

Digital Twin Network of a 5G COTS Device: Concept, Implementation Limitations, and Classification

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Abstract—Fifth and sixth generation (5G/6G) mobile communication systems introduce highly flexible architectures that support diverse services and dynamic network behavior. However, this increased flexibility also leads to greater system complexity and distribution, making it challenging to monitor, analyze, and systematically troubleshoot networks or conduct controlled experiments. Digital Twin Networks (DTNs) have emerged as a promising approach to address these challenges by creating synchronized digital representations of physical networks for continuous observation and evaluation. To date, most DTN research has focused on simulation environments or open-source platforms that offer full internal visibility. In contrast, the applicability of DTN concepts to commercial 5G systems remains largely unexplored. This gap is particularly significant in the context of future 6G systems, where access to internal processes is also expected to be limited. This work investigates the feasibility of constructing a digital twin for a commercial 5G system, using the Amarisoft Callbox Classic as a reference implementation. The analysis focuses on both the Radio Access Network (RAN) and the 5G Core Network (5GC), leveraging configuration data, runtime logs, and API-accessible information. It examines the availability and suitability of these data sources for representing system state, as well as the degree of possible interaction with the physical network and system. The results indicate that commercial systems provide sufficient observable information to enable a basic realization of a digital twin. However, the achievable fidelity is constrained by limited access to internal system processes and restricted control interfaces, particularly in the core network domain.

Keywords— *Digital Twin Networks, 5G/6G, Radio Access Network, Core Network, Amarisoft*

I. INTRODUCTION

Modern cellular communication systems have evolved significantly over the past decades, transitioning from voice-oriented infrastructures to highly complex systems capable of supporting broadband services, industrial automation, and large-scale machine-type communication. The introduction of 5G networks represents a major architectural shift, based on a service-based design where network functions interact through standardized interfaces defined by the 3rd Generation Partnership Project (3GPP) [1]. This architecture enables flexible deployment, independent scaling of network functions, and integration with cloud-native infrastructures. However, despite this flexibility, network operators face challenges in understanding and controlling system behavior, particularly in commercial deployments where visibility into internal processes is limited. Tasks such as performance debugging, parameter optimization, and validation of new configurations often rely on intrusive testing or offline

simulations, which may not accurately reflect live network conditions. This creates a gap between theoretical analysis and practical network operation. Future 6G systems are expected to further increase this complexity through AI-native functionalities, highly distributed architectures, and heterogeneous service requirements [2].

Digital Twin Networks (DTNs) have recently emerged as a promising approach to address these challenges by creating synchronized digital representations of physical communication systems [3;4]. In the context of 5G networks, a Digital Twin Network (DTN) represents a virtual instance of the RAN and core network that mirrors configuration, runtime behavior, and user activity based on observable system data. Unlike traditional network simulations, which operate on predefined models and assumptions, a DTN is driven by live data from the physical system and maintains continuous synchronization with its real-world counterpart and supports bidirectional interaction through control interfaces [3]. This enables real-time analysis, performance evaluation, and supports closed-loop optimization and control of the network [5].

Recent research has explored the application of digital twin concepts to communication networks, including simulation-based models and data-driven approaches for representing and managing network operation [3;4]. However, most existing work assumes full access to system internals and complete observability, often relying on detailed modeling and deployment methodologies that require extensive system knowledge [6]. Such assumptions do not necessarily hold in commercial deployments, where visibility is limited to exposed interfaces.

To address this gap, this study explores a commercial-off-the-shelf (COTS) 5G system, specifically the Amarisoft Callbox Classic, which integrates both RAN and 5GC functionalities and can be deployed in laboratories as well as small-scale real network environments. The system exposes configuration data, runtime information, and interface-based access to network state, which are used to analyze the network and assess the feasibility of constructing a DTN under practical constraints.

