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Spatio-temporal correlation-based incomplete time-series traffic prediction for LEO satellite networks

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Key words: Incomplete time series; Denoising autoencoder (DAE); Spatio-temporal correlation; Traffic prediction; LEO satellite networks

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Motivation

Due to the high mobility of the low Earth orbit (LEO) satellites, the coverage area of each satellite varies rapidly. Factors such as population size and economic conditions in different coverage areas lead to significant differences in service traffic accessing to the satellites, and dramatic changes in the traffic load can easily lead to network congestion. Therefore, it becomes necessary to introduce traffic prediction to sense future traffic changes. However, due to collector failures, transmission errors, and memory failures in the harsh space environment, traffic values may usually be lost at unexpected moments. Such incomplete traffic time series undoubtedly create difficulties in data analysis, which poses a significant challenge for traffic prediction in the LEO satellite networks.

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Main idea

- To overcome this problem, we propose a novel spatio-temporal correlation-based incomplete time-series traffic prediction (ITP-ST) model, which consists of two phases: reconstituting incomplete time series by missing data imputation and making traffic prediction based on the reconstructed time series.
- In the first phase, we propose a novel missing data imputation model based on the improved denoising autoencoder (IDAE-MDI).
- In the second phase, we propose a traffic prediction model based on a multi-channel attention convolutional neural network (TP-CACNN) by combining the spatio-temporally correlated traffic of the LEO satellite network.

