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Bridging Centrality: Identifying Bridging Nodes in Transportation Network

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ABSTRACT

To identify the importance of node of a network, several centralities are used. Majority of these centrality measures are dominated by components' degree due to their nature of looking at networks' topology. We propose a centrality to identification model, bridging centrality, based on information flow and topological aspects. We apply bridging centrality on real world networks including the transportation network and show that the nodes distinguished by bridging centrality are well located on the connecting positions between highly connected regions. Bridging centrality can discriminate bridging nodes, the nodes with more information flowed through them and locations between highly connected regions, while other centrality measures cannot.

Keywords : Betweenness centrality, Bridging centrality, Bridging coefficient, Degree, Transportation network.

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1. INTRODUCTION

Now a days Transportation network is an important part of our daily life. Transportation network can be represented as G(V,E), where V denotes vertices, E denotes edges. If G consists of public bus systems, V means all stations, E means all available lines between stations. However, if the air transport systems or highway systems of a country are expressed as G, V signifies all cities of the country, E signifies all airlines or highways between cities.

To study the transportation network is to identify the centralities in the network which represent the more critical nodes whose degrees of reliability have major impact to the network efficiency. Freeman[1] discussed many centrality measures, designed to capture different aspects of the centrality concept in the study of social network. He also discussed the betweenness[2] centrality as the total fraction of shortest paths between each pair of vertices that pass through a given vertex. Woochang Hwang et al.[3] discussed the bridging centrality on scale-free networks. Bridging centrality provides an entirely new way of scrutinizing network structure and measuring components importance.

This understanding guides traffic and transport engineers and planners to resolve many burning issues related to traffic flow [4]. Therefore, "quantitative analysis and modeling of traffic flow has become a hot topid few years, empirical and theoretical studies of networks are the most popular subjects of recent researches in many areas including technological, social, and biological fields. Network theories have been applied with good success to these real world systems and many centrality indices, measurements of the importance of the components in a network, have been introduced [8,9,10].

In this paper, we focus the network analysis to identifying the central nodes to another new and important direction. We introduce a new centrality measure called bridging centrality that successfully identifies the bridging nodes locating among densely connected regions.

2. OVERVIEW OF NETWORK CENTRALITY

Our model, a transportation network as an undirected graph which is represented by (V, E) with node set V and edge set E. Here V represents the stations and E represents the connection between stations. We now define some existing network centrality measures used in different network analysis.

2.1 Degree Centrality : It is the simplest and the first measure of centrality .Degree centrality of a node v is the number of connections of that node is defined as

$$C_D(v) = d(v)$$

2.2 Betweenness Centrality : The betweenness centrality, $C_B(v)$, for a node v of is defined by:

$$C_B(v) = \sum_{s \neq v \neq t \epsilon V} \frac{g_{st}(v)}{g_{st}}$$

In the above equation, g_{st} is the number of shortest paths from node s to t and $g_{st}(v)$ the number of shortest paths from s to t that pass through the node v.

2.3 Closeness Centrality : If we denote the shortest path distance between two nodes i and j by $d(i, j)$, then the closeness centrality of a node i is defined as

$$C_{cls}(i) = \frac{1}{d(i)} \text{ where } d(i) = \sum_{j \in V, j \neq i} d(i, j)$$

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2.4 Bridging Coefficient : The bridging coefficient of a node is defined as

$$BC(v) = \frac{\frac{1}{d(v)}}{\sum_{i \in N(v)} \frac{1}{d(i)}}$$

where *d(v)* is the degree of node v and *N(v)* is the set of neighbors of node v.

2.5 Bridging Centrality : Identifying important nodes in a network structure is crucial for the understanding of the associated real-world system. A bridging node is a node lying between modules, i.e., a node connecting densely connected components in a graph. The bridging nodes in a graph are identified on the basis of their high value of bridging centrality relative to other nodes on the same graph. The bridging centrality of a node is the product of the betweenness centrality (C_B) and the bridging coefficient (BC), which measures the global and local features of a node, respectively.
Mathematically,

$$C_R(v) = BC(v) \times C_B(v)$$

where $C_R(v)$ is the bridging centrality.

