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Significance of Eigenvector Centrality for Routing in a Delay Tolerant Network

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Abstract

Centrality measure is an important concept in networks. It indicates the relative importance of nodes in a network. Various centrality measures have been proposed in the literature, such as degree centrality, closeness centrality etc. Practically all these measures are some values based on the properties of the node concerned. Eigenvector centrality takes into account the centrality value of the neighbours of a node to assign a centrality value to it. In this paper, we show how this value can be utilized to select relay nodes in a delay tolerant network and improve the delivery delay.

Keywords: Eigenvector, Routing Protocols, Delay Tolerant Networks

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1 Introduction

A Delay Tolerant Network (DTN) is a sparse and mobile ad hoc network. In a typical DTN, some node pairs never meet each other. The mobility of the nodes causes connectivity to be intermittent and may lead to even more unpredictability of routing information. A routing protocol for a DTN should address all these issues.

Several methods have been proposed to achieve effective routing in a DTN environment, starting with the flooding approach, which blindly sends the message to all the nodes that it meets [12]. Other methods intelligently choose the relay nodes based on metrics like history of contacts, context information etc. [2, 3].

This work proposes a method that chooses the relay nodes based on human mobility characteristics. Fundamental to the development of this concept is the fact that human mobility pattern is 93% deterministic [4] and the distribution of the mobility parameters like contact duration, inter-contact duration and location visiting preference follows heavy tailed power law, up to a characteristic time [4]. The objective of this work is to identify suitable relay nodes that will improve the delivery latency in a DTN, using centrality measure.

The rest of the paper is organized as follows. Section 2 explains the human mobility characteristics and how it can be utilized in the design of a routing protocol for DTN. Section 3 brings out the related work in this area. Section 4 explains the theory behind eigenvector centrality and section 5 develops an algorithm that utilizes the same. Section 6 studies the simulation result. The concluding remarks are made in section 7.

2 Characteristics of Human Mobility

For long, human mobility pattern was considered to be fundamentally stochastic and random mobility models were used in the studies that based itself on human mobility. Failure of these models to relate to real life scenario, gave rise to other mobility models that captured some aspects of human mobility. Chaintreau et al. [4] showed that human mobility is semi deterministic and followed power law over a large period of time. Power law distribution is characterized by the equation

$$p(t) \sim t^{-a} \tag{1}$$

where $p(t)$ is the inter contact time (ICT) distribution and α is the power law exponent. It was noticed that the value of a was typically ≤ 1, in all the available traces. This means that the mean delay for any routing algorithm based on ICT distribution is infinite.

Karagiannis et al. [8] further showed that ICT followed power law up to a characteristic time and after that, it followed exponential decay. The authors found that the characteristics time was of the order of about 12 hours. They also noticed that the mean ICT is of the same order as the characteristic time. The implication of this dichotomy is that the expected forwarding delay becomes finite, unlike the case where $a \leq 1$ and without the exponential decay. Hence the node contacts can be utilized to transfer message in a DTN, with a finite delay.

3 Related Work

The recent research on routing messages in DTNs utilizing human mobility characteristics has shown that incorporating social information in routing decision improves the performance. The HiBOp algorithm proposed by Boldrini et al. [1], work of Miklas et al. [9], and SimBet routing protocol proposed by Daly and Haahr [5] are a few examples.

This motivates us to investigate how the delivery latency can be improved in a DTN, by intelligent selection of the relay nodes. A relay node is an intermediary node that meets the source in slot p and the destination in slot q, such that $p < q < r$, where r is the slot where the nodes directly meet.

4 Centrality Measures

It is well known that in a network some nodes are more popular than others. Such nodes are known as central nodes and can function as effective relay nodes. Several metrics have been proposed as a measure of this centrality. Degree, closeness, betweenness etc. are a few of them. This work proposes another method to identify these popular nodes and demonstrates that it improves the delivery ratio and delivery latency.

4.1 Eigenvector centrality

Degree centrality is one of the simplest centrality measures. It is the count of the connections that a node has. Having a large number of connections has its significance. However, a node with a few high-quality contacts may outrank another one with a large number of mediocre contacts. We will now derive a method that contains this concept.

Let the centrality of a node i be x_i and A be the adjacency matrix of node i.

Since the connection to nodes that are themselves important, makes a node more central, we can say that x_i is proportional to the average of the centralities of the neighbours of node i, i.e.,

$$x_i \propto \sum_{j=1}^{n} A_{ij} x_j$$

$$x_i = \frac{1}{\lambda} \sum_{j=1}^{n} A_{ij} x_j \,, \qquad (2)$$

where λ is a constant.

Let x be the vector of centralities. Then,

$$x = (x_1, x_2, \ldots)$$

Now (2) can be rewritten in matrix form as

$$Ax = \lambda x \quad (3)$$

Hence we see that x is an eigenvector of the adjacency matrix A of the network with eigenvalue λ.

We want all the components x_i, for all i, of the eigenvector to be positive, as they are centrality values. Perron-Frobenius theorem states that all the elements of the eigenvector corresponding to the largest eigenvalue will be positive. Hence λ must be the largest eigenvalue of the adjacency matrix of the network. This makes x to be the principal eigenvector of the adjacency matrix defining the network. Each element of this vector represents the centrality of the corresponding node in the network. The highest element is the largest centrality value. Hence the corresponding node is the most central node.

