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ELUCIDATING ON THE VERIFICATION OF TECHNICAL SYSTEMS IN NETWORKING INFORMATION-CENTRIC SYSTEMS OF SYSTEMS

Chandan Bansal

Shivaji College, University of Delhi, New Delhi, India

ABSTRACT

Networking Information-Centric Systems of Systems represent a network-centric, information-driven paradigm crucial for combat systems in information warfare scenarios. These systems encompass a complex array of interconnected technical systems, including communication networks, combat applications, and information services. Effective design of such systems necessitates thorough verification of each technical component, followed by iterative optimization to bolster the overall capability of the Networking Information-Centric System. This paper delineates the essence of Networking Information-Centric Systems and technical systems, while presenting a comprehensive framework for verifying and optimizing the technical components within Networking Information-Centric Systems. The framework encompasses verification processes, verification technologies, and optimization decision methodologies.

INTRODUCTION

As engineering requirements grow in complexity and scale, numerous independent systems increasingly collaborate to achieve common goals, forming what we term as Systems of Systems (sos).

The Networking Information-Centric System of Systems represents a network-centric, information-driven, system-supported complex giant system, shaping combat systems in information-based warfare. Academically, the Networking Information-Centric System of Systems is characterized by: 1) its network-centric, information-oriented, and system-supported nature, 2) functionalities including intelligence reconnaissance and surveillance, communications, command and decision-making, fire control, and comprehensive support, and 3) its intelligent evolution based on information systems.

Supported by a System of Systems aggregating elements and data information, the Networking Information-Centric System of Systems adopts theories and methods from system science and engineering, as well as System of Systems engineering, to address related challenges.

A technical system represents the technical pathway toward achieving system functions and performance, along with associated technical standards. Effective design of the Networking Information-Centric System of Systems necessitates thorough verification of each technical system, iteratively optimizing the design to enhance the system's capability.

The construction of Networking Information-Centric System of Systems is intertwined with warfare, construction, management, and protection, involving multiple technical systems such as combat applications, communication networks, and information services, each tightly interconnected.

This paper analyzes the essence of Networking Information-Centric System of Systems and technical systems, outlining a general framework for verifying technical systems within the Networking Information-Centric System of Systems, including verification processes, techniques, and optimization decision methods.

The second part of this paper provides the background of Networking Information-Centric System of Systems, the third part elaborates on the essence of technical systems, and the fourth part analyzes the general framework for technical system verification within the Networking Information-Centric System of Systems.

NETWORKING INFORMATION-CENTRIC SYSTEM OF SYSTEMS

A. System of Systems

The prevalence of scenarios where multiple independent systems collaborate towards a shared objective is on the rise, defining what we term as Systems of Systems (sos). A System of Systems comprises a collection of independent constituent systems, distinct in their characteristics from individual systems. Within a System of Systems, these constituent subsystems collaborate to achieve a unified goal. The independence, heterogeneity, evolution, and emergence of systems pose challenges to systems engineering.

Generally, the characterization of Systems of Systems comprises five key points [3]:

- Operational Independence

- Managerial Independence

- Geographic Distribution

- Dynamic Evolutionary Development

- Emergent Behaviour: Systems collaborate to achieve a higher-level, common goal that individual systems cannot accomplish alone.

To gain a deeper understanding of Systems of Systems, it is helpful to compare them with individual systems [13].

Table 1: Difference between Systems and systems of system

System	System of systems
Have a clear set of stakeholders	Have multiple levels of stakeholders with mixed and possibly competing interests
Have clear objectives and purpose	Have multiple, and possibly contradictory, objectives and purpose
Have clear operational priorities, with escalation to resolve priorities	Have multiple, and sometimes different, operational priorities with no clear escalation routes
Have a single lifecycle	Have multiple lifecycles with elements being implemented asynchronously
Have clear ownership with the ability to move resources between elements	Have multiple owners making independent resourcing decisions

B. Networking Information-centric system of systems

1) The networking information-centric system of systems is characterized by its network-centric approach, focus on information, and reliance on system support.

2) It encompasses functions such as intelligence reconnaissance and surveillance, communications, command and decision-making, fire control, and comprehensive support.

3) It represents an intelligent evolution rooted in information systems.

This system is pivotal in modern warfare, not only facilitating information transmission but also providing comprehensive support through advanced technologies for various military services. Its construction intersects with multiple aspects of warfare, management, and protection, involving specialized fields like combat applications, communication networks, and information services, all tightly interconnected.

