IEC/ISA FieldBus: PhL-DLL Interfacing and FCS Considerations

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The following text is taken from Draft 10 of the IEC/ISA Fieldbus Data Link Protocol Specification. It is submitted as background to assist in the treatment of Data Link (MAC) to PHY issues in IEEE 802.11

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5.4 Service assumed from the Physical Layer

This clause defines the assumed Physical Service (PhS) primitives and their constraints on use by the DLPM.

NOTE — Proper layering requires that an (N+1)-layer entity not be concerned with, and that an (N)-service interface not overly constrain, the means by which an (N)-layer provides its (N)-services. Thus the Ph-service interface does not require DLEs to be aware of internal details of the PhE (e.g., preamble, postamble and frame delimiter signal patterns, number of bits per baud), and should not prevent the PhE from using appropriate evolving technologies.

5.4.1 Assumed primitives of the PhS

The granularity of transmission in the Fieldbus protocol is one octet. This is the granularity of PhS-user data exchanged at the PhL – DLL interface.

5.4.1.1 PhS characteristics reporting service

The PhS is assumed to provide the following service primitive to report essential PhS characteristics used in DLL transmission, reception, and scheduling activities:

Ph-CHARACTERISTICS indication (minimum-data-rate, framing-overhead)

where

minimum-data-rate — specifies the effective minimum rate of data conveyance in bits/second, including any timing tolerances.

NOTE 1 — A PhE with a nominal data rate of 1 Mbit/s ± 0,01% would specify a minimum data rate of 0,9999 Mbit/s.

framing-overhead — specifies the maximum number of bit periods (where period = $\frac{1}{\text{data rate}}$) used in any transmission for PhPDUs which do not directly convey data (e.g., PhPDUs conveying preamble, frame delimiters, postamble, inter-frame "silence", etc.)

NOTE 2 — If the framing overhead is F and two DL message lengths are L_1 and L_2, then the time to send one message of length $L_1 + F + L_2$ will be at least as great as the time required to send two immediately consecutive messages of lengths L_1 and L_2.

5.4.1.2 PhS transmission and reception services

The PhS is assumed to provide the following service primitives for transmission and reception:

Ph-DATA request (class, data)

Ph-DATA indication (class, data)

Ph-DATA confirm (status)

where

class — specifies the Ph-interface-control-information (PhICI) component of the Ph-interface-data-unit (PhIDU). For a Ph-DATA request, its possible values are:

START-OF-ACTIVITY — transmission of the PhPDUs which precede Ph-user data should commence;

DATA — the single-octet value of the associated data parameter should be transmitted as part of a continuous correctly-formed transmission; and

END-OF-DATA-AND-ACTIVITY — the PhPDUs which terminate Ph-user data should be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission.

For a Ph-DATA indication, its possible values are:

START-OF-ACTIVITY — reception of an apparent transmission from one or more PhEs has commenced;

DATA — the associated data parameter was received as part of a continuous correctly-formed reception;

END-OF-DATA — the ongoing continuous correctly-formed reception of Ph-user data has concluded with correct reception of PhPDUs implying END-OF-DATA;

END-OF-ACTIVITY — the ongoing reception (of an apparent transmission from one or more PhEs) has concluded, with no further evidence of PhE transmission; and

END-OF-DATA-AND-ACTIVITY — simultaneous occurrence of END-OF-DATA and END-OF-ACTIVITY.

data — specifies the Ph-interface-data (PhID) component of the PhIDU. It consists of one octet of Ph-user-data to be transmitted (Ph-DATA request) or which was received successfully (Ph-DATA indication).

status — specifies either success or the locally-detected reason for inferring failure.

The Ph-DATA confirm primitive provides the critical physical timing feedback necessary to inhibit the DLE from starting a second transmission before the first is complete. The final Ph-DATA confirm of a transmission should not be issued until the PhE has completed the current transmission.

5.4.2 Notification of PhS characteristics

The PhE has the responsibility for notifying the DLE of those characteristics of the PhS which are relevant to DLE operation. This notification is accomplished by the PhE by issuing a single Ph-CHARACTERISTICS indication primitive at each of the PhE's PhSAPs at PhE startup.

