Biased Backpressure Routing for Multihop Wireless Networks with Heterogeneous Interfaces

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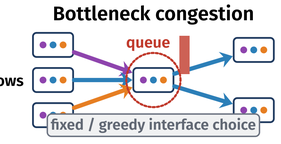
1 Multi-Interface Routing Adds Both Complexity and Flexibility

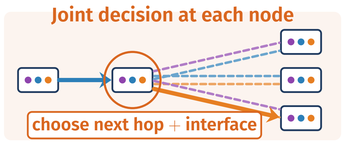
Challenge: Routing must decide both **where to forward** and **which interface to use**, while concurrent flows contend for shared resources.

Opportunity: Multiple interfaces also create new ways around congestion: **reroute and/or switch modality**.

In a **heterogeneous-interface multihop wireless network** (Het-MuNet), every device carries several wireless interfaces, e.g. **5 GHz**, **2.4 GHz** and **UHF**, with different range, rate and interference.

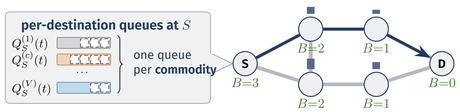
Shared bottleneck: independently good routes can create congestion.





Extra flexibility: unique to multi-interface networks.

2 Why Shortest-Path Biased Backpressure (SP-BP)? Queues Reveal Congestion in Real Time



Queue differential is a local congestion signal

$$U_{ij}^{(c)} = \underbrace{Q_i^{(c)} - Q_j^{(c)}}_{\text{queue pressure}} + \underbrace{B_i^{(c)} - B_j^{(c)}}_{\text{shortest-path bias}}$$

✓ Distributed routing ✓ Path finding ✓ Throughput optimality ✗ Support heterogeneous interfaces

SP-BP reacts differently to the network state

Light load shortest path ⟶ follow the **bias**

Congestion queue builds up ⟶ **pressure** pushes traffic away

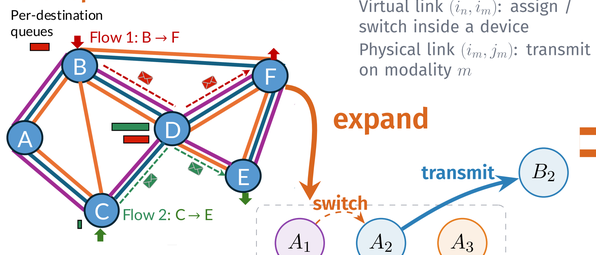
Classical 4 steps

1 Select optimal commodity → **2** Link weighting → **3** Conflict-aware MaxWeight → **4** Assign link capacity

3 Lift Interface Selection into Routing: Multi-layer Graph Representation

Original network

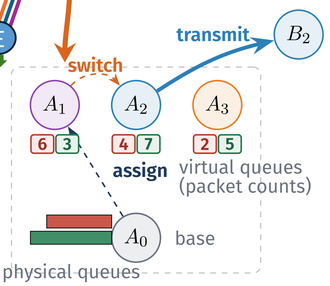
Next hop? + Which interface?



Virtual link (i_n, i_m): assign / switch inside a device

Physical link (i_m, j_m): transmit on modality m

expand



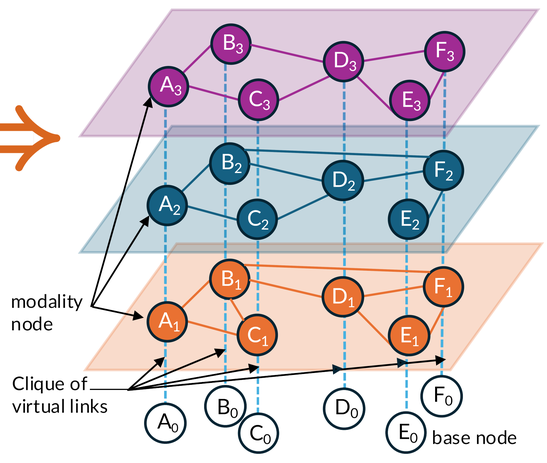
Physical queue $Q_i^{(c)}$: holds the packets

Virtual queue $q_{i_m}^{(c)}$: a count, not a packet buffer

Inside device A (our extension)

Multi-layer graph

A routing hop now chooses both.



Choosing *where to forward* and *which interface* are **two coupled decisions**, because changing the interface changes both the available routing options and interference.

interface selection + next-hop selection

↓

one routing primitive:

next-hop selection on the multi-layer graph

Interface selection → choose a **virtual** next hop within the same device $i_m \to i_{m'}$

Routing → choose a **physical** next hop within the same modality layer $i_m \to j_m$

4 Adapting SP-BP to the Multi-Layer Graph

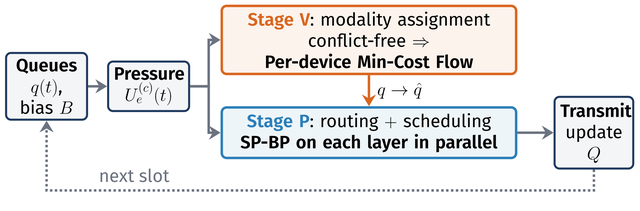
$U_e^{(c)}$: biased pressure on link e, virtual or physical.

$$(\mu^\star, \nu^\star) = \arg \max_{(\mu,\nu)\in\Pi(t)} \Big(\underbrace{\sum_{e\in\mathcal{E}^p}\sum_c \mu_e^{(c)} U_e^{(c)}}_{W_p\text{: physical}} + \underbrace{\sum_{e\in\mathcal{E}^v}\sum_c \nu_e^{(c)} U_e^{(c)}}_{W_v\text{: virtual}} \Big)$$

One max-weight objective, but two link types require different solvers.

