Comparative Analysis of Path-Level, and Fragmentation-as-a-Picture Methods for Blocking Prediction in Elastic Optical Networks

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***Index Terms*—Elastic optical networks (EON), Bandwidth fragmentation, Fragmentation metrics, Blocking rate, Machine Learning, Fragmentation Visual Representation, Fragmentation as a picture.**

I. Notes on Results

This document contains detailed results for the performance of models used to predict blocking of connections at k, $k+1$, $k+3$, $k+5$, $k+7$, $k+9$, and $k+11$ steps for Low, Medium, High, and Very High loads. It is important to note that High and Very high, loads were evaluated only for experimentation purposes in the fragmentation as a picture approach since they cause network blocking to go beyond 20%.

Appendix A
Complete Tables and Figures

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.89651	0.66128	0.66125	0.66127
	1	0.88816	0.62720	0.62716	0.62718
	3	0.88434	0.60237	0.60234	0.60236
	5	0.88421	0.59514	0.59511	0.59513
	7	0.88397	0.59174	0.59171	0.59172
	9	0.88440	0.59258	0.59254	0.59256
	11	0.88480	0.59368	0.59365	0.59367
Medium	0	0.92445	0.64167	0.64161	0.64164
	1	0.91731	0.60010	0.60004	0.60007
	3	0.91636	0.58192	0.58186	0.58189
	5	0.91660	0.57568	0.57562	0.57565
	7	0.91696	0.57508	0.57502	0.57505
	9	0.91497	0.56406	0.56400	0.56403
	11	0.91737	0.57628	0.57622	0.57625

TABLE I: NA - Arithmetic Mean. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.92999	0.77087	0.77083	0.77085
	1	0.92083	0.73612	0.73608	0.73610
	3	0.91814	0.71859	0.71855	0.71857
	5	0.91870	0.71573	0.71569	0.71571
	7	0.91830	0.71254	0.71250	0.71252
	9	0.91933	0.71570	0.71566	0.71568
	11	0.91868	0.71319	0.71316	0.71318
Medium	0	0.94781	0.75247	0.75239	0.75243
	1	0.93873	0.70373	0.70366	0.70370
	3	0.93858	0.69301	0.69293	0.69297
	5	0.93625	0.67565	0.67558	0.67562
	7	0.93809	0.68321	0.68313	0.68317
	9	0.93888	0.68668	0.68661	0.68664
	11	0.93648	0.67429	0.67422	0.67426

TABLE II: NA - Sum. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.93667	0.79273	0.79269	0.79271
	1	0.92544	0.75148	0.75144	0.75146
	3	0.92249	0.73353	0.73349	0.73351
	5	0.92382	0.73363	0.73359	0.73361
	7	0.92414	0.73310	0.73306	0.73308
	9	0.92413	0.73260	0.73256	0.73258
	11	0.92433	0.73310	0.73306	0.73308
Medium	0	0.95122	0.76864	0.76857	0.76860
	1	0.94161	0.71763	0.71756	0.71760
	3	0.93996	0.69987	0.69980	0.69983
	5	0.94137	0.70174	0.70166	0.70170
	7	0.94156	0.70099	0.70091	0.70095
	9	0.94129	0.69900	0.69892	0.69896
	11	0.94234	0.70432	0.70425	0.70428

TABLE III: NA - Sum, Kurtosis, Standard Deviation and Skew. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.94109	0.80721	0.80717	0.80719
	1	0.93090	0.76968	0.76964	0.76966
	3	0.92826	0.75336	0.75332	0.75334
	5	0.92824	0.74909	0.74905	0.74907
	7	0.92773	0.74573	0.74569	0.74571
	9	0.92864	0.74851	0.74847	0.74849
	11	0.92884	0.74903	0.74899	0.74901
Medium	0	0.95598	0.79123	0.79115	0.79119
	1	0.94555	0.73672	0.73665	0.73668
	3	0.94474	0.72378	0.72371	0.72374
	5	0.94573	0.72389	0.72381	0.72385
	7	0.94624	0.72492	0.72484	0.72488
	9	0.94598	0.72308	0.72300	0.72304
	11	0.94607	0.72346	0.72338	0.72342

