Optical Networking Interconnecting Disaggregated Compute Resources: An enabler of the 5G Vision

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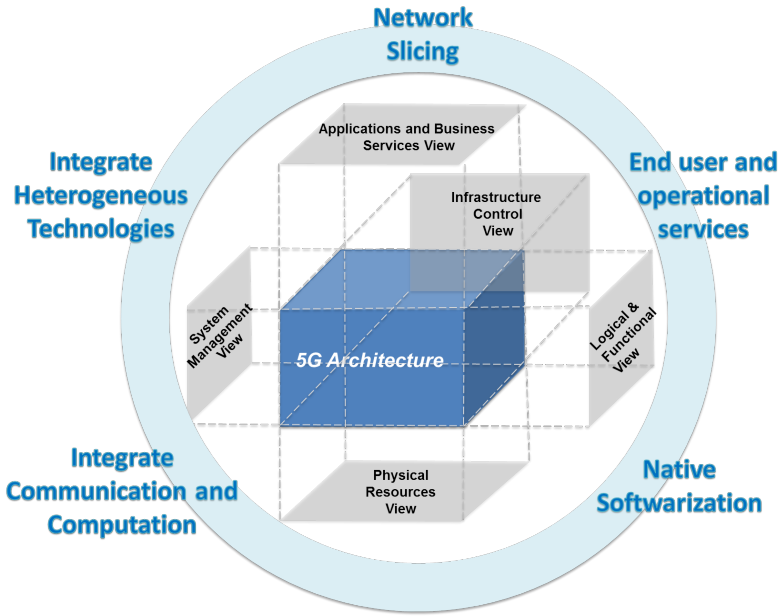
Outline

- Motivation 5G vision
- Proposed 5G architecture
- Optical Networking Interconnecting Compute Resources
  - Inter- and Intra-DC connectivity
  - Disaggregation of Resources
  - Increase granularity in the control of resources and utilisation efficiency
- Modelling results: power consumption
- Conclusions

Motivation - 5G Vision

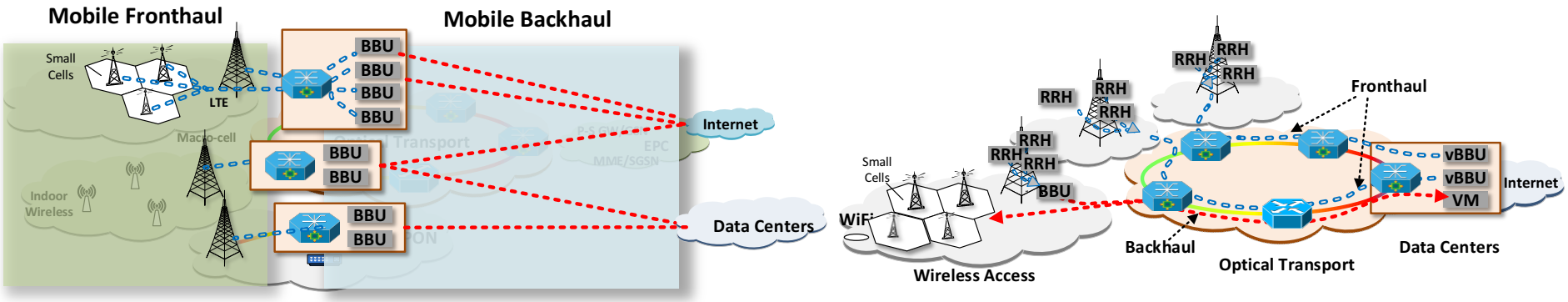
- New business opportunities meeting the requirements of large variety of use cases (enabling verticals)
- 5G Networks to be future proof (i.e. design to evolve and change and not to be replaced)



5G PPP View on 5G Architecture – (White Paper), https://5g-ppp.eu/white-papers/

- *by means of implementing* ***network slicing*** *in a cost efficient way*
  - *addressing both* ***end user and operational services***
  - *supporting* ***native softwarization***
  - *integrating* ***communication and computation***
  - *integrating* ***heterogeneous technologies*** *(incl. fixed and wireless technologies)*

Supporting operational and end-user services



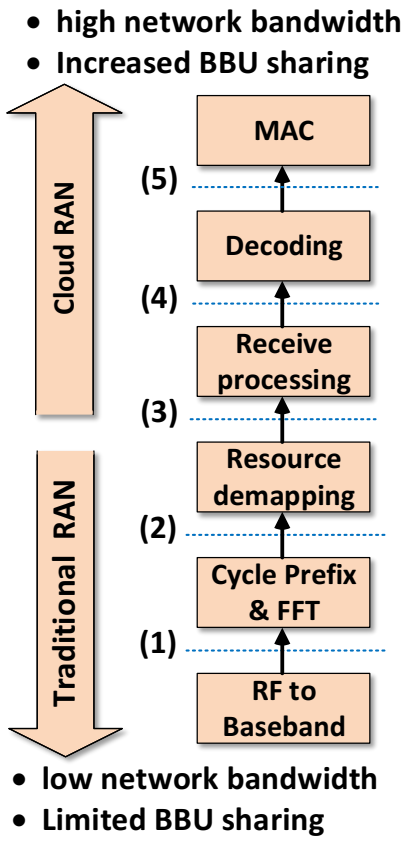
- **Early solutions**: Separate Fronthaul and Backhaul networks
  - Fronthaul: Network between RRHs and dedicated BBUs
  - Backhaul: Between the core network and the sub-networks at the edge
- **C-RAN:** Sharing of BBUs but Separate Fronthaul and Backhaul networks
- **Proposal:** Adopt C-RAN and offer a common transport to support jointly converged FH and BH functionalities.
  - high transport bandwidth
  - Strict delay constraints
  - enhanced synchronisation capabilities
  - flexibility and elasticity in bandwidth allocation

A. Tzanakaki et al., Wireless-Optical Network Convergence: Enabling the 5G Architecture to Support Operational and End-User Services, IEEE Commun. Mag. 2017 (in press)

