Social Network Analysis

PROJECT REPORT

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Submitted to:

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Contents

INTRODUCTION

Objective: To Generate a Scale- free network by implementing BA algorithm and analyzing the network.

The Barabási–Albert (BA) model is a popular algorithm for generating scale-free networks, which are characterized by a small number of highly connected nodes (hubs) and a large number of poorly connected nodes. In social network analysis, the BA model can be used to simulate the growth and evolution of real-world networks, such as citation networks, collaboration networks, and online social networks.

BA Algorithm

The BA model starts with a small initial network of m nodes, and then adds new nodes to the network one at a time. Each new node is connected to m existing nodes, chosen with probability proportional to their degree (i.e., the number of connections they already have). This preferential attachment mechanism leads to the formation of hubs, as nodes with high degree are more likely to receive new connections.

To implement the BA model in social network analysis, the following steps can be followed:

1. Start with a small initial network of m nodes, either randomly connected or connected in a specific pattern.
2. Add new nodes to the network one at a time, and connect each new node to m existing nodes according to the preferential attachment mechanism.
3. Repeat step 2 until the desired number of nodes is reached.
4. Analyze the resulting network using various network analysis tools, such as centrality measures, clustering algorithms, and community detection methods.

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CODE IMPLEMENTATION AND EXPLANATION

This .zip file also contains the code in a python file named **cg_project.py**. The code is as:

1. **Implementing the BA Algorithm to generate the scale-free network S over 100,000 nodes.**

```python
    node1, node2 = np.random.choice(S.nodes(), size=2, replace=False)

    # Add an edge between the two nodes
    S.add_edge(node1, node2)

# initial parameters for BA model
m = 4  # Number of edges added at each time step
N = 10000  # Number of nodes in the final network



while len(S) < N:

    nodes = list(S.nodes())
    degrees = np.array([S.degree(node) for node in nodes])
    probs = degrees / sum(degrees)#probability to be selected is depending on the degree ---> preferential attachment
    chosen_nodes = np.random.choice(nodes, size=m, replace=False, p=probs)

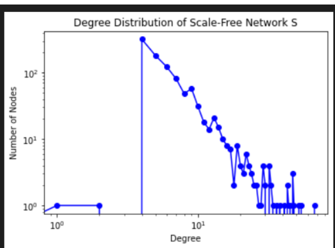
    # Adding new node with edges to the netwrok
    new_node = len(S)
    S.add_node(new_node)
    for node in chosen_nodes:
        S.add_edge(new_node, node)


# Calculate the degree distribution of the network
degree_sequence = sorted([d for n, d in S.degree()], reverse=True)
degree_counts = np.bincount(degree_sequence)
```

Here we implemented the BA algorithm which is used for generating random scale-free networks. We have initialized the parameters as -

m = 4 (these are the number of edges which are added at each time step).
N =10,000 (the number of nodes in the final network).

2. **Plotting the degree distribution of the above scale-free network S.The node with the highest degree and the time interval this node came into the network when you generated the network S.**

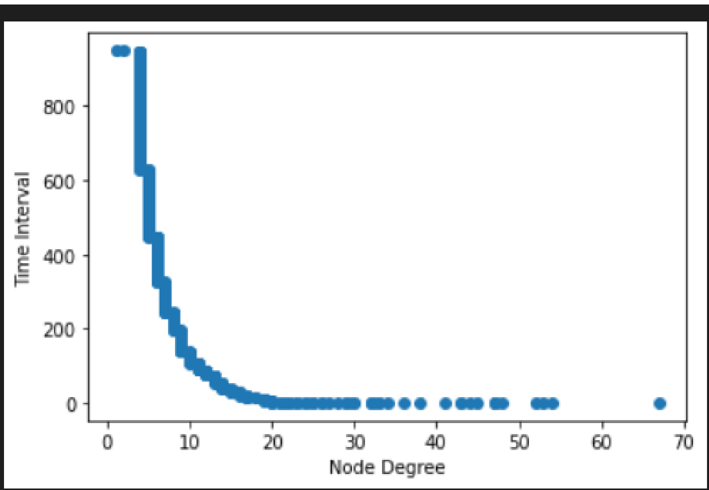



```
The node with the highest degree is 48 with degree 67, entered the network at time interval 1
```

3. **<u>A plot where the x-axis is the node degree, and the y-axis is the time interval in which that node entered the network.</u>**

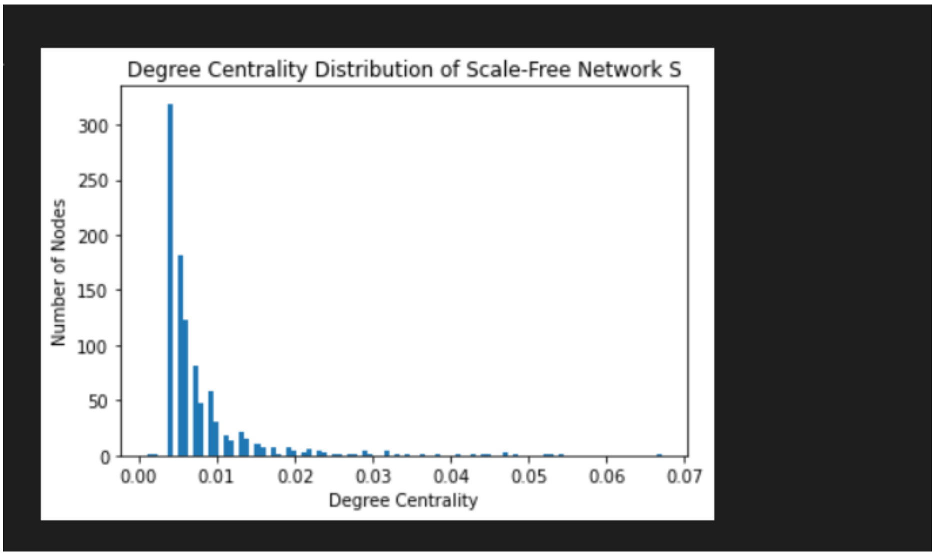
```
# Ploting  the graph for node degree vs time interval
degrees = nx.degree(S)
degree_sequence = sorted([d for n, d in degrees], reverse=True)
time_intervals_sequence = [time_intervals[n] for n, d in degrees]

plt.plot(degree_sequence, time_intervals_sequence, 'o')
plt.xlabel('Node Degree')
plt.ylabel('Time Interval')
plt.show()
```



