Conceptual model of Communication Service Provider Digital Twin based on Infocommunication System Cross-Domain Model

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***Abstract*— Digital transformation in Industry 4.0 today is associated with the transition to cyber-physical systems through the use of digital twin technologies, the industrial Internet, Big Data, Artificial Intelligence, Machine Learning, etc. In this work, an attempt of strict theory developing was made that would allow to determine, "what Digital Twin is" and to determine the place of the Digital Twin among other models. As a result, a cyber-physical Cross-Domain Model of Communication Service Provider and the model of the Digital Twin for the digital service provider was suggested. The models aim to meet new problems in communications management.**

I. INTRODUCTION

Digital Twins (DT) are being developed for industrial enterprise: engineering, manufacturing and operations, and for maintenance and service. The technology of DT is being supported such technologies of Industry 4.0 as IoT, Artificial Reality (AR), CAD, Product Life Cycle Management (PLM), Artificial Intelligence (AI) etc. [4-6]. As argued in [4], DT enable companies to create globally competitive next-generation products in the shortest possible time and manage changes at all subsequent stages of the life cycle.

The main reasons and value for industries are [7]: "It is the collection and use of data in real time that makes it possible to increase the accuracy of modeling and reduce the error of discrepancy with a real object".

The ability to integrate vast data sets into a single model is of particular value. DT bring the greatest effect during implementation, starting from the earliest stages - the design and engineering process, then covering control systems, production and economic data, the stage of model adaptation during operation [7] and the emphasis is on predictive analytics and what-if simulations [9].

However, no source answers the question "what a DT twin is?" from mathematics, information theory, computer science point of view. To date, there is no coherent theory and definition of the concept of DT and, therefore, the place of the DT in the series of models has not been determined.

Today, the DT can be useful for a certain range of problems of the Operations-Administration-Maintenance (OAM) -class, which, as suggested by the author, can be solved by the DT more accurately and dynamically (quickly) together with already known traditional approaches. Requirements for a higher response rate of control systems and high control dynamics follow from the current situation and forecasts for the future - a rapidly growing density of devices, rebuilding their network topology, Internet of Everything, 5G/6G etc. From one side, the OAM tasks of digital service provider (DSP) can be formulated in terms of traditional abbreviation FCAPS. From the other side, we cannot even imagine how many and what kind of DSP problems will be possible to resolve by means DT technology. I believe, by the time we understand very small part of that picture.

Here is some dimensions we can apply DT for DSP:

1) Analysis of extremely rare events, when the Knowledge Base of a large operating company is formed for the case of events that are difficult to predict and difficult to analyze. For example, a meteorite crash caused 30% of services to fall. People use pens to enter data about the state of the object in the knowledge base.

2) Modeling of difficult formalizible and difficult predictable results.

3) Improving service level and reliability through preventive (predictive) maintenance. Preventive maintenance helps you act proactively to reduce the number of problems that may arise.

4) Improving product development and implementation by modeling behavior through understanding the relationships between DTs of the same or different types. Simulation allows for better product and service planning.

5) Improving the reliability of services for certain groups of clients. By knowing ahead of time which clients are actually affected by network problems in a given situation, you can plan quality retention activities for those client groups. The problem here is that infrastructure construction is a complex and expensive aspect of a telecommunications operator's life. At the same time, technologies are developing in parallel and very quickly. A situation arises in which the infrastructure is not yet fully ready for the technology (for example, for mobile video, when it works in general, but overloads occur), but there is a desire to launch the service as soon as possible. DT will help to avoid problems in narrow areas [12, 13].

6) Reducing the time to bring a quality product / service to the market. Modeling a service using a DT.

Here are some possible use-cases we can use DT:

1) to predict and proactive eliminate/avoid a problem;

2) to calculate the period of "network relevance" and predict the timing of the start of network development and the necessary investments;

3) to assess the performance / reliability of the network and the sustainability of services for special cases (football match, elections, meteorite) - guaranteeing the operation of certain services like emergency services - 112/911;

4) to predict customer behavior.

II. Domain Model of a Cyber-Physical System

A. Key definitions

To describe the model (by A.D. Sotnikov) is used [1-3] as a basic we need introduce a number of concepts and definitions

An information system deals with "information objects": manifestations $\{\langle A\rangle, \langle B\rangle, \dots\}$ of entities $\{A, B, \dots\}$ [1].