Flexible Functional Splits

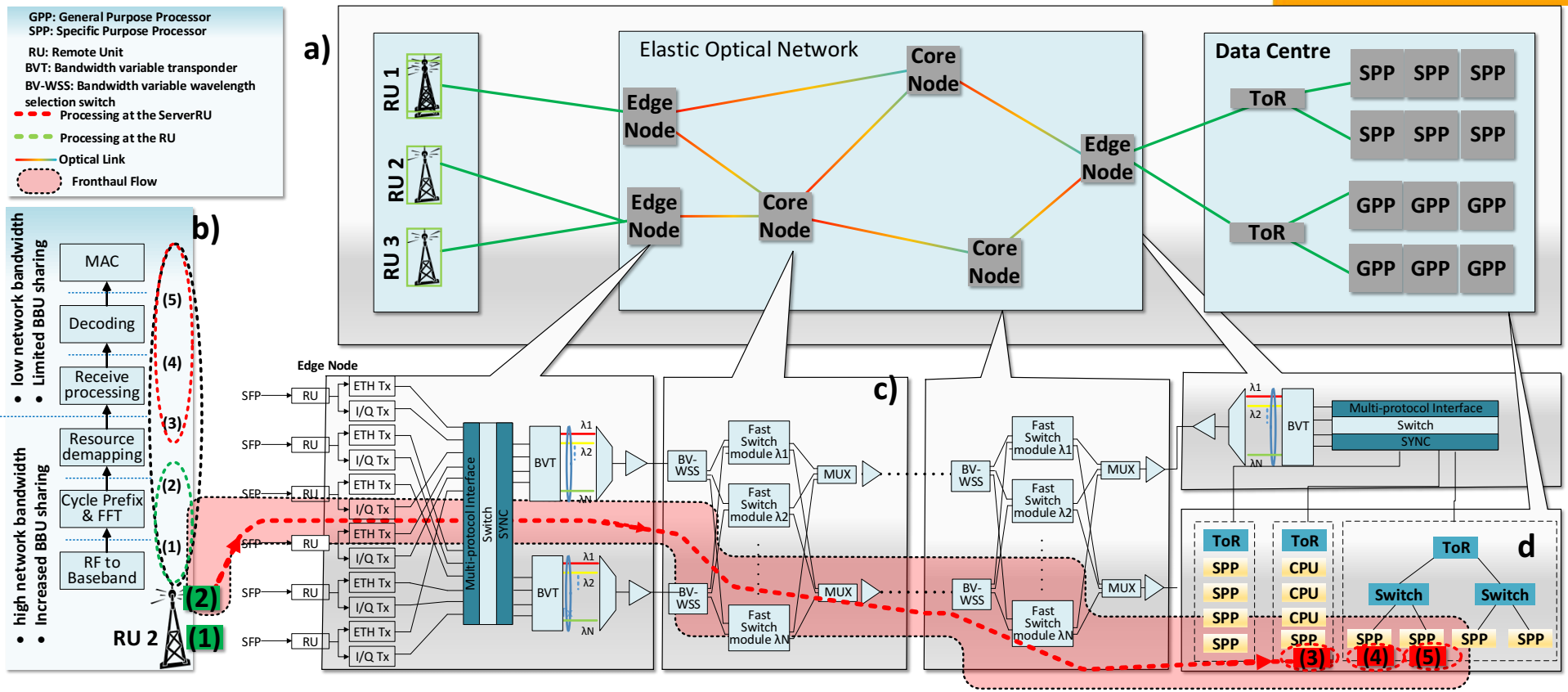
- Flexible split processing to relax the stringent requirements of FH services for:
  - transport capacity
  - delay
  - synchronisation

- Split Options
  - Split (1): “CPRI”
  - Split (2): “load-dependent FH”
  - Split (5): “BH with centralized scheduling”
  - Processing can be also performed at general purpose servers



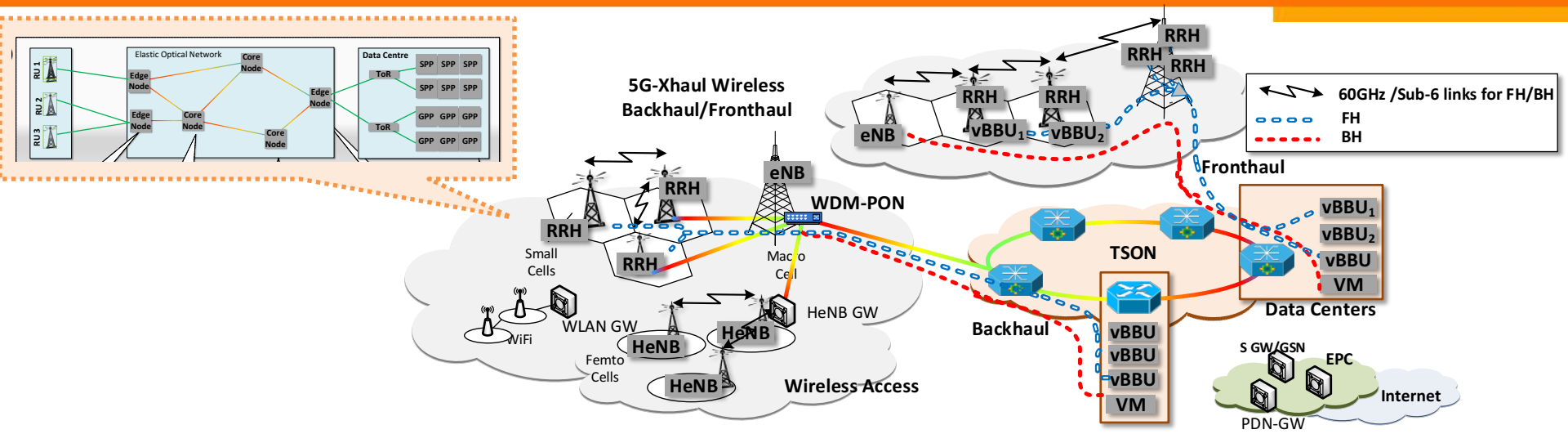
A. Tzanakaki *et al.*, "5G infrastructures supporting end-user and operational services: The 5G-XHaul architectural perspective," *IEEE ICC*, 2016.

