CNF based Appliance for User Plane

The revolution at network edge

Executive summary

The evolution of network technologies has paved the way for innovative solutions that enhance efficiency and flexibility. The introduction of 2G/3G/4G/5G and WiFi packet core's virtualized "Appliances" was a first step towards capacity and performance increase, while optimizing the solution footprint. Evolving Appliance's software to cloud-native is a further testament to this progress, offering a transformative approach to User Plane Function (UPF) deployment at the edge. This document explores the context, the current challenges, and then the required capabilities, benefits, and strategic advancements of the packet core's CNF-based appliance solution.

5G is redefining telecommunications with more capacity, higher speed, lower latency, and greater reliability. To meet these demands, networks must evolve toward cloud-native architectures built for agility, scale, and automation.

Introduction to cloud-native for 5G

At the core of this shift are containers and cloud-native Functions (CNFs). Containers package applications with their dependencies into lightweight, portable units that run consistently across environments. They enable fast deployment, efficient scaling, and strong isolation. CNFs apply the same principles to network functions, making them more flexible, programmable, and easier to automate in modern 5G networks.

Kubernetes (k8s) is the leading platform for container orchestration. It automates deployment, scaling, and lifecycle management of containers across clustered infrastructure. With its control plane, worker nodes, and ecosystem of add-ons, Kubernetes provides the operational foundation for running cloud-native applications and services at scale.

Compared with virtual machines, containers are more resource-efficient and faster to deploy. They support microservices-based design, where network functions are split into smaller, manageable components. This improves modularity, accelerates CI/CD, and shortens time to market. Moving from VNFs to CNFs also strengthens service availability through features such as in-service upgrades and tighter integration with Telco automation frameworks.

For 5G networks, adopting containers and CNFs is no longer optional. It is key to achieving scalability, operational efficiency, and faster innovation. By embracing cloud-native principles, telecom operators can build more resilient networks and deliver services faster in an increasingly dynamic digital landscape.

User Plane transformation: key challenges and trade-offs

Nonetheless, this transition does not come without challenges. The telecom industry must address specific issues related to latency, reliability, and security, ensuring that containerized solutions meet stringent telco-grade requirements.

Special attention must be considered on the User Plane domain: in addition to the above-mentioned requirements, the specific requirements for an efficient User Plane - that is, maximizing the throughput and minimizing latency on a minimum set of hardware resources - appear to be somehow orthogonal to cloud-native concepts and principles.

For instance, high throughput UPF mandates the use of high-end hardware servers, offering dense CPU architecture and a number of high-speed network interfaces cards (NICs). By itself, this already introduces a fragmentation of the Telco cloud architecture as it requires dedicated clusters for the User Plane applications. In addition, low-level specific techniques must be considered to maximize throughput efficiency and minimize latency, such as SR-IOV or CPU pinning, that are not natively supported in a Kubernetes based architecture. This contributes to augmenting the adherence between the User Plane applications and the underlying hardware that must support them. Both considerations, higher throughput demand and dedicated clusters, result in an increased footprint for the overall 5G core solution that integrates the User Plane function (UPF) within the Telco cloud stack solution; this holds true for any CaaS/Kubernetes solution utilized.

Another challenge arises with the need to ever further distribute the User Plane function towards the edge, driven by the introduction of 5G SA services requiring lower latency, local breakout, or increased security (such as enterprise on-premises). Indeed, distributing the UPF at the edge is the enabler for a new set of added-value services that could not be achieved with the same degree of efficiency and flexibility over 4G or 5G NSA.

UPF distribution at the edge also contributes to offloading the overall network wherever possible. For instance, techniques like Local Break-Out alleviate the transport of heavy traffic to centralized core, reducing congestion risks and resource usage. Both capabilities significantly contribute in reducing network operating costs.

Therefore, the dilemma for Telcos is how to provide an efficient and cost-effective solution to address the edge User Plane requirements, while at the same time keeping the consistency and all benefits of flexibility, automation and high availability inherent to cloud-native deployments?