TABLE IV: NA - Granularity Weighted Sum. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.94540	0.82133	0.82129	0.82131
	1	0.93272	0.77576	0.77572	0.77574
	3	0.92962	0.75804	0.75800	0.75802
	5	0.93008	0.75553	0.75549	0.75551
	7	0.93197	0.76064	0.76060	0.76062
	9	0.93146	0.75843	0.75839	0.75841
	11	0.93208	0.76043	0.76039	0.76041
Medium	0	0.95930	0.80700	0.80692	0.80696
	1	0.94635	0.74056	0.74048	0.74052
	3	0.94643	0.73225	0.73218	0.73221
	5	0.94697	0.73022	0.73014	0.73018
	7	0.94757	0.73172	0.73164	0.73168
	9	0.94791	0.73298	0.73290	0.73294
	11	0.94768	0.73171	0.73163	0.73167

TABLE V: NA - Granularity Weighted Sum, Kurtosis, Standard Deviation and Skew. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.91229	0.70850	0.70849	0.70850
	1	0.90605	0.68588	0.68587	0.68587
	3	0.90428	0.67713	0.67712	0.67712
	5	0.90381	0.67392	0.67391	0.67392
	7	0.90363	0.67240	0.67238	0.67239
	9	0.90262	0.66827	0.66825	0.66826
	11	0.90281	0.66848	0.66847	0.66848
Medium	0	0.91658	0.67040	0.67039	0.67040
	1	0.91042	0.64391	0.64390	0.64390
	3	0.90949	0.63671	0.63670	0.63671
	5	0.90846	0.63022	0.63021	0.63022
	7	0.90890	0.63034	0.63033	0.63034
	9	0.90790	0.62500	0.62499	0.62500
	11	0.90729	0.62139	0.62138	0.62139

TABLE VI: Germany - Arithmetic Mean. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.93474	0.78310	0.78309	0.78309
	1	0.92591	0.75229	0.75228	0.75228
	3	0.92534	0.74818	0.74816	0.74817
	5	0.92435	0.74356	0.74355	0.74356
	7	0.92400	0.74165	0.74164	0.74165
	9	0.92347	0.73932	0.73931	0.73931
	11	0.92311	0.73773	0.73771	0.73772
Medium	0	0.94346	0.77663	0.77661	0.77662
	1	0.93517	0.74230	0.74229	0.74229
	3	0.93310	0.73147	0.73146	0.73146
	5	0.93216	0.72599	0.72598	0.72598
	7	0.93242	0.72577	0.72576	0.72577
	9	0.93202	0.72320	0.72319	0.72319
	11	0.93150	0.72024	0.72023	0.72024

TABLE VII: Germany - Sum. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.94417	0.81444	0.81442	0.81443
	1	0.93401	0.77936	0.77935	0.77936
	3	0.93266	0.77288	0.77286	0.77287
	5	0.93235	0.77067	0.77066	0.77067
	7	0.93292	0.77198	0.77196	0.77197
	9	0.93197	0.76828	0.76826	0.76827
	11	0.93154	0.76650	0.76648	0.76649
Medium	0	0.95044	0.80418	0.80417	0.80417
	1	0.94080	0.76467	0.76465	0.76466
	3	0.93858	0.75349	0.75347	0.75348
	5	0.93849	0.75155	0.75153	0.75154
	7	0.93813	0.74897	0.74895	0.74896
	9	0.93852	0.74968	0.74967	0.74968
	11	0.93814	0.74739	0.74737	0.74738

