannot reliably decode the InfoFields, it first instructs the SLAVE to increase transmit power so that it can decode InfoFields.

The MASTER requests changes in the PBO_tx setting of the SLAVE by inserting the desired value in the requested_PBO field of the transmitted InfoFields. The requested PBO_tx value must comply with the minimum PBO values given in Table 55-6, and must not exceed the minimum value by more than 2 *[or just 1?]*. Similarly, the MASTER has to respond to requested changes of its PBO_tx setting by the SLAVE. Each actual change in the PBO_tx setting must be announced to the link partner.

When the MASTER determines that in its receiver section sufficient decision-point SNR is achieved for eventually decoding PCS frames, it sets loc_rcvr_status = OK and transmits LRS = 1 in the InfoFields. When the MASTER receives LRS = 1, it stores this as rem_rcvr_status = OK. When loc_rcvr_status = OK and rem_rcvr_status = OK, the MASTER proceeds to state PMA_Coeff_Exch.

The transition from state PMA_Train2_M to state PMA_Coeff_Exch is not announced, because the characteristics of the transmitted signal will not change. The SLAVE recognizes the state transition by

receiving InfoFields with SI = 10, which indicates that the MASTER is now operating in state PMA_Coeff_Exch.

55.xxx.3.4 State PMA_Train1_S

In state PMA_Train1_S, the SLAVE sets tx_mode = SEND_Z and thus remains silent. The SLAVE first acquires timing from the received MASTER signal and then trains its receiver section until it can reliably decode InfoFields.

The SLAVE checks the received InfoFields for an invitation to start SLAVE transmission. If the SLAVE receives an invitation to start transmission, i.e., an announcement of a "zero power change", it proceeds to state PMA_Train2_S.

55.xxx.3.5 State PMA_Train2_S

In state PMA_Train2_S, the SLAVE sets tx_mode = SEND_T(THP_off) for transmission of PMA training frames without TH precoding. Initially, the SLAVE sets PBO_tx the value of current_PBO in the InfoFields received from the MASTER. At the MDI of the SLAVE, the first PMA training symbol transmitted shall be time aligned with the first training symbol received from the MASTER after the InfoField, in which transmit_count (defining the invitation time) becomes zero. The alignment shall be accurate within ±50 ns *[= ±40 modulation intervals; this requires knowledge of the SLAVE's internal signal processing delays with modest accuracy.]* Thus the MASTER has to check for reception of the SLAVE signal only within a time window, whose width is determined by the alignment tolerance and the expected maximum round-trip propagation delay of the link.

The SLAVE then adjusts its echo and next cancellers in the presence the MASTER signal and reestablishes receiver operation. When the SLAVE has regained the ability to decode InfoFields, operations become symmetrical to those of the MASTER in state PMA_Train2_M (with references to MASTER and SLAVE reversed).

55.xxx.3.6 State PMA_Coeff_Exch

In state PMA_Coeff_Exch, MASTER and SLAVE operations are symmetric. The PHY sends PMA training frames without TH precoding using the PBO_tx setting established in states PMA_Train2_M or PMA_Train2_S, respectively.

The PHYs exchange 16 coefficients for each wire pair, i.e., 64 coefficients, for use as TH precoding coefficients in state PMA_Fine_Adjust and onwards. The exchange method is described in 55.xxx.2.9. After completion, a PHY sets coeff_exch_done = true and correspondingly sends in the InfoFields CED = 1. When the PHY is ready to transition to state PMA_Fine_Adj, it announces the state transition to the link partner by inserting a non-zero value into transition_count. The state transition occurs immediately after the InfoField, in which transition_count becomes zero.

To permit seamless reception of training symbols when switching to TH precoding, the feedback filter of the precoder should be fed with transmitted signals already before transitioning to state PMA_Fine_Adj.