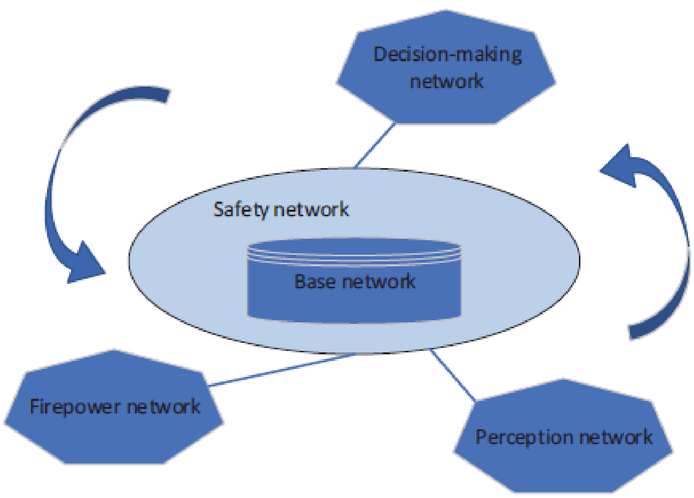

Fig 1: The general structure of the network

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To ensure effective system design and capability definition, verification of each technical component is crucial. Through thorough verification and iterative optimization, the capabilities of the networking information-centric system of systems can be enhanced.

TECHNICAL SYSTEM

The term "technical system" encompasses the pathway utilized to achieve system functionality and performance, alongside the associated technical standards.

Currently, there lacks a universally accepted terminology for technical systems. For instance, the U.S Army employs the term "technical view" to depict the comprehensive framework of technology chosen for the system, representing a facet of the technical system. Conversely, China refers to "technical system" as the overarching framework for demonstrating and designing a system's technical trajectory.

A. Construction of Complex System

Irrespective of the specific terminology, the research focus associated with technical systems remains consistent. This includes aspects such as technology feasibility, compatibility, selection of specific technologies, uniformity, and verification.

Regarding the classification of technical systems, the construction of complex systems involves multiple interconnected levels and types of technical systems, facilitating various perspectives for classification.

We can classify technical systems from the following three perspectives [6]. System composition, classified according to the technical system involved in each component subsystem. Which classifies the technical system according to the technical implementation of the system.

User applications, which are classified according to the technical regime involved in the various aspects of the user's use of the network-centric system.

The common practice of classifying technical systems is to determine the perspective of technical system classification, to classify the technical systems of a system or system from different perspectives, and to decompose each technical system into mutually exclusive subcategories under each perspective, as shown in the following table.

Table II. Prospective of Technology system classification

Technical system	**Perspectives**		
	System Composition	***Technical Architecture***	***User Applications***
1	Communication network	User access	Information generation
2	Information services	Service interfaces	Information applications
3	Security	Service Components	Integrated Management
4	Detection and Surveillanc	Information Transmission	Service Platform
5	....	....	....

B. The content of technical system

We can draw on the conceptual model of technical system [6] to understand what technical system are. The conceptual model of technical system describes the key components of technical system description and their interactions.

The connotation of a technical system consists of the following six main components.

- The classification system of technical system, i.e., the perspective from which technical system understood.
- The names of the technology systems included and available under this classification perspective.
- The evolutionary path of the existing/new technology system development.
- The technical standards that are compatible with the technology system.
- The key products (hardware and software) that support the implementation of the technology system.
- The content of the tests required to verify the feasibility of the technology system, the compatibility of the new technology system with the existing technology system, etc.

The relationship between the components is shown below.

