Cost-Efficient Resource Sharing in Ethernet-based 5G Mobile Fronthaul Networks

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07/27/2018

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Background

- Cost issues with functional split:

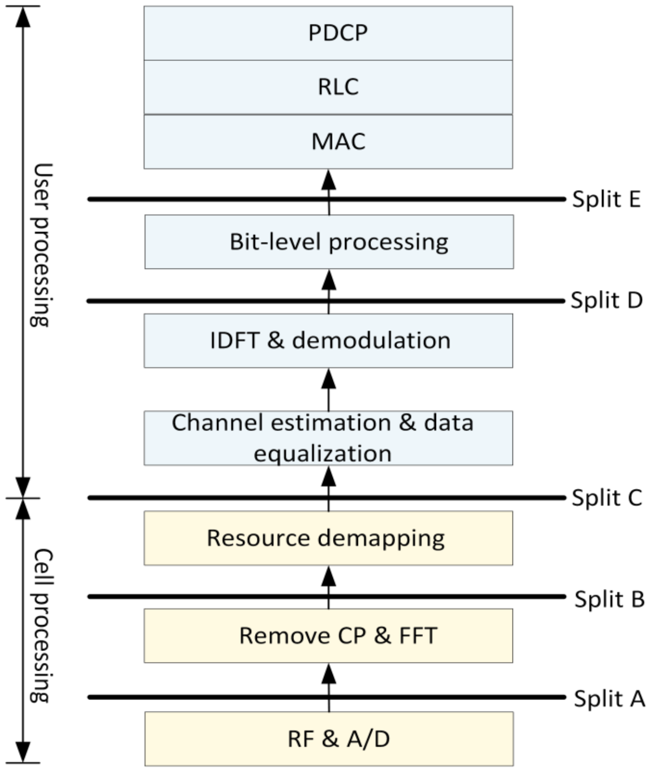
  (1) Massive small cell deployment is foreseeable in the future.
  (2) Fronthaul connection data rate is growing fast.

- Remedies:

  - For (1):
    - Use Ethernet (cheap, statistical multiplexing, point-to-multi-point transmission).
    - Instead of investing on new fibers, use existing networks (**network-resource sharing with background traffic**).
  - For (2):
    - Equip RRH with Baseband Processing Functions (BPFs) to reduce data rate.
    - **Make BPFs sharable among multiple RRHs.**

Background

- Which functional split to use



Entire BBU stack [1]

Split A		Split B		Split C		Split D		Split E	
Bandwidth reduction ratio	Latency requiremen	Bandwidth reduction ratio	Latency requirement	Bandwidth reduction ratio	Latency requirement	Bandwidth reduction ratio	Latency requirement	Bandwidth reduction ratio	Latency requirement
1	150us	0.55	150us	0.54	150us	0.45[2]	150us	0.03[2]	< 10 ms

- However, functional-split options belonging to user-processing category as shown in Fig. 1 (e.g., Split E) are not recommended because they cause difficulty in implementing physical-layer-coordinated technologies (e.g., Coordinated Multipoint (CoMP) transmission) [2].

- The cost of implementing more BPFs at RRHs in a large scale are non-trivial.

