Advanced Smart Drone Swarm Security Network by Using Strategic Alliance for Blockchain Governance Game*

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ABSTRACT
This paper deals with the design of the secure network of the Advanced Smart Drone Swarm security network by using the Strategic Alliance for Blockchain Governance Game (SABGG). The SABGG is the system model of the stochastic game to find best strategies towards preparation for preventing a network malfunction by an attacker and the newly proposed adapts this innovative game model into the artificial drone swarm security.

Keywords: Drone, swarm, Blockchain Governance Game; artificial intelligence, mixed game; stochastic model; fluctuation theory; 51 percent attack

I. INTRODUCTION
Drones occupy an essential place in both military and civilian applications for various roles including criminal investigations, public safety organizations, transportation management facilities, and surveillance forces [1]. Because of dynamic mobility, quick reaction and easy deployment, drones offer new possibilities for different applications with affordable expense [2]. A drone swarm is multiple drones being used at once and drones in a swarm communicate and collaborate, making collective decisions of collective actions. In a militarized drone swarm, instead of 10 or 100 distinct drones, the swarm forms a single, integrated weapon system guided by some form of artificial intelligence [3]. The Blockchain Governance Game (BGG) has been designed as a stochastic game model with the fluctuation and the mixed strategy game for analyzing the network to provide the decision making moment for taking preliminary security actions before attacks. The model is targeted to prevent blockchain based attacks (i.e., the 51 percent attack) and keeps the network decentralized. Atypical case which an attacker tries to build an alternative blockchain (blockchain forks) faster than regular miners [18].

Fig 2. BGG vs. SABGG [18, 21]

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II. STOCHASTIC GAME FOR ASDS SECURITY FRAMEWORK

The proposed ASDS network structure is considered and the drones in a swarm are connected each other and a swarm is hooked up as single Blockchain network (see Fig. 2). Drones in a swarm are fully connected but these may not connected with a command center (or a control center). This drone swarm could execute their command artificially and independently even with disconnection with a command center. Each drone randomly generates unique data (e.g., GPS coordinates, motor RPM values) and broadcast these data to other drones (which is equivalent with transaction in a blockchain network). Each drone generates the value based on its mechanical action and the generated values are sharing with all other drones in a swarm.

To apply the SABGG into the ASDS network structure, the antagonistic game of two players (called "A" and "H") are introduced to describe the Blockchain network in a drone swarm as a defender and an attacker. The joint functional of the Blockchain network model with the strategic alliance is as follows:

\[
\Phi(\xi, g_0, g_1, b, z_0, z_1) = \mathbb{E}\left[\xi' \cdot g_0^{A_{-1}} \cdot g_1^{A_{-1}} \cdot b^{A_{-1}} \cdot z_0^{H_{-1}} \cdot z_1^{H_{-1}} \cdot 1_{\{\nu < \nu_2 < \mu\}}\right],
\]

where \(M\) indicates the total number of nodes (or ledgers) in the swarm network for each drone (see Fig. 2). The Theorem of SABGG establishes an explicit formula \(\Phi(\xi, g_0, g_1, z_0, z_1)\) from (2.7)-(2.10). Based on the theorem [25], the functional \(\Phi(\xi, g_0, g_1, z_0, z_1)\) of the process of (2.16) satisfies following expression:

\[
\Phi(\xi, g_0, g_1, z_0, z_1) = \mathcal{D}_{(g,r,s)}(\xi, g_0, g_1, z_0, z_1) A,
\]

where

\[
A = \sigma \cdot \Gamma\left(\frac{1 - \Gamma_1}{1 - \Gamma}\right) \left(\gamma_0^1 - \gamma_0 + \frac{\zeta \Theta_0}{1 - \zeta \Theta} (\gamma_1 - \gamma)\right),
\]

and

\[
\Theta := \gamma(g_0 g_1 b g r, z_0 z_1 s),
\]

\[
\Theta_0 := \gamma_0(g_0 g_1 b g r, z_0 z_1 s),
\]

\[
\gamma := \gamma(g_1 b g, z_1),
\]
\(\gamma_0 := \gamma_0(g_1 b_i, z_1), \quad (2.23)\)
\(\gamma^1 := \gamma(g_1 b, z_1), \quad (2.24)\)
\(\gamma^1_0 := \gamma_0(g_1 b, z_1), \quad (2.25)\)
\(\Gamma := \gamma(br, s), \quad (2.26)\)
\(\Gamma^1 := \gamma(r, 1), \quad (2.27)\)
\(\sigma := \mathbb{E}[b^{-B}]. \quad (2.28)\)

From (2.13)-(2.14), we can find the PGFs (probability generating functions) of the exit index \(\nu:\)

\[\mathbb{E}[\xi^\nu] = \Phi(\frac{\xi}{\xi^1}) (\xi, 1, 1, 1) \quad (2.32)\]

Let us consider a two-person mixed strategy game, and player H (i.e., a drone swarm) is the person who has two strategies at the observation moment, one step before attackers complete to generate alternative chains with dishonest transactions. In this case, the cost will be not only all drones in a swarm but also the alliance costs. The normal form of games is as follows:

. Players: \(\mathcal{N} = \{A, H\}, \quad (2.37)\)
. Strategy sets:
\(s_a = \{\text{"NotBurst","Burst"}\}, \quad \sigma := \mathbb{E}[b^{-B}]. \quad (2.28)\)
\(s_h = \{\text{"Regular","Safety"}\}. \quad (2.38)\)

