On the Evolution of Finite Sized Complex Networks

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by

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Abstract

Any complex physical system, man-made or natural, consists of entities each of which interacts with other entities in the system. Such complex systems can be modeled as network graphs where the entities are nodes and their interactions are edges of the network graph. Earlier studies reported possible mechanisms for the evolution of complex networks where size of the network is growing, in the context of nodes and edges, with time. To the best of our knowledge, the characteristics of finite sized complex systems, which can be seen in many real-world networks, such as relationships in community networks, transportation networks, and wireless sensor networks, are not studied in depth. Here, the finite sized networks mean that such complex physical systems are not growing in size when the total number of nodes is concerned. This thesis aims to study the reasoning behind the evolution of such finite sized complex networks.

We find that the greedy decision making, based on the optimization of certain network metrics, results in unique structural characteristics during the evolution of many complex networks. In a finite sized complex network, minimization of the end-to-end hop distance using the optimal/near-optimal long-ranged link (LL) addition for minimizing the average path length (APL), maximizing the centrality measures, or maximizing the overall network flow capacity, constitutes the greedy decision making. It is also observed that when LLs are added optimally/near-optimally, e.g., by minimizing the APL, the resulting network evolves to a scale-free network with a few hub nodes where a large number of LLs are incident.

To study the greedy optimal/near-optimal decision based network evolution, we consider addition of new LLs in a finite sized string topology network with the greedy near-optimal decision to minimize the APL of the string network which can be considered to be one of the most sparse regular network model. We observe that, in an N-node string topology network, the first LL is always optimally connected between the anchor nodes

at the $0.2N^{th}$ and $0.8N^{th}$ fractional locations. The fixed fractional locations of the anchor nodes also have been analytically found at 0.2071 and 0.7929.

We then consider a model motivated by practical limitations, where constraints are placed on the length of the LLs. It is found, in a finite sized complex network, with the optimal addition of length constraint LLs, that there is a visible transition of a fixed sized regular network in the following manner: from a regular network to a small-world network, then to a scale-free network with the truncated degree distribution, and at last, to a fully connected network.

As the greedy decision based LL addition is computationally intensive, a heuristic approach, sequential deterministic LL addition (SDLA) is also proposed in the context of unweighted string network, to efficiently transform the network to a small-world network. SDLA algorithm can help efficient design and deployment of moderate sized string topology networks for various applications, such as community broadband networks, computer networks, tactical networks, and emergency response networks.

Next, we apply our above observations to transform a finite sized string topology wireless sensor network to an APL to the base station (BS) optimal (APLB-optimal) small-world wireless sensor network by introducing a few LLs. The optimal LL addition also incorporates tradeoffs between the excess transmission power and the overall path length reduction. Our analytical observations on the locations of newly added links (single and two LLs) also satisfy the simulation and the approximate observations.

To the end of this thesis, we propose an exhaustive search based LL addition algorithm, maximum flow capacity (MaxCap) that deterministically maximizes the average network flow capacity (ANFC) in a weighted undirected network. Based on the observations from MaxCap, we propose a new link addition heuristic, average flow capacity enhancement using small-world characteristics (ACES), that improves the end-to-end distance traversed by incorporating the small-world characteristics, and also enhances the overall performance of a network. We also validate our observations through exhaustive simulations on various real-world road networks. ACES can find many real-world applications in communication networks, transportation networks, and tactical networks where ANFC is a very critical parameter.