Performance Evaluation of the User Quality of Service Extension Block for Space DTNs

ComNets

Space DTNs

- Space communication systems must support heterogeneous applications with different requirements over high-latency disrupted environments.
- Delay- and Disruption-Tolerant Networking (DTN) addresses the challenges present in space communications through a store-and-forward approach.
- The Bundle Protocol (BP) provides the networking layer for DTN.
- However, Quality of Service (QoS) support in DTN and BP remains limited [1].
- Previous work proposes a User Quality of Service Extension Block (UQEB) as a manner of signalling QoS requirements to the network [2].
- This work presents a performance evaluation of the UQEB.

User Quality Of Service Extension Block Evaluation

- The UQEB adds QoS information to individual bundles through a BP extension block.
- It must be inmutable, which can be achieved through the use of BPSec (Fig. 1).

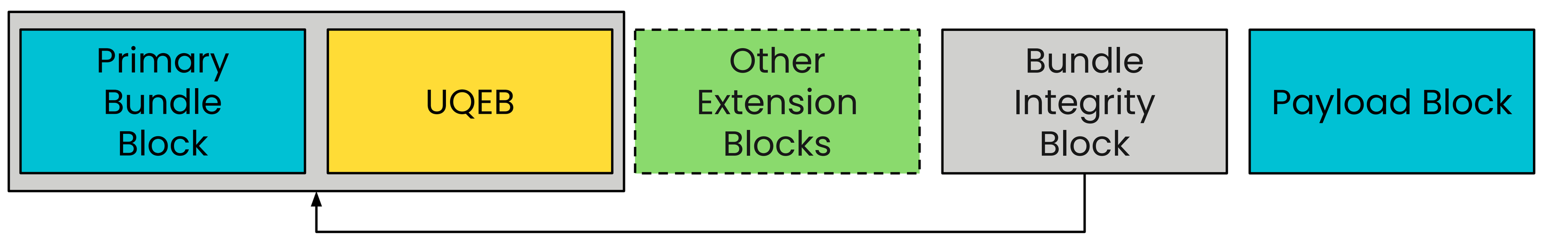

Fig. 1: Bundle structure including the UQEB.

- Three main QoS aspects are implemented:
  - Timely delivery through traffic prioritization with a fair scheduling algorithm.
  - Retransmission signalling.
  - Storage management through latest-only delivery and bundle retention classes.
- Performance evaluation is done using a SimPy discrete-event simulator.
- Channel conditions are chosen as representative for a Ka-band communication link at the New Norcia ESA ground station, modelled with a three-state Markov model as presented in previous work [3] (Figs. 2 and 3).

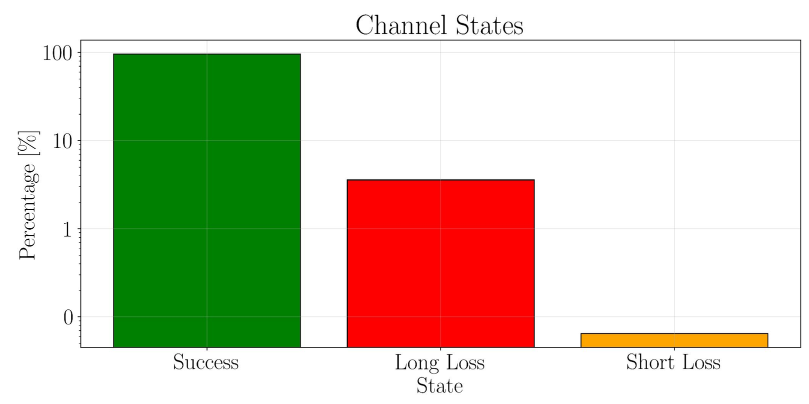

Fig. 2: Channel conditions for the representative channel model.