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Method

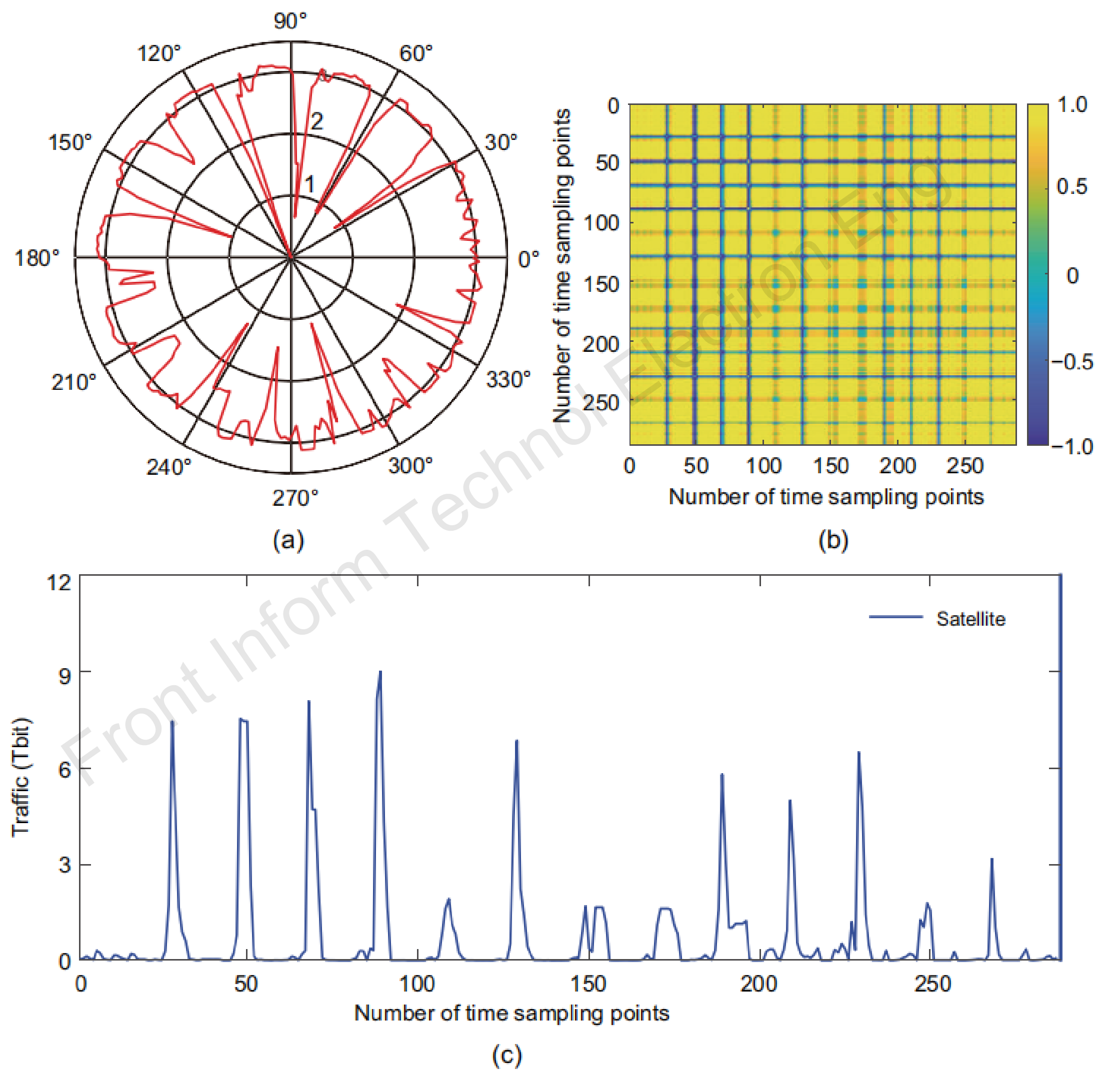

Fig. 2 Conversion of 1D time series into a 2D GASF image: (a) polar coordinate representation; (b) GASF image; (c) 1D time series