TABLE VIII: Germany - Sum, Kurtosis, Standard Deviation, and Skew. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.94906	0.83069	0.83068	0.83069
	1	0.93947	0.79764	0.79762	0.79763
	3	0.93788	0.79046	0.79044	0.79045
	5	0.93787	0.78937	0.78936	0.78937
	7	0.93685	0.78534	0.78532	0.78533
	9	0.93647	0.78358	0.78357	0.78358
	11	0.93646	0.78326	0.78324	0.78325
Medium	0	0.95651	0.82818	0.82817	0.82817
	1	0.94517	0.78205	0.78204	0.78205
	3	0.94384	0.77458	0.77456	0.77457
	5	0.94317	0.77043	0.77042	0.77042
	7	0.94248	0.76660	0.76659	0.76660
	9	0.94257	0.76617	0.76616	0.76617
	11	0.94211	0.76358	0.76357	0.76357

TABLE IX: Germany - Granularity Weighted Sum. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.95625	0.85459	0.85458	0.85458
	1	0.94489	0.81575	0.81573	0.81574
	3	0.94310	0.80809	0.80808	0.80809
	5	0.94245	0.80492	0.80491	0.80492
	7	0.94282	0.80563	0.80561	0.80562
	9	0.94178	0.80169	0.80168	0.80169
	11	0.94241	0.80358	0.80356	0.80357
Medium	0	0.96142	0.84759	0.84758	0.84759
	1	0.95007	0.80153	0.80152	0.80153
	3	0.94772	0.79018	0.79016	0.79017
	5	0.94710	0.78634	0.78633	0.78633
	7	0.94706	0.78517	0.78516	0.78517
	9	0.94659	0.78254	0.78252	0.78253
	11	0.94697	0.78343	0.78342	0.78342

TABLE X: Germany - Granularity Weighted Sum, Kurtosis, Standard Deviation, and Skew. Path based fragmentation.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.93960	0.93534	0.93634	0.93584
	1	0.84232	0.80627	0.87105	0.83741
	3	0.84063	0.80833	0.85564	0.83131
	5	0.84286	0.80814	0.85748	0.83208
	7	0.83754	0.79777	0.85811	0.82684
	9	0.84636	0.80851	0.86414	0.83540
	11	0.84724	0.81248	0.85935	0.83526
Medium	0	0.96511	0.91694	0.91870	0.91782
	1	0.90586	0.77076	0.77967	0.77519
	3	0.90341	0.74603	0.79038	0.76757
	5	0.90466	0.74280	0.79501	0.76801
	7	0.90451	0.74090	0.79398	0.76652
	9	0.90530	0.74504	0.78994	0.76684
	11	0.90518	0.74476	0.78984	0.76664
High	0	0.97565	0.91425	0.91622	0.91523
	1	0.93018	0.74165	0.77223	0.75663
	3	0.93051	0.74030	0.75304	0.74662
	5	0.93229	0.73556	0.77067	0.75271
	7	0.93042	0.71514	0.79253	0.75185
	9	0.93406	0.74986	0.75615	0.75299
	11	0.93403	0.74442	0.76714	0.75561
Very High	0	0.98540	0.93899	0.91472	0.92670
	1	0.95240	0.74648	0.78484	0.76518
	3	0.95347	0.74460	0.78133	0.76252
	5	0.95618	0.77298	0.75768	0.76526
	7	0.95499	0.76152	0.75758	0.75954
	9	0.95633	0.76903	0.76341	0.76621
	11	0.95576	0.76215	0.76733	0.76473

