# Innovative Usages for Intel® Software Guard Extensions

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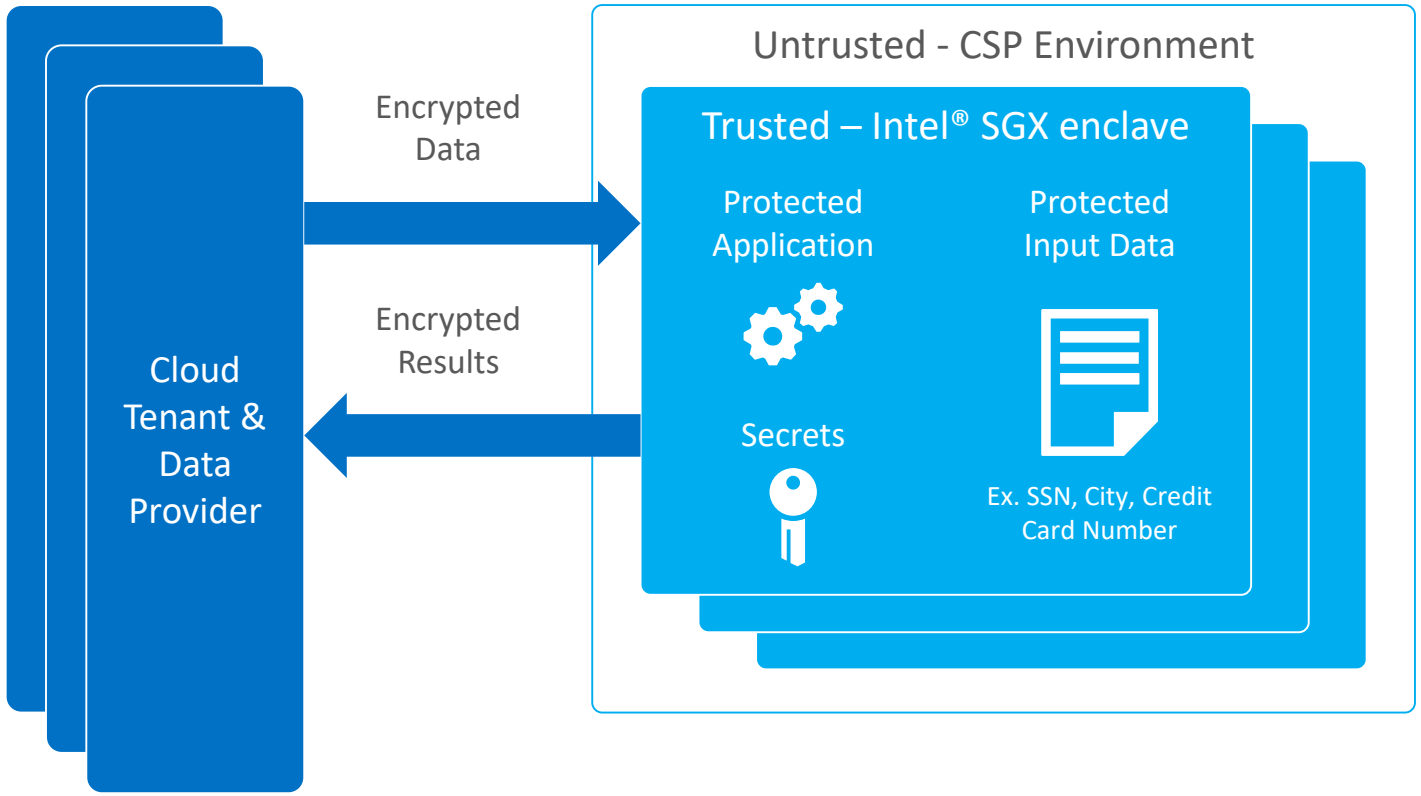
# INTEL® SOFTWARE GUARD EXTENSIONS

## APPLICATION ISOLATION AT THE MOST GRANULAR LEVEL, ENABLING FINE-GRAINED DATA PROTECTION WITHIN A HYPER-FOCUSED TRUST BOUNDARY