The current solution for User Plane

Working out the business case for such edge UPF quickly reaches the conclusion that any type of legacy Telco cloud stack would not be suitable due to higher footprint and increased electrical power (mainly due to the overhead of the cloud's operating system), complexity to operate (especially if located in customer premises in the context of a corporate service) and overall cost of solution.

In this context, the concept of "appliance" - that is, a virtualized telco application running over a self-contained lightweight operating system in one or more COTS servers - can turn out to be a compelling alternative due to its compactness, easy installation, management and maintenance, as well as some potential optimizations as running as single tenant application on dedicated CPU/server.

Moreover, the combination of leading-edge CPU architecture with optimized software design is indeed the cornerstone of an ever-increasing level of performance as CPU technology evolves with higher core densities, higher clock frequencies, faster memory access, etc.

But such benefits do not end with data throughput – the appliance solution also achieves drastic savings on power consumption (plus space, rack cooling requirements, etc). For sake of comparison, the UPF appliance solution requires up to 60% less power than a UPF NF that would be deployed over a "traditional" Telco cloud stack, for the same level of capacity and performance.

However, despite the undebatable advantage of the appliance concept regarding hardware optimization, minimized overhead of operating system and reduced power consumption, the cloud-native paradigm still offers superior benefits when it comes to agile life cycle management, high availability (based on in-service software upgrade (ISSU)), and seamless integration into Telco's automation and/or CI/CD chain. It is also the case for the "observability" domain in which the cloud native solution can leverage numerous open-source and widely adopted tools, such as Prometheus for monitoring, Grafana for visualization, Fluentd for logging, and the ELK stack (Elasticsearch and Kibana) for log management and analysis.