TABLE XI: CNN-LSTM Model Results for NA Topology. Fragmentation as a Picture.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.95757	0.95038	0.95455	0.95246
	1	0.88649	0.87130	0.87294	0.87212
	3	0.88493	0.86635	0.87352	0.86992
	5	0.88735	0.87713	0.86439	0.87071
	7	0.88425	0.86437	0.87251	0.86842
	9	0.88498	0.86583	0.87211	0.86896
	11	0.88646	0.87588	0.86227	0.86903
Medium	0	0.97075	0.93013	0.94625	0.93812
	1	0.91915	0.82789	0.82430	0.82609
	3	0.91598	0.81381	0.82475	0.81924
	5	0.91602	0.80951	0.82926	0.81927
	7	0.91600	0.81403	0.81984	0.81692
	9	0.91509	0.80592	0.82638	0.81602
	11	0.91630	0.81193	0.82234	0.81710
High	0	0.97944	0.92274	0.94040	0.93149
	1	0.94033	0.81032	0.77788	0.79377
	3	0.93547	0.77178	0.79250	0.78200
	5	0.93437	0.75559	0.80935	0.78155
	7	0.93634	0.78180	0.77576	0.77877
	9	0.93606	0.76986	0.79284	0.78119
	11	0.93630	0.76903	0.79528	0.78193
Very High	0	0.98277	0.91369	0.94364	0.92842
	1	0.94907	0.78390	0.78241	0.78315
	3	0.94173	0.72392	0.80607	0.76279
	5	0.94488	0.76037	0.76260	0.76148
	7	0.94638	0.76717	0.76535	0.76626
	9	0.94566	0.75769	0.77210	0.76483
	11	0.94415	0.74031	0.78673	0.76282

TABLE XIII: CNN-LSTM Model Results for German Topology. Fragmentation as a Picture

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.89537	0.89390	0.88234	0.88808
	1	0.85763	0.84751	0.84702	0.84726
	3	0.85311	0.84167	0.83749	0.83957
	5	0.85280	0.83963	0.83538	0.83750
	7	0.85000	0.83699	0.82974	0.83335
	9	0.85420	0.83865	0.83812	0.83838
	11	0.85173	0.83632	0.83425	0.83528
Medium	0	0.93408	0.84889	0.83845	0.84364
	1	0.91434	0.79436	0.79404	0.79420
	3	0.91283	0.78414	0.78377	0.78395
	5	0.91222	0.78042	0.77622	0.77832
	7	0.91320	0.78312	0.77499	0.77903
	9	0.91292	0.78064	0.77645	0.77854
	11	0.91335	0.78033	0.78025	0.78029
High	0	0.94778	0.82219	0.81156	0.81684
	1	0.93597	0.77475	0.76758	0.77115
	3	0.93538	0.76439	0.75842	0.76140
	5	0.93555	0.75946	0.75806	0.75876
	7	0.93717	0.76388	0.76366	0.76377
	9	0.93677	0.76216	0.76212	0.76214
	11	0.93750	0.76845	0.75840	0.76339
Very High	0	0.96461	0.82678	0.82139	0.82407
	1	0.95421	0.76963	0.76580	0.76771
	3	0.95475	0.76360	0.76287	0.76324
	5	0.95606	0.76924	0.76256	0.76588
	7	0.95554	0.76388	0.76162	0.76275
	9	0.95528	0.76149	0.76136	0.76143
	11	0.95546	0.76342	0.76037	0.76189

TABLE XII: Random Forest Results for NA Topology. Fragmentation as a Picture.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.90898	0.89979	0.89531	0.89754
	1	0.88277	0.86943	0.86561	0.86751
	3	0.88230	0.86860	0.86340	0.86599
	5	0.88163	0.86774	0.86158	0.86465
	7	0.88030	0.86416	0.86209	0.86313
	9	0.87995	0.86468	0.86007	0.86237
	11	0.88011	0.86368	0.86153	0.86260
Medium	0	0.93764	0.86875	0.86453	0.86664
	1	0.91563	0.81893	0.81891	0.81892
	3	0.91697	0.82019	0.82017	0.82018
	5	0.91678	0.81892	0.81844	0.81868
	7	0.91666	0.81864	0.81626	0.81745
	9	0.91580	0.81613	0.81385	0.81499
	11	0.91604	0.81702	0.81274	0.81487
High	0	0.95374	0.84438	0.84435	0.84437
	1	0.93763	0.78967	0.78714	0.78841
	3	0.93853	0.78958	0.78955	0.78956
	5	0.93875	0.78892	0.78881	0.78887
	7	0.93882	0.79015	0.78483	0.78748
	9	0.93842	0.78612	0.78611	0.78611
	11	0.93843	0.78563	0.78558	0.78561
Very High	0	0.96151	0.83846	0.83598	0.83722
	1	0.94705	0.77636	0.77189	0.77412
	3	0.94814	0.77760	0.77565	0.77662
	5	0.94801	0.77523	0.77370	0.77447
	7	0.94727	0.77055	0.77009	0.77032
	9	0.94815	0.77488	0.77094	0.77290
	11	0.94802	0.77231	0.77229	0.77230

