IEEE Hong Kong 6G Wireless Summit

11-12 September 2024
Hong Kong, China

IEEE ComSoc IEEE Communications Society | IEEE


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# Tackling Distribution Shifts in Task-Oriented Communication with Information Bottleneck


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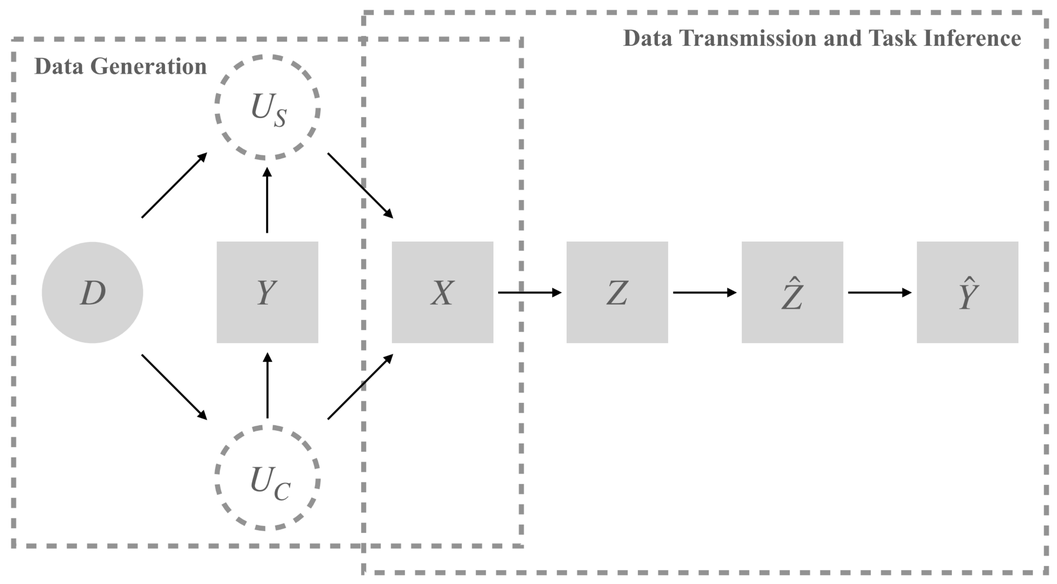
## Background and Problem Formulation

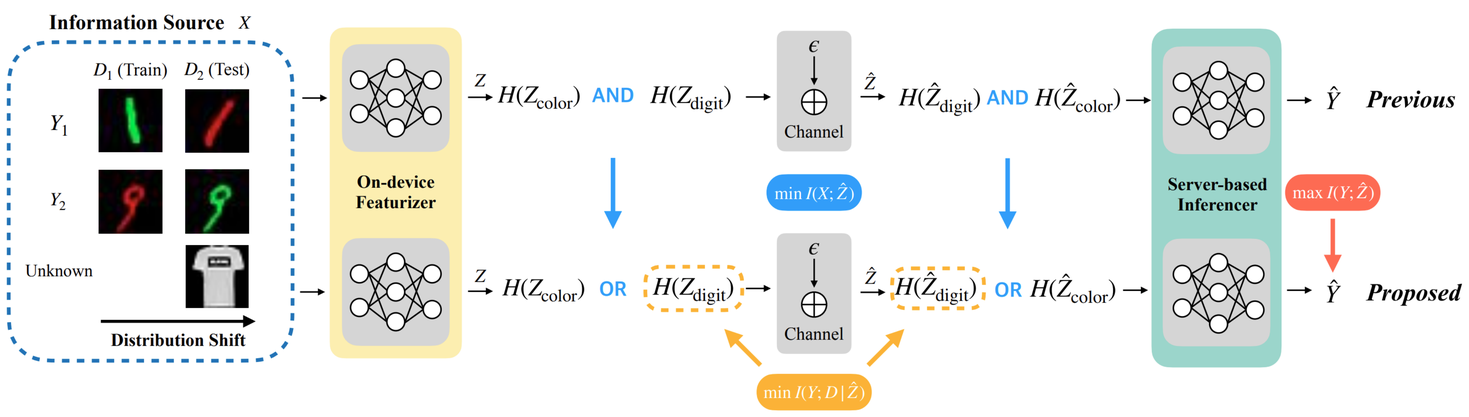
- Task-oriented communication aims to extract and transmit only task-relevant information for reducing the communication overhead and transmission latency. However, the ***distribution mismatch*** between training and test data is a challenging problem. Main issues include:
  - How to ***generalize to domain-shifted data***?
  - How to ***detect semantic-shifted data***?
  - How to address above issues ***without compromising rate-distortion trade-off***?

- We propose an ***invariant information bottleneck***-based method for domain-shift generalization. Specifically, we ***penalize the complexity and domain dependence*** of the encoded feature through mutual information term. Furthermore, we enhance task-oriented communication systems with ***conditional information bottleneck*** for feature encoding to detect semantic-shifted data.
- To avoid the intractable computation of mutual information term, we use Taylor expansion approximation and variational approximation to derive a tractable upper bound.




The probabilistic graphical model of data generation, data transmission and task inference of the proposed task-oriented communication system. $U_C$ is the causal part of information source which including the task-relevant information. $U_S$ is the spurious part of information source which including the task-irrelevant information.

