Quantitative Models of Imperfect Deception in Network Security using Signaling Games with Evidence [IEEE CNS 17 Poster]

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Abstract—Deception plays a critical role in many interactions in communication and network security. Game-theoretic models called “cheap talk signaling games” capture the dynamic and information asymmetric nature of deceptive interactions. But signaling games inherently model undetectable deception. In this paper, we investigate a model of signaling games in which the receiver can detect deception with some probability. This model nests traditional signaling games and complete information Stackelberg games as special cases. We present the pure strategy perfect Bayesian Nash equilibria of the game. Then we illustrate these analytical results with an application to active network defense. The presence of evidence forces majority-truthful behavior and eliminates some pure strategy equilibria. It always benefits the deceived player, but surprisingly sometimes also benefits the deceiving player.

I. INTRODUCTION

Advanced cyberattackers employ deception to evade signature detection, release misleading information, and frustrate attempts at attribution. Deceptive opinion spam [5] and identity deception in social networks [9] are two examples. Deception can also be used in active cyber defense to manipulate the beliefs of an adversary [8], leveraging the advantage of information-asymmetry typically enjoyed by attackers (Fig. 1).

Quantitative metrics are needed to optimally deploy defensive deception and optimally detect and mitigate malicious deception. These metrics would also allow policymakers, entrepreneurs, and cyber-insurance vendors to assess the influence of new legislation, technology, or risk mitigation strategies. Game theory provides a set of tools to make quantitative, verifiable predictions about the outcome of the strategic and decentralized decisions characteristic of network security. In particular, cheap talk signaling games [1] capture the dynamic and information-asymmetric nature of deceptive interactions. These games are two-player, dynamic, information asymmetric games. The players are a sender (S) and a receiver (R), which correspond to the party which may attempt deception and the party which may be deceived, respectively.

Cheap talk signaling games are often used to model deception in cybersecurity. But these games inherently model deception which is undetectable [4]. Of course, both security administrators and cybercriminals invest heavily in detecting deception. Examples include detection of false opinion spam [5], malicious logins [7], and social network identity deception [9]. Therefore, we extend cheap-talk signaling games to capture the possibility of detecting deception.

II. MODEL

Figure 2 depicts the traditional signaling game between S and R, augmented by a detector block (D). We can call this augmented signaling game a signaling game with evidence [6]. Our contribution is to add block D, which denotes a detector that emits evidence $e \in E = \{0, 1\}$ with probability $\lambda(e | \theta, m)$. The detector classifies the message as suspicious ($e = 1$) or not suspicious ($e = 0$). Two examples of detectors are email clients which warn users about possible phishing emails and browser warnings which alert users if websites do not have verifiable website security certificates. Let $\beta \in [1/2, 1]$ and $\alpha \in [0, 1/2]$ denote the power and size of the detector, respectively. R uses both the message $m$ and the evidence $e$ to form belief $\mu(\theta | m, e)$ about the likelihood that $S$ has type $\theta$.

1In some signaling games, equilibrium conditions allow the message to convey the true private information. But there is no exogenous constraint on deception, i.e., it is just as easy for the sender to lie as it is for him to reveal the truth.
Table I

| Prior Probabilities | Sender w/o Evidence | Sender w/ Evidence |
|---------------------|---------------------|--------------------|
| 0-Dominant          | Reveal or deceive   | Reveal or deceive  |
| 0-Majority          | Reveal or deceive   | Majority reveal    |
| Mixed               | Reveal or deceive   | No Eq.             |
| 1-Majority          | Reveal or deceive   | Majority reveal    |
| 1-Dominant          | Reveal or deceive   | Reveal or deceive  |

III. ANALYTICAL RESULTS AND APPLICATION

Theorem 1. Table I summarizes the pure strategy PBNE. Theorem 1 states the perfect Bayesian Nash equilibria (PBNE) of the game. Remark 1 and Remark 2 discuss important properties of the PBNE, especially focusing on the ways in which signaling games with evidence differ from traditional signaling games.

Remark 1. Without evidence, it is equivalent for S to always reveal the truth or to always lie. One effect of evidence is to force majority-truthful signaling. In the 0-Majority regime, S of type 0 reveal truthfully and S of (the minority) type 1 deceive. The opposite occurs in the 1-Majority regime.

Remark 2. In the Mixed prior probability regime, the evidence eliminates all PBNE by playing a dominant role. Here R always trusts S if e = 0 and does not trust S if e = 1. It can be shown that S and R can never mutually counter each other’s strategies. Now consider an application in which a network administrator S is defending a network from an attacker R by camouflaging normal systems as honeypots or honeypots as normal systems. Let θ = 0 and θ = 1 denote normal systems and honeypots, respectively. Let m = 0 and m = 1 denote camouflaging (or revealing) a system as a normal system or a honeypot. But this camouflage is not perfect, because the attacker can try to detect honeypots through tests such as measuring the execution time of control-modifying CPU instructions. This produces evidence e = 1 for a suspicious system (i.e., one in which it is likely that m ≠ θ), and e = 0 for a system which is not suspicious. R uses this to decide whether to move into the system or to withdraw.

Figures 3 and 4 use Gambit to illustrate the results. Evidence always improves the expected utility of the attacker R. He always benefits from being able to detect honeypots. Interestingly, the defender S also sometimes benefits from evidence, as illustrated by Fig. 4. This implies that she sometimes wants to imperfectly obscure the network characterization.

IV. CONCLUSION

Traditional signaling games model deception which is impossible to detect. We have introduced signaling games with evidence, which allow an exogenous probability of detecting deception. Evidence forces majority-truthful behavior in some parameter regimes. It also eliminates all pure strategy equilibria in others. The capability to collect evidence is always beneficial for the uninformed player. Surprisingly, detection is sometimes advantageous to the deceiver. We have illustrated an application to network defense using honeypots, but our model applies to any active cybersecurity defense which imperfectly leverages information asymmetry.

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