TABLE XIV: Random Forest Results for German Topology. Fragmentation as a Picture.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.94655	0.93944	0.94109	0.94026
	1	0.85931	0.82808	0.86071	0.84408
	3	0.85866	0.83000	0.84850	0.83915
	5	0.85995	0.82019	0.86339	0.84124
	7	0.86243	0.84073	0.83636	0.83854
	9	0.85701	0.82892	0.83668	0.83278
	11	0.85488	0.81022	0.85960	0.83418
Medium	0	0.97095	0.93505	0.92678	0.93090
	1	0.91602	0.79581	0.79995	0.79787
	3	0.91607	0.78616	0.79970	0.79287
	5	0.91463	0.76966	0.81055	0.78958
	7	0.91776	0.79151	0.78910	0.79031
	9	0.91496	0.77965	0.78891	0.78426
	11	0.91713	0.78341	0.79696	0.79012
High	0	0.98151	0.93111	0.94078	0.93592
	1	0.93847	0.76993	0.80209	0.78568
	3	0.93986	0.77909	0.77838	0.77873
	5	0.94078	0.78031	0.77547	0.77788
	7	0.94063	0.77359	0.78253	0.77803
	9	0.94046	0.77541	0.77667	0.77604
	11	0.94170	0.78493	0.77308	0.77896
Very High	0	0.98673	0.93404	0.93453	0.93428
	1	0.95437	0.76270	0.78127	0.77187
	3	0.95448	0.75204	0.78160	0.76654
	5	0.95557	0.75712	0.77833	0.76757
	7	0.95541	0.74860	0.79021	0.76884
	9	0.95532	0.74870	0.78776	0.76773
	11	0.95617	0.76025	0.77742	0.76874

TABLE XV: CNN-LSTM Model Results for NA Topology using KSP Weighted Pictures. Fragmentation as a Picture.

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.96139	0.95523	0.95821	0.95672
	1	0.88843	0.87103	0.87846	0.87473
	3	0.88929	0.87515	0.87325	0.87420
	5	0.88898	0.87896	0.86629	0.87258
	7	0.88800	0.86324	0.88426	0.87362
	9	0.88646	0.86457	0.87787	0.87117
	11	0.88672	0.86927	0.87177	0.87052
Medium	0	0.97634	0.94170	0.95838	0.94997
	1	0.92042	0.83654	0.81829	0.82732
	3	0.91650	0.81999	0.81783	0.81891
	5	0.91655	0.81519	0.82303	0.81909
	7	0.91498	0.80494	0.82892	0.81676
	9	0.91706	0.82820	0.80247	0.81513
	11	0.91720	0.82433	0.80796	0.81607
High	0	0.98302	0.93320	0.95402	0.94350
	1	0.94120	0.80335	0.79667	0.80000
	3	0.93537	0.76691	0.80092	0.78354
	5	0.93557	0.77767	0.77841	0.77804
	7	0.93441	0.75952	0.79874	0.77863
	9	0.93410	0.75517	0.80233	0.77804
	11	0.93668	0.77777	0.78264	0.78020
Very High	0	0.98429	0.91663	0.95412	0.93500
	1	0.94901	0.78444	0.78085	0.78264
	3	0.94518	0.76563	0.76141	0.76351
	5	0.94541	0.76206	0.76600	0.76403
	7	0.94463	0.75039	0.77588	0.76292
	9	0.94591	0.76523	0.76077	0.76300
	11	0.94534	0.75458	0.77239	0.76338