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Method

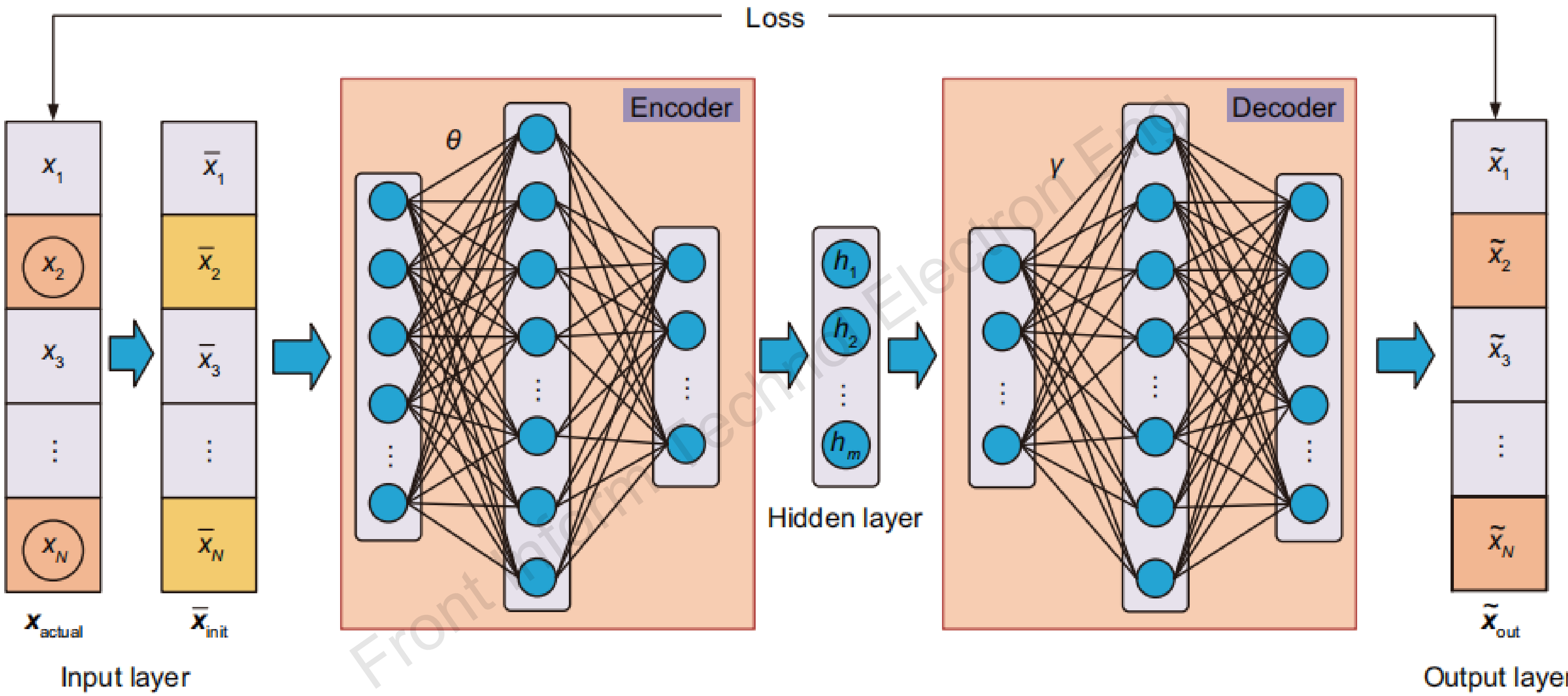

Fig. 3 Network structure of the basic DAE

Method

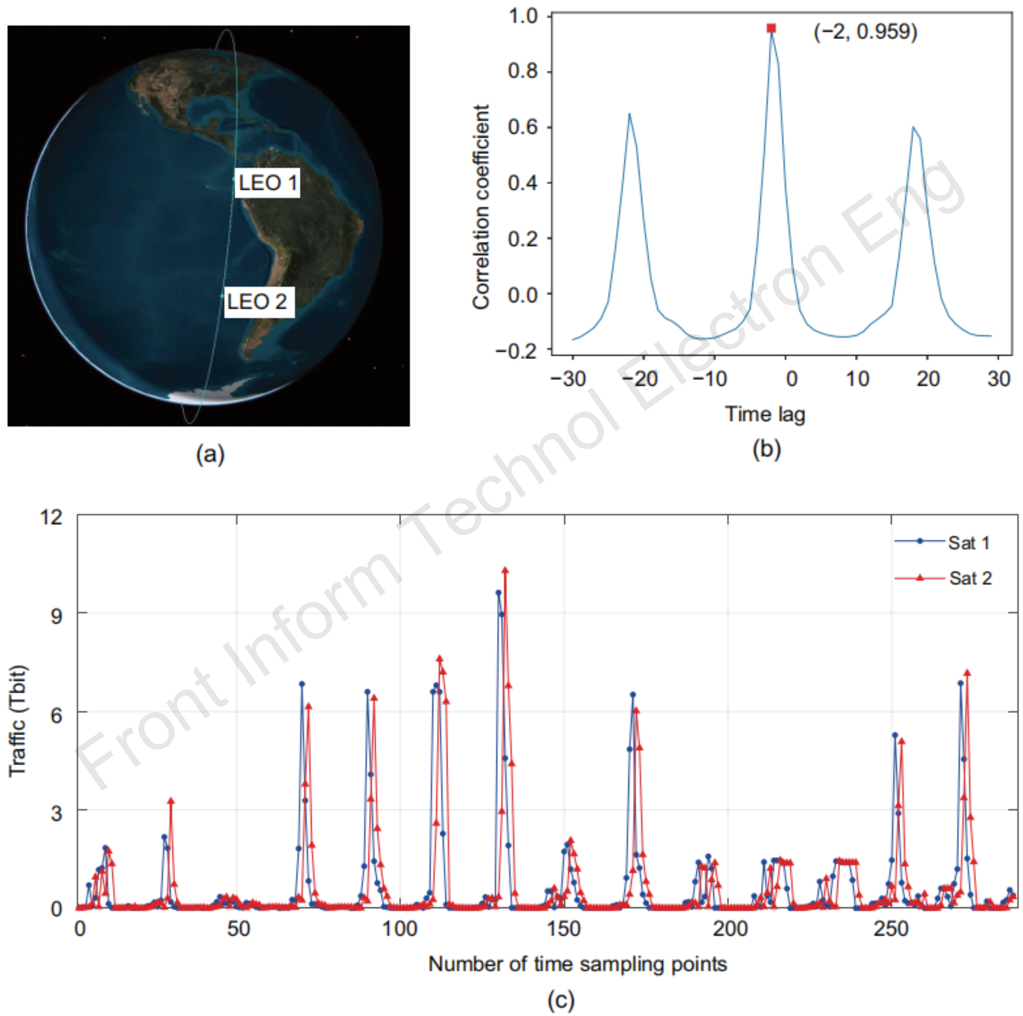

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Fig. 4 Two neighboring satellites in the same orbit (a), the Pearson correlation coefficient of those two traffic time series with different time lags (b), and the 24-h traffic time series of these two satellites (c)

