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Generating Realistic ISP-Level Network Topologies

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Abstract—**Simulations are an important tool in network research. As the selected topology often influences the outcome of the simulation, realistic topologies are needed to produce realistic simulation results. Using several similarity metrics to compare artificially generated topologies with real world topologies this letter gives hints how to use the wide-spread topology generators BRITE, TIERS, and GT-ITM to create realistic topologies.**

Index Terms—**Communication networks, simulation, topology.**

I. Introduction

THE wide-spread topology generators BRITE [1], TIERS [2], and GT-ITM [3] offer a big range of configuration parameter. GT-ITM, for example, has 16 different configuration parameters (for the transit-stub model). How realistic a generated topology is depends on the combination of these parameters. Usually the generated topologies are judged realistic or not by pure visual inspection. In this letter, we define objective criteria (similarity metrics). Based on those we search for parameter combinations of the generators mentioned above to generate topologies that are similar with respect to the metrics to two real world ISP topologies. Those real world topologies are: 1) the rather large U.S. AT&T continental IP backbone and 2) the smaller DFN G-Win (German research network), see Fig. 1. With these results we can compare how realistic artificially created topologies are and derive parameter combinations for the generators. They can act as a starting point for anyone who wants to do ISP level simulations using topology generators.

Similar work was done in [4] on AS level graphs with at least 1000 nodes in order to evaluate topology generators for AS level graphs.

The paper is structured as follows: In Section II we present our similarity metrics. After that we present as results the best combinations for the two example topologies and three generators. We conclude with a short summary and an outlook.

II. Similarity Metrics

To measure the similarity of two network topologies we define the following metrics that capture the basic connectivity properties of the topology graph. We are interested in graphs with the same connectivity properties but not in equivalent graphs. In the graphs we distinguish between edge nodes (which are connected to end-users and other networks) and core/backbone nodes (which are only connected to nodes of the same network). We define the following metrics.

1) The first metric uses the hop-plot of all nodes. For each graph g we look at all n nodes and calculate how many other nodes can be reached within $h = 1, 2, 3 \ldots$ hops. From this we derive the relative frequency distribution F_h^g. We then compare the frequency distributions of both graphs.
2) The second metric F_h^{ge} is similar to the first but only looks at edge-nodes.
3) Next, from the outdegree d_i of each node i we derive the relative frequency distribution of all nodes for both graphs, and use the significance level of a Wald–Wolfowitz test for the similarity of the two distributions.
4) We also compare the rank exponent $\Re$.
5) The outdegree exponent O of the first and second power-laws are as defined in [5].
6) We also used the relative difference $|n_{\text{generated}} - n_{\text{reference}}/n_{\text{reference}}|$ in the number of nodes.
7) The relative difference in the number of links are considered as additional metrics.

To express the difference in two distributions we sum up the accumulated absolute difference over all classes. Every metric is normalized to return a value between 0 and 1 with 1 resembling the highest similarity. All metrics are added to a combined metric and the result is normalized again.

We used a heuristic similar to Hook and Jeeves [6] to search for the parameter combination that yields the maximum combined similarity metric. If multiple topologies are created with the same parameter combination the resulting combined similarity metric varies less than 2% for all tested topology generators.

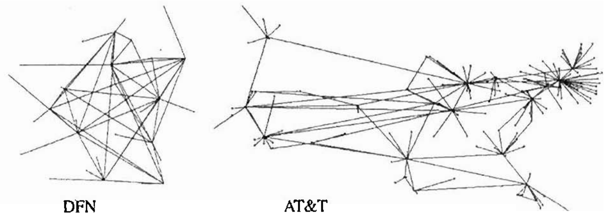

Fig. 1. The DFN and AT&T topologies.

III. Results

The parameters of Table I were found for Brite and the DFN and AT&T topologies with a high and satisfying combined and normalized similarity of 0.972 rsp. 0.951. Please note that the values α and β do not seem to significantly influence the outcome of the measurements when the parameter links/node is set to 2.

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TABLE I
PARAMETERS OF BRITE FOR DFN/AT&T-LIKE TOPOLOGIES

topology	type	method	AS	nodes	router model	α	β	links/node
DFN	Bottom up	random pick	17	30	GLP	0.42-0.46	0.62-0.68	3
AT&T	Bottom up	random pick	31	154	GLP or BA	irrelevant	irrelevant	2

TABLE II
PARAMETERS OF TIERS FOR DFN/AT&T-LIKE TOPOLOGIES

DFN	WAN	MAN	LAN	nodes/WAN	nodes/MAN	nodes/LAN
	1 *	1	1	9	4	17
	redundancy for WAN	redundancy for MAN	redundancy for LAN	redundancy for MAN to WAN	redundancy for LAN to MAN	
	6	4	1 [a]	7	2	
AT&T	WAN	MAN	LAN	nodes/WAN	nodes/MAN	nodes/LAN
	1 [a]	1	3	25	6	41
	redundancy for WAN	redundancy for MAN	redundancy for LAN	redundancy for MAN to WAN	redundancy for LAN to MAN	
	3	4	1 [a]	3 - 4	4	

Parameter cannot be changed in TIERS 1.2

TABLE III
PARAMETERS OF GT-ITM FOR DEFN-LIKE TOPOLOGIES

method	avg stubs/ transit	extra t-s links	extra s-s links
transit-stub	1	10	6
top nodes	edge method	alpha	beta
1	3	0.99	-
transit nodes	edge method	alpha	beta
5	4	0.35	100
stub nodes	edge method	alpha	beta
5	2	0.5	100

TABLE IV
PARAMETERS OF GT-ITM FOR AT&T-LIKE TOPOLOGIES

method	avg stubs/ transit	extra t-s links	extra s-s links
transit-stub	3	12	12
top nodes	edge method	alpha	beta
3	3	0.3	-
transit nodes	edge method	alpha	beta
4	3	0.5	-
stub nodes	edge method	alpha	beta
4	3	0.2	-

The parameters for Tiers result in a similarity of 0.998 and 0.995, the highest similarities found in our experiments, they are depicted Table II.

The results for GT-ITM are displayed in Tables III and IV and have a similarity of 0.966 rsp. 0.879.

To conclude, Tiers was able in both cases to produce topologies that had the highest similarity to the real world ISP topologies, GT-ITM produced the least similarities. The level of similarity that could be reached is quite high and indicates that hierarchical topology generators are able to produce realistic router level topologies. This is contrary to the findings of [5] for AS level topologies.

Further experiments showed that the similarity with regard to most metrics (except of course the number of links and nodes metrics) remains roughly equal if the number of nodes and links are increased proportionally for all topology generators. The found parameters can thus be easily scaled.

IV. CONCLUSIONS AND OUTLOOK

In this work we have presented similarity metrics for network topologies and based on these we derived the combination of input parameters for three topology generators that lead to the highest similarity with two real world ISP-level topologies. The results show ranges of parameter combinations that generate realistic topologies and can act as a starting point for anybody who wants to do realistic ISP level simulations.

We are aware that our results are only estimations for a limited number of topologies and metrics and plan to continue it using more topologies as well as more and different combinations of similarity metrics. We created a website *www.kom.e-technik.tu-darmstadt.de~heckmann/topologies/* where we give access to our software and collect information about realistic ISP level topologies.

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