CHARISMA – A Hierarchical, Intelligent, SDN/NFV-Based 5G Architecture Supporting Low Latency, Intrinsic Security and Open Access

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***Abstract* — The CHARISMA project proposes a 5G network architecture able to satisfy the demanding requirements of emerging business paradigms, such as Smart Cities, eHealth, ITS/autonomous driving, and Industry 4.0. In this paper, we present the requirements stemming from a variety of 5G use cases and set the specifications for a hierarchical, distributed-intelligence, SDN/NFV-based 5G architecture, offering low latency, enhanced security and open access.**

Keywords — 5G, VNF, SDN, Virtualized Security, Open Access, Low Latency

I. INTRODUCTION

With the advent of IoT as well as the increase in the usage and numbers of the mobile devices requiring vast amounts of bandwidth, the next generation mobile communication technology, which is termed 5G or 5th generation, is expected to be available by 2020. 5G will offer data rates of up to 10 Gbps to the end mobile users, with latency of less than 1 millisecond [1]. The offered bandwidth is envisioned to increase by 1000 times per unit area while the number of connected devices will increase by 10 to 100 times. In addition, the new technology has promised a 90% reduction in energy usage. 5G is a swiftly evolving and broad concept [2], encompassing seamless fixed-mobile convergence over an intelligent open access infrastructure. Integrating such diverse technologies into a single architecture with software-defined networking (SDN) and networking functions virtualisation (NFV) presents key technology challenges, while making issues such as security, energy efficiency, and scalability ever more critical.

CHARISMA's main objective is to develop a converged, open-access 5G networking solution, via virtualised slicing of network resources to different service providers (SPs), with network intelligence distributed out towards end-users over a hierarchical architecture. Such an approach offers a means to achieve important 5G key performance indicators (KPIs) related to low latency, high and scalable bandwidths, energy efficiency and virtualised security (v-security). CHARISMA's ambitious approach for low latency and enhanced security builds upon present and future high-capacity developments that are currently being mooted for 5G deployment, such as 60 GHz/E-band, CPRI-over-Ethernet, cloud-RAN (C-RAN), distributed intelligence across the back/front/perimetric-haul, ad-hoc mobile device interconnects, content delivery networks (CDN), mobile distributed caching (MDC) and improved energy efficiency. Practical implementation of the aforementioned concepts is challenging and technological solutions need to satisfy strict requirements stemming from suitable use cases (UCs). The next section of this paper outlines the CHARISMA high-level architecture, section 3 presents the selected use cases, and section 4 describes the requirements extracted from these UCs.

II. CHARISMA Architecture Definition

A key architectural innovation of CHARISMA is the adoption of an integrated and hierarchical approach, assuming the existence of active nodes between the central office (CO) and the end-users. Each active node is called CHARISMA Aggregation Level (CAL) and it has its own scalable intelligent management unit (IMU) performing data storage/caching, processing and routing functionalities. Distributing intelligence even closer to the end-user assists in reducing network latency, and allows for more precise SDN and NFV control of the CHARISMA 5G network.

In such an approach, data is routed, where possible, to the lowest common aggregation point, to assist in achieving low-latency networking. For example, for Device-to-Device (D2D) communications, data is routed directly among the devices, whereas routing to the lowest CAL, e.g. at CAL0 (see Figure 1), means the data is routed between devices via the local (e.g. home or access) gateway. For devices within a micro-cell, routing is via the CAL1 level; within a macro-cell, it is via the CAL2 level, e.g. at the macro base station (BS) or active remote node [3]; and finally for non-local routing, this is performed at the CAL3 level, at CO or Distributed Caching (DC). The architecture integrates beside the mobile network also the fixed access network.

