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Open Digital Twin Framework for Digital Operation
- with Case Study on 5G Co-Sharing Network for Smart City

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Executive Summary

As the latest generation of wireless communication technology, 5G has great impact on the construction of smart city due to its ultra-high bandwidth, ultra-low latency and super large connection. The ubiquitous sensor network based on 5G realizes the intelligent connection of everything in smart city and deep integration among human, machine and things. At the same time, 5G is deeply integrated with the new generation of information technology represented by cloud computing, big data, artificial intelligence and the Internet of things, which makes the 5G network flexibly configure network resources according to the end application scenarios, so as to meet the differentiated needs of smart city for network. Thus 5G has become the most important infrastructure to enable smart cities.

Relying on the key capacity of 5G communication network resources, the natural advantages of big data and cloud computing services, telecom operators play an irreplaceable role in the digital infrastructure construction of smart city. While we are looking forward to “4G changes life, 5G changes society”, Telco operators are facing the dilemma for 5G business. On one hand 5G is quite expensive in both network construction and operation comparing with 4G, but on the other hand both individual customer and enterprise are expecting to benefit from the 5G advantages as quick as possible. In view of the various challenges in the construction of smart city, telecom operators have to consider not only how to provide efficient infrastructure and connection services, but also how to jointly undertake the development and construction of smart application with the partners in the smart city ecology. Telecom operators need to think about to build a new pattern of co-construction and co-governance and sharing to create the ecological environment in the construction of new smart city in 5G era.

The next generation of city development requires adhering to the mode of "simultaneous planning and construction of digital city and real city". It is an important basis to create a digital platform showing multi-dimensional urban space. The digital twin has gradually become one of the core innovation elements of the new smart city construction, supporting the city brain and promoting the construction of digital city. This white paper will describe how we build an open digital twin framework to address three key challenges to build digital system for future smart city: 5G network infrastructure sharing; trusted data circulation and sharing cross domain; city digital twin development and operation.

On top of the open digital twin framework, a catalyst project C20.0.10 “Inception: digital twins for 5G network infrastructure-sharing” has been conducted as proof of concept in 2020. This Catalyst demonstrates how digital twins can help China Telecom and China Unicom succeed with the joint construction and network sharing of 5G radio access network, including effectively planning 5G base stations, pinpointing performance issues and ensuring personalized customer experience. Technically, this catalyst project integrates three digital twins of customer, network and space by knowledge graph on top of big data platform, and establishes cloud-edge collaboration mechanism in the container based implementation. On one hand it enhances the real time interaction between digital twin and its physical entity on the edge, and on the other hand it leverages the machine learning to simulate and predict the customer behavior and network performance in a designated space in the cloud. In addition, the federal learning technology is adopted to realize collaborative modeling among digital twins cross operator. Under the premise of data privacy, the network data and customer data from different operators can be effectively used to improve the customer experience management under joint construction and sharing of 5G network.

Open Digital Twin Framework is a reference software architecture that describes the digital model, function and interactions of its physical entity. It not only categorizes the common functions that a digital twin should implement but also classifies the data intelligent model a digital twin can build. The goal of Open Digital Twin Framework is to provide an integrated object framework for developers to build domain specific digital twin with interoperability for agile solution development in 5G enabled smart city.

This document will be further developed in future iterations.
1. Problem Definition

1.1. Business Background

Information and communication technology is showing an increasingly accelerated development trend in the world. A series of key technologies such as 5G network, Internet of things, cloud computing, big data analysis, new generation geographic information system and other key technologies are gradually carried out from the proposal of concept to the test and implementation of practical application, which has spawned many emerging urban application scenarios and innovative management modes, bringing much more possibility for the construction of 5G enabled smart city.

The ubiquitous perceived networks led by 5G will become an important cornerstone of the development of smart city. The Cloud-Edge-Endpoint software mode on top of 5G network has the ability to meet the different requirements of multi scenarios of smart city in the new era, and it creates edge intelligent system with a variety of technologies to realize the collaborative intelligence of smart city. Thus how to use the characteristics of 5G network to empower vertical industries has become one of the most concerned topics in the development of smart city. There are quite some important application scenarios on 5G network:

- 5G technology creates favorable conditions and enables the realization of new application scenarios of intelligent transportation, and improves the safety guarantee and dredging efficiency.
- The combination of 5G and AI can support the three-dimensional intelligent security monitoring system covering the whole city, and effectively guarantee the city security in all time and space.
- 5G technology can solve the problems of insufficient regional coverage and time frequency of traditional environmental monitoring methods, and the environmental protection supervision mode will usher in a new era.
- 5G technology can meet the needs of smart health care, and vigorously promote fair, accessible and inclusive health care reform.
- 5G and its combination with Internet of things, big data technology, cloud computing, AI and other emerging information technologies can help the government effectively respond to major emergency events and realize intelligent governance.

Obviously, there will be many challenges to adopt 5G and combined technologies for smart city construction. Firstly, there are many application scenarios and scattered fields involved in the construction of the new smart city, which requires the top-level design, and then adopt the proper functions according to city conditions. The specific implementation should be carried out from bottom to top and from point to surface to build "smart city micro unit". Secondly, the investment of smart city construction is large without clear business model, which is not able to effectively stimulate the joint efforts of the society. Therefore, it is necessary to build a new mode to realize the co-construction and co-governance and sharing. Thirdly, it is easy to form information silo if lack of unified framework to build smart city, thus operators should effectively integrate urban resources, establish operation service ecosystem, and lead market-oriented operation.

In addition to providing efficient infrastructure and connection services, telecom operators should undertake the development and construction of smart applications with partners in smart city ecology, and build a new pattern of co-construction, co-governance and sharing. Operators need to clarify their role positioning, make full use of resources, and provide high-quality services for all participants in smart city. Operators shall innovate in business type, business model and collaborative mechanism and provide more possibilities to promote the construction of smart city.

