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ECORAN Project Report (MS9)

DG7: Project closure report

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Executive Summary

Ultracell Networks Ltd has prepared this document for DSIT as evidentiary information of achievement of key milestones and objectives relating to the deliverables of the ninth milestone (MS 9) for the Energy-Efficient Cloudlets for ORAN (ECORAN).

We are confident that we have understood and met the objectives and are providing a high quality, value-based report that meets the requirements as defined in the project. In summary, we achieved the GFA deliverable DG7 where we discuss the project closure report.

This document forms a detailed report on the work undertaken on ECORAN project from the 1st April 2024 to the 31st July 2024. The organisation of this report is as follows:

- **Section 1** provides a review of ECORAN project covering the C-PON technology before ECORAN project, ECORAN aims and objectives, and ECORAN achievements.
- **Section 2** explains the challenges and lessons learned throughout the ECORAN project.

Table of abbreviation

MILP	Mixed Integer Linear Programming
OLM	optical line manager
ORAN	Open Radio Access Network
LLMs	Large Language Models
C-PON	Cellular Passive Optical Network
TRL	Technology Readiness Level
NIC	network interface cards
RL	reinforcement learning
GANs	generative adversarial networks
VM	Virtual Machine
CA	Consortium Agreement
IPR	Intellectual Property Rights

1 ECORAN Project Review

This project review aims to provide a comprehensive evaluation of ECORAN project's R&D efforts, technical and operational components, and overall performance. We will assess the project's success against its intended scope, aims, and benefits, and identify key lessons learned. This review will offer valuable insights to inform and enhance future projects.

1.1C-PON Technology Before ECORAN

Prior to the ECORAN project, the cellular passive optical network (C-PON) technology was implemented as a lab-based demonstrator at low TRL3 where essential software was implemented in servers. Furthermore, the optical line manager (OLM) control functions were also implemented in servers. The backplane of proposed C-PON architecture was implemented by electronic switches and thus, several optical electrical optical conversions was required in the lab-based demonstrator. Consequently, the lab-based demonstrator was not in production form and was characterised by high power consumption and slow operation. This lab-based demonstrator was established to investigate the functionalities and performance of the C-PON architecture. It is important to note that the scope of this deployment did not encompass the exploration or implementation of Open Radio Access Network (ORAN) applications.

1.2 Project Aim and Objectives

ECORAN project aims to transform the C-PON architecture from TRL3 to TRL 6 which is achieved by firstly implementing the key C-PON functions in FPGA commercial grade accelerators instead of being implemented in the operating systems of servers. Secondly, customise the C-PON architecture for the ORAN environment and introducing a new ORAN use case, Processing Steering, implemented over C-PON. Thirdly, introduce intelligence through reinforcement learning to implement the ORAN processing steering use case. Finally, demonstrate the key concepts in the testbed.

This results in ORAN OPEX reduction, which is dominated by power consumption, noting also that 65%-70% of cost of ownership of the network is in RAN. In addition, this Increases ORAN efficiency through processing steering which results in several benefits. These benefits include reduced intervention, reduced processing hardware needed, faster response to changes in processing demands, reduced human errors associated with manual intervention, and introduction of a new ORAN use case with potential revenue generation through intelligence (reinforcement learning) driving processing steering.

To achieve this, the scope of the ECORAN project includes several technical deliverables. The key technical deliverables are C-PON networking hardware, ML algorithms for ORAN processing steering, demonstration of processing steering in ORAN for the first time for future operator networks, and the development of Generative Algorithms (Large Language Models (LLMs)).

Regarding C-PON networking hardware deliverables, they include technical development activities to link processing servers and results in up to 82% power saving. These power savings are verified in the lab following construction of the C-PON cells, although the focus is on implementing the Processing Steering use case. As for ML algorithms for ORAN processing steering deliverables, reinforcement learning algorithms are developed and demonstrated for processing steering in the lab as evidence. Regarding the development of LLMs, it focuses on the development of LLMs model and applying it to a use case proposed by the commercial partners.

