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Game Theoretic Modeling for Mobile Malicious Node Detection Problem in Static Wireless Sensor Networks

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Abstract

Game theory has been regarded as a useful theoretical tool for modeling the interactions between distinct entities and thus it has been harnessed in various research field. In particular, research attention has been shown to how to apply game theory to modeling the interactions between malign and benign entities in the field of wireless networks. Although various game theoretic modeling work have been proposed in the field of wireless networks, our proposed work is disparate to the existing work in the sense that we focus on mobile malign node detection problem in static wireless sensor networks. More specifically, we propose a Bayesian game theoretic modeling for mobile malign node detection problem in static wireless sensor networks. In our modeling, we formulate a two-player static Bayesian game with imperfect information such that player 1 is aware of the type of player 2, but player 2 is not aware of the type of player 1. We use four strategies in our static Bayesian game. We obtain Bayesian Nash Equilibria with pure strategies under certain conditions.

Keywords: *Game Theory, Bayesian Game, Bayesian Nash Equilibrium, Pure Strategies*

1. Introduction

In the sense that game theory [1] is suitable for modeling the interactions between benign entities and malign entities, game theory has been adapted to multiple problems in wireless network security field [2], [3], [4]. In this paper, we put to use of game theoretic approach on analysis for mobile malicious node detection problem managed in our prior work [5]. More precisely, we propose a Bayesian game theoretic modeling for the interactions between benign and malign entities in mobile malicious node detection problem tackled in our prior work [5]. In our Bayesian game theoretic modeling, we formulate a static Bayesian game with imperfect information and derive Bayesian Nash Equilibrium with pure strategies.

2. Related Work

The work of [2], [3], [4] apply a Bayesian game theoretic approach to the problems with respect to malign nodes in wireless networks. More particularly, [2] utilizes a Bayesian game to model the interactions among benign, selfish, malign nodes in wireless ad hoc networks. In [3], malign node detection procedure is formulated as a Bayesian game in wireless networks. In [4], a Bayesian game is harnessed to make an analysis

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of the interactions between regular and malign nodes in mobile ad hoc networks.

In our prior work [5], a distributed detection method is developed against mobile malicious nodes in static wireless sensor networks. However, game theoretic analysis for mobile malicious node detection problem is not explored in our prior work [5]. In this work, we propose a Bayesian game theoretic modeling for mobile malicious node detection problem handled in our prior work [5]. From the perspective that our game theoretic modeling is focused on mobile malicious node detection problem in static wireless sensor networks, our work is distinct to the work of [2], [3], [4].

3. A Bayesian Game Theoretic Modeling for Mobile Malicious Node Detection Problem

In our prior work [5], we tackled the mobile malicious node detection problem by harnessing the Sequential Probability Ratio Test (SPRT) [6]. More particularly, we considered the static wireless sensor networks in which benign nodes are static such that they are fastened to their initial deployment spots while malicious nodes are mobile such that they freely roam in the network. In this scenario, a benign static node will be likely in attendance within communication range of its neighboring nodes. However, a mobile malicious node will be likely away from communication range of its neighboring nodes. Under this intuition, every benign static node performs the SPRT on its neighboring nodes to decide whether they get out of the communication range of it, resulting in the detection of mobile malicious nodes.

For game theoretic modeling for mobile malicious node detection problem in static wireless sensor networks, we adopt the modified version of the SPRT-based mobile malicious detection scheme proposed in our prior work [5]. More particularly, the modified part is that each benign static node can choose whether or not to run the SPRT instead of mandatorily participating in the SPRT. As far as game theoretic modeling is concerned, we formulate a two-player static Bayesian game with imperfect information as follows: We consider a Bayesian signaling game in which there are players of sender and receiver such that the type of sender is private and thus it is not known to receiver while the type of receiver is known to sender. Putting it in different way, receiver has imperfect information of type of sender while sender has perfect information of type of receiver. Moreover, sender transmits messages to receiver in line with its type and receiver determines how to act in conformity with the messages sent by sender.

We have two players of player 1 and player 2 such that player 1 and player 2 act as sender and receiver respectively. Therefore, player 2 is not aware of the type of player 1, but player 1 is aware of the type of player 2. Player 1 has two types of mobile malicious and static benign. Player 2 has one type of static benign. In other words, player 1 is either mobile malicious node or static benign node and player 2 is static benign node. Additionally, player 1 and player 2 are in neighboring relationship each other. Nature makes a decision on the type of player 1 in such a way that it reaches a decision about the mobile malicious type of player 1 with probability ξ and it reaches a decision about the static benign type of player 1 with probability 1-ξ. In our static Bayesian game, we consider four strategies: *Pause*, *Move*, *Do-SPRT*, *No-SPRT*. In the modified version of our prior work [5], we define these four strategies as follows: *Pause* strategy indicates that mobile malicious node sends messages to static benign neighboring node while staying at a position. *Move* strategy means that mobile malicious node leaves its static benign neighboring node and moves to other position. *Do-SPRT* strategy represents that static benign node performs the SPRT with incoming messages received from its neighboring node. *No-SPRT* strategy means that static benign node does not run Do-SPRT strategy in order to eliminate the cost incurred by Do-SPRT strategy. Player 1 with mobile malicious type has strategies of Pause and Move; Player 1 with static benign type has strategies of Do-SPRT and No-SPRT. Player2 has also strategies of Do-SPRT and No-SPRT.

