The Role of Complex Network Dynamics in the Emergence of Multiagent Coalition

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Abstract

Emergence of a single coalition among self-interested agents operating on large scale-free networks is a challenging task. Many existing approaches assume a given static network platform and do not use the network dynamics to facilitate the dynamics of agent interactions. In this paper, we present a decentralized game-theoretic approach to this single coalition emergence problem in which agent communications are limited only to their immediate neighbors. Our coalition emergence algorithm is based on the heuristic that agents benefit by forming coalitions with wealthy (higher payoff) and influential (higher accumulated coupling strength) neighbors. Simulation results show that the emergence phenomenon is significantly enhanced when the topological insights, such as increasing degree-heterogeneity and clustering, are embedded into the agent partner selection strategy.

Introduction

There has been a great deal of interest in the multiagent systems (MAS) community about the emergence and maintenance of coalitions among agents (Salazar et al. 2011; Shehory, Sycara, and Jha 1997). A coalition is defined as a group of agents who have decided to cooperate in order to perform a common task. However, in the interaction of selfish agents where defection may be benefecial in the short-term, emergence of stable coalitions becomes challenging.

Traditionally this problem has been modeled by a Prisoner's Dilemma (PD) game (Nowak and May 1992) in which the only dominant strategy equilibrium is pareto dominated. In iterated PD games it has been shown that the likelihood of cooperation is increased if the agent interaction is constrained by the underlying complex networks such as scale-free (SF) (Santos and Pacheco 2005) networks. However, in these approaches agents do not use the network dynamics to enhance the emergence phenomenon. These works start by assuming a pre-established static complex network platform and then employ agents on the nodes of the network for mutual interactions. These approaches use a given structure of the complex network with fixed properties and do not explore the other possible network configurations. In addition to this, they do not explore how the topological insights could reinforce agent dynamics to emerge the collective phenomena of cooperation.

In this paper, we present a decentralized *coalition emergence* approach where self-interested agents in a MAS operating on large SF networks exploit the complex network dynamics to facilitate the convergence into a single coalition. We use an iterated PD game to capture the agent interactions and provide a coalition emergence algorithm based on the heuristic that agents benefit by forming coalitions with wealthy (higher payoff) and influential (higher accumulated coupling strength) neighbors. We enable the agents to acquire the social status of its coalition by adding its neighbors coupling strength with its own (accumulation of the coupling strength) as it joins the neighbors coalition. **The novelty of our approach lies in the fact that, unlike many previous works that assume pre-established static networks, we determine the topological insights for the agents to choose their interaction partners to form a dynamically growing SF network and show that this network formation process significantly enhances the emergence phenomenon**.

Decentralized Coalition Formation

We assume that agents are self-interested, rational and can communicate only with their immediate neighborhood to form coalitions. In the beginning we enable the agents to form the network by choosing their interaction partners dynamically. The network consists of *N* agents where agents are embedded on the nodes of the network. Every agent is equipped to play a *2-person* iterated PD game with each one of its neighbors and their interactions are represented by the network links. After every round of the game, the payoff for each agent gets aggregated. We assume that every agent knows the aggregated payoff of its immediate neighbors.

Agents use the aggregated payoff and the *accumulated coupling strength* (ACS) of their neighbors to join/form coalitions. The ACS is defined as follwing: when a new node i joins another node j in a coalition, its coupling strength (CS) gets increased by the addition of the CS of j with which it has coupled: $ACS_i = CS_i + CS_j$, where node j either belongs to a coalition or is an independent agent with higher payoff and $CS_i <= CS_j$. We define the CS of an interacting node based on its social influence which is represented by its degree: $CS_i = \frac{k_i}{M}$ where k_i is the degree of node i and M is a pre-defined large number (e.g., Avogadro constant).

Simulation and Results Analysis

In order to gain insights about the impact of topological features over the process of coalition emergence, we build the interaction topology using two types of SF network models: (1) Barabasi-Albert (BA) model (Barabasi and Albert 1999) and (2) the extended BA model (Holme and Kim 2002).