The information is transferred, when the signal transmitting an image (notion) from the varifold thesaurus of the source system *A* into the varifold thesaurus of the target system *B* is changed

$$\langle \mathrm{A}\rangle^{\xi_\mathrm{A}} \xrightarrow{\text{Signal}} \langle\langle \mathrm{A}\rangle^{\xi_\mathrm{A}}\rangle^{\xi_\mathrm{B}} \tag{1}$$

The information is received when a new image of the source is formed within the varifold thesaurus of the target system.

$$\langle A\rangle^{\xi_A} \xrightarrow{Q_1} \langle \mathrm{C}\rangle^{\xi_\mathrm{C}} \xrightarrow{Q_2} \langle\langle\langle A\rangle^{\xi_\mathrm{A}}\rangle^{\xi_\mathrm{C}}\rangle^{\xi_\mathrm{B}} \tag{2}$$

B. The domain-based infocommunication model

The least generic and abstract model is the "domain model" (DM) [1-3], which makes it possible to identify infocommunication systems components, define the inter-component interfaces and consider the information interaction processes. There are three domains within the DM, associated with three relatively independent, albeit closely linked, types of activity. The *Physical Domain* (PD) is mostly concerned with energy processes and the interaction of material objects. The situation analysis and intellectual activity producing evaluations and solutions is the product of mental and psychic activity of the *Cognitive Domain* (CD). The *Information Domain* is the area for the circulation of data used in the CD, representing the objects, phenomena and process of the PD.

According to the DM, the sphere of telecommunications lies on the boundary between the physical and information domains. The perception of physical reality, represented by ID entities, is linked with information interaction and occurs on the border of ID and CD. Thus, infocommunications embrace all three domains, although at present, the cognitive domain remains insufficiently explored, since the categories of cognition and other entities and relations within the CD, linked to the generation and consumption of the meaningful-semantic nucleus of information, remain underdeveloped.

The general view of *elementary interaction* between two information systems within the ID is a unidirectional transfer/receiving of the representation of the object of PD, described as follows:

$$\langle\langle An\rangle^{\xi_{An}}\rangle^{\xi_{C^m}} \xrightarrow{Q_{22}^{\xi_{C^m C^k}}} \langle\langle An\rangle^{\xi_{An}}\rangle^{\xi_{C^k}}. \tag{4}$$

The information interaction occurs by means of exchanging "messages", which are the subsets of the set of information representations $\langle A_1\rangle^{\xi_{An}}$ of the object $\langle A_1\rangle^{\xi_{An}}$, transferred between IS C_m and C_K. Thus, the interaction of several IS within the ID is described as follows:

$$\left[\begin{array}{l} \left\lfloor\langle A_n\rangle^{\xi_{A_n}}\right\rfloor_{n=1,..N} \xleftarrow[Q_{22}^{\xi_{C^k}\xi_{C^m}}]{} \\ \xrightarrow{Q_{22}^{\xi_{C^m}\xi_{C^k}}} \langle\left\lfloor\langle A_n\rangle^{\xi_{A_n}}\right\rfloor_{n=1,..N}\rangle^{\xi_{C^k}} \end{array}\right]_{m=1,..M}^{k=1,..K} \tag{5}$$

The information process is a combination of elementary information interactions within the ID. Expression (5) represents the "domain model", a description of information interaction linked to the nature of three domains. Let $\{A_1, \dots A_6\} \in \boldsymbol{A}$ the set of objects in the PD, $\{C_i^j\} \in \boldsymbol{C}$: the set of objects in the ID, where $i = \{1,\dots,9\}$, $j = \{1,\dots,5\}$, while the subsets of representations $\{C^i{}_m\}$ are within *m* autonomous IS active within the ID. Thus, for objects *An* and consumers *Bk* generally:

$$\langle A_n\rangle^{\xi_{A_n}} \xrightarrow{Q_{12}^{\xi_{A_n}\xi_{C^m}}} \langle\langle A_n\rangle^{\xi_{A_n}}\rangle^{\xi_{C_n^m}} \xrightarrow{Q_{23}^{\xi_{C_n^m}\xi_{B_k}}} \langle\langle C_n^m\rangle^{\xi_{C_n^m}}\rangle^{\xi_{B_k}} \tag{6}$$

