P802.1CBec

Text Contribution

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Annex X

(informative)

Guidance for Sequence Recovery Function Parameter Configuration

X.1 Introduction

This annex provides informative guidance for the configuration of parameters of the Sequence recovery function (CLAUSE-REF).

Incorrect parameter settings can compromise the reliability of FRER. This annex help users of the standard to understand the implications of the parameter settings and derive safe parameter values. The content of this annex is based on concepts and results presented in [B1].

This annex covers the configuration of the following parameters:

1. `frerSeqRcvyAlgorithm` (CLAUSE-REF)
2. `frerSeqRcvyHistoryLength` (CLAUSE-REF)
3. `frerSeqRcvyResetMSec` (CLAUSE-REF)

For the purpose of this annex, the term *eliminating device* refers to the device that applies the Sequence Recovery Function to remove replicates, e.g., a destination end system or a relay system. Additionally, *valid* frames refer to the first received instances of a frame with a given Sequence Number that is to be forwarded by the Sequence Recovery Function.

An overview of the risks is provided below; the configuration details and mitigation strategies are discussed in X.3.

1. Selecting MatchRecoveryAlgorithm (CLAUSE-REF) via the `frerSeqRcvyAlgorithm` variable is only appropriate for Intermittent Streams (CLAUSE-REF). If applied to other types of Streams, this algorithm may incorrectly forward replicates. Therefore, it is important to identify whether a given Stream qualifies as intermittent.
2. If the `frerSeqRcvyHistoryLength` parameter is configured too small, valid frames may be classified as rogue and discarded. If the value is too large, excessive processing time may result, potentially leading to frame loss in resource-constrained implementations.
3. If the `frerSeqRcvyResetMSec` parameter is configured with a value that is too low, replicate frames may be forwarded due to the premature reset of the `SequenceHistory` (CLAUSE-REF). If the value is too high, valid frames may be classified as rogue and discarded.

X.2 Terminology

The following variables are used throughout this annex.

- T_S: Minimum duration of the transmission interval associated with the stream. This refers to the duration over which a stream may transmit up to N_S frames. The timing between individual frames within the interval (inter-frame spacing) is not constrained, but the total number of frames and the interval duration are bounded. This variable can correspond to the Class Measurement Interval (CLAUSE-REF).
- N_S: Maximum number of frames a stream is allowed to transmit during one transmission interval of length T_S. This variable can correspond to Max Interval Frames (CLAUSE-REF).
- L_{max}: Maximum size of frames in the stream. This variable can correspond to Max Frame Size (CLAUSE-REF).
- V_G: Maximum deviation in the frame generation time from its expected schedule. This term captures the variation in the timing behavior of the talker, e.g., due to clock inaccuracy. The deviation is assumed to be bounded and non-accumulating across intervals. If the transmission of a frame may occur up to v_1 later or up to v_2 earlier than its nominal time, the generation deviation is defined as $V_G = v_1 + v_2$, representing the maximum variation.

The following guideline distinguishes between two classes of streams, illustrated in Fig. 1: *Periodic streams* that generate frames in a strictly periodic pattern. Each frame is generated every T_S time units, with a maximum deviation V_G from the expected time. *Interval-constrained streams* that generate up to N_S frames during each interval of length T_S. Only the number of frames and the interval duration are constrained; no assumptions are made on the inter-frame spacing.

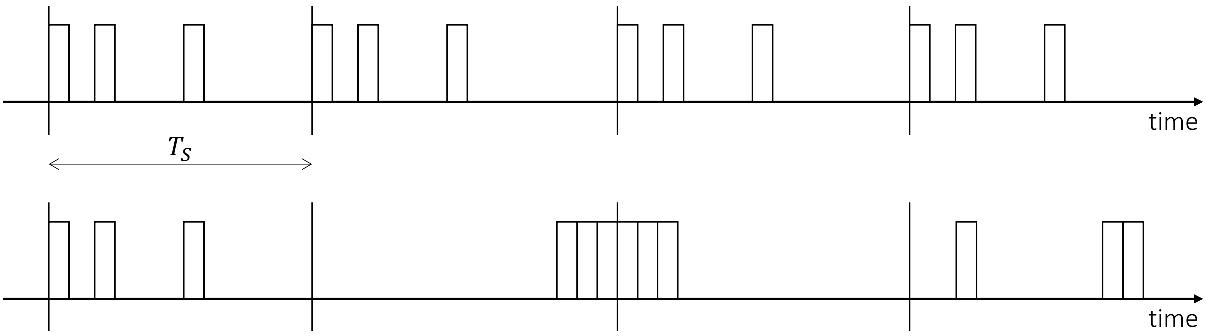

Figure 1: Example for Talker sending behavior. Top: Periodic stream. Bottom: Interval-constrained stream. $N_S = 3$ and $V_G = 0$.

