COMPUTING OF PERFECT BAYESIAN EQUILIBRIUM INVOLVED IN RADIO-JAMMING WARFARE BASED ON INCOMPLETE INFORMATION DYNAMIC GAMES WITH KNOWN CHANCE *p*

Andrei LUCHIAN[*], Horațiu MOGA[**], Razvan BOBOC[*]

[*]Transilvania University, Brașov, Romania (riesigen@gmail.com, razvan_13_13@yahoo.com)
[**]CNIF-MFP, Braşov, Romania (horatiu.moga@gmail.com)

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Abstract: *The actual research paper proposes a model of radio-jamming warfare based on incomplete information dynamic games with known chance, with two actors and competing jamming and anti-jamming strategies. Our model based on the computing of perfect Bayesian equilibrium proof that anti-jamming solutions are more efficient than the classic ones.*

Keywords: *radio-jamming warfare, incomplete information dynamic games, known chance p*

1. INTRODUCTION

The current scientific and technological revolution has led to the rapid computerization of modern society. In this respect, the development of contemporary science and technology has enabled the world's armies to acquire electronic equipment and systems for research, command and control, communications, warning and protection, among which: modern electronic control systems, electronically controlled electronic systems integrated (as elements that condition the conduct of modern military actions), electronic sensors, performing computers capable of complex operations, satellite communications systems.

On these latest acquisitions, modern armies base their mobility, reaction speed and destruction capacity.

Electronic systems ensure and condition the holding and processing, as well as the transmission of a great deal of information, the optimization of troop leadership and the directing of the weapon at the real time scale, amplifying the power of the means of fire with precision, opportunity and efficiency. The operation of these systems is based on the use of electromagnetic energy, with the armies of the world becoming extremely dependent on the use of the electromagnetic space in their own interest.

As the share of electronic equipment in military equipment increased, the general aspect of combat action has changed, along with the energy component of the war, which defines the destructive character, and the information-decision component is also stated. With the introduction of these electronic systems a distinct form of the information warfare and a component of the command-control war appeared, namely RADIO-JAMMING WARFARE [1, 2, 3].

Electronic warfare is the main element of confrontation for achieving superiority in the use of electromagnetic space and plays an important role in achieving security, functioning of electronic systems, ensuring the social, political, economic and military activities of a country. We can say about the battlefield configuration that it has been heavily affected by the performance of all the technical and weapon categories provided by the defense industries under the impact of the technical-scientific revolution.

The actual research paper proposes a model of radio-jamming warfare based on incomplete information dynamic games with known chance [4, 5], with two actors and competing jamming and anti-jamming strategies [6, 7].

2. METHDOLOGY

The first step in this research is to define the jamming and anti-jamming strategies. The next approach are the next jamming strategies: Partial Dwell Jamming of FHSS Systems, Noise Jamming, Swept Jamming, Pulse Jamming, Follower Jamming. Follow the exposure of the anti-jamming strategies like: Direct Sequence Spread Spectrum, Fast Frequency Hopping Systems, Slow Frequency Hopping Systems, Ultra wideband Systems, Hybrid Spread Spectrum Systems. After define all the strategies propose a mathematical model of radio-jamming warfare between two actors using incomplete information dynamic games with known chance [6].

2.1.For radio-jamming strategies present below:

2.1.1.Partial Dwell Jamming of FHSS Systems - Frequency Spread-Spectrum (FHSS) systems are extensively used in military communications to neutralize the effects of various types of intentional blocking, including jamming and anti-jamming. FH communication can be locked effectively by blocking the successor [1, 2, 3, 6].

2.1.2.Noise Jamming - One way to prevent the proper functioning of a radar receiver (or any other receiver) is to saturate it with noise. The noise is a continuous signal and is different from the radar signal. Radar signal or echo is a periodic pulse sequence [1, 2, 3, 6].

2.1.3.Swept Jamming - Major techniques of noise interference. In the general blocking class, there are three different techniques for generating the night signal to be used. In the case of spot blocking, all the output power of the jamming antenna is concentrated in a very narrow bandwidth, ideally identical to that of the radar. The propagation barrier and jam propagate their energy over a bandwidth much higher than that of the radar signal [1, 2, 3, 6].