4. The centrality measures of all the nodes in S and through proper visualization.

- ### Degree Centrality-



Degree Centrality of 500 nodes in the network-

```
Degree Centrality for top 500 nodes
Node: 48, degree centrality = 0.067067
Node: 27, degree centrality = 0.054054
Node: 25, degree centrality = 0.053053
Node: 40, degree centrality = 0.052052
Node: 34, degree centrality = 0.048048
Node: 8, degree centrality = 0.047047
Node: 23, degree centrality = 0.047047
Node: 28, degree centrality = 0.047047
Node: 1, degree centrality = 0.045045
Node: 20, degree centrality = 0.044044
Node: 11, degree centrality = 0.043043
Node: 65, degree centrality = 0.043043
Node: 38, degree centrality = 0.041041
Node: 30, degree centrality = 0.038038
Node: 59, degree centrality = 0.036036
Node: 74, degree centrality = 0.034034
Node: 29, degree centrality = 0.033033
Node: 49, degree centrality = 0.033033
Node: 0, degree centrality = 0.032032
Node: 4, degree centrality = 0.032032
Node: 32, degree centrality = 0.032032
Node: 37, degree centrality = 0.032032
Node: 35, degree centrality = 0.03003
Node: 36, degree centrality = 0.03003
Node: 7, degree centrality = 0.029029
Node: 33, degree centrality = 0.029029
Node: 45, degree centrality = 0.029029
Node: 68, degree centrality = 0.029029
Node: 55, degree centrality = 0.028028
Node: 51, degree centrality = 0.027027
Node: 13, degree centrality = 0.026026
Node: 31, degree centrality = 0.026026
Node: 26, degree centrality = 0.025025
Node: 44, degree centrality = 0.025025
Node: 2, degree centrality = 0.024024
Node: 21, degree centrality = 0.024024
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Node: 22, degree centrality = 0.024024
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Node: 81, degree centrality = 0.023023
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Node: 75, degree centrality = 0.019019
Node: 84, degree centrality = 0.019019
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Node: 143, degree centrality = 0.019019
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Node: 285, degree centrality = 0.019019
Node: 165, degree centrality = 0.018018
Node: 189, degree centrality = 0.018018
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Node: 78, degree centrality = 0.017017
Node: 150, degree centrality = 0.017017
Node: 216, degree centrality = 0.017017
Node: 227, degree centrality = 0.017017
Node: 243, degree centrality = 0.017017
Node: 294, degree centrality = 0.017017
Node: 73, degree centrality = 0.016016
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Node: 611, degree centrality = 0.006006
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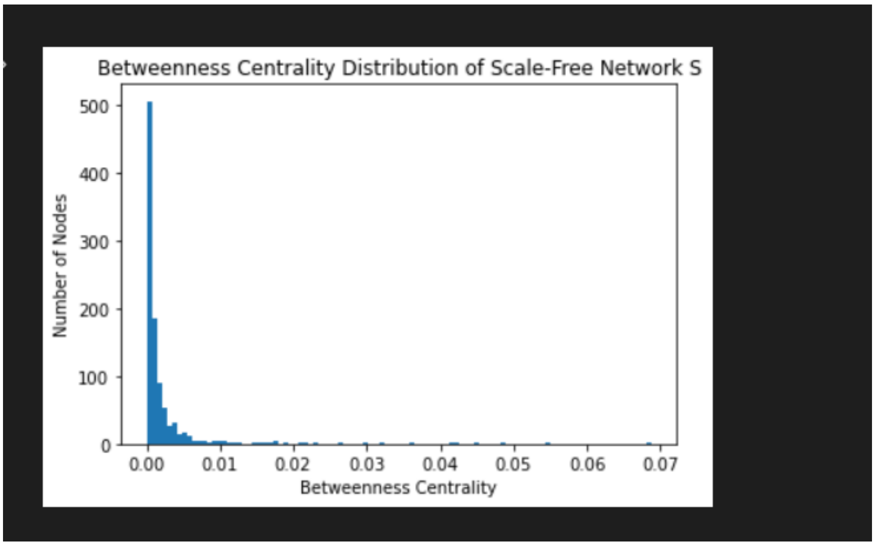
Node: 619, degree centrality = 0.006006
Node: 623, degree centrality = 0.006006
Node: 631, degree centrality = 0.006006
Node: 643, degree centrality = 0.006006
Node: 646, degree centrality = 0.006006
Node: 660, degree centrality = 0.006006
Node: 666, degree centrality = 0.006006
Node: 667, degree centrality = 0.006006
```

```
Node: 671, degree centrality = 0.006006
Node: 678, degree centrality = 0.006006
Node: 682, degree centrality = 0.006006
Node: 683, degree centrality = 0.006006
Node: 696, degree centrality = 0.006006
Node: 703, degree centrality = 0.006006
Node: 709, degree centrality = 0.006006
Node: 716, degree centrality = 0.006006
Node: 725, degree centrality = 0.006006
Node: 726, degree centrality = 0.006006
Node: 734, degree centrality = 0.006006
Node: 739, degree centrality = 0.006006
Node: 755, degree centrality = 0.006006
Node: 765, degree centrality = 0.006006
Node: 780, degree centrality = 0.006006
Node: 789, degree centrality = 0.006006
Node: 840, degree centrality = 0.006006
Node: 845, degree centrality = 0.006006
Node: 849, degree centrality = 0.006006
Node: 859, degree centrality = 0.006006
Node: 865, degree centrality = 0.006006
Node: 121, degree centrality = 0.005005
Node: 133, degree centrality = 0.005005
```