- d_{BC}: Best-case delay, defined as the minimum time from the transmission of a frame by the talker to the arrival of the first copy at the eliminating device, considering all member stream paths.
- d_{WC}: Worst-case delay, defined as the maximum time from the transmission of a frame by the talker to the arrival of its last copy at the eliminating device, considering all member stream paths.
- $\Delta d = d_{WC} - d_{BC}$: Reception window, represents the time interval during which frames with identical Sequence Numbers may arrive at the eliminating device via different member stream paths.

The delay values are out of the scope of this annex and have to be determined according to the network configuration.

Figure 2 illustrates the concept of reception windows. The following guidlines base on modeling the worst-case overlap of reception windows for every parameter.

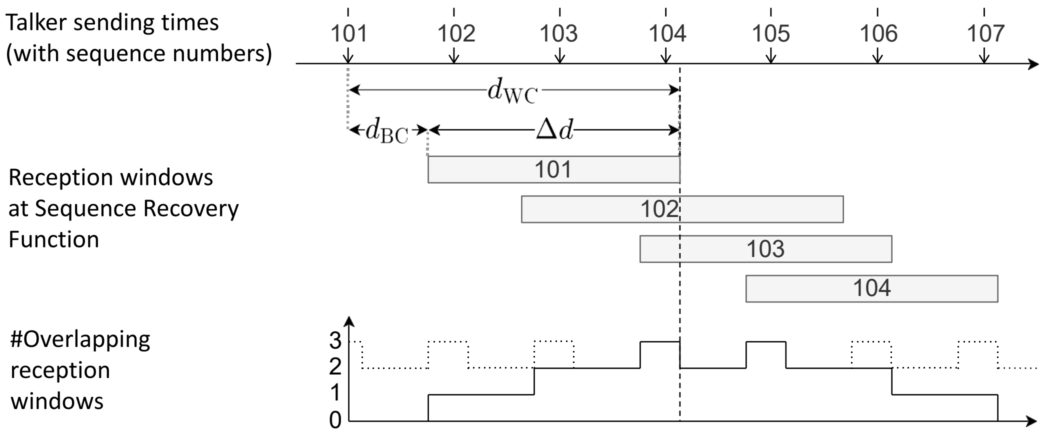

Figure 2: Reception window illustration for periodic stream.

All time values are expressed in consistent time units.

X.3 Parameter Configuration

X.3.1 Recovery Algorithm Selection

For the elimination of replicate frames, two recovery algorithms are available: the MatchRecoveryAlgorithm (CLAUSE-REF) and the VectorRecoveryAlgorithm (CLAUSE-REF). The selection is performed with the `frerSeqRcvyAlgorithm` parameter.

The MatchRecoveryAlgorithm stores a single Sequence Number and eliminates only replicate frames with that exact value. All other frames are accepted and forwarded. This method is applicable to Intermittent Streams; for all other Stream types, it may result in forwarding replicates. If the following equations are true, a Stream can be classified as Intermittent.

For *periodic Streams*, a sufficient condition for Intermittent Stream behavior is that the transmission interval T_S exceeds the reception window Δd, including the maximum deviation V_G between the current and the next frame:

$$T_S > \Delta d + V_G \tag{X-1}$$

This ensures that all replicates of a frame with a given Sequence Number have arrived before a new Sequence Number is received, as the reception windows do not overlap.

X.3.1.1 Interval-constrained Streams. For *interval-constrained Streams*, frames may be transmitted at any point within the interval T_S. In this case, the condition becomes:

$$T_S > \Delta d + T_S + V_G \tag{X-2}$$

X.3.1.2 Multiple Frames. If $N_S > 1$, the MatchRecoveryAlgorithm is generally not applicable. Overlapping arrivals of multiple Sequence Numbers are possible, and the VectorRecoveryAlgorithm shall be used instead.

X.3.2 Sequence History Length

If a Stream requires the `VectorRecoveryAlgorithm`, the `frerSeqRcvyHistoryLength` parameter must be configured accordingly. This parameter defines the number of Sequence Numbers that are retained by the sequence window of the Sequence Recovery Function. The sequence window is defined as:

$$RecovSeqNum \pm (frerSeqRcvyHistoryLength - 1) \quad \text{(X-3)}$$

The parameter `RecovSeqNum` is initialized with the first Sequence Number received. Frames with Sequence Numbers inside this window and higher than `RecovSeqNum` lead to an update of the `RecovSeqNum`. Frames falling within this window are handled correctly, frames falling outside this window are marked as rogue and are discarded, even if they are the first arrival of that Sequence Number.

