Empirical Evaluation of the Ensemble Framework for Feature Selection in DDoS Attack

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I. INTRODUCTION

This document is meant to be used alongside the article "Empirical Evaluation of the Ensemble Framework for Feature Selection in DDoS Attack". The rest of this document is a collection of ROC curves and tables containing results of conducted all experiments. ROC curves are also stored as an image format in https://github.com/simplysaikat/EnFS/tree/master/ROC_AUC/

II. More Experimental Results

In this section, ROC curves using seven selection methods and the overview of all experimental results are shown in graphically and in tabular form, respectively.

A) ROC Curves

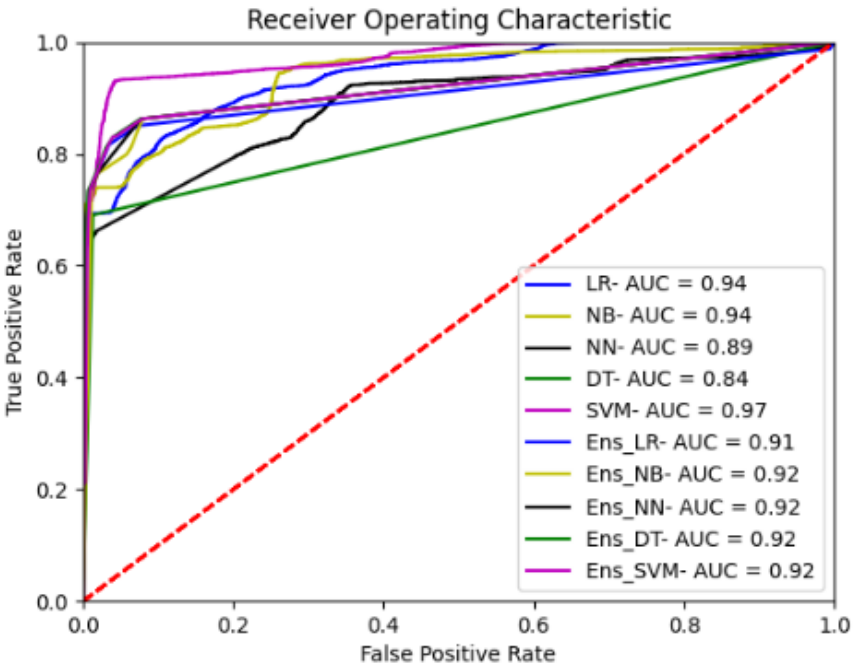

