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Traffic Engineering for Software-Defined Radio Access Networks

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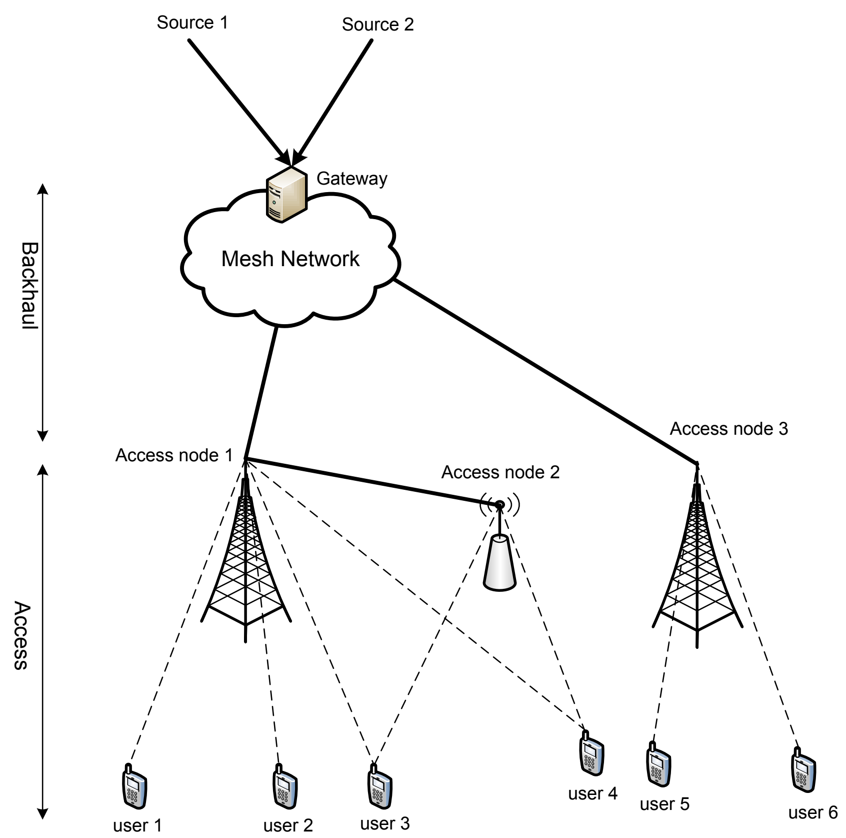
Central Traffic Engineering in RAN

- Traffic engineering (TE) in a network entails
  - Finding path(s)
  - Splitting flow among path(s)
- TE is modeled as a multi commodity flow (MCF) problem
  - Optimize some objective and/or satisfy flow demands subject to network link capacity constraints.
- We introduce a framework for *central TE* as the main enabler for software-defined radio access network (SD-RAN).
  - The routing and traffic splitting decisions are made by a central controller which has knowledge of network parameters.



Related Work

- **Traditionally, the TE problem in RAN is split into two separate problems:**
  - Cell selection in the access network, where a user is associated to a single access node, and
  - TE in the backhaul network, where the aggregated traffic of users associated to an access node is routed to the access node.

- **Performance of cell selection can be enhanced by considering backhaul limitations [Galeana-Zapién, 7].**

- **Multi-path TE provides** higher network capacity through efficient use of multiple paths between sources and destinations [Danna, 8,9].

Our Contribution

- **Multi-path TE framework for SD-RAN with general backhaul topology.**
- **Incorporating link buffer status usage by TE.**

System Model

- **The backhaul links have fixed capacities.**
- **The capacity of a wireless access links is not fixed and depends on**
  - the amount of bandwidth assigned to it by the corresponding access node, and
  - the spectral efficiency (SE) of the link
- **The capacity of a wireless link with assigned bandwidth *r* and SE of *s* is given by *r* x *s*.**
- **The SE of a wireless access link**
  - depends on radio transmission configuration at the access node and the interference on the link.
  - is measured in bits/s/Hz.
- **We assume fixed radio transmission configuration. In particular, we assume that transmit power at an access node does not change as a result of change in its transmission rate.**