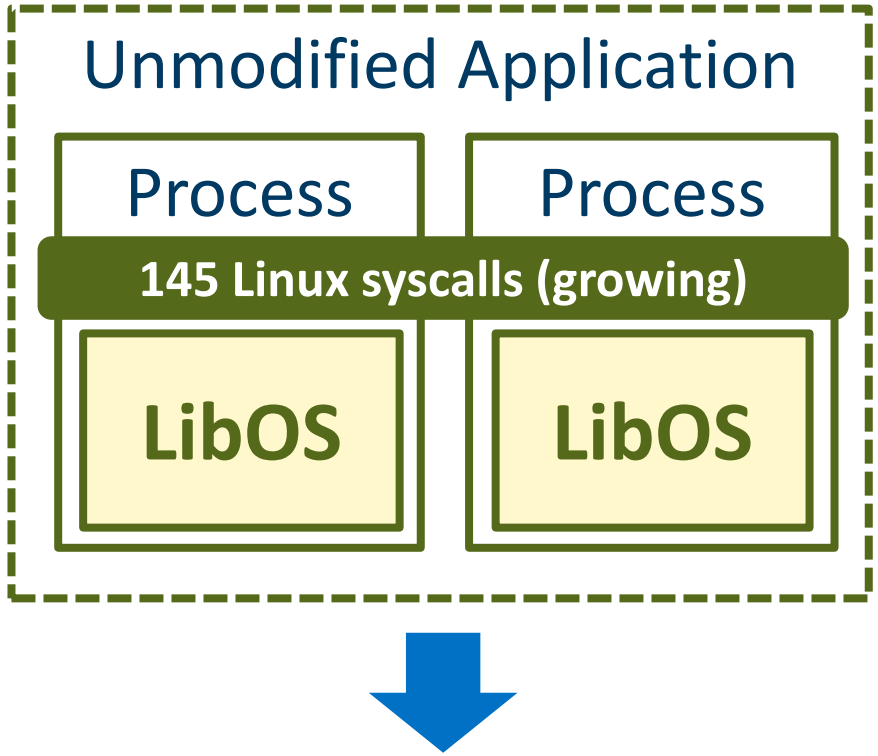

- Increases protection against SW attacks even if OS/drivers/BIOS/VMM/SMM are compromised
  - Smallest possible TCB
- Increased protection applies even when attacker has full control of platform
  - Other technologies allow some privileged sw in their boundary
- Increases protection against memory bus snooping, memory tampering, and “cold boot” attacks against memory images in RAM
  - Protection in unprotected spaces
- Provides hardware-based attestation capabilities to measure and verify valid code and data signatures
  - Increasing Transparency and accountability
- In-band execution utilizing the full power of the Intel® processor

# Reducing Enabling Costs

# The Graphene LibOS Project [Eurosys14]

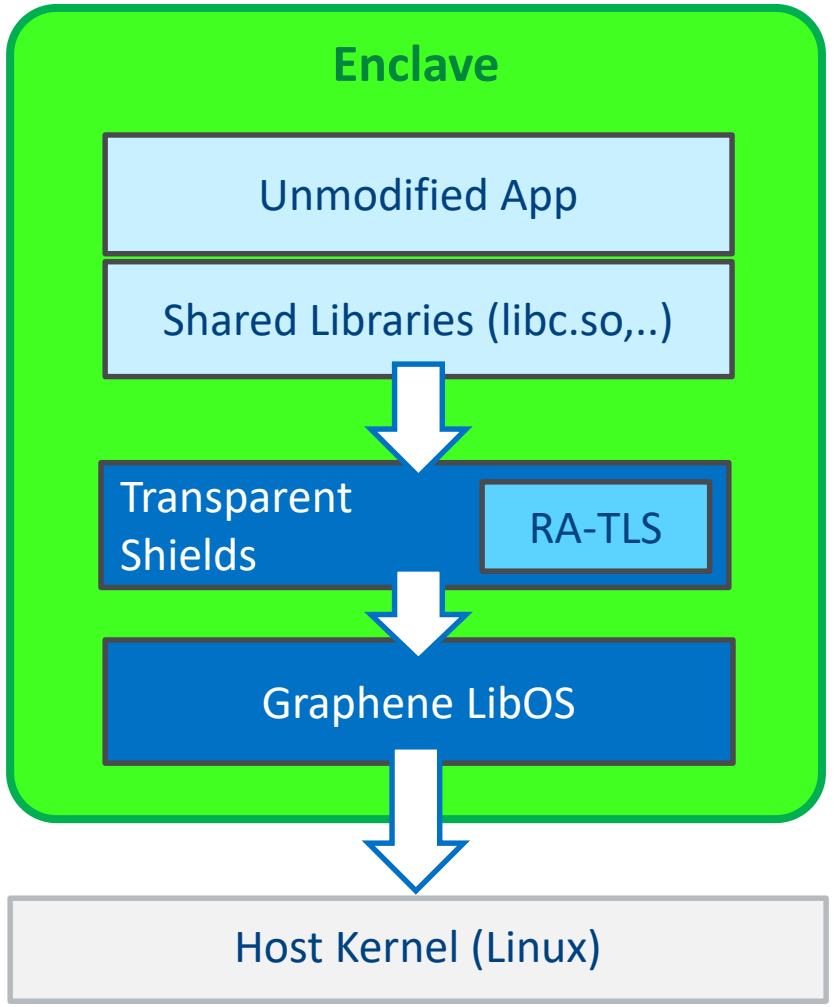
## An open libOS for running unmodified multi-process Linux applications (**github.com/oscarlab/graphene**)

