Technische Universität Braunschweig

INSTITUTE OF COMPUTER AND NETWORK ENGINEERING

Informative Annex Project Proposal for IEEE Std 802.1CB Sequence Recovery Function Parameter Configuration

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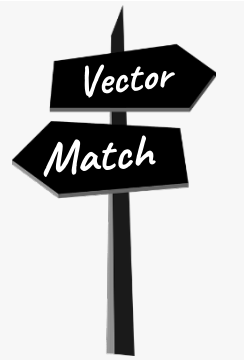
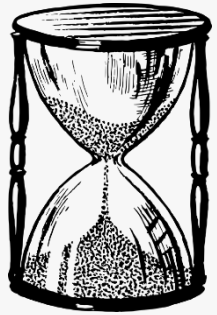
Background – User guidance for configuring FRER

Challenges: Incorrect configuration of parameters for elimination in IEEE Std 802.1CB can result in valid frames to be discarded entirely, passing of duplicates, and unexpected bursts.
Too high and too low values can jeopardize the reliability of FRER [Maile2022].



Match Recovery Algorithm (MRA):

only applicable to **intermittent streams,**
otherwise MRA passes duplicates
→ missing support for
intermittent stream identification



Reset Timer:
SequenceRecoveryResetMSec

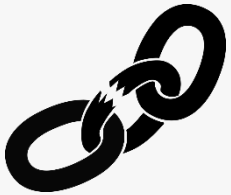
too low: unnecessary resets [Maile2022] &
duplicates passed [Varga2023]

too high: discards (non-duplicate)
frames [Maile2022]

Vector Recovery Algorithm (VRA)
– History Length: *frerSeqRcvyHistoryLength*

too short: discards (new) frames [Hofmann2020]

too high: increased processing time can result in
frame loss [Rana2023], $O(n)$ with n window size



Burst & Peak Rate Increase:

delay increase for flow [Thomas2022] and for
interfering flows [Hofmann2020]
& buffer must be increased [Hofmann2020]

Background – Resources on the Topic

Previous presentations:

TSN TG (Jun. 2023 & Jun. 2024):
https://www.ieee802.org/1/files/public/docs2023/new-maile-ensuring-reliable-and-predictable-behavior-of-FRER-0623-v02.pdf

https://www.ieee802.org/1/files/public/docs2024/new-maile-FRER-sequence-recovery-configuration-0624-v01.pdf

Nendica (Feb. – Apr. 2024):
https://mentor.ieee.org/802.1/documents?is_dcn=maile

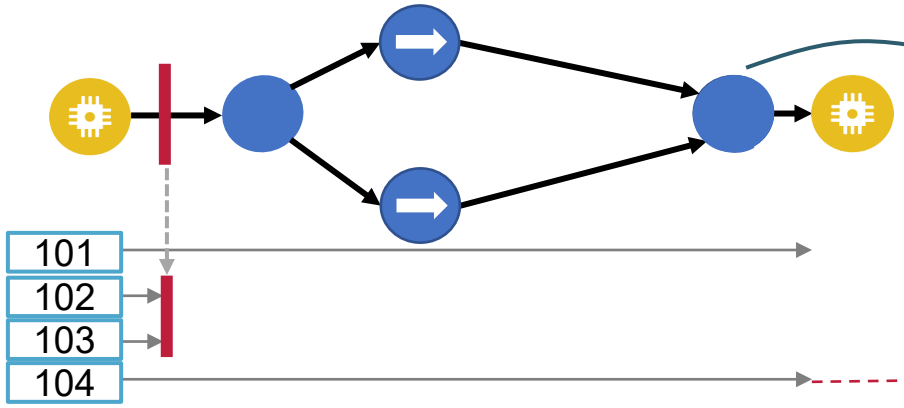
Original contribution:

Including analytical models and proofs.
http://arxiv.org/abs/2306.13469 / https://ieeexplore.ieee.org/document/9838905

Example Solution - *SequenceRecoveryReset* timer value

Sequence Recovery Reset*:*

- Reset of the sequence history (= which sequence number have been
- triggered after a period (*SequenceRecoveryResetMSec*) in which no packets have been accepted, e.g., because talker loses its connection
- Reason: Next sequence number is indefinitely higher than last one received.