Method

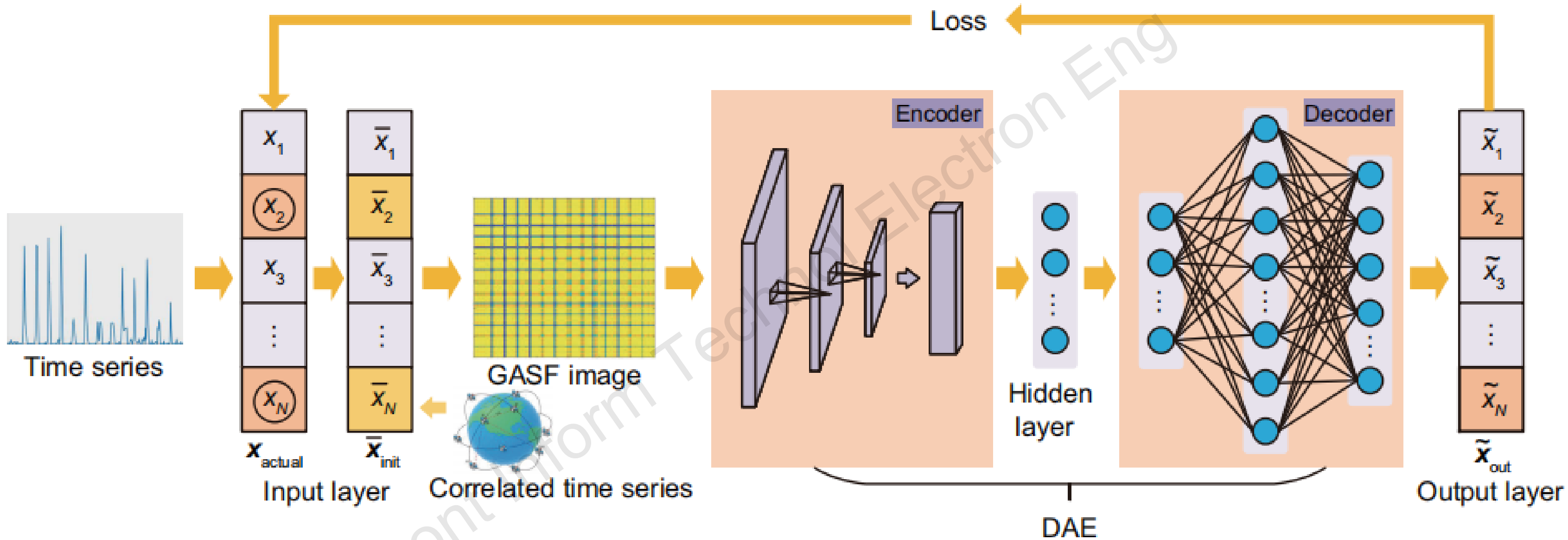

Fig. 5 Framework of the IDAE-MDI model

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Method

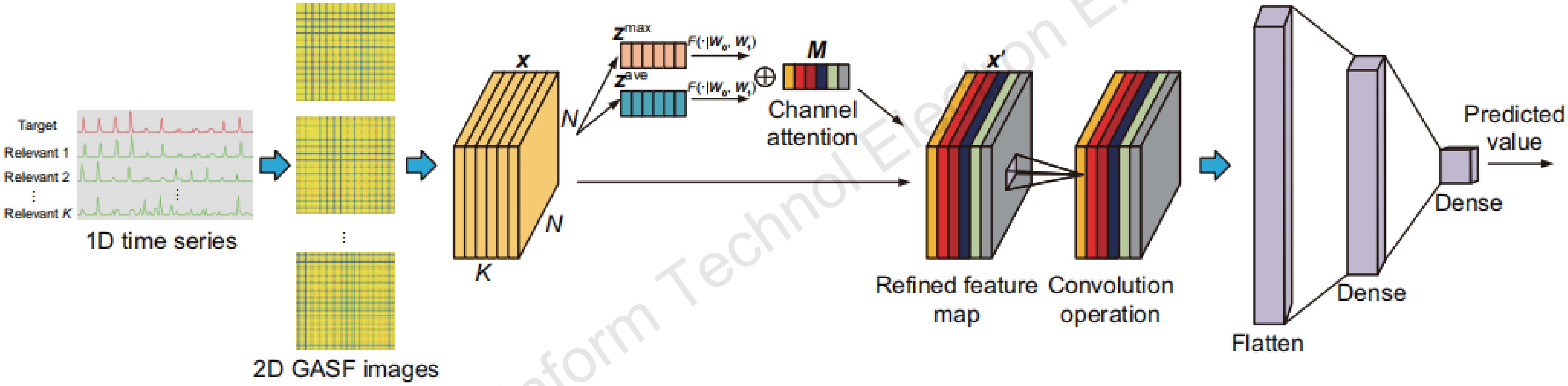

Fig. 6 Principle of the TP-CACNN model

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Results