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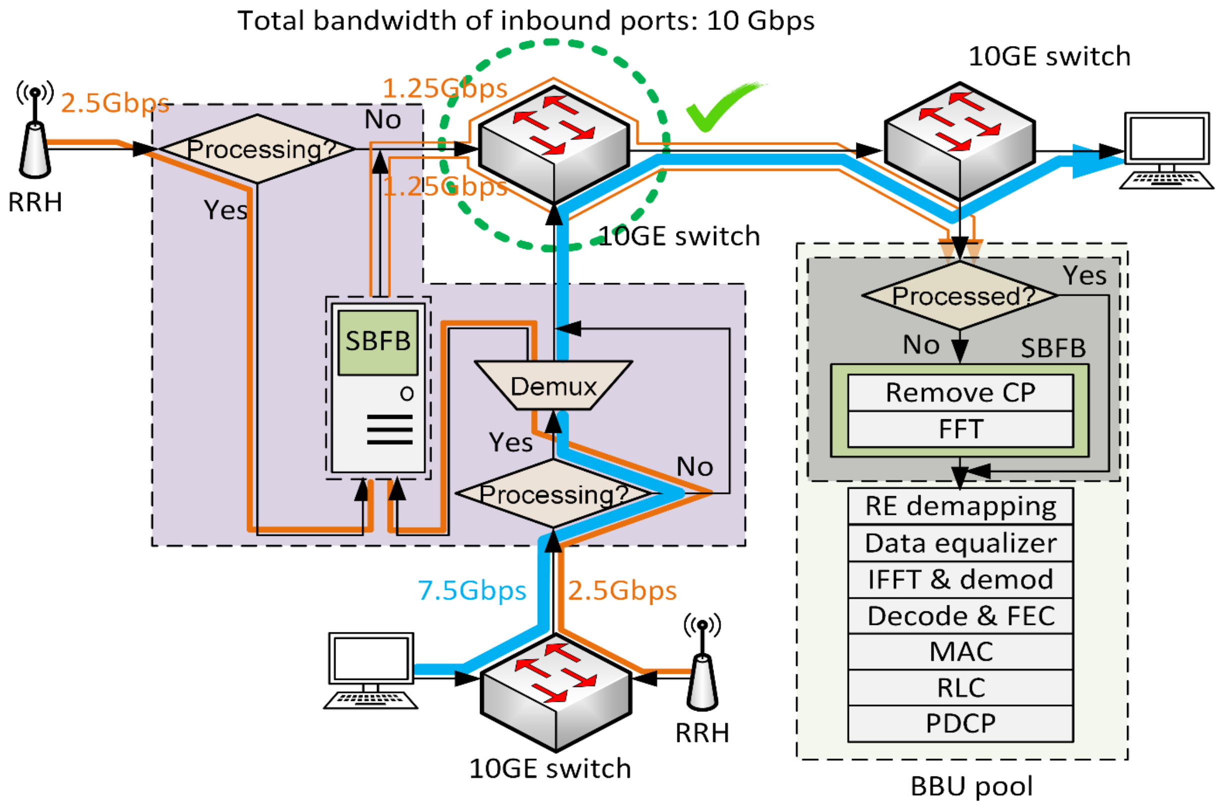
1. R. Knopp, *et. al.*, "Prototyping of Next Generation Fronthaul Interfaces (NGFI) using OpenAirInterface," *EURECOM white paper*, 2017.
2. C. I, *et.al.*, "Rethink fronthaul for soft RAN," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 82-88, 2015.

Our proposal

- Mobile Fronthaul Resource Sharing (MFRS): Network-resource sharing + BPF sharing

- To implement the above sharing scheme, we formulate a routing and BPF placement problem.
  - **Objective:**
    - Minimize number of sets of BPFs (cost) to be placed in order to accommodate MF traffic;
  - **Inputs:**
    - Network topology;
    - Background traffic load;
    - Number of supported RRHs;
  - **Constraints:**
    - Latency.

Our proposal



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Latency

Mobile transport	Network Entities	Transport Connection	Distance Range	Latency	Band-width	Multiplexing
Front-haul	RRU-DU	p2p	1~10km	50-200us	100G+	Transparent L0 or L1
Middle-haul	DU-CU	p2p	20-40km	~1ms	>100G	L1 multiplexing and L2 statistical multiplexing could be used.
	N*DU-CU	p2mp				
Backhaul	CU-CU or CU-MEC	p2mp	1-10km	<10ms	>400G	Statistical multiplexing , L3 Dynamic connection based on IP address and 5G signalling
	CU-5G NG or MEC-5G NG/MEC	mp2mp	40-200km			

Steve Gorshe, " 5G/IMT2020 Transport Requirements Considerations and Next Steps," presentation slides, 2018.

Contributions/differences

❑ Difference of our work compared to existing works (network-resource sharing)

❖ Network-resource-wise, most research works focus on sharing among multiple RRHs.
   ➢ For example, Ref. [1] proposed a virtualization-based WDM-PON architecture to improve system performance in terms of throughput, energy efficiency, and mobility management.
   ➢ Ref. [2] proposed a MF TDM-EPON architecture, based on which several optimization schemes were proposed to improve throughput [3], reduce latency [4-5], and jitter [5], etc.

❖ Our work differs from existing works by enabling a different type of network-resource sharing, i.e., sharing between MF traffic and background traffic on existing Ethernet network [6], which, to the best of our knowledge, is still at its early stage and under development.

1. X. Wang, *et. al.*, "Virtualized Cloud Radio Access Network for 5G Transport," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 202-209, 2017.
2. X. Liu, *et. al.*, "Emerging optical access network technologies for 5G wireless," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no. 12, pp. B70-B79, 2016.
3. Y. Wu, *et. al.*, "Traffic Classification and Sifting to Improve TDM-EPON Fronthaul Upstream Efficiency," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 10, no. 8, pp. C15-C26, 2018.
4. W. Wang, *et. al.*, "Coordinating Multi-access Edge Computing with Mobile Fronthaul for Optimizing 5G End-to-End Latency," *Proc. IEEE/OSA Optical Fiber Communications Conference and Exposition (OFC)*, 2018.
5. D. Chitimalla, *et. al.*, "5G Fronthaul–Latency and Jitter Studies of CPRI Over Ethernet," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 9, no. 2, pp. 172-182, 2017.
6. IEEE Standards Association, "IEEE Standard for Local and metropolitan area networks — Time-Sensitive Networking for Fronthaul," *IEEE Std 802.1CM*, 2018.