Overall Infrastructure



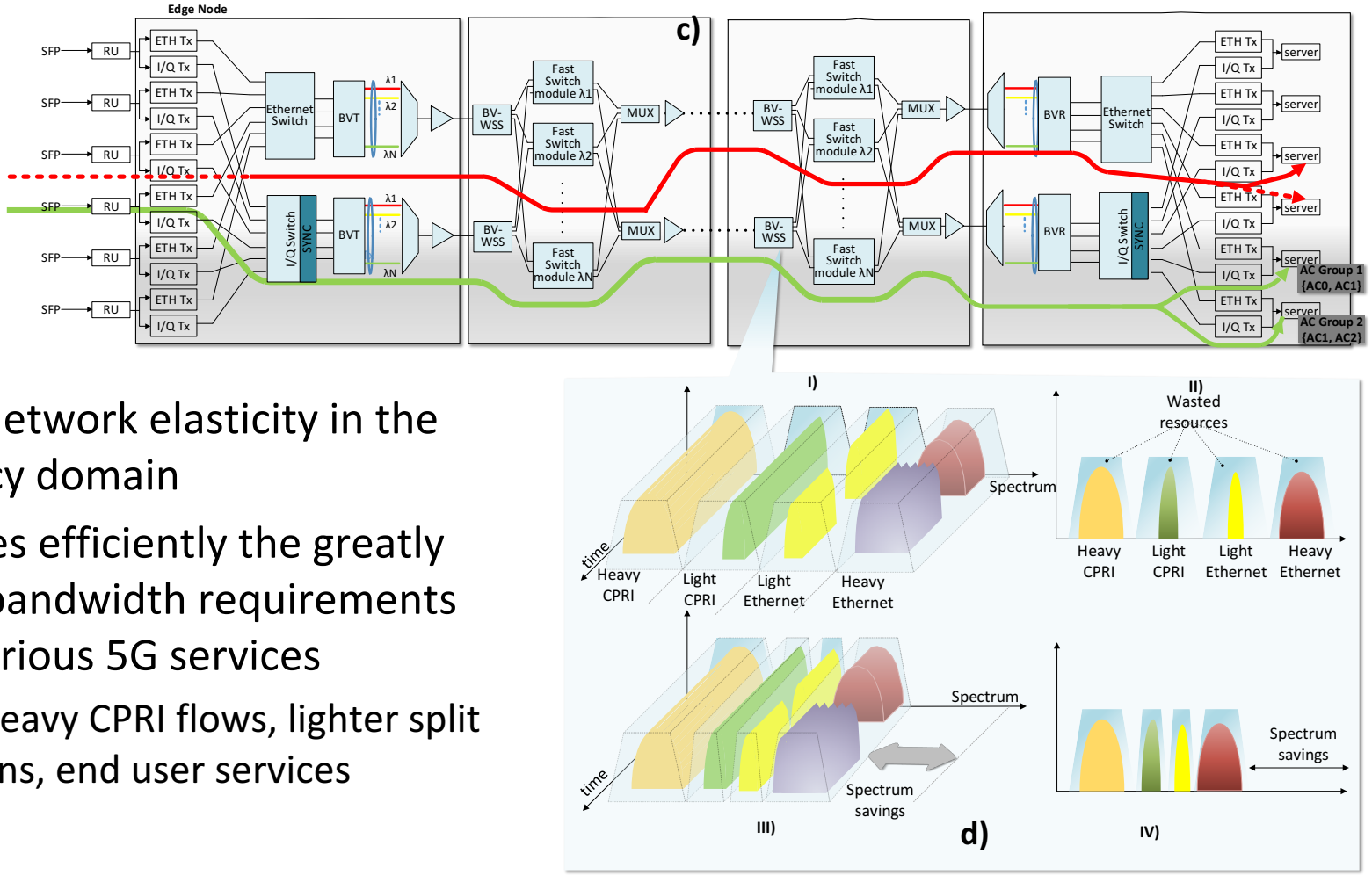
- Key Challenge:
  - Converged Fronthaul and Backhaul Services
  - Converged Network and Compute Services
  - Disaggregation of Resources

Physical Network Infrastructure



- Integrated optical and wireless network infrastructure for transport and access
- Wireless domain:
  - Dense layer of small cells complemented by macro cells to ensure ubiquitous coverage
  - Small cells can be backhauled to the macro-cell site either wirelessly using a combination of mm-Wave and sub-6 wireless technologies or using a hybrid optical network platform
- Optical Domain
  - Adoption of a dynamic and flexible/elastic frame based optical network solution combined with enhanced capacity WDM PONs
- BB Processing: RUs are connected to remote BB processing pools through high bandwidth transport links

