Computational Modelling and Simulation of Core-Periphery Terrorist Network

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Abstract - Terrorism and terrorist organizations are becoming more vulnerable nowadays. Understanding the terrorism and the organizational structures of terrorist networks are most important to devise successful defensive strategies against the terrorist activities. Terrorist organizational network is a real world complex system which is the association of numerous entities and has significant structural features. Core-Periphery terrorist network structure is one type of terrorist organizational structure which favours when the network members are very few to achieve the task. This paper presents Core-Periphery Terrorist Network (CoPTeN) model to synthetically simulate the core-periphery terrorist network structure based mainly on the preferential growth feature of complex networks. The structural characteristics of this model were analysed and discussed elaborately. As this model simulates the Core-Periphery terrorist network structures with imprecise inputs, it can help the anti-terrorism agencies by giving more insight into the structure of terrorist network to develop effective dismantling strategies against terrorist networks.

Keywords: simulation, terrorist network, organizational structures, computational modelling, core-periphery.

1 Introduction

Networks are widely used to describe most natural phenomena and this can be defined as a collection of vertices and edges between vertices. These edges can be directed or undirected, and weighted or un-weighted. Entities in a social context and the relationship between them can be represented as a social network. Graphs are used to visually represent the social network. Complex networks are conceptualized as a set of entities intermingled in certain fashion and with significant characteristics. To construct these complex networks in order to analyse them, theory of networks is used predominantly. Violent acts which brings fear in to the people is called terrorism; nowadays terrorism becoming a serious threat to the human life. Terrorist networks are social networks with lot of secrecy about the connectivity and membership in the network.

Core-Periphery Terrorist Network (CoPTeN) structure is an existing configuration of terrorist organizational forms. Many economic and social networks also exhibit this core-periphery structure. Core-Periphery network structure is defined as alliance of two set of vertices namely core and peripheral, in which core is a small sized and heavily connected network and peripheral is big sized and loosely connected network[1]. Previously no terrorist network structures were taken into account to analyse and get an insight into it, in order to frame effective dismantling strategies. But terrorist organizations use the various network structures for better security and efficiency in operations.

In the following discussion, various works in simulation and analysis of core-periphery terrorist network structure are presented. Basic Core-Periphery network model was developed based on the characteristic definition of core and periphery nodes. Core network is formed by highly interconnected actors and periphery is formed by loosely interconnected actors[2]. Basic model of Core-Periphery[2] was enhanced by employing information measures which exhibits great degree of coherence and accuracy in developing core-periphery network[3].Core-Periphery model with randomness was developed in which probability values differ for connectivity between core nodes, peripheral nodes and between core-periphery nodes[4].

Measure to analyse the dichotomy of Core-Periphery structure was proposed and the findings suggested that the Core-Periphery structure of social networks was weak when compared to geographical networks[5].Studies in Core-Periphery structure revealed that this complex network lies in between several extreme properties like random/condensed structures and hierarchy/anti hierarchy structures. These high complex properties ensures the robustness of Core-Periphery structure[6].The basic assumptions reflected for this research work were; the actors in the network are dependent on each other and not autonomous when making decisions; the interactions that the edges denote are pathways for the flow of resources; the structure of the network affords opportunities or restrictions on the actions of the actors; the network represents lasting ties among the actors [5].

Based on the above literature investigation, the Core-Periphery structure exists in different complex network types like economic, transportation, geographical and social networks differs in their characteristics was observed. The
Core-Periphery structure involved in terrorist organizational structure was analysed in real time networks to find the core and periphery nodes respectively. In literature no model has been proposed to simulate Core-Periphery structure exists in terrorist networks and analysed its structural features. The objectives of this research work are to model Core-Periphery structured terrorist network and analyse its structural characteristics.

The remaining structure of the paper is arranged to explain the proposed framework of CoPTeN model. The following section presents the principal model with the use of the algorithm. The later section presents the detailed results of the proposed CoPTeN model and discusses the simulated Core-Periphery terrorist network results. Finally, this paper concludes by mentioning the future enhancements that could improvise the CoPTeN model.

2 CoPTeN Model

Terrorist networks organize themselves into a suitable organizational structure based on the secrecy/efficiency trade-off. Understanding of the dynamics of terrorist organizational structure helps to dismantle them effectively. When the secrecy is given higher priority the Core-Periphery structure is adopted by the terrorist organizations. Hezbollah terrorist group has adopted this core-periphery structure for its operations. Core-Periphery structure can also act as a sub network of a terrorist group in which hybrid more than one network structure is in practice. General patterns of core-periphery network structure witnessed in terrorist networks are listed below.

