Physica A 437 (2015) 322–332

Contents lists available at ScienceDirect

Physica A

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

Multi-level tolerance opinion dynamics in military command and control networks

Xiao Song [a,*], Wen Shi [a], Gary Tan [b], Yaofei Ma [a,*]

[a] Science and Technology on Aircraft Control Lab, School of Automation Science, Beihang University (BUAA), Beijing 100191, China
[b] School of Computing, National University of Singapore (NUS), 117417, Singapore

HIGHLIGHTS

- A multi-level tolerance opinion dynamics model is proposed and applied in military C2 network.
- Links added based on tree structure, small-world show better consensus performance than scale-free network.
- For opinion dynamics with tree network, additional links make them to converge.

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 3 April 2015
Available online 21 May 2015

Keywords:
Opinion dynamics
Multi-level tolerance
Military command and control
Network

ABSTRACT

Opinion exchange is useful when a military agent needs to take the opinions of others into account before decision making. Few studies have addressed opinion dynamics in military command and control (C2) organizations, which are often hierarchically ranked in a tree structure. Moreover, military agents should have different tolerance levels when communicating with differentially ranked agents, which is our reasoning for proposing an opinion dynamics model with multi-level tolerance in this study. We can use this model to test opinion dynamics models in depth and further analyze and compare them to traditional tree organizations and other organization forms, including small-world and scale-free networks. Opinion dynamics experiments show that although traditional indices such as a clustering coefficient or the average distance of a small-world network are worse than those of a scale-free network, opinion dynamics indices, which include the number of rounds to fixed opinions, number of opinion clusters, and relative size of the largest small-world cluster are unexpectedly better than those of a scale-free network. Moreover, adding links to a tree network can enhance the tendency to consensus, while a small-world network needs fewer links compared to a scale-free network.

1. Introduction

Command and Control (C2) systems are the exercise of authority and direction by a properly designated commanding officer over assigned and attached forces in the accomplishment of the mission [1]. Generally military C2 systems are enabled by their hierarchical organization, for example, in land army, commanders are ranked as Division, Regiment, Battalion, Company and Platoon. In peacetime or combats, the opinion exchange process is essential before headquarters or commanders make their decisions. The process can help to gain consensus and facilitate engagement synchronization.

* Corresponding authors.
E-mail addresses: mayaofeibuaa@163.com (Y. Ma), songxiao@buaa.edu.cn (X. Song).

http://dx.doi.org/10.1016/j.physa.2015.05.082
0378-4371/

In most cases, the process is carried out iteratively for commanders to communicate with superiors and subordinates and then form convergent opinions among the organization. Thus it is important to study the opinion dynamics characteristics of C2 networks and propose better organizational and technological structures that can be built for future effective military operations [2].

In the context of numerous information exchanges before any adoption decision, modeling adoption dynamics through methods inspired from information contagion is more appropriate than game theory as often used in economics [3]. For this reason, research on public opinion formation has been gaining favor for a long time, and numerous mathematical opinion dynamics models have been developed [3–7] in social and political domain.

Opinion dynamics models can be classified as discrete or continuous, depending on the representation of opinions with either discrete or continuous values. Well-known discrete models include Voter model [8], Sznajd model [9,10], Social Impact model [11], Axelrod Culture model [12], and Rumors model [13,14]. Examples of continuous opinion dynamics models include Deffuant model [15], Hegselmann–Krause model [16], and CODA model [7,17].

The first two continuous models are bounded-confidence models [18] with similar opinion representation and opinion exchange, since agents only influence one another when their opinions are close enough. These two models, however, differ in the opinion update rule, which characterizes whether agents interact with compatible neighbors one-by-one or all at once [19]. The CODA model is a hybrid approach, where agents hold continuous opinions as in the bounded-confidence model, but make binary decisions. Following Bayesian rules, agents update their opinions based on the observed actions of their peers [7]. These classic models and their modified versions have been widely applied in exploring public opinion formation and social contagious behavior.

Agent-based modeling on networks is another rapidly growing, intelligent approach to study social dynamics. Models of this kind study collective effects resulting from the interaction of a number of "simple" agents in a social network [20]. Members of social groups are considered to be adaptive rather than rational agents, and no individual strategy is implied except a common rule of opinion updating. Bounded confidence and relative agreement (BC/RA) models of opinion dynamics comprise an important example of agent-based modeling [21–24].

As to military organizations, if we interpret the opinion value in terms of agent's uncertainty of the decision choice, agents take into account others' opinions by conducting multi-rounded opinion exchanges among connected C2 nodes, because other agents from different ranks (such as regiment, battalion, company and platoon) often have different understanding of choices.

Therefore, by summing up all the related studies and studying the military C2 opinion dynamics model, it is necessary to identify one important characteristic of military applications. That is, agents engage in interaction only with those connected agents (higher rank, lower rank and equal rank) whose opinion does not differ too much from their own opinion, in proportion of their own uncertainty. The difference is called tolerance in Ref. [25], or threshold in Ref. [26]. Compared with the previous works [25], which use single level tolerance no matter who is communicating with, multi-level tolerance is more realistic for military applications where the higher rank agent often has smaller opinion tolerance than the lower rank agent. For instance, when a battalion agent communicates with his superior, a regiment agent, the former should be more likely to accept the opinion of the latter, and the latter may be less compliant with the opinion of the former.

To address this issue in the military opinion dynamics model, models presented in Refs. [3,14,25,26] are mainly referenced and modified to simulate the opinion dynamics among agents, because they have similar characteristics, including hierarchical structure, continuous opinion exchanging rules of tolerance and influence. Models of previous works [13–15] have been conceived to model communications among agents in exchange for common situation awareness and action decisions, which matches our research questions in the background. In some original models, agents are often connected on a square lattice. These opinion dynamics models are criticized for a lack of connection to the real world, because the models are often only tested on oversimplified social networks, such as nearest neighbor interactions on a square lattice. Thus, paper [25] advocated for a military network to replicate the actual relationships between hierarchical agents. However, this work neglected the multi-level tolerance issues regarding the communication between the high- and low-ranked officers.

Opinion models that can predict the voting process and hierarchical structures presented in previous works [12,13] are also useful in our work. However, compared with C2 opinion dynamics models in this paper, the voting model focuses more on bottom-up voting procedures, while C2 organization always allows multi-rank communication between any layers in the hierarchical structure. Furthermore, the models in Refs. [27–29] refer to a multi-party competition strategy in voting a leader, while the C2 model is more like a negotiation and compromising method to gain consensus. Therefore, although the pioneering works are useful for opinion evolution simulation and analysis, they failed to address some distinct characteristics of C2 opinion evolution model. The C2 opinion model has specific characteristics such as hierarchical agents, relatively fixed communication pairs with heterogeneous tolerances, and so on, which are all worthy of further studies.

We have reviewed recent opinion evolution models in social and military networks in this section. The remainder of this paper is divided into the following sections. In Section 2, previous opinion evolution model of the C2 network organization is revised and improved with a multi-level tolerance (threshold) model. Section 3 devises tree-based small-world and scale-free organization and studies its opinion dynamics performance. In Section 4 the conclusion is presented.