In regard to the demonstration of processing steering in ORAN, it introduces a new use case in ORAN that can help operators reduce CAPEX (by deploying processing equipment less than the peak needed) and reduce OPEX with improved QoS. The technical development activities of the ECORAN project aimed to engage with standardisation bodies to seek to standardise the processing steering use case and key related elements of the energy efficient C-PON processing cells.

The technical development activities led to the construction of a testbed (i.e., C-PON demonstration prototype) where key performance indicators (i.e., latency, power consumption and resilience) of the C-PON platform are monitored, measured, and optimised in lab environment and in field trial test sites of industrial partners. The testbed demonstrates reduction in power consumption, reduction in latency and greater resilience. The testbed provides an agile, flexible, and scalable platform which can efficiently utilise resources to satisfy dynamic demand patterns.

Achieving the technical deliverables of the ECORAN project is expected to de-risk the C-PON technology for venture funds (by advancing the C-PON technology from TRL3 to TRL6). Hence, the ECORAN project provides a prototype that will enable third parties to validate both business and technical propositions of the C-PON technology. Beyond the end of the ECORAN project, the C-PON platform and the processing steering technologies introduced will continue to mature and will be showcased in the UK and internationally. This will help introduce new opportunities in the Open RAN ecosystem in the UK and beyond. During this time new 5G services will be introduced that build on and use edge processing. The C-PON ORAN platform will find additional applications as a platform to implement new ORAN use cases in an energy efficient manner, making use of the hardware accelerators that are open and accessible to users; as well as the use of the platform for user data processing and caching at the network edge.

1.3Project Achievements

The ECORAN project has reached its successful closure, delivering on several critical objectives that have substantially advanced the energy-efficient processing for Open Radio Access Networks (ORAN). Over the course of the project, several key objectives were met, concluding in notable technical achievements.

The objectives of the technical development activities of the ECORAN project are the energy efficient processing cells for ORAN, intelligent Processing Steering in ORAN, demonstration, and the development of LLMs model. These achievements of the ECORAN project are reviewed as follows.

1.3.1 Energy efficient processing cells for ORAN

The ECORAN project aims to build energy efficient processing cells using a new form of cellular passive optical network (C-PON) technology for interconnecting servers. The C-PON cell is the smallest modular unit that can be operated alone. A C-PON cell is constructed by integrating C-PON functional elements. Such elements include the servers, racks, the OLM, the control software, the C-PON fabric and the backplane.

A central achievement of the ECORAN project is the development of energy-efficient processing cells, which directly contributed to the transformation of the C-PON cell from Technology Readiness Level 3 (TRL3) to TRL6. This progress demonstrates that the C-PON technology has evolved from a conceptual stage to a mature system validated in a relevant operational environment.

To achieve this aim, it is needed to accomplish the following:

a. Customise the C-PON card for processing steering use case:

The C-PON card performs networking functions which include interfacing with physical media, parsing of packets, temporary storage of packets and forwarding of packets. These functions are performed by a range of physical sub-components of the C-PON card. These physical sub-components comprise network interfaces, forwarding engines, buffers, and traffic managers. Additionally, for processing steering, C-PON card provides ML inference host and ML actor functionalities to make decisions on the received packets according to the trained ML model. The focus here is on programming the C-PON network interface cards (NIC) in each server implemented using the SmartNIC FPGA Accelerator Card. Following initial specification of the C-PON card in DT1, the development of the C-PON card on the Xilinx U25 smart NIC has been completed in DT8.

b. Developing the OLM for processing steering:

The optical line manager (OLM) is a physical hardware of the C-PON platform that supports intra-cell and inter-cell connectivity. The OLM performs a range of physical, packet forwarding and logical functions in the C-PON platform. The logical functions of the OLM comprise control plane and management plane functions which provide the intelligence that dictates how end-to-end communication is performed over physical connectivity in the C-PON platform. The OLM which links the C-PON ORAN processing cells is implemented using a single Xilinx U25 smart NIC; with scaling to more connections being carried beyond the ECORAN project.