Fig. 1. ROC curve using Pearson Method

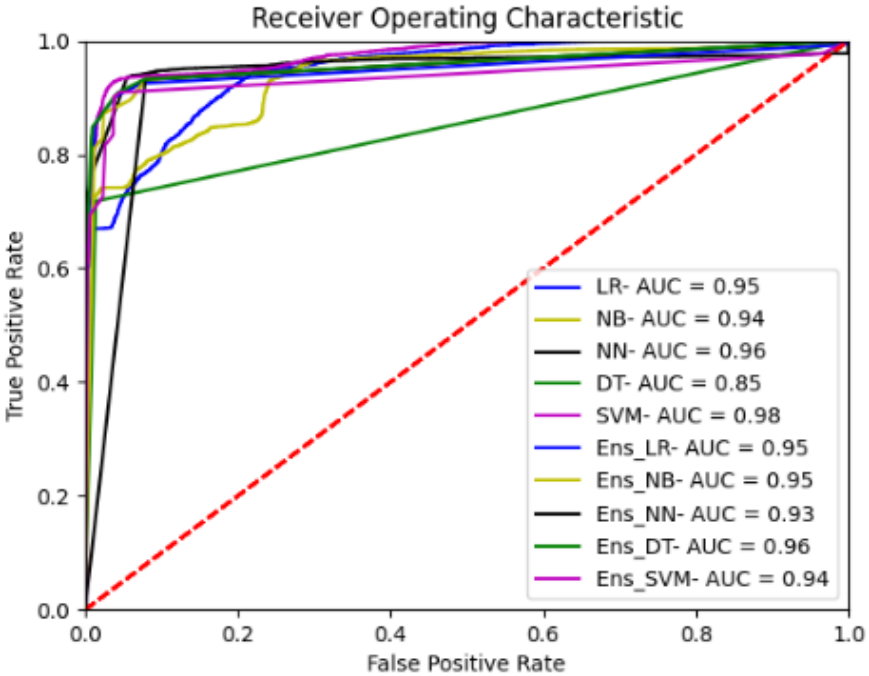

Fig. 2. ROC curve using Chi-Square Method

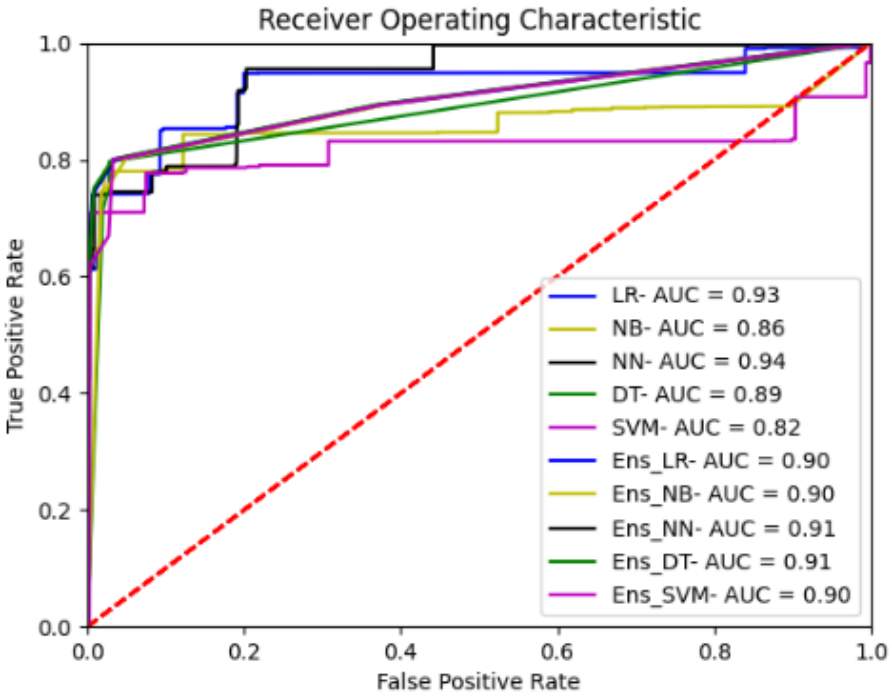

Fig. 3. ROC curve using Mutual Information Method

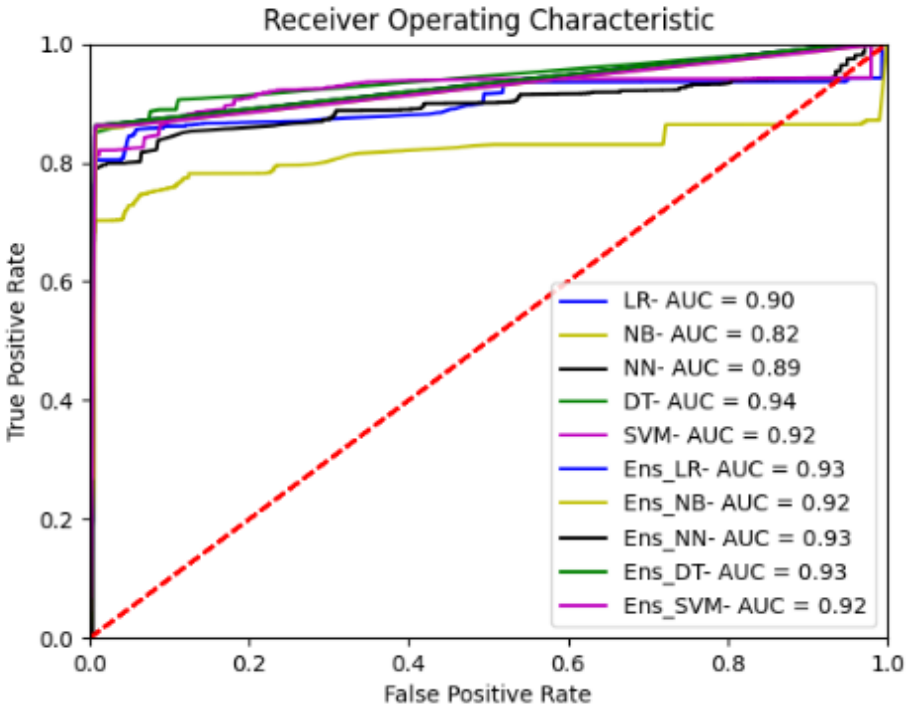

Fig. 4. ROC curve using LASSO Method

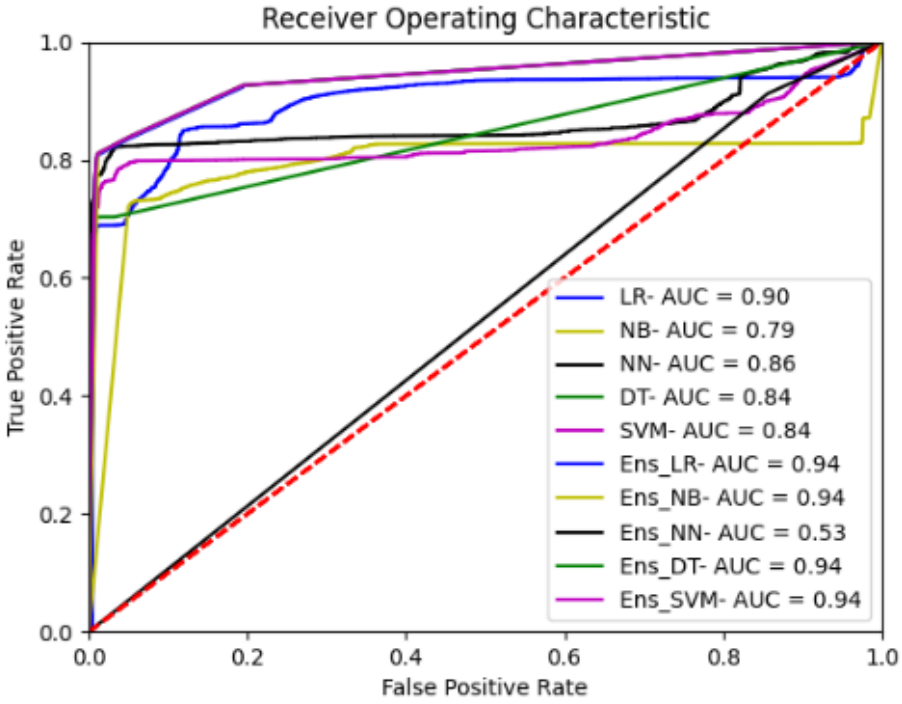

Fig. 5. ROC curve using LR with L1 penalty Method