5.4.3 Transmission of Ph-user-data

The PhE determines the timing of all transmissions. When a DLE has a DLPDU to transmit, and the DL-protocol gives that DLE the right to transmit, then the DLE shall send the DLPDU, including a concatenated FCS, by making a well-formed sequence of Ph-DATA requests, consisting of a single request specifying START-OF-ACTIVITY; followed by three to 300 consecutive requests, inclusive, specifying DATA; and concluded by a single request specifying END-OF-DATA-AND-ACTIVITY.

The PhE signals its completion of each Ph-DATA request, and its readiness to accept a new Ph-DATA request, with a Ph-DATA confirm primitive; the status parameter of the Ph-DATA confirm primitive conveys the success or failure of the associated Ph-DATA request. A second Ph-DATA request should not be issued until after the Ph-DATA confirm corresponding to the first request has been received from the PhE.

5.4.4 Reception of Ph-user-data

The PhE reports a received transmission with a well-formed sequence of Ph-DATA indications, which shall consist of either

a) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA; followed by a single indication specifying END-OF-DATA; and concluded by a single indication specifying END-OF-ACTIVITY; or

b) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA; followed by a single indication specifying END-OF-DATA-AND-ACTIVITY; or

c) a single indication specifying START-OF-ACTIVITY; optionally followed by one or more consecutive indications specifying DATA; and concluded by a single indication specifying END-OF-ACTIVITY.

NOTE — This last sequence is indicative of an incomplete or incorrect reception. Detection of an error in the sequence of received PhPDUs, or in the PhE's reception process, disables further Ph-DATA indications with a class parameter specifying DATA, END-OF-DATA, or END-OF-DATA-AND-ACTIVITY until after both the end of the current period of activity and the start of a subsequent period of activity have been reported by Ph-DATA indications specifying END-OF-ACTIVITY and START-OF-ACTIVITY, respectively.

In the first two cases, the DLE concatenates the received data and then attempts to parse it into a DLPDU followed by a concatenated FCS. In the last case the DLE simply discards all reported data.

6.1 PhIDU structure and encoding

Each PhIDU consists of Ph-interface-control-information (PhICI) and in some cases one octet of Ph-interface-data (see 5.4). When the DLE transmits a DLPDU, it computes a frame check sequence for the DLPDU as specified in 7.1.1, concatenates the DLPDU and frame check sequence, and transmits the concatenated pair as a sequence of PhIDUs as follows:

a) The DLE issues a single Ph-DATA request primitive with PhICI specifying START-OF-ACTIVITY, and awaits the consequent Ph-DATA confirm primitive.

b) The DLE issues a sequence of Ph-DATA request primitives with PhICI specifying DATA, each accompanied by one octet of the DLPDU as Ph-interface-data, from first to last octet of the DLPDU, and after each Ph-DATA request primitive awaits the consequent Ph-DATA confirm primitive.

c) The DLE issues a sequence of two Ph-DATA request primitives with PhICI specifying DATA, each accompanied by one octet of the FCS as Ph-interface-data, from first to last octet of the FCS, and after each Ph-DATA request primitive awaits the consequent Ph-DATA confirm primitive.

d) The DLE issues a single Ph-DATA request primitive with PhICI specifying END-OF-DATA-AND-ACTIVITY, and awaits the consequent Ph-DATA confirm primitive.

The DLE forms a received DLPDU by concatenating the sequence of octets received as Ph-interface-control-information of consecutive Ph-DATA indications, computing a frame check sequence for those received octets as specified in 7.1.1, and checks the syndrome of the computed FCS for correctness as follows:

e) The DLE receives a single Ph-DATA indication primitive with PhICI specifying START-OF-ACTIVITY, and initializes its computation of an FCS for the received DLPDU.

f) The DLE receives a sequence of Ph-DATA indication primitives with PhICI specifying DATA, each accompanied by one octet of the received DLPDU as Ph-interface-data, incrementally computes an FCS on the received octet, and concatenates all but the last two of those received octets to form the received DL-PDU.

g) The DLE receives a single Ph-DATA indication primitive with PhICI specifying either END-OF-DATA, END-OF-DATA-AND-ACTIVITY or END-OF-ACTIVITY, and checks the syndrome of the computed FCS for correctness:

1) If the PhICI specified END-OF-DATA or END-OF-DATA-AND-ACTIVITY, and the computed FCS syndrome was correct, then the DLE reports the reconstructed DLPDU and the two octets of received FCS as a correctly-received DLPDU suitable for further analysis.