It is recommended that the state transition of the SLAVE is scheduled to occur simultaneously with or shortly after the transition of the MASTER. *[There exists no strict logical necessity for this rule.]*

55.xxx.3.7 State PMA_Fine_Adj

In state PMA_Fine_Adj, MASTER and SLAVE operations are symmetric. The PHY sets tx_mode = SEND_T(THP_on) for transmission of PMA training frames with TH precoding using the coefficients received from the link partner. Enabling TH precoding, i.e., closing the feedback loop with an already initialized feedback filter, permits seamless reception of PMA training symbols.

The objective of operation in state PMA_Fine_Adj is to ensure proper reception of TH precoded PMA training frames on both sides of the link and achieve final convergence of all adaptive filters. Initially, the PHY sends LRS = 0 corresponding to loc_rcvr_status = NOT_OK. When after a dwell time of at least 10 ms sufficient decision-point SNR margin for receiving PCS frames is observed, the PHY sends LRS = 1 corresponding to loc_rcvr_status = OK. It then checks for reception of InfoFields with SI=10 and LRS = 1 corresponding to rem_rcvr_status = OK from the SLAVE. If loc_rcvr_status = OK and rem_rcvr_status = OK, the local PHY announces a state transition to state PCS_Test by inserting a non-zero transition_count value into the transmitted InfoFields. The state transition occurs after the InfoField, in which transition_count becomes zero.

It is recommended that the state transition of the SLAVE is scheduled to occur simultaneously with or shortly after the transition of the MASTER. *[There exists no strict logical necessity for this rule.]*

[The InfoField format for state PMA_Fine_Adj leaves room for fields current_PBO, next_PBO, and requested_PBO as needed for making transmit power adjustments. The inclusion of this capability is left open for further discussion.]

[Note: The PHY Control state primarily reflects the state of the transmitter. The receiver has to track the state of the remote PHY. One cannot expect that state transitions of the link partners to state PCS_Test occur precisely synchronously on both sides of the link. Hence, a PHY operating in state PMA_Fine_Adj must be able to receive already PCS frames. Similarly, a PHY operating in state PCS_Test must be able to still receive a PMA training frame.]

55.xxx.3.8 State PCS_Test

In state PCS_Test, MASTER and SLAVE operations are symmetric. The PHY Control sets tx_mode = SEND_N for transmission of PCS frames. If at least 3125 PCS frames *[3125 x 320 ns = 1 ms]* have been transmitted, and loc_rcvr_status = OK, and at least 3125 PCS frames have been received and PCS_status = OK, PHY Control transitions to state PCS_Data.

55.xxx.3.9 State PCS_Data

In state PCS_Data, MASTER and SLAVE operations are symmetric. The PHY sets link_status = OK and transmits PCS frames and receives PCS frames.

55.xxx.3.10 Returns to state PHY_Disabled

If in state PCS_Test loc_rcvr_status = NOT_OK or at least 3125 PCS frames have been received and PCS_status = NOT_OK, PHY Control transitions to state PHY_Disabled. Similarly, if in state PCS_Test loc_rcvr_status = NOT_OK or PCS_status = NOT_OK, PHY Control transitions to state PHY_Disabled.

Then, if after a period of 1 ms PHY Control still receives link_control = ENABLE from Auto Negotiation, PMA retraining is started. The 1 ms period interrupts signal transmission and thus facilitates rapid detection of the failure situation by the link partner.

Dealing with failure situations that may occur in the PMA training states (PMA_xxx) is left to implementers.

[Suggestion: change 'NOT_OK' to 'NOK' or 'FAIL']

55.xxx.4. PHY Control variables, timers, and processes

55.xxx.4.1 PHY Control variables

coeff_exch_done

This variable expresses the status of coefficient exchange and corresponds to the value of bit CED sent in the InfoFields during state PMA_Coeff_Exch (see 55.xxx.2.9).
Values: 1 if coefficient exchange is complete, 0 otherwise.

config

This variable is defined in 55.2.2.2.
Values MASTER or SLAVE.

link_control

This variable is defined in 28.2.6.2.
Values DISABLE or ENABLE.

link_status

This variable is defined in 45.2.7.2.6.
Values FAIL or OK.