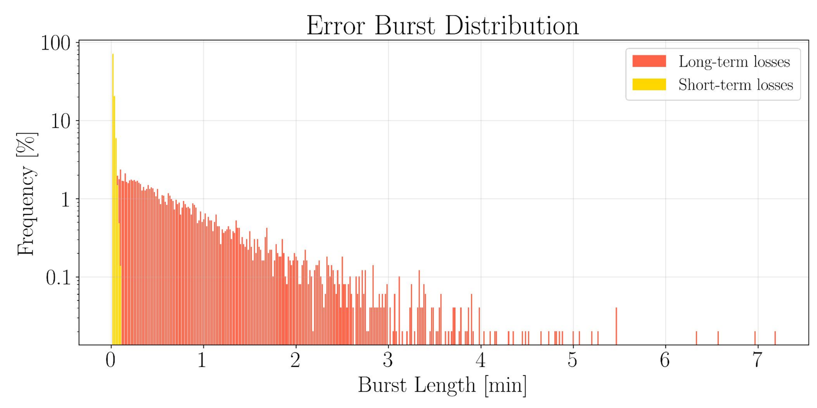

Fig. 3: Burst error distributions for the representative channel model.

Timely Delivery

Traffic Prioritization [4, 5]

- Three traffic classes:
  - Expedited: critical information.
  - Normal: operational data.
  - Bulk: time-insensitive transfers like scientific data.
- Prioritization determines in which order bundles are transmitted first when communication becomes available, thus achieving a lower end-to-end delay.

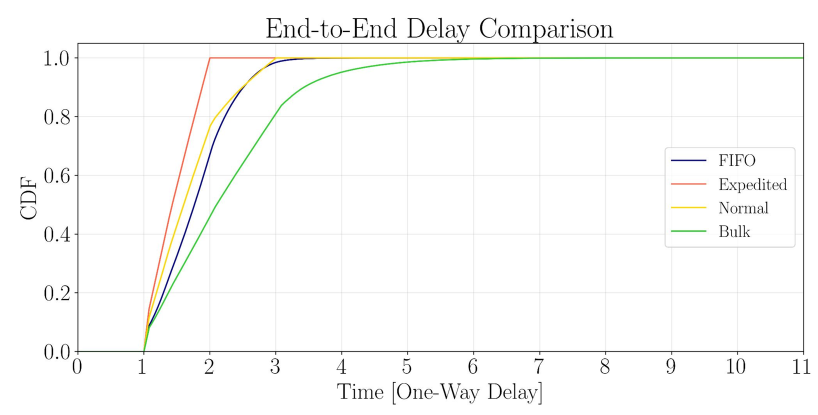

Fig. 4: Impact of traffic prioritization on the end-to-end delay.

- The delay becomes redistributed, with higher-priority bundles experiencing lower queueing delay and bulk traffic absorbing the congestion (Fig. 4).

Nested Interleaving Scheduling [6]

- Strict priority can cause starvation of low-priority traffic.
- Nested interleaving allocates transmission opportunities according to predefined traffic shares, so that higher-priority traffic receives more opportunities while lower-priority traffic still receives periodic access (Figs. 5 and 6).

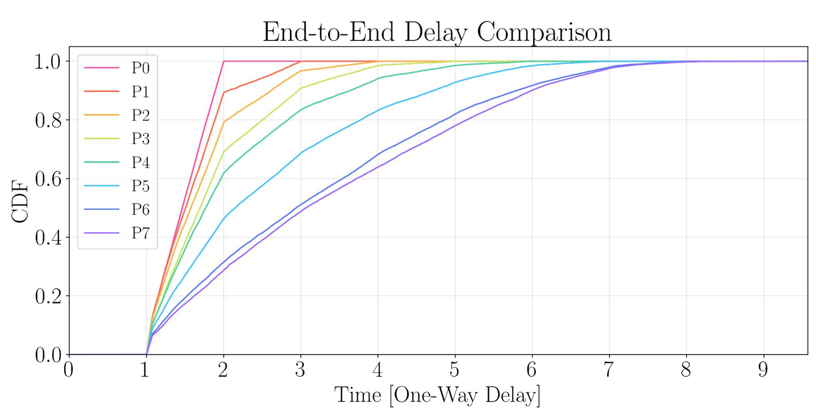

Fig. 5: Impact of nested interleaving on the end-to-end delay.

