On the Design and Benchmarking of Interfacing Strategies for Delay-Tolerant Inter-Networking

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1. Motivation & Requirements

State-of-the-art internetwork forwarding models capture the network structure and the paths along which bundles are routed across networks [1], [2].

We assume that the next-hop region has already been determined by an internetwork routing process, and evaluate the performance of pathfinding to the gateway under different topologies for network interconnection.

To evaluate internetwork interfaces equitably in Schedule-Aware Bundle Routing [3], three strict constraints must be verified:

1. **R1 (Robustness):** There must not be a single point of failure in the network.
2. **R2 (Topological Stability):** The approach must be non-destructive (no contacts or nodes removed).
3. **R3 (Membership Stability):** Network membership must be stable from one approach to another.

2. Interfacing Strategies

Gateway Networks

To solve the violations of R1 and R3 inherent to traditional gateway nodes (also called passageway nodes [1]), we introduce **gateway networks**. A gateway network encapsulates the internetwork contacts along with their associated nodes into a dedicated interface network. Their visibility remains bounded (they do not observe the network as a whole), preserving symmetry and intended network sizes.

Gateway Contacts

A *group nodes / share contacts* policy. The internetwork interface is formed by contacts that connect nodes of the local network with nodes of the adjacent network. A gateway contact (also called a passageway contact [4]) appears in the contact plan of both network.

3. Static Anycast & Vertex Contraction

Vertex contraction is a graph-theoretic operation in which two vertices are merged into a single vertex (a *virtual node*). This virtual node serves as an anycast group identifier statically defined in the contact plan.

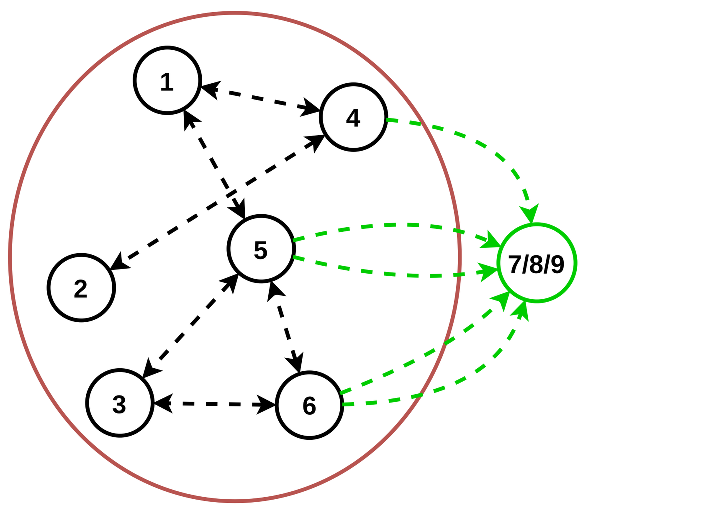

Figure 1. **Gateway Contacts:** Outgoing contacts to external nodes are reattached to the virtual node.

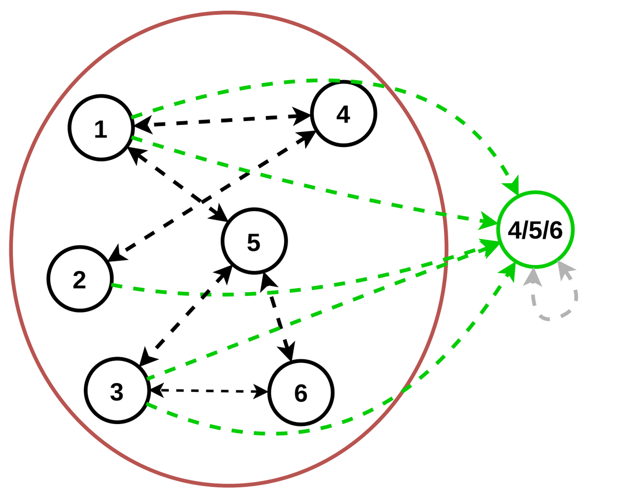

Figure 2. **Gateway Nodes:** Outgoing contacts are connected to the virtual node. The original contact reference is dropped to preserve contact-volume management soundness.

With this setup, we have a single vertex added to the graph for both approaches. Thus we can consider that in both interfacing strategies, the nodes of the local network have a scope of the same size.

4. A-SABR Implementation & Scenarios

To support internetwork routing, A-SABR extends the contact plan format with two new node types: `enode` (external node) and `vnode` (virtual node).

We simulated routing between two adjacent networks (A and B) using 6 routing algorithms across 3 network sizes. The scenario notation **XgYsZp** describes the nodes **per network**: **Xg** ground stations, **Ys** satellites, and **Zp** of those satellites acting as gateway nodes ($Z \leq Y$). Contacts between ground stations are constant links. There are no contacts between satellites other than internetwork contacts. Median contact duration is 8 minutes.