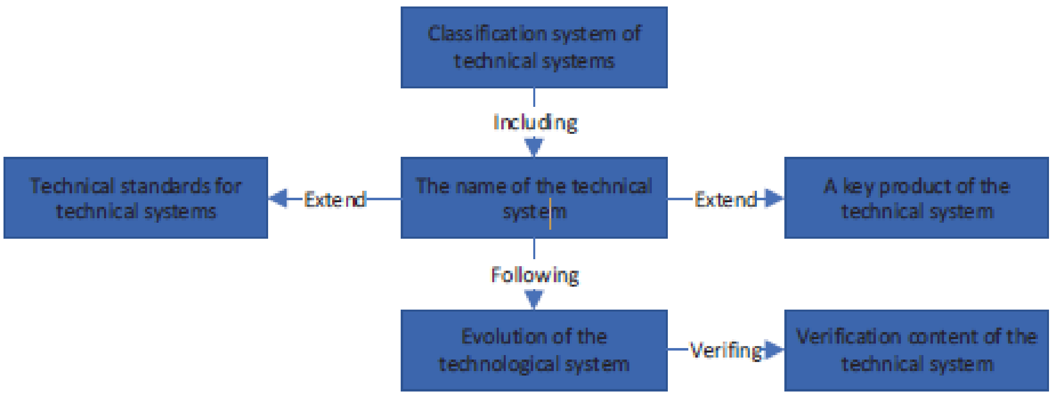

Fig 1: The relationship between the components

C. Technical system of networking information-centric system of systems

The networking information-centric system of systems is a complex combination of systems, and its construction usually needs to go through three stages. The first stage is to achieve unobstructed communication transmission on one's own side. The second stage is to achieve comprehensive access to battlefield information through various equipment and technical means. The third stage is to deliver the processed information to each node on the battlefield in real time through the network, providing systematic support for combat decision making, strikes, etc.

The networking information-centric system of systems involves multi-level and multi-type technical systems such as communication networks, combat applications and information services, and the technical systems are closely coupled with each other.

From the perspective of technical architecture, we can analyze and obtain that to achieve the goal of building a networking information-centric system of systems, we must rely on many technologies, including information acquisition technology, information transmission technology, information encryption/cracking technology, big data analysis technology, power supply technology, etc. [7].

Information acquisition technology refers to the technology of rapid analysis and identification of information in order to dig out reliable intelligence. Currently this technology is realized mainly with the help of visible light, microwave, electromagnetic waves, etc., while future developments tend to be low energy consumption, long-lasting and high-precision technologies.

Information transmission technology not only requires communication channels with high-capacity characteristics, but also to be able to resist interference and destruction.

Information encryption/cracking technology needs to be continuously improved to effectively deal with risks.

Big data analysis technology can be applied to all aspects of information acquisition, transmission and processing.

Networking information-centric system of systems cannot be separated from electricity. In future warfare, especially in the field environment, continuous power supply equipment and rapid charging and discharging equipment become necessary. Strengthen the construction of electric power security facilities and the development of new batteries to become the response.

THE GENERAL FRAMEWORK OF TECHNICAL SYSTEM VERIFICATION OF NETWORKING INFORMATION-CENTRIC SYSTEM OF SYSTEMS

The networking information-centric system of systems involves multi-level and multi-type technology systems such as communication networks, combat applications and information services, and each technology system is closely coupled with each other. In order to do a good job of designing the networking information-centric system of systems, it is necessary to effectively verify each technical system, and through effective verification, iteratively optimize the design and enhance the capability of the networking information- centric system of systems.

At present, the common practice of networking information-centric system of systems to carry out technical system verification is to first determine the function and performance index system of technical system, then carry out the verification of technical system in a targeted manner, study the corresponding system verification method, iterate and optimize the design, and finally determine the technical system.

From the research results, the research related to the technical system verification of networking information- centric system of systems is focusing on the research directions of network comprehensive integration verification, networked group communication verification, full chain verification, distributed environment joint verification, and network system comprehensive verification.

A. Verification process

The general process of verifying the technical system of the networking information-centric system of systems is depicted in the following figure and comprises the subsequent components [7].

• identify the content for verification within the technical system.

• utilize verification techniques to confirm the content.

• acquire the data produced during the verification process.

• establish the evaluation criteria for the technology system verification content and devise the evaluation algorithm.

• compute the evaluation outcomes.

• implement optimization decisions and iterate based on the evaluation results.

• establish a closed-loop optimization design process encompassing verification, evaluation, optimization decisions, and performance evaluation of the technical system and system.

After identifying the content requiring verification within the technical system, we employ various verification techniques. Based on research findings, three commonly utilized methods in ensuring the integrity of the networking information-centric system of systems are semantic review, testing, and formal methods [8].