In Table 1, we denote the notations used in payoffs, which are represented in the strategic form and extensive form of our static Bayesian game with imperfect information. In Do-SPRT strategy, static benign node performs the SPRT one time in a stage. Moreover, the SPRT brings to an end in the acceptance of the null hypothesis (H_0) or alternate hypothesis (H_1) such that H_0 (resp. H_1) is linked to a decision of regarding neighboring node as static benign (resp. mobile malicious). Under this description, let us explain B_0 and B_1, which are described in Table 1, in detail: B_1 can be considered as benefit from hastening the SPRT to go toward the acceptance of H_1, resulting in mobile malicious node detection. B_0 can be considered as benefit from recording mobile malicious node as neighboring node of static benign node running Do-SPRT strategy, contributing to discernment of Move strategy of mobile malicious node. Note that we do not count costs, which can be incurred by the decision error of the SPRT such as false positives and false negatives, for payoffs in our static Bayesian game with imperfect information. Furthermore, our static Bayesian game considers only a stage, which corresponds to a time slot used in the modified version of the mobile malicious node detection scheme proposed in our prior work [5]. However, we do not count the final decision stage of the SPRT in the modified version of our proposed scheme for our Bayesian game theoretic modeling.

Table 1. Notations for payoffs in our static Bayesian game.

B_P	Benefit from adopting Pause strategy
E_P	Expense incurred by adopting Pause strategy
B_M	Benefit from adopting Move Strategy
E_M	Expense incurred by adopting Move Strategy
B_0	Benefit from adopting Do-SPRT strategy contributing to the H_0 decision of the SPRT on player 1 with mobile malicious type
B_1	Benefit from adopting Do-SPRT strategy contributing to the H_1 decision of the SPRT on player 1 with mobile malicious type
E_{SPRT}	Expense incurred by adopting Do-SPRT strategy

Table 2. Strategic form of our static Bayesian game between player 1 and player 2 when player 1 is mobile malicious node.

		Player 2	
		Do-SPRT	No-SPRT
Player 1	Pause	(B_P-E_P , B_0-E_{SPRT})	$(B_P-E_P , -B_0)$
	Move	(B_M-E_M , B_1-E_{SPRT})	$(B_M-E_M , -B_1)$

Table 3. Strategic form of our static Bayesian game between player 1 and player 2 when player 1 is static benign node.

		Player 2	
		Do-SPRT	No-SPRT
Player 1	Do-SPRT	$(-E_{SPRT} , -E_{SPRT})$	$(-E_{SPRT} , 0)$
	No-SPRT	$(0 , -E_{SPRT})$	$(0 , 0)$

