# Improving Network Performance in Semantic Communications: A Survey

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***Abstract*****—** Semantic communication enables devices to interact in a meaningful way by transmitting and compressing data at the semantic level. This approach reduces bandwidth usage and enhances understanding, leading to improved decision-making and tailored services. Semantic communication is particularly relevant for emerging technologies like metaverses, augmented reality, virtual reality, smart factories, and autonomous vehicles, which require efficient communication systems. However, to fully benefit from semantic communication, optimal resource management and energy efficiency are crucial. This survey paper aims to provide a comprehensive overview of research in this area, identify gaps and challenges, and serve as a valuable resource for researchers and practitioners.

***Keywords—Semantic Communication, 6G wireless networks, intelligent networks, network optimization***

## I. Introduction

Semantic communication enables devices to understand and interact with each other in a semantically meaningful way. Unlike traditional communication that focus solely on transmitting and exchanging data, semantic communication goes beyond the data level by compressing and transmitting data at the semantic level. So, semantic communication approach reduces the bandwidth usage in networks by minimizing unnecessary traffic and enhances understanding by communicating at the semantic level. This leads to improved decision-making, personalized experiences, and tailored services for users

Semantic communication holds great promise for the development of 6G and beyond, especially in the context of applications involving massive data, metaverses, augmented reality (AR), virtual reality (VR), smart factories, and autonomous vehicles. These emerging technologies require efficient and intelligent communication systems to handle the increasing volume and complexity of data.

Similarly, in smart factories, semantic communication enables devices to exchange information about production processes, sensor data, and control commands with a higher level of understanding. This improves the system efficiency, safety, and reliability of operations, leading to enhanced quality of experience (QoE) for both operators and users.

However, to fully harness the benefits of semantic communication, it is crucial to ensure optimal network performance. By focusing on improving network performance, we can address key challenges such as bandwidth usage, latency. For example, efficient utilization of network resources minimizes bandwidth consumption and maximizes system throughput, resulting in faster data transmission and reduced latency. This is particularly critical for real-time applications like augmented reality, virtual reality, smart factories, and autonomous vehicles, where delays or lags can significantly impact user experience and system functionality.

Our survey paper provides an extensive overview of existing research, methodologies, and advancements in improving network performance in semantic communications. In Section II, we delve into various studies and explore the methodologies employed to optimize network performance in the context of semantic communication. By examining existing research, we identify trends, challenges, and innovative approaches that have emerged in this field. This comprehensive analysis provides valuable insights for researchers, practitioners, and industry professionals seeking to enhance network performance and maximize the benefits of semantic communication.

## II. Literature Reivew

Semantic source coding is important because it enables efficient representation and transmission of information by considering the underlying meaning and context of the data being communicated. Unlike traditional source coding techniques that focus solely on compressing data based on statistical patterns, semantic source coding takes into account the semantics and relationships within the data. By capturing the inherent meaning of the information, semantic source coding can achieve higher compression ratios while preserving the essential content and reducing redundancy. The papers [1-5] address the semantic source coding.

In [1], the authors propose a novel encoding and decoding semantic communication framework, which considers channel states, semantic information and the contextual correlations to improve the reliability of the communication system over various channels. The authors define average semantic loss by combining both the semantic distance between message items and the Hamming distance into the source encoding process, resulting in the generation of binary source code words. The semantic source encoding scheme is developed to minimize the average semantic loss with simulated annealing method. To further improve communication reliability, the semantic decoding strategy utilizes the semantic and the context information to recover messages. The research compares the performance of the proposed semantic coding and decoding strategies with state-of-the-art semantic coding policies across various communication channels. The simulation results demonstrate a notable enhancement in the reliability of the communication system, specifically in terms of the semantic accuracy achieved between the transmitted and recovered messages. Furthermore, extensive simulation results confirm the superiority of the proposed strategies over existing semantic coding and decoding policies on different communication channels. The reliability performance of the novel separate semantic coding/decoding strategies is evaluated using metrics such as bilingual evaluation understudy (BLUE), metric for evaluation of translation with explicit ordering (METEOR), and Bert similarity. A comparison is made with the performance of up-to-date deep learning-enabled and separate semantic coding/ decoding techniques under different modulation modes and noisy channel conditions.

In [2], the authors introduce a novel unified framework for semantics-guided source and channel coding. This framework serves as a transmission paradigm for semantic communications, leveraging the diversity of data semantics and wireless channels to enhance the overall system performance. With this approach, the communication system can tolerate higher levels of distortion in wireless channels, making it more robust. Additionally, the processing of semantic information at the source is also improved in terms of its resilience.

In [3], the authors propose a novel semantic communication system for image transmission that utilizes semantic segmentation. The proposed system distinguishes regions of interest (ROI) and regions of non-interest (RONI) in images and utilizes different semantic channels to transmit ROI with improved accuracy. It includes a data compression algorithm to reduce communication overhead and introduces an improved metric for evaluating ROI transmission accuracy. Experimental results demonstrate the system's superiority over existing approaches in terms of performance and robustness.

