Fixed-Mobile Convergence in 5G Networking

Michael C. Parker, University of Essex, UK (mcpark@essex.ac.uk)

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• Fixed-Mobile Convergence (Seamlessness, QoE, QoS)
• Key Performance Indicators (KPIs)
  ▪ Low latency (1 ms)
    o End-to-end; service access time
  ▪ Data rates (1-10 Gb/s to end-users)
  ▪ x1000 in connected devices (IoT)
    o Internet of Everything, Cyber-Physical Systems (CPS), Machine Type Comms (MTC)
  ▪ Energy & Spectral Efficiency (x10 improvement)
• Virtualisation (Cloud, Cloudless, Fog)
  ▪ Control, management, & orchestration (CMO) plane, Anything-as-a-Service (AaaS)
• Software-defined networking (SDN)
• Open Access (Multi-tenancy)
  ▪ NP, NO (VNO, MVNO), SP, Physical infrastructure provider (PIP)
  ▪ New business models & techno-economics
• Security (Encryption, authorisation, resilience)
• Centralised v. Distributed architecture
• Device-to-Device (D2D) communications

Trends in 5G Networking
New Technologies in 5G Networking

- Multi-Gb/s wireless transmission
  - Visible light communications (VLC)
  - Use mm-waves (24 GHz, 60-90 GHz)
  - Novel antenna designs
    - Holographic beam steering, patch, MIMO, leaky feeder

- D2D & D2I communications – new networking topologies
  - Mobile distributed caching (MDC),
  - Content Distribution Networking
  - Cloud2Cloud, IoT, MTC,..,

- Latency (1 ms)
  - Hardware acceleration
  - Hierarchical Routing – lowest common aggregation level
  - Hierarchical caching (CDN)
SODALES: SOFTWARE-DEFINED ACCESS USING LOW ENERGY SUBSYSTEMS

- Active remote node (ARN) enabling open access and a converged fixed-wireless architecture
- The ARN enables a software-defined network (SDN) architecture
  - Enables future virtualisation functionalities
- It can also be used for implementing the fronthaul

• Central office (CO)
• 1st aggregation point (AGP): passive WDM-PON with flexible BWA at CO
  Remote antenna units (RAU) need a separate wavelength, no sharing possible
• 2nd AGP: Active remote node (ARN) co-located with radio base station (RBS)
  connects also SME & residential users
SODALES: Software-Defined Access using Low Energy Subsystems

ARN: Active Remote Node

SODALES Anything-as-a-Service architecture

Software-Defined Open Access for Flexible and Service-Oriented 5G Deployment. Software-defined Open Access offers clear advantages for advanced 5G infrastructures, such as low-cost, low-energy and scalable deployment.
iCIRRUS: intelligent Converged Network Consolidating Radio & Optical Access Around User Equipment

EU H2020 Project

C-RAN: Cloud Radio Access Network
Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access

EU H2020 5G-PPP Phase-1

Paravirtualized Security: A thin network management layer that coordinates access over multiple optimised hierarchical routing protocols.

* End-to-end security across all layers of the converged and virtualised open access network
* Physical layer low-latency security for both wireless and optical, in open, dynamic, multi-user, highly connected, and decentralized 5G networks.
CHARISMA proposes an intelligent hierarchical routing and virtualised architecture that unites two important concepts:

- devolved offload with shortest path nearest to end-users
- end-to-end security service chain via virtualised open access physical layer security.
Key Features of CHARISMA

• Low Latency & Low Access Times
  ▪ 1 ms KPI -
  ▪ Caching, TrustNode, Accelerated NIC
  ▪ Data routed via lowest common aggregation node

• Virtualised Security Functions (VSFs)
  ▪ Firewall (active)
  ▪ Intrusion Detection System (IDS) - passive

• Open Access (multi-tenancy)
  ▪ Tenant isolation
  ▪ Service delivery

• Hierarchical, distributed-intelligence architecture
  ▪ Converged Aggregation Levels (CALs)
**CHARISMA Schematic Architecture**