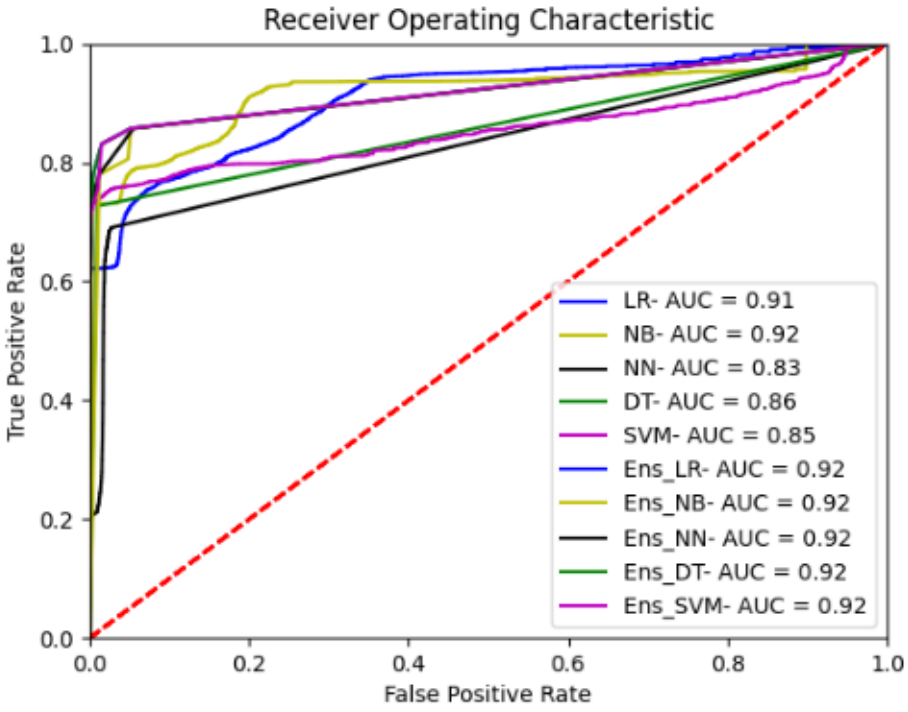

Fig. 6. ROC curve using Random Forest Method

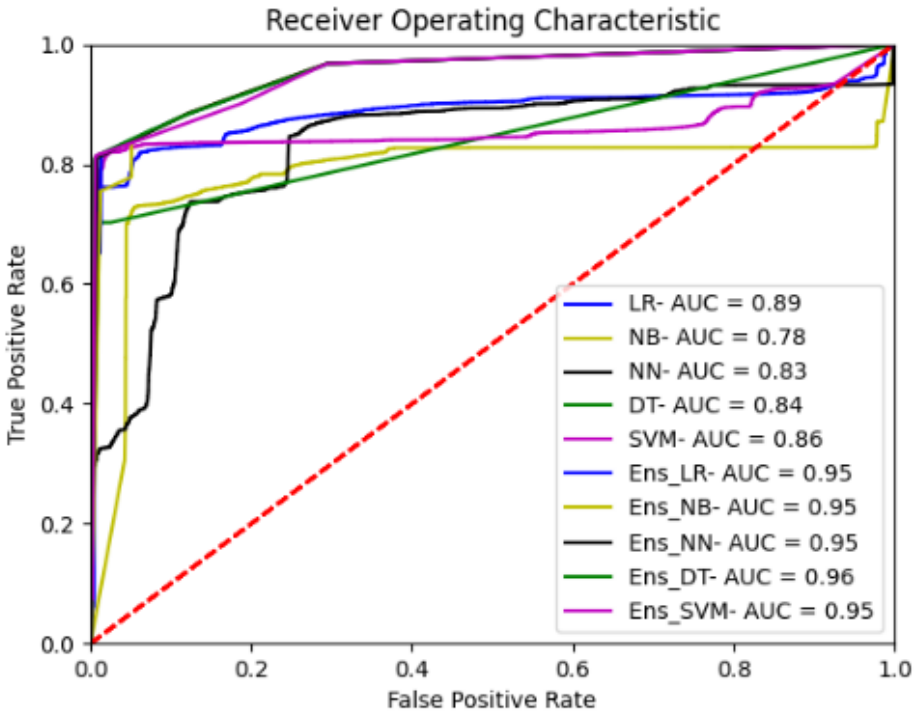

Fig. 7. ROC curve using Recursive Feature Elimination Method

B) Tables

TABLE I. DATA CLASSIFICATION OVERVIEW WITH ENSEMBLE SUPERVISED FRAMEWORK [2] USING EXTRACTED FEATURES FROM SEVEN SELECTION METHODS AND FROM ENFS, AND WITHOUT USING ANY FEATURE SELECTION METHOD.

