**Edge-Betweenness Analysis**

**Shortest-path graph**

[Definition of shortest path][1] Consider a directed network  with an arc length  associated with each arc . The network has a distinguished node *s*, called the *source*. The length of a directed path is defined as the sum of the lengths of arcs in the path. The shortest path problem is to determine for every non-source node  a shortest length directed path from node *s* to node *i*.

[Definition of shortest-path graph][1] In the shortest path problem, one may wish to determine a shortest path from the source node *s* to all other (n-1) nodes. Combining all the shortest paths together will form a shortest-path graph. It should be emphasized that the shortest-path graph for every source node will have the same number of nodes of the original graph if it is undirected. However, it is possible that there are some nodes unreachable for the source node *s* in a directed graph, thus the corresponding shortest-path graph may be smaller than the original graph.

[Create the shortest-path graph by depth first traversal]Original directed graph (the number inside the boxes are the weight for corresponding nodes, equal to the shortest distance to the source node, similar in all the graphs): Let the source node’s weight to be zero, while all the other node weights to be infinite, since they have not been reached yet. A stack is used to track the depth-first traversal, with the source node pushed into it.

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Select the top of the stack (node 1) as current node, there are two edges started from node 1 and terminated at node 2 and node 3, respectively, node 2 is with smaller index, push 2 into the stack. Since , so the weight of node 2 should be updated to 6. Shown in next picture.

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Select the top of the stack (node 2) as current node, there are two edges started from node 2 and terminated at node 3 and node 4, respectively, node 3 is with smaller index, push 3 into the stack. Since , so the weight of node 3 should be updated to 8. Shown in next picture.

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Select the top of the stack (node 3) as current node, there are two edges started from node 3 and terminated at node 4 and node 5, respectively, node 4 is with smaller index, push 4 into the stack. Since , so the weight of node 4 should be updated to 9. Shown in next picture.

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Select the top of the stack (node 4) as current node, there are one edge started from node 4 and terminated at node 6, push 6 into the stack. Since , so the weight of node 6 should be updated to 16. Shown in next picture.

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There is no new edge started from the top of the stack (node 6), pop 6 from the stack. Now the top of the stack is node 4, there are no new edges started from node 4, pop 4 from the stack. Now the top of the stack is node 3, there is a new edge (3, 5). Since , so the weight of node 5 should be updated to 10, and node 5 should be pushed into the stack. Shown in next picture.

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Select the top of the stack (node 5) as current node, there are one edge started from node 5 and terminated at node 6. push 6 into the stack. Since , so the weight of node 6 should be updated to 13, while 6 should be pushed into the stack. Shown in next picture.

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There is no new edge started from the top of the stack (node 6), pop 6 from the stack. Now the top of the stack is node 5, there are no new edges started from node 5, pop 5 from the stack. Now the top of the stack is node 3, there are no new edges started from node 3, pop 3 from the stack. Now the top of the stack is node 2, there is a new edge (2, 4). Since , so the weight of node 4 should be updated to 8, and node 4 should be pushed into the stack. Shown in next picture.

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Node 4 is revisited, thus all the steps later than node 4 should be repeated. Select the top of the stack (node 4) as current node, there is one edge started from node 4 and terminated at node 6, but since , so the weight of node 6 should be kept to 13, thus there is no new edge started from the top of the stack (node 4), pop 4 from the stack. Now the top of the stack is node 2, there are no new edges started from node 2, pop 2 from the stack. Now the top of the stack is node 1, there is one new edge started from node 1 and terminated at node 3, since , the weight of node 3 should be updated to 4, while 3 should be pushed into the stack. Shown in next picture.

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Select the top of the stack (node 3) as current node, there are two edges started from node 3 and terminated at node 4 and node 5, respectively, node 4 is with smaller index, since , push 4 into the stack and update the weight of node 4 to 5. Shown in next picture.

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Select the top of the stack (node 4) as current node, there are one edge started from node 4 and terminated at node 6. Since , so the weight of node 6 should be updated to 12, with 6 pushed into the stack. Shown in next picture.

