A NEW SDN-BASED CONTROL PLANE ARCHITECTURE FOR 5G

With a Case Study on Connectivity Management

M. OĞUZ SUNAY
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OUTLINE

A New SDN-Based Control Plane Architecture for 5G

WHAT IS SDN?

SOFTWARE-DEFINED NETWORKING

- Origins of SDN
- Decoupling of Hardware and Software
- Decoupling of Control and Data Planes
- Programmable Control Plane
- OpenFlow

5G

THE NEEDS OF MOBILE SERVICE PROVIDERS

- New Physical Layer Options
  - M-MIMO
  - D2D Communication
  - HetNets
- End of Profitability for MSPs
- Cloudification: NFV as a solution?

PROPOSED CONTROL PLANE

HIERARCHICAL PROGRAMMABILITY

- All SDN-Based
- Flow/UE Granular Programmability
- For CN as well as RAN - Hierarchical
- New <Match,Action> Based Protocols

CONNECTIVITY CONTROL

COMBINED MOBILITY, HANDOFF & ROUTING CONTROL

- Connectivity Management as a Service (CMaaS)
- D2I Links: Reactive and Proactive
- D2D Links: Reactive
- Performance Results
WHAT IS SDN?
INTERNET IS A GREAT SUCCESS

- Thanks to a large part due to networking abstractions in the form of layering
  - Applications build on Reliable/Unreliable Transport
    - Best Effort Global Packet Delivery
      - Best Effort Local Packet Delivery
There are problems

• The layers are defined for the data plane only
• We have no abstractions for the control plane
• To control the network, we continuously develop new protocols
• With increasing Internet usage and new trends, we seem to be requiring more and more advanced control protocols
PROBLEM STATEMENT

• Compute the configuration (state) of each physical device: Forwarding tables, access control lists....

CONSTRAINTS

• Perform this over non-reliable communication links
• Operate within given network-level protocol (IP)
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CONTROL PLANE ABSTRACTIONS

Network Virtualization

Global Network View

Network OS

Packet Forwarding

Packet Forwarding

Packet Forwarding

Packet Forwarding

SPECIFICATION

DISTRIBUTION

FORWARDING

Scott Shenker, 2010 - UC Berkeley
SOFTWARE-DEFINED NETWORKING

DATA/CONTROL PLANE DECOUPLING DEFINITION

• SDN is a networking architecture where the data and control planes are separated.

CONTROL PLANE LAYERING DEFINITION

• SDN is a networking architecture where the network control problem is layered into abstractions

HARDWARE/SOFTWARE DECOUPLING DEFINITION

• SDN is a networking architecture where the hardware and software components are decoupled with a well-defined open-interface
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**ABSTRACTIONS**

**NETWORK OS**
- Is a distributed system that creates consistent up-to-date network view
- Runs on servers (or controllers) in the network
- NOX, POX, Trema, Beacon, Floodlight, Maestro, Open Daylight....

**CONTROL PROGRAM**
- Operates on view of network
- INPUT: Abstraction of Global Network View (Graph/Database)
- OUTPUT: Configuration of each device
- Control program is not a distributed system
- Abstraction hides details of distributed state

**FORWARDING ABSTRACTION**
- Abstract away forwarding hardware
- Flexible: Behavior specified by control plane; Built from basic forwarding primitives
- Minimal: Streamlined for speed and low power
- Control program not vendor specific
- OpenFlow is one example
PART II

5G
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Challenges

Traffic Increase

Unprecedented Increase in Wireless Traffic

Increase in Capex/Opex Increase

Increase in Capex/Opex to Satisfy This Demand

Loss of Existing/New Revenue Sources to OTT Providers

Loss of Profitability

MSPs May Become Unprofitable Very Soon

Telecom companies count $386 billion in lost revenue to Skype, WhatsApp, others
WHAT CAN BE DONE

**DISRUPTIVE TECHNOLOGIES**
- HETNETS
- A VARIETY OF NEW FREQUENCY BANDS INCLUDING THE MILLIMETER-WAVE
- MASSIVE-MIMO
- D2D COMMUNICATION
- MOVE FROM CELL-CENTRIC TO DEVICE CENTRIC NETWORKS