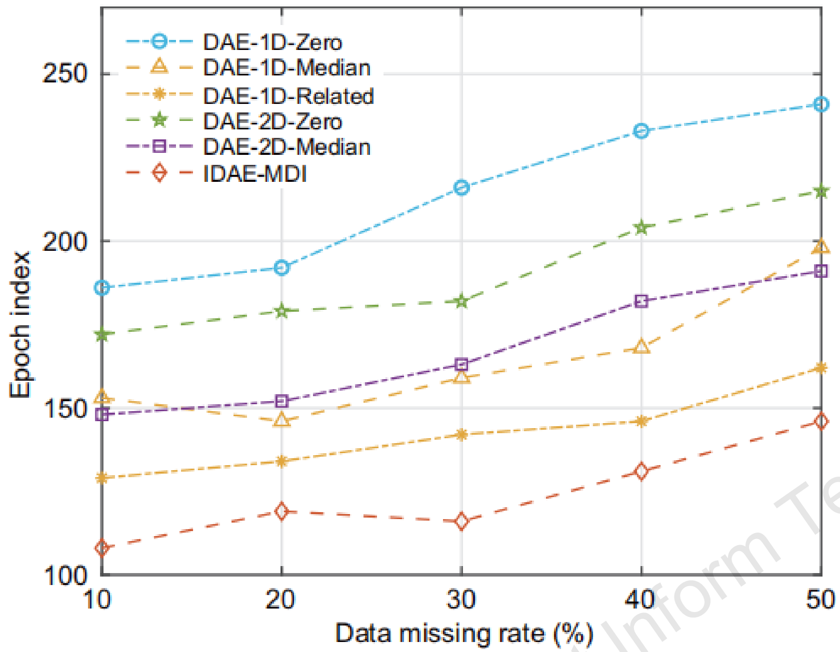

Fig. 8 Comparison of convergence speed of the IDAE-MDI model and its variants at different data missing rates

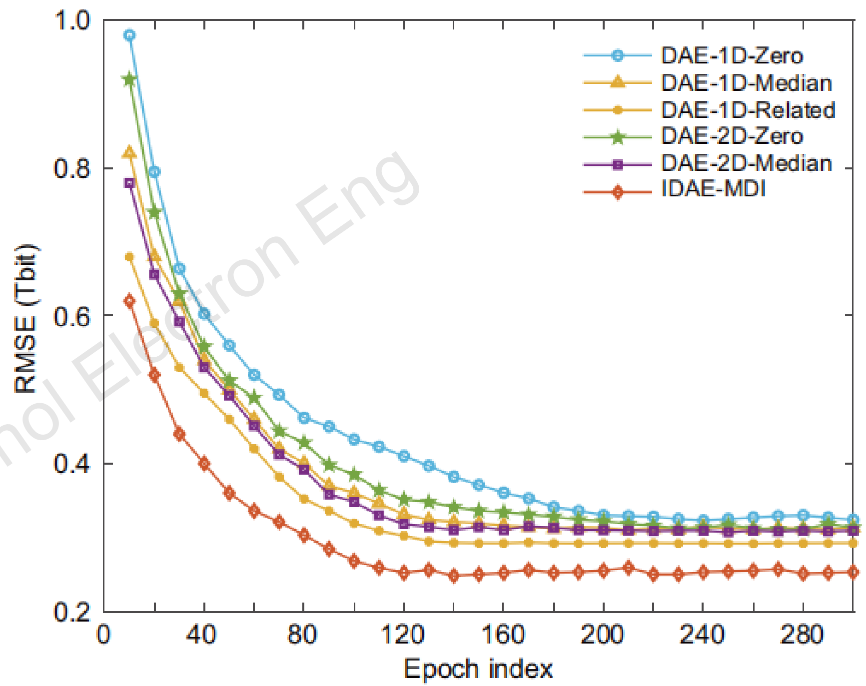

Fig. 9 RMSE comparison of the IDAE-MDI model and its variants during training at 10% data missing rate