SD-RAN TE Problem Formulation

- **Notation:**
  - K users with traffic demands: $d_1, d_2, \ldots, d_K$
  - Number of paths for user k: l_k, $k = 1, \ldots, K$.
  - Path j of user k: p^k_j , $j = 1, \ldots, l_k$
  - Traffic allocation for user k on path j: x^k_j
  - c_a : capacity of wired link a; r_n : resource at wireless access node n
- **Demand constraints**

$$\sum_{j=1}^{l_k} x_j^k = d_k, \quad k = 1, \ldots, K \qquad (1)$$

- **Wired link constraints**

$$\sum_{\text{path } p_j^k \text{ passing link } a} x_j^k \le c_a, \quad \forall \text{ wired link } a \qquad (2)$$

- **Wireless access node constraints**

$$\sum_{\text{path } p_j^k \text{ passing node } n} \frac{x_j^k}{s_{a(k,j)}^k} \le r_n, \quad \forall \text{ wireless access node } n \qquad (3)$$

SD-RAN TE Problem Formulation (2)

- **Weighted Max Min (WMM)**

$$\max_{\lambda, x_j^k} \lambda$$

$$\text{s.t.}$$

$$\sum_{j=1}^{l_k} x_j^k = \lambda d_k, \quad k = 1, \ldots, K,$$

$$(2), \text{and}\, (3).$$

- **If λ* < 1, the TE problem is infeasible. The WMM TE solution provide every flow with a fixed fraction (λ*) of their demand.**
- **If the problem is feasible , i.e., λ* ≥ 1, we divide resulting flow allocations by λ* to obtain final flow allocations to satisfy the original flow demands.**
- **If feasible, the WMM TE solution provides (λ*-1)x100% over provisioning for flows.**

SD-RAN TE Problem Formulation (3)

- **Min Radio Resource Usage (MRRU)**

$$\min_{x_j^k} \sum_{n} \sum_{\text{path } p_j^k \text{ passing node } n} \frac{x_j^k}{s_{a(k,j)}}$$

$$\text{s.t.}$$

$$(1), (2), \text{and } (3).$$

- **For lightly loaded networks (wired links and wireless node constraints inactive), flow demands are satisfied using only one path per flow in MRRU TE solution.**
- **As the network load increases, the MRRU TE approach uses more paths per flow as necessary to satisfy flow demands.**

TE Using Link Buffer Status

- **Buffer may build up occasionally at some links due to wireless channel transients, unpredicted change in flow demands, imperfect traffic splitting at routers, etc.**