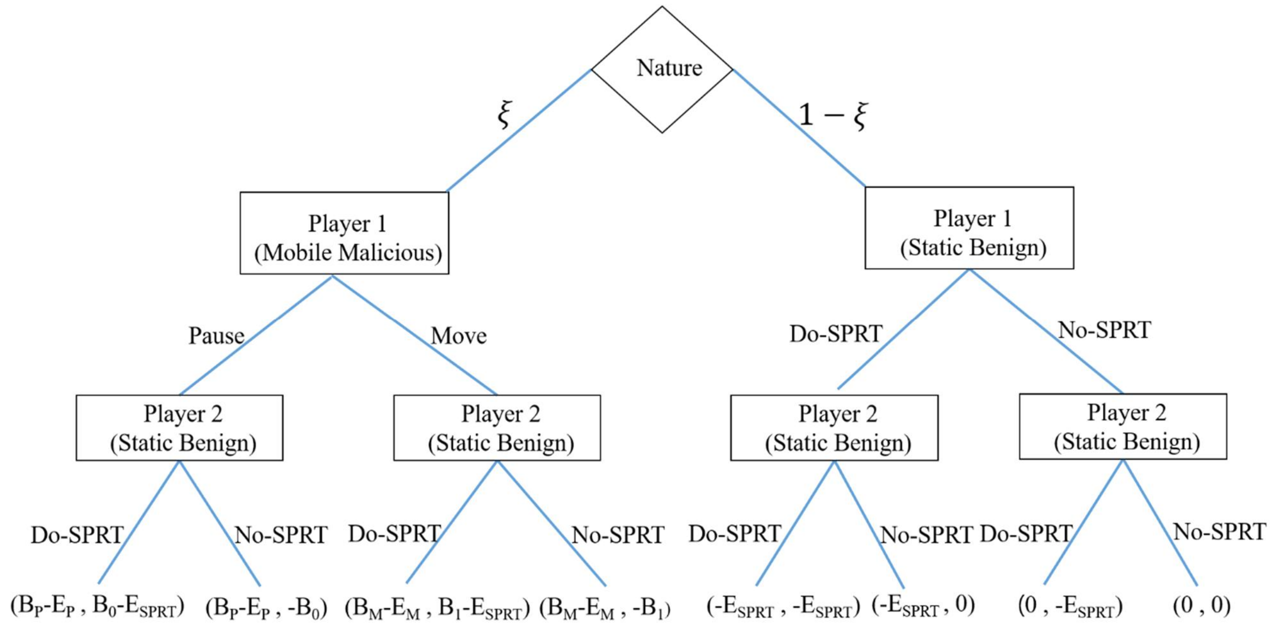

Figure 1. Extensive form of a stage in our static Bayesian game between player 1 and player 2.

Table 2 (resp. Table 3) displays a strategic form of our static Bayesian game when player 1 is mobile malicious node (resp. static benign node). Figure 1 shows an extensive form of a stage in our static Bayesian game.

We obtain Bayesian Nash Equilibria with pure strategies as follows: We denote the expected payoff of Do-SPRT (resp. No-SPRT) strategy of player 2 by E_{D0} (resp. E_{N0}) under the condition that player 1 with mobile malicious type takes Pause strategy and player 1 with static benign type takes No-SPRT strategy. E_{D0} and E_{N0} are given by

$$E_{D0} = \xi(B_0 - E_{SPRT}) - E_{SPRT}(1-\xi)$$
$$E_{N0} = -\xi B_0 + 0(1-\xi)$$

If $E_{D0} > E_{N0}$ and $B_p - E_p > B_M - E_M$ hold, we have Bayesian Nash Equilibrium of ((Pause if Mobile Malicious, No-SPRT if Static Benign), Do-SPRT). If $E_{D0} < E_{N0}$ and $B_p - E_p > B_M - E_M$ hold, we have Bayesian Nash Equilibrium of ((Pause if Mobile Malicious, No-SPRT if Static Benign), No-SPRT).

We denote the expected payoff of Do-SPRT (resp. No-SPRT) strategy of player 2 by E_{D1} (resp. E_{N1}) under the condition that player 1 with mobile malicious type takes Move strategy and player 1 with static benign type takes No-SPRT strategy. E_{D1} and E_{N1} are given by

$$E_{D1} = \xi(B_1 - E_{SPRT}) - E_{SPRT}(1-\xi)$$
$$E_{N1} = -\xi B_1 + 0(1-\xi)$$

If $E_{D1} > E_{N1}$ and $B_p - E_p < B_M - E_M$ hold, we have Bayesian Nash Equilibrium of ((Move if Mobile Malicious, No-SPRT if Static Benign), Do-SPRT). If $E_{D1} < E_{N1}$ and $B_p - E_p < B_M - E_M$ hold, we have Bayesian Nash Equilibrium of ((Move if Mobile Malicious, No-SPRT if Static Benign), No-SPRT).

We summarize Bayesian Nash Equilibria with conditions in Table 4.

Table 4. List of Bayesian Nash Equilibria with pure strategies in our static Bayesian game.

Condition	Bayesian Nash Equilibrium
$\xi > \frac{E_{SPRT}}{2B_0}$, $B_p - E_p > B_M - E_M$	((Pause if Mobile Malicious, No-SPRT if Static Benign), Do-SPRT)
$\xi < \frac{E_{SPRT}}{2B_0}$, $B_p - E_p > B_M - E_M$	((Pause if Mobile Malicious, No-SPRT if Static Benign), No-SPRT)
$\xi > \frac{E_{SPRT}}{2B_1}$, $B_p - E_p < B_M - E_M$	((Move if Mobile Malicious, No-SPRT if Static Benign), Do-SPRT)
$\xi < \frac{E_{SPRT}}{2B_1}$, $B_p - E_p < B_M - E_M$	((Move if Mobile Malicious, No-SPRT if Static Benign), No-SPRT)

4. Conclusion

In this paper, we explore a Bayesian game theoretic modeling for mobile malicious node detection problem in static wireless sensor networks dealt in our prior work [5]. In particular, we formulate a static Bayesian game with imperfect information for mobile malicious node detection problem in static wireless sensor networks managed in our prior work [5] and acquire Bayesian Nash Equilibria with pure strategies under certain conditions.

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