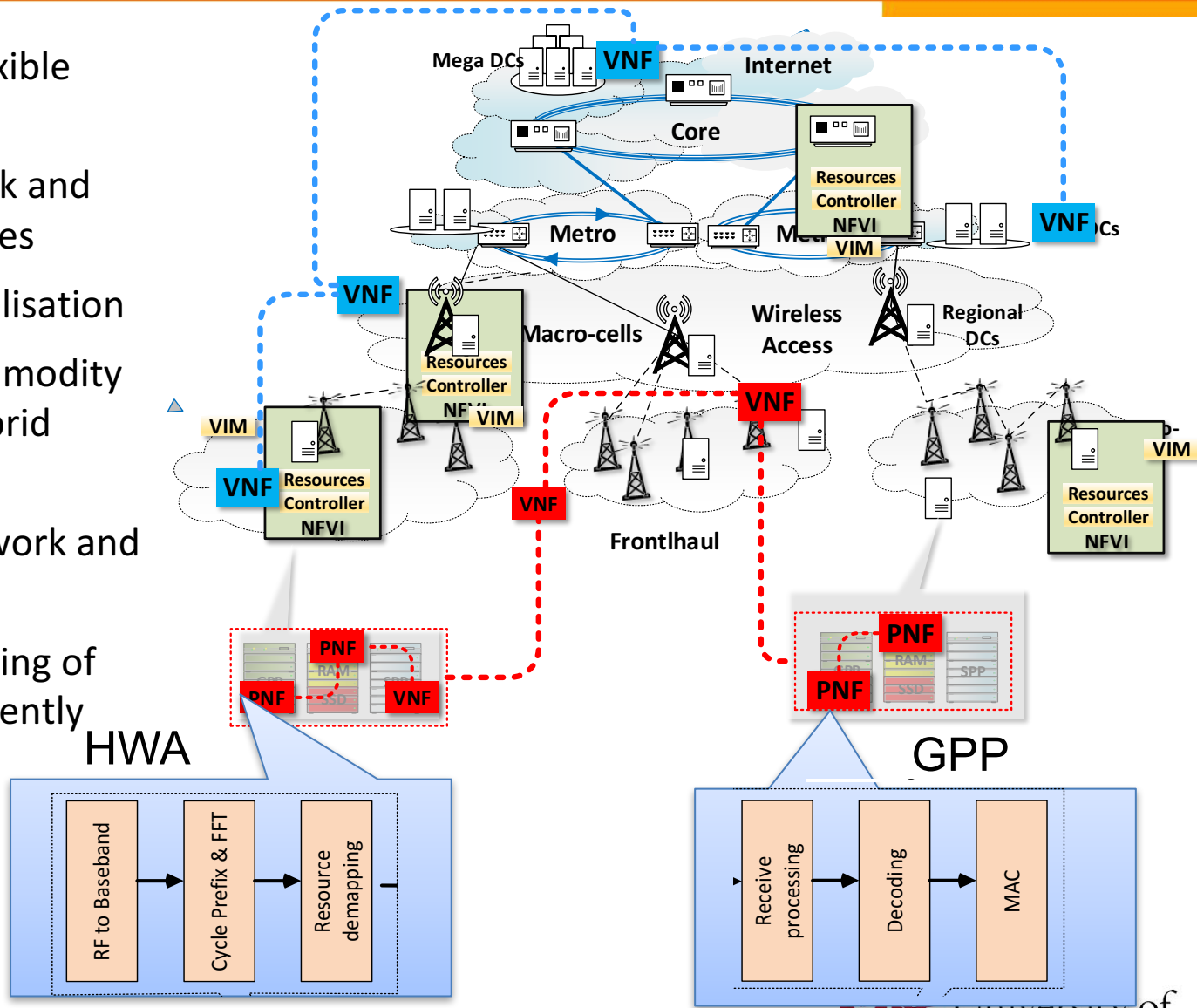
Elastic Optical Network



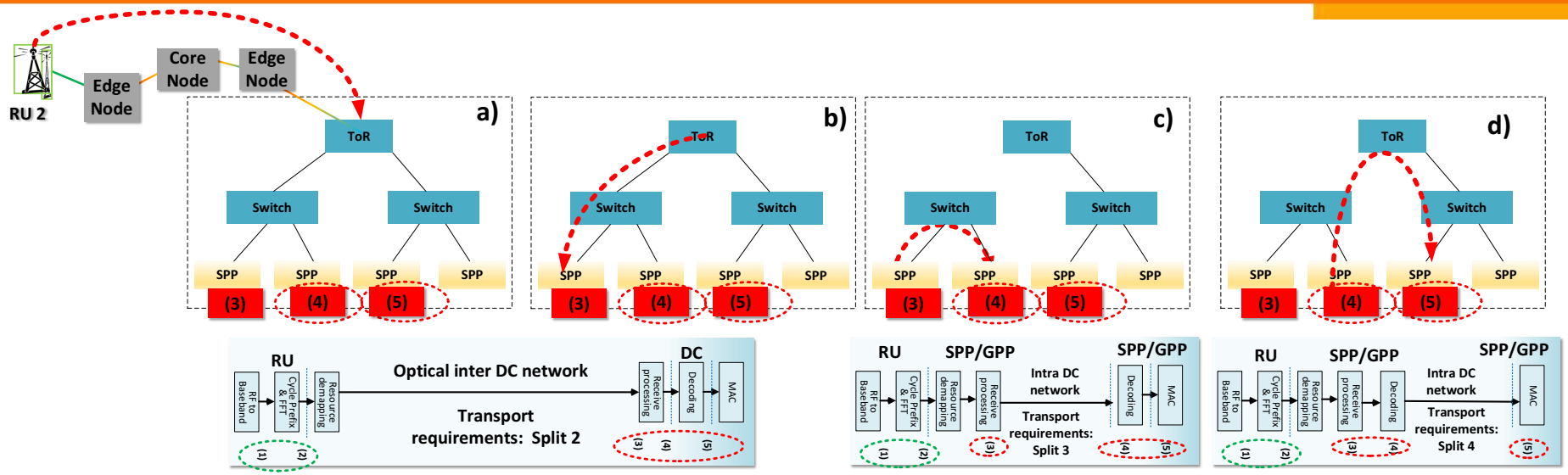
- Optical network elasticity in the frequency domain
- Addresses efficiently the greatly varying bandwidth requirements of the various 5G services
  - E.g. heavy CPRI flows, lighter split options, end user services

Convergence of Networking and Computation

- Fronthaul adopting flexible functional splits
  - Transport Network and Compute Resources
  - Processing parallelisation
  - Full GPP with commodity hardware and hybrid solutions
- Disaggregation of Network and Compute resources
  - Mixing and matching of resources to efficiently support services