Under above situation, China Telecom and China Unicom put forward the strategy of 5G network infrastructure sharing in September, 2019, with the win-win business goal to build high quality 5G networks for the digital transformation.
1.2. Problem Description

The construction of a 5G smart city needs to address three key challenges in its digital system: first of all, it has to realize the interconnection and perception of everything and everyone based on 5G network; then it must break the data island and realize data intelligence through data circulation and sharing cross domain; at last it needs to realize smart digital operation quickly and effectively through standardized interoperability technology in the face of diverse scenes.

1.2.1 5G Network Infrastructure Sharing

5G ubiquitous perception network is one of the key infrastructure for intelligent connection of all things in smart city and the deep integration of human, machine and material. It aims not only to have full coverage without dead corner, but also to meet the differentiated needs of smart city in multiple scenarios. However Telco operators are facing the dilemma for 5G business, on one hand 5G is quite expensive in both network construction and operation comparing with 4G, but on the other hand both individual customer and enterprise are expecting to benefit from the 5G advantages as quick as possible.

There are many choices for 5G co-construction and sharing scheme, which also brings different impacts and difficulties to the follow-up maintenance, optimization and operational support.

- The cooperation of the co-construction and sharing work between the two sides need to reach an agreement in terms of business philosophy, network strategy, data system and technical standard.
- It requires partners to communicate smoothly in many key processes, including complaint support, network parameter management, end-to-end positioning and emergency support etc. In order to improve work efficiency, it is necessary to consider the needs of organization and staffing at all levels of both sides, and build an innovative collaboration mode.
- Technically, 5G network co-construction and sharing has significantly increased the complexity in many aspects, including anchor configuration and optimization, 4G and 5G interoperability optimization, voice and data service perception optimization. All these problems need to be solved to build a 5G based internet of everything.

1.2.2 Cross Domain Trusted Data Sharing

The development of data-driven new smart city faces many problems. The root cause lies in the failure to achieve a good integration of urban big data resources and urban business. Specifically speaking, the challenges include three aspects: first, there are numerous information system chimneys, which hinder data sharing; second, data governance is generally weak, and the value is greatly reduced; third, the level of data management is different, lacking of overall linkage.

Although Telco operators like to realize big value from big data, it is quite challenge for them to share their data, same as other enterprise data owners:

- First of all the data owner is not willing to share the data and information if their data right is not well protected.
- Secondly the data is classified with level of confidential, thus Telco operators need to obey the law and order to ensure the privacy information is well protected.
- Thirdly it is lack of technology for people to share data efficiently, with the protection of privacy and the data rights.

1.2.3 Smart City Digital Operation

As the multi-trillion-dollar communications industry looks forward to the fifth generation of mobile technology, seizing the range of growth opportunities attached to 5G demands more than just technology transformation – it demands a “fifth generation” business. This requires a holistic business transformation, encompassing new approaches to strategy and innovation; customer centricity; digital
business operations and agility; and the ability to engage in new, multi-sided and platform-based business models.

Digital Smart City Operation is an urban infrastructure that represents the highly intelligent operation surveillance, command and dispatch center that integrates resources from various departments and industries, presents city information and operation status, provides decision making support for city management through indicator system and analysis models, provides precaution, monitoring, management, tracking and control of city manageable events, and connects different smart city systems, and achieves efficient and unified linkage according to city operation and management requirements.

The digital systems hold the key to monetizing these new opportunities at scale, but transformation of these systems is not easy – as they run the existing business, and often represent long-term capital investments. As more service providers grapple with the challenges of overhauling their IT systems, it is clear that a new and radical approach is needed to meet the Total Cost of Ownership (TCO) and agility goals. A new generation of systems is needed, embracing state of the art IT technology such as Service Oriented Architectures (SOA) and micro service based approaches, open source, virtualization and cloud architectures.
2. Solution Proposal

2.1. Overview

2.1.1 Terminology

Digital Twin
A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning. This pairing of the virtual and physical worlds allows analysis of data and monitoring of systems to head off problems before they even occur, prevent downtime, develop new opportunities and even plan for the future by using simulations.

Smart City
An innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.

City Digital Twins
Information technology and urban information space model based on digital identification, automatic sensing, network interconnection, generalized computing, intelligent control, platform service, re-create a digital city corresponding to physical city matching in digital space.

City Information Model
City Information Model refers to an urban three-dimensional model with urban semantic information. The main functions include model data source collection, model construction, data visualization and model rendering. It is the basis of the City Digital Twins that superimposes real-time data, business data etc. on that model.

Building Information Modeling
Building Information Modeling is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. It is an intelligent 3D model-based process for creating and managing all of the information on a project: before, during and after construction. It is the digital working method for the building industry.

Smart City Information Infrastructure
Smart city information infrastructure refers to realize dynamic and all-around city status real-time sensing, rapid transmission of seamless integration and efficient processing of shared interconnection, providing effective support and strong guarantee for smart city applications. Smart city information infrastructure includes urban ICT infrastructure, spatiotemporal infrastructure, newly infrastructure for integration of smart city systems, the intelligent/smart parts of urban infrastructure, etc.

Federated Learning
Federated learning is an algorithmic solution that enables the training of machine learning models by sending copies of a model to the place where data resides and performing training at the edge, thereby eliminating the necessity to move large amounts of data to a central server for training purposes.
Secure multi-party computation

Secure multi-party computation (MPC) allows a set of parties, each with a private input, to securely and jointly perform any computation over their inputs.

2.1.2 5G Smart City System Design

The next generation of city development requires adhering to the mode of "simultaneous planning and construction of digital city and real city". It is an important basis to create a digital platform showing multi-dimensional urban space. The digital twin has gradually become one of the core innovation elements of the new smart city construction, supporting the city brain and promoting the construction of digital city.

