Understanding Information Dissemination Dynamics in Delay Tolerant Networks using Theory of Bipartite Networks

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***Abstract*—A delay tolerant network is composed of mobile handheld devices carried by mobile agents (humans). The connectivity between any two such nodes is of wireless and opportunistic /intermittent in nature. Therefore, the search and dissemination algorithms designed for these dynamic networks, employ the store and forward paradigm. Subsequently, the performance of these algorithms depend on the underlying mobility pattern of the mobile agents. Recent updates on the human mobility model explore the impact of the social behavior and the heterogeneity of the attractiveness of the common places as well as preferential selection of these places depending on their attractiveness. This makes it even more complex to use traditional mathematical tools to analyze the performance such as coverage in any search or dissemination algorithm designed for DTN. In this research work, we visualize the delay tolerant network as a bipartite network where one partition corresponds to the common places and the other partition corresponds to the mobile agents. This enables us to model the intractable characteristics of the DTN through the well established mathematical tools available for bipartite network. Finally, we show that the coverage of the information dissemination process in the delay tolerant network matches with the size of the largest component in the one mode projection of the formed bipartite network after application of suitable threshold. As far as our knowledge, this is the first such work which correlates the dynamics of the delay tolerant network with the theories of the bipartite network.**

I. Introduction

Different aspects of the bipartite network and its different variations have been studied immensely in the past [1]–[4]. In our research, we try to exploit this strong mathematical tool to analyze the coverage of information dissemination process in delay tolerant networks [5], where the connectivity between the nodes are of opportunistic and intermittent in nature. The medium of communication among the devices in such a network is wireless and therefore the connectivity among them is short range (eg. bluetooth connectivity) and inefficient. Hence connectivity in such networks is almost fully defined by the mobility pattern of the agents specifically depending upon the time of their contact as well as the contact duration. Consequently it is reasonable to advocate that the performance of any search or information dissemination application developed for such a network is strongly influenced by this mobility pattern of the participating agents. The destination of the mobile agents in general are selected on a purely random basis as is the case for the random way point model and various other similar models. However, in a realistic scenario, it becomes important to incorporate the social behavior of the agents (as in for humans) that has been recently introduced in the form of the *'Self Similar Least Action Walk'* based mobility model [6]. In this article, the authors posit that the agents have a tendency to visit places depending on the attractiveness of those places. In other words, there is a preferential choice driving the mobility pattern of the agents. In this work, we exploit this preferential choice to connect the dynamics of a delay tolerant network with a strong theoretical framework of evolution of bipartite networks [1]. The primary reason for drawing this connection is to analytically investigate the otherwise intractable characteristics of the former through the well known mathematical properties already established through a series of publications [1]–[4].

In the following, we describe a realistic scenario of DTN (Section II) and subsequently examine it under the lens of the analytical framework of the bipartite networks (Section III). In particular, we show that the time evolution of the fraction of nodes to which a message gets disseminated in the DTN has a perfect overlap with the growth of the giant component size of the one-mode projection of the bipartite network suitably threshold-ed by a time varying threshold.

II. Information dissemination process in the delay tolerant network

We consider a certain number of mobile agents (t) who participate in the information dissemination process and a certain number of common places (N) where the agents usually go. An agent is assumed to make on average μ number of visits to different places by selecting the places in a preferential fashion. Each place to be visited is chosen preferentially from the pool of places. We assume that each of the places as well as the devices carried by the agents, has a buffer where several piece of information can be stored. We consider here only the dissemination of a single message. Due to the limited size, a message will be discarded from a buffer, after a certain duration b, termed as buffer time. The information dissemination process along with the observable in the process are described below.

- Initial Condition : We assume that initially i.e. prior to the start of the dissemination process, the buffers of each place and device of the agents are assumed to have enough space to participate in the dissemination process.
- Start: The initiator of the dissemination process brings or creates a message in its buffer and sequentially visits b number of places (preferentially) where the messages are dropped so that other agents can pick up the message and participate in the dissemination process.
- Dissemination through places: When some agent comes in a place where the initiator has already dropped the message, the message gets transferred to the buffer of the agent if the agent is not already containing the message. A message can be stored in a place until there are b such interactions with the agents and thereby a place gets b chances to convey a certain message to a maximum of b distinct agents.
- Dissemination though other agents: Once some agent picks up a message from some place, it also participates in the dissemination process. The message can be stored in the agents' device, until it gets b chances to convey the stored information to a maximum of b distinct places.
- Observable: In the process described above, we measure, the number of distinct places, the buffers of which contain the message after different number of agents have participated in the process. We denote this quantity by G_d. This specific quantity is of interest from the perspective of dissemination because, the probability that any other mobile agent will receive the information while visiting any of the places, is directly proportional to the value of G_d.

In the next section we describe the analysis of this process of dissemination using evolution of bipartite network.

III. Modeling by Bipartite Network

We visualize the DTN dynamics as a bipartite network where one of the partitions corresponds to the places while the other corresponds to the agents. The number of places is fixed and finite (=N) while the number of agents grow over time and is modeled by the parameter t. Each agent is allowed to make μ connections sequentially one by one, each time choosing a place in a preferential fashion. From this bipartite network, we take the one-mode projection on the place set which is a place to place graph where two places are connected by an edge if there is one common agent who has visited/connected both of the places.

In this projection we have allowed parallel edges going through different agents as well as same agents (if one agent has visited two places each twice, then there will be four parallel edges in the one mode projection which captures the fact that there are actually four different possible communications between the two places). To construct the backbone network of the one mode projection where the edges denote a strong and stable communication in between two places, we

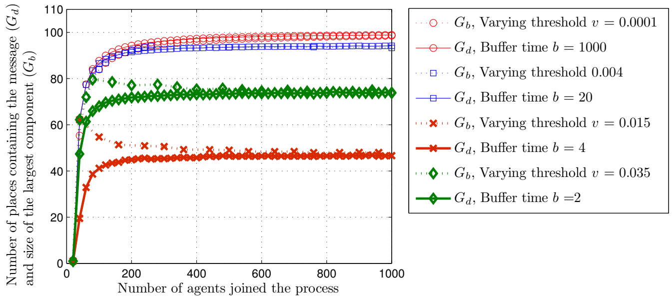

Figure 1. Comparison of the size of the largest component (G_b) in in the threshold-ed one mode projection of the bipartite network and the number of places where the information being disseminated is found (G_d). The bipartite network is formed corresponding to a delay tolerant network set up consisting of (N=) 100 common places and (t=) 1000 mobile agents each of which creates (μ=) 10 connections with the places i.e. visits 10 places.

prune the edges of the one mode projection by employing a threshold and varying its value with the number t. Therefore, we assume a quantity v which when multiplied to t, gives the actual threshold value at that point of time. We put exactly one edge between two places in the final place to place graph if the number of edges in between the two places crosses the threshold number of edges in the one mode projection. Subsequently, we measure the number of nodes in the largest component in the threshold-ed one mode projection and denote this quantity by G_b. We find that the time evolution of G_b and G_d match with each other for different pairs of values of v and b. Figure 1 shows a comparison between these two quantities for few values of v and b.

IV. Conclusion

The existence of this correlation between the v and b brings a new direction which is to be explored further. As a future step, we plan to exploit this correlation and employ the existing theories to compute the largest component in the threshold-ed one mode projection of the bipartite network for estimating the coverage in DTN.

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