Reproducing Scafida: A Scale-free Network Inspired Datacenter Topology

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1 INTRODUCTION

Large datacenters have been at the heart of the increasingly content-centric internet for the past decade. Many architectures have been proposed, such as fat-tree, BCube, and Jellyfish, a choice which does not come without tradeoffs. On the one hand, fat-trees are deterministic, symmetric architectures with constant inter-server path lengths and minimal room for implementation errors. Symmetric architectures work well for pre-planned, fixed-size data centers when the equipment is homogeneous and known in advance. However, these assumptions break down once we factor in incremental expansion as a requirement.

Jellyfish attempts to mitigate this problem by following a quasi-random iterative approach to incrementally add equipment to the network. Nevertheless, after building the initial network, and given that edges are not removed once added (with a very specific exception), it's still unclear whether the process of incrementally expanding Jellyfish maintains the desired properties of random graphs at scale, such as short paths, or too heavily depends on the existing network. Moreover, Jellyfish doesn't address the problem of homogeneous equipment: all switches are assumed to have the same number of ports, and servers only have 1 port, sitting at the edge of the network as a result.

In this paper, we reproduce the main findings of *Scafida: A Scale-Free Network Inspired Data Center Architecture*. The paper proposes and evaluates Scafida, a datacenter topology that breaks the symmetry traditionally found in state-of-the-art architectures, while allowing for arbitrary numbers of heterogenous equipment in the network and involving servers with more than one port in the routing process. The Scafida topology is inspired by scale-free networks (e.g. ordinary Barabasi-Albert topology), and attempts to exploit all the desirable properties that come along, namely short paths and high fault tolerance (path redundancy.) However, it imposes the additional constraint of limiting the degrees of nodes in the network, since neither switches nor servers can have arbitrary numbers of ports in practice. The original paper finds that such degree constraints have little negative effect on the resulting topology, and that Scafida has favorable properties, such as mean path lengths, diameter, and bisection bandwidth, which are comparable to state-of-the-art topologies, despite its asymmetric structure.

Our reproduction starts with understanding the ordinary Barabasi-Albert scale-free network, and implementing the Scafida variation to limit node degrees and parametrize for heterogeneous equipment; as in the Scafida paper, nodes are added in the network prior to being designated as switches or servers. The iterative process with some backtracking is inherently slow, and the significant number of data structures involved in tracking the growing network increases the complexity and runtime of the implementation. Standard algorithms are ran on the generated topology to compute mean path lengths, bisection bandwidth, and amount of disjoint paths, and the process repeats so that the results presented are averaged over many simulations.

Finally, we compare Scafida with other state-of-the-art topologies, and discuss limiting factors in terms of both its implementation and practicality. In reproducing the original paper's results, we find that the degree-limited approach of Scafida maintains, to some extent, some of the desired properties of scale-free networks. However, we fail to reproduce the high failure tolerance numbers of the original paper; we discuss our findings in section 4. Although the authors claim that with 20% of switches failing there still exist two disjoint paths between 90% of server pairs, we find this number to be closer to 70%.

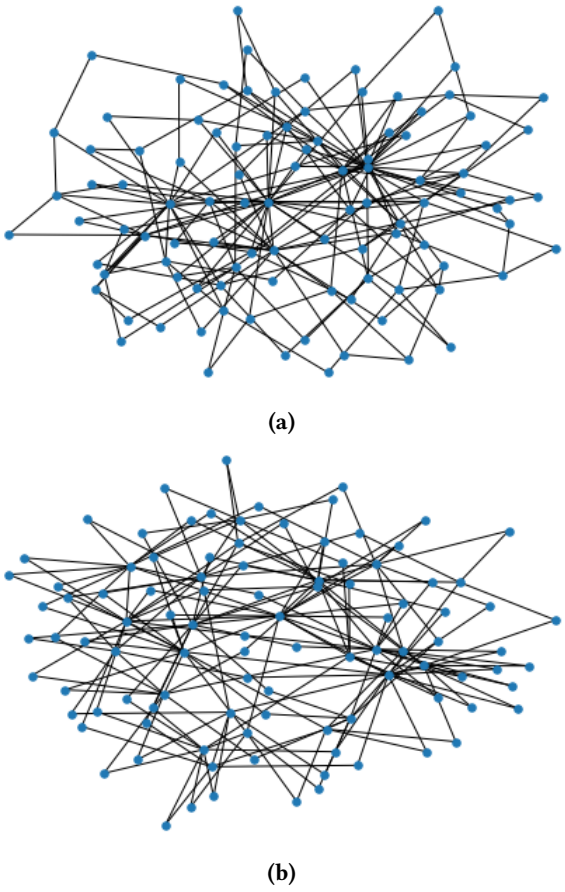
2 THE ALGORITHM

Several algorithms exist for generating scale-free networks, i.e. networks whose degree distribution asymptotically approaches a power law. One such method is the Barabasi and Albert approach, which generates random scale-free networks using the preferential attachment principle. Preferential attachment refers to the iterative way in which the algorithm constructs the topology; nodes are added one at a time, and attached probabilistically to an existing node. The probability of attachment is directly proportional to the current degree of the node; as a result, high-degree nodes are preferred in the attachment process, hence the name of the principle.

