Orion: RAN Slicing for a Flexible and Cost-Effective Multi-Service Mobile Network Architecture

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Service-oriented 5G view

Connected Car
Connected City
Factory Automation
Video
Smart Sensors
Smart Grid

Mobility
Data Rate
Latency
Reliability
Density
Limitations of conventional mobile network architectures

Conventional One-size Fits All Mobile Network Architecture - Optimized for Mobile Broadband
Towards a service-oriented architecture

Radio Access Network (RAN)  
Physical Network 1  
Physical Network 2
Towards a service-oriented architecture

Radio Access Network (RAN)

Physical Network 1

Virtual Network – Slice 1

Virtual Network - Slice 2

Virtual eNodeB

Virtual MME

Virtual S-GW
Towards a service-oriented architecture

Radio Access Network (RAN)

Virtual eNodeB

Virtual MME

Virtual S-GW

Virtual Network - Slice 2

Virtual Network – Slice 1

Physical Network 1

Physical Network 2
RAN Slicing

RAN Slicing Approaches
RAN Slicing

Efficient and adaptive use of radio resources

No functional isolation

RAN Sharing
(e.g. [NVS - IEEE/ACM TON 2012], [FlexRAN use case – CoNEXT 2016])
RAN Slicing

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✔ Efficient and adaptive use of radio resources
X No functional isolation

Full isolation
(e.g. [FLARE – JIP 2017])

✔ Functional isolation
X Inefficient use of radio resources
RAN Slicing

RAN Sharing
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RAN Slicing Approaches

Full isolation
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✔ Functional isolation

X Inefficient use of radio resources
Our contribution: **Orion**

**Orion RAN slicing system**

- Enable functional isolation among slices and the efficient utilization of the underlying RAN resources
- Introduce a novel set of abstractions for the virtualization of the radio resources
- Deployment in an end-to-end setting
- Concrete prototype implementation & Detailed experimental evaluation
- Multi-Service slice extensions for support of OTT service providers
Orion overview

- **Slice 1**
  - Virtual Control Plane

- **Slice 2**
  - Virtual Control Plane

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**Orion Hypervisor**

**Physical Base Station**
Orion overview

Slice 1
- Virtual Control Plane

Slice 2
- Virtual Control Plane

Orion Hypervisor

Physical Base Station

Hardware and spectrum owned by infrastructure provider

Shared physical layer
Orion overview

- **Slice 1**: Virtual Control Plane
- **Slice 2**: Virtual Control Plane

**Orion Hypervisor**

**Physical Base Station**

Control-data plane separation
Orion overview

- **Orion Hypervisor**
  - **Physical Base Station**
  - **Slice 1**
    - Virtual Control Plane
  - **Slice 2**
    - Virtual Control Plane
  - Virtual Network Functions
  - Customized Control Operations (Schedulers, Mobility managers etc.)
Orion overview

Radio resources and data plane state must be isolated among control planes.
Orion overview

- Physical Base Station
- Orion Hypervisor
  - Slice 1: Virtual Control Plane
  - Slice 2: Virtual Control Plane

Ensures isolation among slices:
- Virtualization of the radio resources
- Virtualization of the data plane state
Virtualizing the radio resources

Dynamically partition resources to slices based on SLAs
- Omit resources not dedicated to a slice
  - Random Access and Broadcast handled by the physical base station

Abstract the frequency dimension
- Inference and manipulation of resources from competing slices is prevented

Generic and applicable to different OFDM-based RATs
Virtualizing the radio resources

Virtual Radio Resource Block (vRRB)

- **Slice 1**
- **Slice 2**

Frequency Dimension (Sub-carriers)

Physical Radio Resources

View in Slice Control Planes
Virtualizing the radio resources

Virtual Radio Resource Block (vRRB)

Slice 1
Slice 2

Frequency Dimension (Sub-carriers)

Physical Radio Resources

View in Slice Control Planes

vRRB 1
Capacity = 2

vRRB 2
Capacity = 1

Abstract index-based Dimension

Capacity = 1
Virtualizing the radio resources

Virtual Radio Resource Block (vRRB)

Slice 1
Slice 2

Frequency Dimension (Sub-carriers)

Physical Radio Resources

View in Slice Control Planes

vRRB 1
Capacity = 2

vRRB 2
Capacity = 1

vRRB 1
Capacity = 2

Abstract index-based Dimension
Virtualizing the radio resources

Physical radio resources (and vRRBs) cannot always be used in all combinations for the scheduling of a UE
Virtualizing the radio resources

Physical radio resources (and vRRBs) **cannot** always be used in all combinations for the scheduling of a UE

e.g. UL scheduling in LTE

Valid resource allocation (contiguous allocation)
Virtualizing the radio resources

Physical radio resources (and vRRBs) cannot always be used in all combinations for the scheduling of a UE

E.g. UL scheduling in LTE

- Valid resource allocation (contiguous allocation)
- Invalid resource allocation (non-contiguous)
Virtualizing the radio resources

Physical radio resources (and vRRBs) **cannot** always be used in all combinations for the scheduling of a UE.

