JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

TARGET CONTROLLABILITY APPLICATIONS ON WATER DISTRIBUTION NETWORK

[1]S.V.S. Santhi and [2]Lumbini Devi. D

[1]Professor, [2]Cyber security Analyst
[1]Department of Computer Science and Engineering,
[1]Sri Venkateswara College of Engineering and Technology, Etcherla, Srikakulam, Andhra Pradesh, India.

***Abstract**:* In the real-world scenario, infrastructure systems or networks like Water Distribution Networks (WDN) plays major role in public safety and protection of health which results in critical infrastructure protection. The drinking water supply system network comprises of nodes (junctions) and links (pipes). It is a Critical Infrastructure in the sector of water and waste water systems. Drinking water is a primary need of the public. The drinking water supply system network is a complex network system, executed and maintained by the Government organizations. The maintenance of the water supply system is very critical and complex. Hence there arises the need to protect the existing real world network to supply drinking water to the public. For the same reasons, it is essential to control the WDN using control theory. Former studies concentrated on driver nodes' or critical nodes' identification using maximum matching concept. The controllability of complex network is critical in numerous applications. Controlling large infrastructure networks is an exquisite challenge. Ways of controlling a small fraction of target nodes is a usual task in numerous real control scenarios. Existing works present algorithms to discover the driver nodes used to control partial nodes of the network. Here, we present a novel algorithm WDNTC (Target Control for Water Distribution Networks), to find optimum count of driver nodes for the purpose of target node control. WDNTC algorithm shows efficient results for both synthetic data and real-world WDN.

Index Terms **- Driver nodes, Infrastructure network, Target control, Water distribution network.**

I. INTRODUCTION

Complex networks are the real-world systems which play a major role in the technical and infrastructure regions. Hence it is important to control these networks. A system is controlled to any desired state from any initial state in given time using control theory [1-3]. For this controllability driver nodes are used to input the external signals [4]. However, in a large number of real-control scenarios, controlling is necessary only for a small fraction of nodes. These nodes are called target control nodes [5]. In order to locate driver nodes for controlling particular target nodes, current works [5] convey an analysis framework for the process of investigating target control of complex network.

The traditional framework of network control is only applicable for the simple networks. It cannot inscribe large scale of network's target control problem. For solving the same, Lin Wu.et.al [6] has initiated a weighted bipartite network to overcome the target control problem [10]. This method might not work in case of no perfect matching in many of the cases. Meantime, Gao et al. [5] initiated another procedure for target controlling the networks by approximating minimum set of input nodes [5]. Still, the focus was only on controlling the system using any minimal driver-node set, ignoring the possibility of numerous candidate driver node sets corresponding to a targeted subset of the network.

Complex networks are strong tools for designing dynamic systems [4][7][8]. In real-world networks, target controllability problem is a specific instance of output controllability problem [9], [10]. Lately, the authors in [11][12] suggested constraints for strong target controllability by utilizing zero-forcing sets. Complex networks are strong tools for designing dynamic systems [4][7][8]. In real-world networks, target controllability problem is a specific instance of output controllability problem [9], [10]. Lately, the authors in [11][12] suggested constraints for strong target controllability by utilizing zero-forcing sets.

II. PROPOSED METHOD

The suggested approach identifies the driver nodes for specified target nodes of the network. Initially, it accepts the network in the form of adjacency matrix and selects randomly the target nodes as input, then finds the parent nodes for each target node. Using bipartite representation it finds the count of each node frequency of the bipartite graphs. Then, these frequencies are sorted in ascending order of their count. Finally, by back-tracking is we identify the optimal count of driver nodes which will control the target nodes specified. The proposed system is represented using a block diagram in figure 1.