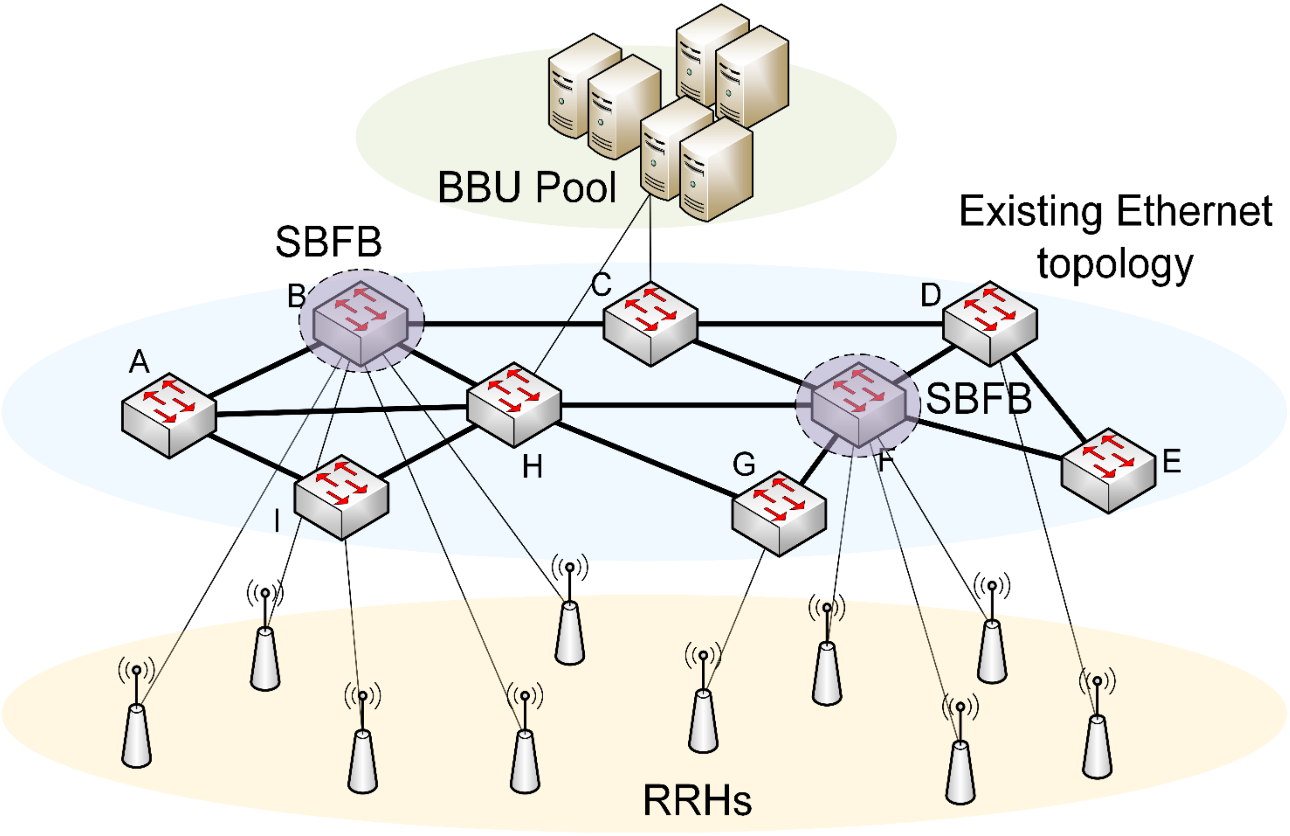
Contributions/differences

- ❑ Difference of our work compared to existing works (BPF sharing)

- ❖ In terms of BPF sharing:
  - ➢ Ref. [1] formulated a static BBU placement problem trying to solve for a balance among number of BBUs, latency, and network-capacity utilization. And a dynamic version of the same problem was later proposed in Ref. [2]. Both of them exploited the sharing of full-stack BBUs with the focus on resource aggregation/consolidation.
  - ➢ The works focusing on functional split were mostly into exploring the tradeoff between increased cost by implementing too many BPFs at RRH and decreased transmission cost at MF [3-4].
  - ➢ There is no work focusing on sharing of BPFs at a particular functional split.
- ❖ Our work aims at achieving cost reduction at functional-split level by allowing sets of BPFs: i) to be placed in between BBU and RRH, and ii) to be shared among RRHs. Doing so also facilitates network-resource sharing between MF traffic and background traffic to improve transmission efficiency.