TABLE XVII: CNN-LSTM Model Results for German Topology using KSP Weighted Pictures. Fragmentation as a Picture

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.91279	0.90336	0.90133	0.90234
	1	0.88144	0.86820	0.86306	0.86562
	3	0.87965	0.86304	0.85940	0.86121
	5	0.88266	0.86626	0.85968	0.86295
	7	0.88227	0.86392	0.85979	0.86185
	9	0.88227	0.86354	0.85910	0.86131
	11	0.88230	0.86225	0.86028	0.86126
Medium	0	0.94249	0.86474	0.86255	0.86365
	1	0.92580	0.82380	0.81654	0.82016
	3	0.92800	0.82083	0.82070	0.82076
	5	0.92859	0.81934	0.81925	0.81929
	7	0.92957	0.82073	0.82064	0.82068
	9	0.92882	0.81890	0.81747	0.81819
	11	0.92828	0.81718	0.81616	0.81667
High	0	0.95827	0.85747	0.85073	0.85409
	1	0.94535	0.80798	0.80192	0.80494
	3	0.94545	0.80080	0.79704	0.79891
	5	0.94752	0.80559	0.80082	0.80319
	7	0.94741	0.80228	0.80219	0.80223
	9	0.94679	0.79973	0.79964	0.79969
	11	0.94762	0.80300	0.80281	0.80290
Very High	0	0.96722	0.83958	0.83468	0.83712
	1	0.95781	0.78651	0.78646	0.78649
	3	0.95903	0.78624	0.78479	0.78552
	5	0.96033	0.79180	0.78570	0.78874
	7	0.96010	0.78867	0.78526	0.78696
	9	0.96011	0.78727	0.78714	0.78720
	11	0.96017	0.78899	0.78490	0.78694

TABLE XVI: Random Forest Classifier results for NA Topology using KSP Weighed Pictures. Fragmentation as a Picture

Load	Steps	Performance			
		Accuracy	Precision	Recall	F1
Low	0	0.91470	0.90616	0.90182	0.90398
	1	0.88876	0.87650	0.87199	0.87424
	3	0.88985	0.87547	0.87430	0.87488
	5	0.88946	0.87520	0.87252	0.87386
	7	0.88853	0.87322	0.87199	0.87260
	9	0.88843	0.87363	0.87084	0.87223
	11	0.88905	0.87458	0.87090	0.87273
Medium	0	0.93861	0.86932	0.86861	0.86897
	1	0.91817	0.82437	0.82436	0.82437
	3	0.91972	0.82614	0.82609	0.82611
	5	0.91972	0.82529	0.82489	0.82509
	7	0.91912	0.82440	0.82103	0.82271
	9	0.91876	0.82264	0.82031	0.82148
	11	0.91924	0.82433	0.81938	0.82185
High	0	0.95445	0.84781	0.84524	0.84653
	1	0.93845	0.79242	0.78997	0.79119
	3	0.93998	0.79570	0.79259	0.79414
	5	0.93953	0.79161	0.79154	0.79158
	7	0.93982	0.79260	0.79011	0.79135
	9	0.93976	0.79218	0.78839	0.79028
	11	0.93968	0.79071	0.78872	0.78971
Very High	0	0.96162	0.84014	0.83465	0.83738
	1	0.94750	0.77746	0.77532	0.77639
	3	0.94868	0.77922	0.77914	0.77918
	5	0.94886	0.77844	0.77817	0.77831
	7	0.94809	0.77414	0.77366	0.77390
	9	0.94897	0.77782	0.77562	0.77672
	11	0.94880	0.77680	0.77385	0.77532

TABLE XVIII: Random Forest Classifier Model Results for German Topology using KSP Weighted Pictures. Fragmentation as a Picture.