The advanced specification of the OLM and its physical components was reported in DT6. In DT6, the design of the OLM leveraged the chassis of an x86 server to support the installation of multiple C-PON cards and an open-source control software. Subsequently, the developed OLM for processing steering use case and linking the C-PON processing cells through their OLMs using a centralised architecture was performed in DT8.

c. C-PON cell development for ORAN:

The C-PON cell is the smallest modular unit that can be operated alone. A C-PON cell is constructed by integrating C-PON functional elements. Such elements include the servers, racks, the OLM, the control software, the C-PON fabric and the backplane. The specification of a generic C-PON cell was given in DT2 while DT3 and DT4 discussed in-depth the hardware and software components of the C-PON cell. Subsequently, the C-PON cell testbed has been implemented in DT6 and tested in DT8.

The development of energy-efficient processing cells encompasses the successful transformation of the C-PON architecture from TRL3 to TRL6. This transformation signifies the maturation of the C-PON technology, demonstrating its viability and readiness for real-world applications.

1.3.2 Intelligent Processing Steering in ORAN

The ECORAN project has successfully implemented intelligent processing steering within the ORAN framework. This includes the creation and deployment of sophisticated algorithms that optimise network processing, enhancing the efficiency and adaptability of the system to dynamic network conditions.

The project focuses on developing the reinforcement learning (RL) algorithms to decide when to join cells, which cells to join and how to join them (Processing Steering). To achieve this aim, it is needed to accomplish the following:

a. Selection and optimisation of ML algorithms

ML and RL are used to develop the intelligence needed to join different processing cells that are geo distributed in response to processing demand variation. Machine learning is introduced in DT1 along with the discussion of the choices for machine learning algorithms for processing steering in the interconnected energy-efficient C-PON processing cells. DT1 also discussed some ML algorithms to generate data for the variations in the processing demands by users in edge networks with ORAN. Initial choices of ML algorithms and potential optimisation routes were discussed in DT2.

b. Processing steering scenarios

ECORAN project focuses on selecting low, medium and high processing demand scenarios with variable data rates between servers and between servers and users and with different CPU and memory demands and NIC IO data rates to test and stretch the processing steering use case. It used generative adversarial networks (GANs) to generate synthetic processing demands that are hard to distinguish from real demands, and train GANs on real processing traces, publicly available. This work is covered in DT3 while DT4 Provided further in-depth explanation of the clustering algorithms and approaches used in this project.

c. Mapping the ML algorithms to ORAN framework

This part maps the ML intelligence framework and the C-PON cells into the ORAN. Therefore, making use of O1 interfaces for sensing and ORAN A1 and E2 interfaces to provide ML based control and guidance to O-CU and O-DU. An overview of mapping the ML algorithms to the ORAN framework was provided in DT1. More detailed explanation of how to map the processing steering use case to the ORAN architecture is in DT4. DT7 provided a summary of the mapping of the ML algorithms to ORAN framework.

1.3.3 Demonstration

Several key technology demonstrations were conducted during the project, effectively showcasing the practical applications and benefits of the developed technologies. These demonstrations have provided concrete evidence of the solutions' effectiveness and their potential impact in real-world scenarios.

ECORAN project carried out experimental research and experimentally demonstrated the key concepts while engaging our industrial contacts (eg. BT, Vodafone, Orange). This work covers the following:

a. Modelling tool development

In ECORAN, a GUI is used to allow users to graphically interact with the modelling tool and try out various what-if scenarios. The GUI has various windows that allow the user to explore the capabilities of ECORAN such as clustering and VM placement. A software modelling tool was developed in DT4.

b. Commercial engagement

This work focused on engaging the ORAN community and our commercial contacts in different operator companies. It also was responsible for dissemination of the results in the commercial community. This all is covered in DT5.

c. Experimental demonstration

This task is responsible for the demonstration of the C-PON cell implementation and RL algorithms implementation and serves to demonstrate the key concepts including reduced power consumption and processing steering. DT9 introduced the key functionalities of the ECORAN ML-assisted solution. In addition, DT9 covered the design and implementation of the reinforcement learning based Virtual Machine (VM) placement (processing steering) solution of ECORAN. Moreover, it covered a requirements analysis for the implementation of the ECORAN ML assisted solutions on the FPGA and a description of the implementation techniques that can be used to implement the ECORAN

ML assisted solution on the C-PON card. Finally, DT9 discussed and examined the processing steering results.