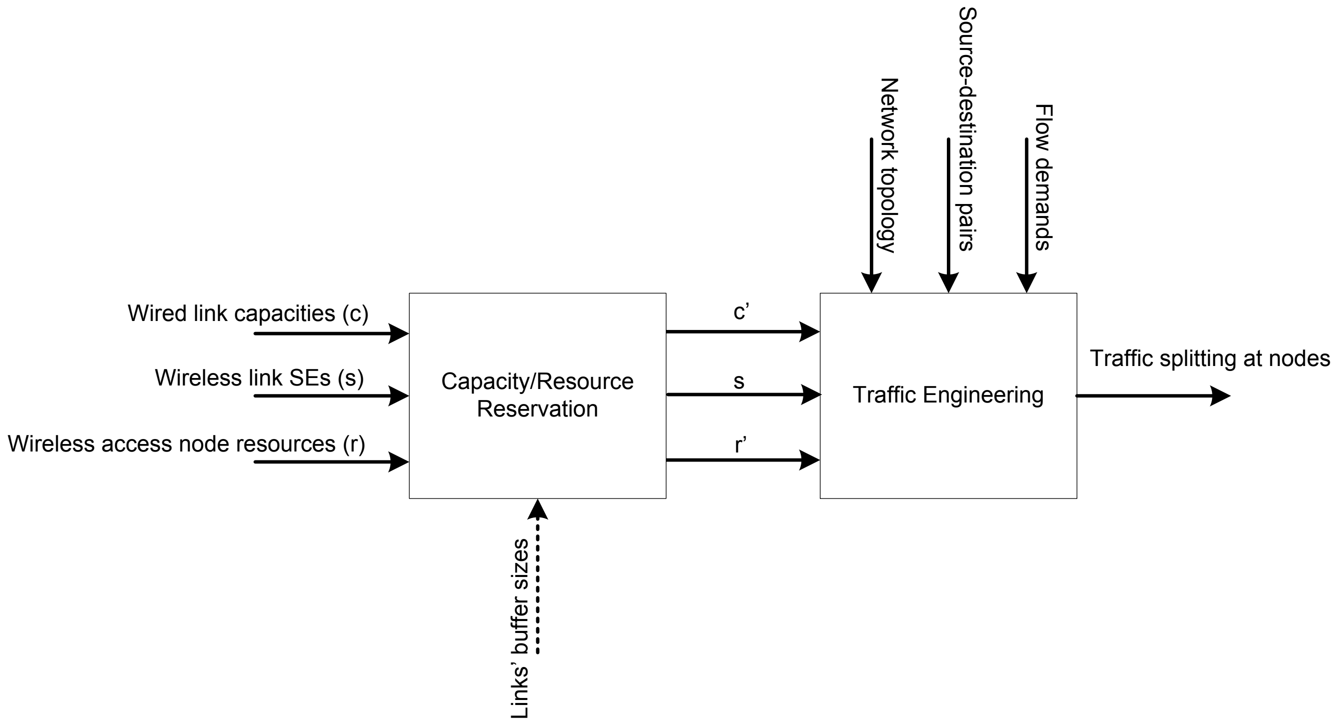
- **Buffer accumulation results in packet delay and overall QoE degradation.**

- **Using buffer status of links at central TE controller provides robustness against inaccuracies in TE inputs.**

- **How to utilize buffer status at TE?**
  - Treat data stored at buffers as additional sources →TE problem too complex.
  - Our solution: Capacity/bandwidth reservation.

TE Using Link Buffer Status (2)

- **Capacity/Bandwidth reservation**



TE Using Link Buffer Status (3)

- **Capacity reservation for backhaul links**
  - t_e: a predefined time for a backhaul link buffer to get empty
  - b_a: the number of bits queued in the buffer of backhaul link *a*
  - Reserved capacity at link a:

$$c_a^{\text{reserved}} = \frac{b_a}{t_e}, \qquad \forall \text{ wired link } a$$

  - Available link capacity in TE formulation:

$$c'_a = c_a - c_a^{\text{reserved}}$$

- **Bandwidth reservation at wireless access nodes**
  - Reserved resource (bandwidth) at access node *n*:

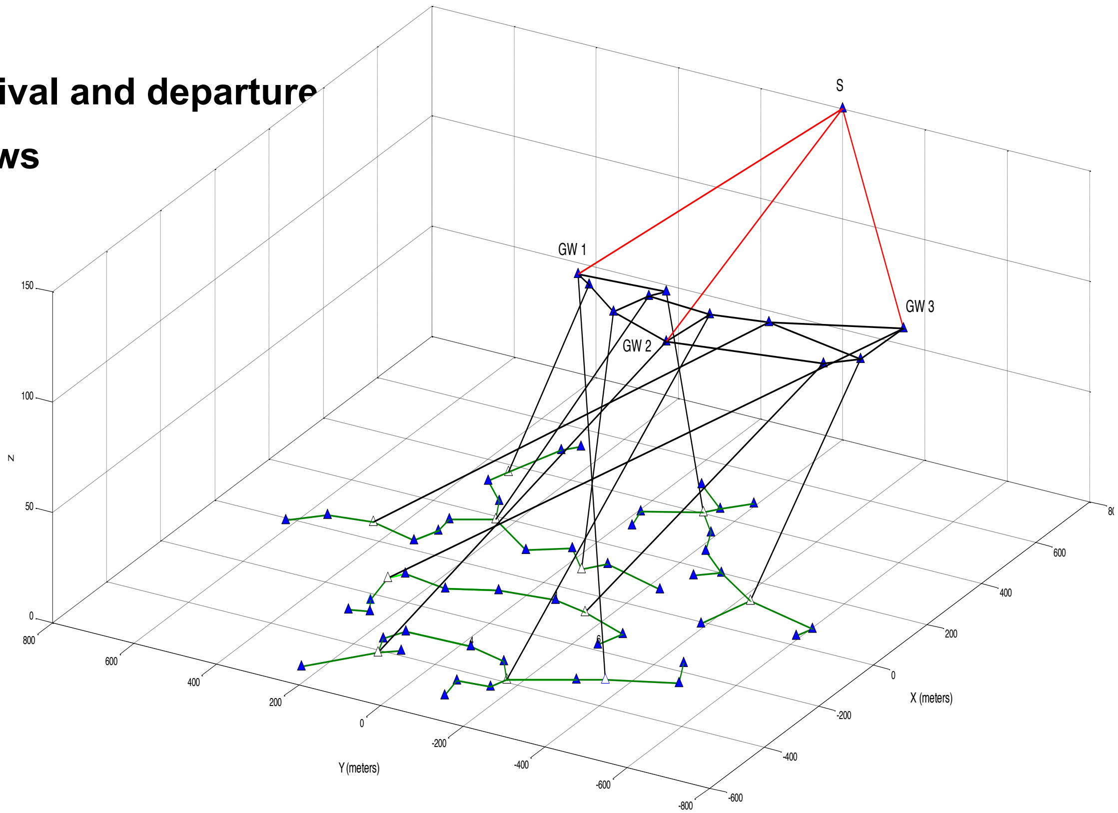
$$r_n^{\text{reserved}} = \frac{1}{t_e} \sum_{\text{link } a \text{ connected to node } n} \frac{b_a}{s_a}, \qquad \forall \text{ wireless node } n$$

  - Available resource for access node *n* in TE formulation:

$$r'_n = r_n - r_n^{\text{reserved}}$$

Sample RAN Topology

- 57 wireless access nodes (on X-Y plane)
- Users dropped randomly on the X-Y plane (not shown in the picture)
- Backhaul as shown
- Dynamic flow (session) arrival and departure
- Constant bit rate (CBR) flows
- QoE at least 0.99



Performance Gains

- **Supported rate (demand) for 570 users**

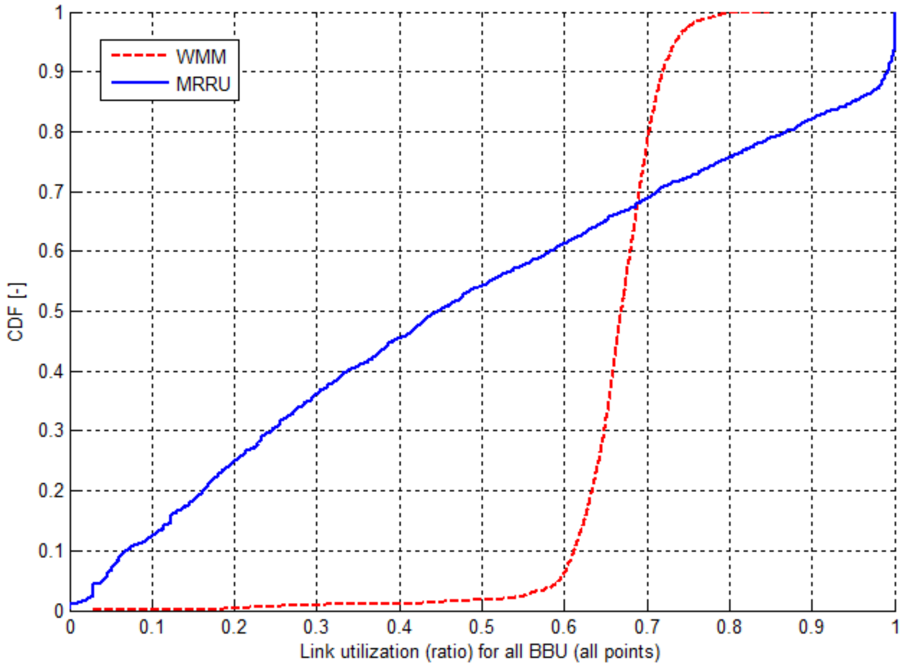
Number of paths (L)	1 (Baseline)	2	3	4
Supported user rate	1.0 Mbps	1.6 Mbps	1.9 Mbps	2.1 Mbps
Gain w.r.t. baseline	0%	60%	90%	110%