loc_rcvr_status

This variable expresses a judgement of the local PHY on the quality of signal reception at the decision points of its receiver section.
Values: OK in states PMA_xxx indicates proper synchronization and reception of PMA training symbols and anticipation of sufficient decision-point SNR margin for decoding LDPC-coded 128DSQ symbols while still receiving training symbols, and that requesting a change in the PBO_tx setting of the link partner and/or making further adjustments of the local cancellers and receiver settings are not warranted; OK in states PCS_Test and PCS_Data indicates

sufficient decision-point SNR margin for reception of LDPC-coded 128DSQ symbols. Otherwise, NOT_OK.

min_transition_count

This is the smallest value at which transition_count (see 55.xxx.2.6) can be started.
Value: 128 *[128 x 20.48μs = 2.6 ms, subject to further discussion; further possibility: min_transition_count is obtained from link partner during Auto Negotiation]*.

PBO_tx

This variable indicates the power backoff level from nominal (=maximum) transmit power Ptx. PBO_tx is reflected in the InfoFields as current_PBO.
Values: PBO_tx = 0, 1, 2, 3, 4 ,5, 6, 7 correspond to Ptx -0 dB, -2 dB, -4 dB, -6 dB, -8 dB, -10 dB, -12 dB, -14 dB, respectively.

PCS_status

This variable is defined in 55.3.6.1. *[Question: how many PCS frames must be received before PCS_status becomes valid?]*
Values: NOT_OK and OK.

rem_PBO_tx

This variable represents the value of current_PBO in the InfoFields received by the SLAVE, when the MASTER invites the SLAVE to start transmission.

rem_rcvr_status

This variable reflects the value of bit LRS (local receiver status) in the InfoFields received from the remote PHY.
Values: OK if LRS = 1 is received, NOT_OK if LRS = 0 is received.

slave_signal_detected

This variable is set in state PMA_Train1_M
Values: 1 if MASTER has detected the SLAVE signal, 0 otherwise.

start_slave_transmission

This variable is set in state PMA_Train1_S
Values: 1 if SLAVE received an invitation to start SLAVE transmission, decides to start SLAVE transmission, and transition_count in received InfoFields becomes zero, i.e., the invitation time elapses. Otherwise, 0.

step

An auxiliary variable used in state PMA_Train1_M to determine values of PBO_tx and starting values of wait_timer.
Values: 0, 1, 2, 3.

transition_time_elapsed

This variable indicates in connection with an announced state transition the status of

transition_count in the transmitted InfoFields.
Values: 1 if the transition_count has reached zero, 0 otherwise.

tx_mode

This variable determines the code groups sent by the PCS Transmit function.
Values:
SEND_Z: send zero signal
SEND_T(THP_off): send symbols of PMA training frames without TH precoding
SEND_T(THP_on): send symbols of PMA training frames with TH precoding
SEND_N: send symbols of PCS frames.

wait_timer_done

Values: 0 if wait_timer > 0, 1 if wait_timer = 0.

55.xxx.4.2 PHY Control timers and counters

nr_PCS_frames_rcvd

This counter variable contains the number of PCS frames received since the link partner entered state PCS_Test.
Values: 0 to 4095 (larger values represented by 4095).

nr_PCS_frames_sent

This counter variable contains the number of PCS frames sent since the local PHY entered state PCS_Test
Values: 0 to 4095 (larger values represented by 4095).

wait_timer

A timer used to measure time. When started at values given in the PHY Control state diagram wait_timer counts down to zero and then remains zero.

55.xxx.4.3 PHY Control processes

Process 1 – 8

These processes are briefly verbally explained in Figure 55.bb. They are fully described in the state descriptions of 55.xxx.3.