Expression (6) represent the model of information interaction of two subjects of CD, expressed in terms of ID system representations and PD objects. The representation of object A_1 in the user thesaurus B_1 serves as the basis for making decision $\langle R_1\rangle^{\xi_{B_1}}$ by subject (B_1) of CD.

$$\langle\langle\langle A_1\rangle^{\xi_{A_1}}\rangle^{\xi_{C_1^1}}\rangle^{B_1} \overset{\theta B_1}{\Longrightarrow} \langle R_1\rangle^{\xi_{B_1}} \tag{7}$$

where $\overset{\theta B_1}{\Longrightarrow}$ decision making operator

The whole sequence of forming the image of object A_1 in the ID, its perception by subject B_1 in the CD, decision making and transfer via the ID to subject B_4 in the CD, is described as follows:

$$\langle\langle\langle A_1\rangle^{\xi_{A_1}}\rangle^{\xi_{C_1^1}}\rangle^{B_1} \overset{\theta B_1}{\Longrightarrow} \langle R_1\rangle^{\xi_{B_1}} \xrightarrow{Q_{32}^{\xi_{B_1}\xi_{C_7^A}}} \langle\langle R_1\rangle^{\xi_{B_1}}\rangle^{\xi_{C_7^A}} \xrightarrow{Q_{23}^{\xi_{C_7^A}\xi_{B_4}}} \langle\langle C_7^A\rangle^{\xi_{C_7^A}}\rangle^{B_4} \tag{8}$$

This expression represents the information interaction model for CD subjects in terms of ID system representations, PD objects and CD subject decisions.

III. Cross-Domain Model

A. Domain Model Transformation

A considerable number of target management models have already been developed, for example, the TeleManagement Forum NGOSS/Frameworx concept [13] as most well known. Among them, the above-described domain model proposed by A.D. Sotnikov in [1-3] for describing the processes of transferring information from source to receiver in infocommunication systems, is very well suited as a basis for building a specialized model for managing infocommunications. This model is the best suited for developing a management model, which will also allow developing a theoretical basis for introducing the idea of DT for the field of infocommunications. In this work, the task is posed as the development of the theoretical foundations of the CSP DT.

In the already known domain-model, it is necessary to introduce a number of additions reflecting management focus and the DT focus. The model is not suitable as is, as it lacks a feedback loop. The second reason is the lack of coordination with the developed concept NGOSS / Frameworx, which is currently the dominant and de facto standard in the direction of automation of infocommunications. Although the ideas of NGOSS/Frameworx also contain their shortcomings, which currently do not allow building a DT model on its basis (using the Shared Information and Data Model (SID) [13] model) without significant changes.

In the new Cross-Domain Model, we have added horizontal domains reflecting the specifics of infocommunications were introduced into the model. The horizontal domains are taken from a model called Shared Information and Data (the new name is Information Frameworx) and other concept tools - enhanced Telecom Operations Map (eTOM) and Telecom Applications Map (TAM). This is a mature enough concept and tools, so we should rely on them when developing our new model.

Fig.1 shows only few of the horizontal domains. The meaning of the term "domain" in the new cross-domain model proposed here should be clarified. The fact is that for vertical domains of the domain model [1-3] this term means the unified nature and unity of the rules for interaction between entities in each separate domain. These rules, like the nature of entities, differ from domain to domain. The horizontal domains from the SID model of the NGOSS/Frameworx concept contain aggregated entities of interacting digital service provider objects. They are collected in different domains according to the principle of functional departments of the organization. For example, in the organizational structure of a service provider there is a sales department, a customer service department, a technical department, a supplier relationship department, etc. Therefore, in the context of this model, it is more correct to name horizontal domains "area" in order to avoid terminological confusion and not to confuse the reader. However, we will retain the name “domain” due to the fact that it has been present in the documents of the TM Forum and the International Telecommunications Union (ITU) for a quarter of a century. The eTOM is standardized by ITU-T. Because of in the new model we have intersecting horizontal and vertical domains, this model named "Cross-Domain Infocommunications Management model" (CDM) (Fig.1).