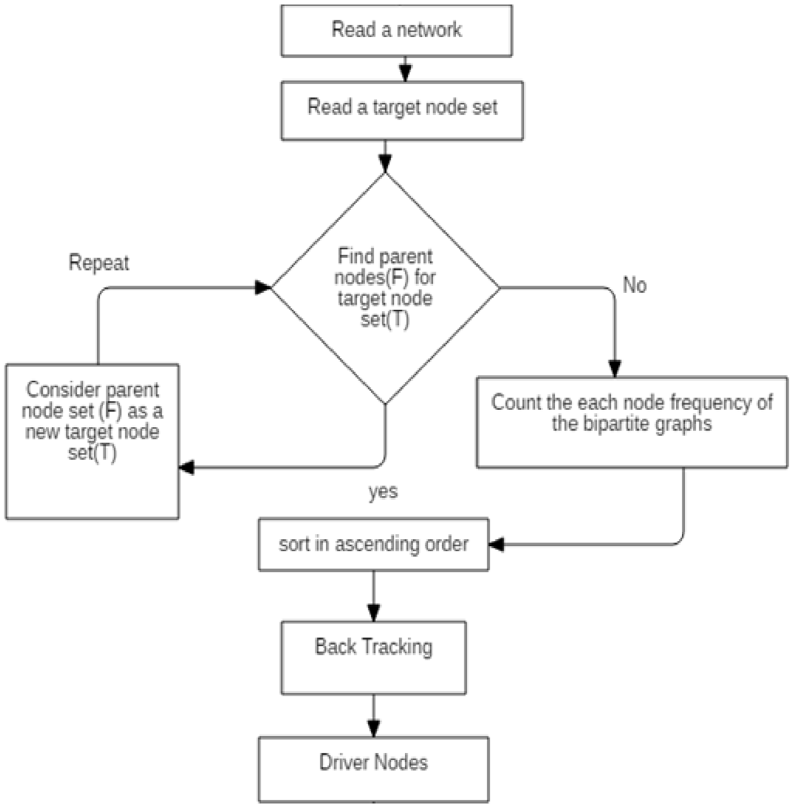

Figure 1. Block Diagram of the Proposed Method

The proposed method is explained by considering a sample directed network. It consists of six nodes. The directed edges between the nodes are represented in the figure 2. The detailed procedure is described as follows

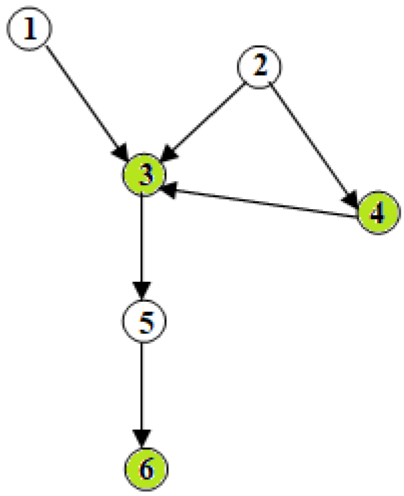

Figure 2. Example Directed Network

0	**0**	**0**	**0**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**
1	**1**	**0**	**1**	**0**	**0**
0	**1**	**0**	**0**	**0**	**0**
0	**0**	**1**	**0**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**

In the second step, we select randomly the target nodes needed to be controlled by driver nodes. The count of target nodes is three. We choose 3, 4, 6 as target nodes randomly.

In the third step, we have to identify the parent nodes of the selected target nodes and also remove repeated nodes. Whereas in the fourth step, parent nodes found in the step 3 will be replaced as new target nodes. This operation will be repeated until no parent node is found. The representation is as follows.

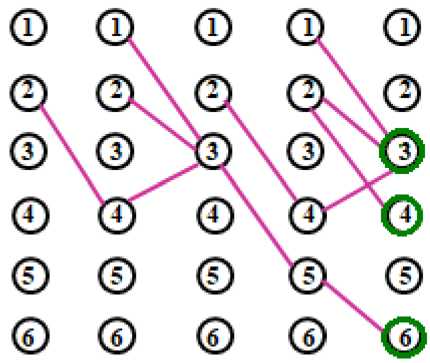

Figure 3. Backtracking the Target Nodes to Present Parent Nodes

Backtracking the target nodes until no parent nodes are found is performed. The parent nodes in each iteration are {[3, 4, 6]; [1, 2, 4, 5]; [2, 3]; [1, 2, 4]; [2]}.