Virtual links: inside one device
- no wireless interference
- no conflict graph
- packet availability / conservation

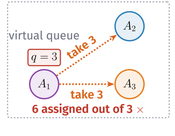
Physical links: across devices
- wireless interference
- conflict graph
- link-rate constraints



5 Virtual Interface Switching as a Flow-Assignment Problem

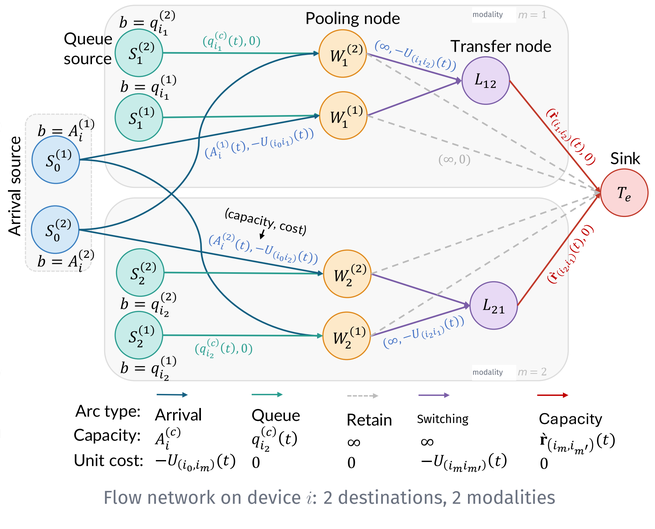
Why not plain BP?

Problem: non-interfering virtual links may simultaneously drain the same backlog. Packets are assigned twice, breaking **packet conservation**.



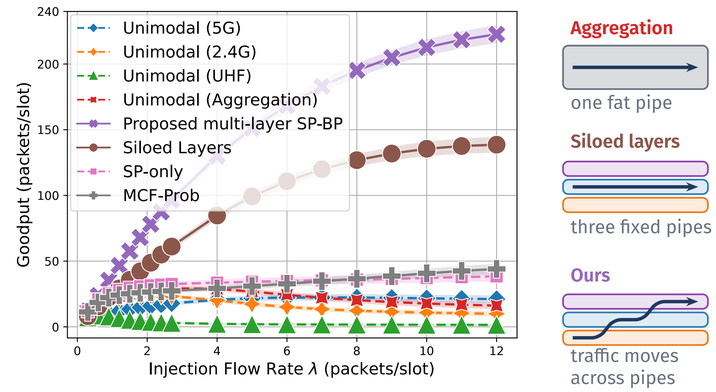
Fix: per device, solve Stage V as a **min-cost flow** with cost $= -U_e^{(c)}$.

A **high-pressure virtual link** in the multi-layer graph becomes a **low-cost edge** in the flow network.



Flow network on device i: 2 destinations, 2 modalities

6 Dynamic Modality Switching Unlocks More Transmission Opportunities

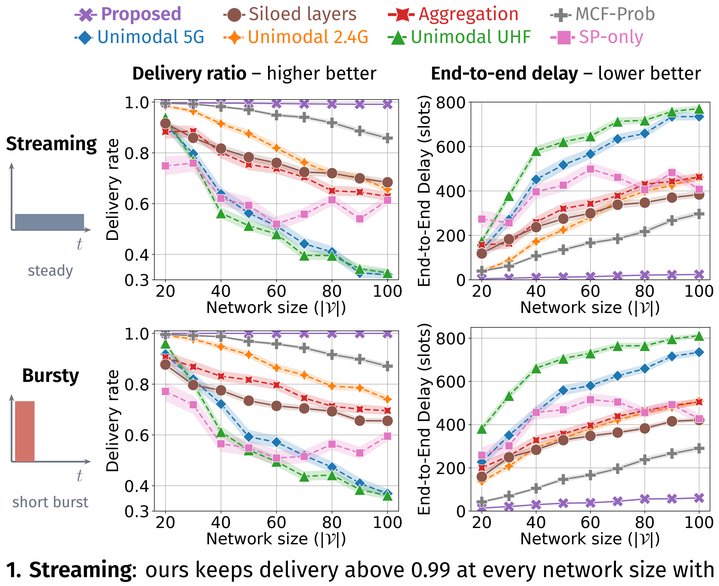


Goodput vs. per-flow arrival rate λ; 100 nodes, streaming. Higher is better.

1. **Multi-layer SP-BP** has the highest goodput at every load, and the gap widens as load grows. **Aggregation** peaks near $\lambda \approx 3$ and then declines: **more rate alone is not enough**.

2. **Siloed layers** uses the same modalities and the same SP-BP but fixes the layer at injection, and stays below ours. The gain comes from **dynamic cross-modality switching**.

7 Queue-Aware Routing Handles Both Sustained and Bursty Congestion



1. Streaming: ours keeps delivery above 0.99 at every network size with the lowest delay, vs. **MCF-Prob** (0.86 at 100 nodes).

2. Bursty: ours maintains the highest delivery ratio while keeping delay low as the network scales.

Takeaways

Lift: interface selection and routing become one next-hop decision on the multi-layer graph

Adapt: biased pressure dynamically exploits both path and modality diversity

Gain: dynamic cross-modality routing improves resource utilization and robustness

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