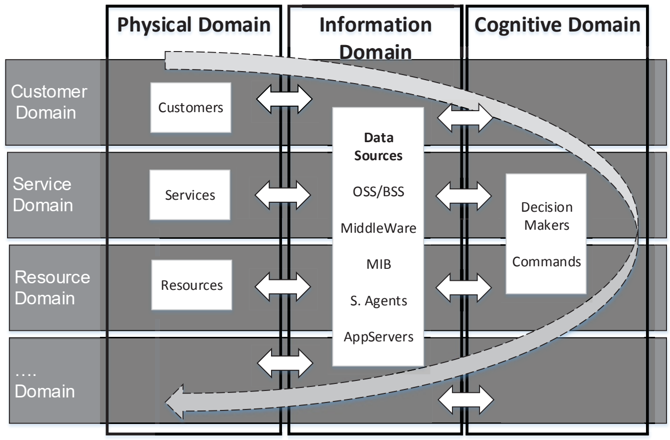

Fig. 1. The conceptual view of the Cross-Domain Model

CDM consists of vertical domains and horizontal areas. Physical Domain (PD) domain includes: operator's physical infrastructure; services with which the infrastructure is loaded; customers with whom the operator interacts in the course of his activities; other entities of the physical world objects necessary for the realization of the business goals of the digital service provider. The Information Domain (ID) includes all sorts of data and information about PD objects obtained from all sorts of available information sources. In general, this is information and data presented in various formats. The Cognitive Domain (CD) in this work is the least studied, since much of it goes beyond the scope of infocommunication topics.

Cross-domain interaction is described in section 2 of this work. This is a cross-domain information exchange with feedback, which is necessary for the implementation of management and control functions. Feedback forms a closed control loop, which is introduced here into the CDM of the DT, reflecting activity of cognitive function (decision-making, analysis, etc.) in the CD.

Interaction within the ID domain will be described in Section 4 of this work. Filling in the ID is also a very important task when designing DT. This requires answering a number of questions, and the main one is what DT is from informatics and information process point of view, what is its place in the proposed model, etc.

B) TM Forum Frameworx concept

eTOM serves as the blueprint for process direction and the starting point for development and integration of Business and Operations Support Systems (BSS and OSS respectively) and, helps to drive TM Forum members work to develop NGOSS/Frameworx solutions. For CSP, it provides a neutral reference point as they consider internal process reengineering needs, partnerships, alliances, and general working agreements with other providers. For suppliers, the eTOM outlines potential boundaries of software components, and the required functions, inputs, and outputs that must be supported by products. In the framework of the NGOSS/Frameworx [13] concept, in 1998 TM Forum developed its own domain model. There are eight domains in total: Market, Product, Client, Service, Resource, Partner, Enterprise, General business entities (Fig. 2). According to the principle of organization of eTOM and TAM, the SID is implemented within Frameworx: the same domains containing information entities are highlighted in it. The SID captures the concepts and principles necessary in defining a shared information model, and defines in detail many of the business elements (known in the SID as "Entities") of interest to service providers and the attributes, which describe these entities. The SID provides business oriented UML class models, as well as design oriented UML class models and sequence diagrams to provide a system view of the information and data.

This domain architecture is based on the Telecommunications Management Network (TMN) approach, which is now outdated, but leaves behind a number of great useful ideas. The TM Forum focus is on providing pragmatic solutions to business problems and is based on the business layering principles articulated in the ITU-T layered TMN model.

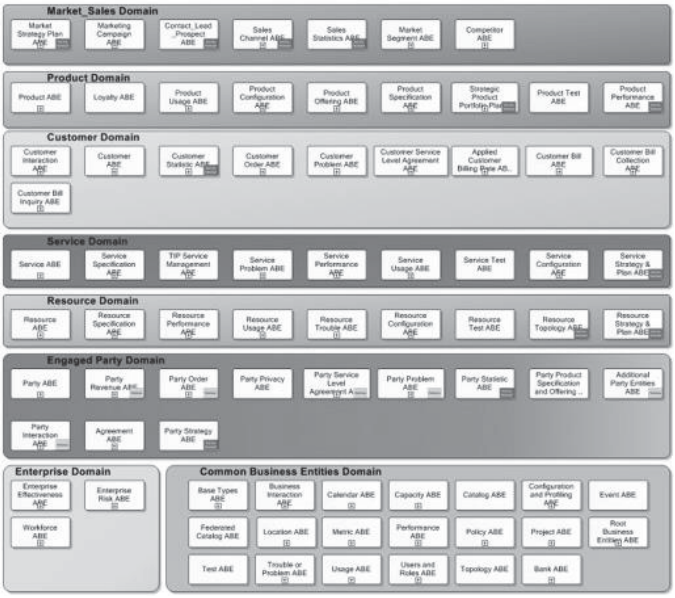

Fig. 2. TM Forum Information Framework (SID)

IV. DIGITAL TWIN OF DIGITAL SERVICE PROVIDER

A. Data sources for Digital Twin

Operations Support Systems (OSS) and Business Support Systems (BSS) - are designed to automate all business-processes of CSP. Mediation System is designed to integrate the OSS / BSS system with heterogeneous active network equipment and provide two-way interaction between all elements of the network and IT infrastructure.