Method	Model Category	Model Name	F-1 Score	Accuracy	Precision	Recall	FPR
Pearson Correlation (F#1)	Individual	LR	0.814	0.855	0.921	0.729	0.048
		NB	0.822	0.859	0.911	0.750	0.056
		NN	0.344	0.656	0.998	0.208	0.000
		DT	0.808	0.857	0.976	0.689	0.013
		SVM	0.834	0.874	0.977	0.728	0.013
	Ensemble	Ens_MV	0.808	0.859	0.989	0.684	0.006
		Ens_LR	0.874	0.895	0.903	0.848	0.070
		Ens_NB	0.852	0.880	0.913	0.799	0.058
		Ens_NN	0.879	0.897	0.895	0.863	0.077
		Ens_DT	0.882	0.904	0.941	0.830	0.040
		Ens_SVM	0.882	0.904	0.940	0.830	0.041
Chi-Square (F#2)	Individual	LR	0.802	0.848	0.923	0.709	0.045
		NB	0.820	0.857	0.909	0.747	0.058
		NN	0.859	0.892	0.987	0.761	0.008
		DT	0.826	0.869	0.975	0.717	0.014
		SVM	0.887	0.910	0.980	0.810	0.013

	Ensemble	Ens_MV	0.841	0.880	0.985	0.734	0.008
		Ens_LR	0.912	0.929	0.980	0.853	0.013
		Ens_NB	0.908	0.922	0.921	0.895	0.058
		Ens_NN	0.916	0.926	0.900	0.932	0.079
		Ens_DT	0.925	0.936	0.941	0.909	0.043
		Ens_SVM	0.924	0.935	0.939	0.909	0.045
Mutual Information (F#3)	Individual	LR	0.754	0.826	0.979	0.613	0.010
		NB	0.732	0.731	0.646	0.846	0.357
		NN	0.780	0.842	0.986	0.646	0.007
		DT	0.848	0.881	0.955	0.763	0.028
		SVM	0.822	0.867	0.977	0.710	0.013
	Ensemble	Ens_MV	0.823	0.867	0.981	0.709	0.011
		Ens_LR	0.864	0.891	0.937	0.802	0.041
		Ens_NB	0.859	0.886	0.925	0.803	0.050
		Ens_NN	0.868	0.895	0.948	0.801	0.034
		Ens_DT	0.869	0.895	0.950	0.801	0.032
		Ens_SVM	0.867	0.894	0.945	0.801	0.036
LASSO (F#4)	Individual	LR	0.869	0.894	0.936	0.811	0.043
		NB	0.812	0.852	0.907	0.735	0.058
		NN	0.873	0.901	0.988	0.781	0.007
		DT	0.914	0.931	0.991	0.848	0.006
		SVM	0.873	0.901	0.989	0.781	0.007
	Ensemble	Ens_MV	0.870	0.899	0.989	0.777	0.007
		Ens_LR	0.918	0.934	0.989	0.856	0.007
		Ens_NB	0.898	0.915	0.939	0.859	0.042
		Ens_NN	0.921	0.936	0.989	0.862	0.007
		Ens_DT	0.921	0.936	0.989	0.862	0.007
		Ens_SVM	0.919	0.935	0.988	0.859	0.008
LR with L1 (F#5)	Individual	LR	0.796	0.844	0.917	0.703	0.049
		NB	0.565	0.447	0.429	0.828	0.846
		NN	0.861	0.893	0.985	0.765	0.009
		DT	0.820	0.866	0.986	0.702	0.008
		SVM	0.826	0.870	0.988	0.709	0.007
	Ensemble	Ens_MV	0.829	0.871	0.984	0.715	0.009
		Ens_LR	0.887	0.911	0.982	0.808	0.011
		Ens_NB	0.888	0.912	0.982	0.811	0.011
		Ens_NN	0.921	0.936	0.989	0.862	0.007
		Ens_DT	0.886	0.910	0.985	0.804	0.009
		Ens_SVM	0.888	0.912	0.982	0.811	0.011
Random Forests (F#6)	Individual	LR	0.798	0.846	0.928	0.700	0.042
		NB	0.835	0.871	0.934	0.755	0.041
		NN	0.325	0.650	1.000	0.194	0.000
		DT	0.834	0.875	0.983	0.725	0.010
		SVM	0.825	0.870	0.997	0.703	0.001
	Ensemble	Ens_MV	0.804	0.857	0.999	0.672	0.001
		Ens_LR	0.898	0.918	0.977	0.831	0.015
		Ens_NB	0.862	0.889	0.927	0.806	0.048
		Ens_NN	0.889	0.907	0.923	0.857	0.055
		Ens_DT	0.898	0.918	0.977	0.831	0.015
		Ens_SVM	0.898	0.918	0.977	0.831	0.015
Recursive Feature Elimination (F#7)	Individual	LR	0.841	0.874	0.928	0.770	0.046
		NB	0.786	0.824	0.833	0.743	0.114
		NN	0.778	0.785	0.705	0.866	0.278
		DT	0.818	0.864	0.981	0.702	0.011
		SVM	0.825	0.870	0.986	0.710	0.008