Seq. No.	99	100	101	102	103
Received?	1	1	1	0	0

discarded

jump can be arbitrarily large
→ reset sequence history

Seq. No.	102	103	104	105	106
Received?	0	0	1	0	0

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Sequence Recovery Reset*:*

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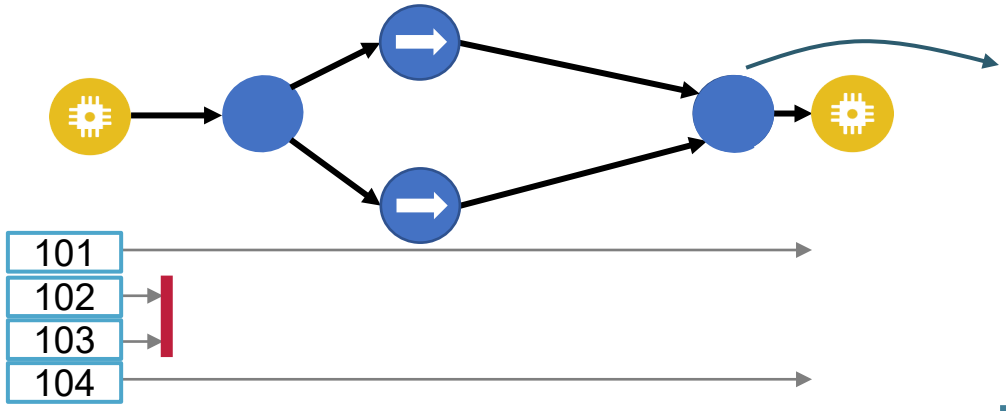

Seq. No.	99	100	101	102	103
Received?	1	1	1	0	0

reset too short
→ duplicate of 101 arrives and is forwarded

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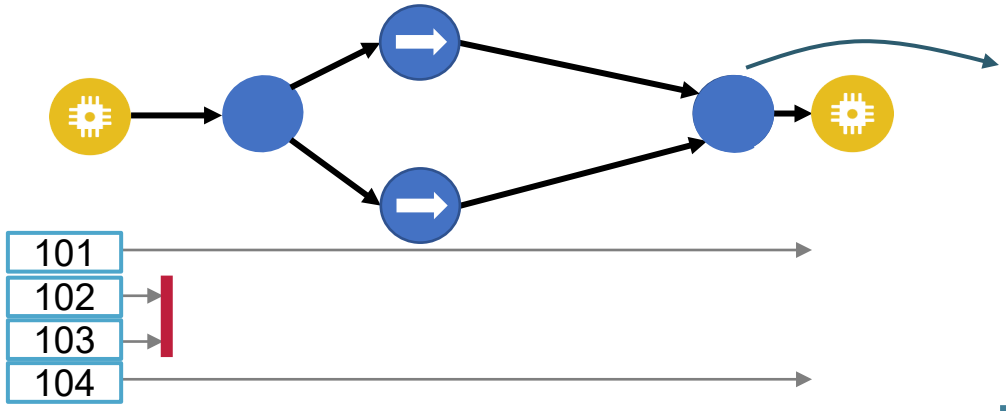

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Seq. No.	99	100	101	102	103
Received?	0	0	1	0	0

Challenge:

- Define SequenceRecoveryResetMSec. **Too short**: Duplicates forwarded. **Too long**: Valid packets can get discarded entirely.

Example Solution - *SequenceRecoveryReset* timer value

Stream Characteristics:

- Class Measurement Interval (CMI)
- Maximum Interval Frames (MIF)
- Maximum Frame Size (MFS)

CMI is used as variable name,
it represents **arbitrary** sending intervals,
possibly **individual** for each stream

A stream sends at most MIF packets during an interval of length CMI.
Each packet is smaller or equal to MFS.

