IoT in the Era of the Continuum Computing: Challenges and Opportunities

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Oppportunity

- IoT devices and the emergence of 5G in our daily lives are bringing new data-driven and increasingly autonomous scenarios.

- Possibilities of highly distributed processing capacities from IoT-Edge-Cloud in a continuum:
  - New services require efficient and effective management of computing and network resources
  - Means to deal with huge amounts of data and at different levels of the future NG infrastructure

- Need for configuration, architecture and coordination of processing nodes at different levels: end-device – edge – cloud ... and beyond

- Need for intelligent methods to offload processing operations to the proper levels of the computing network to meet e.g. delay and processing constraints

- Support heterogeneous processing infrastructures, offering decentralized and adaptive coordination of virtual resources that accommodate QoE, mobility and security requirements
IoT, 5G, Virtualization and Intelligent

- 5G as infrastructure for flexible processing distribution
- Dynamic management of resources through virtualization
Research and Innovation priorities - a look ahead

• Intelligent methods to optimize the offload processing operations to the proper levels of the computing continuum
• Distributed model for assigning computing resources
• Increase embedded intelligence on IoT devices
• Active and adaptive security within:
  – IoT lifecycle
  – Mobility and transition of the devices
• (ML) techniques can be key for a more effective detection and mitigation of security and privacy attacks
• Contextual management and reactive adaption
• Lower and upper edges of the network need **computing offloading**:
  – **End devices** with energy constraints: IoT hardware, smart phones, sensors...
  – **Cloud data centres** can suffer from scalability issues
• **Exploit MEC** for delay-sensitive services, instead of cloud computing: one of the main focus of 5G
  – MEC reduce delay when accessing telematic services
  – Processing in the access network
  – Intermediate solution between edge and cloud schemes
  – Under standardization (ETSI, 3GPP)
• **Context-awareness** in processing distribution
  – Use of contextual data to adapt processing
  – Adaptation of the networked system according to the user/network context
• **Exploitation of pre-processing** in MEC/fog/edge computing
  – Filtering, aggregation, event extraction
  – Offloading high levels of fine-grain data analysis
Distributed Computing Resources

- **Application of AI techniques** for dynamic distribution of computing
  - Machine learning to extract computation patterns in the network
  - Predictive adaptation of the processing resources
  - Distributed AI for network adaptation: agents

- **Migration of computing nodes**
  - Movement of virtualized resources to accommodate computing needs
  - Computing nodes “follow” physical devices in the network topology

- **Vertical and horizontal coordination**
  - Vertical: from the end-node to the cloud
  - Horizontal: across a network level (end-nodes, network gateways, access networks, data clouds, etc.)
TinyML advantages

• TinyML proposes to optimize and compress ML models in order to make them runnable by small IoT devices

• On-device data processing presents a series of advantages:
  – Local intelligent decisions can be made without the support of the cloud
  – Reduce the amount of data sent to the cloud:
    • Decrease energy (battery) consumption: Wireless transmissions are highly power-demanding
    • Data privacy/security is improved
  – Low cost: Devices are already deployed and they are cheap
  – Reduce latencies in the decision process
Virtual Things

- **Virtual Things** are emulation of real things
  - Sharing of real things
  - Analytics
  - Physical Control

- **Virtual Sensors**
  - Virtual Face Detector
  - Virtual Person Finder
  - Hygrometer

- **Virtual Actuator**
  - Rented Drones
  - Door locks
Offloading and distributed processing

• Several image processors may use DNN Pre-Trained Models and can be also orchestrated.

• Several instance can be available, i.e. the operator can be implemented using CUDA acceleration to speed up the process and reduce the energy use.
• Coordinated MEC nodes for AI operations
• Cooperative model building, data privacy, etc.

• Typical Intrusion Detection Systems (IDS) are based on centralized approaches, where devices need to share their data with the data center for further analysis
  • It could represent a privacy concern in IoT scenarios where devices’ network traffic could disclose users’ daily activities
• FL represents a collaborative learning approach where devices share their data, only share partial updates
IoT today a fragmented verticalized world
Federated Learning for Intrusion Detection

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- Relations between entities (business, regulation, control)
- Policies
- Trust management

- Supporting tools and composition refining
- Templates and blueprinting capabilities
- Interoperable Application Interfaces & SDKs
- Digital markets

- Intelligence modelling and execution
- Choreography and workflows configuration and triggers
- Life Cycle Management of services and processes
- Execution control and monitoring

- Native and automated data transformation
- Data description, discovery, forwarding and retrieving
- AutoML & AI auditability /explainability support

- Network aware computing
- Peering, availability, consistency, cohesion & consolidation
- Multi-tenancy, confidentiality

- Perception & Actuation
- Data, services & capabilities

(A distributed network-fabric service architecture)
Create a substrate where your application simply works, somewhere, in the best location. Simplify applications deployment and management. Make better use of available resources. For a greener, more efficient, and no lock-in distributed computing.

