

# Deep BiLSTM with Attention for Network Intrusion Detection

## Training Results Summary

### Model Configuration

Parameter	Value
Model Architecture	Deep BiLSTM with Attention
Device	CUDA
Total Parameters	4,295,362
Trainable Parameters	4,295,362
Maximum Epochs	50
Early Stopping Patience	10
Training Completed at Epoch	41
Best Model Epoch	31

### Final Performance Metrics

Metric	Value
Test Loss	0.0799
Test Accuracy	95.02%
Precision	97.91%
Recall (Detection Rate)	94.21%
F1 Score	96.02%
AUC-ROC	99.23%
False Positive Rate (FPR)	3.56%
Detection Time	0.0190 ms/sample
Throughput	52,709.98 samples/second

Confusion Matrix (Best Model - Epoch 31)

	Predicted Normal	Predicted Attack
Actual Normal	TN: 17,938	FP: 662
Actual Attack	FN: 1,907	TP: 31,028
Total Samples: 51,535		

Training Progress Analysis

Loss Evolution

Stage	Train Loss	Test Loss	Reduction
Initial (Epoch 1)	0.1512	0.1358	-
Final (Epoch 41)	0.0900	0.0784	40.45%

Accuracy Evolution

Metric	Initial	Final	Best	Improvement
Test Accuracy	91.73%	94.46%	95.02%	+3.29%
F1 Score	93.35%	95.52%	96.02%	+2.67%
Precision	95.97%	98.88%	99.07%	+3.10%
Recall	90.87%	92.39%	95.45%	+4.58%

False Positive Rate Evolution

Stage	FPR	Change
Initial	6.76%	-
Final	1.86%	-4.90%
Best	1.51%	-5.25%

**Learning Rate Schedule**

Epoch Range	Learning Rate
1-16	0.001000
17-26	0.000500
27-36	0.000250
37-41	0.000125

**Key Performance Highlights**

**Detection Capabilities**

- Successfully detects **94.21%** of all attacks (True Positive Rate)
- Maintains a low false alarm rate of only **3.56%**
- Achieves **99.23% AUC-ROC**, indicating excellent discrimination ability

**Operational Efficiency**

- Average detection time: **0.0189 ms per sample**
- Processing throughput: **52,709 samples/second**
- Suitable for real-time network monitoring

**Model Reliability**

- Precision of **97.91%** means very few false alarms
- F1 Score of **96.02%** shows excellent balance between precision and recall
- Early stopping at epoch 41 prevented overfitting

Training Timeline

Milestone	Epoch	F1 Score
First checkpoint	1	93.35%
Significant improvement	6	95.55%
Another improvement	11	95.79%
Learning rate reduced	17	94.62%
Best performance achieved	21	95.97%
Global best model	31	96.02%
Training stopped	41	95.52%

Summary

The Deep BiLSTM with Attention mechanism demonstrated excellent performance for network intrusion detection:

- 1. **High Detection Accuracy:** Achieved 96.02% F1 score with 94.21% recall
- 2. **Low False Positives:** Only 3.56% false positive rate
- 3. **Fast Processing:** 0.019 ms per sample enables real-time detection
- 4. **Robust Training:** Converged after 41 epochs with effective early stopping
- 5. **Excellent Generalization:** High AUC-ROC (99.23%) indicates strong model reliability

The model is production-ready for deployment in network security monitoring systems.  
Check.