3 METHOD

3.1 Terminology and Representation

Real world systems can be represented using graph theoretic methods. In this paper we focus on undirected graphs. An undirected graph G = (V, E) consists of a set V of nodes or vertices and a set E of edges. An edge e(i, j) connects two nodes i and j where e(i, j) ϵ E. The neighbors N(i) of node i are defined to be a set of directly connected nodes to node i. The degree d(i) of a node i is the number of the edges connected to node i. A path is defined as a sequence of nodes (n_1,...,n_k) such that from each of its nodes there is an edge to the successor node. The length of a path is the number of edges in its node sequence. A shortest path between two nodes, i and j, is a minimal length path between them. The distance between two nodes, i and j, is the length of its shortest path.

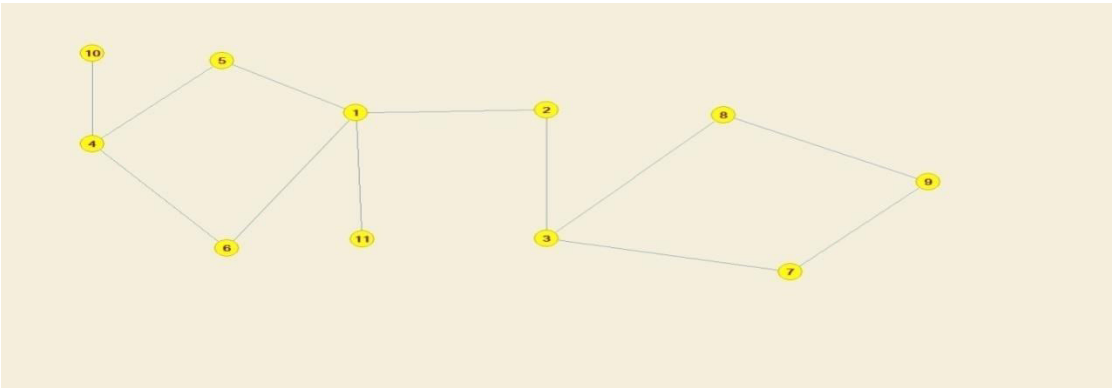

Figure 1: A small synthetic network example.

Node	Degree	C_B	BC	C_R
1	4	0.655556	0.1	0.065556
2	2	0.533333	0.85714	0.457141
3	3	0.477778	0.22222	0.106172
4	3	0.211111	0.16666	0.035184
5	2	0.155556	0.85714	0.133333
6	2	0.155556	0.85714	0.133333
7	2	0.088889	0.5	0.044445
8	2	0.088889	0.5	0.044445
9	2	0.011111	0.5	0.005556
10	1	0	3	0
11	1	0	3	0

Table 1: Centrality values of Figure 1, including Betweenness centrality(C_B), Bridging coefficient (BC) and Bridging centrality (C_R) .

Figure 1 and Table 1 clearly illustrates the significant of bridging centrality. Although node 1 has the highest degree and betweenness value, nodes 2 , 5, and 6 have much higher bridging centrality values since node 1 is located on the center of a module not on a bridge which results in the lowest bridging coefficient value. In other words, more number of shortest paths goes through node 1 than other three nodes, but nodes 2, 5, and 6 position on bridges much better. So, nodes 2, 5, and 6 have higher bridging centrality values since they are on the bridges between modules which leads much higher bridging coefficient values than node 1. Betweenness centrality decides only the extent how much important the node of interest is from information flow standpoint, and it does not consider the topological locations of the node. On the other hand, nodes 5 and 6 have the same bridging coefficient value with node 2, but nodes 5 and 6 have much less betweenness centrality values since far more number of shortest paths passes through node 2 than through nodes 5 and 6. Even though nodes 2, 5, and 6 are located on similar local topological positions, i.e., similar local topological surroundings, node 2 is taking a much more important location than nodes 5 and 6 in the information flow viewpoint. Bridging coefficient measures only the extent how well the node is located between highly connected regions .Therefore we can think that node 2 is taking a better bridging position than nodes 5 and 6 are in Figure 1.