- ## **Betweenness centrality-**



Betweenness Centrality for top 500 nodes -

```
betweeness Centrality for top 500 nodes
Node: 48, betweeness centrality = 0.068771
Node: 27, betweeness centrality = 0.054743
Node: 25, betweeness centrality = 0.048588
Node: 40, betweeness centrality = 0.045045
Node: 34, betweeness centrality = 0.04236
Node: 23, betweeness centrality = 0.041997
Node: 28, betweeness centrality = 0.041594
Node: 11, betweeness centrality = 0.036016
Node: 1, betweeness centrality = 0.035988
Node: 8, betweeness centrality = 0.035961
Node: 38, betweeness centrality = 0.032071
Node: 20, betweeness centrality = 0.030247
Node: 65, betweeness centrality = 0.030196
Node: 30, betweeness centrality = 0.02656
Node: 29, betweeness centrality = 0.023272
Node: 37, betweeness centrality = 0.021523
Node: 0, betweeness centrality = 0.021195
Node: 74, betweeness centrality = 0.021005
Node: 49, betweeness centrality = 0.019087
Node: 59, betweeness centrality = 0.018737
Node: 68, betweeness centrality = 0.017838
Node: 7, betweeness centrality = 0.017817
Node: 35, betweeness centrality = 0.017674
Node: 4, betweeness centrality = 0.01737
Node: 32, betweeness centrality = 0.017003
Node: 51, betweeness centrality = 0.016862
Node: 33, betweeness centrality = 0.016832
Node: 45, betweeness centrality = 0.016207
Node: 36, betweeness centrality = 0.016199
Node: 26, betweeness centrality = 0.015317
Node: 55, betweeness centrality = 0.015007
Node: 44, betweeness centrality = 0.014652
Node: 5, betweeness centrality = 0.012809
Node: 13, betweeness centrality = 0.012559
Node: 31, betweeness centrality = 0.012481
Node: 2, betweeness centrality = 0.011931
```

```
Node: 63, betweeness centrality = 0.011784
Node: 42, betweeness centrality = 0.011482
Node: 21, betweeness centrality = 0.011168
Node: 70, betweeness centrality = 0.010863
Node: 22, betweeness centrality = 0.01069
Node: 118, betweeness centrality = 0.010553
Node: 81, betweeness centrality = 0.010395
Node: 98, betweeness centrality = 0.010136
Node: 64, betweeness centrality = 0.010032
Node: 90, betweeness centrality = 0.009897
Node: 86, betweeness centrality = 0.009769
Node: 137, betweeness centrality = 0.00968
Node: 41, betweeness centrality = 0.009623
Node: 84, betweeness centrality = 0.009354
Node: 156, betweeness centrality = 0.009282
Node: 71, betweeness centrality = 0.009146
Node: 46, betweeness centrality = 0.009066
Node: 60, betweeness centrality = 0.008723
Node: 52, betweeness centrality = 0.00821
Node: 94, betweeness centrality = 0.008185
Node: 143, betweeness centrality = 0.007748
Node: 189, betweeness centrality = 0.007706
Node: 233, betweeness centrality = 0.007592
Node: 185, betweeness centrality = 0.007539
Node: 124, betweeness centrality = 0.007533
Node: 243, betweeness centrality = 0.0075
Node: 119, betweeness centrality = 0.00733
Node: 75, betweeness centrality = 0.006832
Node: 117, betweeness centrality = 0.006759
Node: 191, betweeness centrality = 0.006448
Node: 108, betweeness centrality = 0.006386
Node: 165, betweeness centrality = 0.006235
Node: 56, betweeness centrality = 0.006188
Node: 73, betweeness centrality = 0.006165
Node: 223, betweeness centrality = 0.006102
Node: 57, betweeness centrality = 0.006001
Node: 39, betweeness centrality = 0.005986
```

```
Node: 53, betweeness centrality = 0.005971
Node: 82, betweeness centrality = 0.005933
Node: 78, betweeness centrality = 0.005864
Node: 72, betweeness centrality = 0.005818
Node: 144, betweeness centrality = 0.005704
Node: 43, betweeness centrality = 0.005628
Node: 227, betweeness centrality = 0.005574
Node: 245, betweeness centrality = 0.005396
Node: 87, betweeness centrality = 0.005349
Node: 216, betweeness centrality = 0.005345
Node: 294, betweeness centrality = 0.005245
Node: 66, betweeness centrality = 0.005211
Node: 76, betweeness centrality = 0.005195
Node: 403, betweeness centrality = 0.005156
Node: 145, betweeness centrality = 0.005112
Node: 150, betweeness centrality = 0.005073
Node: 132, betweeness centrality = 0.005063
Node: 138, betweeness centrality = 0.005046
Node: 89, betweeness centrality = 0.004972
Node: 285, betweeness centrality = 0.004971
Node: 102, betweeness centrality = 0.004872
Node: 299, betweeness centrality = 0.004845
Node: 54, betweeness centrality = 0.004832
Node: 106, betweeness centrality = 0.00479
Node: 242, betweeness centrality = 0.004765
Node: 154, betweeness centrality = 0.004729
Node: 123, betweeness centrality = 0.004689
Node: 326, betweeness centrality = 0.004647
Node: 126, betweeness centrality = 0.004645
Node: 14, betweeness centrality = 0.004554
Node: 91, betweeness centrality = 0.004547
Node: 178, betweeness centrality = 0.004466
Node: 199, betweeness centrality = 0.004419
Node: 170, betweeness centrality = 0.004387
Node: 340, betweeness centrality = 0.004353
Node: 179, betweeness centrality = 0.004278
Node: 100, betweeness centrality = 0.004205
```

```
Node: 220, betweeness centrality = 0.004156
Node: 246, betweeness centrality = 0.004124
Node: 217, betweeness centrality = 0.004075
Node: 147, betweeness centrality = 0.004042
Node: 93, betweeness centrality = 0.003981
Node: 24, betweeness centrality = 0.003971
Node: 97, betweeness centrality = 0.003956
Node: 163, betweeness centrality = 0.003955
Node: 101, betweeness centrality = 0.003909
Node: 207, betweeness centrality = 0.003905
Node: 355, betweeness centrality = 0.00388
Node: 19, betweeness centrality = 0.003827
Node: 278, betweeness centrality = 0.003804
Node: 114, betweeness centrality = 0.003793
Node: 50, betweeness centrality = 0.003763
Node: 128, betweeness centrality = 0.00376
Node: 122, betweeness centrality = 0.003706
Node: 383, betweeness centrality = 0.003694
Node: 168, betweeness centrality = 0.003673
Node: 184, betweeness centrality = 0.003673
Node: 135, betweeness centrality = 0.003658
Node: 420, betweeness centrality = 0.003655
Node: 281, betweeness centrality = 0.003624
Node: 277, betweeness centrality = 0.003551
Node: 110, betweeness centrality = 0.003535
Node: 257, betweeness centrality = 0.003532
Node: 113, betweeness centrality = 0.003515
Node: 254, betweeness centrality = 0.003485
Node: 255, betweeness centrality = 0.00348
Node: 182, betweeness centrality = 0.003469
Node: 125, betweeness centrality = 0.003452
Node: 112, betweeness centrality = 0.00345
Node: 352, betweeness centrality = 0.003434
Node: 85, betweeness centrality = 0.003412
Node: 96, betweeness centrality = 0.003395
Node: 134, betweeness centrality = 0.003388
Node: 303, betweeness centrality = 0.003385
```

```
Node: 16, betweeness centrality = 0.003374
Node: 241, betweeness centrality = 0.003353
Node: 158, betweeness centrality = 0.003299
Node: 389, betweeness centrality = 0.003282
Node: 95, betweeness centrality = 0.003234
Node: 248, betweeness centrality = 0.003213
Node: 67, betweeness centrality = 0.003199
Node: 665, betweeness centrality = 0.003139
Node: 188, betweeness centrality = 0.00312
Node: 9, betweeness centrality = 0.003111
Node: 17, betweeness centrality = 0.003107
Node: 180, betweeness centrality = 0.003003
Node: 260, betweeness centrality = 0.002952
Node: 77, betweeness centrality = 0.002951
Node: 319, betweeness centrality = 0.002925
Node: 402, betweeness centrality = 0.002916
Node: 198, betweeness centrality = 0.002895
Node: 354, betweeness centrality = 0.002842
Node: 88, betweeness centrality = 0.002793
Node: 142, betweeness centrality = 0.002766
Node: 292, betweeness centrality = 0.002753
Node: 270, betweeness centrality = 0.002742
Node: 111, betweeness centrality = 0.002719
Node: 221, betweeness centrality = 0.002682
Node: 273, betweeness centrality = 0.002662
Node: 80, betweeness centrality = 0.00265
Node: 400, betweeness centrality = 0.002639
Node: 99, betweeness centrality = 0.00262
Node: 193, betweeness centrality = 0.002614
Node: 589, betweeness centrality = 0.002612
Node: 333, betweeness centrality = 0.002603
Node: 107, betweeness centrality = 0.00258
Node: 177, betweeness centrality = 0.002566
Node: 69, betweeness centrality = 0.002556
Node: 175, betweeness centrality = 0.002553
Node: 289, betweeness centrality = 0.002542
Node: 10, betweeness centrality = 0.00254
```

```
Node: 210, betweeness centrality = 0.002487
Node: 404, betweeness centrality = 0.002484
Node: 192, betweeness centrality = 0.002478
Node: 346, betweeness centrality = 0.002453
Node: 395, betweeness centrality = 0.002428
Node: 229, betweeness centrality = 0.002423
Node: 276, betweeness centrality = 0.002421
Node: 197, betweeness centrality = 0.002419
Node: 366, betweeness centrality = 0.002411
Node: 521, betweeness centrality = 0.002398
Node: 244, betweeness centrality = 0.002386
Node: 152, betweeness centrality = 0.002382
Node: 166, betweeness centrality = 0.002377
Node: 196, betweeness centrality = 0.002369
Node: 528, betweeness centrality = 0.002364
Node: 539, betweeness centrality = 0.002331
Node: 410, betweeness centrality = 0.002329
Node: 341, betweeness centrality = 0.002267
Node: 363, betweeness centrality = 0.002261