Scafida attempts to exploit several favorable properties of the scale-free network approach by tailoring the algorithm to datacenter topology generation, i.e. making it practical by limiting the degree of network equipment and allowing for heterogenous hardware requirements. The inputs to the algorithm are the number and degree of servers; the number

of switches of each type; the number of ports of each switch type; and the parameter m, which controls the number of nodes each new node is attached to upon addition to the network, typically set to a small value. In this paper, as well as in the original, m is 2. Because the number of ports of each server is also assumed to always be 2 (by the original paper, an assumption which we maintain), each server added to the network is only attached to switches (since after attachment to two ports, the server has no more free ports.)

The iterative addition process works as follows. The total number of nodes, switches plus servers, is computed in the beginning, and the iterative algorithm terminates when the network has reached its node capacity. Importantly, each node added to the network **does not** acquire a role, that of a server or switch, until the entire topology has been generated. This is directly related to the desired flexibility of the topology generation method. Because commodity switches typically have 4, 8, 16, 24, or 48 ports, Scafida should ideally handle switches with different, arbitrary port limits. To achieve this, the algorithm greedily assigns roles to network nodes depending on their degree as determined by preferential attachment. Specifically, each time a new edge is about to be added using preferential attachment, the adjacent nodes are (temporarily) assumed to be of the smallest (lower degree) equipment type that can sustain their current degree; the edge is then added **only if** the specific type of equipment is still available. In short, equipment types are allocated to network nodes greedily, starting from the higher-degree switches, until those fill up, to lower degree equipment. When the algorithm terminates, nodes with degree equal to 2 become servers, while the rest are allocated to the smallest available switch that can accommodate their degree.



(a)

(b)

Figure 1: (a) Original Barabasi-Albert scale-free network w/ 100 nodes, w/o degree limitations (b) Scafida topology w/ 100 nodes, and [10, 20, 10] switches of [4, 8, 16] ports

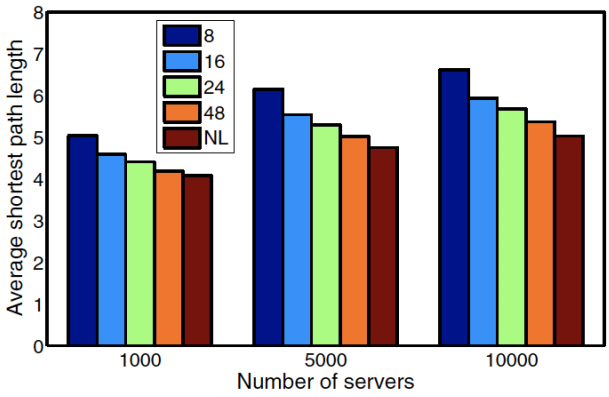
3 EXPERIMENTS & RESULTS

We implemented the Scafida algorithm, as well as the post-processing and plot functionality, in Python 3.6.0, using the Matplotlib, Networkx, Numpy, and Random packages, as well as Jupyter Notebook for ease of development. We also used Networkx's implementation of the Barabasi-Albert algorithm to generate true scale-free networks, where we assigned server and switch roles based on the degree of each node.

Figure 1a shows a Barabasi-Albert scale-free network of 100 nodes without degree limitation; figure 1b plots a Scafida topology with the same number of nodes, of which 60 are servers; 10 are switches of degree 4; 10 are switches of degree 8; and 20 are switches of degree 16.

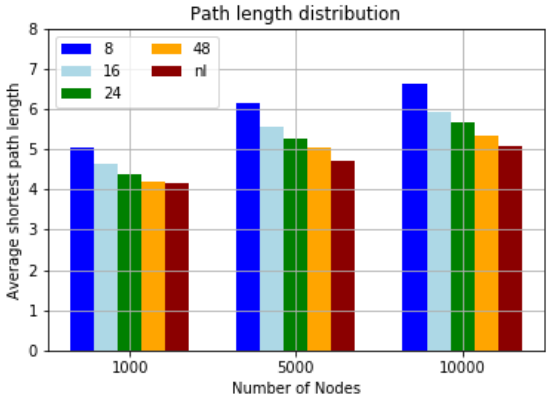
3.1 Path Lengths

We construct topologies using the Scafida algorithm, imposing uniform degree limitations to all switches. For each degree limit (port number) in {8, 16, 24, 48, NL}, NL standing for *no limit*, we obtain the average shortest path length between all server pairs, i.e. the ratio of the sum of shortest path lengths to number of server pairs. Figure 2 shows a reproduction of figure 4a for various numbers of network nodes. The presented values are averaged over 50 topologies generated with the Scafida algorithm, and the value of m (degree of servers) is set to 2, which implies servers may be involved in the routing process. The original figure is presented along with the reproduced figure; it's apparent that they resemble each other closely, which suggests the Scafida re-implementation is successful. Observe that the average length of paths increases moderately with the number of nodes in the topology (for a given port number) due to the constrained degrees; in most cases, however, the increment is less than one full hop.