The core of the smart city digital twin platform is to recreate a digital city matching with the real physical city in the network digital space. Through the one-to-one correspondence, association and coordination between the virtual entity and the physical entity, the digital twin city and the physical city can operate in parallel, realizing the digitalization, virtualization and visualization of the whole urban elements.

A digital twin platform is an important part of the new smart city architecture. Through the Internet of things and big data on 5G network, the digital expression of the city's all elements are presented in the city's three-dimensional space. It integrates the functions of digital modeling, binding and control, simulation and intelligence, and is used for security trajectory tracking, traffic congestion simulation and municipal pipe network monitoring. These smart applications provide vivid visual interactive interface and 1:1 accurate simulation support.

In this 5G smart city top level design, an open digital twin devops platform needs to be built to enable the agile development of standard digital twin service by all industry, such as the spatial twin, vehicle twin, building twin etc. In this way, the smart city operator could leverage these digital twin services to orchestrate the digital thread to support any of the use scenarios. The city digital twin is a data driven software object that may need to aggregate data from different source in order to provide a full view for its physical entity. For example, in order to build the digital twin for a car, you will need not only the current operational data from car owner but also the data from manufactory, and even its location data.
from Telco operators. To build the city information model, a trusted data circulation and sharing mechanism has to be established so that the digital twin can access all of its data from different stakeholders to have a holographic presentation of its physical entity. Different from virtual reality, the digital twin city is connecting with the physical city in real time through a single network regardless which Telco operator is building the physical network infrastructure. This encourages Telco operators to share 5G network infrastructure building the smart city information infrastructure for a cost effective communication. In addition to the functionality of digital twins, there will always have cloud security consists of a set of policies, controls, procedures and technologies that work together to protect the cloud native digital twin system, data and infrastructure. These security measures are configured to protect cloud data, support regulatory compliance and protect customers’ privacy as well as setting authentication rules for individual users and devices. From authenticating access to filtering traffic, cloud security can be configured to the exact needs of the business. And because these rules can be configured and managed in one place, administration overheads are reduced and IT teams empowered to focus on other areas of the business.

2.2. Architecture

In this section, we will first introduce an open digital twin framework to define a software standard for the development, deployment and runtime management of a digital twin. Then we are going to describe three key enablers for 5G digital twin city construction and operation, which are Digital Twin DevOps Platform, trusted data sharing and 5G Radio Access Network sharing.

2.2.1 Open Digital Twin Framework

The digital twin is designed as containerized distributed software built on its digital model, where digital brain is responsible for analysis, AI prediction, simulation and decision making, and digital body is responsible for a real time perception and interaction with its physical entity. Usually the digital brain is running on cloud with centralized data and machine learning, while digital body running on edge that close to its physical entity. These two parts of digital twin communicates through data and information on the high speed network, just like the nerve system.

The digital twin holds not only its static and dynamic characters, but also statistic of past and probability for future. Most importantly, various AI model is embedded into the digital twin to make it intelligent and autonomous. We have defined 3 types of AI model considering the data source used for AI training:

- Single twin model is an AI model trained by the historical data from a single instance, such as a time series prediction model for energy consumption of a 5G base station.
- Homogeneous twin model is an AI model trained by the data of group of twins from same class, such as network trouble shooting model for all 5G base station.
Heterogeneous twin model is an AI model accomplished across multiple types of group twins, such as site selection with consideration of customer, space and network.

As an example, we can build energy saving AI model into network twin for autonomous network operation. It will adjust network capability automatically based on the workload, so that the network will consume less power without affecting its functionality.

2.2.2 Digital Twin DevOps Platform

Digital twin is considered as a key enabler of digital transformation and organizations may receive multiple benefits from digital twin technology. Compared to static 3D models, real-time connectivity and data from both virtual and physical objects enables real-time system product design, simulation and testing with less time and expenses. Further real-time virtual representation of physical object minimizes design errors resulting less failures of physical system in manufacturing or in actual use. Digital twin is also prominent technology to bridge multi-stakeholder teams. Real-time virtual simulation environment extends accessibility of diverse stakeholder groups like global product designers, research and development teams, final users and customers to collaborate jointly in virtual environment.

In the smart city context the Digital Twin DevOps Platform is established to integrate both virtual and real world elements of the smart city. It is virtual meeting points for multi-stakeholder groups within the smart city. It enables smart city developer or project owner easily to integrate heterogeneous stakeholders like architects, engineers, constructors, property owners and managers into the platform. The Digital Twin DevOps Platform thus augments the co-development and collaboration among the smart city stakeholders. It strengthens transparency and communication, but also trusts among diverse urban stakeholder groups. The Digital Twin DevOps Platform is low threshold environment to design and analyze probable scenarios and evaluate risks caused by factors like climate change.

Same as micro service, the DevOps process shall to be followed to develop the cloud native digital twins within a single virtual team composed of cross-functional members all working in collaboration. By following an industry standard development process, the multi-stakeholder groups can deliver the digital twins with maximum speed, functionality, and innovation. Then the business owners can simply instantiate the digital twins and orchestrate the instances to serve different use scenarios.
2.2.3 Trusted Data Sharing

With these major challenges on Rights, Privacy and Obligation for people to share the data, we are proposing several key technology pillars to address them: block chain is used to protect the digital rights of individual or organization, also encouraging data circulation. As for the Privacy protection, data virtualization and privacy computing work together to solve privacy issues and further ensure data security. Data virtualization aims to analyze and display desensitization data. Meanwhile, privacy computing especially federated utilizes all privacy data with multi-party computation environment. Finally for the obligation, data suppliers must adhere to data governance standard.