Node: 263, betweeness centrality = 0.002259
Node: 127, betweeness centrality = 0.002239
Node: 507, betweeness centrality = 0.002213
Node: 258, betweeness centrality = 0.002211
Node: 149, betweeness centrality = 0.002209
Node: 62, betweeness centrality = 0.002201
Node: 215, betweeness centrality = 0.002198
Node: 130, betweeness centrality = 0.002195
Node: 312, betweeness centrality = 0.002195
Node: 417, betweeness centrality = 0.002191
Node: 280, betweeness centrality = 0.002152
Node: 47, betweeness centrality = 0.002149
Node: 298, betweeness centrality = 0.002149
Node: 556, betweeness centrality = 0.002138
Node: 297, betweeness centrality = 0.002121
Node: 146, betweeness centrality = 0.002104
Node: 173, betweeness centrality = 0.002074
Node: 155, betweeness centrality = 0.002061
```

```
Node: 261, betweeness centrality = 0.002061
Node: 356, betweeness centrality = 0.002055
Node: 279, betweeness centrality = 0.002033
Node: 518, betweeness centrality = 0.002032
Node: 265, betweeness centrality = 0.00203
Node: 513, betweeness centrality = 0.002023
Node: 416, betweeness centrality = 0.002016
Node: 61, betweeness centrality = 0.002015
Node: 151, betweeness centrality = 0.002005
Node: 318, betweeness centrality = 0.001976
Node: 247, betweeness centrality = 0.001971
Node: 181, betweeness centrality = 0.001962
Node: 190, betweeness centrality = 0.001957
Node: 129, betweeness centrality = 0.001937
Node: 104, betweeness centrality = 0.001931
Node: 624, betweeness centrality = 0.001931
Node: 413, betweeness centrality = 0.00193
Node: 482, betweeness centrality = 0.001909
Node: 79, betweeness centrality = 0.001901
Node: 238, betweeness centrality = 0.001899
Node: 141, betweeness centrality = 0.001896
Node: 116, betweeness centrality = 0.001884
Node: 331, betweeness centrality = 0.001879
Node: 271, betweeness centrality = 0.001869
Node: 476, betweeness centrality = 0.001862
Node: 195, betweeness centrality = 0.00185
Node: 418, betweeness centrality = 0.001847
Node: 455, betweeness centrality = 0.001844
Node: 12, betweeness centrality = 0.001841
Node: 652, betweeness centrality = 0.001833
Node: 388, betweeness centrality = 0.001829
Node: 691, betweeness centrality = 0.001818
Node: 595, betweeness centrality = 0.001775
Node: 274, betweeness centrality = 0.00177
Node: 415, betweeness centrality = 0.001768
Node: 153, betweeness centrality = 0.001766
Node: 496, betweeness centrality = 0.001766
```

```
Node: 131, betweeness centrality = 0.001759
Node: 407, betweeness centrality = 0.001753
Node: 148, betweeness centrality = 0.001743
Node: 344, betweeness centrality = 0.001737
Node: 384, betweeness centrality = 0.001727
Node: 464, betweeness centrality = 0.001698
Node: 250, betweeness centrality = 0.001684
Node: 291, betweeness centrality = 0.001681
Node: 573, betweeness centrality = 0.001665
Node: 268, betweeness centrality = 0.001652
Node: 506, betweeness centrality = 0.001649
Node: 373, betweeness centrality = 0.001648
Node: 187, betweeness centrality = 0.001646
Node: 295, betweeness centrality = 0.001646
Node: 213, betweeness centrality = 0.001643
Node: 517, betweeness centrality = 0.001638
Node: 433, betweeness centrality = 0.001621
Node: 92, betweeness centrality = 0.001611
Node: 621, betweeness centrality = 0.001603
Node: 105, betweeness centrality = 0.001601
Node: 230, betweeness centrality = 0.001601
Node: 527, betweeness centrality = 0.0016
Node: 436, betweeness centrality = 0.001591
Node: 293, betweeness centrality = 0.001588
Node: 157, betweeness centrality = 0.001584
Node: 361, betweeness centrality = 0.001577
Node: 424, betweeness centrality = 0.001568
Node: 357, betweeness centrality = 0.001566
Node: 266, betweeness centrality = 0.00156
Node: 162, betweeness centrality = 0.001494
Node: 335, betweeness centrality = 0.001492
Node: 208, betweeness centrality = 0.001489
Node: 172, betweeness centrality = 0.001487
Node: 327, betweeness centrality = 0.001465
Node: 374, betweeness centrality = 0.001463
Node: 386, betweeness centrality = 0.00146
Node: 568, betweeness centrality = 0.001457
```

```
Node: 310, betweeness centrality = 0.001449
Node: 376, betweeness centrality = 0.001448
Node: 423, betweeness centrality = 0.001445
Node: 408, betweeness centrality = 0.001442
Node: 348, betweeness centrality = 0.001434
Node: 308, betweeness centrality = 0.001432
Node: 486, betweeness centrality = 0.001422
Node: 169, betweeness centrality = 0.001414
Node: 222, betweeness centrality = 0.001413
Node: 140, betweeness centrality = 0.001411
Node: 432, betweeness centrality = 0.001393
Node: 616, betweeness centrality = 0.001392
Node: 336, betweeness centrality = 0.001384
Node: 481, betweeness centrality = 0.00138
Node: 214, betweeness centrality = 0.001376
Node: 176, betweeness centrality = 0.00137
Node: 259, betweeness centrality = 0.001364
Node: 391, betweeness centrality = 0.001357
Node: 660, betweeness centrality = 0.001346
Node: 283, betweeness centrality = 0.001329
Node: 431, betweeness centrality = 0.001326
Node: 467, betweeness centrality = 0.001323
Node: 288, betweeness centrality = 0.001322
Node: 509, betweeness centrality = 0.001312
Node: 330, betweeness centrality = 0.001306
Node: 371, betweeness centrality = 0.001301
Node: 429, betweeness centrality = 0.0013
Node: 269, betweeness centrality = 0.001299
Node: 353, betweeness centrality = 0.001299
Node: 646, betweeness centrality = 0.001295
Node: 379, betweeness centrality = 0.00129
Node: 231, betweeness centrality = 0.001279
Node: 716, betweeness centrality = 0.001277
Node: 183, betweeness centrality = 0.001276
Node: 359, betweeness centrality = 0.00124
Node: 256, betweeness centrality = 0.001225
Node: 264, betweeness centrality = 0.001219
```

```
Node: 83, betweeness centrality = 0.001218
Node: 194, betweeness centrality = 0.001194
Node: 734, betweeness centrality = 0.001188
Node: 396, betweeness centrality = 0.001186
Node: 642, betweeness centrality = 0.001184
Node: 765, betweeness centrality = 0.001179
Node: 480, betweeness centrality = 0.001178
Node: 473, betweeness centrality = 0.001177
Node: 103, betweeness centrality = 0.001173
Node: 504, betweeness centrality = 0.001172
Node: 109, betweeness centrality = 0.00117
Node: 562, betweeness centrality = 0.00117
Node: 710, betweeness centrality = 0.00117
Node: 611, betweeness centrality = 0.001162
Node: 235, betweeness centrality = 0.001159
Node: 713, betweeness centrality = 0.001151
Node: 372, betweeness centrality = 0.00115
Node: 382, betweeness centrality = 0.001148
Node: 523, betweeness centrality = 0.001143
Node: 306, betweeness centrality = 0.001139
Node: 6, betweeness centrality = 0.001137
Node: 638, betweeness centrality = 0.001132
Node: 459, betweeness centrality = 0.001128
Node: 469, betweeness centrality = 0.001126
Node: 115, betweeness centrality = 0.001124
Node: 516, betweeness centrality = 0.001119
Node: 275, betweeness centrality = 0.001117
Node: 494, betweeness centrality = 0.001112
Node: 339, betweeness centrality = 0.001103
Node: 505, betweeness centrality = 0.001089
Node: 678, betweeness centrality = 0.001085
Node: 419, betweeness centrality = 0.001082
Node: 427, betweeness centrality = 0.001072
Node: 565, betweeness centrality = 0.001069
Node: 745, betweeness centrality = 0.001065
Node: 58, betweeness centrality = 0.001053
Node: 225, betweeness centrality = 0.001049
```

```
Node: 284, betweeness centrality = 0.001042
Node: 457, betweeness centrality = 0.001042
Node: 709, betweeness centrality = 0.001042
Node: 368, betweeness centrality = 0.001041
Node: 426, betweeness centrality = 0.001041
Node: 809, betweeness centrality = 0.001041
Node: 209, betweeness centrality = 0.001034
Node: 409, betweeness centrality = 0.001033
Node: 367, betweeness centrality = 0.00103
Node: 329, betweeness centrality = 0.001013
Node: 370, betweeness centrality = 0.001009
Node: 549, betweeness centrality = 0.001008
Node: 596, betweeness centrality = 0.001005
Node: 614, betweeness centrality = 0.000996
Node: 739, betweeness centrality = 0.000993
Node: 205, betweeness centrality = 0.00099
Node: 525, betweeness centrality = 0.000989
Node: 724, betweeness centrality = 0.000988
Node: 845, betweeness centrality = 0.000986
Node: 711, betweeness centrality = 0.000981
Node: 385, betweeness centrality = 0.000978
Node: 219, betweeness centrality = 0.000977
Node: 576, betweeness centrality = 0.000976
Node: 632, betweeness centrality = 0.000974
Node: 345, betweeness centrality = 0.000971
Node: 619, betweeness centrality = 0.00097
Node: 202, betweeness centrality = 0.000965
Node: 252, betweeness centrality = 0.000964
Node: 186, betweeness centrality = 0.000962
Node: 435, betweeness centrality = 0.000961
Node: 629, betweeness centrality = 0.00096
Node: 237, betweeness centrality = 0.000958
Node: 591, betweeness centrality = 0.000958
Node: 397, betweeness centrality = 0.000952
Node: 290, betweeness centrality = 0.000951
Node: 446, betweeness centrality = 0.000951
Node: 358, betweeness centrality = 0.00094
```