1.3.4 The development of LLMs model

Another significant achievement is the integration of LLMs into the Processing Steering system. This development has improved the system's ability to process and analyse complex data, contributing to enhanced network intelligence and operational efficiency.

ECORAN project introduced and evaluated the use of LLMs for clustering algorithms and development of high demand use cases such as AR/VR applications. This work was done as follows:

a. Development of use case with commercial partner

The development of the use case for high demand applications with the commercial partner improves the processing on demand process which enables the correct amount of processing to be orchestrated and provisioned on demand at the correct location at low power consumption and low latency using ORAN. An in-depth look into the development of use cases with commercial partners including NZIP, Vodafone and BT is provided in ADT1.

b. Development of Cell Clustering for processing steering using Generative Algorithms

As there are limited studies leveraging LLMs in communication networks in general and processing steering in O-RAN in particular. We explored the potential of LLMs in ECORAN by investigating the potential of customising LLMs to perform VM Placement in ECORAN, and the potential of training LLMs to generate new Heuristics, Clustering, and ML i.e., DRL models based on existing working models with similar dimensions and complexity.

ADT1 provides a technical overview of LLMs, including their architectural frameworks and key components. It further analyses the integration of LLMs within the ORAN framework, comparing and contrasting four distinct methodologies. Finally, it examines the applicability of LLMs within the ECORAN environment, focusing on their potential for synthetic data generation, cell clustering, and data driven VM placement. ADT2 introduces the LLM based ECORAN clustering where it provides an overview of LLMs and how they are leveraged in ECORAN to provide a ML assisted solution to managing network resources. It also discusses in detail how the ECORAN ML-assisted solution leverages LLMs to process and cluster user demands, generated by GANs, to create cell buddies that facilitate efficient resource sharing.

c. Experimental Demonstration

The demonstration showcases the processing steering use case over the C-PON cell. It also shows the added features of the LLMs in the modelling tool which is discussed in detail in ADT3.

2 Project Challenges and Lessons Learned

Over the course of the ECORAN project some challenges were encountered and mitigated. Several lessons were also learned during the ECORAN which would inform and direct the development of the C-PON technology to higher TRLs.

2.1 Challenges

The completion of all tasks and deliverables in the ECORAN project is not without challenges. However, the team of engineers on the project were able to mitigate the challenges to ensure successful completion of the ECORAN project. Some notable challenges are discussed as follows.

- **Supply Chain and Component Acquisition Delays**: the lead time required to obtain necessary components such as servers, racks, cards, cables, and transceivers could cause delays in the project timeline. To mitigate this risk, collaboration with Lenovo and Gtech has been established to streamline the procurement process. This partnership aims to ensure that all required components are available in a timely manner, thus minimising potential delays and keeping the project on track.

- **Consortium Agreement Finalisation Delays:** The project has faced delays in signing the Consortium Agreement (CA) with the new Lead Partner, which has, in turn, postponed the release of grant payments. Despite this setback, the delivery of the project continues on schedule. To ensure that progress is not affected, the company has utilised its own capital to cover the necessary project expenses during this interim period. This proactive approach has allowed the project to proceed without financial interruptions while the CA is being finalised.

- **Grant Payment Delays**: Another challenge was the delay in receiving the grant claim, caused by the postponed signing of the CA with the new Lead Partner. This delay has created financial strain, as the anticipated grant funds have not been available. In response, Ultracell Networks has used its capital to cover essential costs such as payroll and equipment purchases. This strategy ensures that the project delivery remains unaffected, maintaining momentum and adherence to the project timeline despite the funding delays.