When multiple stakeholders collaborate to accomplish some task or set of tasks, a contract is required among them. In many cases, there is lack of trust among the stakeholders involved in a contract. To address this issue, it is necessary to verify and reliably trace the contributions of the things engaged in the contract. Based on blockchain technology we can build a general mechanism of data asset management and data sharing, establish a trust-chain from consumers to parties to realize lifecycle management and visualization of data assets. There will be following advantage to encourage the data circulation and data sharing among stakeholder with the trust:

- **Standardization of Data Asset Management**
  - Decentralization of enterprise data asset management to ensure consistency of data asset sharing and exchange process

- **Private Data Security**
  - Data sharing authorization, privacy data protection, authority records management, security risks control

- **Normalization of Data Transactions**
  - Build an end-to-end information chain for data distribution to achieve data mashing, two-way anonymity, and traceability for data sharing

2.2.4 5G Radio Access Network Sharing

In 5G era, the demand of network co construction and sharing is more urgent than 4G time due to following reasons:

- **Network sharing can reduce the initial investment pressure of 5G operators**
  - The number of 5G base stations will far exceed 4G with high cost of single base station and high price of 5G spectrum, which will increase the investment of supporting infrastructure and make a large the initial investment;

- **Regulators require network sharing to encourage business competition for better service**
  - Compared with the acquisition and merger of operators, telecommunication regulators obviously prefer network sharing among operators, and introduce more companies into the telecom industry to ensure a sufficient competitive environment;

- **Network sharing can improve the experience and speed up the 5G business**
  - 5G services have high requirements on spectrum bandwidth, thus the operators with limited spectrum resources can share carriers to form a continuous large spectrum, which can significantly improve the user experience;

5G RAN co-construction and sharing is mainly composed of NSA wireless access network and SA wireless access network. Network construction must cover all scenarios that users can access, such as high-end office buildings, shopping malls, central CBD in dense urban areas, general urban roads, residential areas, subways, city high-speed rail, high-speed rail, rural coverage, etc., so as to realize independent and complete 5G network continuous coverage and give users the ultimate user experience.
2.3. Scenarios

The digital twin smart city refers to the use of new generation information technology on 5G communication technology to manage the urban operation system in an integrated and systematic way, so that all functions in the city can operate intelligently and coordinately, and comprehensively improve the satisfaction of citizens. During Covid-19 epidemic, the digital twin technology based on 5G are considered in several typical smart city scenarios, from the planning and construction of shelter hospital and severe hospital with 5G network infrastructure, to the remote medical consultation and ambulance scheduling. Here we are going to discuss how digital twin is applied in these scenarios as an example.

2.3.1 Digital Twin City Planning

Digital twin city refers to the city in digital space corresponding to physical space, in which a matching twin city is reconstructed. At the beginning of urban planning, the digital twin realizes the digital modeling of the city, and supports the simulation and development deduction of urban planning and design, construction and operation, and realizes the analysis of population space, public facilities layout, infrastructure construction, urban governance services, etc.

The digital twin city provides support for scientific and reasonable urban decision-making and management, promotes urban construction and governance to the "cell level" refinement level, and realizes the business integration of planning, construction and management and dynamic data integration.

2.3.2 Digital Twin Telemedicine

In the medical field, the ideal digital twin should be an accurate replica of a complete human body, showing all the current and future physiological and pathological results, and drawing it in a highly detailed visual form. However, the reality is that the process is not yet mature, and it is full of complex statistics, genetic pathways and many other possible outcomes that can only be explained by trained professionals.

The concept of digital twin will be applied to EMR, personalized treatment, collaborative data research and determination of successful treatment, as well as running treatment simulation without harming patients to help diagnosis. The ultimate goal is to use various current AI concepts simultaneously to help develop a fully functional digital twin. In addition, digital twin can be used to monitor and maintain equipment, and simulate possible problems in use. By creating many types of digital twins, healthcare
workers can receive real-time information about ward management, equipment, and treatment options. All of these will greatly save costs, shorten patient waiting time, thus it can treat more patients.

5G network can support 4K/8K remote high-definition consultation with high-speed transmission of medical image data. It enable experts to carry out consultation anytime and anywhere, improve the diagnostic accuracy and guidance efficiency, and utilize high-quality medical resources. Through 5G network, the medical equipment status, vehicle position and video images inside and outside the vehicle can be transmitted in real time, which is convenient for remote consultation and remote guidance. The collection, processing, storage, transmission and sharing of pre hospital emergency information can fully improve the efficiency of management and treatment, improve the quality of service, and optimize the service process and service mode. Based on the big data technology, the value of medical information data can be fully exploited and utilized, and the application, evaluation and decision-making can be carried out to serve the emergency management and decision-making.

2.3.3 Digital Twin Automatic Drive

Since autonomous driving involves the complexity of perception of the environment, it requires a lot of verification and testing to ensure its driving safety. Through digital twin technology, it can simulate multiple domain models and compile sensors and edge devices, which greatly improve system performance and verification efficiency with the advantages below:

- Comparative test training: virtual test technology based on computer simulation technology enables the test system to handle quantitative tests of thousands of tasks in a short time, and can replace the original physical test of tens of billions of kilometers for autonomous driving. But this technology requires scenario simulation design based on expert knowledge, and certain scenarios that have passed the simulation test also need to be re-evaluated and verified in the field test. By fusing the advantages of human experts and computer systems, the system can be automatically upgraded under the guidance of human experts. The cognitive mechanism also introduces adversarial learning models to automatically generate new task instances and further enhance its automatic testing and verification capabilities.

- Parallel driving system: the parallel driving system based on the digital twin consists of the description car, the prediction car, the command car and the real car digital quadruplets. Among them, the description car mainly describes the behavior of the autonomous driving vehicle and the traffic environment in a formal way to build virtual vehicles and environment models. The predictive cars go through a large number of computational experiments with trial and error, and then complete the prediction and optimization of driving schemes in complex driving environments. The command cars have real interaction with physical vehicles, guide real cars drive safely.
2.3.4 Digital Twin Autonomous Network

Digital twin based autonomous network leverages digital twin technology to build network twin in the cyber space through the real-time automatic data acquisition and update in the physical network. It uses well-defined digital model and algorithm, the digital twin autonomous network can automatically carry out relevant correlation and operation according to the relationship between the network elements in the real network, and finally provide autonomous network.

