

Verifiable Byzantine Robust Graph Neural Networks using Federated Learning

2005090 - Tawkir Aziz Rahman
2005074 - Dipanto Kumar Roy Nobo

CSE472: Machine Learning Sessional
Department of Computer Science and Engineering
Bangladesh University of Engineering and Technology (BUET)

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Problem & Motivation

Problem Statement

Graph Neural Networks (GNNs) are vulnerable to adversarial attacks and fail catastrophically when deployed in federated learning settings with Byzantine (malicious) participants.

Challenges:

- **Privacy:** Multiple parties need to collaborate without sharing sensitive graph data
- **Security:** Malicious clients can poison both graph structure and model parameters
- **Robustness:** Existing defenses fail under adaptive attacks

Real-World Applications:

- **Healthcare:** Disease networks across hospitals
- **Finance:** Fraud detection across banks
- **Social Networks:** Privacy-preserving community detection
- **IoT/Cybersecurity:** Distributed attack detection

Background & Related Work

Base Paper: RUNG (NeurIPS 2024)

- **Problem:** ℓ_1 -based robust GNNs suffer from estimation bias
- **Solution:** Minimax Concave Penalty (MCP) for unbiased aggregation
- **Key Innovation:** Quasi-Newton IRLS algorithm with convergence guarantees

RUNG Aggregation

$$F^{(k+1)} = (\text{diag}(q^{(k)}) + \lambda I)^{-1} [(W^{(k)} \odot \tilde{A}) F^{(k)} + \lambda F^{(0)}]$$

$$\text{where } W_{ij}^{(k)} = \max\left(0, \frac{1}{y_{ij}^{(k)}} - \frac{1}{\gamma}\right)$$

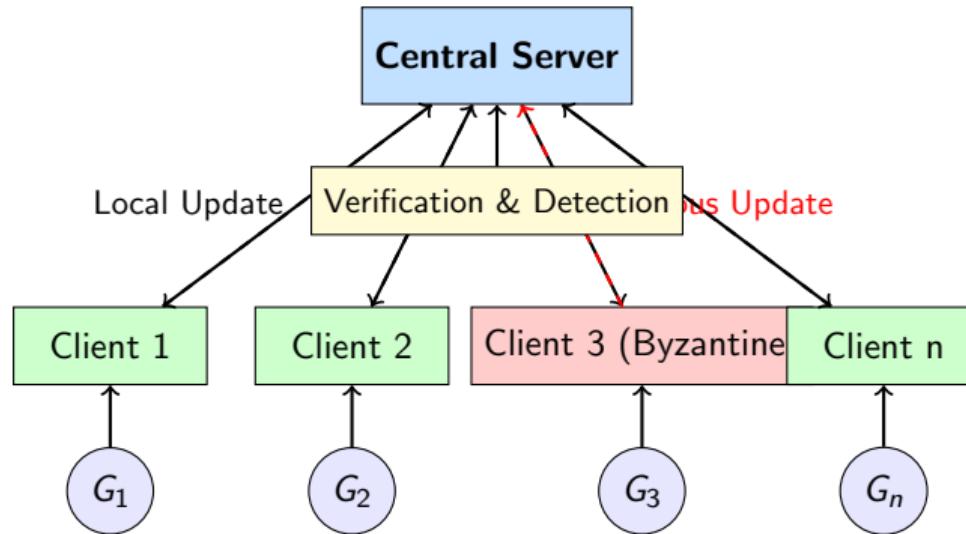
Federated Learning Challenges

- **Byzantine Attacks:** Up to f out of n clients are malicious
- **Data Heterogeneity:** Non-IID graph distributions
- **Communication Cost:** Iterative model exchanges

Byzantine-Robust FL Methods

- *Krum:* Distance-based filtering
- *Median/Trimmed Mean:* Coordinate-wise aggregation
- *BRIDGE:* Bucketing with averaging

Proposed Approach: System Architecture



Key Components

- ① **Local Training:** Each client trains RUNG on local graph G_i ;
- ② **Verifiable Aggregation:** Cryptographic proofs ensure correct local computation
- ③ **Byzantine Detection:** Statistical tests identify malicious clients

Proposed Approach: Technical Innovations

1. Verifiable Aggregation Protocol

- **Commitment Scheme:** Client commits to local edge weights $W_i^{(k)}$
- **Zero-Knowledge Proof:** Proves $W_i^{(k)}$ computed correctly without revealing graph structure
- **Lightweight Verification:** Server verifies proofs in $O(1)$ per client

Local Update with Proof

$$\theta_i^{(t+1)} = \theta_i^{(t)} - \eta \nabla \mathcal{L}(F_i^{RUNG}, y_i; \theta_i^{(t)})$$

$\pi_i = \text{ZKP}(W_i^{(k)} \text{ satisfies MCP})$

2. Byzantine Detection Mechanism

- **Distance-Based Filtering:** Compute pairwise distances between client updates
- **Statistical Outlier Test:** Detect updates with abnormal magnitudes or directions
- **Adaptive Weighting:**
 $\alpha_i \propto \exp(-\text{dist}(\theta_i, \text{median}))$

Global Aggregation

$$\theta^{(t+1)} = \frac{\sum_{i=1}^n \alpha_i \cdot \theta_i^{(t+1)}}{\sum_{i=1}^n \alpha_i}$$

where $\alpha_i = 0$ if client i fails verification

Experimental Plan

Datasets

Dataset	Nodes	Edges
Cora	2,708	5,429
CiteSeer	3,327	4,732
PubMed	19,717	44,338
ogbn-arxiv	169,343	1,166,243

Federated Setup

- **Clients:** $n = \{10, 20, 50\}$
- **Byzantine Ratio:**
 $f/n = \{0\%, 10\%, 20\%, 40\%\}$
- **Data Split:** Dirichlet distribution
($\alpha = 0.5$) for non-IID

Baselines

- ➊ **FedAvg:** Standard federated averaging
- ➋ **FedProx:** Proximal regularization
- ➌ **Krum:** Distance-based Byzantine-robust FL
- ➍ **Median/TrimmedMean:**
Coordinate-wise aggregation
- ➎ **RUNG (centralized):** Upper bound performance

Evaluation Metrics

- **Accuracy:** Node classification accuracy vs Byzantine ratio
- **Attack Detection Rate:**

Timeline & Expected Contributions

Project Timeline (12 Weeks)

Week	Milestone
1-2	Literature review & problem formulation
3-4	Design verification protocol & detection
5-6	Implement Fed-RUNG framework
7-8	Implement baselines & datasets
9-10	Run experiments & collect results
11	Analyze results & ablation studies
12	Paper writing & final presentation

Team Responsibilities

- **Member 1:** Verification protocol, theoretical analysis
- **Member 2:** Implementation, experiments.

Tawkir, Nobo

Expected Contributions

- ➊ **Novel Algorithm:** First verifiable Byzantine-robust federated GNN
- ➋ **Theoretical Analysis:** Convergence guarantees under Byzantine attacks
- ➌ **Empirical Validation:** Comprehensive experiments on multiple datasets
- ➍ **Open-Source:** Release code for reproducibility

Target Venue

NeurIPS 2026 or ICML 2026

December 2025

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