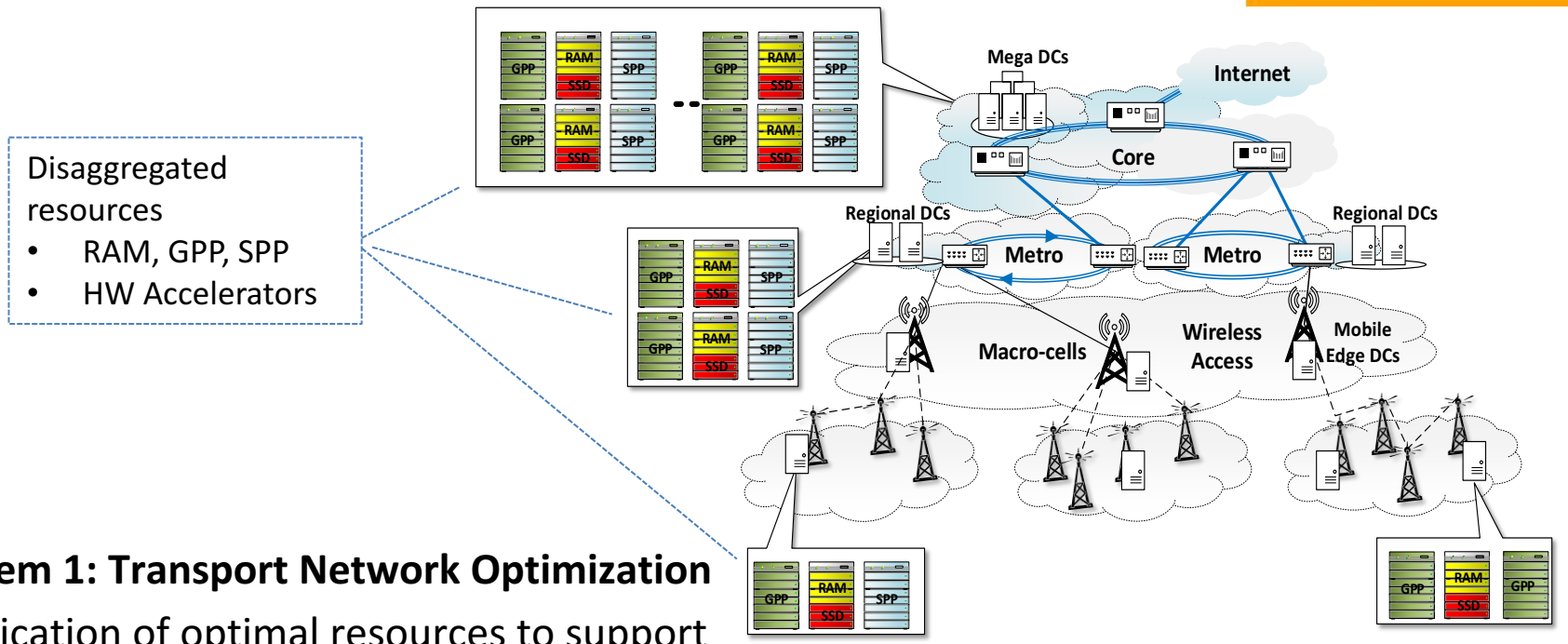


Processing Parallelization



- BBU sub-frame processing time < 1ms
- To reduce processing delay, BB processing is handled in parallel over disaggregated compute resources
- Model 1: parallel (or sequential) processing mode
  - each function is distributed across multiple processing units (1:N)
- Model 2: Pipelining
  - each processing unit handles a specific function adopting 1:1 mapping

Use case: Joint optimization of Inter-intra DC network for FH services



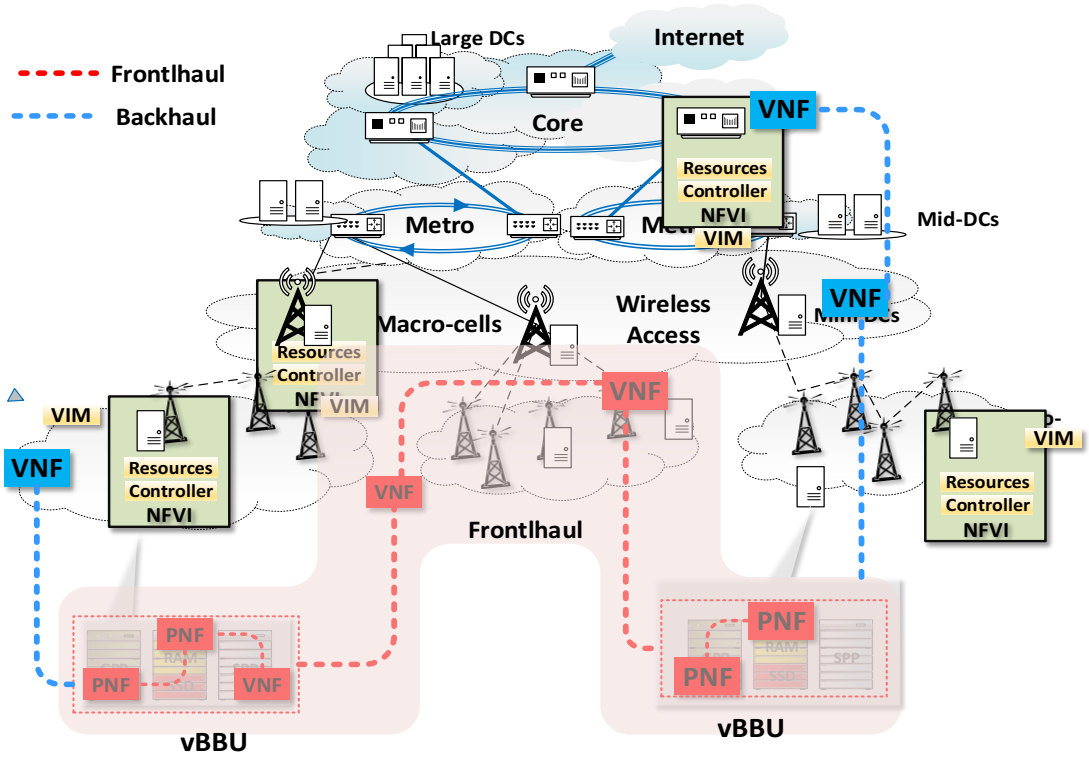
Sub-problem 1: Transport Network Optimization

- Identification of optimal resources to support FH or BH services in terms of both topology and resources includes:
  - Ordering (SC) of the relevant functions (VNF or PNF)
  - Estimating virtual resources required to support SC and executing the corresponding applications
  - Mapping virtual resources to physical resources

M. P. Anastasopoulos, A. Tzanakaki and D. Simeonidou, "Energy-aware offloading in mobile cloud systems with delay considerations," 2014 IEEE Globecom Workshops (GC Wkshps), Austin, TX, 2014, pp. 42-47.