In the step 6 and 7, count the frequency of nodes and sort them in ascending order using an array.

Table 1. Node Frequency Count in Sorted Order

Count	Node
4	2
3	4
2	3
2	1
1	5
1	6

In the next step, we find maximum matching edges as {2→4, 3→5, 4→3, 5→6} and in the final step the driver node with node id 2 will be the output and is represented as follows

Maximum Matching Edges: {2→4, 3→5, 4→3, 5→6}

Driver Nodes: {[2]}

Algorithm: WDNTC: Water Distribution Network Target Control

1. Read a n*n matrix[A] i.e., directed network.
2. Read an array of size m i.e., target node set[T].
3. Identify the parent node set[F] & remove repeated nodes for target node set[T].
4. Let us consider the parent node set[F] as a new target node set[T].
5. Repeat step 3 & 4 until no parent node set is found for target node set.
6. Count the frequency of each node.
7. Sort nodes in ascending order and place it in an array[Q].
8. Find the maximum matching for every bipartite graph based on the order of nodes in Q.
9. Find driver nodes are found as output.

III. Results

In this section, we exhibit the experimental results on real-world directed Water Distribution Network of Bheemili, Visakhapatnam in Andhra Pradesh. It consists of 40 nodes and 40 edges. The WDN is known as directed when the flow in the network is open. The directed WDN is considered as an input which is shown in the figure.4.

The input for the network shown in figure.4 is considered as 40*40 matrix as in figure 5. The count for the target nodes generated is 3 and the three target node ids are 2, 5, and 6.

Now perform the back tracking operation for the WDN target nodes 2, 5, 6 to find the parent nodes until no parents are found. The parent nodes for target nodes for WDN are

{[2, 5, 6]; [5, 6, 9]; [6, 9, 10]; [9, 10, 14]; [10, 14, 16]; [14, 16, 19]; [16, 19, 20]; [19, 20, 21]; [20, 21, 22]; [21, 22, 23]; [22, 23, 25]; [23, 25]; [25]}