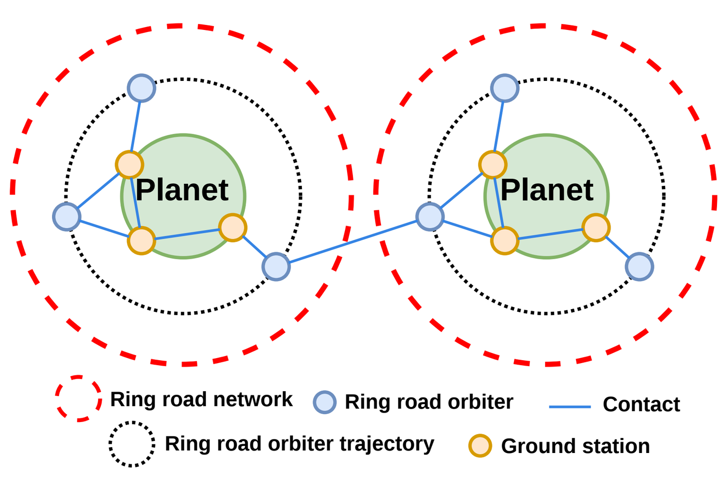

Figure 3. Topology used for the simulations.

Scenario	Nodes	Contacts
5g5s5p	20	476
15g15s10p	60	3600
25g25s15p	100	9831

Table 1. Overview of the simulated network scenarios, generated using `https://gitlab.com/d3tn/dtn-tvg-util`

5. Results & Conclusion

Simulations were run 100 times per network size and interfacing strategy. The simulated delivery rate of bundles is 100% across all scenarios, for 16500 bundles sent and received.

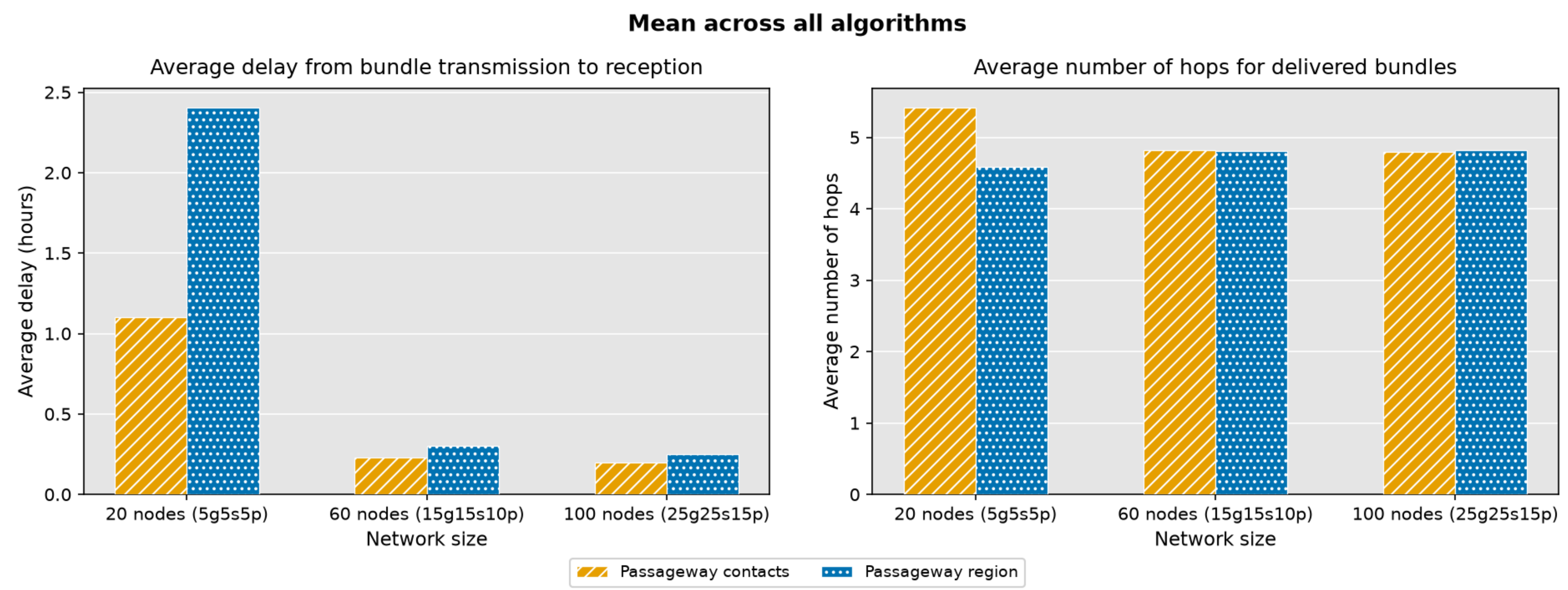

Figure 4. Average end-to-end delivery delay (hours) and hop count for each scenario across all algorithms.