55.xxx.5 PHY Control state diagram

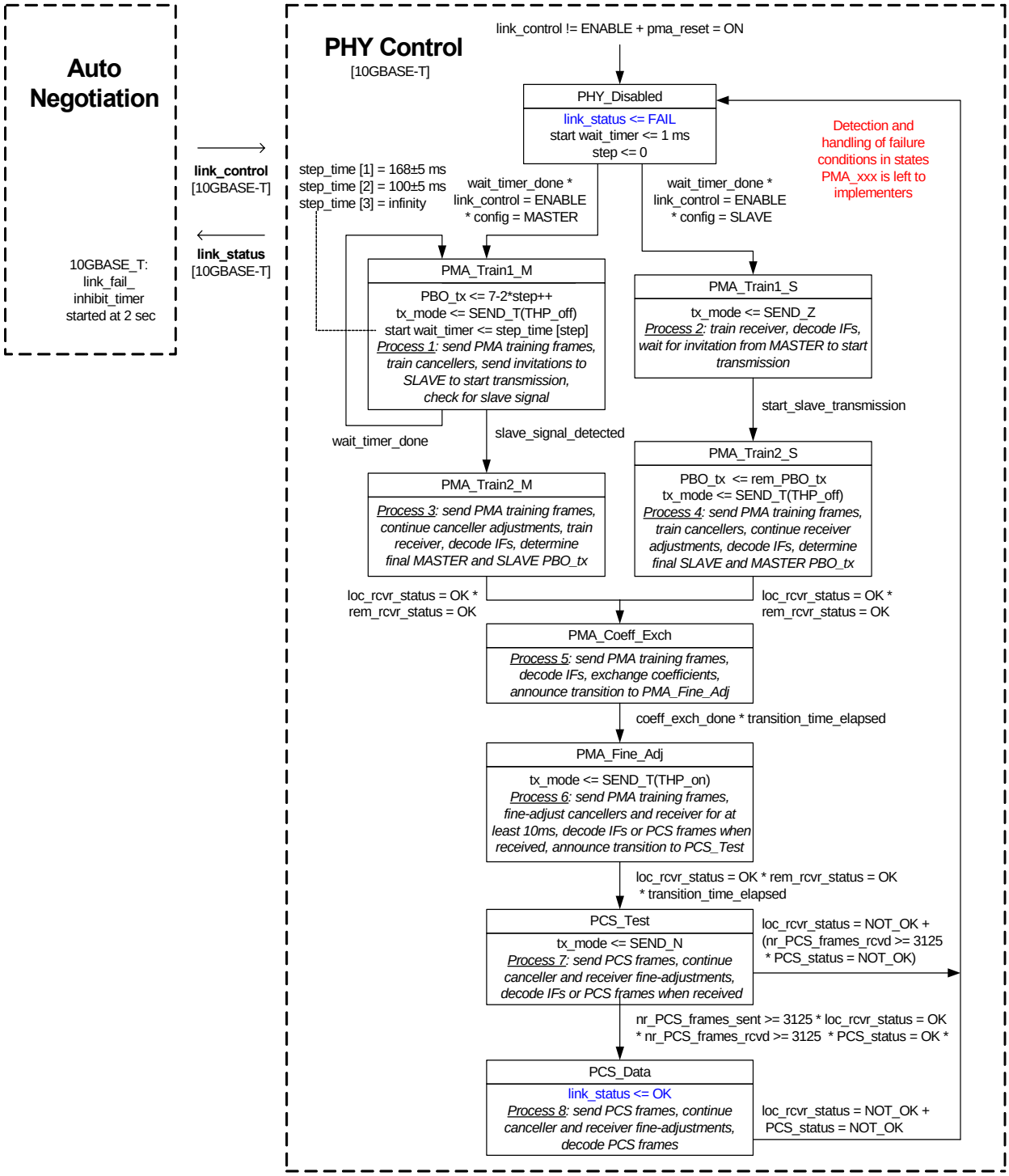
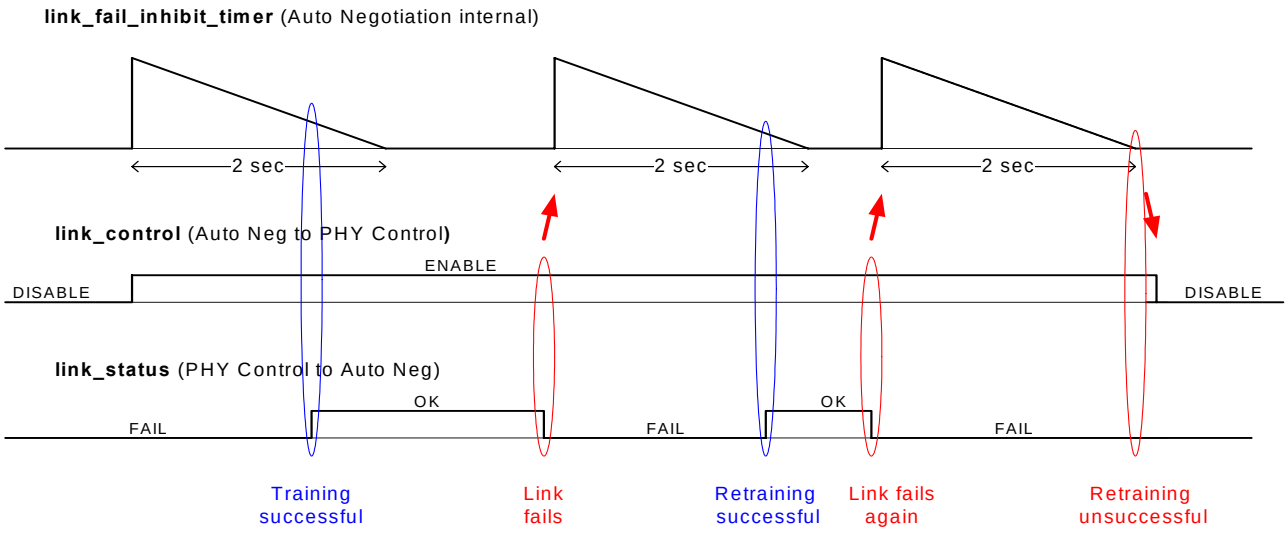