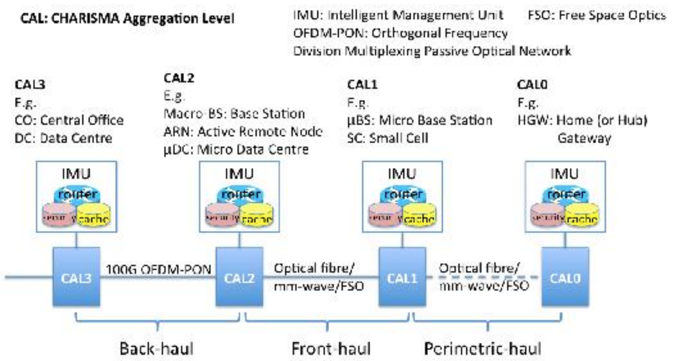

Fig. 1: Hierarchical CHARISMA Aggregation Levels (CALs)

III. CHARISMA Use Cases

The CHARISMA UCs have been selected to highlight the main drivers of the project including: support of low latency, multi-tenancy and enhanced security, while being in-line with the UC families described by NGMN [4]. The purpose of these UCs is twofold:

- To highlight how the key innovations of CHARISMA architecture will benefit the various stakeholders involved (e.g., end-users, network/ service providers).
- To define the widest range of performance and functional requirements that the CHARISMA architecture should meet.

For each of the following UCs (A-I) we present its objective, a brief description and general requirements.

A. High-speed Railway Services

The objective of this UC is to demonstrate CHARISMA's support for high capacity and high data transmission rate for innovative railway services and applications for high-speed trains. High speed trains could easily exceed 350km/h. This leads to a high Doppler shift, which causes several transceiver impairments such as channel estimation errors and Inter Carrier Interference (ICI) in Orthogonal Frequency Division Multiplexing (OFDM) systems. Also, the channel characteristics along the tracks vary greatly. It is considered as a noisy and challenging environment such as the 25kVA overhead line equipment (OLE), tunnels, trenches, cut- tings, stations, viaduct-like structures or bridges. The virtualization and security management provided by SDN/NFV control of CHARISMA 5G network will significantly improve network usage efficiency of public transport network and reduce service latency for train passengers. Coverage gaps will be covered by deploying additional mobile base stations.

B. ITS / Collision Avoidance / Platooning

The objective of this UC is to ensure that 5G networks can provide the low latency and enhanced security required for the provision of advanced ITS (Intelligent Transport Systems) innovative services / applications necessitating the exchange of information in real-time under strict delay constraints -in the order of 1ms- among the vehicles and/or central infrastructure.

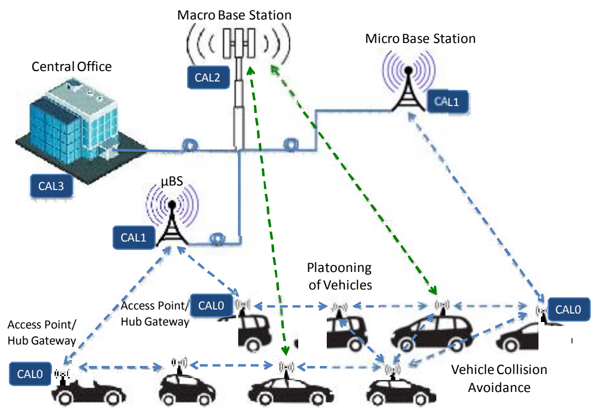

Fig. 2: Public bus transport

The existing mobile communications technologies (4G/4G+) are not capable of supporting extra low latency and security sensitive communications. The provisioning of vehicle related information (timestamp, location, speed, bearing, altitude, acceleration/deceleration etc.) can be communicated either directly (D2D) to other vehicles or via 5G (Figure 2). Example ITS services that could be offered are: (i) Real time positioning of vehicles moving in the vicinity (same direction, within a certain distance depending on the speed); (ii) Detailed information (e.g. speed, distance, acceleration/deceleration) regarding the vehicle in front (on the same lane); (iii) Visual and/or audio alerts in case of an imminent collision; (iv) Live streaming content ("See-What-I-See") from the vehicle in front (same lane, within a certain distance depending on the speed); (v) Hazardous event and obstacle recognition – see stopped vehicle ahead in dead spot, vehicle ahead moving with an extremely slow speed; (vi) Personalized "time to destination" based on driver profile/behavior (average speed, average number of line changes, etc.) and current traffic statistics. Additional applications could include the automated upload of HD video/audio streaming to the nearest PSAP (Public Safety Answering Point) in case of an accident.