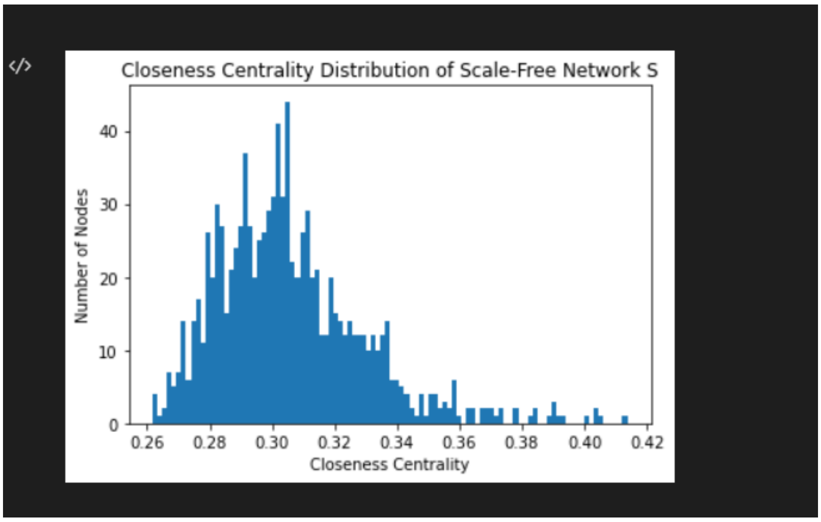
```
Node: 438, betweeness centrality = 0.00094
Node: 627, betweeness centrality = 0.000937
Node: 206, betweeness centrality = 0.000932
Node: 211, betweeness centrality = 0.000929
Node: 483, betweeness centrality = 0.000923
Node: 696, betweeness centrality = 0.000919
Node: 661, betweeness centrality = 0.000917
Node: 703, betweeness centrality = 0.000914
Node: 601, betweeness centrality = 0.000908
Node: 463, betweeness centrality = 0.000906
Node: 324, betweeness centrality = 0.0009
Node: 120, betweeness centrality = 0.000889
Node: 381, betweeness centrality = 0.000888
Node: 741, betweeness centrality = 0.000888
Node: 160, betweeness centrality = 0.000877
Node: 742, betweeness centrality = 0.000874
Node: 309, betweeness centrality = 0.000873
Node: 447, betweeness centrality = 0.000871
Node: 552, betweeness centrality = 0.000869
Node: 315, betweeness centrality = 0.000867
Node: 602, betweeness centrality = 0.000867
Node: 204, betweeness centrality = 0.000865
Node: 325, betweeness centrality = 0.000859
Node: 547, betweeness centrality = 0.000859
Node: 350, betweeness centrality = 0.000854
Node: 592, betweeness centrality = 0.00085
Node: 643, betweeness centrality = 0.000844
Node: 461, betweeness centrality = 0.000843
Node: 683, betweeness centrality = 0.00084
Node: 305, betweeness centrality = 0.000838
Node: 537, betweeness centrality = 0.000835
Node: 714, betweeness centrality = 0.000832
Node: 422, betweeness centrality = 0.00083
Node: 908, betweeness centrality = 0.00083
Node: 226, betweeness centrality = 0.000828
Node: 337, betweeness centrality = 0.000825
Node: 203, betweeness centrality = 0.000824
```

```
Node: 406, betweeness centrality = 0.000812
Node: 444, betweeness centrality = 0.000812
Node: 585, betweeness centrality = 0.000808
Node: 531, betweeness centrality = 0.000807
Node: 849, betweeness centrality = 0.000802
Node: 540, betweeness centrality = 0.000799
Node: 667, betweeness centrality = 0.000797
Node: 387, betweeness centrality = 0.000787
Node: 390, betweeness centrality = 0.00078
Node: 411, betweeness centrality = 0.000766
Node: 484, betweeness centrality = 0.000765
Node: 731, betweeness centrality = 0.000762
Node: 542, betweeness centrality = 0.000761
Node: 365, betweeness centrality = 0.00076
Node: 399, betweeness centrality = 0.00076
Node: 489, betweeness centrality = 0.000756
Node: 960, betweeness centrality = 0.000754
Node: 421, betweeness centrality = 0.000753
Node: 590, betweeness centrality = 0.000753
Node: 159, betweeness centrality = 0.00075
Node: 434, betweeness centrality = 0.00075
Node: 378, betweeness centrality = 0.000744
Node: 757, betweeness centrality = 0.000744
Node: 251, betweeness centrality = 0.000743
Node: 212, betweeness centrality = 0.00074
Node: 852, betweeness centrality = 0.000739
Node: 937, betweeness centrality = 0.000739
Node: 964, betweeness centrality = 0.000738
Node: 996, betweeness centrality = 0.000736
Node: 564, betweeness centrality = 0.000735
Node: 538, betweeness centrality = 0.000734
Node: 787, betweeness centrality = 0.000729
Node: 789, betweeness centrality = 0.000729
Node: 622, betweeness centrality = 0.000726
Node: 555, betweeness centrality = 0.000724
Node: 200, betweeness centrality = 0.000717
Node: 440, betweeness centrality = 0.000714
```

```
Node: 699, betweeness centrality = 0.000713
Node: 670, betweeness centrality = 0.000711
Node: 314, betweeness centrality = 0.00071
Node: 737, betweeness centrality = 0.00071
Node: 682, betweeness centrality = 0.000708
Node: 332, betweeness centrality = 0.000706
Node: 666, betweeness centrality = 0.000704
Node: 377, betweeness centrality = 0.000702
Node: 526, betweeness centrality = 0.000698
Node: 164, betweeness centrality = 0.000696
Node: 174, betweeness centrality = 0.000694
Node: 139, betweeness centrality = 0.000693
Node: 532, betweeness centrality = 0.000693
Node: 819, betweeness centrality = 0.000693
Node: 311, betweeness centrality = 0.00069
Node: 615, betweeness centrality = 0.000684
Node: 262, betweeness centrality = 0.000682
Node: 586, betweeness centrality = 0.000682
Node: 559, betweeness centrality = 0.000681
Node: 671, betweeness centrality = 0.000681
```