2) Otherwise, the DLE increments its management statistics to reflect the erroneously-received DLPDU.

6.1.1 Frame check sequence

NOTE — The generator polynomial for this FCS is specified in Eq. 5. The polynomial for the receiver's expected residue is specified in Eq. 10. Exemplary implementations are discussed in NOTES, and are shown in Annex E.

In this part of this International Standard, as in other International Standards (e.g., ISO 3309, ISO 8802), DLPDU-level error detection is provided by calculating and appending a multi-bit Frame Check Sequence (FCS) to the other DLPDU fields during transmission to form a "systematic code word"[1] of length n consisting of k DLPDU message bits followed by n - k redundant bits, and by calculating during reception that the message and concatenated FCS form a legal (n,k) code word. The value of n - k for this part of this International Standard is 16. The mechanism for this checking is as follows:

6.1.1.1 At the sending DLE

The original message (i.e., the DLPDU without an FCS), the FCS, and the composite message code word (the concatenated DLPDU and FCS) shall be regarded as vectors M(X), F(X), and D(X), of dimension k, n - k, and n, respectively, in an extension field over GF(2). If the message bits are $m_1 \dots m_k$ and the FCS bits are $f_{n-k-1} \dots f_0$, where $m_1 \dots m_8$ form the first octet sent, $m_{8N-7} \dots m_{8N}$ form the Nth octet sent, and $f_7 \dots f_0$ form the last octet sent, then the message vector M(X) shall be regarded to be

$$M(X) = m_1X^{k-1} + m_2X^{k-2} + \dots + m_{k-1}X^1 + m_k \qquad \text{(Eq. 1)}$$

and the FCS vector F(X) shall be regarded to be

$$\begin{aligned} F(X) &= f_{n-k-1}X^{n-k-1} + \dots + f_0 \qquad \text{(Eq. 2)} \\ &= f_{15}X^{15} + \dots + f_0 \end{aligned}$$

and so the composite vector D(X), for the complete DLPDU, shall be constructed as the concatenation of the message and FCS vectors

$$\begin{aligned} D(X) &= M(X)\,X^{n-k} + F(X) \qquad \text{(Eq. 3)} \\ &= m_1X^{n-1} + m_2X^{n-2} + \dots + m_kX^{n-k} \\ &\quad + f_{n-k-1}X^{n-k-1} + \dots + f_0 \\ &= m_1X^{n-1} + m_2X^{n-2} + \dots + m_kX^{16} + f_{15}X^{15} + \dots + f_0 \end{aligned}$$

The DLPDU presented to the PhL shall consist of an octet sequence in the specified order.

The redundant check bits $f_{n-k-1} \dots f_0$ of the FCS shall be the remainder, after division by G(X), of

$$F(X) = L(X)\,(X^k + 1) + M(X)\,X^{n-k} \pmod{G(X)} \qquad \text{(Eq. 4)}$$

where G(X) is the degree n-k generator polynomial for the code words

$$\begin{aligned} G(X) &= X^{n-k} + g_{n-k-1}X^{n-k-1} + \dots + 1 \qquad \text{(Eq. 5)} \\ &= X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^6 + X^3 + X^2 + X + 1 \end{aligned}$$

and L(X) is the maximal weight (all ones) polynomial of degree n-k-1

$$\begin{aligned} L(X) &= \frac{X^{n-k}+1}{X+1} = X^{n-k-1} + X^{n-k-2} + \dots + X + 1 \qquad \text{(Eq. 6)} \\ &= X^{15} + X^{14} + X^{13} + X^{12} + \dots + X^2 + X + 1 \end{aligned}$$

NOTES —

1 The L(X) terms are included in the computation to detect initial or terminal message truncation or extension.

2 This G(X) polynomial is relatively prime to all, and is thus not compromised by any, of the polynomials commonly used in DCEs (modems): the differential encoding polynomial $1 + X^{-1}$ and primitive scrambling polynomials of the form $1 + X^{-j} + X^{-k}$.

