Celtic-Plus
Smart Connected World

# Project Achievements

PICCOLO

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## Piccolo: In-Network compute for 5G services

Piccolo's aim was to develop a novel flexible distributed computing framework that can support the operation and requirements of relevant application scenarios. A set of key 5G and related use cases around Automotive Intelligence, Mobile Edge Compute and Factory Automation were used to explore how certain barriers to entry and technical limitations of existing solutions could be addressed and enhanced.

## Main focus

Piccolo's vision is that "compute" becomes integrated into the network and storage fabric, with emphasis on deep/edge deployments to service edge use cases linked to 5G, Mobile Edge Compute (MEC), Industry 4.0, Automotive, and Internet-of-Things (IoT). It is not simply a case of being able to "lift and shift" existing solutions prevalent in Data Centres and leveraged by web-scalers to the distributed edge domain however, as many obstacles exist, including the following:

- Existing technologies are generally based on heavyweight management solutions e.g., OpenStack, Kubernetes.
- Existing solutions often assume the use of large scale, homogeneous resources under total control & secured in the same way.
- It is challenging to provide concrete assurances of data privacy/security.
- It is challenging to meet guaranteed performance KPIs e.g., latency.

Other, more general barriers to adoption of edge compute include business case uncertainty, the fact that public edge clouds are not widely available, the relative immaturity of edge computing technologies and commercial applications, plus the overall governance of the edge ecosystem. The over-riding aim of Piccolo was to tackle these obstacles **in the context of a network operator**, and to develop use cases, PoCs, architecture, and protocols/APIs directly.

## Approach

The Piccolo approach has been to rethink in-network computing from the edge by not simply treating as an extension of existing cloud and microservice platforms. This is motivated by the nature of many real-world applications whereby edge data production and processing such as video analytics is often done for high-volume data feeds (e.g., multiple camera feeds).This often requires careful configuration of processing pipelines with efficient direct communication (not via cloud-based servers and relays) and a continuous adaptation to changes in

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data flow characteristics, analytics results and so on. This calls for functions such as direct local communication, good visibility into application needs and resource availability, and local resource management leverage, i.e., through edge orchestration. In the case of security-sensitive and latency-sensitive applications, in-network computing systems such as Smart Factory control applications cannot afford cloud-based in-network computing approaches. Such applications would typically run completely on-premises, without wider Internet connectivity, which does not only mandate independence from any third-party computing service provider, but also means to setup secure distributing computing contexts, authenticate devices, etc. The Piccolo project has built its architecture and system based on these objectives and has made notable strides in this area.

## Achieved results

The following Proof-of-Concepts were used to validate some of the key principles of Piccolo:

- **PoC1- In-vehicle Real-time Behavioural Risk Monitoring**. This PoC deals with determining a real-time risk index by utilizing in-vehicular data and vision analytics while exploiting the edge cloud continuum for computing resources. A version of this PoC was successfully integrated with BT's private "Vinni" 5G network at is R&D labs.
- **PoC2- Smart Factory**. This PoC developed a new kind of smart conveyor belt consisting of macro modules each with its own small controller nodes. The modular approach with many small nodes necessitated orchestration of fully distributed computation scaling automatically with the size and complexity of the assembly line.
- **PoC3- In-Network Hardware Acceleration for Time-Sensitive Networking**. This PoC focused on light-weight solutions to implement Quality-of-Service (QoS) as required by applications with time-sensitive characteristics best delivered at the network edge- one example of this would be a motor control application which must establish TSN connectivity to motors and sensors for speed measurement.

The research-oriented elements of the project made noteworthy advances in distributed computing systems, coordination, orchestration and resource allocation:

- Information-centric dataflow (Emden University)
- uActor stateful serverless at the edge (TUM)
- Distributed Coordination for In-network computing (Bosch)
- VineIO- Self organising service orchestration (TUM)
- Oakestra edge orchestration (TUM)
- Bushfire resource allocation (Stritzinger and TUM)
- Deterministic networking and computing (Innoroute)

Papers have been presented at ACM ICN22, ACM IMC 22, and ACM SIGCOMM 22. Standards bodies have been engaged and influenced including talks by Piccolo participants at IETF and IRTF: COIN (Compute in the Network), ICNRG (Information-Centric Research Group) and DINRG (Decentralized Internet Infrastructure Research Group).

## Impact

Piccolo essentially lays some very solid foundations for impact on business, further R&D and future industry activities. In the short term, it has confirmed the technical viability of certain edge-oriented use cases anchored in specific vertical segments. Although we have confirmed the benefits of light-weight and intelligent resource allocation and orchestration of workloads offloaded onto edge compute for specific use cases like automotive risk and smart factory, the concepts are easily extensible to other scenarios. Healthcare, aviation, logistics as well as market segments that will drive more bandwidth-demanding use cases (cf 6G), will all benefit from an efficient and securely managed edge compute infrastructure. From a more academic and research perspective, Piccolo has embraced two existing worlds i) the networking world which is based on IP and its associated protocols ii) the application world which is now largely based on containerised components communicating via the microservices architecture. It is evident that these two areas can be taken as the start point for evolutionary development.

## About Celtic-Plus

Celtic-Plus is an industry-driven European research initiative to define, perform and finance through public and private funding common research projects in the area of telecommunications, new media, future Internet, and applications & services focusing on a new „Smart Connected World" paradigm. Celtic-Plus is a EUREKA ICT cluster and belongs to the intergovernmental EUREKA network. Celtic-Plus is open to any type of company covering the Celtic-Plus research areas, large industry as well as small companies or universities and research organisations. Even companies outside the EUREKA countries may get some possibilities to join a Celtic-Plus project under certain conditions.

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