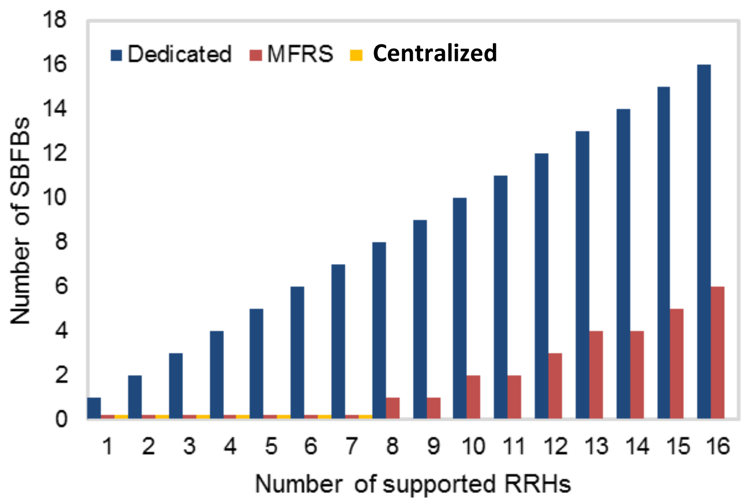
1. F. Musumeci, *et al.*, "Optimal BBU placement for 5G C-RAN deployment over WDM aggregation networks," *IEEE/OSA Journal of Lightwave Technology,* vol. 34, no. 8, pp. 1963-1970, 2016.
2. F. Musumeci, *et. al.*, "Dynamic placement of baseband processing in 5G WDM-based aggregation networks," Proc. *IEEE/OSA Optical Fiber Communications Conference and Exposition (OFC)*, 2017.
3. J. Liu, *et al.*, "Graph-based framework for flexible baseband function splitting and placement in C-RAN," *proc. IEEE International Conference on Communications*, 2015.
4. X. Wang, *et. al.*, "Centralize or distribute? A techno-economic study to design a low-cost cloud radio access network," *proc. IEEE International Conference on Communications*, 2017.

Simulation

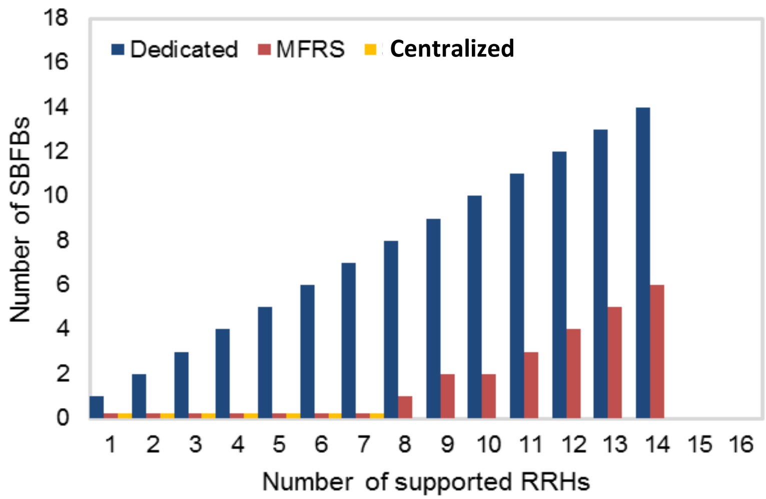

BBU Pool
SBFB
B
C
D
Existing Ethernet topology
A
SBFB
H
G
F
E
I
RRHs

Simulation

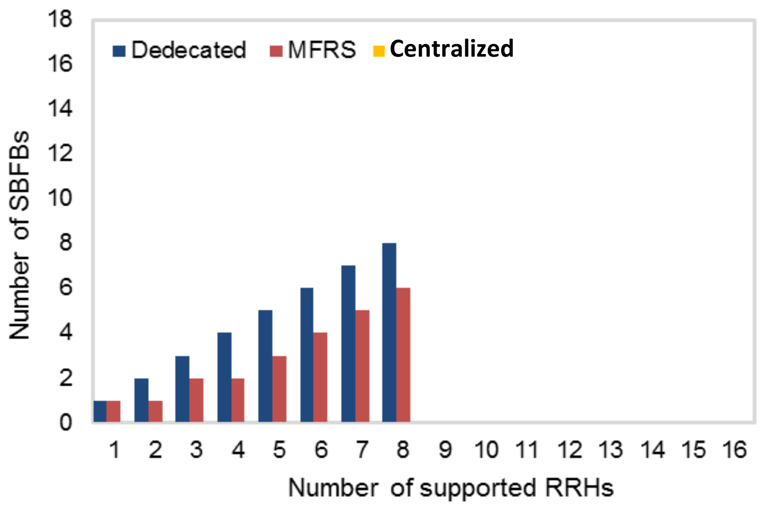
- Number of required BPF sets vs. number of supported RRHs at constant background traffic load.



(a) Background traffic load ≤ 0.6



(b) Background traffic load = 0.7



(c) Background traffic load = 0.8

Thank you!