Nokia Packet Core Appliances
From Central Cloud to Network edge

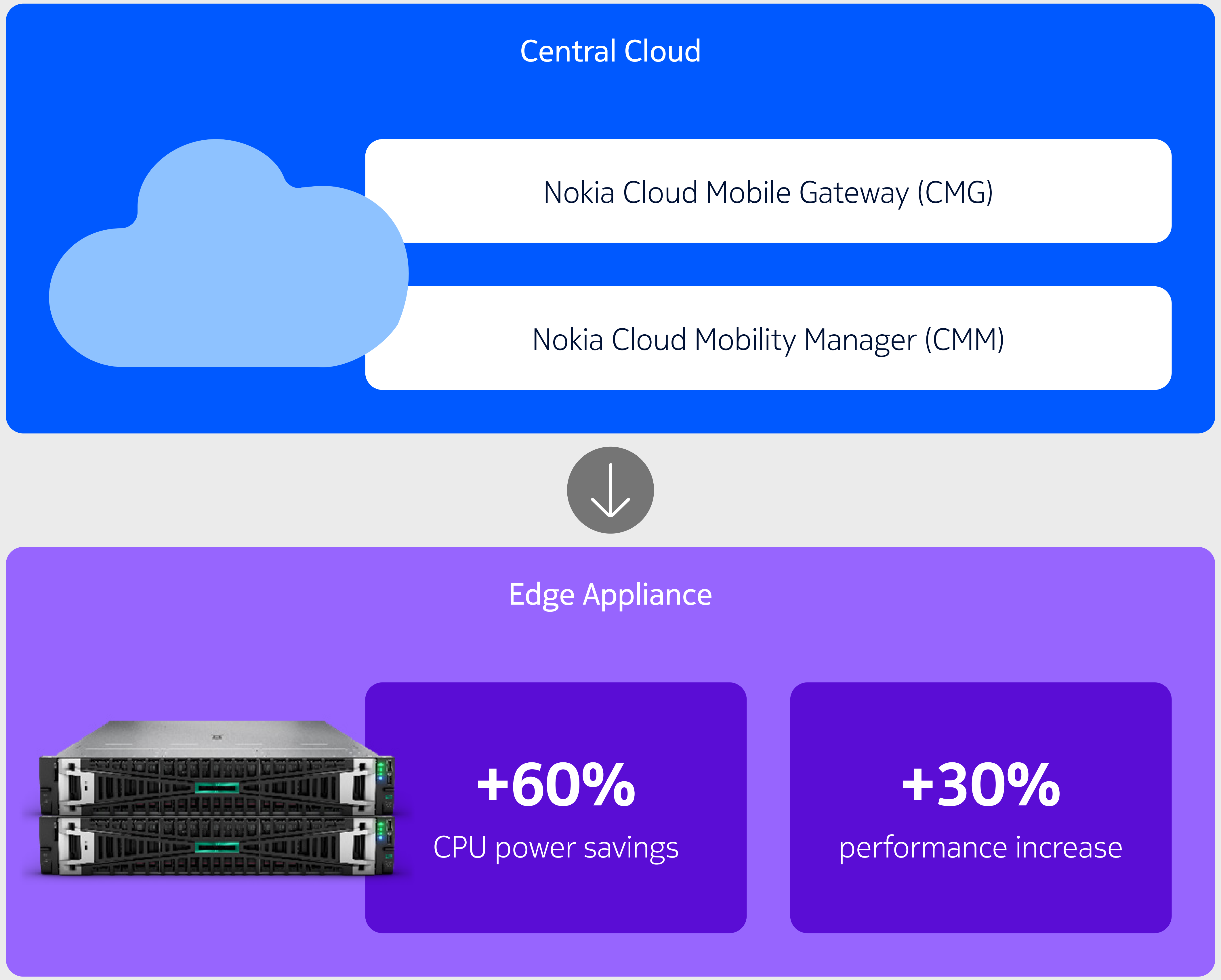

Figure 01: Edge appliance key benefits

Evolving edge appliances to containers: making the best of breed

A strategic evolution of a VNF-based appliance would then be to transform it into a CNF-based system. The solution would keep all benefits from current appliances (including capacity and performance) while inheriting the agility, flexibility and observability capabilities of cloud native software technology.

To achieve this, such new solution shall offer comprehensive Kubernetes integration, leveraging Helm and Kubernetes Operator framework for automated deployment and Life Cycle Management (LCM) operations. In other words, LCM, network/service management and automation of such new UPF deployments shall seamlessly integrate into an existing Telco cloud's cluster management solution, which is already managing all other control plane, signaling and subscriber data management network functions (NFs) provided by the 5G Core.

That transition would also enhance high availability through ISSU and native integration into Telcos' automation chains.

The architecture shall implement rolling updates with Canary deployment strategy. Networking functionality would be handled through K8s core components including Ingress Gateways, Services, and Load Balancers.

The platform shall obviously combine 5G's SMF with 4G's SGW-C and PGW-C components, alongside merged 4G PGW-u and 5G UPF functionalities, thereby enabling seamless EPC interworking with 5GC (including 2G and 3G through NIESGU capabilities, as well as Wifi access through ePDG/N3IWF). For operational excellence, the system shall integrate with the essential observability management tools above mentioned.

Finally, the evolution of current VNF-based appliances to the new CNF-based appliances shall be achieved through simple software upgrades, without any required investment in new hardware or in hardware forklift.

Nokia Packet Core

CNF Appliances

CKD - Compact K8s Distribution

A single node container orchestration runtime designed to extend the benetite or usine containers for running applications to low-envronments because single node distros are primarily a platform for deploying applications, only the APis and features Cosens to operatine in edge and small form factor computing environments are included.