This work presents a feasibility study of Digital Twin Network realization for a commercial 5G COTS system based on the Amarisoft Callbox Classic. It provides a systematic evaluation of DTN realization in a grey-box setting, based on observability, representability, and interactivity, maps the achievable functionality to ITU-T Y.3091 [7] capability levels, and identifies limitations arising from restricted system visibility in commercial deployments. These insights are relevant for the design of DTN solutions in future 6G systems. The remainder of this

paper is structured as follows: Section II describes the digital twin architecture and capabilities, Section III presents the analysis framework, Section IV discusses the observations and results, Section V details the digital twin capability assessments and Section VI concludes the paper.

II. LAYERED ARCHITECTURE AND CAPABILITY LEVELS OF DIGITAL TWIN NETWORKS

Digital Twin Networks provide a structured approach for representing communication systems in a digital environment. The digital twin network framework concept is defined by ITU-T in terms of layered architecture and capability levels.

A. Layered Architecture

A DTN follows a three-layer, three domain architecture with a double closed-loop mechanism as illustrated in Fig. 1.

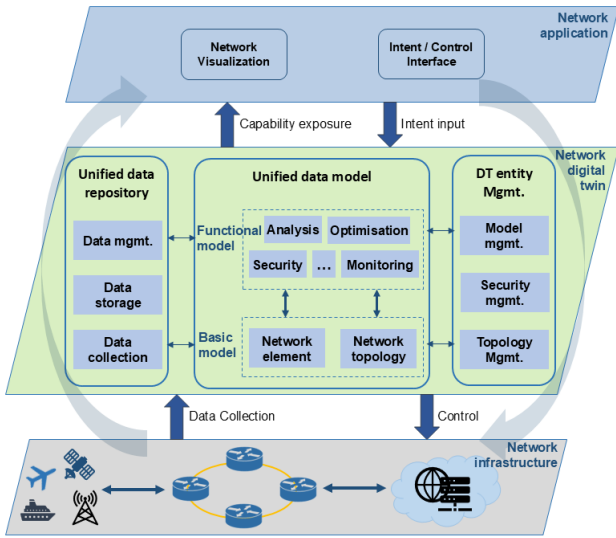


Fig. 1. Reference architecture of DTN adapted from ITU-T Y.3090

The physical network layer represents the real communication infrastructure, including the RAN and core network components. Above this, the digital twin layer maintains the virtual representation of the network. It consists of three domains, namely, the data domain, the model domain, and the management domain [5].

The data domain collects and synchronizes information from the physical network, including configuration parameters, runtime statistics, and logs. The model domain uses this information to construct digital models representing network components and system behavior. The management domain uses digital models to support monitoring, analysis, optimization, and possible control actions. The double closed-loop mechanism ensures communication between the layers, enabling data flow from the physical system to the twin or application layer and control actions to be applied back to the network [5].

B. Capability Levels of DTN

ITU-T Y.3091 [7] defines five capability levels, that describe the maturity of the digital twin. Lower capability levels focus on representing network state, while higher levels enable predictive analysis, optimization, and automated control of the physical network as shown in Fig. 2.

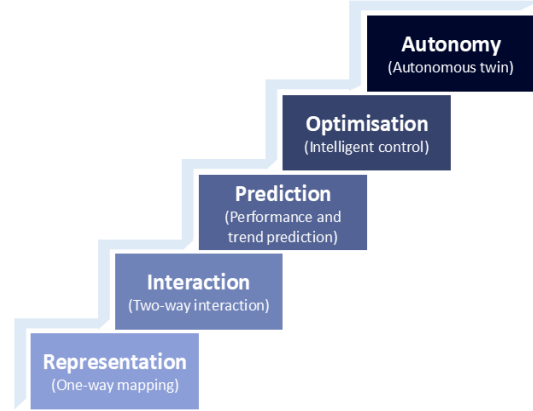


Fig. 2. Capability levels of a DTN derived from ITU-T Y.3091

At the representation level (Level 1), the digital twin network provides a one-way mapping from the physical network to the digital twin, enabling monitoring and visualization. At the interaction level (Level 2), bidirectional communication is introduced, allowing control actions to be applied from the digital twin to the physical system. At the prediction level (Level 3), the twin system supports data-driven analysis, enabling performance evaluation, fault diagnosis, and scenario-based prediction. Higher levels introduce increasing degrees of automation. The optimization level (Level 4) enables intelligent decision-making and real-time optimization, while the autonomy level (Level 5) represents a fully autonomous system with minimal human intervention.