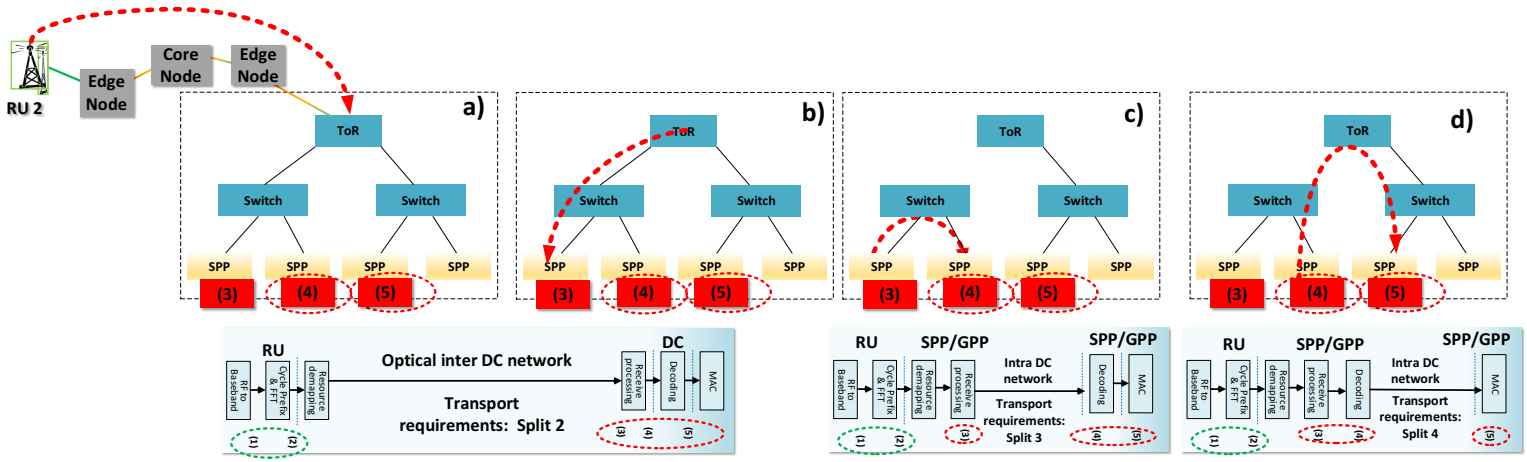
Sub-problem 1: Constraints

- BBU chaining: VNFs are processed in the order defined by the corresponding SC
- Flow conservation as well as mapping and aggregation/de-aggregation of traffic between different domains
- End-to-end delay guarantees
- Flexible FH processing splits
  - BBU Processing constraints
  - RU Demand Constraints
- Transport network capacity requirements
  - Constraints imposed by the elastic optical network



Sub-problem 2: Disaggregated DC Network Optimization

Sub-problem 1



Sub-problem 2:

- Identifies the optimal processing modules where parts of the FH SC have to be allocated.
- Establishment of a path interconnecting edge DC node with the GPP/SPP modules that will process the remaining FH functions
- The order of FH functions processing is defined by the corresponding SC

Optimization framework

- Joint optimization of Inter/Intra DC Network
- *1st Sub-problem*: Optimal transport network is identified through the minimization of the energy cost:

FH energy, local processing **FH energy, transport**

$$\min F_1 = \sum_{r \in \mathbf{R}} \mathcal{E}_r \left(\sum_{i \epsilon \Sigma} p_{ri}^{RU} \, \sigma_{ri} \right) + \sum_{e \in \mathbf{E}} \mathcal{E}_e \, C_e$$

subject to capacity, latency and demand constraints.

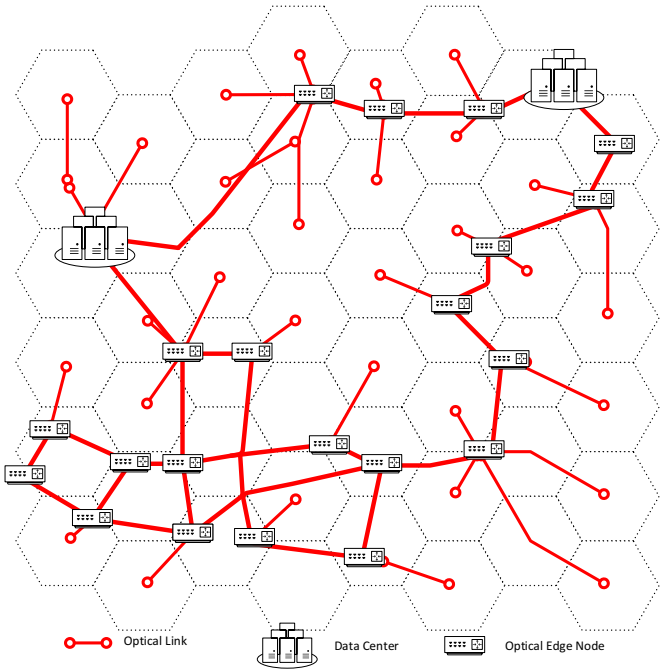
- *2nd Sub-problem* : Disaggregated DC Network Optimization

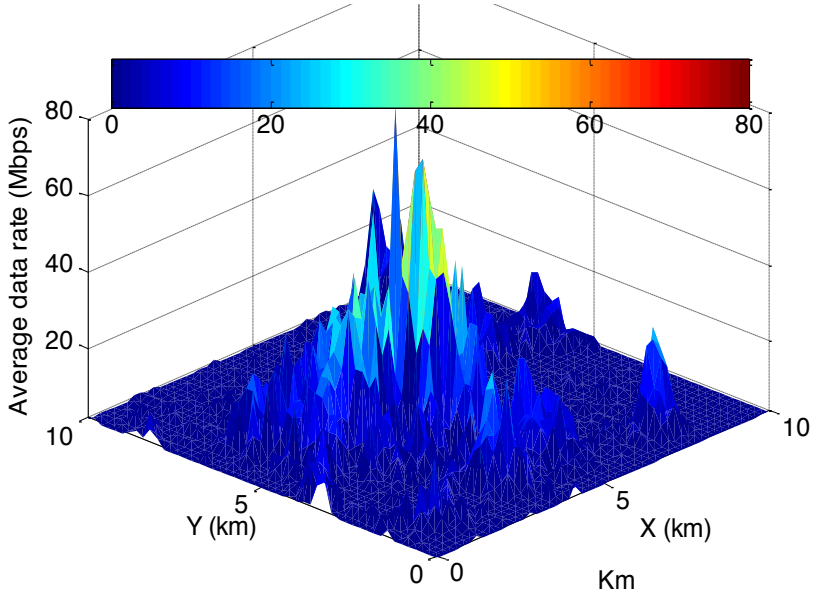
subject to demand processing and capacity constraints

