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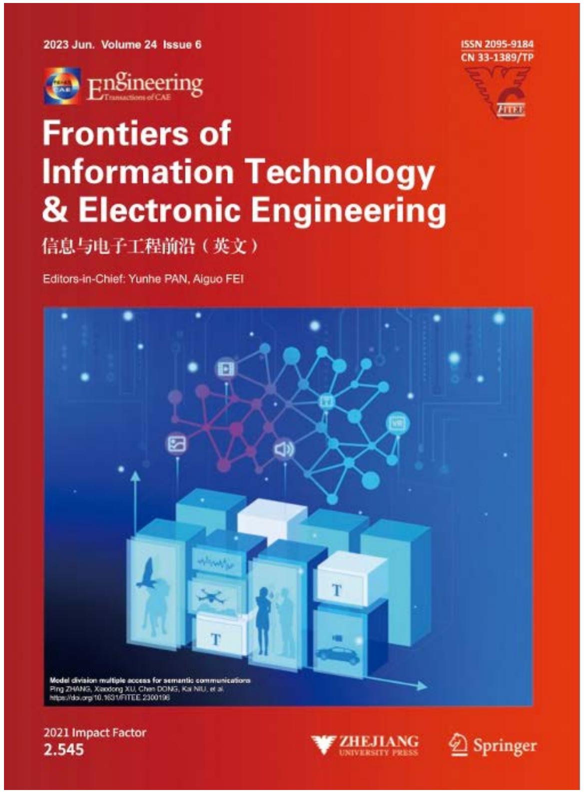
Model division multiple access for semantic communications

Key words: Model division multiple access (MDMA); Semantic communication; Multiple access

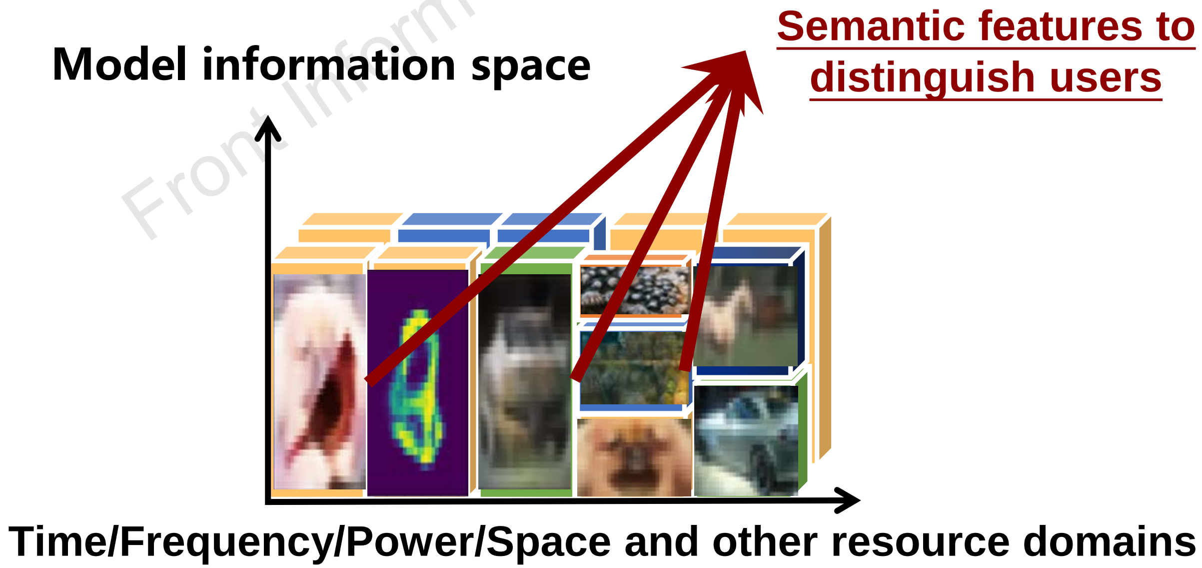
Ping ZHANG
E-mail: pzhang@bupt.edu.cn
ORCID: https://orcid.org/0000-0002-1485-5849



Model division multiple access (MDMA)

1. In the 40 years of development from first-generation (1G) to fifth-generation (5G) communication systems, each generation had representative and breakthrough multiple access (MA) technology.