2.1.4.Pulse Jamming - The impulse requires the operator to know the rotation of a fixed enemy radar installation. At a prescribed point in the rotation of that radar, the jammer activates, thus negating the radar view of a particular sector. This sector does not have to align with the location of jamming, which makes it difficult for the enemy to locate the source of the jamming [1, 2, 3, 6].

2.1.5.Follower Jamming - Loop blocking is a jamming signal blocking means that can track the frequency of hopping, the instantaneous frequency of the jitter signal being narrower, but the frequency of each frequency may overlap. Tracker lock is a correlation of the blocking of a certain condition that the jamming power must reach the VHF receiver before moving to a new set of frequency channels [1, 2, 3, 6].

2.1.6. Conclusion 1: The most efficient jamming technique necessary to annihilate and comprehend the enemy's might over the battlefield is Follower Jamming followed by Partial Dwell Jamming. Thus using these types of jamming one does not reveal their position while executing vast maneuvers to annihilating the enemy's systems.

2.2.For anti-jamming strategies follow the next ones:

2.2.1.Direct Sequence Spread Spectrum - DSSS is a spread spectrum modulation technique used to transmit digital air wave signals.

It was originally developed for military use and used hard-to-detect broadband signals to resist jamming attempts. It is also developed for commercial purposes in local and wireless networks [1, 2, 3, 6].

2.2.2.Fast Frequency Hopping Systems - In the scattered spectrum with fast propagation frequency, the signal is a large cost on a random frequency spectrum from Frequency to Frequency, speaking a receiver unreliably. A reception between the frequency in synchronization with the transmitter, the part of the message signal reaches the "lock". It is a method of transmitting a radio signal by radio that rapidly switches a carrier between several frequency channels, using a pseudo administration sequence known to both the transmitter and the receiver [1, 2, 3, 6].

2.2.3.Slow Frequency Hopping Systems - Low Frequency Load is a process of changing the radio frequencies of a communication on a regular basis (model). The single frequency transmission is usually much longer than the time it takes to send multiple bits of digital information. Slow frequency synchronization is used to reduce the effects of fading radio signals and to minimize the effects of interference from radio channels operating on the same frequency [1, 2, 3, 6].

2.2.4.Ultra wideband Systems - Ultra-lateral communication systems (UWB) can be broadly classified as any communications system whose instantaneous bandwidth is often higher than the minimum needed to provide specific information. This excessive bandwidth is the defining feature of the UWB [1, 2, 3, 6].

2.2.5.Hybrid Spread Spectrum Systems - In recent years, there has been a great deal of interest in the use of HSS for commercial applications, especially within the Intelligent Network, in addition to their inherent uses in military communications. This is because HSS can accommodate high data rates with high integrity of links, even in the presence of significant multipath effects and interference signals [1, 2, 3, 6].

2.2.6. Conclusion 2: The best method to protect one's team would be to use the Ultra Wideband System followed by the Fast Frequency Hopping System. Using wideband one can extend its security measure thus assuring the enemy to use full force and expose itself while doing so and using fast frequency hopping system in the same time with wideband to intensify its protection.

Following conclusion 1 and 2 may we constructed table 1 with efficiency of anti-jamming versus jamming strategies. The meaning of the tables numbers are the following: 1 – the lowest efficiency; 2 - the low efficiency; 3 - the average efficiency; 4 - the high efficiency; 5 – the highest efficiency.

Table 1. Table established a ranking between anti-jamming and jamming methods

Jamming / Anti-Jamming	Partial Dwell Jamming of FHSS Systems	Noise jamming	Sweep jamming	Pulse jamming	Follower jamming
Direct Sequence Spread Spectrum	1	3	3	2	2
Fast Frequency Hopping Systems	5	2	3	2	4
Slow Frequency Hopping Systems	1	4	3	3	2
Ultra wideband Systems	5	2	3	3	4
Hybrid Spread Spectrum Systems	3	5	4	3	2

2.3. Scenario of using radio jamming strategies and radio electronic jamming - in our research we consider two W and V actors using radio-electronic / anti-jamming strategies in their radio-electronic confrontation.

The model of confrontation between W and V assumes that actor W maintains the average 3 radio-electronic and anti-jamming strategies. Actor V with a known p probability will improve his resilience and overwhelming capabilities from his original strategy of 1 or 2 jamming versus anti-jamming strategies efficiency to 4 or 5 final efficiency.