Based on the evaluation framework defined in [7], DTN capability is assessed across multiple dimensions that describe different aspects of system maturity. Each dimension is further divided into indicators that are evaluated at different levels, which indicate how well specific functions are supported. This helps determine the achievable maturity level. Lower capability levels rely on basic network state information to support system representation and limited interaction. Higher capability levels build on this by requiring more detailed and timely data to support accurate modeling and prediction, ultimately assisting with optimization and automated control of network functionality. In practical systems, these requirements are often constrained by limited visibility into internal processes and restricted access to control interfaces. The six evaluation dimensions defined by ITU-T are summarized in Table I.

TABLE I. EVALUATION DIMENSIONS ADAPTED FROM ITU-T Y.3091

Dimension	Description
Data Service	Ability to collect, integrate, and provide network data for DTN use
DT Modeling	Ability to construct and maintain structured models of network elements and functions
Interactive Mapping	Ability to synchronize and exchange information and control between the network and the digital twin
Intelligence	Ability to analyze data, make decisions, and support automated control
User Experience	Ability to present data and models in an intuitive and usable form
Trustworthiness	Ability to ensure secure, reliable, and resilient DTN operation

In this work, DTN realization is assessed based on three key aspects: *observability*, *representability*, and *interactivity*. These aspects, derived from ITU-T recommendations, determine whether sufficient data can be obtained, whether the system can be meaningfully modeled, and whether interaction with the physical network is possible. The relationship between these aspects and DTN capability levels is further discussed in the following section and shown in Table II.

TABLE II. MAPPING OF OBSERVABILITY, REPRESENTABILITY, AND INTERACTIVITY TO THE ITU-T DTN ARCHITECTURE

Aspect	Role within the ITU-T DTN Framework	DTN Architecture Relation
Observability	Ability to access configuration data and live data metrics from the physical network	Data Collection Layer
Representability	Ability to construct a digital model reflecting the current network structure and its characteristics.	Modeling Layer
Interactivity	Ability of DTN to influence the physical network through control interfaces.	Control Layer

III. FEASIBILITY ASSESSMENT APPROACH

The construction of a DTN requires access to configuration parameters, runtime measurements, signaling information, and control interfaces to support system representation, modeling, and interaction. Based on the ITU-T Y.3090, Table III summarizes the generic parameter domains required for DT realization. Using this framework, the feasibility assessment evaluates whether the configuration data, runtime statistics, logs, and Remote API interfaces available in the Amarisoft platform are sufficient to support DTN realization for both the RAN and the 5GC.

TABLE III. GENERIC PARAMETER DOMAINS REQUIRED FOR DIGITAL TWIN NETWORK REALIZATION BASED ON THE ITU-T Y.3090 ARCHITECTURE

Parameter Domain	Representative Parameters	Role in Digital Twin Realization
Network topology	gNB ID, cells, UE count	Structural representation of network entities
Radio configuration	Frequency, bandwidth, numerology, antennas	PHY-layer modelling
RF status	TX/RX gain, hardware state	Physical-layer state mirroring
UE measurements	Channel Quality Indicator, throughput	Link quality modelling
Resource utilization	PRB usage, scheduler state, BLER	Performance state representation
Signaling procedures	Registration, attach/detach, session setup	Dynamic state tracking
Session information	PDU sessions, IP allocation, slice ID	Core network representation
Subscriber parameters	Authentication data, policies	Identity and access modelling
NF interaction relations	AMF and SMF signaling	Functional architecture mapping
Control interfaces	TX power adjustment, configuration updates	For closed loop DT interaction

The feasibility assessment is based on information obtained from the running Amarisoft system, through configuration files, runtime logs, and the Remote API interface. Configuration files provide static system parameters, logs capture runtime events and signaling activity, and the Remote API facilitates access to current network state and selected control operations. In addition, system documentation is used to interpret available parameters and interface capabilities.