- **Eigen-Vector Centrality -**

- ## Closeness Centrality-



Closeness Centrality of top 500 nodes -

```
closeness Centrality for top 500 nodes
Node: 48, closeness centrality = 0.413665
Node: 27, closeness centrality = 0.404945
Node: 25, closeness centrality = 0.403473
Node: 28, closeness centrality = 0.403473
Node: 34, closeness centrality = 0.400722
Node: 40, closeness centrality = 0.392843
Node: 1, closeness centrality = 0.391918
Node: 23, closeness centrality = 0.390692
Node: 8, closeness centrality = 0.389778
Node: 38, closeness centrality = 0.389778
Node: 11, closeness centrality = 0.388112
Node: 0, closeness centrality = 0.383935
Node: 29, closeness centrality = 0.383493
Node: 20, closeness centrality = 0.382612
Node: 37, closeness centrality = 0.378552
Node: 65, closeness centrality = 0.378123
Node: 49, closeness centrality = 0.373179
Node: 30, closeness centrality = 0.372761
Node: 74, closeness centrality = 0.372206
Node: 26, closeness centrality = 0.370686
Node: 68, closeness centrality = 0.37
Node: 45, closeness centrality = 0.36918
Node: 44, closeness centrality = 0.368907
Node: 33, closeness centrality = 0.367956
Node: 35, closeness centrality = 0.366875
Node: 51, closeness centrality = 0.3642
Node: 5, closeness centrality = 0.363934
Node: 22, closeness centrality = 0.363405
Node: 7, closeness centrality = 0.363141
Node: 59, closeness centrality = 0.359611
Node: 63, closeness centrality = 0.358965
Node: 2, closeness centrality = 0.358707
Node: 55, closeness centrality = 0.358707
Node: 42, closeness centrality = 0.35845
Node: 32, closeness centrality = 0.358193
Node: 31, closeness centrality = 0.357552
Node: 70, closeness centrality = 0.357424
Node: 4, closeness centrality = 0.356023
Node: 90, closeness centrality = 0.355769
Node: 60, closeness centrality = 0.35539
Node: 81, closeness centrality = 0.354885
Node: 118, closeness centrality = 0.35413
Node: 108, closeness centrality = 0.353004
Node: 36, closeness centrality = 0.352381
Node: 46, closeness centrality = 0.352257
Node: 98, closeness centrality = 0.352257
Node: 52, closeness centrality = 0.351637
Node: 71, closeness centrality = 0.351142
Node: 84, closeness centrality = 0.351019
Node: 19, closeness centrality = 0.350896
Node: 64, closeness centrality = 0.350035
Node: 13, closeness centrality = 0.349301
Node: 21, closeness centrality = 0.348084
Node: 39, closeness centrality = 0.347357
Node: 87, closeness centrality = 0.347237
Node: 57, closeness centrality = 0.347116
Node: 137, closeness centrality = 0.346394
Node: 86, closeness centrality = 0.345197
Node: 73, closeness centrality = 0.34389
Node: 143, closeness centrality = 0.343653
Node: 97, closeness centrality = 0.343535
Node: 56, closeness centrality = 0.343063
Node: 17, closeness centrality = 0.342945
Node: 53, closeness centrality = 0.34224
Node: 124, closeness centrality = 0.341889
Node: 72, closeness centrality = 0.341189
Node: 145, closeness centrality = 0.341072
Node: 134, closeness centrality = 0.340956
Node: 135, closeness centrality = 0.340491
Node: 117, closeness centrality = 0.339912
Node: 24, closeness centrality = 0.33968
Node: 66, closeness centrality = 0.33968
Node: 223, closeness centrality = 0.33968
Node: 243, closeness centrality = 0.339334
Node: 94, closeness centrality = 0.338989
Node: 185, closeness centrality = 0.338759
Node: 89, closeness centrality = 0.338644
Node: 418, closeness centrality = 0.3383
Node: 43, closeness centrality = 0.337842
Node: 165, closeness centrality = 0.337842
Node: 62, closeness centrality = 0.337614
Node: 156, closeness centrality = 0.3375
Node: 41, closeness centrality = 0.337386
Node: 355, closeness centrality = 0.337272
Node: 75, closeness centrality = 0.337158
Node: 191, closeness centrality = 0.337158
Node: 277, closeness centrality = 0.337045
Node: 126, closeness centrality = 0.336931
Node: 214, closeness centrality = 0.336817
Node: 233, closeness centrality = 0.336817
Node: 16, closeness centrality = 0.336704
Node: 265, closeness centrality = 0.336477
Node: 198, closeness centrality = 0.33625
Node: 303, closeness centrality = 0.33625
Node: 96, closeness centrality = 0.336024
Node: 88, closeness centrality = 0.335911
Node: 101, closeness centrality = 0.335911
Node: 102, closeness centrality = 0.335911
Node: 147, closeness centrality = 0.335911
Node: 50, closeness centrality = 0.335798
Node: 119, closeness centrality = 0.335685
Node: 116, closeness centrality = 0.335347
Node: 123, closeness centrality = 0.335235
Node: 389, closeness centrality = 0.335235
Node: 170, closeness centrality = 0.33501
Node: 138, closeness centrality = 0.334898
Node: 10, closeness centrality = 0.334673
Node: 76, closeness centrality = 0.334561
Node: 462, closeness centrality = 0.334561
```