Additional (orthogonal) dimension: capability to handle multiple administrative domains.
1. **Fluidify the edge and unify it** with the cloud through a borderless, decentralised continuum leveraging automatic, autonomous resource discovery and integration.

2. Move the gravity outside the data centre thus creating a cross-provider, community-based computing and service fabric leveraging open-source software.

3. Orchestrate services and hyper-distributed applications in a continuous, automated fashion over multiple devices and domains, leveraging energy-efficient learning algorithms and AI for mobility/behaviour prediction and traffic forecasting.

4. Introduce a Zero Trust paradigm aimed at securing the access of geographically scattered resources in an authenticated, authorised manner.
Security Challenges

• The Cloud Computing paradigm has been growing as well as the demand for storage and processing.

• New paradigms have emerged such as Fog/Edge/Micro-Edge computing, with the goal:
  – Release the Cloud
  – Privacy
  – Latency
  – Security

• At the Edge, we find heterogeneity so it's necessary mechanism of orchestration of services across multiple layer keeping the security.
**Framework Overview**

- **FLUIDOS** (Flexible, scalable, secure, and decentralised Operating System)
- It is a research project that **aims to create a decentralised operating system** that unifies distributed node resources and capabilities under a homogenised view.
- The system allows the deployment and management of services while ensuring their requirements and constraints are met.
- **Each FLUIDOS node can provide and offer any resource or service**.
Security Orchestration involves the coordination of security tools and processes, resulting:

- Improved security posture
- Increased efficiency and reduced human error
- Faster response times

Depending on the subject who triggers the orchestration process and the main goal, the workflow can be separated into two different approaches:

- Proactive
- Reactive
RIGOUROUS will introduce a new holistic and smart service framework leveraging new machine learning (ML) and AI mechanisms, which can react dynamically to the ever-changing threat surface on all orchestration layers and network functions.

Smart service framework is capable of ensuring a **secure, trusted and privacy-preserving** environment for supporting the next generation of trustworthy continuum computing 6G services along the full **device-edge-cloud-continuum on heterogenous multi-domain networks**. This includes establishing compliance with the design of software (SW), protocols and procedures, as well as AI-governed mechanisms to cope with the security-related requirements in the **full DevOps lifecycle**, from the service onboarding up to the day-2 operations.
Policy-based AI-driven Security orchestration

- User intent driven security policy definition
- The orchestrator will be driven by AI to make their chaining and orchestration decision
- Rely on special modules to translate the intents, policies and behavioural profiles coming from the decision into concrete actions
- **Federated Learning (FL)** approach to make orchestration decisions
- Decide best actions for **dynamic** provisioning, deployment, and **reconfiguration** (during operation) of the virtual network security functions and associated intents and policies
- Orchestrator will consider the time- and space-varying parameters of the network, such QoS capacities, actual resources constraints (CPU, RAM, storage), system status, current deployed policies, and threat incidents...
• Extensible orchestration enforcement:
  – NFV, SDN, IoT Controllers
• Integration with Security Enabler Providers (to enforce actions) and Trust Managers to make decisions
• ZSM approach
NANCY’s Architecture B-RAN
Computational Offloading

Closed-loop based orchestration:
- Infrastructure/services monitoring
- IA Analytics and predictions
- Orchestration Scheme --> offloading/caching placement
- Instantiation & Configuration
testbed

GAIA campus
• AI within devices is just the first step towards the development of completely intelligent and evolutive systems.
  – Integration of cognitive self-evolution capabilities in the entire end-to-end network chain (fog, edge, and cloud) will go beyond current limits of AI by permitting end-devices and, by extension, the whole system to grow and refine its own intelligence

• Security VNFs can be timely and dynamically orchestrated through policies to deal with heterogeneity demanded by these distributed IoT deployments, than can be deployed either at the core of at the edge, in VNF entities, in order to rule the security in IoT networks

• Dynamic and intelligent reactive provisioning of services and resources with the edge of the network can enhance scalability, necessary to deal with IoT scenarios

• Continuum merging IoT/far edge/edge/cloud is opening new challenge on how to coordinate the managing of the resources and how the security and privacy can be managed in this dynamic scenario -> Zero trust

• Evolutive Artificial Cognitive Capabilities (EACC) mechanisms will open the door for designing devices and systems with a superior intelligence that will permit them to meta-learn from new situations, scenarios, and environmental changes.
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