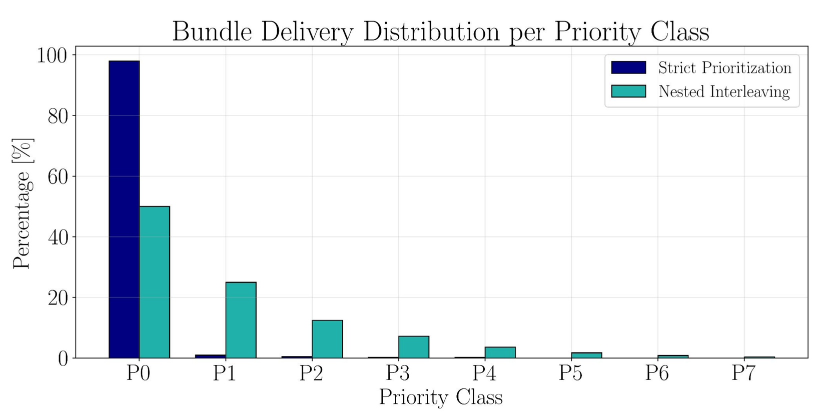

Fig. 6: Comparison of bundle delivery distribution per class.

Reliable Forwarding

- Different applications require different levels of reliability:
  - Completeness ensures lost bundles are detected and retransmitted.
  - Timeliness does not retransmit, avoiding additional transmission and overhead.
- Retransmissions recover lost bundles (Fig. 7), but the recovered bundles must remain in storage until they can be forwarded, thus increasing queue occupancy (Fig. 8) and the overall queueing delay (Fig. 9).

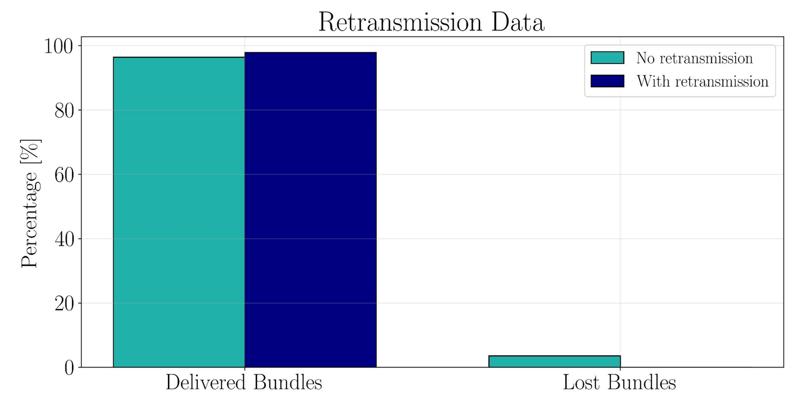

Fig. 7: Impact of retransmission on the bundle delivery rate.

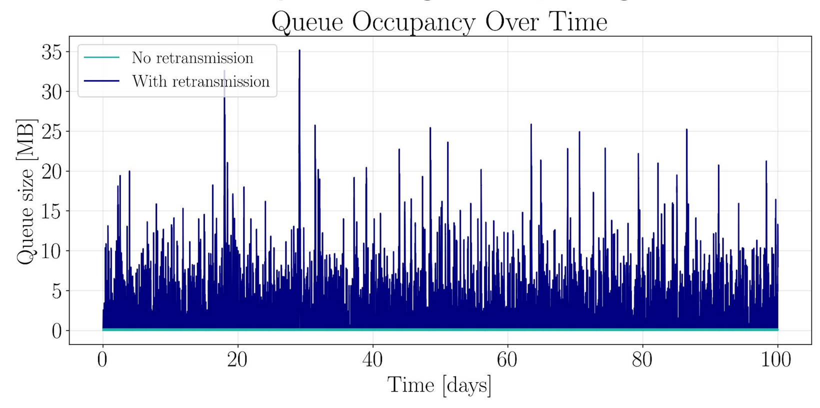

Fig. 8: Impact of retransmission on queue occupancy.

