Optimizing functional split of baseband processing on TWDM-PON based fronthaul network

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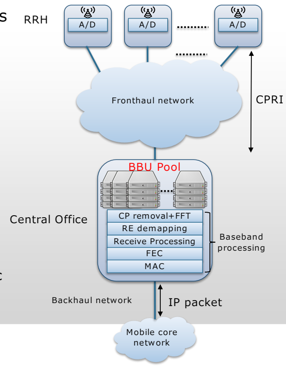
C-RAN (Centralized/Cloud-based Radio Access Network)

- Baseband processing for multiple RRHs is executed at BBU pool on Central office
- Advantages
  - Simplification of base stations
  - Effective usage of server resources on BBU pool
  - Coordinated control of RRHs, e.g. CoMP
- Disadvantages
  - High bandwidth usage of fronthaul network
    - (Ex.) 2.46 Gbps for one RRH (20MHz)
      - Independent on users' network traffic
    - 5G increases the problem
      - Dense deployment of base stations
      - Massive MIMO



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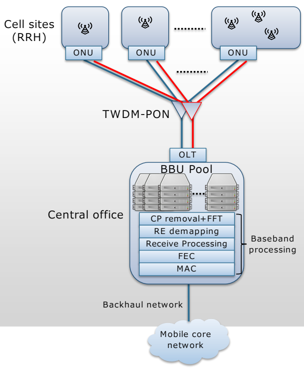
C-RAN fronthaul network based on TWDM-PON

- TWDM-PON is applied to fronthaul network between cell sites (RRHs) and BBU pool (Central office)
  - Low cost
  - Flexible wavelength / time slot allocation to ONUs at cell sites
  - Better latency control compared with packet-based network (e.g. ethernet)
  - Low power consumption by decreasing the number of wavelength for small network traffic
- Large bandwidth usage per RRH does not change



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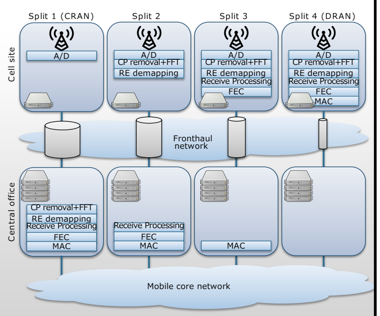
Functional split of baseband processing

- Functions for baseband processing are split at cell site and central office
  - (+) Decreasing bandwidth usage of fronthaul network
  - (+) Optimizing implementation of functons
  - (-) Coordinated control of RRHs becomes difficult
- Appropriate split option is dependent on various factors
  - Network capacity and power consumption characteristics of fronthaul network
  - User traffic amount
  - Capacity and power consumption of servers at cell sites and central office
  - Processing overhead of each function
  - Distance (propagation latency) between cell site and central office
  - …



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Research objective

- Optimization method of functional split of baseband processing on TWDM-PON based fronthaul network
  - Formulate the optimization problem for minimizing the system power consumption considering:
    - Server load for split baseband processing functions
    - Capacity and wavelength constraint of TWDM-PON fronthaul network
    - Power consumption characteristics of servers and networks
    - Constraints for server capacity and processing latency
    - Network topology
    - …
- Evaluating the proposed method through numerical examples
  - Appropriate functional split and resulting power consumption would change dependently on system configuration

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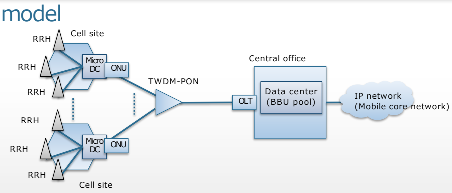
Network model



- TWDM-PON network between cell sites and central office
- Each cell site has one or more RRHs
- Micro Data Centers (Micro DCs) at cell sites and Data Center at central office for baseband processing
- ONU can utilize multiple wavelengths simultaneously
  - Cell site has multiple ONUs for RRHs
- Determine functional split for each traffic from RRH
  - Constraints: server capacity, TWDM-PON capacity, processing latency, …

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Optimization problem

Minimize :

$$\sum_{n=2}^{N}\sum_{i=1}^{R}\sum_{k=1}^{K}\sum_{w=1}^{W} y^i_{n,k,w}(X_{n,k}+X_{1,k}) + \sum_{n=1}^{N} x_n C_n + \sum_{w=1}^{W} l_w L_w \quad (2)$$