**CAL: Converged Aggregation Level**

- **CAL3**
  - E.g.
  - CO: Central Office
  - DC: Data Centre

- **CAL2**
  - E.g.
  - Macro-BS: Base Station
  - ARN: Active Remote Node
  - μDC: Micro Data Centre

- **CAL1**
  - E.g.
  - μBS: Micro Base Station
  - SC: Small Cell

- **CAL0**
  - E.g.
  - HGW: Home (or Hub) Gateway

**IMU: Intelligent Management Unit**

**FSO: Free Space Optics**

**OFDM-PON: Orthogonal Frequency Division Multiplexing Passive Optical Network**

**Back-haul**

- 100G OFDM-PON/wireless

**Front-haul**

- Optical fibre/mm-wave/FSO

**Perimetric-haul**

- Optical fibre/mm-wave/FSO

- Distributing intelligence ever closer to the end-user assists in reducing network latency, and also allows for more precise SDN and NFV control
Broader CHARISMA Vision

CAL: Converged Aggregation Level
OLT: Optical Line Terminal
ARN: Active Remote Node

FP7 SODALES
CHARISMA demonstrates 2 separate concepts:

- **TENANT ISOLATION**
  - By configuring services, GEM ports, VLANs, QinQ in a GPON architecture

- **SERVICE DELIVERY**
  - User normal connectivity plus added features (such as firewall, etc..)
  - Video streaming applications

- Customers 1 to 4 can belong to different operators (VNOs)
- Several VNFs created in the server to provide the traffic processing required.
- VNF is required per Operator per Customer, associated with a combination of S+C tags.
- Automatic provisioning and deployment of VNFs as part of a service.
- Increase the scope of the slice to include:
TrustNode Hierarchy

- Router offering port-to-port latency of less than 3 μs
- Target data path circuitry is optimized at the register level
- IPv6-based routing concept using self-routing mechanism
  - Destination of a packet is contained in the routing address
- Data routed via lowest common Converged Aggregation Level (CAL)
- Hierarchical cluster of TrustNodes configured to allow:
  - short paths, local content caching, with redundancy and dynamic load sharing
**CHARISMA**

Control, Management, Orchestration (CMO)

- Consists of 4 groups of components:
  - Virtualized Infrastructure (VI)
    - Virtualizes HW resources (computing, storage, network) via hypervisor at Virtualization Layer,
  - Virtualized Network Functions (VNFs)
  - Management and Orchestration (MANO),

- Closely follows ETSI NFV architecture
  - Geared towards virtualization and multi-tenancy, security, and performance
CHARISMA vCaching System

- vCache, vCC as a VNF, web manager as a EM which will be initiated to a specific VNO
- Cache system interfacing to VNF manager which will interface to orchestrator
- Cache Engine (similar as decision engine) running as policy manager in service policy manager
- Cache Engine interfaces to Service Monitor. & Analytics
  - Caching related requirements to Service M&A
  - User location, throughput, RTT, packet loss, etc.
- Service M&A has interfaces to VNOs for collecting required monitoring data
CHARISMA virtualized security functions and security service value chain

5G Security Architecture

Security architecture in 4G (left) and CHARISMA proposal for 5G using hierarchical routing to reduce latency (right)
Virtualized Security Functions

• Possible VSFs: Firewall, Intrusion Detection System (IDS), Intrusion Prevention System (IPS), Traffic Classifier (TC), Data Loss Prevention (DLP), Network Tap
• VSFs can be:
  ▪ Passive: Functionality focuses on monitoring/detection and reporting (e.g. IDS)
  ▪ Active: Functionality focuses on prevention of attacks (e.g. Firewall)
• VNOs need to be authenticated and allowed access to authorized virtual network resource
• Comprehensive authorization and authentication solution, with trust framework:
  ▪ Pretty Good Privacy (PGP) and Web of Trust (WOT) techniques.
  ▪ MACsec for authentication and encryption for MAC layer security.
• Security of ICN-based architecture (content caching):
  ▪ OpenFlow, content encrypted through digital signature, private key of content originator
  ▪ Enforces confidentiality, traceability and content access feedbacks
• Distributed caching security:
  ▪ Virtualization of network layer
  ▪ Cluster encryption at PHY layer
    ▪ Reduces content access latency for both mobile and fixed networks
60-GHz for High Capacity Mobile Communications