**Problem for slice control plane when abstracting the frequency dimension**

**e.g. UL scheduling in LTE**

- **Valid resource allocation (contiguous allocation)**
- **Invalid resource allocation (non-contiguous)**
Virtualizing the radio resources

vRRB Pool

- Contains 1 or more vRRBs
- A UE can only be allocated vRRBs from a single pool
Virtualizing the radio resources

Pools of Slice 1

vRRB Pool

vRRB pool #1

vRRB pool #2

Frequency Dimension

Physical Radio Resources

vRRB 1

vRRB 2

vRRB 3
Virtualizing the radio resources

Frequency Dimension

Physical Radio Resources

vRRB Pool

vRRB Pool #1

vRRB 1

vRRB 2

vRRB 3

vRRB Pool #2

Pools of Slice 1

Slice schedules UE using **either** pool 1 or 2 (mutually exclusive)
Virtualizing the data plane state

Slice 1 Virtual Control Plane

Slice 2 Virtual Control Plane

Virtual Data Plane State

Orion Hypervisor

Physical Base Station - Data Plane
Virtualizing the data plane state

Slice 1 Virtual Control Plane

Slice 2 Virtual Control Plane

Virtual Data Plane State

Virtual Data Plane State

Orion Hypervisor

Physical Base Station - Data Plane

Random Access

UE 1
IMSI 1234

IMSI 1234

Slice Information Service
Virtualizing the data plane state

Slice 1 Virtual Control Plane

Slice 2 Virtual Control Plane

Virtual Data Plane State

UE 1 bearers, HARQ, Tx Queue Sizes...

UE 1 IMSI 1234

Orion Hypervisor

Physical Base Station - Data Plane
Virtualizing the data plane state
Slice Isolation

Slice 1 Control Plane
- Custom Control Functions
- Virtual Data Plane State
- Virtual Radio Resources

Slice 2 Control Plane
- Custom Control Functions
- Virtual Data Plane State
- Virtual Radio Resources

Orion Physical Base Station
Slice Isolation

Slice 1 Control Plane

- Custom Control Functions
- Virtual Data Plane State
- Virtual Radio Resources

Slice 2 Control Plane

- Custom Control Functions
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- Virtual Radio Resources

Orion Physical Base Station

Isolated Communication Channels (message-based communication)
Slice Isolation

Slice 1 Control Plane
- Custom Control Functions
- Virtual Data Plane State
- Virtual Radio Resources

Slice 2 Control Plane
- Custom Control Functions
- Virtual Data Plane State
- Virtual Radio Resources

Isolated Communication Channels (message-based communication)

Orion Physical Base Station

Deploy in isolation (e.g. in VMs/containers or separate physical machines)
Slice Flexibility/Configurability

Slice 2 controller

Slice 2 controller
*Cross-layer optimization*

Slice 1 controller
*Load Balancing*

Slice 1 controller
*Load Balancing*

Orion Hypervisor

Orion Hypervisor

Orion Hypervisor

Orion Hypervisor
Orion Implementation

Implemented over OpenAirInterface open source LTE platform

- Implemented Hypervisor component from scratch
- Modified code to capture information relevant to mapping of UEs to slices and to support multiple core networks over the same eNodeB
- Employed FlexRAN SD-RAN platform for separation of control & data plane
- Modified FlexRAN protocol and controller for support of virtualized radio resource abstraction
Evaluation

- **RAN Sharing**
  - FlexRAN use case – CoNEXT 2016
  - ✔ Efficient and adaptive use of radio resources
  - ✗ No functional isolation

- **Orion**
  - Full isolation
  - FLARE – JIP 2017
  - ✔ Functional isolation
  - ✗ Inefficient use of radio resources
Evaluation

Scalability

Comparison with state-of-the-art

Impact of communication channel

Isolation capabilities

**Flexible radio resource allocation**

Deployment in an end-to-end setting
Flexible Radio Resource Allocation

FLARE with 2 slices, each with 5MHz of spectrum as baseline

Orion with 2 slices and a pool of 10MHz of spectrum

Slice 1:
- Constant TCP flow of 2Mbps
- Sporadic short-lived TCP flows with various rates (4-12Mbps)

Slice 2:
- UEs streaming DASH videos supporting multiple bitrates
Flexible Radio Resource Allocation

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Slice 2:
- UEs streaming DASH videos supporting multiple bitrates

UEs in FLARE retain the same video bitrate
Flexible Radio Resource Allocation

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Slice 2:
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Orion slice 2 borrows unused resources from slice 1
Multi-Service Slice Extension

Orion assumes 1:1 relationship between UE and slice
- Good for MVNOs and verticals
- Limited for multi-service environment (e.g. MVNO with OTTs)

Orion service container extension
- Real-time control capabilities for OTT applications
Conclusions

**Orion RAN Slicing System**
- A lightweight and flexible RAN virtualization solution
- Deployment in an end-to-end setting
- Multi-Service slice extensions for support of OTT service providers

**Future Work**
- Support for functional splits to enable RAN-as-a-Service (RaaS) paradigm
- Multi-RAT support