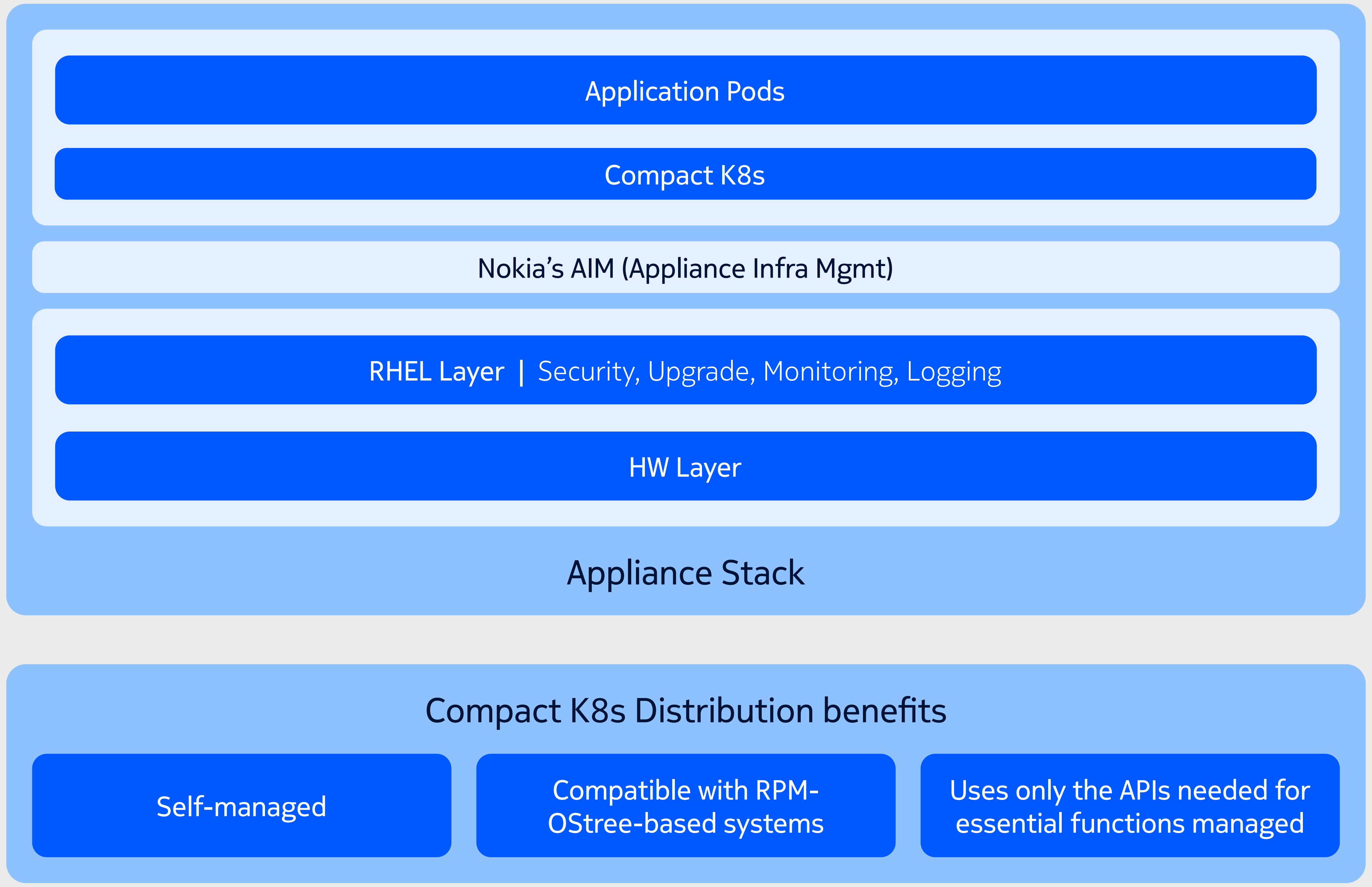

Figure 02: CNF based appliance stack

Monetization and benefits

CNF-based appliances will broaden the field of deployment options for Telcos, including on-premises or hosted hardware, private cloud stacks, or hyperscaler environments.

As a primary objective, they will enable Telco's to further distribute UPF at the edge, unlocking new services that surpass the capabilities of 4G networks. Moreover, Local Breakout capabilities will reduce heavy and costly traffic transport to centralized cores, mitigating congestion risks and optimizing resource usage.

Key applications of such UPF distribution of CNF based UPFs include:

- Hybrid Mobile Private Networks (MPN): to facilitate private networks with slicing, SLA, and seamless connectivity to public services.
- Time sensitive edges: To serve as the foundation for URLLC, AR/VR, Industry 4.0/5.0, and other time-sensitive applications (e.g Time Sensitive Networking - TSN).
- Fixed Wireless Access (FWA): To provide residential, wholesale, and L2 VPN services at ultra-high speeds with mmWave rollout and Ethernet PDU/LAN capabilities.