FH energy, DC processing **FH energy, DC network**

$$\min F_2 = \sum_{k \in \mathbf{M}^d} \mathcal{E}_k \left(\sum_{r \in \mathbf{R}} \sum_{i \epsilon \Sigma} \sum_{\varphi \, \epsilon \, \mathbf{FH}_{ri}^d} p_\varphi \, a_{\varphi \kappa} \right) + \sum_{e \in \mathbf{E}^d} \mathcal{E}_e \, C_e$$

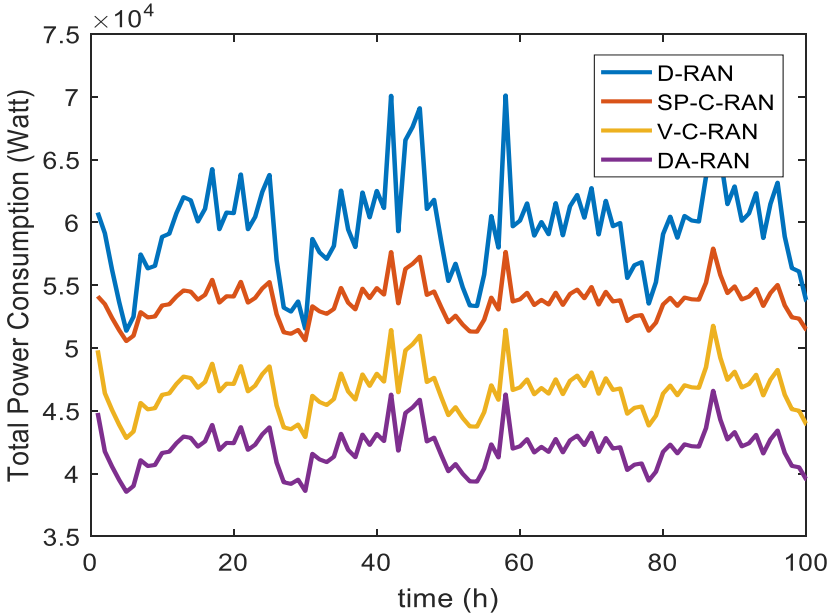
Numerical evaluation: Scenario





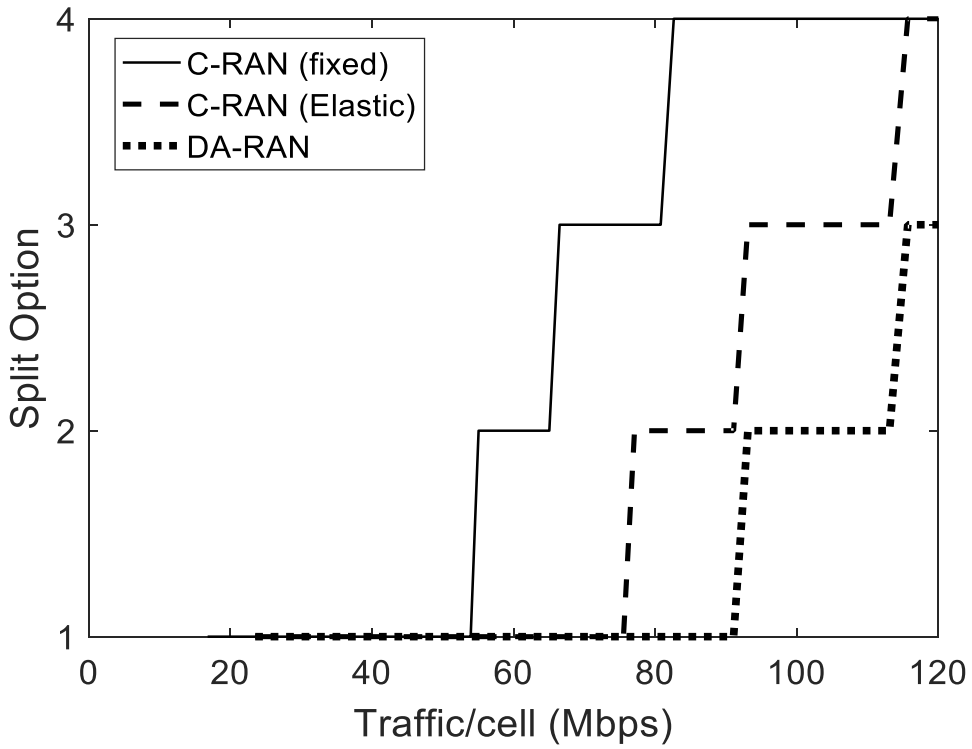
- Bristol is Open (BIO) smart city test-bed topology
- Snapshot of spatial traffic load and average traffic/BS based on real datasets

Numerical results: Energy



- "Distributed-RAN (D-RAN)" RUs and BBUs are co-located and FH service processing is carried out exclusively by specific purpose hardware.
- "C-RAN with specific purpose (SP) BBU hardware (SP-C-RAN)": Specific purpose BBUs are placed at a centralized location to be shared.
- "C-RAN with virtual BBUs (V-C-RAN)-": Allows BBUs to be instantiated as virtual functions and run on GPPS enabling sharing of resources and on-demand resizing of compute resources.
- "Disaggregated-RAN (DA-RAN)": Combines the benefits of SP-C-RAN and V-C-RAN allowing FH functions to be processed either at SPP or GPP based on their specific characteristics.

Functional Splits



Conclusions

- Motivation 5G vision
- Proposed 5G architecture
  - C-RAN
  - Flexible Functional Splits
- *Optical Networking* Interconnecting Compute Resources enabling **Resource Disaggregation**
  - Increased resource efficiency
- Modelling results indicate significant benefits in power efficiency compared to alternative approaches

Thank you!