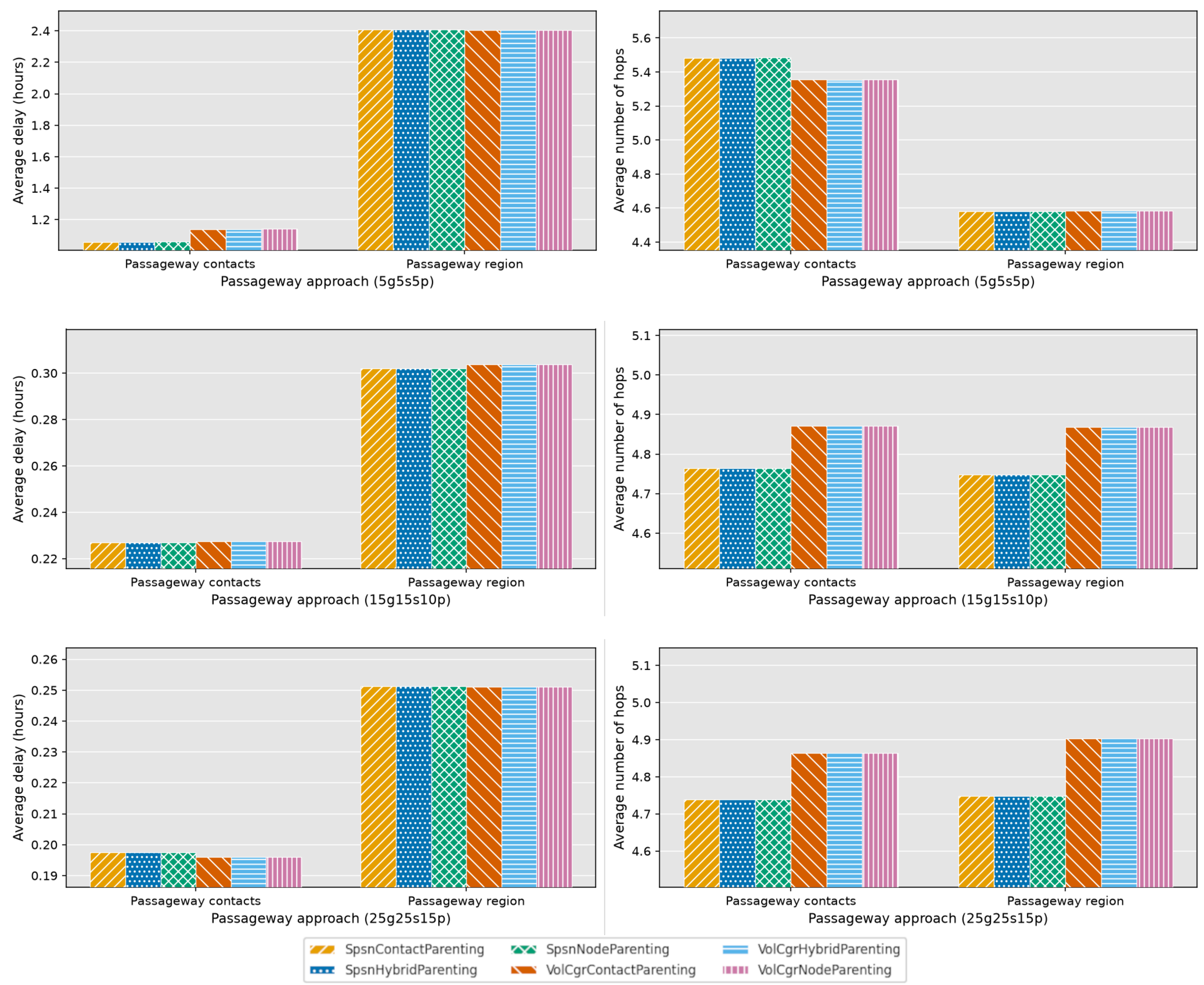

Figure 5. Average end-to-end delivery delay (hours) and hop count across all three networks.

- **Routing Performance:** Across all algorithms and network sizes considered, the gateway contact approach delivers better end-to-end delivery delays than the gateway network approach.
- **Information Concealment:** Intermediary gateway nodes conceal information from adjacent networks, that would otherwise influence path selection, causing missed opportunities and longer paths with a potentially lower hop count in smaller networks.
- **Implementation:** Both strategies are implemented within A-SABR using the same vertex contraction mechanism, allowing them to coexist without requiring an exclusive architectural choice.

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6. References

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[4] O. De Jonckère and J. A. Fraire, “Inter-regional routing in interplanetary networks with shortcuts and contact passageways,” in *2023 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE)*. IEEE, 2023, pp. 87–92.

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