## Proposed Information Bottleneck-Based Method




### Invariant IB

$$\min_{\theta,\phi} \underbrace{-I(Y,\hat{Z})}_{\text{Distortion}} + \beta \underbrace{I(X,\hat{Z})}_{\text{Rate}} + \lambda \underbrace{I(Y,D\mid\hat{Z})}_{\text{Invariance}}$$

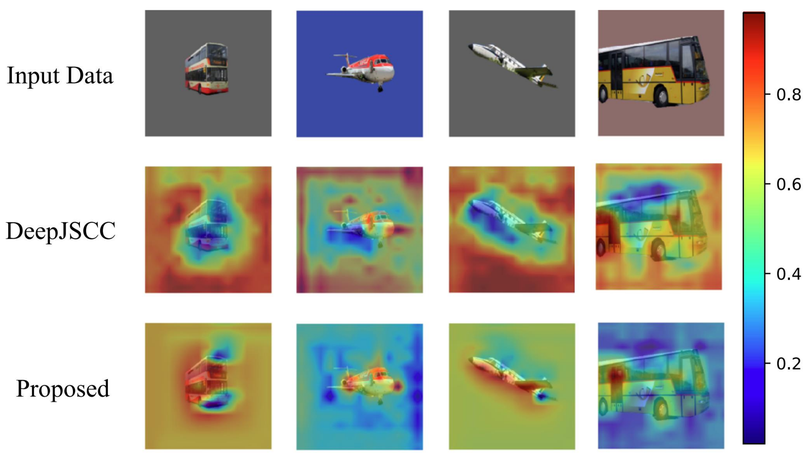
*Extract **Minimal**, **Sufficient** and **Causal** Features*

### Conditional IB with Contrastive Learning

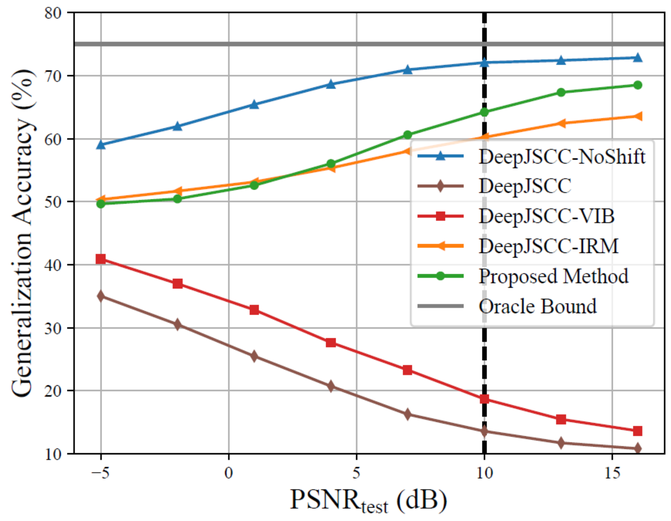
$$\min_{\theta,\phi} \underbrace{-I(Y;\hat{Z})}_{\text{Distortion}} + \beta \underbrace{I(X;\hat{Z}\mid Y)}_{\text{Rate}} + TripletLoss$$

*Extract **Minimal**, **Sufficient** and **Distinguishable** Features*

## Simulation Results




The attention heatmap visualization of different transmission schemes. The proposed method can focus on the task-relevant information, i.e., the object, while the DeepJSCC method focuses on the task-irrelevant information, i.e., the background color.




Accuracy versus test PSNR. The proposed method outperforms baseline methods, indicating the proposed method is more robust. Moreover, the performance of non-causal-based methods, i.e., DeepJSCC and DeepJSCC-VIB, degrades as the PSNR improves.

PERFORMANCE OF JOINT GENERALIZATION AND DETECTION

| Method | Colored-MNIST Gen. Acc. | Colored-MNIST AUROC | Colored-Object Gen. Acc. | Colored-Object AUROC |
|---|---|---|---|---|
| *PSNR= 10dB* | | | | |
| DeepJSCC-ODIN | N/A | 76.27/64.07 | N/A | 71.16/66.41 |
| VIB-ODIN | N/A | 73.21/60.06 | N/A | 72.10/59.56 |
| DeepJSCC-IRM | 62.64 | N/A | 83.19 | N/A |
| **VIFE**(ours) | 64.64 | N/A | 85.39 | N/A |
| **VIFE+VLFE**(ours) | 63.9 | 90.72/87.37 | 83.73 | 89.46/85.97 |
| *PSNR = 20dB* | | | | |
| DeepJSCC-ODIN | N/A | 80.12/79.05 | N/A | 75.77/70.34 |
| VIB-ODIN | N/A | 76.40/73.92 | N/A | 74.33/64.32 |
| DeepJSCC-IRM | 65.97 | N/A | 84.06 | N/A |
| **VIFE**(ours) | 68.62 | N/A | 87.50 | N/A |
| **VIFE+VLFE**(ours) | 66.07 | 98.92/99.42 | 85.57 | 94.72/91.53 |

Performance of joint generalization and detection. The proposed method can achieve the best performance on both generalization and detection tasks. The generalization performance of proposed method is only slightly compromised when adding the detection objective.

## Related Works


1. **H. Li,** W. Yu, H. He, J. Shao, S. Song, J. Zhang, and K. B. Letaief, "Task-Oriented Communication with Out-of-Distribution Detection: An Information Bottleneck Framework," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Kuala Lumpur, Malaysia, Dec. 2023.
2. **H. Li,** J. Shao, H. He, S. Song, J. Zhang, and K. B. Letaief, "Tackling Distribution Shifts in Task-Oriented Communication with Information Bottleneck," submitted to *IEEE J. Sel. Areas in Commun.*


## Acknowledgment


**This work was supported in part by the Hong Kong Research Grants Council under the Areas of Excellence Scheme Grant AoE/E-601/22-R**