The analysis follows a structured framework applied consistently to both RAN and 5GC. First, available data sources are examined to identify observable parameters and events. Next, relevant information is extracted and mapped to network components (e.g., gNB, UE, and core network functions) and system operation (e.g., connection setup, registration procedures, and data transfer events). Finally, these observations are validated through analysis or practical implementation where possible, in order to assess their suitability for DTN realization.

Three key aspects are considered, with the first being *observability*, which evaluates the extent to which network state, events, and performance indicators can be accessed through available system interfaces. For example, in the RAN, network state parameters include gNB configuration attributes such as carrier frequency, bandwidth, subcarrier spacing, cell identifiers, transmit power settings, antenna configuration, and current cell-level resource allocation and scheduler status. Network events include Radio Resource Control (RRC) connection establishment and release, handover procedures, scheduling decisions, bearer setup, and other control-plane signaling activities. Performance indicators include metrics such as throughput, Physical Resource Block (PRB) utilization, Block Error Rate (BLER), Signal-to-Noise Ratio (SNR), Channel Quality Indicator (CQI), uplink path loss, and Reference Signal Received Power (RSRP), collectively reflecting link quality and overall system performance. In the core network, observability is based on user, session, and signaling information that describes system state and activity.

The second aspect is *representability*, which assesses whether available data can support a structured digital twin of network entities and operations. It involves mapping configuration parameters, signaling events, and performance metrics to model elements, including gNB components (cells, carriers, schedulers), UE instances, radio channels, and RF front-end elements. These parameters are used to define the properties and relationships of entities within the digital model.

The third aspect is *interactivity*, which assesses the extent to which digital representation can influence the RAN and core network through control mechanisms exposed by the remote API and configuration interfaces. This includes externally adjusting radio parameters (e.g., transmitting power, scheduling, and resource allocation) as well as core network functions such as session management and traffic handling. The resulting changes are validated through updated runtime measurements, establishing a closed-loop interaction between the digital twin and the physical network.

In the RAN, the framework is applied to evaluate whether system conditions and performance can be observed in detail, whether key parameters can be mapped

to a structured model, and whether external control over radio behavior is possible. In the 5GC, it assesses whether information about users, sessions, and control procedures can be reconstructed from available data, whether the logical structure and relationships between entities can be inferred, and whether interaction with the system can be achieved through exposed interfaces. The outcomes of these analyses are then used to determine the achievable DTN capability in each domain.

IV. RESULTS AND OBSERVATIONS

The analysis shows that both the Amarisoft RAN and the 5GC provide a viable basis for DTN realization, although with different strengths in each domain. Fig. 3 illustrates the digital twin realization architecture, including data acquisition from the gNB and core network components to the digital twin server via the Amarisoft Remote API using WebSocket-based queries over SSH. Configuration parameters, runtime statistics, and UE-related session information are collected from both domains and used for monitoring, modeling, and control.

A. RAN Digital Twin Realization

The realization of the RAN DTN starts with the data retrieval using the Amarisoft Remote API via an SSH commands interface, which provides a comprehensive representation of the live 5G RAN. This comprises radio configuration, runtime metrics, user-level measurements, and RF subsystem status. The retrieved gNB configuration parameters define the static operational context of the network, including radio frequency settings, cell configuration, PHY-layer channel structures, and network integration identifiers. These parameters form the structural foundation for digital twin modeling.

The collected data includes the gNB runtime statistics, which capture the dynamic state of the system at the cell level, including traffic load, resource utilization, transmission reliability, scheduler activity, and control-plane signaling. This allows for real-time observation of network performance. Furthermore, UE-specific runtime parameters provide insights into individual user conditions, including throughput, radio measurements such as SNR and path loss, link adaptation indicators, and session-related information, thereby supporting an accurate representation of the current network state.

At the hardware level, RF front-end runtime exposes lower layer parameters such as transmitting and receiving channel gain settings and operating temperature conditions. For example, changes in the channel transmission and reception gain settings exposed through the RF interface influence the effective signal amplification within the hardware chain and support interpretation of variations in measured link quality indicators such as RSRP, SNR, and CQI during runtime operation. Similarly, monitoring hardware temperature helps identify potential hardware-related performance fluctuations that may affect radio measurements. Collectively, these datasets establish a strong data foundation that allows accurate state representation, performance analysis, and validation of the digital twin network framework against the physical RAN.