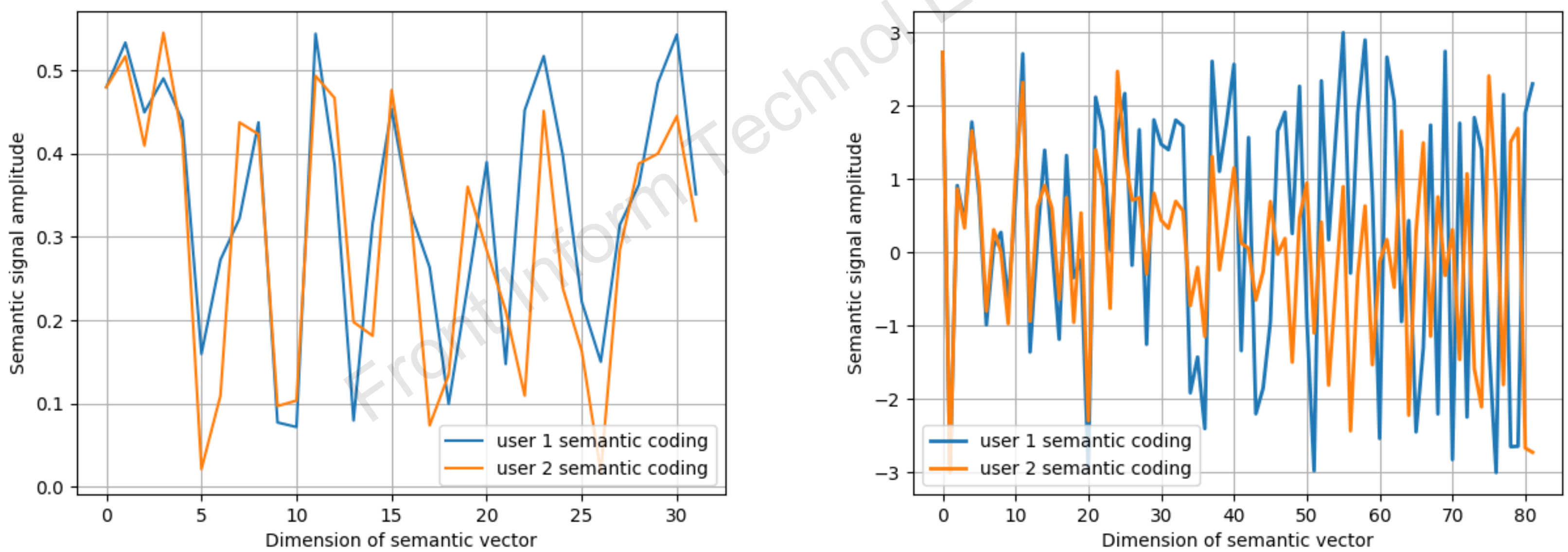
2. Semantic communication is considered a new paradigm with great potential for the next-generation mobile communication system. The new paradigm also creates a new allocation resource, namely, the model information space. The generation of model resources informs the establishment of a new MA technology, namely model division multiple access (MDMA).



Multi-user semantic information

1. The semantic signals are mapped into a high-dimensional space to express the source in another form, and we call the high-dimensional space the semantic model space.

2. The semantic information sets of users 1 and 2 are quite similar, despite the fact that the signal maps are extracted from different-numbered images.