2.2 Lessons Learned

The ECORAN project has provided several critical insights into both management and technical aspects. These lessons not only shaped our approach but also enhanced our project's overall execution and outcomes. Below is a detailed summary of these lessons, their implications, and their value to the project.

1. **Management lessons learned:**

i. Ensure strategic approach to smooth transition management:

- **Significance**: Ensuring continuity of research activities and maintaining project timelines.
- **Impact**: Successful transition management minimised disruptions, thereby safeguarding the project's schedule and objectives.

ii. Clarifying Intellectual Property Rights (IPR) Control:

- **Significance**: Clear definition of IPR ownership and licensing agreements is crucial for protecting project innovations and ensuring their effective use.
- **Impact**: Addressing IPR control issues proactively ensured legal clarity and facilitated smooth collaboration among partners.

iii. Mitigating Component Shortages: Proactive measures, including establishing equipment loan agreements and leveraging simulation tools

- **Significance**: it is essential to mitigate the impact of global shortages of semiconductors to avoid delays in equipment acquisition.
- **Impact**: These strategies ensured project continuity and minimised delays despite supply chain disruptions.

iv. Implementing Comprehensive Maintenance Support:

- **Significance**: Continuous 24-hour maintenance support and regular backups are critical for ensuring operational reliability and minimising downtime.
- **Impact**: These measures enhanced the stability of deployment phases and reduced the risk of operational interruptions.

v. Adjusting to Equipment Price Fluctuations:

- **Significance**: Accurate budget adjustments are essential for effective financial management and project planning.
- **Impact**: Updating CAPEX estimates in response to price changes enabled better financial control and resource allocation.

vi. Preparing Alternative Demonstration Solutions:

- **Significance**: Having contingency plans for demonstrations is crucial for showcasing project outcomes despite unforeseen challenges.
- **Impact**: The preparation of backup demonstrations using IPTV and IoT cameras ensured the project's visibility and effectiveness in meeting its goals.

2. Technical Lessons learned:

i. Flexible staff resource management

- **Significance**: Flexible resource management is vital for maintaining project momentum during staffing and funding challenges.
- **Impact**: Resource reallocation strategies ensured continued project advancement and adherence to timelines.

ii. Computational resources Management:

- **Significance**: Sufficient computational resources are necessary for the successful execution of complex modelling tasks.
- **Impact**: Addressing resource limitations improved model performance and project outcomes.

iii. Ensuring Compatibility

- **Significance**: Ensuring compatibility between system components is essential for meeting technical requirements and achieving accurate results.
- **Impact**: The use of compatible components resolved compatibility issues and fulfilled architectural needs.

iv. Generate the required data:

- **Significance**: High-quality data is critical for the effective training and performance of machine learning models.

- **Impact**: Generating synthetic data with minimal error enhanced the accuracy and reliability of GAN-based models.

v. **Integration of optimisation methods**

- **Significance**: Integration of optimisation methods enhances the efficiency and effectiveness of modelling processes.
- **Impact**: Linking optimisation solvers with the modelling tool improved performance and provided more robust results.

vi. **Careful planning and integration of machine learning assisted solution to the ORAN Framework**

- **Significance**: Proper integration ensures that machine learning models align with network telemetry requirements and operational goals.
- **Impact**: Developing the ECORAN platform as a compatible entity with C-PON and ORAN SMO facilitated effective machine learning support and integration.

vii. **Generating realistic data sets**

- **Significance**: Realistic data sets are crucial for accurate model performance and validation.
- **Impact**: Developing GANs that produced data with only a 4.5% error margin improved model accuracy and project reliability.

viii. **Exploring New Development Platforms**

- **Significance**: Evaluating various deployment platforms provided insights into model performance across different environments. Understanding platform performance helps optimise deployment strategies and model effectiveness.
- **Impact**: Identifying and exploring new development platforms enabled better comparison and optimisation of model performance.