- Inspired by Drawbridge[ASPLOS11] and Haven [OSDI14 Best Paper]
- Continues to be a university open source project
- Very active use of SGX port [ATC'17]
  - Productized by a couple of startups
    - Fortanix, Anjuna
  - In use by many academic research projects
- Docker Integration




**Easy to port to new OS/platform**

# Graphene Library OS




https://grapheneproject.io/

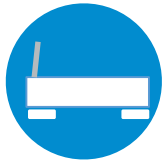
- Graphene Library OS runs Unmodified Linux Application within an Intel® SGX enclave.
- Supports dynamic loading of libraries
- Supports a variety of languages like C, Python, R …
- Transparent Encryption with Network and File System shields
- Transparent Intel® SGX Remote Attestation with RA-TLS
- Docker Integration

# Intel® SGX Usages

# USE CASES – DATA CENTER, CLOUD & INTERNET OF THINGS

## Key Protection

Helping protect keys on local file system; hardening disk protection, building scalable cloud KMS

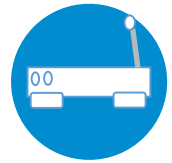


## HSM
Hardware Security Module

Customers and ISVs use enclaves to increase protection of encryption keys and/or HSM replacement

## Encrypted Databases

Encrypted database operations



## Internet of Things

Enhanced security for IoT edge devices and cloud communications

## Enhanced Privacy Analytics
& Workloads

Enables multi-party joint computation on sensitive data in a privacy-preserving manner

## NFV
Network Function Virtualization

Enhanced trust to help protect & virtualize network functions

## Blockchain

Enhanced security transaction processing for Cryptocurrency, Secure Contracts, and Hyperledger protection

## Machine Learning

Enhanced security for machine learning algorithms, models, and data during inferencing.