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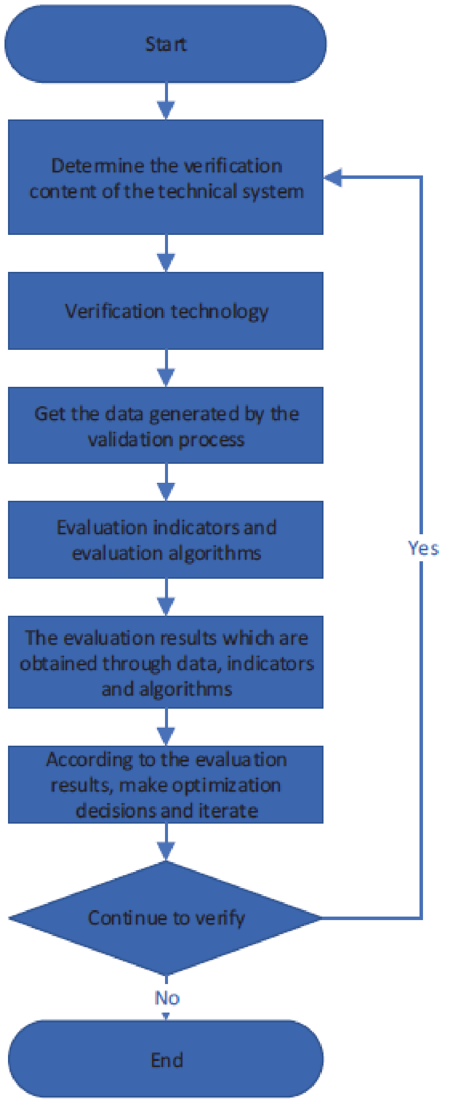

Fig 3: Networking Information-centric system

• semantic review

Semantic review employs a semantic model for verification, depicting object relationships, structures, or actions in a machine-readable format. Examples include system activity and block definition diagrams. Verification of semantic models utilizes inference and computational measurements to assess correctness, often limited to structural accuracy rather than semantic relevance.

Testing

Testing is fundamental, involving dynamic execution of the system model through test cases designed to compare expected and actual outcomes. Simulation, a testing method, replicates natural system behavior through simulation models and specific parameters. In networking information-centric systems of systems, semi-physical simulation methods are prevalent due to the scale and complexity of verification content.

Formal methods

Formal verification ensures model correctness through rigorous mathematical proof. Model checking, a common technique, verifies system properties across all possible states using numerical or symbolic calculations. For instance, finite state machines are verified using model-checking techniques.

Certain articles [8] analyze industry practices and frontier research verification strategies, collecting data from 16 engineering organizations to assess the feasibility, opportunities, and challenges of verification methods in scientific research within the industrial community. The following table summarizes the application of each verification technique.

C. Optimization and decision-making techniques

In the general process of technical system verification of networking information-centric system of systems, it is a very important part to make optimization decisions for the system and iterate continuously to finalize the technical system based on the evaluation results.

With the development of artificial intelligence technology, the optimization decision in the technical system verification of networking information-centric system of systems is evolving to intelligent decision making. Its comprehensive use of a variety of intelligent technologies and tools, based on the established objectives, the process of modeling, analyzing and obtaining decisions on relevant data. The process integrates constraints, policies, preferences, uncertainties, and other factors to automatically achieve optimal decisions for solving optimization and decision-making problems in technical system verification of networking information-centric system of systems [9].

The flow of intelligent decision-making is shown in the following figure. Translating decision constraints, preferences, and goals in real-world problems into mathematical models is a key link in connecting decision-making problems with intelligent means and methods. Enter data on the basis of the established model, and use machine learning, operations research optimization and other technologies to efficiently solve the model.

The related core technologies range from initial search to knowledge rules and then to deep learning. At the same time, intelligent decision making also requires the support of related auxiliary technologies, such as human-computer interface, data science, and knowledge engineering.

The networking information-centric system of systems technical system verification process makes optimization decisions based on the evaluation results, and uses theories and methods of systems science and engineering, systems engineering, technical means of data analysis mining and machine learning, and integration of knowledge management and knowledge system engineering to solve relevant optimization and decision problems.

CONCLUSION

The networking information-centric system of systems is the basic support for winning information warfare. The networking information-centric system of systems involves multi-level and multi-type technical systems such as communication networks, combat applications and information services, and each technical system is closely coupled with each other. In order to do a good job of designing the networking information-centric system of systems, it is necessary to effectively verify each technical system, and through effective verification, iteratively optimize the design to enhance the capability of the networking information- centric system of systems.

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