Digital twin based autonomous networks are self-healing, self-managing and most importantly independent of human interference. Such networks will be able to be developed in a way that avoids wasting effort on maintaining even simple mechanisms such as storage, scalability and data retention.

2.4. Business Capabilities

During the construction of smart city, each stakeholder set up single or multiple relationships with other stakeholders through specific interactions and a value network system has formed gradually. Usually the Smart City Administrator and Smart City Operator act as the central nodes of the network connecting with plenty of organizations and individuals. They play core roles on the implementation and operation of smart city, and rely on a few key business capabilities on a digital twin based 5G smart city system as below.

2.4.1 Connection and Perception

The construction of digital twin city needs to be based on global perception. The aim of digital twin city is to establish a virtual space that mapping with the real world and interacting with the real world. All kinds of physical entities in the real world have corresponding digital virtual bodies in the twin space. It is the foundation for the digital twin city to establish a whole area and full time IoT perception system for the city and realize the multi-dimensional and multi-level accurate monitoring of the urban operation situation. However, objects are not separate individuals. For collaborative interaction between objects, it is necessary to define the spatial location and unique identification of objects in the whole domain, and ensure that the equipment is credible and controllable.

With the 5G network infrastructure sharing, everything in smart city will be connected with IoT sensors. It provides the real time “read and write” a physical city for city administration and city operators in a visualized 3D digital space.

2.4.2 Data Driven Intelligence

After the sensors collect the data, the edge computing node carries out local preliminary processing and rapid response, then gathers the high-value data to the cloud center. Cloud computing does big data analysis and mining, processing and analysis data with sharing and opening, optimizes and upgrades business rules or algorithm models, and distributes them to the edge side, and the edge computing runs the calculation based on the updated algorithms or rules, update and upgrade the end equipment, so as to achieve a complete closed-loop self-learning optimization.

Taking advantage of semantic technology to extract the structure and automatically connect the attributes, the new urban model representation CIM has become the core of the digital twin city. On the one hand, CIM carries the attribute information of urban elements in addition to the 3D visual representation. On the other hand, the geometric structure and attribute information of CIM can be understood by computer. The 3D model of city is introduced into the field of city computing from the visualization stage to realize the mining, statistics, analysis and decision-making. The digital expression of physical city has experienced the development process from the initial 2D, to 3D and then the holographic city structure.
The application of deep learning and self optimization technology in the field of artificial intelligence in digital twin city can make the city change from the previous grass-roots governance mode of fighting with each other among departments, addressing the symptoms rather than the root cause, passively and slowly, to the mode of global collaborative governance, intelligent response to problems, and demand prediction in advance, so as to construct efficient and intelligent urban operation rules. In the digital twin city, the application of deep learning technology mainly focuses on mass data processing, system operation optimization and so on.

2.4.3 Agile Digital Business Process

In real business environments of cities, the stakeholders will establish various relationships and play relevant roles in various ways. More types of roles and functions of stakeholders will be developed, and it tends to generate diversity of digital ecosystem. Through modeling the relationships of stakeholders in a smart city scenario, it is helpful to make clear of the interactions and collaborations within the smart city operation business processes.

To support the dynamic use scenarios in smart city, the open digital twin framework is built on top of the microservices architecture with modern DevOps development process. The evolution of both microservices and DevOps was not just limited to transforming monolithic applications into decomposed services. DevOps has become an industry shared common approaches to software development to build similar organizational structures and development cultures, while also sharing an affinity for cloud-based infrastructure and automation. The digital twins built on top of microservices could follow a similar progression driven by a desire for development, speed and scalability, all of which fits into the concept of agile development. The adoption of these agile methods will greatly help to achieve continuous integration (CI) and continuous delivery (CD), which speeds the deployment pipeline, achieving a result that culminates in bringing changes to digital city production as quickly as possible.

2.5. Integration Approach

As the digital twins are built into container as a distributed software with Open API, the system integration follows the principles of cloud native and micro services, and adopts the K8S+docker cloud native architecture to provide a more flexible and efficient operating environment for the system integration.

The mature distributed micro service architecture framework accelerates the integration and collaboration between collaborations. Through the integration of various mature development tools and the orchestration of business middleware and data APIs, the digital twins can meet various scenarios of big data analysis, AI model training, production reasoning and service sharing. The digital twin based application product integration enhances data injection intelligence, in addition to the orchestration of digital twin instances.

In short, the DevOps platform integrates the internal mature capabilities of the enterprise, creates a new infrastructure for enterprise digital transformation, and accelerates the speed of cloud-network integration and digital transformation.
3. Validation of the Solution

In order to accelerate the 5G deployment and boost the operational efficiencies, China Telecom and China Unicom announced 5G joint construction and network sharing in September 2019, to shorten the construction cycle and reduce the investment pressure. Definitely this policy may help 2 Telcos to save significant cost in terms of CAPEX, OPEX, and Total Cost of Ownership. On the other hand, the two Telcos will need to co-operate the network from planning, rolling out, optimization, and operation throughout the entire network life cycle. Such a joint-operation mode requires a visible and virtualized simulation system to enable the two Telcos for co-planning and operation but not sharing their data and privacy in 2 silos. This is the motivation for us initialize the catalyst project C20.0.10 “Inception: digital twins for 5G network infrastructure-sharing” in 2020, to consider leveraging digital twins for virtualized simulation and federated learning for network analytics with data in silos.