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Node: 78, closeness centrality = 0.334114
Node: 122, closeness centrality = 0.334114
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Node: 346, closeness centrality = 0.33389
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Node: 113, closeness centrality = 0.333445
Node: 127, closeness centrality = 0.333333
Node: 61, closeness centrality = 0.333
Node: 197, closeness centrality = 0.333
Node: 299, closeness centrality = 0.332889
Node: 417, closeness centrality = 0.332667
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Node: 395, closeness centrality = 0.332557
Node: 184, closeness centrality = 0.332446
Node: 9, closeness centrality = 0.332335
Node: 163, closeness centrality = 0.332335
Node: 292, closeness centrality = 0.332335
Node: 106, closeness centrality = 0.332004
Node: 111, closeness centrality = 0.332004
Node: 99, closeness centrality = 0.331673
Node: 326, closeness centrality = 0.331673
Node: 77, closeness centrality = 0.331563
Node: 149, closeness centrality = 0.331453
Node: 281, closeness centrality = 0.331233
Node: 246, closeness centrality = 0.330904
Node: 130, closeness centrality = 0.330795
Node: 103, closeness centrality = 0.330685
Node: 333, closeness centrality = 0.330357
Node: 216, closeness centrality = 0.330248
Node: 114, closeness centrality = 0.330139
Node: 154, closeness centrality = 0.33003
Node: 261, closeness centrality = 0.33003
Node: 402, closeness centrality = 0.33003
Node: 166, closeness centrality = 0.329703
Node: 227, closeness centrality = 0.329485
Node: 241, closeness centrality = 0.329485
Node: 112, closeness centrality = 0.329377
```

```
Node: 125, closeness centrality = 0.329051
Node: 189, closeness centrality = 0.329051
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Node: 196, closeness centrality = 0.328727
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Node: 177, closeness centrality = 0.327971
Node: 180, closeness centrality = 0.327971
Node: 93, closeness centrality = 0.327756
Node: 54, closeness centrality = 0.327648
Node: 179, closeness centrality = 0.327326
Node: 132, closeness centrality = 0.327219
Node: 178, closeness centrality = 0.327219
Node: 245, closeness centrality = 0.327112
Node: 69, closeness centrality = 0.326791
Node: 85, closeness centrality = 0.326684
Node: 105, closeness centrality = 0.326577
Node: 142, closeness centrality = 0.326577
Node: 257, closeness centrality = 0.326577
Node: 194, closeness centrality = 0.326364
Node: 406, closeness centrality = 0.326257
Node: 91, closeness centrality = 0.326151
Node: 104, closeness centrality = 0.325832
Node: 383, closeness centrality = 0.325725
Node: 646, closeness centrality = 0.325619
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Node: 242, closeness centrality = 0.325407
Node: 168, closeness centrality = 0.325301
Node: 47, closeness centrality = 0.325195
Node: 270, closeness centrality = 0.325089
Node: 155, closeness centrality = 0.324772
Node: 366, closeness centrality = 0.324667
Node: 80, closeness centrality = 0.324351
Node: 266, closeness centrality = 0.324351
```

```
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Node: 691, closeness centrality = 0.322258
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Node: 289, closeness centrality = 0.321947
Node: 384, closeness centrality = 0.321843
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Node: 264, closeness centrality = 0.321222
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Node: 613, closeness centrality = 0.320706
Node: 741, closeness centrality = 0.320603
Node: 67, closeness centrality = 0.320398
```

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Node: 819, closeness centrality = 0.319169
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Node: 665, closeness centrality = 0.318559
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Node: 523, closeness centrality = 0.318153
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Node: 181, closeness centrality = 0.317445
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Node: 517, closeness centrality = 0.314646
Node: 186, closeness centrality = 0.314547
Node: 394, closeness centrality = 0.314547
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Node: 907, closeness centrality = 0.314349
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Node: 280, closeness centrality = 0.314052
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Node: 121, closeness centrality = 0.310828
Node: 212, closeness centrality = 0.310828
```

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Node: 549, closeness centrality = 0.310152
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Node: 938, closeness centrality = 0.309288
Node: 999, closeness centrality = 0.309288
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Node: 628, closeness centrality = 0.309097
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Node: 762, closeness centrality = 0.309001
Node: 951, closeness centrality = 0.308905
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Node: 701, closeness centrality = 0.305225
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Node: 917, closeness centrality = 0.304388
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Node: 590, closeness centrality = 0.304295
Node: 201, closeness centrality = 0.304202
Node: 434, closeness centrality = 0.30411
Node: 540, closeness centrality = 0.30411
Node: 560, closeness centrality = 0.30411
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Node: 924, closeness centrality = 0.303279
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Node: 405, closeness centrality = 0.303187
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Node: 636, closeness centrality = 0.303095
Node: 662, closeness centrality = 0.303095
Node: 767, closeness centrality = 0.303095
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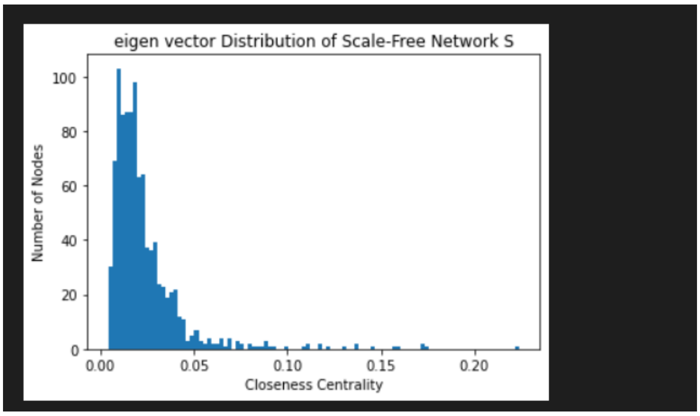
Node: 314, closeness centrality = 0.302452
Node: 680, closeness centrality = 0.302452
Node: 858, closeness centrality = 0.302452
Node: 372, closeness centrality = 0.302361
Node: 425, closeness centrality = 0.302361
Node: 538, closeness centrality = 0.302361
Node: 722, closeness centrality = 0.302361
Node: 498, closeness centrality = 0.302269
```

- Eigen Vector Centrality-



Eigen Vectore centraolity of 500 nodes -

