Cloud computing is a broad term that covers everything from Google* applications to rack-based servers. In the enterprise space, it is driving improved data center efficiency, the result of sharing resources, like computing, networking and storage. At the heart of this approach is infrastructure convergence, which enables IT to more rapidly reallocate equipment to meet fluctuating and unpredictable business demand. At the same time, equipment utilization goes up, energy efficiency increases and support effort decreases.

What does this then mean from a telecommunications point of view? Telecommunications has unique technical challenges when it comes to cloud implementation, including strict real-time requirements, packet latency and high availability. A proof of concept developed by Intel is investigating key challenges and solutions to satisfy these requirements with the use of next generation Intel® Xeon® processors. The proof of concept shows a “communications cloud” designed to more efficiently use network resources, and speed up functional and service deployments compared to today’s cloud platforms.

The foundation for this communications cloud is a single computing architecture capable of supporting all the software workloads in a core network. Put another way, it shows how to have an entire Evolved Packet Core (MME, S-Gw, P-Gw, SGSN, HSS) of an LTE network run on a single Intel® architecture processor platform (Figure 1). In addition, because the platform’s resources are defined in software, they can be retargeted and redeployed quickly to respond to changing demand. This paper describes the implementation and capabilities of the Evolved Packet Core (EPC) communications cloud proof-of-concept and presents benchmark data for packet throughput.
Communications Cloud Challenges

A communications cloud infrastructure enables network equipment to quickly respond to changing demand through improved load balancing, quick application migration and proactive power management. It satisfies the infrastructure needs of telecom service providers with a standardized “elastic network” that meets service quality requirements. As the resources dynamically adapt to changing traffic conditions, it’s critical the network continues to meet service quality measures, including latency, packet loss and jitter, in order to deliver a high level of QoS to subscribers.

For service providers with corporate clients, it may be necessary to offer Service Level Agreements (SLAs). Meeting SLAs may require prioritization schemes (e.g., traffic shaping) used to establish traffic classification categories, for instance, to differentiate between Tier 1 and Tier 2 customers.

With these and other challenges in mind, Intel has developed a flexible communications cloud proof of concept that shows how service providers and network equipment providers can speed up the development and deployment of innovative services through mechanisms that dynamically reallocate computing and I/O resources.

Intel's Workload Consolidation Strategy

Today's wireless and wireline infrastructure can be quite complex, partly due to the diversity of computing platforms used to build network elements. For instance, a rack typically contains various bladed network elements that use different processor architectures, as illustrated in Figure 2. Maintaining these network elements requires expertise across different hardware platforms, operating systems and unique vendor technologies. However, this need not be the case.

Intel Architecture for Data Plane Processing

Intel architecture-based platforms, combined with high-performance packet processing software, provide the capability to consolidate application processing, control processing, data plane processing and signal processing workloads onto a single platform. Moreover, Intel is committed to delivering ever-increasing performance and power-efficiency through an industry-leading beat-rate of manufacturing process improvements and microarchitecture advancements through a predictable “Tick-Tock” model. And optimized data plane software solutions, like the Intel Data Plane Development Kit (Intel DPDK), help to unleash the full potential of Intel architecture-based platforms.

The Intel DPDK is a set of optimized software libraries and drivers, as depicted in Figure 3, that enable high-performance data plane packet processing on network elements based on Intel architecture.
The Intel DPDK consists of the following components:

- **Memory/Buffer Manager:** Responsible for allocating pools of objects in memory. A pool is created in huge page memory space and uses a ring to store free objects. It also provides an alignment helper to ensure that objects are padded to spread them equally on all DRAM channels.
- **Queue Manager:** Implements safe lockless queues, instead of using spinlocks, which allow different software components to process packets while avoiding unnecessary wait times.

**Component Descriptions:**

- **Flow Classification:** Provides an efficient mechanism, which incorporates Intel® Streaming SIMD Extensions (Intel® SSE) to produce a hash based on tuple information so packets may be placed into flows quickly for processing, thus greatly improving throughput.
- **Poll Mode Drivers:** The Intel DPDK includes poll mode drivers for 1 GbE and 10 GbE Ethernet controllers that are designed to work without asynchronous, interrupt-based signaling mechanisms, which greatly speeds up the packet pipeline.
- **Environment Abstraction Layer:** Provides an abstraction to platform-specific initialization code, which eases application porting effort. The abstraction layer also contains the runtime libraries for launching and managing Intel DPDK software threads.

For more information on the Intel DPDK, please visit www.intel.com/go/dpdk.

### Capabilities Facilitated By Software-Defined Network Elements

There are several key tenants of enterprise cloud computing that set the stage for capabilities that open the door to opportunities in telecommunications.

- **Abstract resources** enabling computing and networking resources to be reconfigurable.
- **On-demand provisioning** allowing the composition of the core network to be changed.
- **Multicore scalability** simplifying capacity expansion or reduction.
- **Power management** utilizing network resources more efficiently.

