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Multi-Granularity Reconstruction Error Discrimination for Hidden Danger and Reliability Analysis of Optical Cables in Power Communication Networks

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MOTIVITION

The power communication network is the neural center of modern power systems, and optical cables—as a critical component—directly influence the overall system's security. Traditional rule-based and statistical methods lack flexibility and struggle to handle the multimodal and nonlinear characteristics inherent in network data. To address this, in this paper we propose a multi-granularity reconstruction error discrimination method to identify high-risk optical cable segments, enabling multidimensional risk quantification and intelligent early warning.

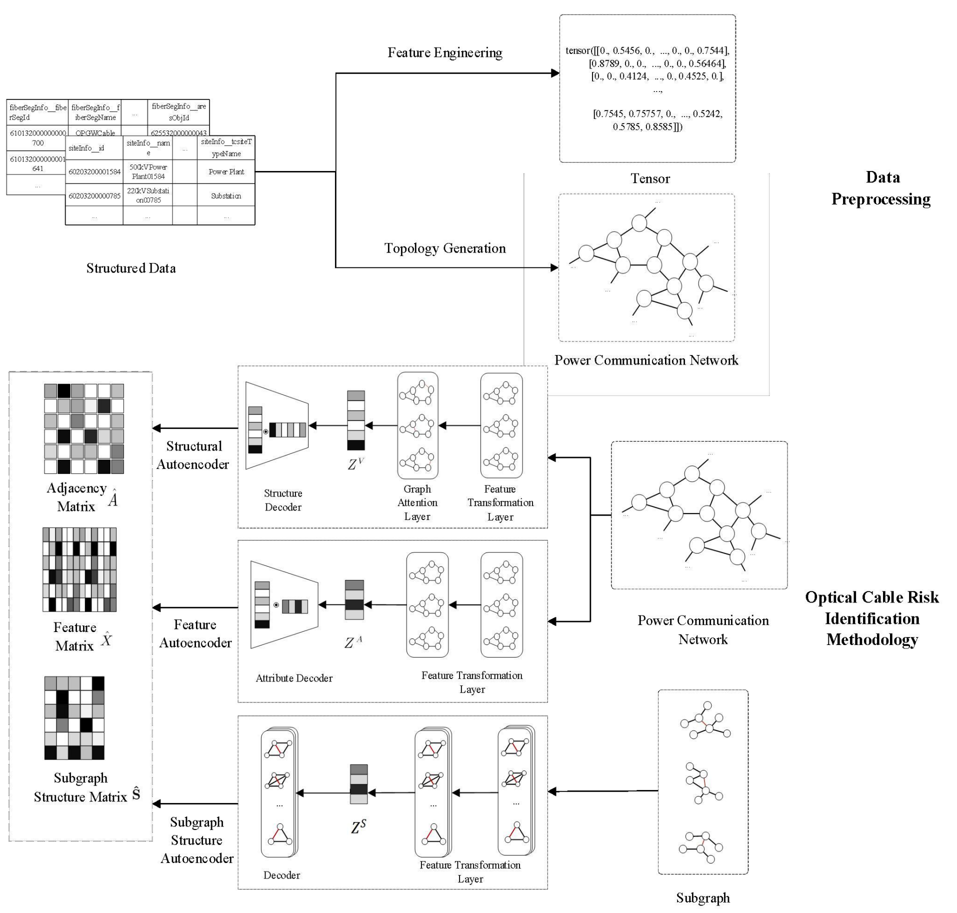
PROBLEM DEFINITION

Power communication network:
graph G=(V,E,X)

- V: nodes (substations, dispatch centers, ...)
- E: edges (optical cables)
- $X \in R^{k}$: edge attributes

Subgraph patterns: $\{M_1, M_2, \ldots, M_t\}$
Task:
Training edges $\{E_1, \ldots, E_N\}$
Test edges $\{E_{n+1}, \ldots, E_m\}$

Multi-Granularity Reconstruction–Error Framework for Optical-Cable



Three-Stage Pipeline:

- Data Pre-processing:
  Multi-source fusion → missing-value impute → outlier scrub → normalize
- Feature Engineering:
  - Structural AE: attention-based topology reconstruction
  - Attribute AE: bandwidth, delay, load matrix reconstruction
  - Subgraph AE: one-hop local pattern reconstruction
- Risk Identification
  Fused error $S = \alpha L_s + \beta L_{∯} + \gamma L_{s\,u\beta}$ → edge anomaly score → rank high-risk cables

EXPERIMENT RESULTS AND ANALYSIS

Anomaly Detection Evaluation Metrics

- ROC-AUC:
  Area-under-curve of TPR-FPR plot; higher AUC ⇒ stronger discrimination.
- Recall@K:
  Proportion of true anomalies in top-K ranked edges; suited for imbalanced data and resource-limited maintenance.

COMPARISON OF AUC FOR DIFFERENT ALGORITHMS

Method	AUC
GCNAE	0.7592
Dominant	0.7713
our Method	0.8935

Attention-based multi-granularity fusion achieves highest discrimination.

COMPARISON OF RECALL@K FOR DIFFERENT ALGORITHMS

Method	K=300	K=500
GCNAE	0.1595	0.4785
Dominant	0.1963	0.4294
our Method	0.7423	0.8344

Top-500 list captures 83 % of true faults, suited for crew scheduling under limited resources.

FRAMEWORK COMPARISON

Method	Kernal	#Encoders	Attention
GCNAE	GCN+AE	1	×
Dominant	GCN+AE	2	×
our Method	GCN+AE	3	√

Subgraph autoencoder + cross-modal attention deliver robust anomaly scoring.