3.2 Application on Transportation network

Dispur is the largest city in Assam and one of the fastest developing cities in India. With the rapid growth of population in the city, the road traffic problems are also increasing at an alarming rate. The development of a city or town leads to the growth of the number of vehicles which is directly linked to increased traffic congestion and a growing number of accidents and fatalities. Road traffic problems like congestion, unpredictable travel-time delays and road accidents are taking a serious shape in the city. The main objective of this study is to analyze the potential of bridging centrality on transportation network, viz. Dispur city map. It is a well planned city and capital of Assam. We take 35 major bus stoppages of this Dispur area to analyze the bridging nodes.

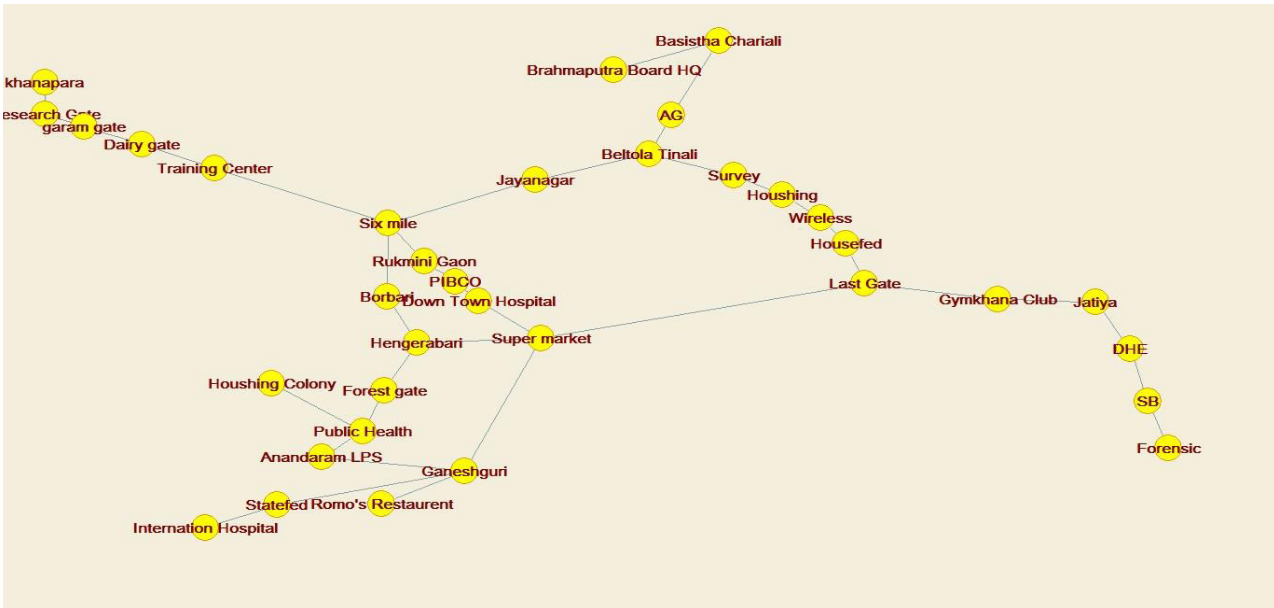

Figure 2 : Major bus stoppages of Dispur city.