C. *Communications in Public Bus Transport*

Offering service continuity and high quality of service (QoS) to commuters in moving vehicles is a challenge due to the varying network conditions/performance (coverage, throughput, latency). Since public transport vehicles (buses, metro) are generally operated along a fixed rail/route and timetable, network resources usage optimization and lower latencies can be achieved by introducing intelligent network services such as caching and flexible routing in addition to the deployment of open access solutions and D2D communication services. More specifically, service continuity and high QoS can be achieved via: (i) D2D communications to reduce network resources in case of traffic jams, (ii) Intelligent cache functionalities to address content high demands of bandwidth and latency and (iii) Cloud-based flexible and dynamic deployment of media services to ensure service continuity, especially in cases of vehicular high mobility.

D. *Big Event*

The objective of this UC is to ensure that 5G networks can support big events, located in confined spaces such as concert halls, stadiums, theatres, etc. The problem is to correctly dimension the infrastructure to offer high QoE while optimizing costs. Typically, most of the time the equipment will be unused while during short periods of time requirements will be very high (during the event). Therefore, dynamic re-configurability and infrastructure sharing (multi-tenancy) are key parameters for resource utilization optimization.

E. *First Responders' Communications*

This UC demonstrates that 5G networks can support emergency cases. In such event, the overall goal is that first responders (such as fire fighters, rescue and first-aid teams) should have the best possible communication available. CHARISMA particularly considers large, unpredictable events, as they pose the highest challenges to the communication infrastructure. Using intelligent remote radio heads (iRRH) CHARISMA can handle D2D and D2RAN2D communications. The flexible iRRHs (interconnected through wire or wireless-technologies) are the basis for network recovery after an emergency scenario. In emergency cases, the iRRHs can be used to establish and supervise a D2D mesh network. Additional relay devices can be easily deployed using autonomous flying or portable devices. However, the main challenges are the ad-hoc nature of the communications infrastructure and the need for secure communications to mitigate malicious or unintentional impairment of the responders' work. Responder-to-responder communications and relaying for wider area coverage, offloading, and resilience must also be considered.

F. *Factory of the Future (IoT)*

The objective of this UC is to evaluate and ensure that 5G networks can support the industrial Internet (Industry 4.0) by providing secure and low latency connectivity. The Industry 4.0 scenario involves customers, who design their intended products on their home computer devices using graphic tools, like configuring a brand new car. The product is then purchased via the Internet, the customized product plans are transferred to the factory of the future, which is entirely defined by software, where the purchased product is then produced automatically according to the customer demands. The 5G network should support off-loading of a control loop calculation as well as industrial production, while still keeping the security and latency requirements. For 5G, this scenario has the implication that the whole production scenario will change and become more flexible and reconfigurable. Communications links inside the future factory will be wireless, but they need to have the same robustness, availability, security and low latency as wired links have.

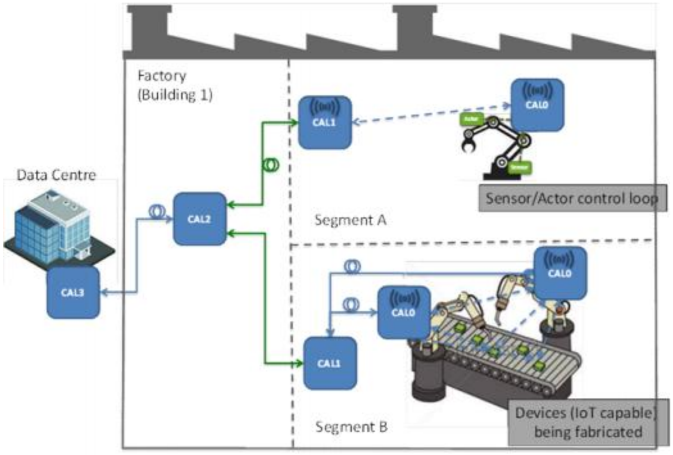

Fig. 3: Factory of the future use case

The principle idea of implementation is to install several wireless access points covering the area like in a small-cell mobile network deployment as shown in Figure 3. These small cells are centrally controlled inside the factory (and not outside at the EPC like in current mobile networks) so that coordinated handover and interference management can be done with high efficiency and at very low latency.