Figure 55-bb— PHY Control state diagram and relation with Auto Negotiation

Appendix



Proposed interaction between Auto Negotiation and PHY Control

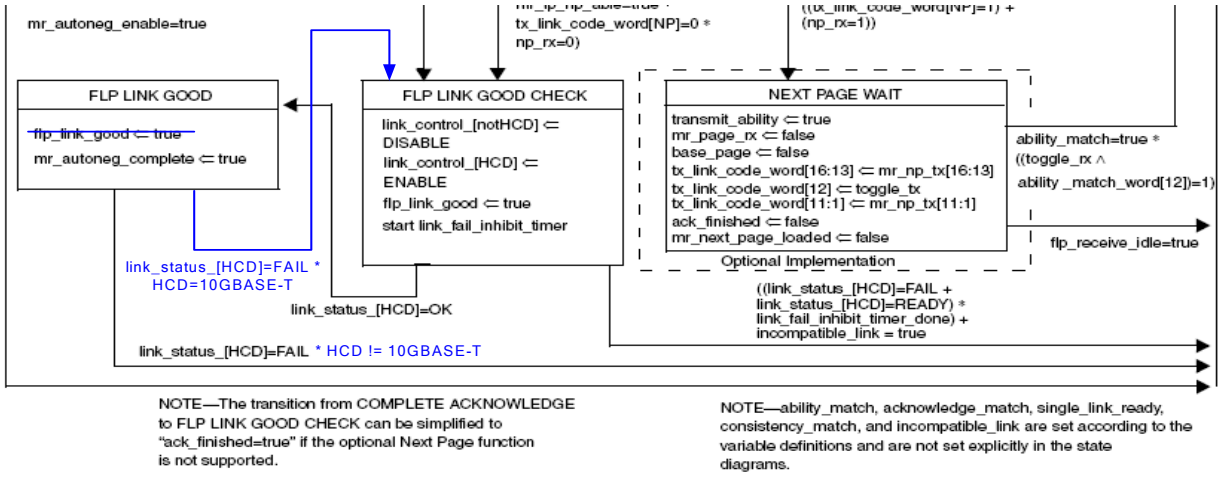


Figure 28–16—Arbitration state diagram

(IEEE Draft P802.3REVam/D2.2 - Section 2, April 24, 2005, page 263)

Required change in Auto Negotiation