# Machine Learning

# Machine Learning as a Service

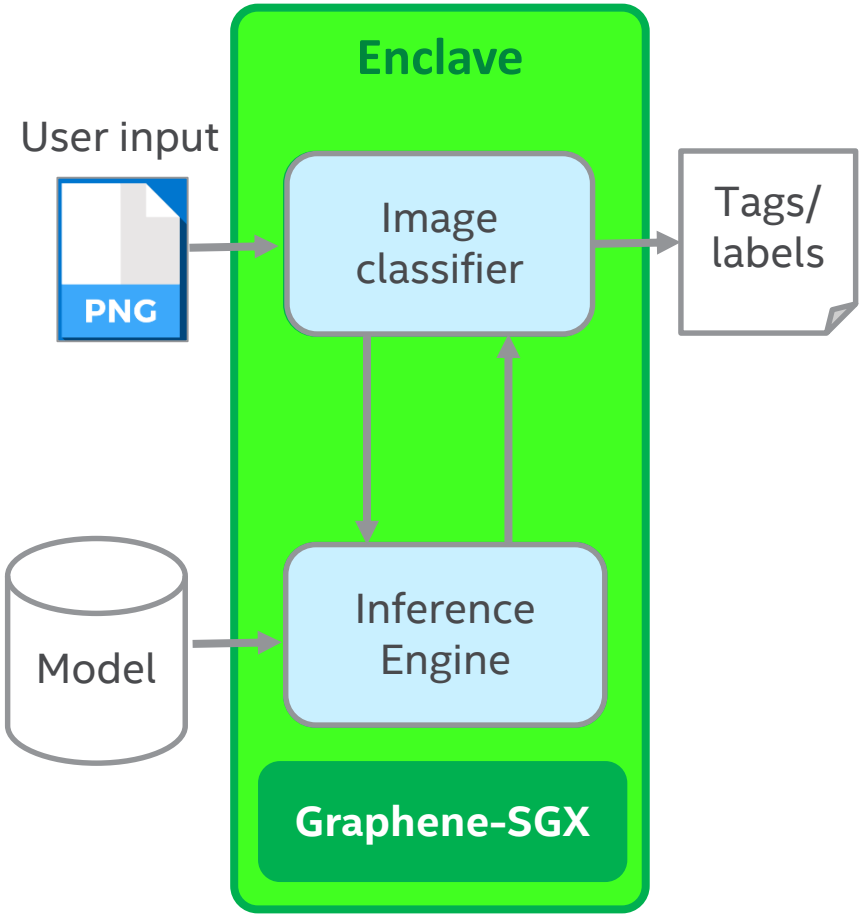
## Deployed on Cloud as ML-as-a-Service

- Models can be provided by the users or by service
- Users provides the data
- Users desired high confidentiality of their models and input data, which is hard in public clouds.