G. *Multi-tenant Access and Video Broadcasting Services*

The objective of this UC is to ensure that CHARISMA can support multi-tenancy, where edge resources are leased to multiple Virtual Network Operators (VNOs) over a single 5G network infrastructure operator. As different end-users may be affiliated with different VNOs, the envisioned setup may result in inter-domain traffic scenarios. In the context of multi-tenancy, it follows that peering between different VNO domains may be realized at the edge i.e., traffic crossing domain borders within the same micro-datacenter (μDC). The envisioned functionality can be demonstrated in the context of a video broadcasting application. Apart from baseline connectivity, in this UC, (virtual) edge network caches are introduced as additional content delivery functions, for reducing latency experience of end-users and offloading the core network traffic.

H. Remote Surgery

This UC demonstrates CHARISMA's ability to ensure support for the vertical industry of health in the area of remote surgeries by guaranteeing low latency communication with high throughput, availability, reliability and security. Remote surgery is foreseen to play a significant role in the future e-health systems. The adoption of remote surgery systems will allow high trained experts that are available in a few hospitals to perform operating procedures without the need to be physically present at the operation location.

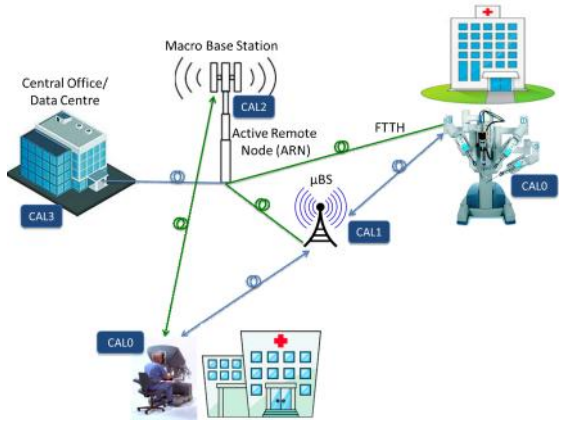

Fig. 4: Remote surgery use case

The surgeons of the future will be able to perform complex operations from their offices using the 5G networks and will be able to collaborate with other doctors. Surgeons will have a live feed through the network, communication with other members of the team, access to patient data and control of the robotic mechanism.

I. Smart Grid

This UC confirms CHARISMA's ability to provide a programmable and flexible network architecture providing low latency, security, QoS and high reliability for Smart Grid applications and services in electricity distribution networks. Smart Grid includes diverse UCs ranging from system protection that requires ultra reliable and low latency communication to smart meters that require support of massive number of network connected devices with relaxed latency and reliability requirements. LTE is not flexible enough to simultaneously meet requirements of such diverse UCs both technically and economically. Thus, programmable and flexible network architecture is required which can satisfy the reliability, security and performance (including QoS) requirements of each smart grid application over a single platform. As a consequence, the increasing demand for low round trip latency and ultra-high reliability appears as a decisive factor for 5G implementation with respect to mission-critical communication within the smart grid. A security and confidentiality solution, which prevents cyber-attacks while meeting the latency requirements, shall be inherent to future power grid communication network.

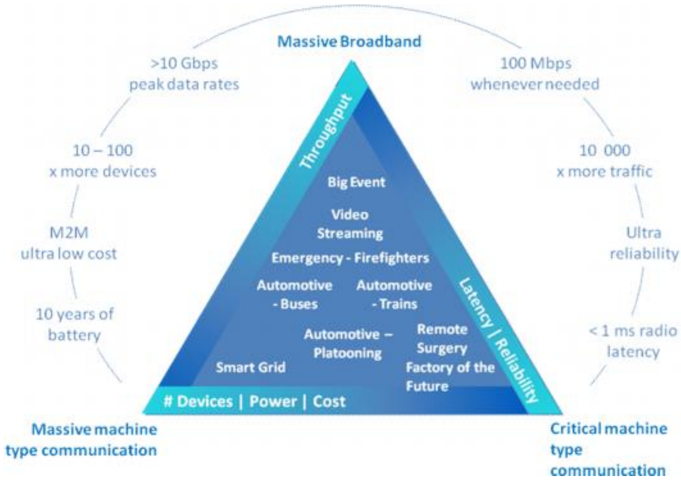

Fig. 5: CHARISMA use cases within the 5G ecosystem

It is important to point out that the above UCs represent quite satisfactorily the large set of use cases identified for 5G (ITU, 3GPP, NGMN, etc.). To cope with the variety of UCs, a number of general categories that share common UCs technical characteristics have been identified (see [5] and Figure 5), including the following:

- Massive machine type communications incorporating a large number of devices per km^2
- High throughput massive broadband communications
- Ultra-reliable and low latency critical machine type communications

IV. CHARISMA REQUIREMENTS

The identification of the main CHARISMA architectural/ functional requirements was based on the characteristics of the representative UCs described above. The requirement analysis process assumed that similar requirements belonging to different use cases are merged and, in cases where different KPIs are considered for the same requirement, the most stringent KPI is taken into account. The high-level consolidated requirements for CHARISMA are listed below:

- Low latency: CHARISMA architecture shall support low latency services (≤ 1ms) via: i) Routing of data at the lowest common aggregation point, ii) devolved offload strategies for D2D, device-to-remote-radio, device-to-baseband, device-to-central office/metro, etc. and iii) mobile distributed caching.
- Advanced e2e security: CHARISMA architecture shall support distributed security as well as physical layer security. The CHARISMA virtualized open access

architecture design needs to have a holistic security approach for the control and management plane as the underlying infrastructure is virtualized and shared among different service providers (SPs) who operate simultaneously on the same physical resources.

- Open access: CHARISMA's architecture shall support ubiquitous, multi-provider, multi-user, multi-technology and multi-service scenarios. The open access enabled infrastructure should have a unified virtualized network management system capable of allocating slices and offering accessible service interfaces for novel and differentiated services to end-users, as the basis for supporting innovative business models. The infrastructure owner has to be able to offer its virtual resources in a way that multiple operators can coexist and function independently from each other. To this end, virtual resources should be easily bundled together into slices of the physical infrastructure so that each slice constitutes an independent virtual edge network and cloud for a VNO.

- High data-rates: CHARISMA's architecture shall support data-rates up to 10 Gbps for SMEs and residential users and up to 1 Gbps for mobile end-users, through the use of a hierarchical intelligent data processing approach at the C-RAN and RRH levels, where statistical multiplexing, aggregation, and caching allow data throughput to be significantly increased.

- Seamless and ubiquitous connectivity: CHARISMA shall be able to offer seamless and ubiquitous 5G services in both densely and under-populated areas by incorporating a highly diversified (heterogeneous) networking architecture (incl. 60 GHz and optical LoS communications) supporting even higher bandwidths.

- Resources' Virtualization: The CHARISMA's architecture shall make extensive use of resource virtualization techniques to abstract computing and network resources, allowing the support of various network and content delivery functions. These functions will be realized with software implementations on top of shared commercial off-the-shelf (COTS) hardware. Computing and network resources will be dynamically leased and managed at fine-grained temporal and volume granularity. Virtualization will also be applied on the RAN with the utilization of C-RAN. CHARISMA will put effort on implementing VNFs for caching, switching, and security.

- Prioritization for emergency communications: The CHARISMA's architecture shall support several QoS classes for emergency communications, assigning different priority levels to end-users.

- Advanced D2D communications: In CHARISMA's architecture each iRRH shall be able to establish and manage a D2D mesh network, to enable low latency D2D communications. In addition, each iRRH shall be able to connect to other iRRHs in case of emergency and establish a CAL1 mesh network between several iRRHs.

- Intelligent routing: When appropriate, traffic should be routed as close to the edge as possible to minimize hops (and thus latency) and traffic impairments.

- Broadcast functionality: CHARISMA shall support broadcast mechanisms in order to be able to warn all users in a certain geographical area in case of a critical event.

- Low packet loss rate: CHARISMA shall provide packet loss rate in the order of 10^{-5} or less.

- High availability: All network elements employed in CHARISMA's architecture shall have an availability of 99.999%.

- High reliability: All network elements employed in CHARISMA's architecture shall have a reliability of 99.999%.

V. CONCLUSIONS

In this paper we have presented an intelligent, integrated, hierarchical, low-latency, intrinsic security, open access, SDN/NFV-based 5G architecture, capable of satisfying the demanding requirements of emerging business paradigms of the future. More specifically, we outlined the high-lever architectural/ functional requirements stemming from a variety of representative UC scenarios.

ACKNOWLEDGMENT

The CHARISMA (Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 671704.

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