```
eigen vector Centrality for top 500 nodes
Node: 48, eigen vector centrality = 0.223891
Node: 28, eigen vector centrality = 0.174657
Node: 27, eigen vector centrality = 0.173071
Node: 25, eigen vector centrality = 0.172999
Node: 34, eigen vector centrality = 0.159164
Node: 1, eigen vector centrality = 0.156905
Node: 40, eigen vector centrality = 0.146565
Node: 38, eigen vector centrality = 0.136397
Node: 23, eigen vector centrality = 0.136226
Node: 8, eigen vector centrality = 0.130133
Node: 20, eigen vector centrality = 0.12143
Node: 0, eigen vector centrality = 0.11778
Node: 11, eigen vector centrality = 0.116411
Node: 29, eigen vector centrality = 0.111359
Node: 37, eigen vector centrality = 0.109706
Node: 65, eigen vector centrality = 0.108676
Node: 30, eigen vector centrality = 0.099942
Node: 49, eigen vector centrality = 0.092406
Node: 26, eigen vector centrality = 0.090351
Node: 68, eigen vector centrality = 0.089365
Node: 59, eigen vector centrality = 0.089101
Node: 45, eigen vector centrality = 0.088006
Node: 35, eigen vector centrality = 0.086395
Node: 74, eigen vector centrality = 0.085123
Node: 44, eigen vector centrality = 0.082333
Node: 22, eigen vector centrality = 0.079576
Node: 51, eigen vector centrality = 0.079109
Node: 33, eigen vector centrality = 0.075482
Node: 5, eigen vector centrality = 0.074631
Node: 42, eigen vector centrality = 0.074081
Node: 7, eigen vector centrality = 0.073003
Node: 31, eigen vector centrality = 0.072411
Node: 81, eigen vector centrality = 0.069617
Node: 55, eigen vector centrality = 0.069577
Node: 4, eigen vector centrality = 0.068165
Node: 46, eigen vector centrality = 0.067925
```

```
Node: 108, eigen vector centrality = 0.066791
Node: 70, eigen vector centrality = 0.065239
Node: 32, eigen vector centrality = 0.06517
Node: 2, eigen vector centrality = 0.064322
Node: 52, eigen vector centrality = 0.063661
Node: 90, eigen vector centrality = 0.061642
Node: 63, eigen vector centrality = 0.06121
Node: 60, eigen vector centrality = 0.060785
Node: 19, eigen vector centrality = 0.059101
Node: 13, eigen vector centrality = 0.058289
Node: 98, eigen vector centrality = 0.058176
Node: 36, eigen vector centrality = 0.05754
Node: 84, eigen vector centrality = 0.057124
Node: 118, eigen vector centrality = 0.055736
Node: 21, eigen vector centrality = 0.055128
Node: 71, eigen vector centrality = 0.054565
Node: 86, eigen vector centrality = 0.053055
Node: 57, eigen vector centrality = 0.052484
Node: 64, eigen vector centrality = 0.052071
Node: 56, eigen vector centrality = 0.051944
Node: 143, eigen vector centrality = 0.051808
Node: 75, eigen vector centrality = 0.051782
Node: 39, eigen vector centrality = 0.051704
Node: 87, eigen vector centrality = 0.051108
Node: 17, eigen vector centrality = 0.050355
Node: 137, eigen vector centrality = 0.050032
Node: 53, eigen vector centrality = 0.049435
Node: 24, eigen vector centrality = 0.048923
Node: 97, eigen vector centrality = 0.048904
Node: 173, eigen vector centrality = 0.04873
Node: 346, eigen vector centrality = 0.04722
Node: 124, eigen vector centrality = 0.047032
Node: 117, eigen vector centrality = 0.046847
Node: 243, eigen vector centrality = 0.045516
Node: 145, eigen vector centrality = 0.045502
Node: 73, eigen vector centrality = 0.045441
Node: 89, eigen vector centrality = 0.044981
```

```
Node: 303, eigen vector centrality = 0.044669
Node: 50, eigen vector centrality = 0.044115
Node: 128, eigen vector centrality = 0.044058
Node: 214, eigen vector centrality = 0.044026
Node: 43, eigen vector centrality = 0.043682
Node: 197, eigen vector centrality = 0.043643
Node: 88, eigen vector centrality = 0.043635
Node: 418, eigen vector centrality = 0.04331
Node: 116, eigen vector centrality = 0.043109
Node: 355, eigen vector centrality = 0.043103
Node: 191, eigen vector centrality = 0.0431
Node: 135, eigen vector centrality = 0.042706
Node: 62, eigen vector centrality = 0.042486
Node: 265, eigen vector centrality = 0.042417
Node: 233, eigen vector centrality = 0.042342
Node: 147, eigen vector centrality = 0.042341
Node: 66, eigen vector centrality = 0.042276
Node: 462, eigen vector centrality = 0.042172
Node: 395, eigen vector centrality = 0.042039
Node: 156, eigen vector centrality = 0.04136
Node: 72, eigen vector centrality = 0.041254
Node: 138, eigen vector centrality = 0.041165
Node: 223, eigen vector centrality = 0.041136
Node: 122, eigen vector centrality = 0.041087
Node: 41, eigen vector centrality = 0.041051
Node: 61, eigen vector centrality = 0.040893
Node: 94, eigen vector centrality = 0.040853
Node: 101, eigen vector centrality = 0.040844
Node: 134, eigen vector centrality = 0.04069
Node: 292, eigen vector centrality = 0.040648
Node: 16, eigen vector centrality = 0.040596
Node: 77, eigen vector centrality = 0.040553
Node: 119, eigen vector centrality = 0.040463
Node: 198, eigen vector centrality = 0.040364
Node: 185, eigen vector centrality = 0.040257
Node: 165, eigen vector centrality = 0.040247
Node: 10, eigen vector centrality = 0.040007
```

5. The giant component in S as G and the ratio of the nodes in G to S -

```
Giant Component Size: 1000
Total Nodes in S: 1000
Ratio of Nodes in Giant Component to S: 1.0
```

```python
#giant component in S
connected_components = list(nx.connected_components(S))
giant_component = max(connected_components, key=len)

#ratio
giant_component_size = len(giant_component)
total_nodes = len(S.nodes)
ratio = giant_component_size / total_nodes

print(f"Giant Component Size: {giant_component_size}")
print(f"Total Nodes in S: {total_nodes}")
print(f"Ratio of Nodes in Giant Component to S: {ratio}")

print()
```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6. Steps required to pass information to the maximum number of nodes in S.

- **We have combined the part a) and part b) of the question i.e for each value of p we calculated the average number of steps required by**

performing the experiment 10 times-

```
for probababílity 0.25  =   1472.1
for probababílity 0.5  =   1924.9
for probababílity 0.75  =   1335.1
for probababílity 1  =   999.0
```

- **Conclusion -**

As every node will get one chance to pass information to its neighbors, with lower probability steps for information to reach the maximum number of nodes will be greater ,with increasing probability steps will decrease. But when probability is very low, steps again decreases as number of nodes susceptible to information will be far more compared to higher probabilities.

REFERENCES