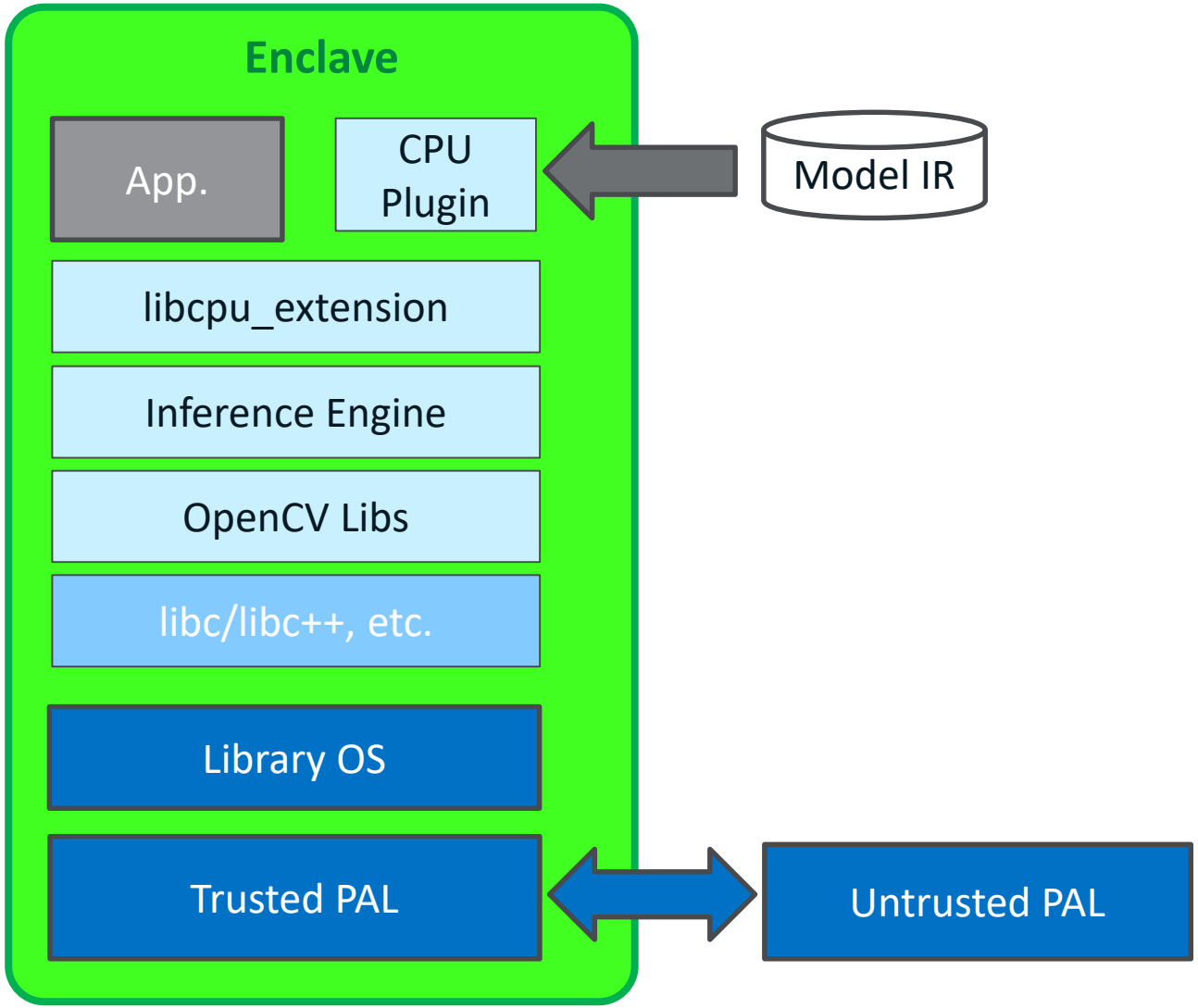
## Deployed on Edge Devices

- ML models can be provided by device vendor
- Vendor desired high confidentiality of their models, which his hard in many edge environments.

## Intel® SGX can provide enhanced security for the ML model and user data.



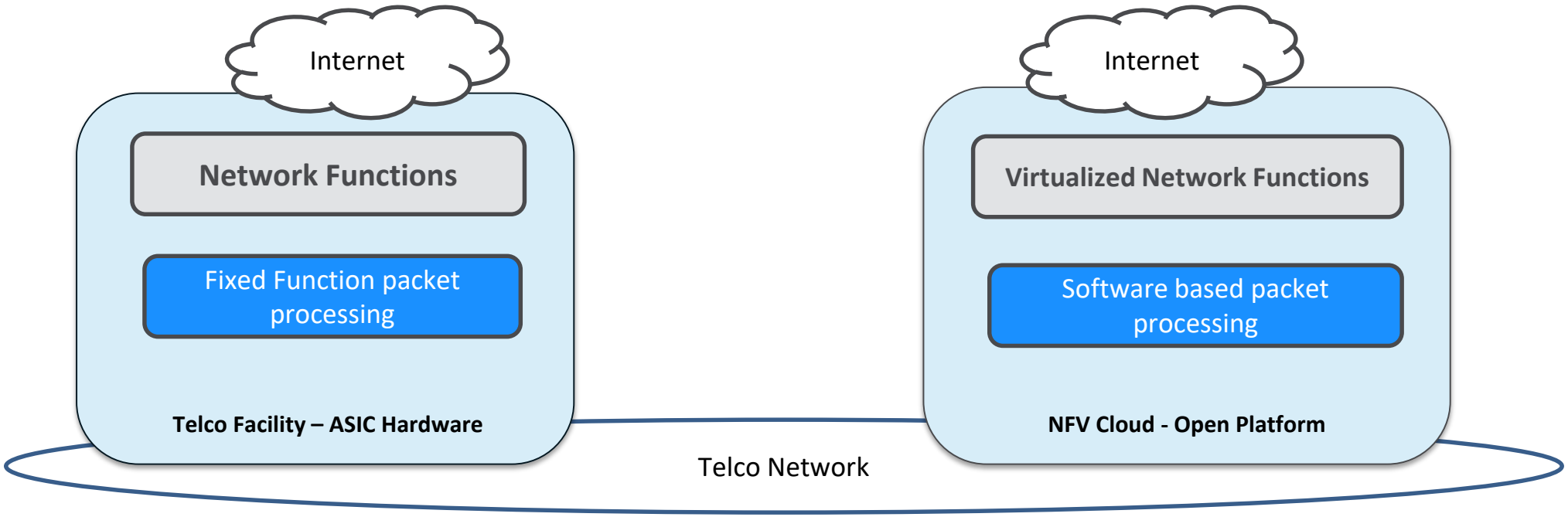
# Graphene-SGX with OpenVINO®




- Graphene-SGX enables SGX use by unmodified OpenVINO ® inferencing stack.
- SGX's provides enhanced isolation on shared cloud servers.
- Using SGX attestation, data owners can remotely detect that the desired ML stack is running in the enclave before delivering sensitive data.
- With additional software enhancements, model owners could also use attestation to detect the OpenVINO® stack is running in an enclave before delivering sensitive model information.