In [4], this research focuses on a multiuser system where an information source provides status updates to two monitors. The authors propose a semantic filtering and source coding approach to improve the efficiency and timeliness of status update delivery. By selecting relevant realizations and optimizing codeword lengths, the authors reduce the amount of communicated updates while maximizing the value of the transmitted information. The results demonstrate the benefits of proposed approach in achieving timely status updates in a diverse monitoring environment.

In [5], this research investigates semantic communication and proposes a novel approach. It combines semantic coding with Reed-Solomon channel coding and hybrid automatic repeat request (HARQ) to improve the reliability of sentence transmission. The authors also introduce an end-to-end architecture for enhanced performance and reduced sentence errors. Furthermore, the authors replace the conventional error detection method with a similarity detection network called Sim32. Numerical results demonstrate significant improvements in semantic sentence transmission, including reduced bit requirements and lower sentence error rates. These findings highlight the effectiveness of integrating semantic coding with conventional transmission techniques and suggest possibilities for further improvements in reliability.

Semantic communication relies on models and representations to convey and understand the meaning of information. Models define how the communication system works, while representations capture the essence of the message. Imagine a knowledge graph as a web of interconnected facts. By using knowledge graphs, we can create more accurate and comprehensive representations of information. These enhanced repressentations allow for better communication of complex meanings, making semantic communication more effective. So, the choice of models and representations, along with the integration of knowledge graph techniques, is crucial for successful semantic communication. The papers [6-8] address the models and representations using knowledge graph.

In [6], the authors presents a cognitive semantic communication framework that leverages knowledge graphs to enhance the effectiveness of semantic communication. The framework incorporates reasoning and error correction, and introduces triples as semantic symbols for information detection. By adapting a pre-trained model, semantic information can be efficiently restored, overcoming the constraints of fixed-length coding. Simulation results illustrate that the proposed system surpasses other benchmark systems in terms of data compression rate and communication reliability.

An essential aspect of semantic communication is the representation of meaning. [7] proposes a semantic communication system based on knowledge graphs, powered by deep learning, to enhance the accuracy and clarity of semantic representation. In this system, sentences are transformed into triplets using the knowledge graph as a semantic symbol. The triplets are then sorted based on their semantic importance. Additionally, the proposed system dynamically adjusts the transmission based on channel quality, allocating more resources to critical triplets to improve communication reliability. Simulation results demonstrate that the proposed system outperforms traditional approaches in low signal-to-noise scenarios. However, further research is needed to determine the optimal number of transmitted triplets for different channels.

Existing approaches often overlook the utilization of prior knowledge and neglect the importance of semantic decoding at the receiver's end. To address these limitations, in [8], the authors propose an enhanced semantic communication framework that leverages knowledge graphs, enabling the receiver to actively utilize knowledge base facts for semantic reasoning and decoding without modifying the transmitter's neural network structure. Specifically, the authors design a knowledge -enhanced semantic decoder that employs a transformer-based knowledge extractor to identify relevant factual triples from noisy signals. Through extensive simulations on the web natural language generation dataset, proposed receiver-side scheme, augmented by the knowledge graph, exhibits superior performance.

Resource management and energy efficiency are vital in semantic communication due to their significant impact on system performance and sustainability. Effective resource management ensures optimal allocation of computing, storage, and network resources, enabling the system to handle increasing data volumes and diverse applications. The papers [9-10] address the resource management.

In [9], The authors review traditional semantic communication frameworks and identifies key challenges that hinder its widespread adoption. Resource-intensive tasks such as semantic detection, knowledge modeling, and coordination can be inefficient in one-to-one communication scenarios. To address this, the authors propose a novel architecture called federated edge intelligence that enables resource-efficient and semantic-aware networking. Users can offload computationally intensive tasks to edge servers, which collaborate to process shared semantic knowledge while safeguarding proprietary model-related information through intermediate results. Simulation results demonstrate the architecture's resource reduction and improved communication efficiency.

In [10], this study focuses on overcoming the limitations of user devices in terms of computation capacity by proposing an edge intelligence system. The system enables users to offload computation tasks to edge servers, thereby reducing energy consumption and enhancing task execution speed. To address the challenge of limited bandwidth in upstream channels, the authors introduces a semantic-aware task offloading system that extracts and offloads semantic information to edge servers. Additionally, a multi-agent reinforcement learning algorithm is employed to coordinate resource management between wireless communications and computation, ensuring distributed resource optimization and reducing computational complexity. The proposed system improves the energy efficiency and performance of edge intelligence in wireless networks, particularly in the context of 6G communications.

## III. CONCULUSION

In conclusion, semantic communication holds great promise for improving network performance and enabling advanced applications in various domains. By transmitting and compressing data at the semantic level, it reduces bandwidth usage and enhances understanding, leading to personalized experiences and improved decision-making. Resource management and energy efficiency are critical factors in ensuring the effectiveness and sustainability of semantic communication systems. Optimal allocation of computing, storage, and network resources is essential to handle the increasing volume and complexity of data. The survey paper presented provides a comprehensive overview of existing research, methodologies, and advancements in these mentioned research topics, serving as a valuable resource for researchers, practitioners, and industry professionals. By explaining some challenges, we expect progress in improving network performance in semantic communication.

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