In our research for the behavior of the two actors W and V are modeled by the incomplete information dynamic game theory in which the nature of the actor V changes with a probability p. The significance of the utility functions for W and V players is the following calculated on the Cartesian product among the sterile ones two pre-modification and post-modification actors of the nature of V. For player W, the utility function grid indices in the game matrix have the meaning: matrix line 1 for the pure use of Noise Jamming jitter strategies; lines 2 and 3 for the concurrent use of Noise Jamming and Anti-Noise Jamming strategies; line 4 of the array is specific to using only Anti-Noise Jamming strategies. For actor V, the significance of the indices assigned to the utility functions in the game matrix are the following: column 1 of the game matrix for conjugate Swept Jamming and Follower Jamming; column 2 of the game matrix for conjugate Swept Jamming and Anti-Follower Jamming; column 3 of the game matrix for Follower Jamming and Anti-Swept Jamming conjugate use; column 4 of the game matrix for using Follower Jamming and Swept Jamming conjugate. For this dynamic game with incomplete information and with exogenous probability p will compute the perfect Bayesian equilibrium with Lagrange multiplier method in results section [4, 5].

Based on the above function definitions, we will define the incomplete information game equations that characterize the interaction between W and V [4, 5]. Where p_1, p_2, p_3 are the probabilities by which W opts for one of the four strategies obtained by the Cartesian product and mentioned above up. The probabilities q_1, q_2, q_3 represent the options V has for the same four strategies composed by Cartesian product [7].

$$\begin{cases} U^W = (p_1, p_2, p_3, 1-p_1-p_2-p_3)\cdot\begin{bmatrix} U_{11}^W & U_{12}^W & U_{13}^W & U_{14}^W \\ U_{21}^W & U_{22}^W & U_{23}^W & U_{24}^W \\ U_{31}^W & U_{32}^W & U_{33}^W & U_{34}^W \\ U_{41}^W & U_{42}^W & U_{43}^W & U_{44}^W \end{bmatrix}\cdot\begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ 1-q_1-q_2-q_3 \end{pmatrix} \\ U^V = (p_1, p_2, p_3, 1-p_1-p_2-p_3)\cdot\begin{bmatrix} U_{11}^V & U_{12}^V & U_{13}^V & U_{14}^V \\ U_{21}^V & U_{22}^V & U_{23}^V & U_{24}^V \\ U_{31}^V & U_{32}^V & U_{33}^V & U_{34}^V \\ U_{41}^V & U_{42}^V & U_{43}^V & U_{44}^V \end{bmatrix}\cdot\begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ 1-q_1-q_2-q_3 \end{pmatrix} \end{cases} \tag{1}$$

3. RESULTS

Applying the Lagrange multiplier method for relations (1), we get next six expressions in (2) [8, 9]:

$$\begin{cases} \frac{\partial U^W}{\partial p_1} = 0 \quad \frac{\partial U^W}{\partial p_2} = 0 \quad \frac{\partial U^W}{\partial p_3} = 0 \\ \frac{\partial U^V}{\partial q_1} = 0 \quad \frac{\partial U^V}{\partial q_2} = 0 \quad \frac{\partial U^V}{\partial q_3} = 0 \end{cases} \tag{2}$$

Development of first partial derivative in expressions (3), (4), (5) with substitutions of (6), (7), (8) drive to system of equations (16).

$$\frac{\partial U^W}{\partial p_1} = (1,0,0,-1) \cdot \begin{bmatrix} U_{11}^W & U_{12}^W & U_{13}^W & U_{14}^W \\ U_{21}^W & U_{22}^W & U_{23}^W & U_{24}^W \\ U_{31}^W & U_{32}^W & U_{33}^W & U_{34}^W \\ U_{41}^W & U_{42}^W & U_{43}^W & U_{44}^W \end{bmatrix} \cdot \begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ 1-q_1-q_2-q_3 \end{pmatrix} = 0 \tag{3}$$