# Network Function Virtualization & 5G

# Network Functions Evolving For NFV Cloud




Physical Appliance

Built into Telco HW Function

In-Building Access

Protection from Insiders

Distributed SW Infrastructure

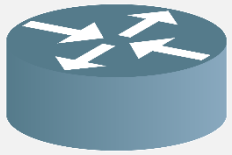
Automated instantiation w/ VNFs

+ Secured Remote Access

+ Protection from Outsiders

# Virtual Network Function – Software Building Blocks

## Fixed network functions on proprietary hardware



Router

EPC

VPN

Firewall

Load Balancer

Deep Packet Inspection/ IDS

VS

## Virtual network functions on commodity hardware

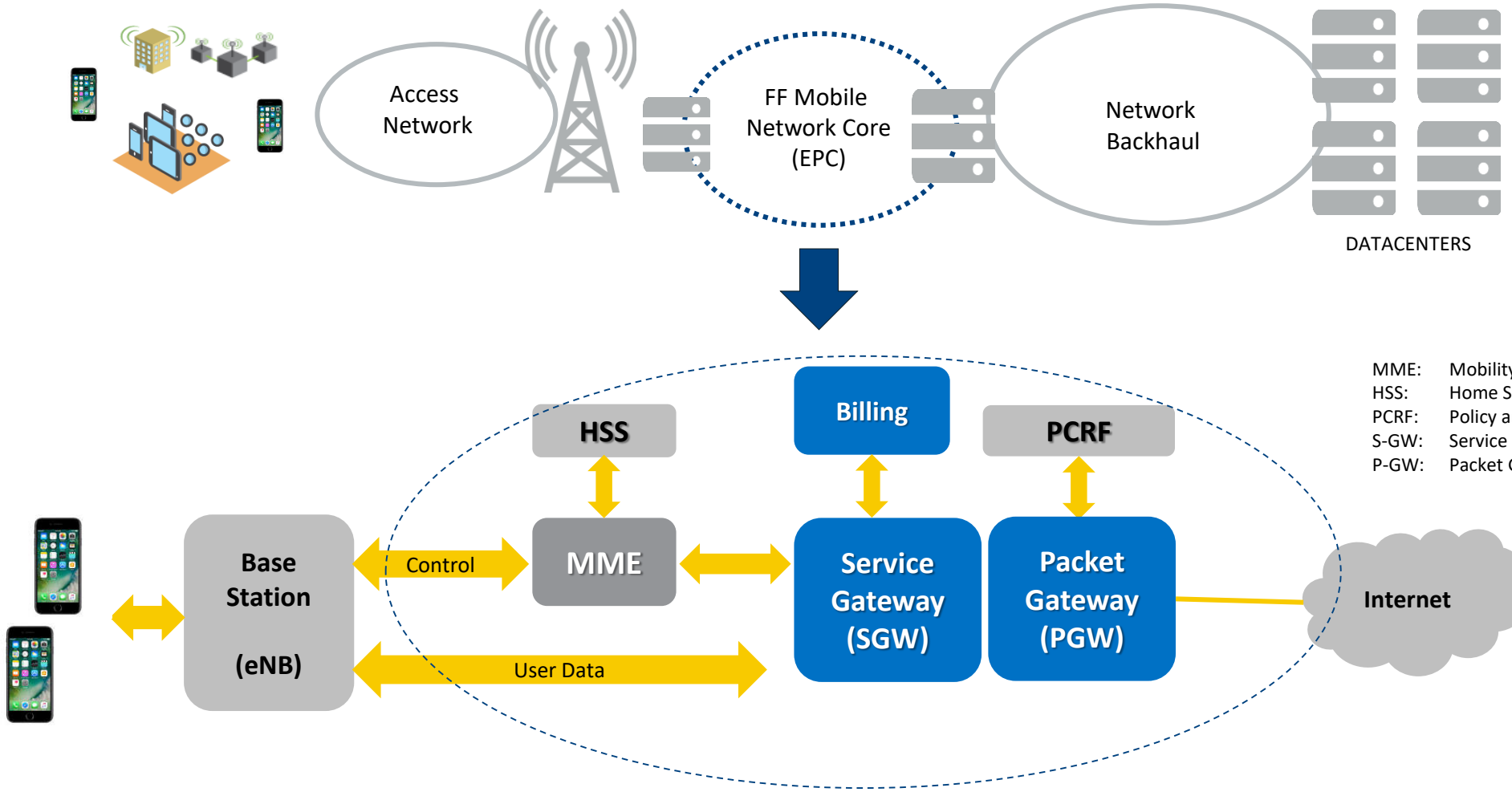
Router | EPC | VPN | Firewall | Load Balancer | DPI/IDS