The collected measurements allow continuous observation of network conditions, including UE throughput, radio resource utilization, and link quality indicators such as SNR, uplink path loss, EPRE, and CQI. Based on the obtained data, a radio propagation and link quality modelling component is constructed, along with a control mechanism to interact with the physical RAN. The modelling component estimates key radio performance metrics, including RSRP and Signal-to-Interference-Plus-Noise Ratio (SINR), as functions of user distance and configurable radio parameters using the Free-Space Path Loss (FSPL) model. Using parameters such as operating frequency, the digital twin system computes RSRP and derives SINR, producing distance-dependent performance representations that reflect expected radio network operation.

The FSPL model is not intended to capture the full complexity of a real-time 5G propagation system. But it serves as a simplified analytical baseline for relating observable configuration parameters to expected link-quality indicators within the Digital Twin. Since exact UE location and detailed channel-state information are not available through the Amarisoft interfaces, distance dependent modeling provides a controlled reference for evaluating how configurable transmission parameters affect expected coverage behavior in the DTN.

Within the digital twin architecture, this modelling component acts as an analytical layer between observable configuration parameters and measurable radio-

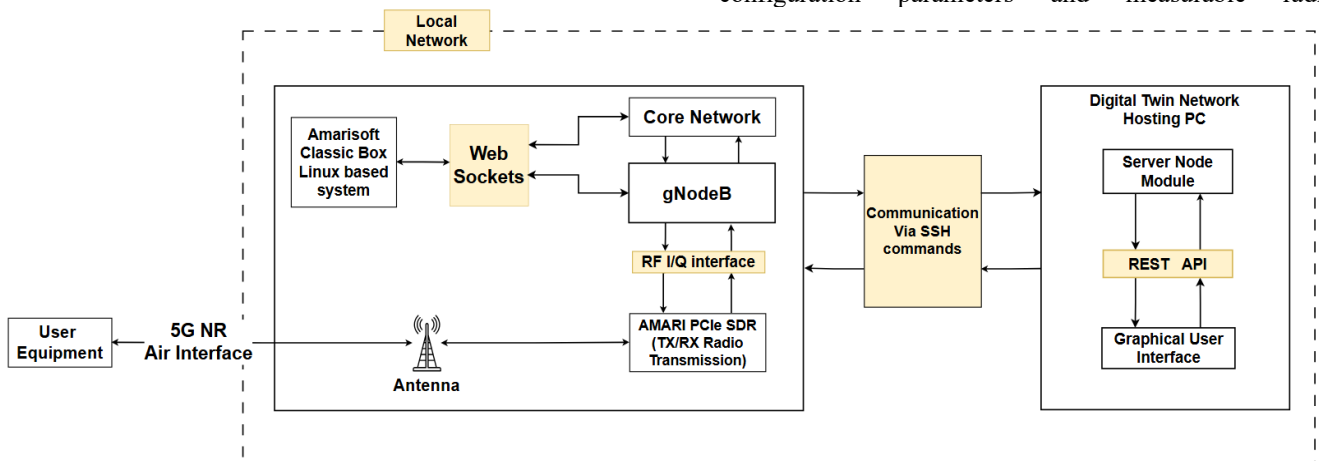


Fig. 3. Architecture of DTN for Amarisoft Callbox Classic

performance indicators. It supports representability by enabling digital twin platform to equate transmission settings such as Synchronization Signal Block (SSB)/Physical Broadcast Channel (PBCH) block power to predicted radio-link behavior prior to applying configuration changes to the physical system. As a result, this modelling approach is considered a proof-of-concept that demonstrates how analytical radio-performance estimation can be integrated into a Digital Twin workflow under limited system visibility conditions typical of commercial 5G platforms rather than as a full propagation-accurate representation of real deployment scenarios.