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Results

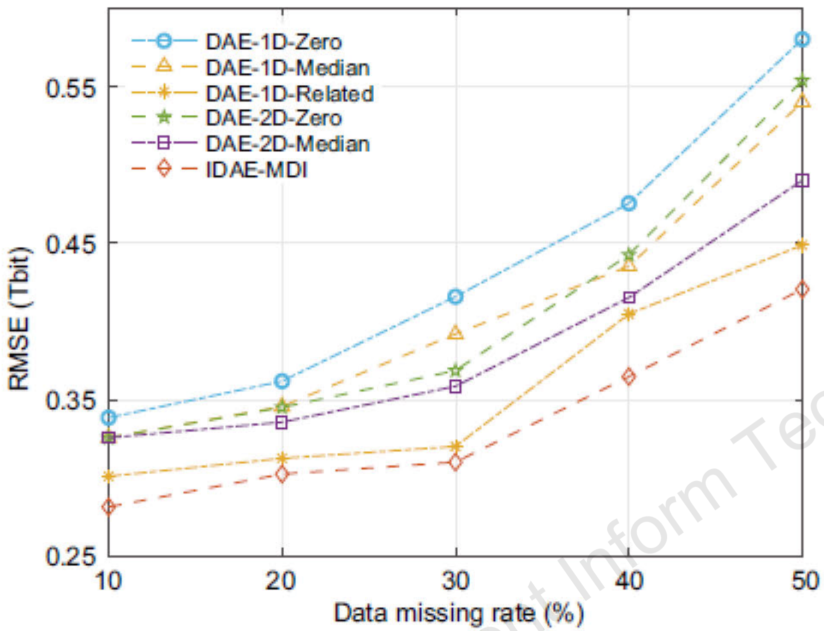

Fig. 10 RMSE comparison between the IDAE-MDI model and its variants at different data missing rates

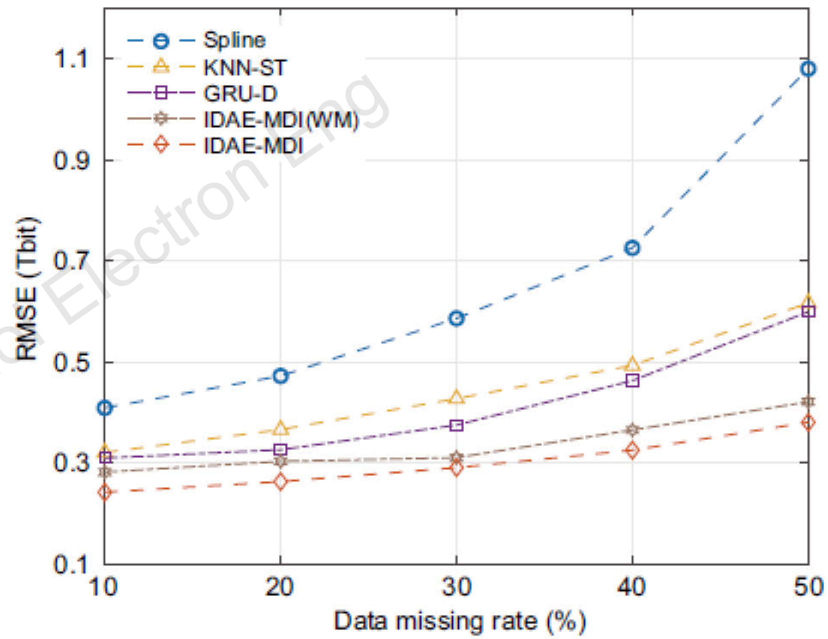

Fig. 11 RMSE comparison between the IDAE-MDI model and the baseline models at different data missing rates

