

Contents

1	Introduction	1
1.1	The Web and Its Users	1
1.2	Web-based Attacks	2
1.2.1	Steps in Launching a Web-based Attack	4
1.3	Types of Web-based Attacks	5
1.3.1	Cross-site Scripting Attacks	6
1.3.2	HTTP Flooding Attacks	10
1.3.3	Attacks in Critical Infrastructure	13
1.4	Sophistication of Attacks	18
1.5	Motivation of Attackers	18
1.6	Defense Approaches	19
1.6.1	Machine Learning for Web-based Attack Defense	20
1.7	Motivation and Objectives	21
1.8	Contributions	25
1.9	Thesis Organization	26
2	Background	28
2.1	Networks	28
2.2	Network Communications	29
2.3	Internet and Its Issues	30
2.4	Network Attacks	31
2.5	Web-based Attacks	32
2.5.1	Cross-site Scripting Attacks	32
2.5.2	Cyber Physical Systems	46

2.5.3	HTTP Flooding Attacks	56
2.6	Raw and Feature Data	58
2.6.1	A Generic Pipeline of Dataset Generation	59
2.6.2	Types of Datasets	63
2.7	Machine Learning Approaches	65
2.7.1	Supervised Learning and Its Significance	66
2.7.2	Unsupervised Learning and Its Significance	69
2.7.3	Ensemble Learning Approaches	70
2.8	Cost Effective Methods for Attack Analysis	72
2.8.1	Feature Selection Methods	72
2.9	Validation Measures	75
3	Datasets Used	81
3.1	Introduction	81
3.1.1	Desired Characteristics of a Dataset	83
3.2	Benchmark Datasets	85
3.2.1	Cross-site Scripting Attack Repositories	85
3.2.2	HTTP Flooding Attack Datasets	86
3.2.3	Cyber Physical Systems Datasets	88
3.2.4	Other Security Datasets	90
3.3	Generated Datasets	93
3.3.1	XSS Attack Dataset	93
3.3.2	Proposed Dataset Generation Framework	94
3.3.3	Stages and Modules	94
3.3.4	Tasks and Sub-tasks	96
3.3.5	XSSD: The Dataset and Its Characteristics	98
3.3.6	Performance Evaluation and Validation	103
3.4	Discussion	104
4	Ensemble Learning Methods	106
4.1	Introduction	106
4.1.1	Motivation	107

4.1.2	Contribution	107
4.2	Background	107
4.2.1	Ensemble Learning	107
4.3	Data-centric Supervised Ensemble Proposed Framework	113
4.3.1	Preprocessing Engine	114
4.3.2	Parameter Tuning Engine	115
4.3.3	Ensemble Engine	116
4.3.4	Performance Analysis Engine	117
4.4	Experimental Results	117
4.4.1	Bagging Results	118
4.4.2	Boosting Results	118
4.4.3	Bagging-Boosting Results	123
4.4.4	Stacking Results	123
4.4.5	Observations	123
4.4.6	Discussion	127

5 MICC-UD: A Mutual Information and Correlation-based Feature

	Selection Method	129
5.1	Introduction	129
5.1.1	Feature	130
5.1.2	Related Work	130
5.1.3	Limitations of the Existing Approaches	132
5.1.4	Motivation	133
5.1.5	Contribution	133
5.2	Problem Formulation	134
5.3	Background	134
5.3.1	Mutual Information for Feature Selection	135
5.3.2	Correlation Co-efficient for Feature Selection	135
5.4	MICC-UD: Proposed Method	136
5.4.1	Preprocessing Engine	137
5.4.2	Feature Selection Engine	137

5.4.3	Optimal Feature Subset Identification using Recursive Feature Elimination	139
5.4.4	Proposed Algorithm	140
5.5	Complexity Analysis	141
5.6	Experimental Results	142
5.6.1	Results and Analysis	143
5.6.2	Comparison with Existing Works	146
5.7	Discussion	147
6	INFS-MICC: An Incremental Feature Selection Method	150
6.1	Introduction	150
6.1.1	Incremental Data	151
6.1.2	Necessity of Incremental Feature Selection	151
6.1.3	Related Work	151
6.1.4	Motivation	154
6.1.5	Contribution	154
6.2	Problem Definition	155
6.3	Background	156
6.3.1	Mutual Information for Feature Selection	156
6.3.2	Correlation for Feature Selection	157
6.4	INFS-MICC: Proposed Method	157
6.4.1	Relevance and Independent Feature Subset Finding	159
6.5	Experimental Results	160
6.5.1	Comparison with other Feature Selection Methods	165
6.5.2	Discussion	167
7	FSRA: A Feature Selection and Rank Aggregation Framework for CPS Attack Classification	172
7.1	Introduction	172
7.1.1	Related Work	174
7.1.2	Motivation	177
7.1.3	Contributions	177

7.2	Problem Formulation	178
7.3	CPSAD: Proposed Attack Detection Framework	178
7.3.1	Detection Module	179
7.3.2	FSRA: Proposed Ensemble Feature Selection Method	180
7.3.3	Alarm Generation Module	183
7.3.4	Feedback Analyzer Module	184
7.3.5	Reference or Rule generation Module	184
7.4	Experimental Results	184
7.4.1	Comparison with Existing Methods	191
7.5	Discussion	194
8	Conclusion	197
8.1	Concluding Remarks	197
8.2	Future Work	199
	Appendices	202
A	Combining continuous outputs	202
B	Hyper-parameter values	203
B.1	Bagging	203
B.2	Boosting	204
	Glossary	237