Based on this modeling framework, the SSB/PBCH transmit power is treated as a controllable parameter within the Digital Twin to evaluate its effect on predicted RSRP and SINR. Through the available control interface, this parameter can be adjusted in the physical RAN, thereby demonstrating the feasibility of integrating model-based analysis into a closed-loop DTN workflow. This shows that the RAN provides observability and supports bidirectional interaction for parameter-level control. However, interactivity remains limited to a small set of exposed configuration parameters, and fine-grained radio controls such as per-beam or per-UE transmit power adjustment and antenna-level power control are inaccessible. As a result, the implementation demonstrates bidirectional interaction between the Digital Twin and the physical radio network, but with a DTN capability limited to Level 2.

B. 5GC Digital Twin Realization

For the 5GC, configuration data provides the primary source for constructing the static system representation. In the Amarisoft platform, multiple core network functions are consolidated within a unified configuration structure, where responsibilities corresponding to functions such as access management, authentication, session handling, and subscriber data management are controlled through shared parameters rather than explicitly separated entities.

Due to this consolidated design, the separation of network functions cannot be clearly identified from the configuration. Interactions that would normally take place between different network functions are handled internally, reducing visibility into how individual functions operate and making it difficult to directly relate the configuration to the standard 5GC architecture. Despite this, configuration parameters can be examined and grouped based on their functional role within the core network. These include identity and reachability, security and authentication, session and data connectivity, and mobility management. This grouping provides a structured view of the 5GC, linking configuration parameters to their corresponding roles in the network.

In addition to configuration data, runtime logs provide visibility into dynamic system state by exposing control-plane signaling events such as UE registration, authentication, session handling, and deregistration. These logs enable tracking of UE state transitions and provide indicators of system activity, allowing estimation of traffic load and user behavior.

The Remote API provides more structured access to runtime system state and control functionality through JSON-based interactions. Using this interface, key

parameters such as UE identity, registration state, session information, slice allocation, and traffic statistics can be obtained in a readily usable form. For example, UE-specific queries expose registration status, assigned IP address, and active PDU session details, capturing UE state within the digital twin. This simplifies data access and allows the twin system to maintain an up-to-date view of system state and user activity.

In addition, control actions such as triggering UE attach or detach procedures, modifying PDU sessions, and updating selected configuration or transport parameters, enable direct interaction with the physical system. This supports closed-loop operation, where the digital representation can both reflect the current system state and influence it. As a result, the digital twin network extends beyond passive monitoring and supports active analysis and control.

V. CAPABILITY ANALYSIS AND DISCUSSION

Based on the observations presented in Section IV with respect to observability, representability, and interactivity within the RAN and 5GC domains, the digital twin network capability of the Amarisoft platform is evaluated as follows.

A. RAN DTN Capability

Based on the capability levels defined in ITU-T Y.3091, the RAN digital twin concept corresponds to Level 2. It can reflect the current network state through continuous data synchronization and support analysis of network behavior and performance based on observed data, with limited interaction through available system interfaces.

B. 5GC DTN Capability

For the 5GC, the DTN shows more limitations compared to the RAN. The available data allows tracking of UE state, session information, and control-plane procedures, which supports a consistent representation of how the network evolves over time.

In terms of modeling, the available parameters are sufficient to represent UEs, sessions, and slice-related information. However, since multiple network functions are combined internally, their interactions are not directly visible. As a result, modeling is limited to a high-level view and does not capture the full internal structure of the core network. Basic interaction with the system is supported through the available interfaces, enabling bidirectional communication between the digital twin and the physical network.

Overall, the 5GC digital twin concept corresponds to Level 2, where network state can be observed and basic interaction is possible, but more advanced modeling and control would require deeper access to internal system behavior and additional development.

The radar diagram in Fig. 4 reflects the assessment across the evaluation dimensions defined in Section II, namely data service, modeling, interaction, intelligence, user experience, and trustworthiness. The scores in each dimension are derived from the observed availability of data, the extent to which system entities can be represented, and the level of interaction supported through available interfaces. The diagram shows that data service and interaction are moderately supported, while modeling

remains limited and higher-level dimensions such as intelligence and trustworthiness are only weakly supported, reflecting constraints in internal system visibility.