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Results

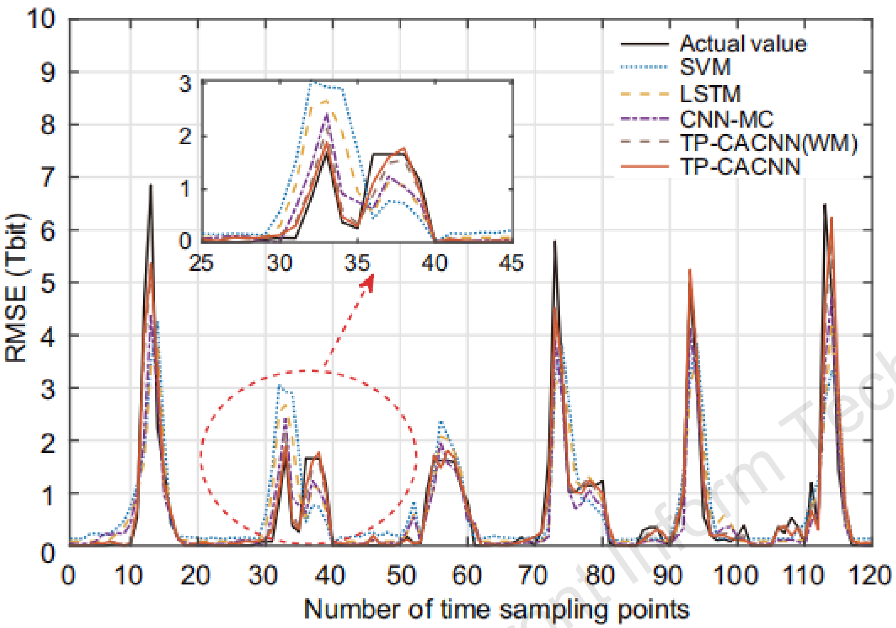

Fig. 12 Comparison curves of the true and predicted values for five different models

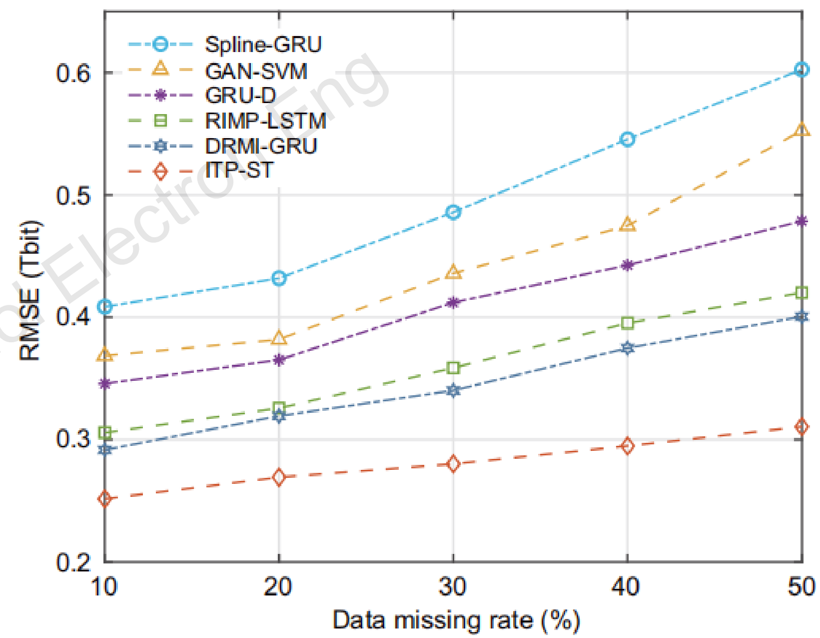

Fig. 13 RMSE comparison between the ITP-ST model and the baseline models at different data missing rates

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Conclusions

This paper proposed a novel spatio-temporal correlation-based incomplete time-series traffic prediction model for LEO satellite networks, i.e., ITP-ST. It consisted of an IDAE-MDI model for missing data imputation and a TP-CACNN model for traffic prediction. The IDAE-MDI model was based on an improved DAE. First, we combined GASF and DAE to explicitly represent the potential relationship between each timestamp by projecting the 1D time series into a 2D image representation. Second, we took the advantages of the unique spatio-temporal correlation of the LEO satellite network to improve the missing value initialization of DAE. After obtaining the reconstructed time series, we performed traffic prediction using the proposed TP-CACNN, which takes into account the degree of influence of different spatio-temporally correlated traffic on traffic prediction. Experiments on the real traffic dataset showed that the ITP-ST model outperforms the baseline models in terms of traffic prediction accuracy at different data missing rates, which demonstrated the effectiveness of our proposed model.

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