- 60 GHz frequency proposed to significantly reduce the demands on crowded 2.4 GHz as well as 5 GHz, minimizing problems such as congestion within the network.
- Multichannel transmission makes wide area coverage possible especially where line of sight (LoS) is not feasible owing to obstructions, obstacles such as walls, furniture, human bodies etc.
- Simultaneous multi-channel transmission affords opportunity to reuse frequency.
- Based on multi-gigabit tri-band 802.11ad wireless standard (WiGig) and enabled by 60-GHz multi-gigabit tri-band Wilocity chipsets to provide speeds of up to 4.6 Gb/s.
IEEE 802.11 is a set of physical layer standards for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5 and 60 GHz frequency bands. 60 GHz is globally unlicensed spectrum.

802.11ad salient features

The table below gives a summary of the salient features of 802.11ad.

<table>
<thead>
<tr>
<th>802.11AD CHARACTERISTIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating frequency range</td>
<td>60 GHz ISM band</td>
</tr>
<tr>
<td>Maximum data rate</td>
<td>7 Gbps</td>
</tr>
<tr>
<td>Typical distances</td>
<td>1 - 10 m</td>
</tr>
<tr>
<td>Antenna technology</td>
<td>Uses beamforming</td>
</tr>
<tr>
<td>Modulation formats</td>
<td>Various: single carrier and OFDM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel ID</th>
<th>Centre Frequency (GHz)</th>
<th>Channel Bandwidth (GHz)</th>
<th>OFDM sampling rate (MHz)</th>
<th>SC chip rate (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.32</td>
<td>2.16</td>
<td>2640</td>
<td>1760</td>
</tr>
<tr>
<td>2</td>
<td>60.48</td>
<td>2.16</td>
<td>2640</td>
<td>1760</td>
</tr>
<tr>
<td>3</td>
<td>62.64</td>
<td>2.16</td>
<td>2640</td>
<td>1760</td>
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<tr>
<td>4</td>
<td>64.80</td>
<td>2.16</td>
<td>2640</td>
<td>1760</td>
</tr>
</tbody>
</table>
Network Topological Rearrangement

D2D – Device-to-Device communications
D2I – Device-to-Infrastructure communications

(A)
A typical device-2-device (D2D) scenario where, for example, a device can act as a gateway/hub to other devices. In this case, the device D1 is connected to the RRH1, while the devices D3 and D2 can only connect to RRH1 via D1.

(B)
shows again three devices in a different topological rearrangement, where in this case we have a D2D connection in the event of a lack communication due to obstruction or distance
Network Topological Rearrangement

(C) shows the scenario where channel bonding is used to increase the bandwidth capacity between the device D1 (i.e. acting as a hub/gateway for the attached devices D2 and D3) and RRH1 by a factor x3, thereby enabling it to be able to better carry the simultaneous traffic for both D2 and D3.

(D) (G) presents a more explicit scenario where channel cross-talk can be avoided using frequency/channel diversity. This is particularly useful when devices are within the same proximity.
Ultra-high (100’s Gb/s) mm-wave capacities

- High bandwidth: 100 Gb/s over mm-wave
- High Spectral Efficiency
  - 5 b/s/Hz
- Massive MIMO:
  - V/E band slot disposition for 100 Gb/s frequency aggregation

**V-Band: 57.1-63.9 GHz**

- 5 Gb/s data on each Polarisation
  \[ \Rightarrow 10 \text{ Gb/s full duplex transmission per 1-GHz frequency BW slot} \]

**E-Band: 71-76 GHz**

- 6.8 GHz bandwidth
  - 4 x 1-GHz BW slots \[ \Rightarrow 40 \text{ Gb/s} \]
- 4.75 GHz bandwidth
  - 4 x 1-GHz BW slots
- 10GBase-T
  - Line code: 128DSQ
  - SE: 5 b/s/Hz
  - NEXT & Echo cancellation
  - Alien noise x-talk