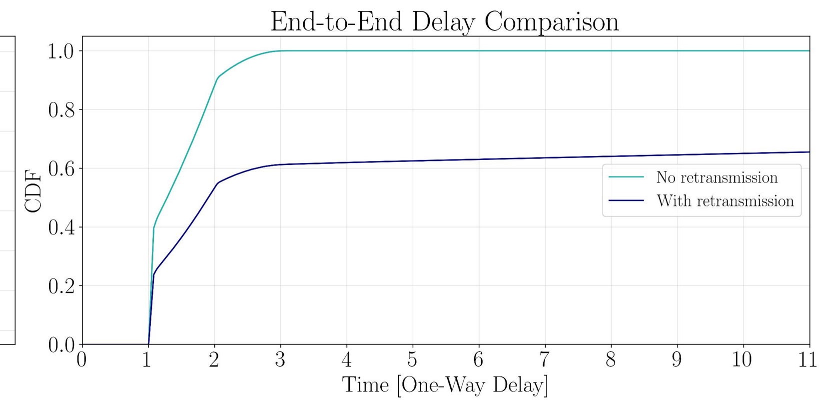

Fig. 9: Impact of retransmission on the end-to-end delay.

Storage Management

- DTN nodes require persistent storage due to its store-and-forward mechanism.
- Long communication outages can cause storage to become saturated.

Latest-Only Delivery

- For applications where only the newest information is relevant, a new bundle can replace an older bundle from the same flow so that obsolete information is removed before transmission.
- This releases space in the queue and shortens the queueing delay (Fig. 10).

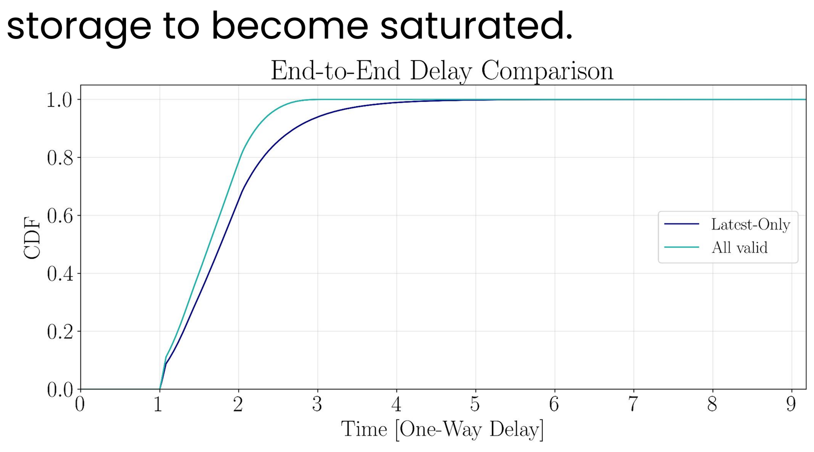

Fig. 10: Impact of latest-only delivery on the end-to-end delay.

Bundle Retention Class

- Bundles are assigned different retention levels according to their storage value. When storage capacity is reached, less valuable bundles are discarded first.
- This also reduces queue occupancy and queueing delay (Fig. 11), while keeping valuable bundles in storage (Fig. 12).