Resource / Inventory Management is responsible for accounting of physical and logical resources and is a data catalog that reflects all aspects of the operator's network infrastructure. The system, as a rule, contains a hierarchical description of active and passive network equipment, including such parameters and metering characteristics as location address, reference to the delivery / installation agreement, commissioning date, mounted capacity, type and serial numbers of cards and units, physical and logical relationships of equipment, timing of preventive and routine maintenance, etc.

The Performance Management System monitors network performance and analyzes its performance and reliability. It collects processes and analyzes information about the load on network elements, including the load of equipment and data transmission channels, stores information about the load for a long period and provides reports on its basis. The module can also support functions for predicting and assessing changes in the load of network elements when the network topology changes or one or more of its elements fail, planning an increase or decrease in network bandwidth with an assessment of the quality parameters of services provided, building customer profiles and models of their behavior. Thus, the performance management module is designed to control the performance and efficiency of communication networks and information systems, allows you to optimize the network configuration, distribute the load between various resources and contributes to the planning of network development.

Fault Management System is an alarm monitoring and management system. It collects and preprocesses information about failures and accidents that occur on network equipment, and establishes a correlation between alarms to determine the root cause of the failure. To collect data, the module periodically updates information about the current state of the monitored equipment and communication channels, as well as forced polling of monitored objects to check their operability. The module stores information about events that have occurred in the network for a long period and provides reports on emergency events, and can also display the relationship of an incident with a client and a service that is affected by this incident.

The Trouble Ticketing System allows operators to track progress and control the troubleshooting process. The troubleshooting lifecycle is supported using Trouble Tickets. The module performs the functions of registering problems recorded on the basis of emergency messages, appointing a responsible executor to solve the problem, monitoring the progress of solving the problem (escalation, informing the management), and notifying customers about the progress of solving problems.

The SLA Management System monitors the quality indicators of service provision for both external and internal users, compares the actual indicators with those specified in the service level agreements and identifies the facts of SLA violations.

The Order Management System is used to support business processes for processing orders for the provision of any type of communication services. The system monitors all stages of order execution throughout its life cycle: ensuring connection, disconnection and configuration changes of services, formation and registration of orders for the activation/release of network resources, monitoring the progress of their execution in structural units; and also allows you to create detailed reports for each stage of the order and the order processing process in general.

Fraud Management System is designed to suppress and prevent cases of unauthorized and unpaid use of the company's services. The main functions of the system are to detect, suppress and forestall cases of fraud affecting the resources of a telecom operator. Tracking of the intruder is usually carried out using mechanisms and algorithms specially designed for various types of connections and services: calling a suspicious number, a non-existent user, exceeding the cost or duration threshold, etc.

Billing System is intended for accounting and tariffication of communication services consumption. The Billing System performs three main functions: collection, primary processing, control and registration of information about the consumption of communication services by users (Accounting). This may also include user authentication and authorization when accessing communication services - then they talk about AAA (Authentication, Authorization and Accounting) functions, but these functions are more related to the fraud prevention system.

The Customer Relationship Management System processes data on contacts with customers and allows you to assess their loyalty, the potential for growth in service consumption, and also provides a basis for analyzing the effectiveness of actions to retain and grow a customer base. The functions of this system include registering new customers and subscribers, working with subscribers (managing services, changing a tariff plan, etc.), as well as tasks related to paying for services: accepting payments from customers and dealers and selling goods from a warehouse (cash register functions operator) and integration with external payment systems, which allows you to organize the acceptance of payments through various sources (card platforms, electronic payment systems).

Traffic Management System is used for analyzing, processing and managing traffic in primary and secondary networks, in signaling networks, at the level of user applications. The module is responsible for generating proposals for optimal traffic routing depending on the quality and cost of providing communication services and monitoring the correct execution of routing tables on the network switching equipment.