### Software Building Blocks

N-tuple Lookup | State Machines | Policy Manager | …

Filters | Key Manager | Hash Table | …

# Open Mobile Evolved Core (OMEC)

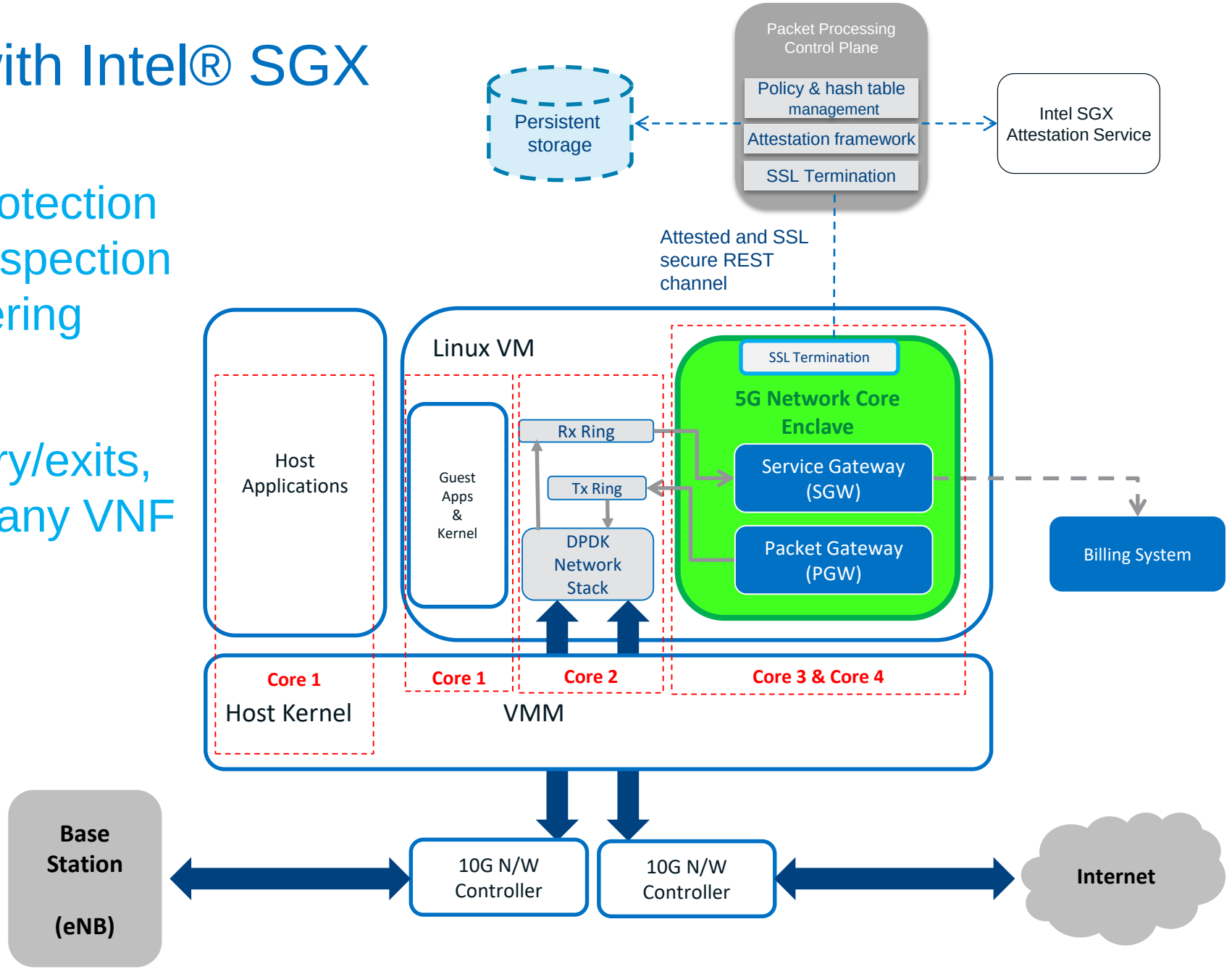



Opensource project with Telco partners to implement 5G Network Core using VNF.

# 5G Network Core with Intel® SGX

Intel® SGX increases protection of the VNF from traffic inspection (confidentiality) or tampering (integrity).

By reducing enclave entry/exits, enclaves can process many VNF at line rate.



# Blockchain

# Intel® SGX Opportunity for Blockchain

Blockchain offers fully decentralized coordination for a variety of uses.

- Examples: cryptocurrency, supply chain tracking, data provenance, IOT enabling.

Consensus algorithms are the core of the blockchain model.

Many consensus algorithms achieve their security using very expensive techniques.

Intel® SGX's enhanced runtime isolation and attestation create opportunities for new, inexpensive, consensus algorithms.

# Example Blockchain Leader Election: Bitcoin

- Proof Of Work:

```
while TRUE:
    nonce = random()
    if (hash(nonce + block) <
difficulty)
                return (nonce)
```

- Leader: First to Complete
  - Fully decentralized—no coordination is required between the participants
