上海科技大学
ShanghaiTech University

Robust Information Bottleneck for Task-Oriented Communication with Digital Modulation

Songjie Xie, Shuai Ma, Ming Ding, Yuanming Shi, MingJian Tang, and Youlong Wu

wuyl1@shanghaitech.edu.cn

1. Introduction

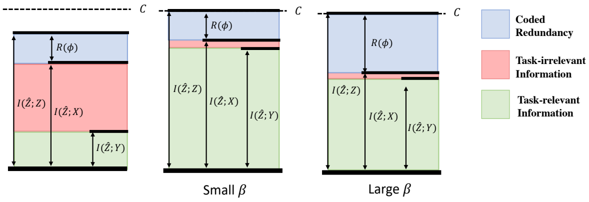
Task-oriented communications, mostly using learning-based joint source-channel coding (JSCC), aim to design a communication-efficient edge inference system by transmitting task-relevant information to the receiver. However, only transmitting task-relevant information without introducing any redundancy may cause robustness issues in learning due to the channel variations, and the JSCC which directly maps the source data into continuous channel input symbols poses compatibility issues on existing digital communication systems. In this paper, we address these two issues by first investigating the inherent tradeoff between the informativeness of the encoded representations and the robustness to information distortion in the received representations, and then propose a task-oriented communication scheme with digital modulation, named discrete task-oriented JSCC (DT-JSCC), where the transmitter encodes the features into a discrete representation and transmits it to the receiver with the digital modulation scheme.

2. Robust Information Bottleneck

To design a communication-efficient model for downstream inference tasks, the encoder needs to extract the informative messages about the task, while neglecting the irrelevant information in the representation. By combining the goals of relevant information extraction and transmission rate maximization, we propose a new principle, Robust Information Bottleneck (RIB), which is formulated by an optimization problem that maximizes the following objective function

$$\max_{p_{\phi}(\mathbf{z}|\mathbf{x})} I(Y;\hat{Z}) + \beta[\underbrace{I(Z;\hat{Z}) - I(X;\hat{Z})}_{R(\phi)}]$$

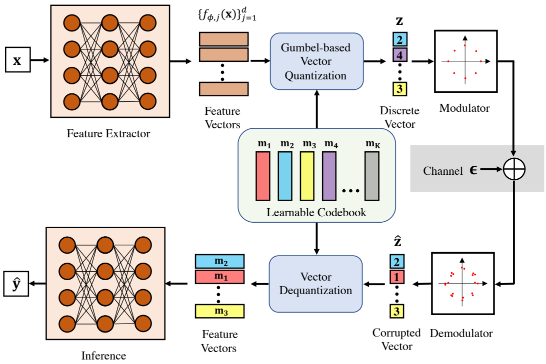
Coded redundancy refers to the amount of redundancy deliberately introduced in the reconstructed representation, which is utilized to improve the robustness of the communication system against information distortion that may occur in the received representation. Therefore, the optimization problem of the proposed RIB principle formulates this inherent informativeness-robustness tradeoff.



In summary, the key idea of the RIB principle is *to keep minimal but sufficient task-relevant information and leave the rest redundancy utilized for robust encoding.*

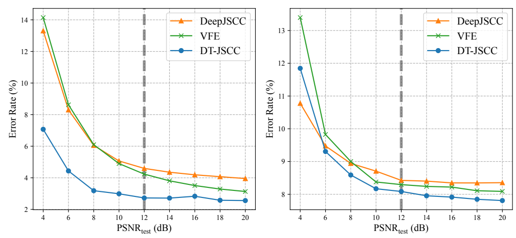
3. Method: DT-JSCC

The RIB-based framework is a generic framework for robust encoding. Considering the challenges of continuous representation transmission in digital communication, we propose to transmit the discrete representations in cooperative inference between the transmitter and the receiver. In this section, we design a robust task-oriented communication scheme with digital modulation, named discrete task-oriented JSCC (DT-JSCC), where the task-relevant information and coded redundancy are encoded into a vector of integers, and transmitted for downstream tasks by digital modulation.

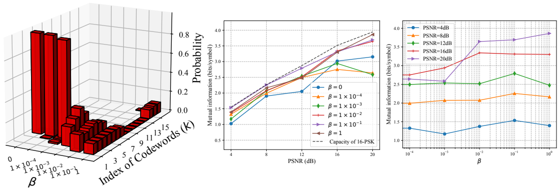


4. Performance

In this section, we present the experimental evaluations of the inference performance and robustness of the proposed DT-JSCC methods on image classification benchmarks compared with the state-of-the-art task-oriented communication schemes. Then, the ablation studies are conducted to verify that the RIB framework can achieve an optimal informativeness-robustness tradeoff and investigate the effect of codebook size on the inference performance of DT-JSCC.



To justify the robust encoding of the RIB framework, we further compare the performance of proposed DT-JSCC methods with different hyperparameter. Furthermore, we conducted experiments to evaluate the effectiveness of the RIB framework in maximizing transmission rate by examining the value of mutual information between transmitted and received representations learned using RIB objectives



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5. Conclusion

In this work, we investigate the tradeoff between the informativeness of the encoded representation and the robustness against channel variation in task-oriented communications. To formalize the informativeness-robustness tradeoff, we propose a theoretical framework, named robust information bottleneck (RIB). Furthermore, we propose a task-oriented communication scheme with digital modulation, DT-JSCC, where informative messages for inference tasks are encoded into discrete representations. It is compatible with canonical finite-point constellations in modern mobile systems.

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