Revenue Assurance System controls all stages of generating revenue from the provision of services, from monitoring the operation of access equipment and ending with the reconciliation of billing information, in order to avoid loss of revenue as a result of loss of billing data, delayed payments, etc. The module's functioning is based on information analysis and signal generation alerts about deviations from normal, reference behavior. Thus, the module can detect the loss of information about the calls made, deliberate or accidental distortion of information at any stage, incorrect tariffication, etc.

Customer Experience Management System allows you to find out the company about how each of its customers treats it, draw conclusions about further steps to improve or maintain the loyalty of its client. Thus, you can try to reduce customer churn and get more profit from each customer.

The Business Intelligence System has access to databases for various purposes and, based on the information stored in them, provides reports that allow company managers to get an adequate idea of the state of the business, analyze the situation and existing trends and make a reasonable forecast of the company's and market development.

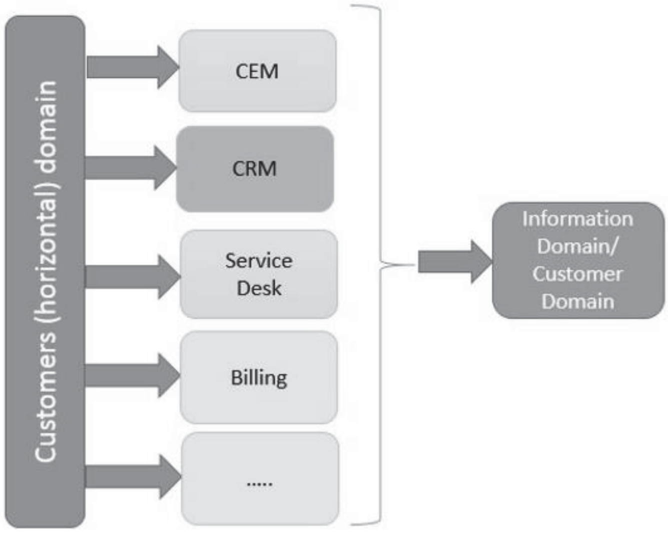

Fig. 3. Source systems for the Customer Horizontal Domain

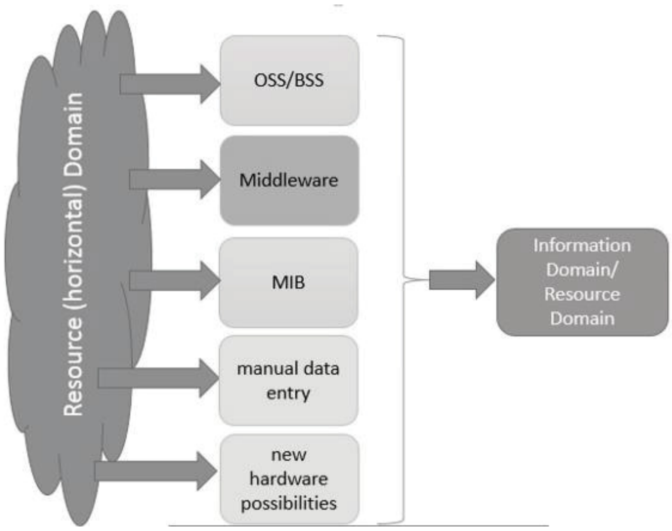

Fig. 4. Source systems for the Resource Horizontal Domain

B. The place of the Digital Twin

Information entities of ID interact as information systems (IS) and form DT of PD. Their interaction can be described as a unidirectional transmission/reception of the representation (image) of the PD object by the expression:

$$\langle\langle A_n\rangle^{\xi A_n}\rangle^{\xi C_n^m} \xrightarrow{Q_{23}^{\xi C_n^m \xi C_k}} \langle\langle A_n\rangle^{\xi A_n}\rangle^{\xi C_k}$$

$$\langle\langle A_n\rangle^{\xi A_n}\rangle^{\xi C^m} \xrightarrow{Q_{22}^{\xi C^m C^k}} \langle\langle A_n\rangle^{\xi A_n}\rangle^{\xi C^k}$$

where ξC_n^m– is the thesaurus of the m -th information system, C_n^m – n – is the n -th information object (element of the system thesaurus), A_n – is an object of a physical domain, $\langle A_n\rangle^{\xi A_n}$ – is one (n - th) from the set of possible representations of the object A_n.