ACKNOWLEDGMENT

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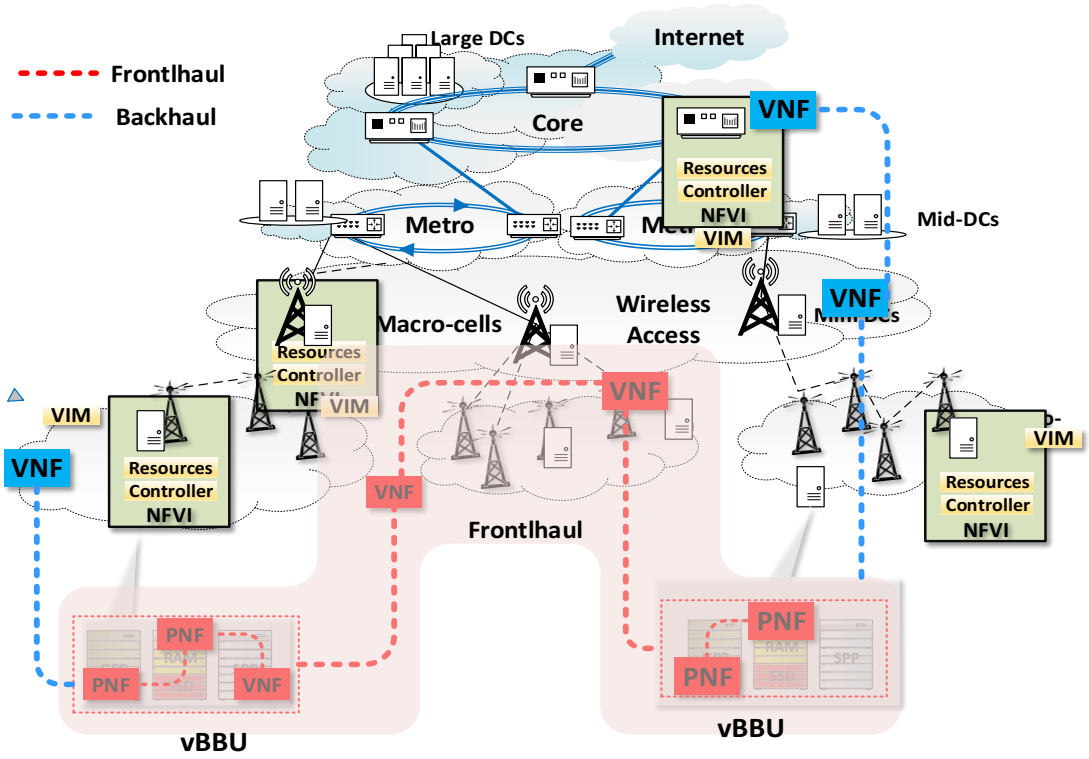
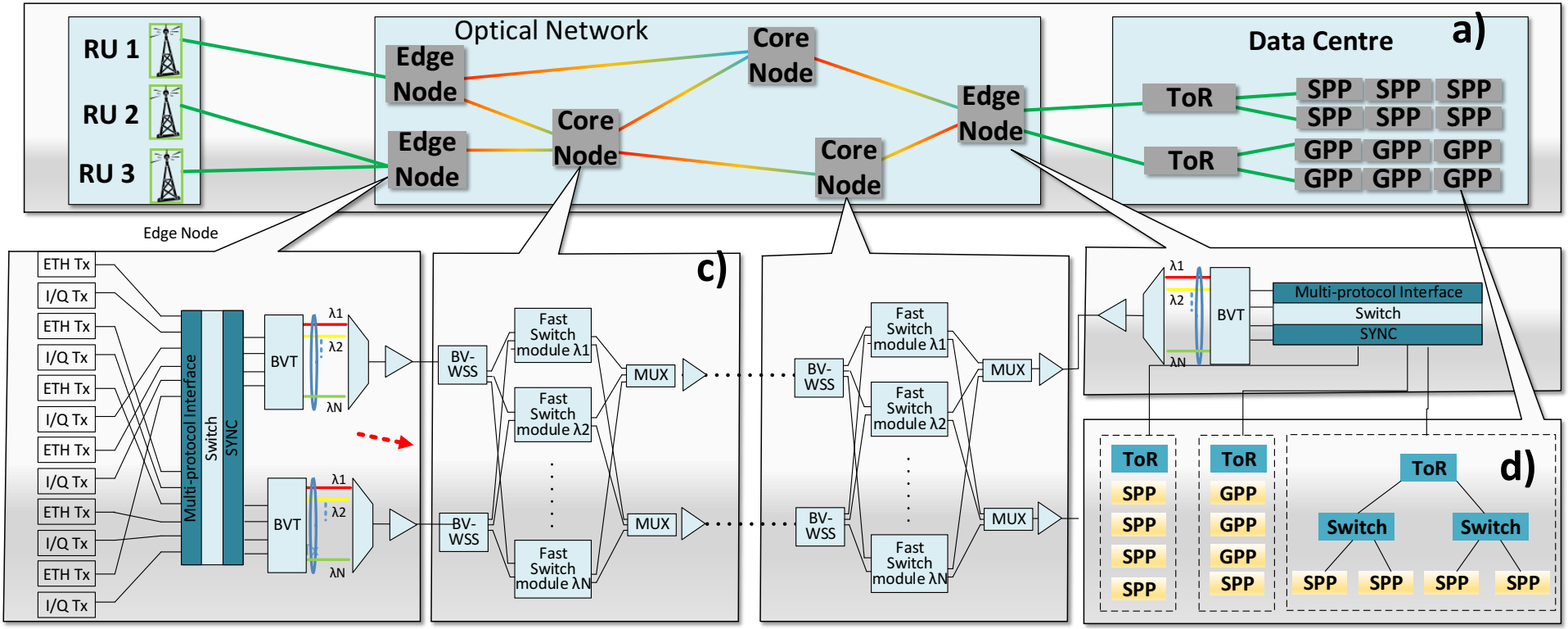


Optical Networking: RU-BBU interconnection



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Key Network Component

- Interfacing between different technology domains:
  - Scheduling
  - Aggregation/De-Aggregation
  - Traffic adaptation
  - QoS Mapping