(a) Path lengths

(a)



(b)

Figure 2: (a) Original Scafida paper average path length distribution graph over 50 simulations. (b) Reproduced figure of average path length distribution over 50 simulations.

3.2 Throughput

The performance of communication-intensive applications relies heavily on the absence of bottlenecks in the topology. To quantify throughput, we explore the bisection bandwidth capabilities of the degree-constrained network in a realization with 5000 nodes. Since the network is too large for solving the minimum weight partition problem exactly, we instead use sampling. Specifically, we randomly partition the servers and switches in half, 200 times in total, after which the edge cut between the two sides of the network is computed. We then plot the cumulative distribution function of bisection bandwidths, i.e. maximum edge cuts, in order to reproduce figure 4b of the original paper. Figure 3 presents the reproduced CDF function. The (amount of) degree limitation does not seem to affect the bisection bandwidth of the explored topologies, with all CDFs, including the one for the true scale-free network without degree limitations, roughly overlapping with each other.

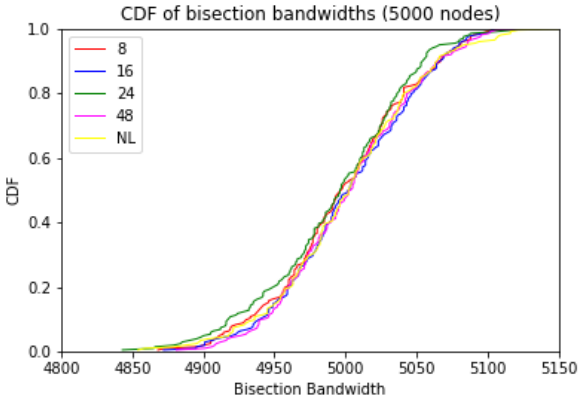


Figure 3: Reproduced CDF of bisection bandwidths over 200 random partitions of servers.

3.3 Failure Tolerance

Finally, we explore the tolerance to failure of the Scafida topology, another useful property of unconstrained scale-free networks. In increments of five percent, from 0 and up to 20, we randomly remove switches and their adjacent edges from the network to mimic random switch failure in the datacenter. We then sample 4000 server pairs, selected uniformly at random, and compute the number of disjoint paths between them; since servers have a degree of 2, the maximum number of disjoint paths is also 2. Figure 4 plots a reproduction of the error tolerance experiments presented in the original paper's figure 5. The adjacent plots show the percentage of server pairs, connected by zero, one, and two *disjoint* paths, respectively, for various fractions of randomly failed switches.

4 DISCUSSION

Limitations - sampling etc. Slow iterative algorithm Vague descriptions If we don't care where the servers are- good. Otherwise a problem.

Surprisingly, although we impose constraints of the maximal degree of each node, the network largely sustains the preferable properties of scale-free networks.

5 CONCLUSION

6 GITHUB

7 REFERENCES

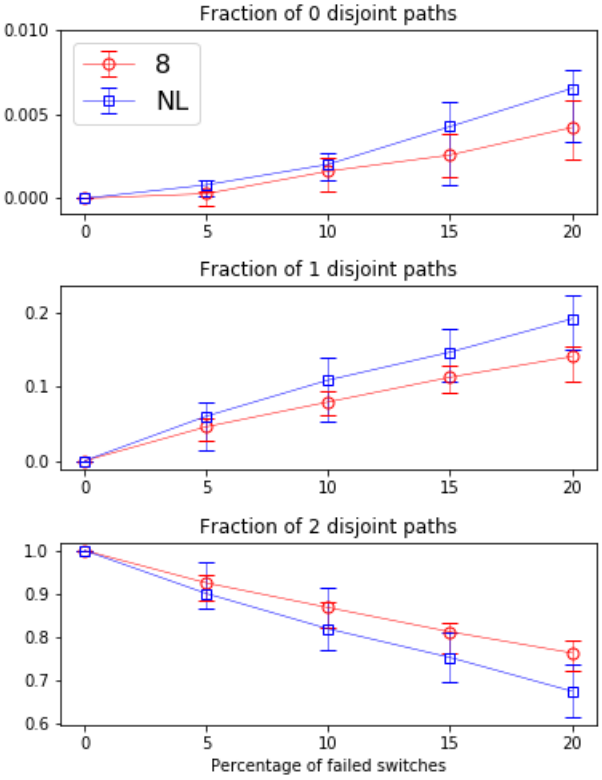


Figure 4: Reproduced failure tolerance figure, showing percentage of server pairs connected by zero, one, and two disjoint paths, after a percentage of switches fail.