Example Solution - *SequenceRecoveryReset* timer value

Stream Characteristics:

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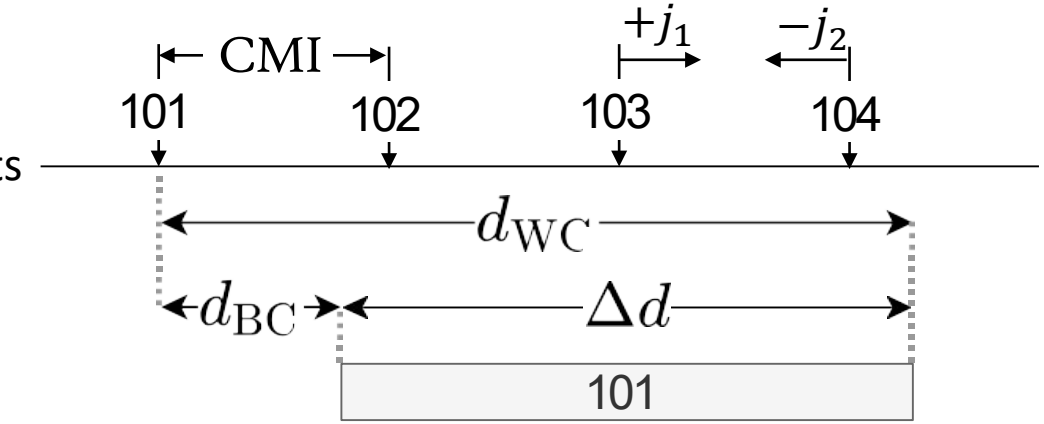
introduction of optional **jitter** term,
if the frames are not guaranteed to be separated
by full interval (e.g., due to clock inaccuracy)
with $j_1 + j_2 = J \leq CMI$

Network Characteristics:

- lowest delay of fastest path d_{BC} (best-case)
- highest delay of slowest path d_{WC} (worst-case)
- reception window: $\Delta d = d_{WC} - d_{BC}$

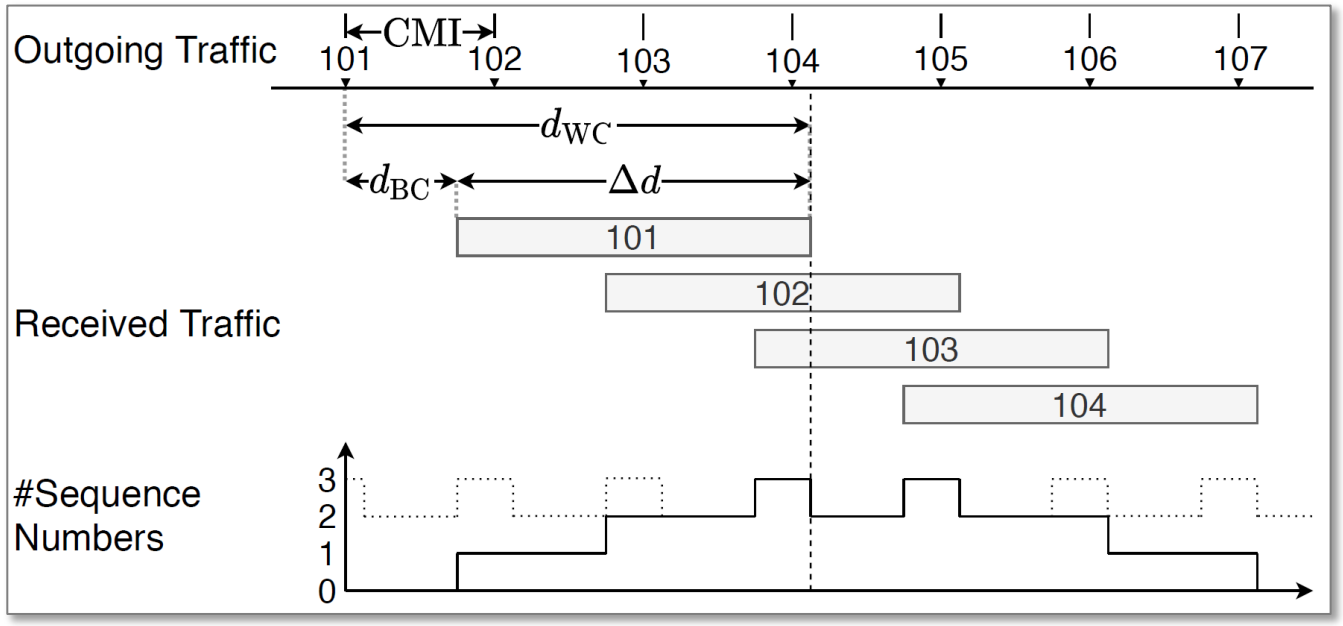
Illustration:



Example Solution - *SequenceRecoveryReset* timer value

Solution:

- *SequenceRecoveryResetMSec* (short: R) is safe when no more duplicate packets can arrive: $R > \Delta d$
- However, for small Δd where the reception windows do not overlap, this configuration may result in many unnecessary resets
- The optimal *SequenceRecoveryResetMSec* is:
  - Periodic Traffic: $R = \Delta d + CMI$
  - Aperiodic Traffic / Jitter:
    $R = \Delta d + J + CMI$ or $\mathrm{R} = \Delta d + 2 \cdot CMI$
  - MIF > 1: Identical



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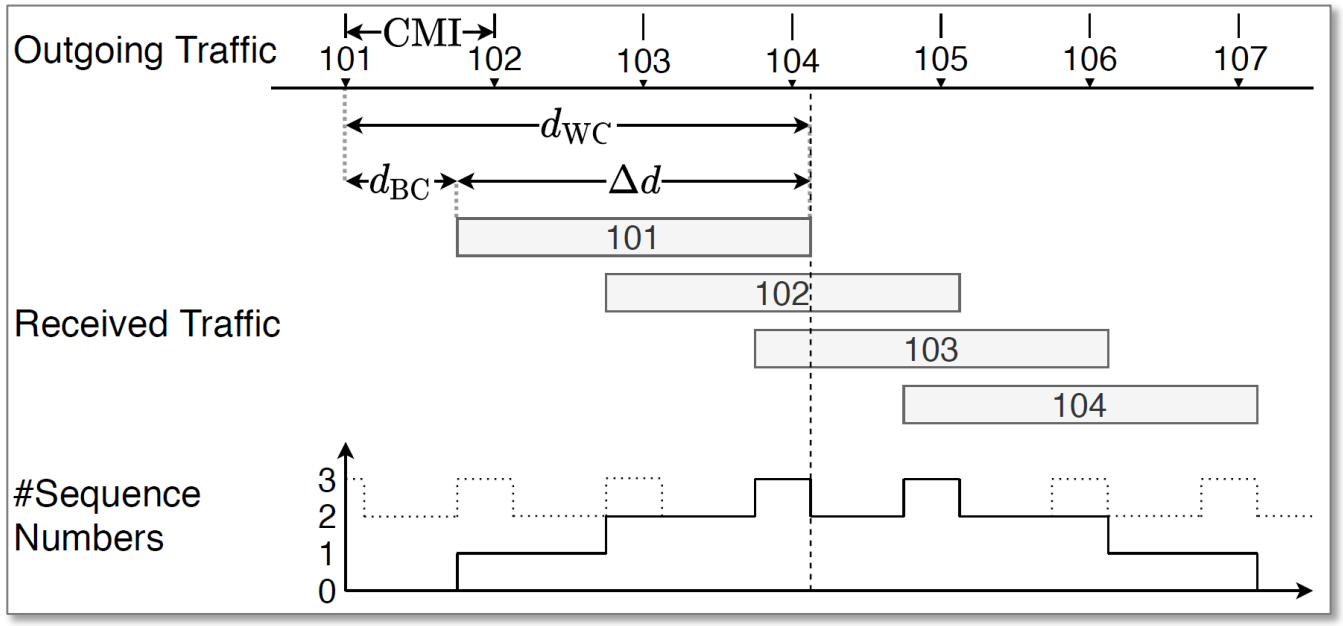
Key Points:

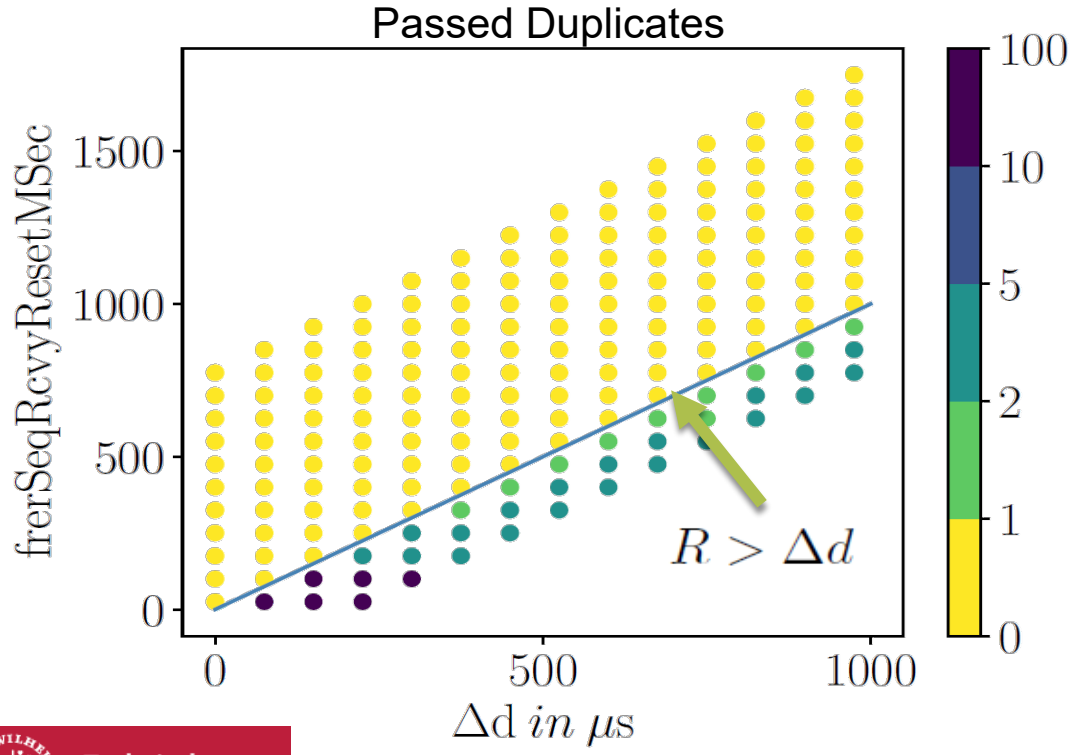
1. Parameters already defined in the standard.
2. The intended annex provides simple formulas which serves as guidance on how to set the parameter values.
3. Formulas only require best- and worst-case path delays of the network and the traffic characteristic.



Reset Timer Configuration

Simulation Results

- 100 packets sent with $CMI = 125\mu s$, one packet lost at talker due to interruption (max. 99 packets received)



Optimal: $R = \Delta d + CMI$

Safe: $R > \Delta d$

R in µs	50	75	100	150	200	300	400	500	600
#Duplicates	99	99	0	0	0	0	0	0	0
#Passed	99	99	99	99	99	99	98	97	96
#Resets	198	101	99	2	2	2	2	2	2

Proposal for PAR

Informative Annex for IEEE Std. 802.1CB
that includes guidelines for the parameter values of FRER

this can help the user / network administrator to understand the effects of duplicate elimination
+ enable proper configuration of FRER

Intended as informative only (i.e., no normative content added)

Proposal for Project

- **Potential Title:**
  Annex (informative): Configuration Parameters for the Sequence Recovery Function

- **Scope of the project:** State what the Amendment is changing or adding.
  - This amendment adds an informative annex **describing recommended values for the existing sequence recovery function parameters and providing guidance useful for determining requirements for frame buffering (in relay and end** systems), to assist in the proper usage of Frame Replication and Elimination for Reliability.

- **Need for the project:** Briefly detail the specific problem that the standard will resolve and the benefit that users will gain.
  - To achieve fault tolerance introduced by IEEE Std 802.1CB, it is necessary to identify and eliminate duplicate frames and store and forward non-duplicate frames. **Currently, there exists no guidance on the configuration of the sequence recovery function parameters and on buffering for proper elimination. This can lead to duplicates being passed and valid frames being discarded entirely.** This informative annex provides a guidance on parameter values and buffering for the proper behavior of IEEE Std 802.1CB.