- Security is given importance more than efficiency [7]
- Core members are densely connected to one another and peripheral members are connected to the core. No connectivity exists in between the peripheral nodes [8]
- Generally the core-periphery structure evolves from multiple hub-spoke structure, which in turn evolved from scattered clusters.[9]
- Insulator members exists in between core and peripheral members, which distant the core member from rest of the network [10]

The following algorithm describes the simulation of Core-Periphery terrorist network simulation based on the general patterns listed above. In that the inputs taken are the number of nodes in the network (N), number of links to be imposed in the simulated network (L) and node density of the core part of Core-Periphery network to be simulated (Cr).

This model basically constructs a random seed network with specific percentage of hub nodes out of core network nodes, then gives this seed to preferential growth procedure, in which the core network is constructed with preferential attachment and growth as the basic evolution stimulants. The generated core network is then analysed to find the potential leaders and insulators. These leaders are the nodes with maximum degree connectivity and the insulators are direct neighbors to these leaders and who can make the core leaders distant from the peripheral nodes and keep the core leaders secure. The procedure create_vertex(x) creates a vertex instance with 'x' as the index.

Algorithm: CoPTeN Model

Input: Network Size (N), Links(L) and Coreness Ratio (Cr)
Output: Core-Periphery Network Instance
Procedure RandomGraph(n)
Begin
For i=1 to n do
    v ←create_vertex(i)
    V(G) ←V(G)U{v}
End for
repeat
    Choose random vertex pair (v,u)
    Generate random number θ ∈ [0,1]
    If θ<p then
        E(G) ←E(G)U{(I,j)}
        n ← n-1
    Until n>1
End

Procedure EvolvePreferentialGrowth(G,LpE,vc)
Begin
    v ←create_vertex(vc)
    V(G) ←V(G)U{v}
    For edgecount=1 to LpE
        Repeat
            Choose vertex pair (v,u) & (v,u)∈ E(G)
            \Psi= (\text{degree}(u)+1) /((|E(G)|+|V(G)|)-1)
            Until (\Psi>p)
            E(G) ←E(G)U{(u,v)}
        End for
    End
End

3 Results and Discussions

Simulation experiments were performed using the above algorithm for a variety of parameter constellations. Experimenting in any combination with N in the range of [30,1000], link density in the range of [0,1] intern L in the range of thousands of links, Cr in the range of [0,1]. Results of these simulation experiments are adjacency matrices of the constructed network instances. The sample simulated Core-Periphery network with N as 100 nodes, L as 990 and Cr as 0.6 is shown in Figure 1. The red, blue and black coloured nodes are leaders, insulators and member nodes respectively in Figure 1.

Figure 1. Sample Simulated Core-Periphery Network

3.1 Structural Characteristics of COPTEN Model

Dynamics of complex networks are generally analysed in terms of the following structural measures. (a) Scale free degree distribution, (b) Small world and (c) Community Structure.

The following section exhibits the structural measures of CoPTeN model derived through extensive simulation experiments.

Scale Free Degree Distribution:

One of the common features that exist among the real world complex networks is the presence of large percentage of nodes with very few links(degree) and very few nodes which has links to many other nodes in the network. This distribution follows power law degree distribution. Power law degree distribution of the undirected network is described as follows,

\[ P_{deg}(k) \propto k^{-\gamma} \]  

Where \( \gamma > 0 \) is the power law exponent which is some constant and \( \propto \) denotes asymptotically proportional to as \( x \to \infty \).

Figure 2. Sample Power Law Degree Distribution of CoPTeN Model

The Figure 2, clearly shows that the CoPTeN model follows power law degree distribution. CoPTeN model evolve the network from a randomly generated seed network with
premeditated number of hubs to induce the leadership in the evolving network. This process is followed with a preferential growth mechanism, which will make these hubs as attractive nodes to get linked with the new nodes whichever coming into the network. This sequence of processes made the degree distribution to follow the power law inturn scale free degree distribution. The power law exponent is one way of endorsing the power law degree distribution of a complex network. Power law exponent of the CoPTeN model is given for various network sizes in Figure 3. Power law exponent of this proposed CoPTeN model falls within the maximum value of 3 frequently. It clearly shows that the CoPTeN model exhibits power law degree distribution.