- **Number of supported users with fixed rates**

Number of paths (L)	1 (Baseline)	2	3	4
Number of supported users	570	1125	1375	1425
Gain w.r.t. baseline	0%	97%	140%	150%

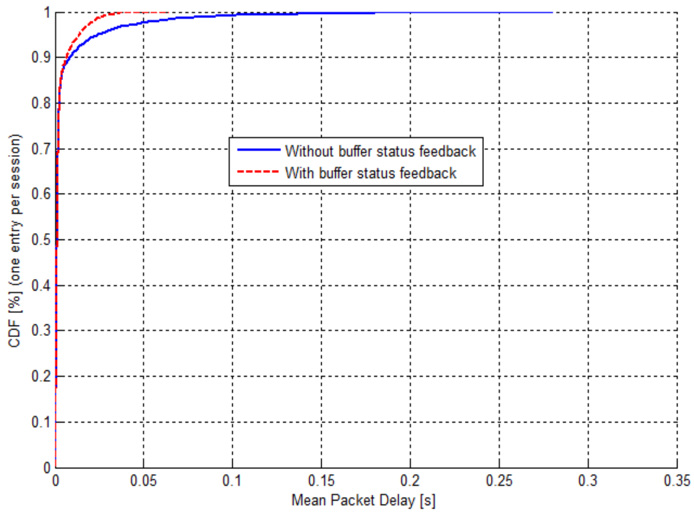
Effect of TE Objective Function

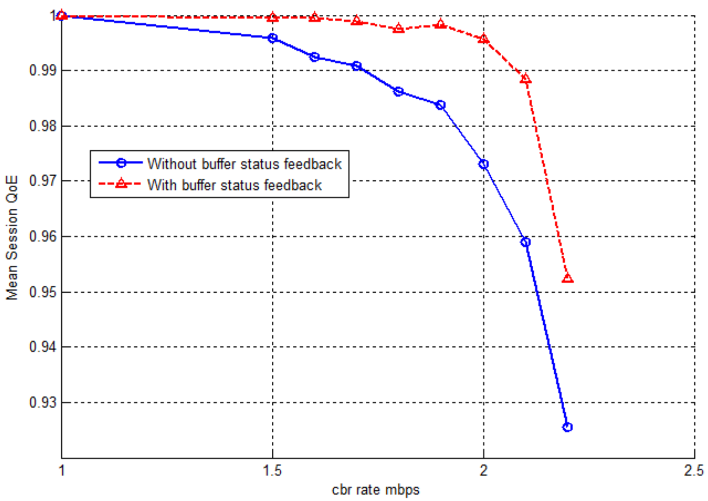
- **CDF of radio resource usage**



TE Using Link Buffer Status Feedback

- **CDF of mean packet delay**
- **QoE vs. rate**





Conclusion

- **Central multi-path traffic engineering for SD-RAN.**
  - Higher network capacity and better user QoE through efficient use of multiple paths between sources and destinations
  - Better control over resource usage across the network for network operator

- Link buffer status usage at TE
  - Robustness against wireless channel transients, flow demand fluctuations, and inaccuracy of wireless network abstraction

- Other TE solutions for SD-RAN

Thank you

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