The following derivation applies to periodic Streams with $N_S = 1$, where L denotes the value of `frerSeqRcvyHistoryLength`:

1. For a reception window of duration Δd, it has to be determined how many reception windows of distinct Sequence Numbers may overlap. This is illustrated with the function at the bottom of Fig. 2. This represents all sequence numbers that may be received concurrently and, therefore, all sequence numbers that must be retained within the sequence window. Only the reception of new frames triggers advancement of the sequence window.

2. With frame transmissions occurring every T_S time units, the number of overlapping reception windows is given by:

$$N = \left\lfloor \frac{\Delta d}{T_S} \right\rfloor + 1 \quad \text{(X-4)}$$

   In the example illustrated in Fig. 2, $N = 3$, and the current `RecovSeqNum` is 101. A frame with Sequence Number 104 may be accepted before Sequence Numbers 102 or 103 have arrived. At the same time, Sequence Number 99 may still arrive after Sequence Number 101 has been accepted.

   Since the sequence window defined by the Sequence Recovery Function covers the range $[RecovSeqNum - L + 1,\ RecovSeqNum + L - 1]$, , the ceiling operation in the earlier bound must be removed, resulting in the following requirement:

$$L > \frac{\Delta d}{T_S} + 1 \quad \text{(X-5)}$$

3. Including the maximum deviation V_G in frame generation timing:

$$L > \frac{\Delta d + V_G}{T_S} + 1 \quad \text{(X-6)}$$

Higher values lead to increased memory and processing requirements. If the processing delay becomes excessive, this can result in frame loss.

X.3.2.1 Interval-constrained Streams. In this case, frames may occur at any time during the interval T_S, leading to:

$$L > \frac{\Delta d + V_G}{T_S} + 2 \tag{X-7}$$

X.3.2.2 Multiple Frames. For Streams with $N_S > 1$, each overlapping Sequence Number may correspond to multiple frames. The worst-case scenario occurs when one frame is sent at the beginning of an interval and the remaining $N_S - 1$ frames at the end. The required sequence window length becomes:

$$L' \geq N_S \cdot L \tag{X-8}$$

X.3.3 Reset Timer Configuration

The Sequence Recovery Function is reinitialized with the SequenceRecoveryReset function if no frame is accepted and forwarded for the duration defined by `frerSeqRcvyResetMSec`. This timeout prevents frames from being incorrectly handled after interruptions. Each time a new frame is accepted, the timer is reset.

If the timeout is configured too short, the sequence window may reset prematurely and allow replicates to be forwarded. If the timeout is too long, valid frames may be discarded as being outside the current Sequence Number window.

The following derivation applies to periodic Streams with $N_S = 1$, where R denotes the value of `frerSeqRcvyResetMSec`:

1. To prevent the forwarding of replicates, a safe reset can occur when no more replicates of the current Sequence Number can arrive. Assuming the first frame of a Sequence Number arrives at the beginning of Δd, no replicates will be forwarded it the timeout is:

$$R > \Delta d + V_G \tag{X-9}$$

2. However, if Δd is small and no overlap exists between reception windows of Sequence Numbers, this may lead to unnecessary resets after each frame. To avoid this, the timer can wait until the entire interval of the next frame has passed:

$$R = \Delta d + T_S + V_G \tag{X-10}$$

This value ensures that the Sequence Recovery Function resets only when no further replicates are expected, without delaying the acceptance of new Sequence Numbers. Higher values are not recommended, as they may cause valid frames to be discarded.

X.3.3.1 Interval-constrained Streams. In this case, frames may occur at any time during the interval T_S, leading to:

$$R = \Delta d + 2 \cdot T_S + V_G \quad \text{(X-11)}$$

X.3.3.2 Multiple Frames. The reset timer only depends on the timing of the frame arrivals, not on the number of frames. Therefore, the equations above apply for all values of N_S.

Bibliography

[B1] L. Maile, D. Voitlein, K.-S. Hielscher, and R. German, "Ensuring reliable and predictable behavior of IEEE 802.1CB frame replication and elimination," in Proc. IEEE International Conference on Communications, Seoul, Korea, Republic of, 2022, pp. 2706-2712, doi: 10.1109/ICC45855.2022.9838905.