Physica A 469 (2017) 572–587

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

An efficient link prediction index for complex military organization

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HIGHLIGHTS

- For the first time, we quantify the nodes' types effect on their linking behaviors, and empirically proved that it could remarkably improve the prediction accuracy of 25 current methods.
- We design a new link prediction index for heterogeneous military network and it is superior to all the other methods both in missing links prediction and spurious links identification tasks.
- We investigate the algorithms' robustness under noisy environment, and demonstrate that our method maintains the best performance under the condition of small noise.

ARTICLE INFO

Article history:
Received 23 June 2016
Received in revised form 27 August 2016
Available online 18 November 2016

Keywords:
Complex military organization
Link prediction
FINC-E model
Social organization

ABSTRACT

Quality of information is crucial for decision-makers to judge the battlefield situations and design the best operation plans, however, real intelligence data are often incomplete and noisy, where missing links prediction methods and spurious links identification algorithms can be applied, if modeling the complex military organization as the complex network where nodes represent functional units and edges denote communication links. Traditional link prediction methods usually work well on homogeneous networks, but few for the heterogeneous ones. And the military network is a typical heterogeneous network, where there are different types of nodes and edges. In this paper, we proposed a combined link prediction index considering both the nodes' types effects and nodes' structural similarities, and demonstrated that it is remarkably superior to all the 25 existing similarity-based methods both in predicting missing links and identifying spurious links in a real military network data; we also investigated the algorithms' robustness under noisy environment, and found the mistaken information is more misleading than incomplete information in military areas, which is different from that in recommendation systems, and our method maintained the best performance under the condition of small noise. Since the real military network intelligence must be carefully checked at first due to its significance, and link prediction methods are just adopted to purify the network with the left latent noise, the method proposed here is applicable in real situations. In the end, as the FINC-E model, here used to describe the complex military organizations, is also suitable to many other social organizations, such as criminal networks, business organizations, etc., thus our method has its prospects in these areas for many tasks, like detecting the underground relationships between terrorists, predicting the potential business markets for decision-makers, and so on.

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http://dx.doi.org/10.1016/j.physa.2016.11.097
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1. Introduction

With the rapid development of information technology and military science, the state-of-art complex military organization named "System of System, SOS" has been playing an increasingly significant role in nowadays' warfare, disaster response, nation building, peace operations and counter-terrorism [1]. The complex military organization is often formed as a complex network, where nodes represents functional entities that are themselves complex, edges denotes various kinds of communication relationships, functional entities interact with each other to obtain the common shared goals [2].

Modeling complex military organization is a challenging task, due to the following three reasons. One is the complexity of the functional entities, these numerous entities are distributed in the multi-dimensional physical space, such as land, ocean, inner space, outer space, electromagnetic space and cyberspace, and in the virtual space like information space, cognitive space and social space; second is the complexity of dense, real time, and frequent relationships between entities, making the whole system nearly seamless; the last is that nearly all entities are involved with human, to model the human-level adaptability is very hard. Despite the above problems, there are still some inspiring works which motivate a more accurate model. Alberts et al. [3] pointed out the integrative system should produce and utilize the information superiority, and integrate the Command and Control units, weapon system and forces effectively to improve the ability of information sensing, intelligence sharing and coordination. In 2011, he proposed the concept of "Edge Organization" [4], and proved its agility advantages on the basis of complex military organization. Inspired from the recent advances of network science, network is confirmed to be an useful tool, which reflects the import characteristics of military organization model. These network models for military organization are not simply recognized as a communication network, but complex networks including command and control, society, environment, weapon, radar, etc [5]. Cares [6], Carley [7] and Krackhardt [8] all attempt to build network models to complex military organizations, however, their proposed nodes and edges are all homogeneous, which is not reliable in reality. Dekker [9–12] put forward the FINC model, and depicted the heterogeneous nodes, which shed new lights on the complex military organization. And Guoli Yang [13] added the heterogeneous edges in FINC model, and proposed an extended FINC model, named FINC-E, with weighted functional nodes and edges.

FINC (Force, Intelligence, Networking and C2) methodology classified the nodes into three types: C2 node (C2), like command post, control center, etc., Intelligence node (I), like radar, AWACS, etc., and Force node (F), like missile position; and links provide communications between nodes, indicated by lines or arrows, depending on whether information flow is bidirectional or unidirectional. Fig. 1 is an illustration for FINC model, where circle nodes represent C2 nodes, square nodes denote force nodes, triangle nodes indicate intelligence nodes. In FINC-E model, there are five types of links, Intelligence link ($I \rightarrow C2$, unidirectional), C2 link ($C2 - C2$, bidirectional), Fire link ($I- > F$, unidirectional), Decision link (C2-F, bidirectional) and Communication link (I–I, bidirectional). Each node has many attributes, like attack cost, InEdge, OutEdge, etc., each link also has attributes, such as information transfer delay, information load, information accuracy, attack cost, InNode, OutNode, etc. More details see in Ref. [13]. In this paper, FINC-E model is utilized to model the complex military organization.

As for the problem of link prediction, it was originated from computer science study, also known as link mining, and has been studied for a long time. Recent researches about link prediction on complex network [14] have drawn much attention, since it utilizes structural information only, and obtains satisfactory performance. Link prediction on complex network attempts to estimate the likelihood of the existence of links between nodes based on the attributes of nodes as well as the structure of networks [15,14,16]. It is divided into three categories, one is predicting missing links, i.e., existent yet unknown links; one is predicting future links, i.e., may exist or appear in the future of evolving networks; last is identifying spurious links, i.e., nonexistent yet observed links, also known as noise [17]. Due to its formal simplicity, theoretical value and practical significance, link prediction has attracted increasing attentions from various fields of researches and engineers, such as physicists, mathematicians, computer scientists, statisticians, biologists, etc.

As for complex military organization, link prediction may be more significant, since the war determines a country of vital significance, and quality of intelligence is critical to military decisions, as a formal representation of military intelligence, network topology for complex military organization has to be true enough to guarantee the reliability of the subsequent analysis, such as critical operational units analysis, community analysis and network evolving analysis. However, due to the complex battle field situations and the expensive costs of military intelligence collection, it is nearly impossible to obtain an absolute accurate military network, there must be some missing information or spurious noise, in other words, missing links and spurious links in the network topology. If we can predict them or identify them in advance with link prediction methods, it would be both meaningful to optimize the military organization structure for our side and attack the other side's critical operational components, which are sure to enhance the accuracy of military decisions and accelerate the process of victory.

Current link prediction methods are mainly designed basing on the definition of node similarity, which assumes that the greater the similarity values between nodes are, the higher the likelihood of the existence of links between them [18]. There are many methods to measure node similarity, and one of the simplest is calculated just by the observed node attributes, i.e., two nodes are defined to be similar if they share many common characters [19], Popescul and Ungar [20] have done

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