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There is no new edge started from the top of the stack (node 6), pop 6 from the stack. Now the top of the stack is node 4, there are no new edges started from node 4, pop 4 from the stack. Now the top of the stack is node 3, there is a new edge started from node 3 and terminated at node 5. Since , so the weight of node 5 should be updated to 6, and node 5 should be pushed into the stack. Shown in next picture.

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Select the top of the stack (node 5) as current node, there are two new edges started from node 5 and terminated at node 4 and 6, respectively. Since , so the weight of node 4 should be kept to 5. Since , so the weight of node 6 should be updated to 9, while 6 should be pushed into the stack. Shown in next picture.

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There is no new edge started from the top of the stack (node 6), pop 6 from the stack. Now the top of the stack is node 5, there are no new edges started from node 5, pop 5 from the stack. Now the top of the stack is node 3, there is no new edge started from node 3, pop 3 from the stack. Now the top of the stack is node 1, there is no new edge started from node 1, pop 1 from the stack. Now the stack is empty, the algorithm is finished successfully.

The shortest-path graph of node 1 should includes all the edges (i, j) that fulfill , in which ,  and  are weights of node i, node j and edge (i, j), respectively. Thus from the figure above one can get the shortest-path graph shown as follow:

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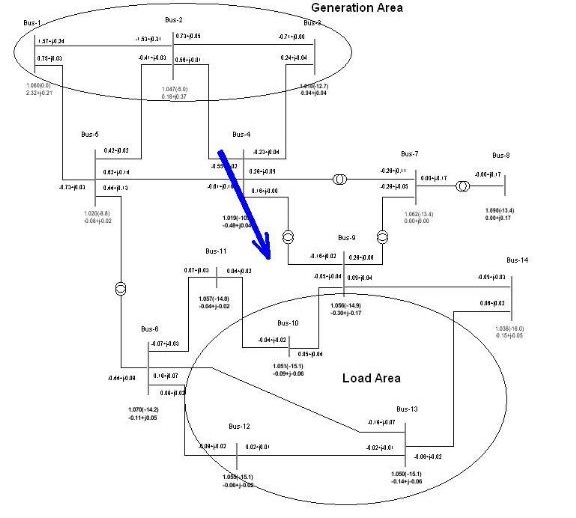
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**Edge-betweenness**

  
--------------------------------------------------------------------------  
What I have done in pan-European network as well as the InterPSS UCTE sample case is to analyze the so-called "edge-betweenness" for all the branches within the network. The edge-betweenness is an index to describe how many shortest paths (of all possible vertex pairs) are passing current branch. Those branches with higher edge betweenness values should be more important than other branches.  
  
In AC power system, electric current (or electrical power) will be always trying to find shortest paths to go, thus the edge-betweenness index has inherent advantage to evaluate related things. However, it is also important to consider the "weight" of the branch.  
  
I have successfully write my own code to calculate such edge betweenness from Eurostag load flow results as well as InterPSS AclfNetwork object, with the help of two classical references:  
  
1. M. E. J. Newman and M. Girvan, Finding and evaluating community structure in networks, Physical Review E69, 026113 (2004)  
2. R. K. Ahuja, T. L. Magnanti, and J. B. Orlin, Network Flows: Theory, Algorithms, and Applications, Prentice Hall, Upper Saddle River,  New Jersey (1993)  
  
Now I am analyzing the statistic properties of all the edge betweennesses for bulk power systems under both normal condition and critical condition. However, it highly depends on Tony's CPF algorithm, because right now I have no efficient tool to reach the critical point of a power system.  
  
Furthermore, the edge betweenness calculation may be easy to be "grid-enabled", because the calculation is done by:  
1. For a certain node, create its shortest-path digraph;  
2. Calculate the contribution of this shortest-path digraph to all the branches' edge-betweenness;  
3. Repeat step 1~2 for every node.  
  
You can see that the calculation of different nodes are totally independent with each other, thus it should be not too difficult to be transplanted into a grid-computing environment.

Reference

1. R. K. Ahuja, T. L. Magnanti, and J. B. Orlin, Network Flows: Theory, Algorithms, and Applications, Prentice Hall, Upper Saddle River,  New Jersey (1993)
2. M. E. J. Newman and M. Girvan, Finding and evaluating community structure in networks, Physical Review E69, 026113 (2004)