This catalyst project is championed by China Telecom and China Unicom, with the participation of AsiaInfo, ZTE, Si-Tech and Tianyuan Dic closely work together to complete the catalyst project and prove the digital twin based collaborative solution will address 5G business challenges effectively. It demonstrates how digital twins can help two Telcos succeed with the joint construction and network sharing of 5G radio access network, including effectively planning 5G base stations, pinpointing performance issues and ensuring personalized customer experience.

3.1. Scope

In the business model of 5G network infrastructure sharing, China Telecom and China Unicom focus on the life cycle management of 5G RAN. Simply, one operator is network constructor responsible for building 5G network in designated area, another joint operator can share 5G capability equally. The network constructor expects to have better return of investment through network sharing, also reducing the operation cost with autonomous network ability. The joint operator expects its business requirement is fully considered in 5G site selection. Also its customers should be equally treated on 5G experience during routine operation.

Hence, we are trying to address the following three challenges in this catalyst project:

- First of all, the business requirement from all stakeholders has to be considered comprehensively and precisely to conduct the network planning.
- Secondly, it will be quite challenge for efficient network operation especially when a customer walk through 5G zone from different operators.
- At last, how could joint operator manage their customer experience on 5G without sharing the customer data to other constructor?

3.2. Prototype

In order to overcome the three challenges above, a customer centric Intelligent Network Co-operation Platform is designed to manage the business process of 5G network infrastructure sharing.

The Intelligent Network Co-operation Platform is built on top of 5G digital twin service centers from both Telcos, to manage the life cycle of 5G network infrastructure sharing. Each digital twin service center is responsible for creating its own corresponsive digital twins based on the network, customer and space they are responsible for. The digital twin is implemented with digital brain and digital body that has cloud-edge interaction with their physical entity. One on hand, the service center creates the digital thread to coordinate among different digital twins running through business process for one Telco operator. On the other hand, two service centers can also have cross boarder collaboration through federated learning.
among digital twins. This technical architecture is scalable for Telco operators to manage their 5G network infrastructure sharing collaboratively.

3.3. The Digital Thread

To become an intelligent digital operator, first of all we digitalized the business process of network planning, construction, operation and optimization. This business process is implemented as a customer centric digital thread, that we leverage TM Forum’s Customer Experience Lifecycle model as the metrics framework to measure user experience in a customer’s network journey.

We have developed a state of the art user experience algorithm portfolio named ECS-Emotional Connection Score to derive user’s true experience with the data metrics defined by TMForum’s Customer Experience Lifecycle model. At first, the individual user behavior can be simulated in digital twins. The aggregated user traffic is then converted to network capacity and performance metrics for the Telco to better plan and operate the network. Later on, we will also use ECS algorithm portfolio to bridge the network capacity and performance to user quality of experience with an ultimate target to maximize user experience of the 5G network.
3.4. The Digital Twins

3.4.1 Network Twin

Network twin can create accurate simulation environment for network planning, monitoring the running state and health of the network.

Through network twin, the CSP can do more tests their network operation’s affect and make the decision on whether an operation can bring a predictable result to the network. This can reduce the risk of high risky operation on the physical network.

3.4.2 Customer Twin

Customer Twin represents the corresponding physical individual in digital world. It collects the data and information of individual’s character, behavior, time allocation, location and other elements in real time and analyzes them in real time in its digital brain. In this way, Customer Twin can depict customer behavior patterns, have insight into customer life cycle, simulate and predict the business effect based on customer experience. As a result, it will accelerate the analysis cycle to discover new customer demand accurately, improve user experience and stickiness, and then improve enterprise efficiency.

3.4.3 Spatial Twin

Based on the needs of business scenarios, Spatial Twin uses GIS and BIM information to conduct digital modeling for the physical area space concerned, and uses the Internet of things to establish a comprehensive and dynamic connection between physical space and digital space through real-time data. At the same time, the future changes of physical space can be simulated, analyzed and predicted by means of simulation in digital space.

3.5. Key Features

3.5.1 Real time Data Perception

To become a customer centric Telco operator, it is critical tasks to improve real time network perception on performance to manage customer experience and ensure customer satisfaction. Traditionally Telcos obtain customer satisfaction through market research and customer survey, which has long response period and limited range. The traditional network optimizations only rely on the
indicators of network connection and disconnection to locate the poor quality area. This kind of method has been difficult to meet the needs of the current market competition and fast response requirements. Therefore, a set of comprehensive user network perception model is established to calculate the user network perception score, provide reasonable and high-quality services to users, improve user perception, maintain user loyalty and enhance user experience.

3.5.2 AI Driven Autonomous Network

AI technology has natural advantages in terms of cross-field feature mining, in-depth data analysis, and dynamic policy generation. Introducing AI technology into network digital twin can provide new capabilities for network operation and maintenance in the 5G era, helping telecom operators build more flexible and efficient information infrastructure. The network AI can play important roles in four aspects: reducing simple repetitive network operations, forward-looking prediction and prevention based on historical data, high-complexity and multi-dimensional analysis, and seeking the optimal solution for resource and service requirements.

With the help of AI, the digital twin can reduce the manpower investment, change passive maintenance into active intervention beforehand, and perform data analysis in business, management and operation domains to empower service operation. In this way, we can achieve optimal match between network resources and services and help operators to broaden sources of income and reduce expenditure at the same time.

**Figure**  Network AI Helps Operators to Meet Challenges

At present, operators are gradually increasing their investments in network automation and intelligence, and are seeking to use AI to achieve all-round network cost reduction and efficiency increase and business opportunity exploration. In terms of research and practice, setting up AI related strategy, designing AI solution architecture and developing AI platform to enable applications that can support much more complex data analysis and decision making in network O&M and services are the common selections for most operators regarding AI as a great opportunity to establish leader position in the future market. Operators also play leading roles in network AI related projects in standard and open-source organizations to study and pilot valuable applications. The ability to harness AI will become imperative for operators of future 5G networks.
3.5.3 Federated Learning to Share

Federated learning solves the problem that network data and customer data belong to different operators, but need to address the network troubleshooting and equal customers’ treatment under the situation of 5G network sharing. It builds the cross operator collaborative modeling scheme that aims at each operator’s own privacy data, realizes collaborative modeling under the premise of ensuring data security. In this scheme, multiple operators participate in modeling and calculation to realize:

- Horizontal federated learning can build a unified data computing model with expanded samples among operators to achieve a unified caliber of complex computing for different user groups but similar data characteristics.
- Vertical federated learning can achieve cross operator cross domain computing by constructing a joint model to take into account the data characteristics of multiple operators according to the different data characteristics of different operators.