It can be seen that, a node that has a high eigenvector score is adjacent to nodes that are themselves of high scorers. Thus eigenvector centrality is an influence measure, that depends both on the number and quality of its connections. We apply this approach to identify the central nodes in a network and use them as relay nodes.

5 Proposed Algorithm

R. J. D'Souza and Johny Jose [10] have proposed an algorithm that uses a single relay, utilizing human mobility characteristics, to improve the delivery ratio and delivery latency in a DTN. This algorithm is based on the semi-deterministic nature of human mobility, as proved by Song et al [4]. It divides the time into several slots and keeps track of the neighbours in each slot, as a contact graph.

The high degree of semi-determinism in human mobility results in the contact pattern to be repeated daily. This knowledge is used to find routes by R. J. D'Souza and Johny Jose [10] and the results are found to be better than those of the existing DTN routing algorithms. In the present work, we identify relay nodes by computing the eigenvector of the contact graph in each time slot. The result is compared with that of [10].

5.1 Algorithm to Find the Optimal Path

Assume that the simulation time is divided into S slots of duration T.

Check if the source meets the destination in any slot.
If the meeting takes place in the 1st or 2nd slot,
    Handover the message directly.
Endif.
If the meeting takes place in a later slot, say slot r,
    Generate the adjacency matrix of the node contacts in slot r.
    Find the eigenvalues of this matrix.
    Find the largest eigenvalue.
    Find the corresponding eigenvector.
    Find the highest value in this eigenvector.
    Find the node corresponding to this value.
    Assign this node as the relay node.
Endif

5.2 Calculation of Delivery Latency

The above algorithm gives the earliest slot for handing over the message. In the best case, the message generation and the message handover takes place in the same slot. If the message handover takes place in a later slot, it entails latency. This latency can be calculated as follows.

Let the message handover for the i^{th} message take place in slot s_i.

Width of each slot $= t$ time units.

Delivery duration $= s_i \cdot t$ time units.

Delivery latency $= (s_i - 1) \cdot t$ time units.

The latency experienced by each packet is different. The average latency experienced by a packet is calculated as the average of the sum of latencies, experienced by the packets that were successfully delivered.

Average latency = (∑delivery time of the delivered packets) ÷ number of packets delivered.

6 Experimental Results and Discussion

The communication opportunities for various values of communication range and node density were simulated using Matlab. The synthetic mobility trace available from North Carolina State University [11] was used for the same.

Most of the modern handheld devices are equipped with IEEE 802.11n wireless port, which provides an indoor range of 70 m [12]. Keeping this in mind, the communication range was set as 70 m. Scenarios with various node densities were created. The simulation time was divided into slots of 10 minutes each. For each source-destination pair, the relay node is found out, using the eigenvalue approach. The average time taken by a single packet to be delivered was noted for these scenarios. They were compared against the algorithm in [10]. The result is plotted in Figure 1.

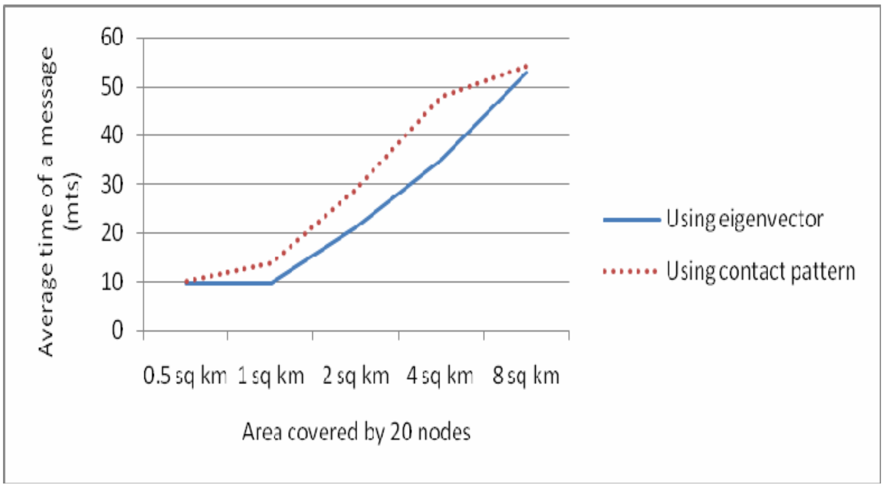

Figure 1: Comparison of delivery latency

When the relay nodes are selected based on the eigenvector centrality, there is a reduction in the delivery time. However, the difference in delivery time is less when the node density is high. We also noticed that at high node density, the number of relay nodes available is less. But these nodes were able to deliver the message with shorter delivery latency. This is the reason for the improved performance. This shows that eigenvector centrality is able to select more appropriate relay nodes, than the contact based algorithm.

7 Conclusion

Identifying suitable relays is important while designing a routing protocol for a DTN. Utilizing human mobility characteristics is a novel concept in this direction. This work proposes to apply the concept of eigenvector, to identify suitable relay nodes for routing messages. Simulation results show improvement in delivery latency, compared to similar works.

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