Small World Property:
Diameter and Average path length are the measures to capture the small world property in complex networks. These terms describe the degrees of separation in the network. The longest path among the shortest paths from each node to every other node in the network is called as the diameter of the network.

$$\text{Average Path Length} = \log_{\text{coresize}} \text{network size} + 1$$  \hspace{1cm} (2)$$

Community Structure:
A community is usually considered to be a set of nodes where each node is closer to the other nodes within community than to nodes outside it. Widely used measure for community structure is clustering coefficient; it measures the clumpiness of a graph and has relatively high values in many graphs.
The Figure 6, shows the average clustering coefficient of the proposed model, it shows that the CoPTeN model clusters well the nodes in the network as there is an increase in the network size and number of links, the clustering coefficient increases. This demonstrates the existence of community effects in the CoPTeN model.

### 3.2 Simulations Results

The characteristics of any simulation model in complex systems are best understood when it is compared with the pioneer benchmark network evolution models Erdos-Renyi(E-R) model and Barabasi-Albert(B-A) model[11,12]. The following Table I, compares the basic network measures of the proposed CoPTeN model with Erdos-Renyi and Barabasi-Albert model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Network Size (N)</th>
<th>Links Count (L)</th>
<th>Diameter</th>
<th>Average Path Length</th>
<th>Average Betweenness Centrality</th>
<th>Average Eigenvector Centrality</th>
<th>Average Closeness Centrality</th>
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<tr>
<td>CoPTeN Model</td>
<td>125</td>
<td>1716</td>
<td>4</td>
<td>2.40</td>
<td>0.089</td>
<td>0.003</td>
<td>0.008</td>
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<tr>
<td></td>
<td>285</td>
<td>10760</td>
<td>4</td>
<td>1.95</td>
<td>136.144</td>
<td>0.0018</td>
<td>0.0035</td>
</tr>
<tr>
<td></td>
<td>355</td>
<td>15673</td>
<td>4</td>
<td>2.05</td>
<td>219.187</td>
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<td>0.0028</td>
</tr>
<tr>
<td></td>
<td>465</td>
<td>26502</td>
<td>4</td>
<td>2.31</td>
<td>304.763</td>
<td>0.0009</td>
<td>0.0022</td>
</tr>
<tr>
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</tr>
<tr>
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<td>447.302</td>
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<td>0.0015</td>
</tr>
<tr>
<td></td>
<td>755</td>
<td>38570</td>
<td>4</td>
<td>2.36</td>
<td>514.885</td>
<td>0.0006</td>
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<tr>
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<td>1.86</td>
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<td>327.254</td>
<td>0.0007</td>
<td>0.0021</td>
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</table>

From the above Table I, it is clear that the diameter and average path length of the CoPTeN model is high when compared to the E-R and B-A models of comparable sizes. The reason behind this increased diameter and average path length is the deployment of insulator node inbetween the peripheral and core nodes, to make the core leaders distant. Average betweenness centrality of CoPTeN model is high when compared to E-R model and B-A model of comparable sizes, it shows the dominance of hubs i.e. core leaders and insulators in the CoPTeN model, as the betweenness centrality is a measure of the extent to which the nodes being a point of communication in the network.

E-R & B-A model possess the high eigven vector centrality when compared to the CoPTeN model as shown in the above table. As there are few hubs which are the base for making well connected communities in the B-A model, the eigen vector centrality is high when compared to the CoPTeN model. Where as in CoPTeN model to make the core leaders distant from the peripheral nodes, insulators are used, hence the eigen vector centrality is low when compared to more reachable B-A and E-R model. Average closeness centrality is the inverse of distance measure, which inturn depicts how close a node is from all other nodes in the network. B-A model generates scale free graph with notable number of hubs, hence
it can reach every node from every other node, the closeness centrality of this model is high when compared to the CoPTeN model. The E-R model possesses low closeness centrality when compared to the CoPTeN model as there are no significant hubs (leaders) in it.

4 Conclusion

The model presented in this paper simulates the Core-Periphery organizational structure of terrorist organizations based on the building block of Core-Periphery terrorist network structure found from broad literature and based on the properties of complex networks. The structural properties and measures of the proposed model are derived on top of extensive simulation experiments and the results confirmed the proposed model synthetically generates the core-periphery structure of terrorist networks with significant features. The proposed model simulates the Core-Periphery network based on the random seed graph solely nonetheless the role of the seed in altering the structural properties of the simulated network. The significance of random seed graph in this proposed model can be analysed further in detail.

5 References