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論文審査の要旨（2000 字程度）

This dissertation is entitled “Consensus and Clustering of Dynamic Resilient Multiagent Systems under Repeated Games” and composed of seven chapters, wherein a framework for analyzing resilient multiagent networks under the attacker-defender-type security problems is studied.

In Chapter 1 (Introduction), current works and results of game-theoretical approach in analyzing network security are reviewed and the motivation and the goals of the research are also stated. Furthermore, general decision makings for attack and defense under repeated game setting are characterized.

In Chapter 2 (Sequential Two-player Game Formulation), the general problem formulations used in the subsequent chapters are characterized, which include the game structure between two strategic players of the game (the attacker and the defender) as well as the general sequence of the interaction between them. Specifically, the attacker launches its jamming attacks by removing some edges in the network whereas the defender recovers by rebuilding some of the attacked edges. Furthermore, a subgame perfect Nash equilibrium used as a solution concept of the game is explained. It is assumed throughout the dissertation that both players are constrained in making their decisions by their limited resources, which have to be used efficiently in achieving their goals. The effect of players’ actions in the games on the agents’ state evolution in a multiagent consensus setting is outlined.

In Chapter 3 (Dynamic Resilient Network Games with Applications to Multiagent Consensus), a one-stage game in a continuous-time framework played repeatedly over time is discussed, where the players do their actions for certain intervals. The attacker and the defender consider graph connectivity in determining their optimal actions, consisting of optimal edges and optimal action intervals. Each game is different due to different energy conditions of the game affected by their previous actions. By reducing the infinite strategy space by deriving equilibrium candidates, the subgame perfect equilibrium of the game is obtained. It turns out that this equilibrium depends on the players’ energy parameters as well as the connectedness of the underlying network. It is revealed that the consensus speed of the agents under the attacks and recoveries depends on network connectivity and the players’ energy parameters.

In Chapter 4 (Cluster Forming in Multiagent Consensus in Continuous Time), the problem formulation in the previous chapter is extended into a multiple-stage game in continuous time, where both players can think further forward when determining their optimal actions. The attacker is assumed to be able to use stronger jamming signals which makes the attacks unrecoverable. Under this situation, the players consider how the agents are divided and connected as well as how their states evolves when making their decisions. The long-term effect of the players’ actions on the agents’ consensus process is analyzed, where the attacker needs to possess sufficiently high energies characterized by high recharge rate in order to be able to prevent consensus among the agents at infinite time.

In Chapter 5 (Consensus and Clustering with Repeated Games under Rolling Horizon Approach), a discrete-time setting of the sequence of attacks and recoveries are discussed. Specifically, the players may change its strategies that have been planned for certain time steps in a rolling horizon fashion. The consensus and clustering process of agents impacted by players’ strategies are analyzed in the form of necessary conditions and sufficient conditions, where the attacker needs to possess sufficiently high energy parameters in order to be able to prevent consensus and divide agents into more clusters at infinite time. Through the simulation results, it is also shown that the distribution of initial states of the agents affect the clustering of agents at infinite time.

In Chapter 6 (Players' Performance, Consensus, and Clustering with Non-uniform Horizons), the performance of the attacker and the defender with non-uniform horizon lengths and game periods are examined. With non-uniform horizons, the game consists of asynchronous optimization problems, which may cause the players to waste their resources without obtaining any payoff. It is shown by the theoretical and simulation results that the player with longer horizon length and shorter game periods generally perform better in the long-term, especially in dense networks. The impact of the players' optimal strategies on the agents' states following the consensus protocol are discussed, where it is stated that the attacker may be able to prevent consensus and divide agents into more clusters with relatively low energy parameters if the defender's horizon parameters are sufficiently low.

Finally, in Chapter 7 (Concluding Remarks), the results and takeaway messages of each chapter are summarized and discussed, as well as the potential applications of the general results. Then, future possible extensions and some ongoing works are presented.

In summary, this dissertation develops a game-theoretic framework for investigating resilience, consensus, and clustering of multiagents in the face of communication failures caused by a malicious player. The contribution of this dissertation in the field of control of noncooperative multiagent systems is scientifically significant in that the dissertation develops analytical framework for characterizing the structure of the Stackelberg-type sequential repeated games with time-varying constraints. Consequently, it is concluded that this dissertation is of sufficient merit as a doctoral thesis, deserving the degree of doctor of philosophy.