Based on the above conditions, the general cost matrix at the prior time to be burst \(\tau_{\nu-1}\) could be composed as follows:

|       | NotBurst \((1 - q(s_h))\) | Burst \((q(s_h))\) |
|-------|--------------------------|------------------|
| Regular | 0                         | \(V\)            |
| Safety  | \(c_h\)                  | \(c_h + V\)      |

Table 1. Cost matrix

where \(q(s_h)\) is the probability of bursting blockchain network (i.e., an attacker wins the game) and it depends on the strategic decision of player H:

\[q(s_h) = \begin{cases} 
\mathbb{E}\left[1_{\{A \geq B\}}\right], & s_h = \{\text{Regular}\}, \\
\mathbb{E}\left[1_{\{A < B\}}\right], & s_h = \{\text{Safety}\},
\end{cases} \quad (2.38)\]

and the alliance (i.e., "Safety" strategy of player H) cost should be less than the cost of other strategies. Otherwise, player H does not have to spend the cost of the strategic alliance with genuine drones. Recalling from (2.38), the probability of bursting a Blockchain network (i.e., an attacker wins the game) under the memoryless properties becomes the Poisson compound process:
where
\[
q(s_h) = \begin{cases} 
\sum_{k > \frac{N}{2}} \mathbb{E} \left[ 1_{\{A_\nu = k\}} \right], & s_h = \{\text{Regular}\}, \\
\mathbb{E} \left[ \mathbb{E} \left[ \sum_{k > \frac{N}{2} + B} \mathbb{E} \left[ 1_{\{A_\nu = k\}} \right] B \right] \right], & s_h = \{\text{Safety}\},
\end{cases}
\tag{2.39}
\]

III. THE ASDS OPTIMIZATION PRACTICE

A network security in an ASDS network is considered in this subsection. The strategy for protecting the ASDS is for priority connection with neighbor drones to give the less chance that an attacker catches blocks with false control requests. The example in this paper is targeting 20 drones in single swarm and each estimated drone value is around 1,500 USD in the swarm (see Table II).

| Name | Value | Description |
|------|-------|-------------|
| \(M\) | 20 [Drones] | Total number of the nodes in a drone swarm |
| \(V\) | 1,500 [USD/Drone] \(\times\) \(M\) [Drone] | Total value of a Blockchain enabled swarm |
| \(c(q)\) | \(3\left(\frac{N}{2} - 1\right) \cdot q\) [USD] | Cost for reserving nodes to avoid attacks per each car |
| \(\mathbb{E}[\nu]\) | 3 [Trial] | Total number of blocks that changed by an attacker at \(\tau_0(= 0)\) |
| \(B\) | – | Number of accepted allies at \(\tau_0\) |

**Table II.** Initial conditions for the cost function

Based on the above conditions, the LP (Linear Programming) model could be described as follows from (2.43)-(2.46):

**Objective**
\[
\text{minimizing } G = \mathbb{G}(q)_{\text{Total}} \tag{3.30}
\]

**Subject to**
\[
n \geq \frac{c(q)}{V \cdot q^0 - c(q)}; \tag{3.31}
\]

From (2.46), the total cost \(\mathbb{G}(q)_{\text{Total}}\) is as follows:
\[
\mathbb{G}(q)_{\text{Total}} = (c(q)(1 - q^1) + (c(q) + V)q^1(q))p_{A-1} + V \cdot q^0(1 - p_{A-1}) \tag{3.32}
\]

where
\[
p_{A-1} = P\{A_{\nu-1} < \frac{M}{2}\}
\approx P\left\{A_{\nu} < \frac{M}{2} - \lambda_0 \delta \right\}
\approx \sum_{k=0}^{\frac{M - \lambda_0 \delta}{2}} \left( e^{-\lambda_0 \delta} \frac{\lambda_0 \delta^k}{k!} \right)^{\frac{M}{2}} \cdot e^{-\lambda_0 \delta} \frac{\lambda_0 \delta^k}{k!} \tag{3.33}
\]
\[ q^0 \simeq 1 - \sum_{k=0}^{M/2-1} \left( \frac{\lambda_k \left( \gamma_0 + \mathbb{E}[\nu-1]\bar{\gamma} \right)^k}{k!} \cdot e^{-\lambda_0 \left( \gamma_0 + \mathbb{E}[\nu-1]\bar{\gamma} \right)} \right) \]  \hspace{1cm} (3.34)

\[ q^1(\varrho) = \sum_{j=0}^{M/2-1} \sum_{k \geq M/2+j} \left( \frac{\lambda_k \left( \gamma_0 + \mathbb{E}[\nu-1]\bar{\gamma} \right)^k}{k!} \cdot e^{-\lambda_0 \left( \gamma_0 + \mathbb{E}[\nu-1]\bar{\gamma} \right)} \right) P_j, \]  \hspace{1cm} (3.35)

\[ P_j = \left( \frac{M}{2} - 1 \right) \varrho^j \left( 1 - \varrho \right)^{M/2 - 1 - j}. \]  \hspace{1cm} (3.36)

The total cost \( \mathcal{G}(\varrho)_{\text{Total}} \) could be minimized by given \( \varrho \) is the optimal value of the reserved nodes. The below illustration in Fig. 3 is a typical graph of an optimal result by using the SABGG based ASDS network based on the given conditions in Table II.

Fig. 3. Optimization Example for the ASDS

IV. CONCLUSION

The Advanced Smart Drone Swarm (ASDS) is an enhanced secure drone swarm network architecture for protecting a drone swarm from an attacker. The ASDS is designed based on the decentralized network and adapts the SABGG for improving connectivity of drones in a swarm. The SABGG is a mathematically proven game model to develop optimal defense strategies to protect systems from attackers. The practical case in the paper demonstrates how an ADSD network could be implemented for a drone swarm.

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