The overall solution shall be offered as self-managed or available as a managed service (SaaS), providing the following key benefits:

- Performance and Efficiency: CNF based appliance solution, powered by advanced CPU architecture, shall deliver unmatched performance, in the order of several hundreds of Gigabits per second off a single server,
- Power Savings: The appliance solution shall enable tremendous power saving (up to 60% less power than traditional Telco cloud stacks shall be the objective), in addition to significant savings in space and cooling requirements.
- Security and Cost Efficiency: The appliance approach shall optimize hardware and resource usage, reducing infrastructure costs and enhancing security by minimizing exposure to external attacks. Over time, UPF on appliances shall provide lower TCO overall due to fast evolving CPU technology.

High-performance Edge UPF Benefits

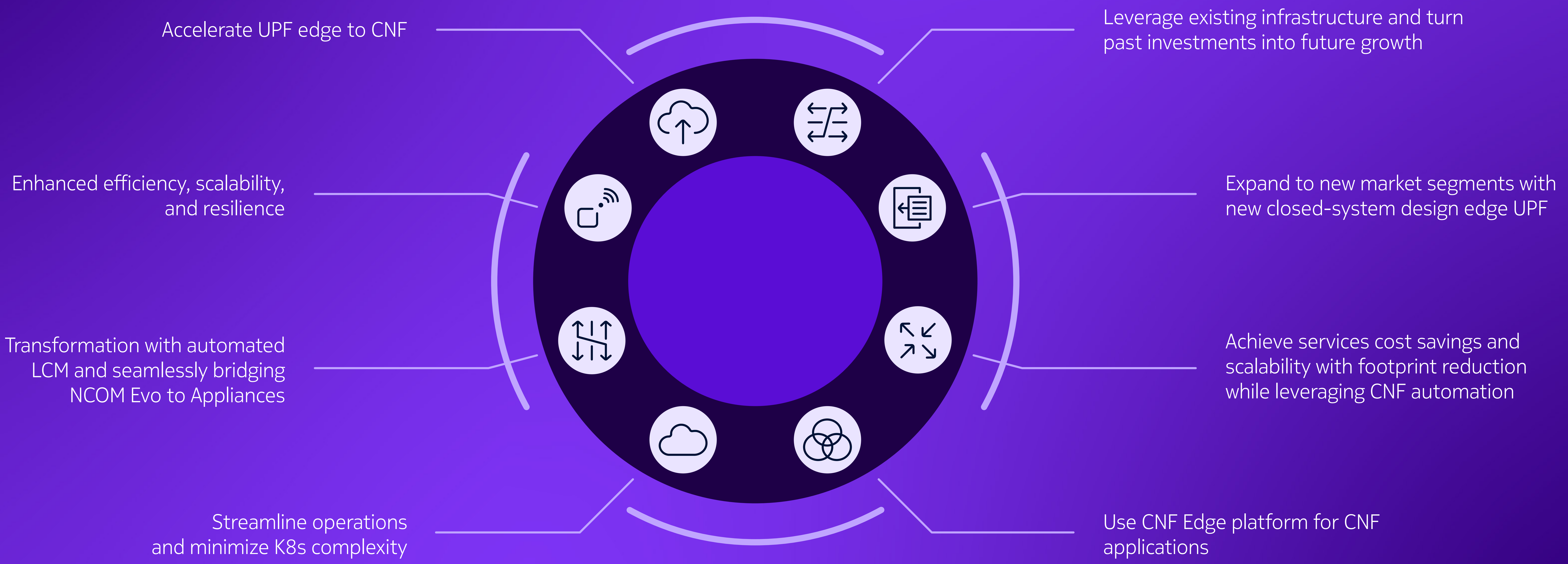

Figure 03: CNF based appliance key benefits

Conclusion

Strategic evolution of the User Plane in unified 5G networks leads to new solutions that shall combine the benefits of appliances and cloud-native approaches. Such transformation will maintain current appliance advantages while integrating the agility, flexibility, and observability of cloud-native software technology. The transition from VNF-based to CNF-based appliances will be seamless, requiring only software upgrades without new hardware investments.

Those requirements call for key technical innovations to take next generation Edge UPFs at the forefront of performance, efficiency and flexibility, setting new industry standards.

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Prometheus: Prometheus - Monitoring system & time series database

Kibana: Kibana: Explore, Visualize, Discover Data | Elastic

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