Chapter 8 Improving C2 Effectiveness Based on Robust Connectivity

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ABSTRACT

This chapter describes an approach to develop an improved metric for network effectiveness through the use of Cares' (2005) Information Age Combat Model (IACM) as a context for combat (or competition) between networked forces. The IACM highlights the inadequacy of commonly used quantifiable metrics with regards to comparing networks that differ only by the placement of a few links. An agent-based simulation is used to investigate the potential value of the Perron-Frobenius Eigenvalue (λ_{PFE}) as an indicator of network effectiveness. The results validate this assumption. Another measurement is proven to be equally important, namely the robustness of a configuration. Potential applications from the domain of ballistic missile defense are included to show operational relevance.

INTRODUCTION

The application of network theory enables us to investigate alternatives to the traditional hierarchical organizations of Command and Control (C2) processes and systems. Traditional hierarchical organizations were the result of centralized command and control cultures and the significant costs, both in time and money, of distributing the necessary information to enable sound decisionmaking. The increased desire for peer-to-peer negotiation and self-synchronization and the incredible reduction in these costs during the past decade has made non-hierarchical organizations viable alternatives. It also introduced a significant challenge: what should we measure to determine which organization can be more effective?

The effectiveness of a C2 network is more than just the sum of its nodes and arcs, which can be measured by the link-to-node ratio (l/N). A maximally-connected network, where every node is connected to every other node (i.e., l =(N-1)!), not only remains prohibitive in monetary cost; it is undesirable due to the inability of a node to manage or process the overwhelming information flow represented by the arcs. However, a minimally-connected network may not be desirable due to either insufficient capability or capacity or an increased vulnerability of the network. Additionally, the link-to-node ratio metric cannot discriminate between alternative network organizations that have the same numbers of nodes and links, but differ solely in their arrangement. The mere counting of a link does not account for its significance, or lack thereof.

The *degree distribution* metric is a measurement of whether the number of links connected to each node is uniformly distributed throughout a network. Adaptive, complex networks have a small number of highly connected nodes (i.e., a skewed degree distribution). Such highly connected nodes can be clustered together or can be distanced from each other, and is expressed as a clustering coefficient calculated from the proportion of a node's direct neighbors that are also direct neighbors of each other. This represents a measurement of a network's cohesion and selfsynchronization. The characteristic path length is a related metric, and is measured as the median of the mean of the lengths of all the shortest paths in the network. While these metrics begin to account for link significance, they are insufficient in discriminating between network configurations that vary in the placement of just a single link.

Jain and Krishna (2002) introduced the relationship between the Perron-Frobenius Eigenvalue (λ_{PFE}) of a graph and its autocatalytic sets, and used graph topology to study various network dynamics. Cares (2005) employed a similar approach to describe combat (or competition) between distributed, networked forces or organizations. His Information Age Combat Model (IACM) focused on the λ_{PFE} as a measure of the ability of a network to produce combat power. Cares proposed that the greater the value of the λ_{PFE} , the greater the effectiveness of the organization of that networked force.

Deller, et al (2009, 2012) confirmed this proposal by constructing an agent-based simulation that enabled networked organizations to compete against each other in the context of Cares' IACM. The results of the agent-based simulation indicated that the value of the λ_{PFE} was a significant measurement of the performance of a networked force. However, the effectiveness of the λ_{pere} measurement was dependent on the existence of unique $\lambda_{_{PFE}}$ values for the configurations under consideration. When alternative organizations had a shared λ_{PFE} value, additional measurements were required to enable discrimination. Of the additional metrics considered, robustness proved the most effective in improving the value of the λ_{PFF} as a quantifiable metric of network performance. Ultimately, the best indicator of network effectiveness was a metric that combined both the λ_{PEE} and robustness values.

THE INFORMATION AGE COMBAT MODEL

Cares designed the IACM to facilitate his investigation into how a networked force organizes. It is not intended to be a combat simulation or a tool to test weapon platforms. Instead, the basic objects of the IACM are generic nodes defined by the simple functions they perform, not by any performance specifications they were built or designed to. For example, Sensor nodes receive signals about observable phenomena of other nodes in the model. The types of signals received are not relevant; just that the Sensor "sensed" something about that node and passed that information on to a Decider node. 13 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage: www.igi-global.com/chapter/improving-c2-effectiveness-based-on-robustconnectivity/109737

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