  - Easy to prove correct execution—the nonce is trivial to validate
  - Completely fair—anyone can be elected leader for any block
- And…
  - Incredibly high power requirements

# The Key Insight About Bitcoin Leader Election


Observation: Interval between blocks is random and exponentially distributed

It is the distribution (in time) of leader election that is critical to the protocol not the hashing

# Leader Election With Intel® SGX

- Proof Of Elapsed Time (PoET):
  - wait(random(difficulty))
  - return sign(block)

- Leader: First to Complete
  - Fully decentralized—no coordination is required between the participants
  - Easy to prove correct execution—SGX provides verifiable attestation
  - Completely fair—anyone can be elected leader for any block
- And…
  - Very little compute/power required

# Power Efficiency of Consensus

**Proof of Work**

Transaction Validation

Communication

**Hashing**

50 TWh/year

(small country)

**Proof of Elapsed Time**

Transaction Validation

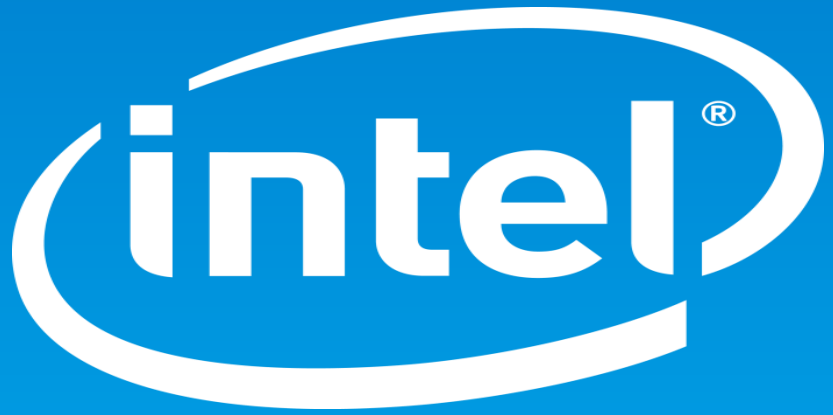
Communication

**Enclave Entry/Exit**

5 GWh/year

(500K servers, 1W estimate)

Leverage enclave's strengths to deliver significant power savings for some usages.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