The interaction of several IS within the ID is described as:

$$\left[\begin{array}{l} \langle \lfloor \langle A_n\rangle^{\xi A_n}\rfloor_{n=1,..N}\rangle \xleftarrow[Q_{22}^{\xi C^k \xi C^m}]{} \\ \xrightarrow{Q_{22}^{\xi C^m \xi C^k}} \langle \lfloor \langle A_n\rangle^{\xi A_n}\rfloor_{n=1,..N}\rangle^{\xi C^k} \end{array}\right]_{m=1,..M}^{k=1,..K} \qquad (3)$$

All interactions within an ID, reflecting the behavior and properties of a physical entity, are the DT in case

$$\xi C_n^m = \xi A_n^m \qquad (4)$$

Formula (4) says that thesaurus of the information domain (ID) systems equals to thesaurus of the physical domain (PD) systems.

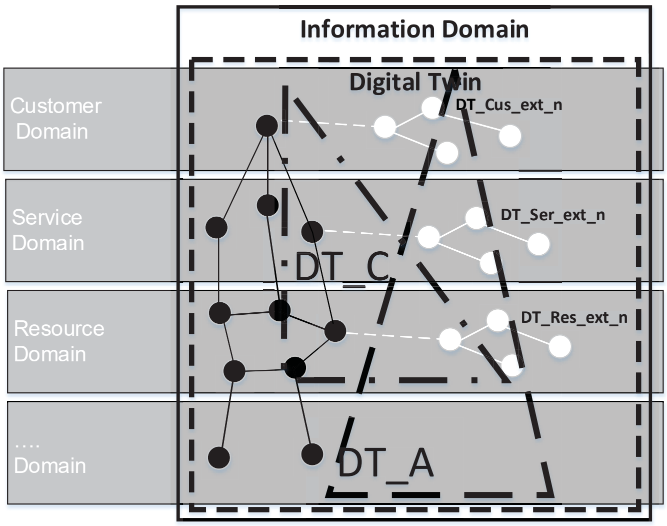

Fig. 5. CDM based Digital Twin Model

Based on the definition (4) and based on the figure, it can be argued that DT includes all "single-task" twins DT_A, DT_C, etc. of ID (Fig. 5).

C. *Digital Twin in Digital Service Provider's OSS-landscape*

Now, we can assume how the technologies and capabilities of infocommunication equipment will change by the time the first DTs are introduced into the OSS landscape of digital service operators. From the point of view of the author of this article, DT should be part of the OSS landscape. Given that DT is the most accurate model of a physical entity, it is necessary to involve all IT systems and all possible equipment interfaces. Top-tier architecture as shown at Fig.6.

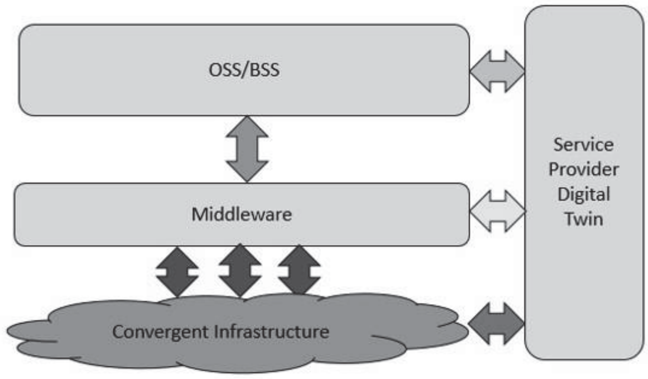

Fig. 6. The suggested place of Digital Twin in OSS-landscape

The most important feature that DT DSP will provide is the ability to carry out simulations in real time without affecting the physical infrastructure of the operator. That is, it becomes possible to use DT to solve a variety of (described at the beginning of this article) tasks. At the same time, the existing DT will not be a "black box" with unknown content. It will be a very close to real complex object model with input and output, which will be included in the feedback of the large "control mechanism".

VII. Conclusion

1. A cyber-physical cross-domain model for Communication Service Provider has developed.

2. A strict consistent definition of CSP DT based on thesauruses (4) has given.

3. The place of the CSP DT in the proposed cross-domain model has determined. It has defined as the intersection of a vertical Information Domain and a number of horizontal domains that reflect the specifics of the operation of a digital service operator.

4. The place of the CS in the OSS/BSS landscape of digital service provider has suggested.

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