Subject to :

$$y^i_{k,n,w} \in \{0,1\} \quad (3)$$

$$y^i_{k,n,w} \le a^i_n \ \forall i,n,k,w \quad (4)$$

$$y^i_{k,n,w} = 1 \rightarrow x_n = 1, l_w = 1$$

$$\sum_{n=2}^{N}\sum_{k=1}^{K}\sum_{w=1}^{W} y^i_{n,k,w} = 1 \ \forall i \quad (5)$$

$$\sum_{n=2}^{N}\sum_{i=1}^{R}\sum_{k=1}^{K} y^i_{n,k,w} B^i_{n,k,w} \le B_w \ \forall w \quad (6)$$

$$y^i_{n,k,w}\{D_{n,k} + z_k \tau_n + D_{1,k}\} \le \Delta_i \ \forall i,n,k,w \quad (7)$$

$$\sum_{k=1}^{K}\sum_{i=1}^{R}\sum_{w=1}^{W} y^i_{n,k,w}\rho_{n,k} < 100 \cdot P_n \ \forall n \quad (8)$$

- Objective function
  - (2) Minimizing power consumption
    - Servers for baseband processing
    - + wavelength utilization of TWDM-PON
- Constraints:
  - (3) y is binary variable
  - (4) Network topology (Locations of RRHs)
  - (5) Traffic from RRH_i is processed at only one node
  - (6) Network capacity constraints
  - (7) Latency constraints
  - (8) Server capacity constraints

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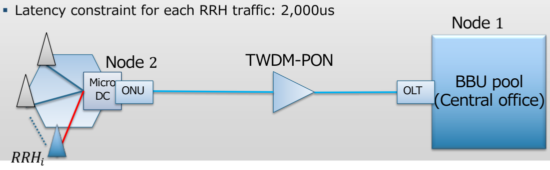
Numerical evaluation: Parameter settings (1)

- LTE network
- Number of cell sites: 1
- Number of RRHs: 1∼
- Data rate of user traffic from each RRH: 54Mbps
- TWDM-PON: 10Gbps and 20W for each wavelength
- Power consumption of physical server: 200W
- Propagation delay of TWDM-PON: 10us
- Latency constraint for each RRH traffic: 2,000us



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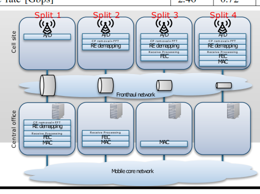
Numerical evaluation: Parameter settings (2)

- Processing delay and CPU utilization for each split function are determined by existing experimental results [13][14]
- Server power consumption is determined by CPU specification
- Low and high performance servers

TABLE I
RESOURCE CONSUMPTION AND PROCESSING LATENCY OF SPLIT OPTIONS

	Low performance server				High performance server			
Split option	Split 1	Split 2	Split 3	Split 4	Split 1	Split 2	Split 3	Split 4
CPU utilization at micro data center [%]	0	32.2	126.7	139.5	0	12.4	48.7	53.7
Processing latency at micro data center [μs]	0	111	1,772	1,972	0	43	682	758
CPU utilization at CO data center [%]	139.5	107.3	12.8	0	53.7	41.3	4.9	0
Processing latency at CO data center [μs]	1,972	1,861	200	0	758	716	77	0
Traffic rate [Gbps]	2.46	0.72	0.054	0.054	2.46	0.72	0.054	0.054



[13] N. Nikaein, "Processing radio access network functions in the cloud: Critical issues and modeling," in Proceedings of MCS 2015, Sept. 2015.

[14] M. Kist, J. A. Wickboldt, L. Z. Granville, J. Rochol, L. A. DaSilva, and C. B. Both, "Flexible fine-grained baseband processing with network functions virtualization: Benefits and impacts," Computer Networks, vol. 151, pp. 158–165, Mar. 2019.