Id	Label	Degree d(v)	C_B	$d(v)^{-1}$	$\sum_{i \in N(v)} \frac{1}{d(i)}$	BC	C_R
1	khanapra	1	0	1	2	0.5	0
2	Research Gate	2	0.05882	0.5	1.5	0.33333	0.01961
3	Garm gate	2	0.11408	0.5	1	0.5	0.05704
4	Dairy gate	2	0.16578	0.5	1	0.5	0.08289
5	Training Center	2	0.2139	0.5	0.75	0.66667	**0.1426**
6	six mile	4	0.42335	0.25	2	0.125	0.05292
7	Rukmini gaon	2	0.04556	0.5	0.75	0.66667	0.03038
8	PIBCO	2	0.04635	0.5	1	0.5	0.02317
9	Down town hospital	2	0.05704	0.5	0.75	0.66667	0.03803
10	Super market	4	0.4492	0.25	1.41667	0.17647	0.07927
11	Ganeshguri	4	0.22727	0.25	2.25	0.11111	0.02525

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12	Statefed	2	0.05882	0.5	1.25	0.4	0.02353
13	International Hospital	1	0	1	0.5	2	0
14	Houshing colony	1	0	1	0.33333	3	0
15	Public Health	3	0.07576	0.33333	2	0.16667	0.01263
16	forest gate	2	0.08645	0.5	0.66667	0.75	0.06484
17	Hengerabari	3	0.35116	0.33333	1.25	0.26667	0.09364
18	Borbari	2	0.2959	0.5	0.58333	0.85714	**0.25363**
19	Gymkhana club	2	0.2139	0.5	0.83333	0.6	**0.12834**
20	Jatiya	2	0.16578	0.5	1	0.5	0.08289
21	DHE	2	0.11408	0.5	1	0.5	0.05704
22	SB	2	0.05882	0.5	1.5	0.33333	0.01961
23	Forensic	1	0	1	0.5	2	0
24	Last gate	3	0.35027	0.33333	1.25	0.26667	0.0934
25	Housefed	2	0.13102	0.5	0.83333	0.6	0.07861
26	Wireless	2	0.10873	0.5	1	0.5	0.05437
27	Houshing	2	0.09804	0.5	1	0.5	0.04902
28	Survey	2	0.09626	0.5	0.83333	0.6	0.05775
29	Beltola Tiniali	3	0.22371	0.33333	1.5	0.22222	0.04971
30	AG	2	0.11408	0.5	0.83333	0.6	0.06845
31	Basistha Chariali	2	0.05882	0.5	1.5	0.33333	0.01961
32	Brahmaputra board HQ	1	0	1	0.5	2	0
33	Jayanagar	2	0.19341	0.5	0.58333	0.85714	**0.16578**
34	Romo's restaurent	1	0	1	0.25	4	0
35	Anandaram LPS	2	0.03922	0.5	0.58333	0.85714	0.03361

Table 2 : Centrality values of Figure 2, including Betweenness centrality (C_B), Bridging coefficient (BC) and Bridging centrality (C_R)

4 DISCUSSION AND CONCLUSION

Theoretically, we see that Borbari (Id number 18) has higher bridging centrality than Jayanagar (Id number 33), Training center (Id number 5), Gymkhana Club (Id number 19) and other places. So we select Borbari is a important node among the clusters, though it has less betweenness centrality than other some places. From this we can design some special construction at that point such that the increased of traffic congestion and a growing number of accidents and fatalities are decrease, which is link to other cluster from this Dispur city region.

Throughout the experiments we performed in this paper, bridging centrality did a good job to find out the important bridging nodes in a real world network. Bridging centrality has many possible applications on many research areas. The identification of the bridging nodes and information about the bridging nodes should be very valuable knowledge for further fruitful achievements in other researches and in other fields too.

Bridging centrality has many potential applications in several areas. First, it can be used to break up modules in a network for clustering purpose. Second, it also can be used to identify the most critical points interrupting the information flow in a network for network protection and robustness improvement purposes for networks etc.

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BIOGRAPHIES AND PHOTOGRAPHS

Prof. A.K. Baruah is a senior Professor in the Department of Mathematics at Dibrugarh University, Assam, India. He did his Ph. D degree in Mathematics from Dibrugarh University in 1989. His area of interest are Numerical analysis and Differential Equation, Graph theory and data structure, Mathematical modeling in Traffic control problems using Graph theory. He guided many M.Phil and Ph. D research scholar. He also acted as a resource person in various mathematical programmes and social activities. He has many publications in different refereed journals of National and International repute.

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