Proposal for Project

- **Stakeholders for the Standard:** Any parties that have an interest in or may be impacted (e.g., telecom, medical, environmental).
  - Developers, providers, and users of IEEE Std 802.1CB for networking services and equipment. This includes industrial automation, in-vehicle networking, aerospace onboard networking, professional audio-video, and other systems requiring communication with the increased reliability of duplicate frame transmission.

- **Are there other standards or projects with a similar scope? If yes, explain:** Identify any standard(s) or project(s) of similar scope(s), both within or outside of the IEEE, and explain the need for an additional standard in this area.
  - No.

Proposal for Project

Broad market potential

Each proposed IEEE 802 LMSC standard shall have broad market potential. At a minimum, address the following areas: a) Broad sets of applicability. b) Multiple vendors and numerous users.

a) *As in IEEE Std 802.1CB-2017.*

b) All vendors and users of Frame Replication and Elimination for Reliability can benefit from the informative annex.

Economic Feasibility

Demonstrate the economic including:
a) Known cost factors. b) Balanced costs. c) Consideration of installation costs. d) Consideration of operational costs (e.g., energy consumption). e) Other areas, as appropriate.

The amendment **does not imply additional hardware cost** as it only adds description and recommendations for existing parameter settings. The proposed parameters and guidelines **could potentially lower implementation costs by reducing over-provisioning for memory (required for the vector recovery algorithm and buffering).**

Proposal for Project

Technical Feasibility

Each proposed IEEE 802 LMSC standard shall provide evidence that the project is technically feasible within the time frame of the project. At a minimum, address the following items to demonstrate technical feasibility: a) Demonstrated system feasibility. b) Proven similar technology via testing, modeling, simulation, etc.

a) The informative annex describes the setting of existing parameters that are currently deployed. All addressed parameters are already defined by IEEE Std 802.1CB; therefore, setting these parameters is feasible.

b) The informative annex relies on the proven technology provided by the base standard. Additionally, the proposed parameter values have been modeled, proven, and simulated.
See https://ieeexplore.ieee.org/document/9838905 (http://arxiv.org/abs/2306.13469).

Acknowledgement

Special thanks to

- Johannes Specht
- Stephan Kehrer
- and Roger Marks

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References

“IEEE standard for local and metropolitan area networks–frame replication and elimination for reliability,” IEEE Std 802.1CB-2017.

[Hofmann2020] *R. Hofmann, B. Nikoli´c, and R. Ernst, “Challenges and limitations of IEEE 802.1CB-2017,” IEEE Embedded Systems Letters, vol. 12, no. 4, pp. 105–108, 2020.*

[Maile2022] *L. Maile, D. Voitlein, K. -S. Hielscher and R. German, "Ensuring Reliable and Predictable Behavior of IEEE 802.1CB Frame Replication and Elimination," ICC 2022 - IEEE International Conference on Communications, Seoul, Korea, Republic of, 2022, pp. 2706-2712, doi: 10.1109/ICC45855.2022.9838905.*

[Thomas2022] *L. Thomas, A. Mifdaoui and J. -Y. Le Boudec, "Worst-Case Delay Bounds in Time-Sensitive Networks With Packet Replication and Elimination," in IEEE/ACM Transactions on Networking, vol. 30, no. 6, pp. 2701-2715, Dec. 2022, doi: 10.1109/TNET.2022.3180763.*

[Rana2023] *S. K. Rana, H. Verma, J. Pal, D. Choudhary, T. V. Prabhakar, and C. Singh, “Enhancing Reliability of Scheduled Traffic in Time-Sensitive Networks using Frame Replication and Elimination,” in IEEE 29th International Symposium on Local and Metropolitan Area Networks, Jul. 2023, pp. 1–6. doi: 10.1109/LANMAN58293.2023.10189416.*

[Varga2023] *B. Varga, J. Farkas, F. Fejes, J. Ansari, I. Moldován, and M. Máté, “Robustness and Reliability Provided by Deterministic Packet Networks (TSN and DetNet),” IEEE Trans. Netw. Serv. Manage., vol. 20, no. 3, pp. 2309–2318, Sep. 2023, doi: 10.1109/TNSM.2023.3284590.*

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Thank you!

More questions? lisa.maile@tu-braunschweig.de