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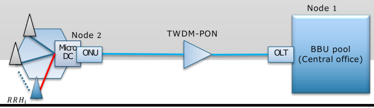
Numerical evaluation: Parameter settings (3)

- Evaluation scenarios: Assessing facility expansion methods for increasing system capacity (= # of RRHs that can be accommodated)
  - Scenario 1: Baseline setting
    - 3 wavelengths, 3 servers at Micro DC, Low performance servers at cell site, high performance servers at central office
  - Scenario 2: Enhancing cell site servers
    - 3 wavelengths, 3 servers at Micro DC, **High performance servers** at cell site, high performance servers at central office
  - Scenario 3: Increasing number of servers at cell site
    - 3 wavelengths, **8 servers** at Micro DC, Low performance servers at cell site, high performance servers at central office
  - Scenario 4: Increasing the number of wavelength of TWDM-PON
    - **6 wavelengths**, 3 servers at Micro DC, Low performance servers at cell site, high performance servers at central office
  - Parameters of scenarios 2, 3, and 4 are configured for equalizing system capacity
- ILP solver: IBM CPLEX



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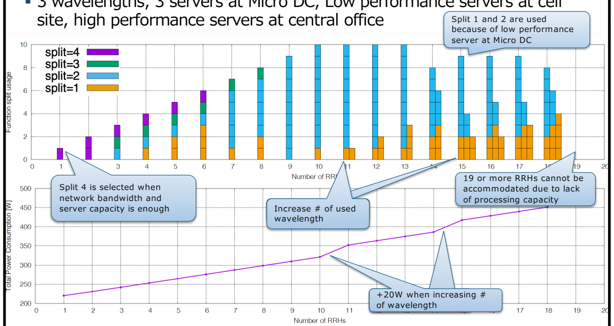
Scenario 1: Split usage and power consumption

- 3 wavelengths, 3 servers at Micro DC, Low performance servers at cell site, high performance servers at central office



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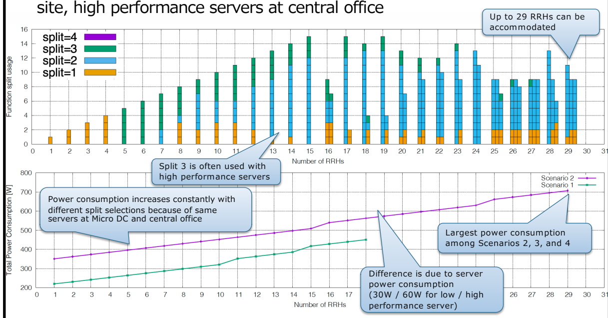
Scenario 2: High performance servers at Micro DC

- 3 wavelengths, 3 servers at Micro DC, **High performance servers** at cell site, high performance servers at central office



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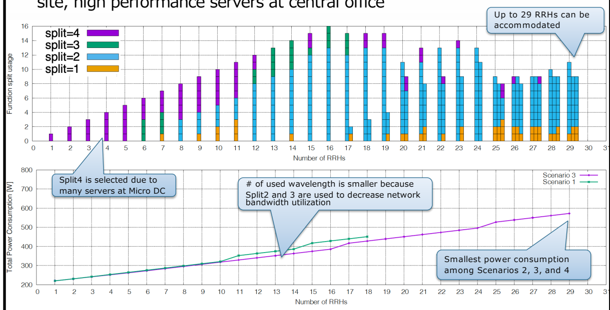
Scenario 3: Increasing # of servers at Micro DC

- 3 wavelengths, **8 servers** at Micro DC, Low performance servers at cell site, high performance servers at central office



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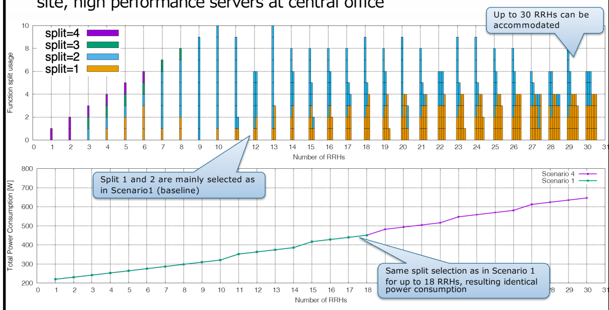
Scenario 4: Increasing # of wavelength of TWDM-PON

- **6 wavelengths**, 3 servers at Micro DC, Low performance servers at cell site, high performance servers at central office



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Summary and future work

- Summary
  - Optimization method of functional split of baseband processing on TWDM-PON based fronthaul network
    - Optimization problem is formulated as ILP
  - Evaluation results
    - Split selections for minimizing power consumption can be obtained
    - Different facility expansion methods for increasing system capacity would result in different split selections and power consumption
- Future work
  - Evaluation for 5G scenario
  - Optimization of core network functions and application servers
  - Evaluations for larger-scale network

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