Customer experience management: using the horizontal federated learning technology, we can fully train the cross operator customer samples to form a unified AI model with comprehensive data to calculate the emotional connection score in their own area.

Network planning: using vertical federated learning technology, the existing 4G network construction of multiple operators is completely considered to build the AI model through fusion calculation of data characteristics across operators, then guide the network planning in grid.

3.6. Use Cases

During Covid-19 epidemic, the 5G network has to be jointly constructed and shared by Telco operators efficiently and effectively to support the medical need from shelter hospital and severe hospital. The digital twin based solution ensures real-time perception, optimization, simulation and prediction of 5G network, which guarantees high quality service in public health emergency. Here we have four demo cases that leverage digital twin based Intelligent Network Co-operation Platform to complete effectively.

3.6.1 5G RAN planning

- Scenario: the 5G RAN has to be planned and constructed shortly after the location is selected for shelter hospital and severe hospital in a epidemic
- Technology: federated learning among digital twins from multiple Telco operators are applied for 5G RAN site selection, and a live simulation by digital twins will provide visualized effect for network planning
- Value: the visualized live simulation based on federated learning makes what you plan is what you will have. This leads to a high rate of ROI because of accurate planning with the consideration of both parties.

3.6.2 Real time Network Slicing

- Scenario: on the way from the shelter hospital to the severe hospital, a low latency network connection need to be guaranteed to monitor critical patient's condition in ambulance.
- Technology: the network twins will be provisioned with low latency slicing, based on the speed of ambulance and scheduled route information provided by spatial twin. Edge-cloud collaboration in customer twin will ensure the real time monitoring for patients.
- Value: TThe digital twin from network supplier can serve the emergency situation intelligently and automatically with the consideration of special requirement regardless whose customer it is.

3.6.3 Customer Experience Management

- Scenario: when concurrent remote consultation sessions occur, the experience of remote medical expert on video conference has to be satisfied for treatment effect.
Technology: the network experience of customers will be scored by customer twins and notify related network twin to tune performance and automatically ensure the high bandwidth demand of the network.

Value: ensure customer experience through intelligence and personalization. It combines customer characteristics, network characteristics and special scenes to guarantee the network needs of specific business.

3.6.4 Energy Saving

- **Scenario:** the number of people changed dynamically at the late stage of epidemic, some areas have become vacant when more patients recovered and leave. Telco expects to save energy on 5G RAN when less users in hospital.

- **Technology:** the network twins perceive a decrease in the utilization of network resources and gradually adopt appropriate policy for energy saving, which is based on a trained AI model according to the network usage.

- **Value:** enabling self organized network to adapt the environment automatically.
3.7. Results

Empowered by the AI model, the digital twin based solution can deliver cost effective network planning, autonomous network operation and personalized customer experience management. The federated learning cross Telco operators enabled both parties benefit from AI without confidential data exposure. This builds an innovative business model through digital synergy. In this way, one Telco itself will become an intelligent digital operator that could run a autonomous network, while efficiently collaborate with other Telco on network sharing.

This catalyst contributes practical technologies to TM Forum asset as a reference for 5G joint construction and network sharing.

Value by Digital Twin:
- High rate of ROI by fine granularity network planning;
- Cost effective operation through autonomous network;
- Customer loyalty with real time experience management
- High productivity as a digital twin enabled digital operator

Value by Federated Learning:
- Innovative business model through digital synergy
- Data sharing cross boarder through federated learning
4. Conclusion and Value

4.1. Conclusion

The digital twin technology architecture changes governance model of smart city. The digital twin based 5G smart city is constructed by city information model with real time data, cloud-edge collaborative distributed software and peripheral intelligent facilities on 5G. This loose couple integration architecture has completely broken through the previous All-in-One technology architecture, with several unique advantages in supporting urban governance. Firstly, it provides a panoramic perspective, multi-dimensional observation and full data analysis of the city, which can deeply grasp the urban signs and observe the urban operation rules, so as to achieve accurate implementation based different type of digital twin. Secondly, it improves the fine management, 360 degree monitoring without dead angle, three-dimensional perception of land, sea, air and sky. The operators can master the pulse and breath of the city and make a decisive decision with each individual instance of digital twin. The third is to provide collaborative means, emergency response, global coordination and linkage among digital twins, and dispatch resources nearby. The fourth is to promote scientific decision-making, predict the development trend of the city in advance, drive the decision with data, verify the decision by simulation, so as to promote the optimal allocation of resources and capacity and the optimal operation of the city.

As an important element of digital twin city, urban brain has its professional and efficient operation ability, which determines whether the digital twin city can be sustainable development. The operation of urban brain cannot rely solely on the strength of government departments, but should unite with all sectors of society to gather wisdom, and form a professional operation team of digital twin urban governance, which is composed of government management, business operation, platform operation, data operation and safe operation. Based on the principle of "unified management and one-stop service", a long-term operation mechanism should be established and relevant industries related to urban operation should be formulated. Business application, platform operation, data operation, technical operation and maintenance and other processes on top of open digital twin framework will promote the evolution of the city to a highly intelligent modern governance system with self optimization, self decision-making and endogenous development.