With respect to the communications cloud, these tenets are attainable with software-defined network elements that run the full complement of telco-centric workloads, as is possible with Intel architecture-based platforms. Moreover, this approach, combined with standardized architecture, enables the rapid deployment of new services and simplifies the operation and maintenance (O&M) of the infrastructure.

### Granular Load Balancing

Distributing the workload across multiple network elements, referred to as load balancing, is an essential function to maximize resource utilization and minimize bottlenecks. With hardware-focused networks, load balancing is typically performed across similar or identical network elements. However, load balancing of software-defined network elements is more granular because they are less physically constrained. The software can run on a single processor core, multiple cores, an entire processor, a blade, a rack or even multiple racks, as depicted in Figure 4.

**Benefit:** Granular load balancing gives greater control over platform resource utilization, which helps to make the communications cloud realize more operational efficiencies.

### Granular Power Control

When granular load balancing is implemented, it is possible to significantly reduce power consumption during periods of low demand. This is accomplished by routing the workload to a subset of the available resources and powering down the rest. For example, a given traffic profile may require resources with eight processor cores during peak time, whereas only two cores may be needed during off-peak; thus six cores can be powered down. When

**Figure 3. Intel® Data Plane Development Kit**

**Figure 4. Load Balancer Functions Across Different Architectural Levels**

**Figure 5. Power Control Can Be Managed at the Processor Core Level**

...
Traffic Consolidation

The application workload within the system can be re-assigned or balanced among a smaller number of physical entities (e.g., processor core, blades or racks) in the system to improve power efficiency.

**Benefit:** During periods of low demand, it’s possible to conserve energy by moving live sessions so they run on fewer blades, which makes it possible to power down the unused blades.

Multi-Standard

Conceptually, a communications cloud will concurrently support multiple types of core networks (2G, 3G, 4G, fixed), as depicted in Figure 6.

**Communications Cloud Supports Multi-Standards**

<table>
<thead>
<tr>
<th>4G Network</th>
<th>3G Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSS</td>
<td>HLR/VLR</td>
</tr>
<tr>
<td>PCRF</td>
<td>MSC</td>
</tr>
<tr>
<td>P-GW</td>
<td>GGSN</td>
</tr>
<tr>
<td>S-GW</td>
<td>SGSN</td>
</tr>
<tr>
<td>MME</td>
<td>RNC</td>
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</tbody>
</table>

**Benefit:** Network operators can reduce capital expenditure and equipment support cost by deploying a single platform that implements all the network standards they support in a given location.

Multi-Tenancy

Similar to the multi-standard usage model, the communications cloud can support multiple instances of the same core network, enabling a common infrastructure to concurrently host several service providers (i.e., tenants), as illustrated in Figure 7. The ability to share core network infrastructure can significantly reduce time-to-market for service providers using the cloud and provide the framework for infrastructure sharing and virtual operator provisioning (SLA enforcement).

**Communications Cloud Supports Multiple Tenants**

![Figure 7. A Communications Cloud Supporting Multiple Tenants](image)

**Benefit:** Sharing hardware infrastructure across multiple operators reduces capital and operating expenses (CapEx/OpEx).

Network Reconfiguration

At any time, a computing resource in the communications cloud can be reconfigured to run any software associated with another software-defined network element. This enables the cloud to accommodate fluctuating service patterns, as in high demand for VoIP services during the day and for transcoding services in the evening when people like to download videos.

**Benefit:** Network operators can better adjust to changing demand by changing the mix of network elements and/or services, as in an explosive increase in traffic in a very small physical area. Another example is an unforeseen catastrophic event (e.g., earthquake) that damages existing network infrastructure, where network reconfiguration enables network operators to quickly replicate the core network in another location and restore services.

Communications Cloud Program

Intel is developing a multiphase communications cloud proof-of-concept and industry initiative to benchmark performance and demonstrate the power management and load balancing capabilities of the Intel platform for communications infrastructure.

The program has the following objectives:

1. Understand and communicate the business drivers and technical challenges for evolving traditional, custom-built telecoms networks to a cloud-based network architecture on general-purpose Intel architecture-based platforms

**Communications Cloud Program**

**Multiphase Communications Cloud Program**

**Phase 1: EPC Network Implementation**

**EPC Network**

- Control and user plane performance is measured
- The hardware is decoupled from the network function
- The proof-of-concept scales from a single core to multiple blades

**Power management (processor-based)**

- The traffic load is balanced across multiple cores
- Unused cores transitioned to lower power state

**Live load balancing (across processor cores)**

- The traffic is offloaded onto a second S-Gw instance
- A S-Gw is removed when traffic falls below a threshold

**Phase 2: S-Gw Implementation**

**Power management (blade-based)**

- The traffic load is balanced across two blades
- A blade is powered down when traffic abates

**Live load balancing (across blades)**

- Calls are migrated live without interruption
- When the traffic load lessens, all calls are moved to one blade
- Quality of service (QoS) mechanisms are implemented

**Intel® platform for communications infrastructure**

- The platform cost-effectively supports line rates ranging from a few Gbps, all the way up to 80 Gbps

Table 1. Multiphase Communications Cloud Proof-of-Concept
Two phases of the program have been completed, as detailed in Table 1. A platform description is provided in Appendix A, and performance details are discussed in the following.