**CLOUDIFICATION**
- NETWORK FUNCTIONS VIRTUALIZATION (NFV) FOR THE CORE NETWORK (CN)
- NFV FOR THE RADIO ACCESS NETWORK (RAN) - CLOUD RAN - DEVELOPED BY CHINA MOBILE

**PROGRAMMABILITY**
- SOFTWARE-DEFINED NETWORKS (SDN)
- PER-FLOW PROGRAMMABLE SERVICE CHAINING
- MODULARLY CUSTOMIZABLE NETWORKS & NETWORK COMPONENTS
- DYNAMIC/STATIC SHARED RAN COMPONENTS
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**DISRUPTIVE TECHNOLOGIES**

- A variety of frequency bands, including the millimeter wave
- Massive-MIMO
- Move from a cell-centric to a device-centric architecture
- Smarter devices
- D2D communication
5G: WHAT TO EXPECT

• HetNet with densely populated small cells
• A set of different carrier frequencies with different propagation characteristics
• D2I as well as D2D links
• An extensive set of adaptive physical layer components relying on large numbers of transmit and receive antennas
The key differentiator for 5G systems will be in how we architect and orchestrate the overall system (RAN+CN) control to realize the benefits of cloudification while taking full advantage of the transport capacity distributed over a large geographical area.

We envision fully decoupled, independently scalable and programmable user and control planes for 5G.
PART III

PROPOSED SDN-BASED CONTROL PLANE
For this vision, SDN is a natural architectural choice.

Complex control plane functions (CPF) are removed from forwarding elements and placed behind a logically centralized controller.

Forwarding elements are simplified, CPFs are shipped to physical or virtual servers running in a data center.
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SDN FOR 5G

CONTROL PLANE FUNCTIONS
- Per flow packet processing, caching
- Raw or Abstracted Network State

LOGICALLY CENTRALIZED HIERARCHICAL CONTROLLERS
- Packet processing rules
- Distributed Network State

FORWARDING ELEMENTS
• Considering the mobility of the UEs, the delay constraints associated with various control functionalities are significantly different

• The proposed all-SDN architecture is composed of a set of hierarchical set of controllers as opposed to a single controller overseeing the entire network control

• The hierarchy allows for
  • locally optimized control decisions
  • a new dimension in service provisioning to enable different grades of service
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**SDN FOR 5G**

NF: Network Function  
CA: Control Application  
SLA: Service Level Agreement

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Radio Resource Management  
HetNet Management

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Radio Link Control  
Medium Access Control  
Transmission Control

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Policy & SLA Management  
Service Chaining  
Network Virtualization  
Traffic Optimization  
L1-L7 Routing  
QoS Control  
Failover

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D2X Discovery  
D2X Connection Control

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Control Interface

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The control of the end-to-end network may operate over tables of <Match, Action> tuples sent by the controllers to the forwarders.

These rules are created by distilling the CPF outputs.

They are adaptive.

MATCH: A subset of the mobile network state

ACTION: Corresponding actions per each flow.
**MATCH**:
User identity, flow and connection type, user mobility, user observed channel quality, network carrier frequency, mobile unit capability, user billing plan, roaming information, OTT identity, etc.

**ACTION**:
Select RAT, schedule or avoid a specific wireless resource, initiate handoff, set modulation and coding, initiate ARQ, charge according to a specific policy, initiate CoMP, initiate ICIC, forward on a specific port, pause/resume a flow, limit the data rate and bandwidth, allow/disallow D2D communication, act as a relay, etc.
A controller at a higher hierarchy may send constraints to a controller at the lower hierarchy using a similar <Match, Action> tuple

- **MATCH**: Any subset of the network state

- **ACTION**: Selection of a control application, disabling or enforcing the joining of a RAT, limiting modulation and coding options, disallowing simultaneous scheduling of the same resource to matching flows, disallowing handoffs to certain types of base stations, disallowing or only allowing D2D communication, limiting transmit power of a given resource, powering on/off a base station, etc.
A controller at a lower hierarchy sends abstracted feedback to a controller at the higher hierarchy upon demand or with regular intervals.
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EXAMPLE OPERATION

- RAN CONTROLLER
- BS CONTROLLER
- UE CONTROLLER

<MATCH, ACTION> RULES

COMPOSITE CQI FEEDBACK

COMP USING ALLOWED RESOURCE BLOCKS

D2D RESOURCE BLOCKS ALLOCATED

D2D COMMUNICATION COMMENCES
CONNECTIVITY MANAGEMENT AS A SERVICE
Perhaps the most fundamental goal of network control is to ensure that a route for a given flow between two nodes is quickly and effectively established and maintained.