	Ensemble	Ens_MV	0.817	0.857	0.923	0.732	0.047
		Ens_LR	0.891	0.913	0.979	0.817	0.013
		Ens_NB	0.844	0.876	0.921	0.779	0.051
		Ens_NN	0.890	0.913	0.986	0.811	0.008
		Ens_DT	0.893	0.916	0.990	0.813	0.006
		Ens_SVM	0.893	0.916	0.990	0.814	0.006
EnFS	Individual	LR	0.885	0.905	0.933	0.842	0.046
		NB	0.836	0.861	0.857	0.815	0.104
		NN	0.830	0.866	0.923	0.754	0.048
		DT	0.920	0.935	0.986	0.863	0.009
		SVM	0.967	0.972	0.984	0.949	0.012
	Ensemble	Ens_MV	0.888	0.907	0.938	0.843	0.043
		Ens_LR	0.970	0.974	0.988	0.953	0.009
		Ens_NB	0.946	0.952	0.942	0.950	0.046
		Ens_NN	0.970	0.974	0.992	0.949	0.006
		Ens_DT	0.971	0.975	0.991	0.952	0.006
		Ens_SVM	0.970	0.974	0.989	0.952	0.009
Without any feature selection (Full Feature Set)	Individual	LR	0.846	0.877	0.930	0.775	0.045
		NB	0.807	0.856	0.971	0.690	0.016
		NN	0.840	0.873	0.933	0.763	0.042
		DT	0.875	0.895	0.928	0.832	0.021
		SVM	0.866	0.897	0.990	0.770	0.006
	Ensemble	Ens_MV	0.858	0.891	0.988	0.759	0.007
		Ens_LR	0.804	0.857	0.938	0.722	0.010
		Ens_NB	0.870	0.892	0.925	0.821	0.052
		Ens_NN	0.872	0.901	0.930	0.835	0.013
		Ens_DT	0.884	0.900	0.878	0.890	0.011
		Ens_SVM	0.834	0.845	0.882	0.791	0.012

REFERENCES

[1] M. Tavallaee, E. Bagheri, W. Lu, and A. Ghorbani, “A Detailed Analysis of the KDD CUP 99 Data Set,” Submitted to Second IEEE Symposium on Computational Intelligence for Security and Defense Applications (CISDA), 2009.

[2] Das, Saikat, et al. "DDoS Intrusion Detection Through Machine Learning Ensemble." 2019 IEEE 19th International Conference on Software Quality, Reliability and Security Companion (QRS-C). IEEE, 2019.