**Phase 1: EPC Network Implementation**

**Control and User Plane Performance**

During phase 1 of the proof-of-concept project, Intel measured the performance of a single blade that was simultaneously executing S-GW and MME workloads – two key network elements of an Evolved Packet Core (EPC). The primary workloads for an S-GW and an MME are user plane (i.e., packet processing) and control plane (i.e., signaling), respectively. The proof-of-concept runs representative implementations of S-GW and MME protocols, including SCTP and GTP-U. The application code executes in Linux* User Space using a carrier grade Linux User Space IP stack. The testing simulated multiple subscribers opening a data connection during a phone call to create 80% utilization of a single processor core; the other five cores were unused during the testing. When simulating an MME network element, the core handled over 1.4 gigabits per second (Gbps) of traffic throughput (1,400 byte packets) while consuming 25% of its available CPU cycles.2,3,4

The remaining 75% of the core could be used for applications (MME procedures) or other purposes. When the processor core performed an S-GW function, it delivered over 15 Gbps (1,400 byte packets) throughput at 55% core utilization, leaving 45% for applications (S1AP) and auxiliary functions. This performance scales with the number of processor cores. The significant portion of the performance optimization was achieved by using elements from the Intel DPDK, including Linux User Space “Poll Mode” Ethernet drivers, zero buffer copy techniques, advanced cache utilization and dramatically reduced context switching.

**Power Management**

During phase 1 of this EPC proof-of-concept, unused processor cores are placed into a low power state in order to save energy. This approach can save approximately 4.5 watts5–6 for every core that is temporarily halted.

![Figure 8. Example of Power Savings from Implementing Power States (P-States)](https://example.com)

**Live Load Balancing Capabilities**

The proof-of-concept configuration (i.e., S-GW and MME) in the prior example was extended to include an HSS, Packet Data Network Gateway (P-GW) and a load balancer. The load balancer is the main controller of the cloud functionality, and its responsibilities include:

- Maintaining the system level state: this includes information regarding available cores, blades and elements, and the loads they execute.
- Making load balancing decisions based on the predefined triggers.
- Providing storage for runtime and configuration data.

**Phase 2: S-GW Implementation**

**Power Management**

For phase 2, the serving gateway (S-Gw) from phase 1 incorporates load balancing to manage the traffic across threads, cores and blades, along with the energy savings from powering them off when the traffic load warrants. The example in Figure 9 shows VoIP and live sessions (video download and streaming) moving from one blade (Blade B) to another (Blade A), enabling the system to put Blade B into a low power state and potentially saving significant power and operating cost.

**Live Load Balancing Capabilities**

The phase 1 EPC proof-of-concept balances the load within a blade, whereas phase 2 performs S-GW load balancing among blades via a live call migration demonstration, which could be extended to racks and systems in different locations when an Intel processor-based platform is available. Dynamic load migration also facilitates failover, whether moving the workload from a failed blade to another blade or quickly relocating a core network to a new site in the event of a natural disaster.

The proof-of-concept implements an S-GW using two blades that handles VoIP and live sessions, as illustrated in Figure 9. The primary workloads are packet processing (session management) and control plane. When the traffic falls below a threshold such that all the traffic can be processed by one blade, all of the calls from one blade are migrated live to the other blade without interruption or impact on call quality. As a result, the offloaded blade can either be powered down to save power or used to support other services.

**Quality of Service (QoS) Mechanisms**

The S-GW runs several QoS mechanisms, including classification, shaping and scheduling, implemented using a combination of software components and features supported by Intel’s network cards (NICs). The NICs prioritize...
Incoming traffic by class and send the packets to specific queues, whose order of processing (priority) is enforced by software. In this initial implementation, the QoS mechanism increases the load on the system by approximately 3% to 17% per core for packet sizes between 1,400 bytes and 64 bytes, respectively.

**Intel® Platform for Communications Infrastructure**

Ideal for hosting communications cloud solutions, the Intel® platform for communications infrastructure is specifically designed for communications workload consolidation and is a particularly cost-effective solution for equipment supporting line rates ranging from a few Gbps all the way up to 80 Gbps. The platform is very flexible – able to address workloads in branch office routers, wireless access and wireless core networks, and security appliances. In addition, the platform is highly scalable, allowing architects to design common hardware and software architecture to address multiple price/performance and feature requirements across a product line.

Service providers face a never-ending battle against cyberattacks, which points to the need for pervasive security throughout the network. Moreover, security protection needs to keep up with malicious hackers, meaning it must continually evolve. Addressing this requirement, servers with dual Intel® Xeon® processor ES-2600 series and the Intel® Communications Chipset 89xx Series have demonstrated performance throughput of 160 million packets per second (MPPS) of L3 forwarding and 80 gigabits (Gbps) per second of IPSec acceleration.

For more information about Intel solutions for communications, visit [www.intel.com/go/commsinfrastructure](http://www.intel.com/go/commsinfrastructure)