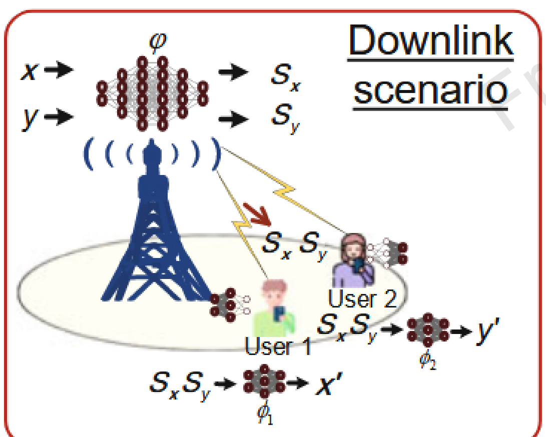
Semantic signals of different images extracted by two users for the MNIST dataset and OpenImage dataset

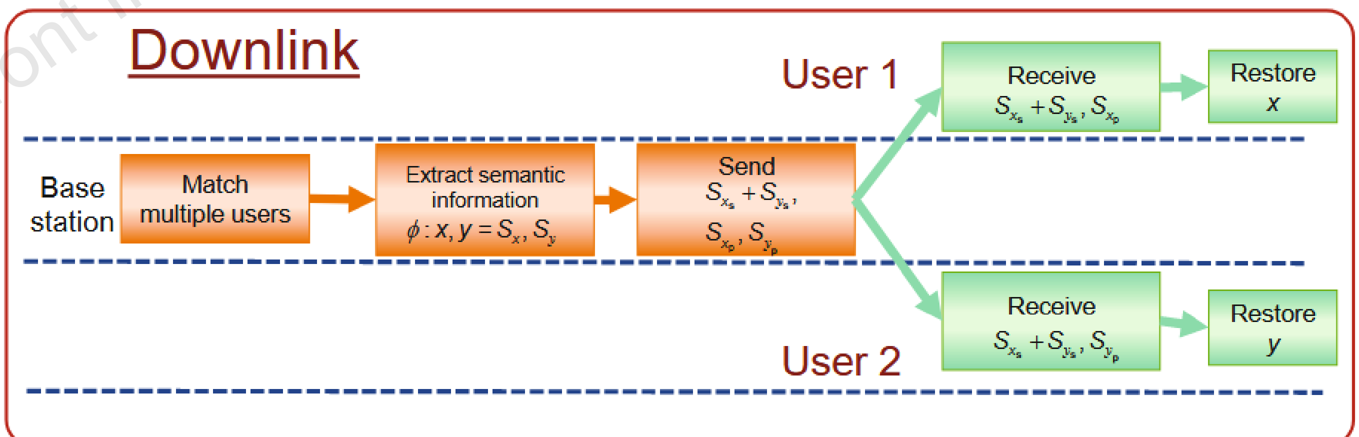
MDMA downlink channel design

1. By comparing the similarity between the two semantic features, the base station can extract the shared information S_{x_s} and S_{y_s} and the personalized information S_{x_p} and S_{y_p}.

2. The signals carrying the shared information S_{x_s} and S_{y_s} are combined and sent together, while the signals carrying personalized information S_{x_p} and S_{y_p} are transmitted separately to the user.

3. Users 1 and 2 receive the shared information and their own personalized information, and the original images X and Y can be restored using the semantic decoder.