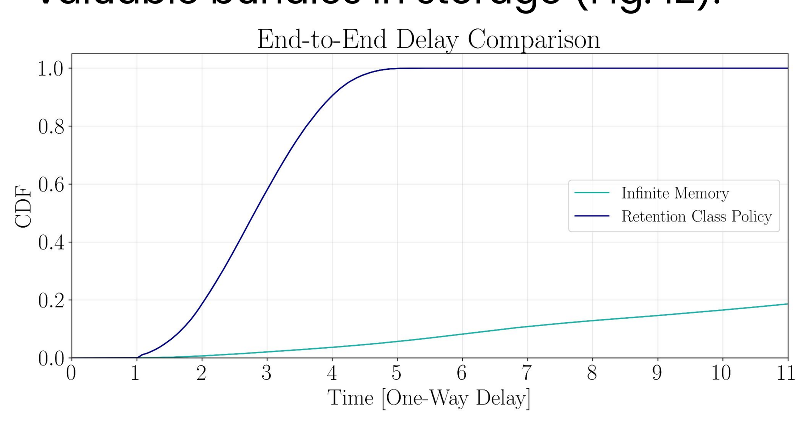

Fig. 11: Impact of bundle retention on the end-to-end delay.

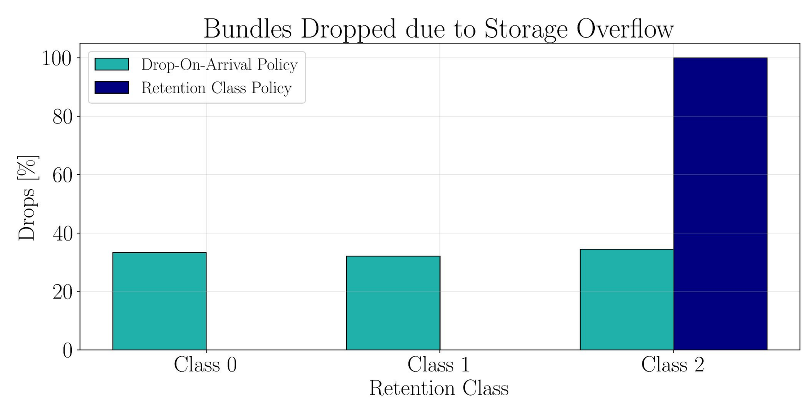

Fig. 12: Impact of bundle retention on bundle drop ratio per class.

Conclusion

- The UQEB enables per-bundle QoS signalling in DTNs.
- Traffic prioritization reduces delay for expedited traffic, at the cost of increased delay for bulk traffic.
- Nested interleaving preserves traffic priorities while preventing starvation of lower-priority data.
- Retransmission signalling enables reliable forwarding when required, while avoiding unnecessary retransmissions and reducing queueing delay when not required.
- Latest-only delivery removes obsolete information, thus shortening queues and proactively freeing storage.
- Retention classes protect valuable bundles during storage congestion through reactive storage management and selective bundle dropping.

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[2] T. Algarra Ulierte, K. Kuladinithi, A. Timm-Giel, and F. Flentge, “Adding quality of service support to BP through an extension block,” in IEEE 10th International Conference on Space Mission Challenges for Information Technology (SMC-IT), 2024, pp. 115–124.
[3] T. Algarra Ulierte, F. Flentge, J. Quintanilla, and A. Timm-Giel, “Characterizing space communication channel behaviour: An analytical approach with European Space Agency (ESA) mission data validation,” in 10th International Workshop on TTC, 2025.
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[5] T. Algarra Ulierte, K. Kuladinithi, A. Timm-Giel, and F. Flentge, “Enabling traffic prioritization for space communications over DTNs,” IEEE Journal of Radio Frequency Identification, vol. 8, pp. 748–760, 2024.
[6] T. Algarra Ulierte, F. Flentge, and A. Timm-Giel, “Quality of service extension for delay- and disruption-tolerant networking,” in 18th International Conference on Space Operations (SpaceOps), 2025.

TUHH Hamburg University of Technology

Technisch ist das möglich.

Teresa Algarra Ulierte
Hamburg University of Technology
Institute of Communication Networks
Hamburg, Germany
teresa.algarra.ulierte@tuhh.de

Felix Flentge
Directorate of Operations
European Space Agency
Darmstadt, Germany
Email: felix.flentge@esa.int

Andreas Timm-Giel
Hamburg University of Technology
Institute of Communication Networks
Hamburg, Germany
Email: timm-giel@tuhh.de