4.2. Contributions to TM Forum

Through this catalyst, the team contributes two sets of general and reusable methodology to TM Forum. One is how the 5G network intelligent operation can build on the digital twin system; another is the joint network construction and sharing methodology through digital synergy across operators. Technically, we have following innovation around digital twin framework and system.

**Digital Synergy:** solve the problem of cross-border intelligent synergy on privacy data.
- Holographic perception: full data from customer, network and spatial twin
- Comprehensive cognition: knowledge graph among digital twins
- Joint construction and sharing: life cycle operation through federated learning

**Digital Thread:** realize complete digital process for full scene coverage in 5G lifecycle.
- Scene choreography: design business process by digital twins orchestration
- Space-time fusion: traceable activities in target space under specific timeline
- Immersive experience: manage the real entities by panoramic visualization

**Digital Twin:** assist to build a real-time, agile and efficient adaptive 5G network.
- Real time synchronization: low latency interaction between two world
- Data driven: self evolution based the continuous intelligence on historical data
- Personalized service: smart network optimization for customer experience
5. Future Work

5.1. Digital Twin DevOp Platform

The 5G enabled Digital Twin Development & Operation Platform will continue to evolve to ensure each digital twin can be upgraded to drive its physical entity with data intelligent.

- Phase 1: global perception, mapping virtual entity to physical entity

In the primary stage of digital twin platform, the main objective is to build digital infrastructure through digital modeling based on the urban information collected by alarm, sensor and controller. Traditional urban elements are gathered in two-dimensional plane, which cannot meet the requirements of immersive experience. The key content of digital twin platform is to realize the three-dimensional elements, including urban buildings, roads, pipe network and other infrastructure, which can achieve accurate digital modeling. At the same time, according to the needs of urban operation and management, the digital twin platform also synchronously carries population information, meteorological information, video monitoring information and other data, becoming a centralized display carrier of urban big data. The three-dimensional model of the city has become the construction trend of innovative smart city.

- Phase 2: real time interaction, virtual entity drive physical entity

The second stage of the development of digital twin platform is to realize the real-time interaction between the digital object and its physical object. The operation instructions of the digital twin platform can be transmitted to the physical entity through the transmission network and the perceptual control equipment, so as to realize the control of the physical object. This ability is mainly based on the perception terminal of municipal, traffic, construction and other facilities. According to the business needs and terminal functions, it provides facilities for health monitoring, remote control, fault alarm and other management and service capabilities, so as to achieve overall management and closed-loop business process. At this stage, the digital twin platform has carried out the development of facilities and equipment management and control functions based on business requirements, including vehicle and personnel trajectory tracking, pipeline and bridge status perception, illegal parking, garbage overflow and other city appearance monitoring, providing technical support for the construction of urban safety and civilization.

- Phase 3: simulation and prediction of physical world from virtual reality

The third stage of the development of the digital twin platform is to realize the simulation and dynamic prediction of the physical world. It will simultaneously form the optimization solution, and deduce the urban operation situation in the digital world. The realization of simulation depends on the cognition of the operation mechanism of the physical world. Through the modeling of natural phenomena, physical laws and crowd activities, the simulation can provide scientific decision support for urban planning, management, governance and service. The starting point of digital city simulation is to make urban construction and development less detours, which is the real embodiment of digital twin value. Enterprises and scientific research institutions are carrying out actual road simulation for automatic driving application.

- Phase 4: independent judgment based on data intelligent

The fourth stage of the development of digital twin platform is the deep integration and application of artificial intelligence into urban details. The granularity of ubiquitous perception determines the
refinement degree of digital twin. The digital twin platform will gradually develop from coarse-grained facilities and equipment perception to fine-grained information perception, constantly enrich data sources and improve the accuracy of urban operation and management. Artificial intelligence technology, including computer vision, natural language processing, biometric recognition, knowledge graph and so on, is further applied to learn, analyze, identify, summarize and discover the urban operation rules from historical data, deduce the future development trend based on the space-time trajectory of urban development, and enable the intelligent operation and management of cities, which has become an advanced form of digital twin platform development.

5.2. Trusted Data Sharing Platform

As cross domain data sharing is critical for 5G smart city, a trusted data sharing platform could be jointly constructed by stakeholders in compliance with the law and regulation of privacy and data asset protection. This digital platform will encourage the data circulation and data sharing across enterprise and support every stakeholder on their rights, privacy and obligation. Besides the block chain, we can further leverage several key technologies to build the platform with trust:

- First of all, the data circulation mechanism is built on block chain to empower data owner to share their data with the functions of authorization preservation, copyright traceability and smart contract;
- Once the data right is protected the stakeholder can share their data in two ways: upload desensitized data to the data virtualization center, or download the secured computation model from privacy computing center. The data virtualization is based on data fabric technology that connecting with the open data APIs from enterprise level big data platform and then compose all the data together to build unified data model for consumers. On the contrast, the privacy computing center use secure multi-party computation technology to allow different stakeholder to compute their own data locally then assemble the partial calculation into final result.
- For each enterprise big data platform, the edge computing as well as the data governance will ensure the real time data quality to meet the requirement for data sharing and win the trust from data consumers.

With trusted data sharing platform, the city, government, company and even individual will have one stop service for the data and information they are eligible, in order to better understand, analyze and predict the situation they are interested in.
Administrative

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Document History

**Version History**

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<td><a href="mailto:dongyc@tydic.com">dongyc@tydic.com</a></td>
</tr>
<tr>
<td>Chuanqiang Peng</td>
<td>Tianyuan DIC</td>
<td><a href="mailto:pengcq@tydic.com">pengcq@tydic.com</a></td>
</tr>
<tr>
<td>Zhimin Li</td>
<td>Tianyuan DIC</td>
<td><a href="mailto:lizhimin@tydic.com">lizhimin@tydic.com</a></td>
</tr>
</tbody>
</table>

Additional input was provided by the TM Forum senior program manager:

- Shengfan Hou, TM Forum