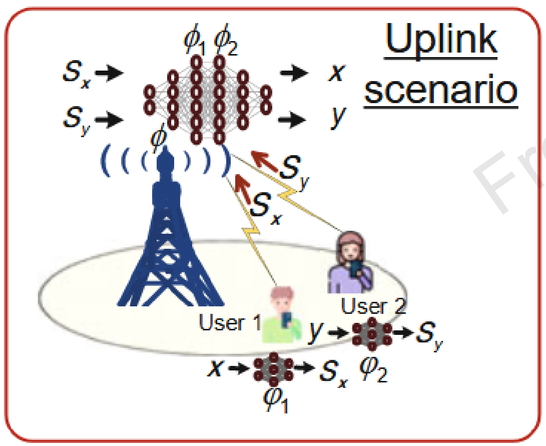


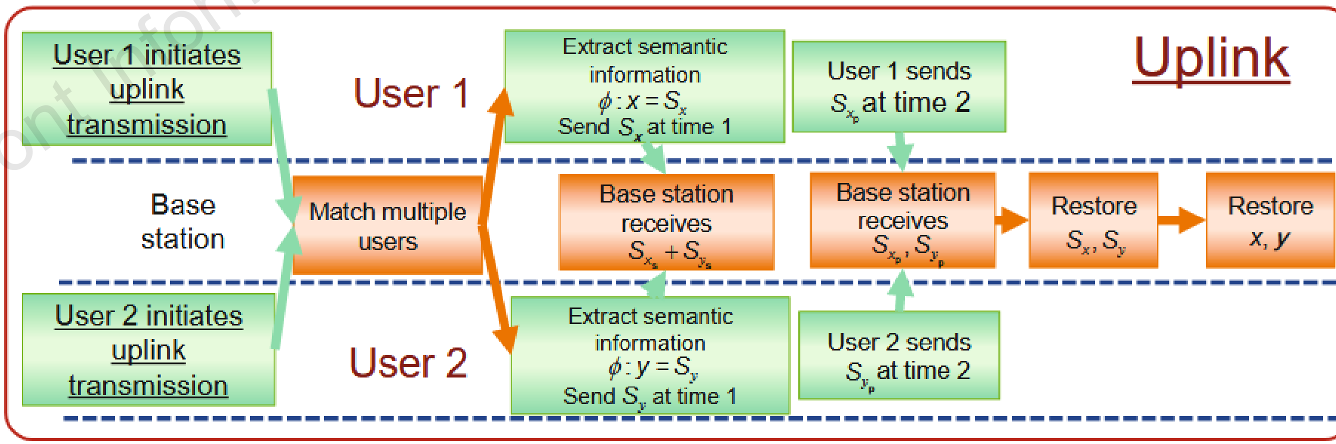
MDMA uplink channel design

1. Users 1 and 2 extract their source semantic information S_x and S_y and send the shared semantic information $S_{x_\mathrm{s}} + S_{y_\mathrm{s}}$ to the base station at time 1 (frequency 1).

2. Thereafter users 1 and 2 send the personalized semantic information S_{x_p} and S_{y_p} to the base station at time 2 (frequency 2).

3. After receiving the shared and personalized information from users 1 and 2, the base station can recover the original semantic signals of each user, and recover the source of information using the semantic decoder.





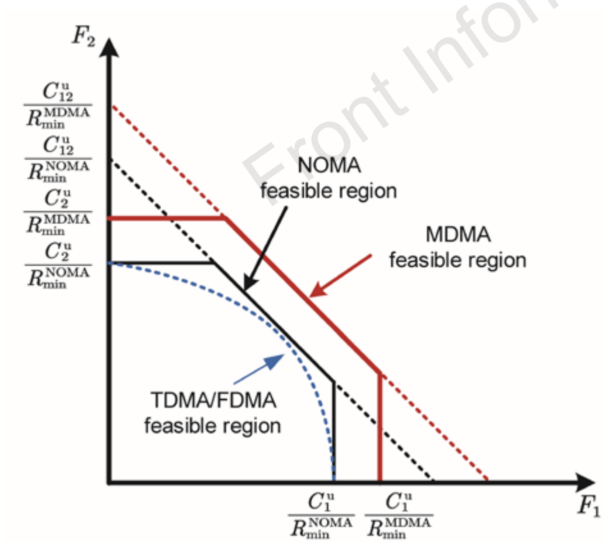
Theoretical analysis

1. The ratio of the channel transmission rates R_{cc} to the source coding rates R_{sc}, as a new metric called feasibility (labeled as F), is used to characterize the service capabilities that the channel can provide for the MA system:

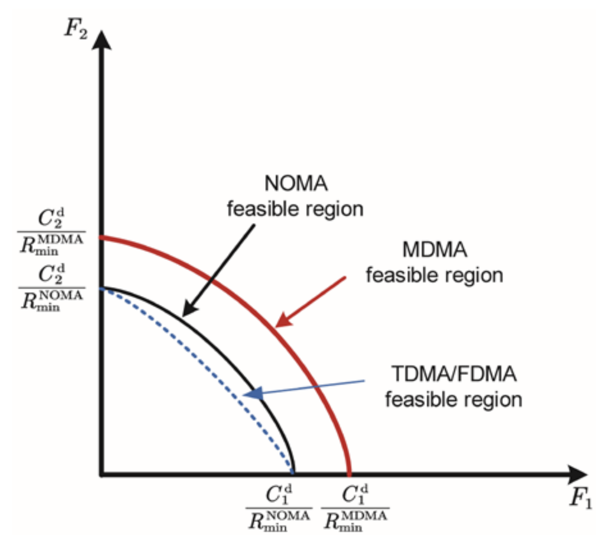
$$F = R_{\mathrm{cc}}/R_{\mathrm{sc}}.$$

2. Since the semantic encoders typically exhibit lower encoding rates compared with traditional encoders, the feasible region of uplink/downlink MDMA can be greater than that of uplink/downlink NOMA.

Feasible region for uplink MDMA



Feasible region for down MDMA



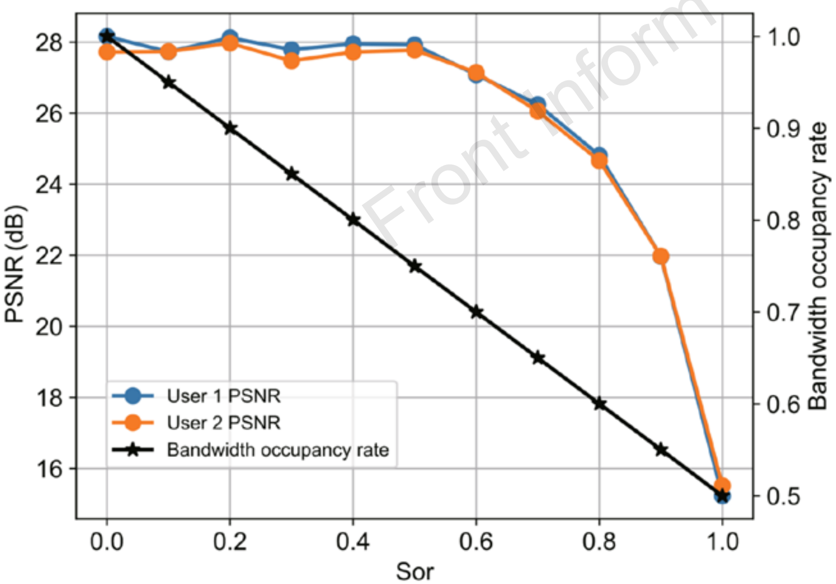
Simulations results

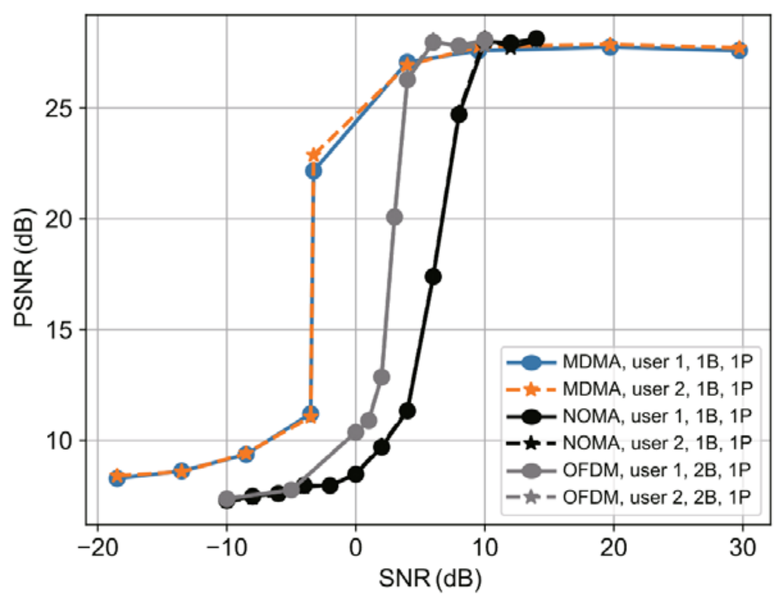
1. A new metric called the semantic overlap rate (Sor) is defined:

$$\mathrm{Sor} = \frac{|T_1 \cap T_2 \cap \cdots \cap T_K|}{|T_1| + |T_2| + \cdots + |T_K|}.$$

2. When Sor reaches 50%, the performance is almost consistent with the original recovery performance, which means that 25% bandwidth can be saved.

3. Under a low SNR condition, MDMA begins to show its superiority with a 5-dB gain over NOMA.





Conclusions

- We mine the shared and personalized information between semantic information from different users in the high-dimensional model information space, and propose a novel MA technology to allocate semantic space resources, named model division MA (MDMA).
- From the perspective of information theory, we define a new metric called "Feasibility" to evaluate the systematic service capability for each user in MA systems, and construct a feasible region based on the upper limit of the feasibility for each user. We prove that MDMA schemes have greater feasible regions than the traditional MA methods, which means that more performance gains can be attained by MDMA schemes compared with the traditional schemes.
- Simulation results show that MDMA has about 5 dB gain over NOMA in the AWGN channel under a low SNR condition. Moreover, MDMA can work in a mixed mode with NOMA, which can lead to additional performance advantages while keeping compatibilities.

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Biography of main authors

Ping ZHANG received his PhD degree from Beijing University of Posts and Telecommunications (BUPT), Beijing, China, in 1990. He is currently a professor with School of Information and Communication Engineering at BUPT, director of the State Key Laboratory of Networking and Switching Technology, a member of the IMT-2020 (5G) Experts Panel, and a member of the Experts Panel for China's 6G Development. He served as Chief Scientist of the National Basic Research Program, an expert in Information Technology Division of the National High-tech R&D Program, and a member of the Consultant Committee on International Cooperation of the National Natural Science Foundation of China. He is an academician of the Chinese Academy of Engineering (CAE). His research interests focus mainly on wireless communication.

Xiaodong XU received his BS degree in information and communication engineering and MS degree in communication and information system from Shandong University, in 2001 and 2004, respectively. He received his PhD degree in circuit and system in BUPT in 2007. He is currently a professor with BUPT, a research fellow with the Department of Broadband Communication of Peng Cheng Laboratory, and a member of the IMT-2030 (6G) Experts Panel. He has authored or co-authored nine books/chapters and more than 120 journal and conference papers. He is also the inventor or co-inventor of 51 granted patents. His research interests cover semantic communications, intellicise communication systems, moving networks, and mobile edge computing and caching.

Biography of main authors

Chen DONG received his BS degree in electronic information sciences and technology from the University of Science and Technology of China, Hefei, China, in 2004, his ME degree in pattern recognition and automatic equipment from the University of Chinese Academy of Sciences, Beijing, China, in 2007, and his PhD degree from University of Southampton, UK, in 2014. After a post-doctoral researcher experience in Southampton, he worked in Huawei Device Company Ltd., China. Since 2020, he has been working with BUPT. He was a recipient of the Scholarship under the UK–China Scholarships for Excellence Programme and the Best Paper Award at IEEE VTC 2014. His research interests include applied mathematics, relay systems, channel modeling, and cross-layer optimization.

Kai NIU received his BS and PhD degrees from BUPT, China. He is currently a professor with BUPT. Since 2008, he has been a senior member of the Chinese Institute of Electronics (CIE) and a committee member of the Information Theory Chapter of CIE. He currently serves as an Associate Editor of *IEEE Communications Letters*. His research interests include coding theory and its applications, space-time codes, and broadband wireless communication.