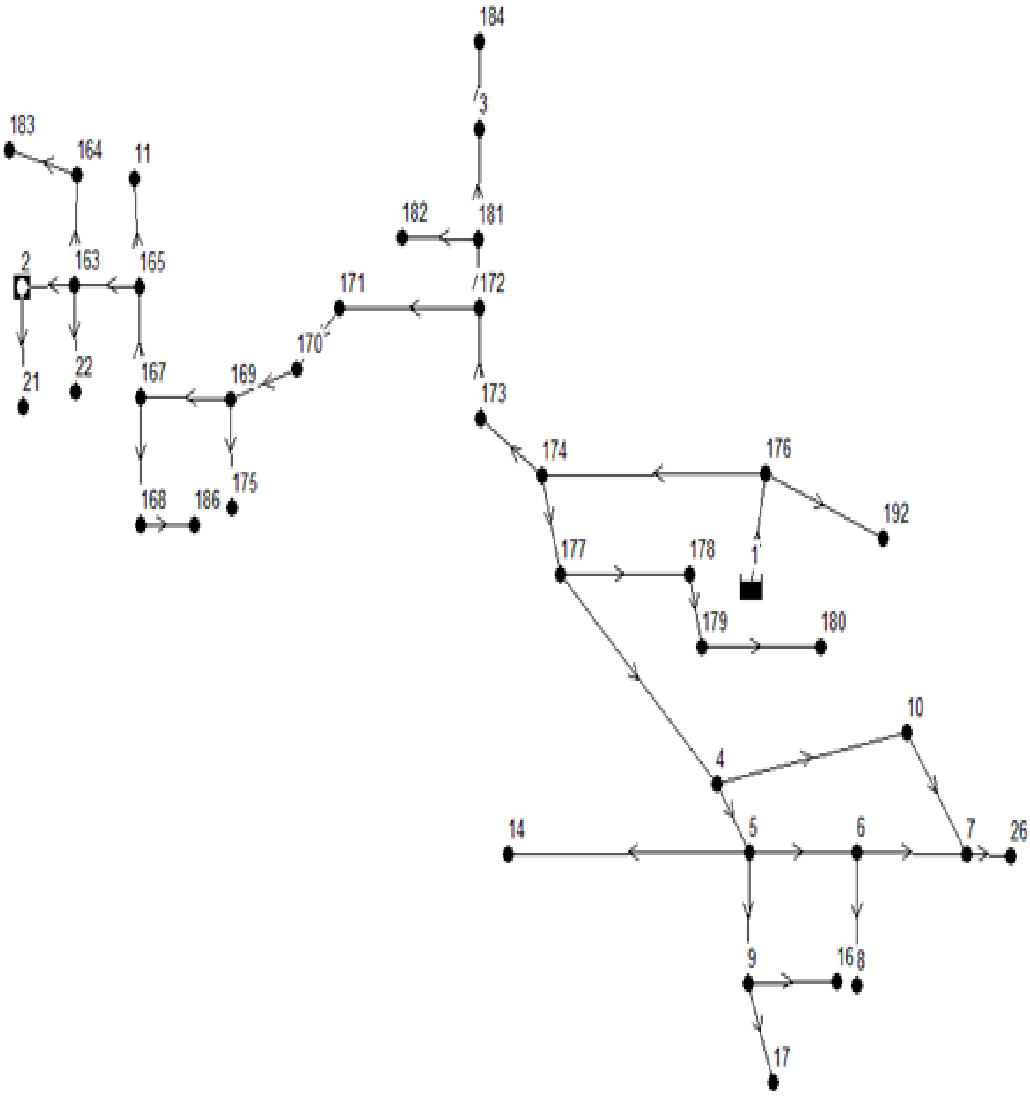

Figure 4. Input Network

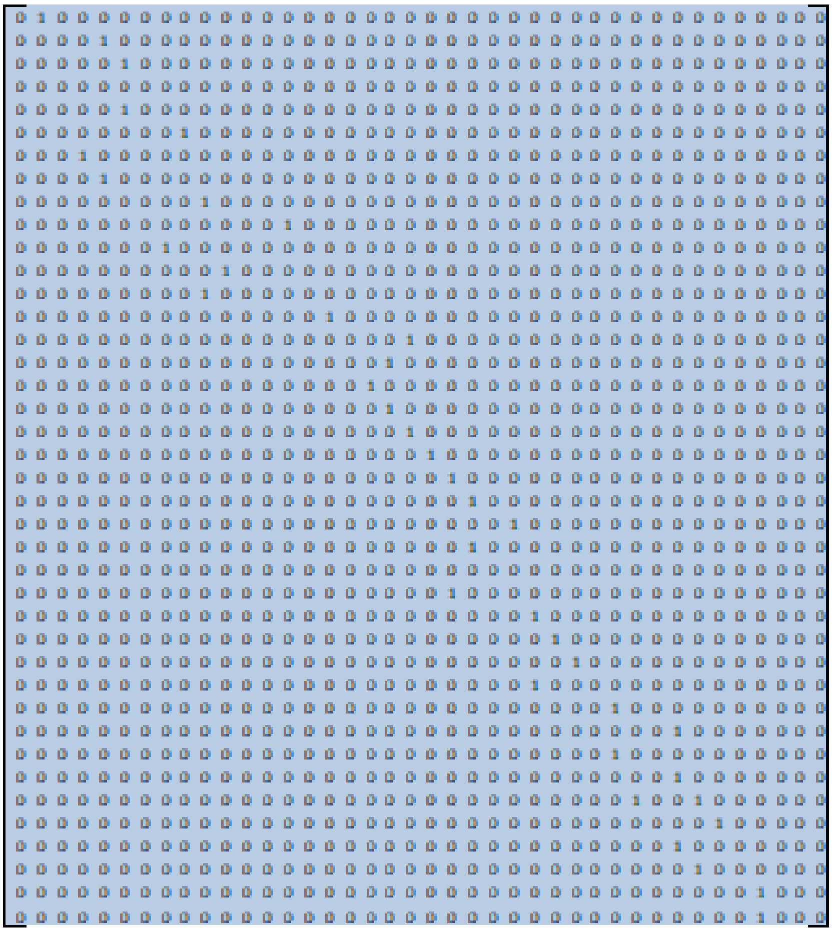

Figure 5. Matrix 40*40 Representation of WDN

Table 2. Node Ids and their Frequency Count as Parent Node

Count	Node-Id	Count	Node-Id	Count	Node-Id	Count	Node-Id
3	6	3	25	0	8	0	31
3	9	2	5	0	13	0	32
3	10	1	2	0	3	0	33
3	14	0	4	0	24	0	34
3	16	0	15	0	11	0	35
3	19	0	12	0	26	0	36
3	20	0	17	0	27	0	37
3	21	0	18	0	28	0	38
3	22	0	1	0	29	0	39
3	23	0	7	0	30	0	40

The maximum matching edges found for the real-world WDN are
{16→14, 19→16, 20→19, 5→2, 21→20, 6→5, 22→21, 23→22, 9→6, 25→23, 10→9, 14→10}

From the above details we will get the driver node which will control the target nodes of WDN (2, 5, 6) is node [25]. From the above results, it is clear that the WDNTC algorithm will identify the controlling node i.e driver node to maintain the safety of the water distribution network and to control the specified target nodes. It is very useful to maintain the WDN in a safe and smoother way. The WDNTC algorithm code is developed in java takes the file input and gives the following output which is shown below as in figure 6.