In LTE, as well as prior cellular networks, mobility is strictly managed identically regardless of the type of service.

If delay constraints are not stringent this may not be necessary.

The proposed architecture allows for a programatic approach to connectivity control with different grades of service.

We call this Connectivity Management as a Service (CMaaS).
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CMAAS FOR D2I LINKS

INTERNET

NET CONTROLLER

BS CONTROLLER

UE CONTROLLER

CONNECTIVITY UPDATE REQUEST

<MATCH, ACTION>

HANDOFF REQUEST

<MATCH, ACTION>

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CMAAS FOR D2I LINKS

- **BS Controller**
- **RAN Controller**
- **Net Controller**
- **UE Controller**

**Connectivity Update Request**

**Handoff Request**

**Proactive**

**Internet**
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### CMAAS FOR D2D LINKS

<table>
<thead>
<tr>
<th>BEFORE</th>
<th>AFTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Mobility CP-Handoff</td>
<td>Single Mobility CP-Handoff</td>
</tr>
<tr>
<td>Dual Mobility CP-Handoff</td>
<td>Dual Mobility CP-Handoff</td>
</tr>
<tr>
<td>D2D to D2D CP-Handoff</td>
<td>D2D to D2D CP-Handoff</td>
</tr>
</tbody>
</table>

**Notes:**
- **BEFORE:** Shows the initial state of the network.
- **AFTER:** Demonstrates the updated state after the implementation of the CMAAS for D2D links.

**Diagram:**
- **Data Plane:** Represented by arrows between devices.
- **Control Plane:** Represented by dashed lines between devices.

**Orientation:**
- **React:** Indicates reactive control plane architecture.
PAUSE/RESUME COMMANDS

• It is beneficial for OpenFlow to include Pause and Resume commands for the wireless CN operation

• These commands require the switches to have local caches

• **PAUSE:** This command asks the router to pause the forwarding operation and store the incoming packets for that link in its cache

• **RESUME:** This command informs the router to resume the transmission of the packets in the link in the received order.
EXPERIMENTAL SETUP

- Fat pipe network
- Links of 1GHz (including the wireless link)
- Mininet 2.1.0
- Floodlight controllers for all controller hierarchies
- Rules expire in \( x \) seconds
EXPERIMENTAL SETUP

- UEs are uniformly distributed across the network at the beginning of the experiments.
- Each UE generates/receives TCP flows randomly to one of the two services following an exponential distribution of parameter 1.
- Flow durations are uniform over [0, 10] seconds.
- A UE may generate/receive multiple parallel flows.
- Sources generate flows with average data rates of 66 Mbps.
- Each UE goes through a handoff with a certain velocity following a random walk.
- Each BS has 6 neighbors in the random walk.
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RESULTS

- Reactive (OpenFlow)
- Reactive (Resume) / LTE
- Proactive (OpenFlow)
- Proactive (Random)
- Proactive (Resume)

D2I

UPLINK

DOWNLINK
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RESULTS

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**UPLINK**

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**DOWNLINK**
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RESULTS

- UpLink
- DownLink

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RESULTS

![Graphs showing controller load vs. handoff period for uplink and downlink communication modes with different proactive and reactive strategies.](image-url)
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RESULTS
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RESULTS
CONCLUSIONS

• The 5G architecture needs to bring a high capacity, agile, low cost solution to ensure both user satisfaction and MSP profitability

• We propose a programmable, all-SDN architecture with hierarchical network control capabilities

• The proposed architecture programmatically orchestrates cloudification and NFV as well as end-to-end flow maintenance on a per-flow granularity with different grades of service

• Multiple grades of service for fundamental network operations may co-exist in the network for different flows

• We introduce CMaaS as an example

• Programmability of the network introduces a new revenue generation path for the MSPs
Thank you