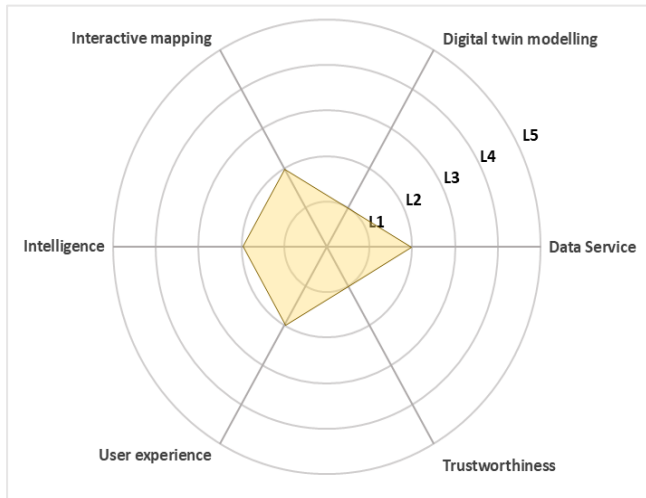


Fig. 4. Radar diagram for qualitative DTN capability assessment.

C. Limitations

The Amarisoft 5GC and RAN platforms exhibit built-in complexity that limits the depth of digital twin representation, effectively positioning the system as a grey-box where only external behavior is observable. Although configuration data, runtime logs, and API interfaces provide partial visibility, detailed understanding of the internal processing remains unavailable. In the core network, multiple functions are integrated within a unified architecture, preventing clear attribution of system behavior to individual network functions. Additionally, intermediate processing steps and internal state transitions are not exposed, reducing the accuracy of DTN modeling to input-output relationships rather than causal mechanisms. Available interfaces make this limitation even stronger, as logs require extensive filtering, and APIs expose only a subset of operational parameters.

From the RAN perspective, similar constraints arise at the control and observability levels. The platform does not expose every radio control such as per-UE or per-beam transmission adjustments, nor antenna-level configurations, thereby restricting interaction to high-level parameters. The absence of explicit UE location information necessitates reliance on assumed distances and analytical propagation models, introducing approximation into performance estimation. Moreover, critical functionalities such as beam management and MAC-layer scheduling remain internally managed and inaccessible, preventing DTN-driven influence over key radio resource decisions.

Collectively, these limitations restrict DTN's capability, restricting detailed modeling, precise control, and advanced optimization. While enhanced performance could be pursued through extended data collection and more sophisticated modeling techniques, such improvements would increase additional computational overhead and increased system complexity.

VI. CONCLUSION

This study investigated the feasibility of implementing Digital Twin Networks for a commercial Amarisoft-based

5G system. The results indicate that the available system information enables the construction of a structured digital representation of both RAN and 5GC operations. In the RAN, runtime measurements support continuous observation and modeling of radio conditions. In the 5GC, configuration data enables a consistent structural model at system startup, while runtime information supports tracking of network state during activity.

The achievable DTN capability level remains dependent on the transparency of the underlying platform and the extent of accessible data and control interfaces. While the exposed data allows tracking of network state and some level of interaction, key internal processes and function-level details are not accessible. This limits how accurately the system can be modelled and makes advanced features such as predictive analysis and autonomous control difficult to achieve.

Future work can extend this analysis toward the development of a prototype DTN that integrates RAN and 5GC representations within a unified framework. This includes establishing a continuous data pipeline for real-time synchronization, developing structured models for both domains, and enabling coordinated interaction across the network. In addition, extending the system toward persistent data storage, advanced modelling techniques, and automated decision-making mechanisms will be necessary to achieve higher DTN capability levels. The findings of this study provide a practical baseline for DTN realization in commercial 5G systems and offer insights into the challenges that must be addressed for future 6G networks. Emerging 6G use cases such as integrated sensing and communication will require tight coupling between physical observations and digital representations, while AI-native network functions will depend on continuous data availability and closed-loop interaction. In such scenarios, constraints on system transparency and interface exposure are expected to play a critical role in determining the achievable DTN capability.

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