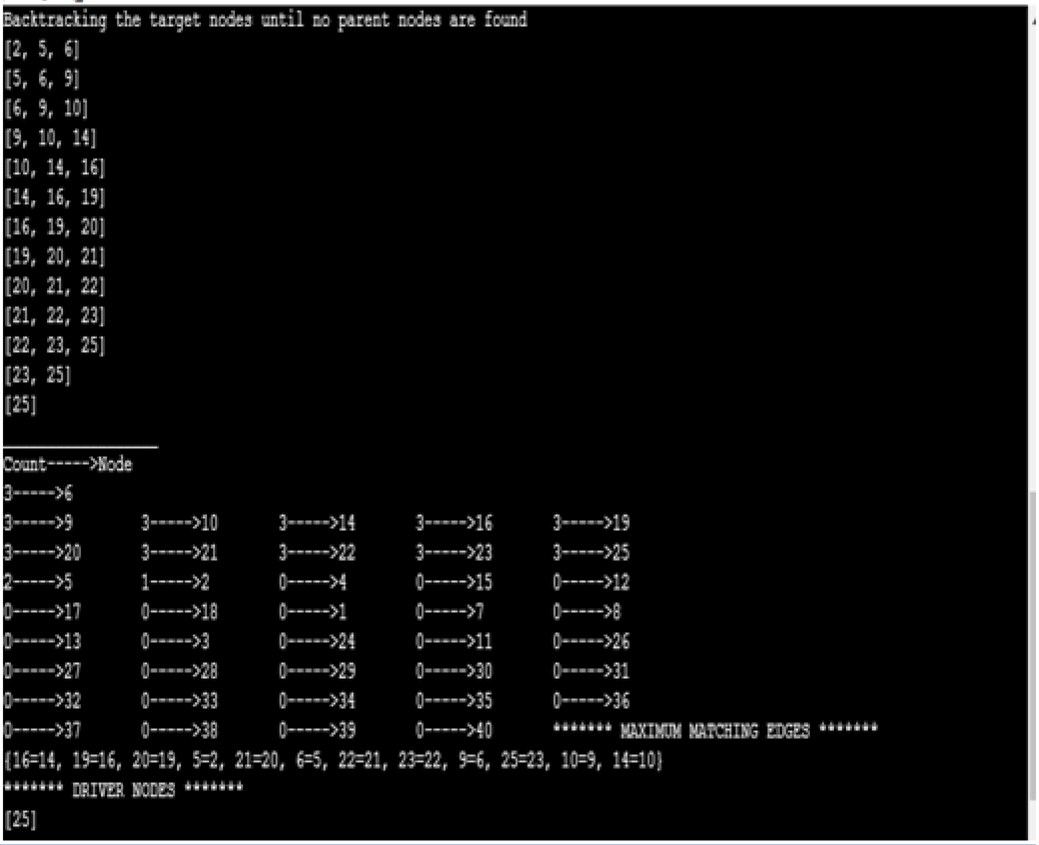

Figure 6. Output for the WDNTC Algorithm

IV. Conclusions

In this paper, we proposed WDNTC algorithm to maintain the water distribution network in safe, smooth and secured way. WDN is a real-world network and also complex hence it needs regular inspection and maintenance. For these reasons, it should be controlled by optimized number of driver nodes to reach target nodes. Hence, by selecting target nodes randomly we identify the controlling nodes which are also known as driver nodes by applying greedy algorithm for back-tracking to get parent nodes. Finally, the algorithm will help in identifying the optimum count of driver nodes which will control the flow to reach the target nodes. In this work, single node is identified to control the entire network to reach the flow to target nodes. The WDNTC takes up a major part in managing the water distribution networks safely and securely in an efficient manner.

REFERENCES

[1] Kalman, R.E. 1963, Mathematical Description of Linear Dynamical Systems, Journal of the Society for Industrial & Applied Mathematics, 1(2)**:** 152-192.
[2] Luenberger, D.G. 1979, Introduction to Dynamic Systems: Theory, Models, & Applications. Proceedings of the IEEE,. 69(9): 1173.
[3] Slotine, J.J.E. and W. Li. 2004, Applied nonlinear control, China Machine Press.
[4] Liu, Y.Y., J.J. Slotine, and A.L. Barabasi. 2011, Controllability of complex networks. Nature, 473(7346): 167-173.
[5] J. Gao, Y.-Y. Liu, R. M. D'souza, and A.-L. Barab´asi. 2014,Target control of complex networks, Nature communications, vol. 5:5415.
[6] Lin Wu, Min Li, Jian-Xin Wang, Fang-Xiang Wu. 2019, Controllability and Its Applications to Biological Networks, Journal of Computer Science and Technology, 34(1): 16-34.
[7] N. J. Cowan, E. J. Chastain, D. A. Vilhena, J. S. Freudenberg, and C. T. Bergstrom. 2012, Nodal dynamics, not degree distributions, determine the structural controllability of complex networks, PloS one, 7(6): 38398.
[8] F. Pasqualetti, S. Zampieri, and F. Bullo. 2014, Controllability metrics, limitations and algorithms for complex networks, IEEE Transactions on Control of Network Systems, 1(1): 40–52.
[9] I. Petre. 2016, Target controllability of linear networks, in Computational Methods in Systems Biology: 14th International Conference, CMSB 2016, Cambridge, UK, September 21-23, , Proceedings, vol. 9859: 67. Springer.
[10] K. Murota and S. Poljak. 1990, Note on a graph-theoretic criterion for structural output controllability, IEEE Transactions on Automatic Control, vol. 35(8):939–942.
[11] N. Monshizadeh, K. Camlibel, and H. Trentelman, "Strong targeted controllability of dynamical networks", in Decision and Control (CDC), 2015 IEEE 54th Annual Conference on. IEEE, **(2015),** pp. 4782–4787.
[12] H. J. van Waarde, M. K. Camlibel, and H. L. Trentelman. 2017, A distance-based approach to strong target control of dynamical networks, IEEE Transactions on Automatic Control, 62(12):6266–6277.