3 Code words D(X) constructed from this G(X) polynomial have Hamming distance 4 for lengths ≤ 344 octets and Hamming distance 6 for lengths ≤ 16 octets.

4 As a typical implementation, at a transmitter, the initial remainder of the division is preset to all ones. The transmitted message bit stream is multiplied by X^{16} and divided (modulo 2) by the generator polynomial G(X), specified in Eq. 5; the ones complement of the resulting remainder is transmitted as the 16-bit FCS.

6.1.1.2 At the receiving DLE

The octet sequence indicated by the PhE shall be concatenated into the received DLPDU and FCS, and regarded as a vector V(X) of dimension u

$$V(X) = v_1X^{u-1} + v_2X^{u-2} + \dots + v_{u-1}X + v_u \qquad \text{(Eq. 7)}$$

NOTE 1 — Because of errors u can be different than n, the dimension of the transmitted code vector.

A remainder R(X) shall be computed for V(X), the received DLPDU and FCS, by a method similar to that used by the sending DLE (in 7.1.1.1) in computing F(X)

$$\begin{aligned} R(X) &= L(X)\,X^u + V(X)\,X^{n-k} \pmod{G(X)} \qquad \text{(Eq. 8)} \\ &= r_{n-k-1}X^{n-k-1} + \dots + r_0 \end{aligned}$$

Define E(X) to be the error code vector of the additive (modulo-2) differences between the transmitted code vector D(X) and the received vector V(X) resulting from errors encountered (in the PhS provider and in bridges) between sending and receiving DLEs.

$$E(X) = D(X) + V(X) \qquad \text{(Eq. 9)}$$

If no error has occurred, so that E(X) = 0, then R(X) will equal a non-zero constant remainder polynomial

$$\begin{aligned} R_{ok}(X) &= L(X)\,X^{n-k} \pmod{G(X)} \qquad \text{(Eq.10)} \\ &= X^{15} + X^{14} + X^{13} + X^9 + X^8 + X^7 + X^4 + X^2 \end{aligned}$$

whose value is independent of D(X). Unfortunately R(X) will also equal $R_{ok}(X)$ in those cases where E(X) is an exact non-zero multiple of G(X), in which case there are

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1 W. W. Peterson and E. J. Weldon, Jr., *Error Correcting Codes* (2nd edition), MIT Press, Cambridge, 1972

"undetectable" errors. In all other cases, $R(X)$ will not equal $R_{ok}(X)$; such DLPDUs are erroneous and shall be discarded without further analysis.

NOTE 2 — As a typical implementation, at a receiver, the initial remainder of the division is preset to all ones. The received bit stream is multiplied by X^{16} and divided (modulo 2) by the generator polynomial $G(X)$, specified in Eq. 6; the resulting 16-bit remainder should be 1110 0011 1001 0100 (X^{15} through X^0, respectively) in the absence of errors.

6.1.1.3 Modification within bridges

When forwarding a DLPDU, it is sometimes necessary for a bridge to alter one or more subfields of a DLPDU's frame control field. When making these modifications, the bridge shall modify the received FCS to compensate for changes in the frame control octet; the bridge shall not discard the received FCS and recompute a new FCS after the DLPDU's frame control field has been altered[1].

When the received DLPDU's length, plus that of its FCS field, is N octets, then the bridge can compensate for a change in bit K (the bit whose weight in a one-octet unsigned integer is 2^K) in the first octet by computing the residual of the polynomial

$$X^{8N+K-8} \quad \text{(modulo } G(X)) \qquad \text{(Eq. 11}$$

and then updating the DLPDU's FCS field by exclusive-ORing the computed residual into that field.

Implementation NOTE — The bridge can precompute the residuals for all permissible DLPDU lengths and bit positions potentially needing alteration when it initializes — for values of N between 3 and 270, and values of K of 0, 1 and 3. Then for any DLPDU it need only apply to the DLPDU's FCS those residuals which correspond to the changes actually made in the DLPDU's frame control octet.

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[1] D. R. Irvin, *Preserving the integrity of cyclic-redundancy checks when protected text is intentionally altered*, IBM Journal of Research and Development, Vol. 33, No. 6, November 1989, pp. 618-626