Table 1: BA & Extended BA Model: Instances of sustainable multiple coalitions (MC), the average Global Clustering Coefficient (GCC) and the average Degree-Heterogeneity (DH) over 500 realizations of the network for various values of the clustering probability *p* and the initial attractiveness parameter A.

	BA Model			Extended BA Model					
	p = 0.0			p = 0.2			p = 0.4		
A	MC	GCC	DH	MC	GCC	DH	MC	GCC	DH
0	63	0.08	19.36	150	0.10	19.81	110	0.13	20.18
10	16	0.11	22.8	38	0.12	22.25	92	0.13	21.86
50	5	0.30	36.07	86	0.23	31.09	182	0.20	27.63
80	3	0.40	41.21	124	0.29	35.24	221	0.23	30.37
100	1	0.45	45.24	133	0.32	37.47	211	0.24	31.86
300	0	0.71	61.85	192	0.47	50.86	200	0.33	41.28
700	0	0.88	76.50	168	0.58	62.92	172	0.40	50.33
	Extended BA Model								
	p = 0.6			p = 0.8			p = 1.0		
A	MC	GCC	DH	MC	GCC	DH	MC	GCC	DH
0	155	0.15		140	0.178	21.24	135	0.20	22.23
10	141	0.15	21.67	135	0.18	21.46	134	0.20	21.60
50	173	0.19	25.13	55	0.19	23.59	10	0.19	22.43
80	128	0.20	26.79	22	0.19	23.99	3	0.19	22.35
100	102	0.21	27.65	13	0.20	24.39	0	0.19	23.10
300	38	0.25	33.48	0	0.21	27.58	0	0.18	24.35
500	8	0.27	37.06	0	0.21	30.24	0	0.17	25.95
700	2	0.29	39.63	0	0.22	31.60	0	0.17	27.17

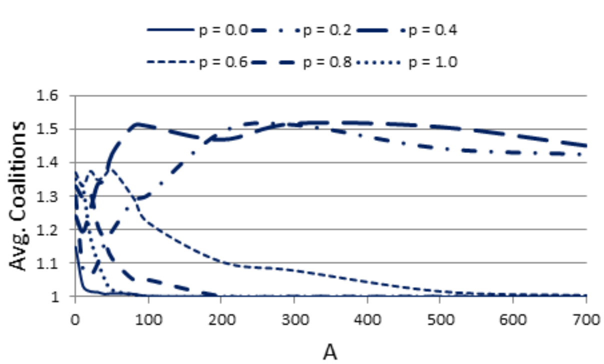

Figure 1: BA & Extended BA Model: Average no. of coalitions for various values of A

BA Model: In order to investigate the impact of large heterogeneity, we gradually increase the value of the initial attractiveness parameter A from 0 to 700. In Figure 1 we observe that as the value of A increases, the likelihood of convergence into a single coalition increases. Therefore, if the agents choose their interaction partners by seting a large value of their initial attractiveness parameter ($A > 0$), the resultant network with large heterogeneity in the degree-distribution would increase the likelihood of the emergence of a single coalition.

Extended BA Model: To investigate the effect of high clustering and large degree-heterogeneity over the emergence of a single coalition, we gradually increase the value of *p* from 0.2 (low-clustering) to 1.0 (high-clustering) and for each value of the *p* we increase the initial attractiveness parameter A from 0 to 700. Figure 1 shows that when the clustering of the model is low ($p < 0.5$), increased degree-heterogeneity does not improve the quality of the emergence. However, we observe an interesting emergent property of the networked MAS that when the value of *p* exceeds 0.5, the likelihood for the convergence into a single coalition is significantly enhanced. Table 1 shows that, unlike the BA model, a single coalition emerges at high clustering ($p = 1.0$) with small heterogeneity (≤ 23).

Conclusions and Future Work

Through the computational model we observed that the coalition emergence process is significantly enhanced when the topological insights, such as increasing degree-heterogeneity and clustering, are embedded into the agent partner selection strategy. As future work, we plan to verify our simulation results analytically and extend our model for incomplete information games.

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