- 6 x 1-GHz BW slots
  \[ \Rightarrow 60 \text{ Gb/s} \]
60-GHz (mm-wave) Multi-Gb/s Transmission

- Theoretical maximum data rates of 7 Gb/s
- 802.11ad backward compatible with existing Wi-Fi standards
- Beamforming to enable communications over longer distances
- Higher propagation and atmospheric loss compared to 24 GHz & 5 GHz

**Omnidirectional antenna basic characterisations**

*Left: 90° azimuth directivity, right: 330° azimuth directivity*

**Live streaming of 4K UHDTV signals over 802.11ad**

**Active antenna**

**Wireless card**
Air Fibre point-to-point transmission (24 GHZ – ISM Band)

- Real-time, 24-GHz, GbE, wireless data communication in non-line-of-sight (NLOS) and multipath-rich scenarios
- Multiple-input–multiple-output (MIMO) technologies, adaptive time/frequency multiplexing
- Even with just 100 MHz available bandwidth, 24-GHz wireless link can support high bit-rate applications
- Aggregated data rate of 1.4 Gb/s recorded in bidirectional transmission experiments

### Attenuation of various building materials @24 GHz

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Material</th>
<th>Attenuation dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Plexiglas</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Perspex</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>Plywood</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Delrin</td>
<td>2</td>
</tr>
<tr>
<td>1.5</td>
<td>Plastic sheet</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Hard board</td>
<td>3</td>
</tr>
<tr>
<td>5.5</td>
<td>Plywood</td>
<td>2</td>
</tr>
<tr>
<td>6.3</td>
<td>Tufnoll</td>
<td>2</td>
</tr>
</tbody>
</table>
mm-Wave Orbital Angular Momentum For Encryption

- Enable higher data-rate capacities
- Encryption:
  - e.g. topological phase coding (hologram)

CHARISMA Architecture Concept for Final Demo
Bus/tram Use Case Scenario

Challenges include:

- Service continuity and high QoS to moving vehicles
- Varying network conditions/performance
  - coverage, throughput, low latency
- Network resources usage optimization, Cloud, D2D
- Intelligent network services: caching and flexible routing
- Open access / multi-tenancy

IMU: Intelligent Management Unit
Use Case: PHY Technologies Deployment

Intermediate Demo configuration:
Low Latency Demo

(See CHARISMA Booth in Exhibition)
CHARISMA Summary

• Distributed-intelligence, hierarchical Converged Aggregation Levels (CALs) for:
  ▪ Low latency, Virtualised Security, Open Access (Multi-Tenancy)

• CAL0: CPE and vCPE supports multiple wireless to provide Internet access to end users. Caching is enabled in CPE to provide good QoS, especially in mobile scenario to end-users by caching popular content close to end-users.

• CAL1: eNodeB, ONT nodes and WiFi AP like 802.11ad router are deployed. A dedicated server equipped with NIC accelerated card implementing vCaches and v-Security solutions.

• CAL2: OLT Node, TrustNode router, and a local server with smart NIC and caching are deployed to accelerate routing and caching procedure and meet low latency objective.

• CAL3: EPC and central caching server with smart NIC are located, where SDN-based CHARISMA management system is deployed to manage VNFs located at different CAL levels to provide open access (multi-tenancy) services.
Some concluding remarks

- 5G networking sees a massive amount of technological change
  - Mobile-fixed convergence
  - Distributed intelligence architectures
  - NFV & SDN
  - IoT, CPS, MTC
  - Open Access / Multi-tenancy (new business models)
- Multi-Gb/s wireless transmission for 5G networking
  - >7 Gb/s over 60-GHz (802.11ad standard)
- Converged Aggregation Levels (CALs)
  - Low latency, virtualisation & SDN, network resources (energy, spectrum)
  - Hierarchical caching
  - Cloud, cloudlet, fog computing
- Security for 5G is very important
  - CHARISMA offers virtualised security solution (VSFs)
  - HW & SW solutions for secure D2D & D2I communications
    - Orbital Angular Momentum & Geometric Phase...

Thank You!
Thank you!