$$\frac{\partial U^W}{\partial p_2} = (0,1,0,-1) \cdot \begin{bmatrix} U_{11}^W & U_{12}^W & U_{13}^W & U_{14}^W \\ U_{21}^W & U_{22}^W & U_{23}^W & U_{24}^W \\ U_{31}^W & U_{32}^W & U_{33}^W & U_{34}^W \\ U_{41}^W & U_{42}^W & U_{43}^W & U_{44}^W \end{bmatrix} \cdot \begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ 1-q_1-q_2-q_3 \end{pmatrix} = 0 \tag{4}$$

$$\frac{\partial U^W}{\partial p_3} = (0,0,1,-1) \cdot \begin{bmatrix} U_{11}^W & U_{12}^W & U_{13}^W & U_{14}^W \\ U_{21}^W & U_{22}^W & U_{23}^W & U_{24}^W \\ U_{31}^W & U_{32}^W & U_{33}^W & U_{34}^W \\ U_{41}^W & U_{42}^W & U_{43}^W & U_{44}^W \end{bmatrix} \cdot \begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ 1-q_1-q_2-q_3 \end{pmatrix} = 0 \tag{5}$$

$$\begin{aligned} &a_{11} \stackrel{\text{def}}{=} (U_{11}^W - U_{41}^W) - (U_{14}^W - U_{44}^W) \quad a_{12} \stackrel{\text{def}}{=} (U_{12}^W - U_{42}^W) - (U_{14}^W - U_{44}^W) \\ &a_{13} \stackrel{\text{def}}{=} (U_{13}^W - U_{43}^W) - (U_{14}^W - U_{44}^W) \quad b_1 \stackrel{\text{def}}{=} U_{44}^W - U_{14}^W \end{aligned} \tag{6}$$

$$\begin{aligned} &a_{21} \stackrel{\text{def}}{=} (U_{21}^W - U_{41}^W) - (U_{24}^W - U_{44}^W) \quad a_{22} \stackrel{\text{def}}{=} (U_{22}^W - U_{42}^W) - (U_{24}^W - U_{44}^W) \\ &a_{23} \stackrel{\text{def}}{=} (U_{23}^W - U_{43}^W) - (U_{24}^W - U_{44}^W) \quad b_2 \stackrel{\text{def}}{=} U_{44}^W - U_{24}^W \end{aligned} \tag{7}$$

$$\begin{aligned} &a_{31} \stackrel{\text{def}}{=} (U_{31}^W - U_{41}^W) - (U_{34}^W - U_{44}^W) \quad a_{32} \stackrel{\text{def}}{=} (U_{32}^W - U_{42}^W) - (U_{34}^W - U_{44}^W) \\ &a_{33} \stackrel{\text{def}}{=} (U_{33}^W - U_{43}^W) - (U_{34}^W - U_{44}^W) \quad b_3 \stackrel{\text{def}}{=} U_{44}^W - U_{34}^W \end{aligned} \tag{8}$$

Development of first partial derivative in expressions (10), (11), (12) with substitutions of (13), (4), (15) drive to system of equations (17).

$$\frac{\partial U^V}{\partial q_1} = (p_1, p_2, p_3, 1-p_1-p_2-p_3) \cdot \begin{bmatrix} U_{11}^V & U_{12}^V & U_{13}^V & U_{14}^V \\ U_{21}^V & U_{22}^V & U_{23}^V & U_{24}^V \\ U_{31}^V & U_{32}^V & U_{33}^V & U_{34}^V \\ U_{41}^V & U_{42}^V & U_{43}^V & U_{44}^V \end{bmatrix} \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \\ -1 \end{pmatrix} = 0 \tag{10}$$

$$\frac{\partial U^V}{\partial q_2} = (p_1, p_2, p_3, 1-p_1-p_2-p_3) \cdot \begin{bmatrix} U_{11}^V & U_{12}^V & U_{13}^V & U_{14}^V \\ U_{21}^V & U_{22}^V & U_{23}^V & U_{24}^V \\ U_{31}^V & U_{32}^V & U_{33}^V & U_{34}^V \\ U_{41}^V & U_{42}^V & U_{43}^V & U_{44}^V \end{bmatrix} \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \\ -1 \end{pmatrix} = 0 \tag{11}$$

$$\frac{\partial U^V}{\partial q_3} = (p_1, p_2, p_3, 1-p_1-p_2-p_3) \cdot \begin{bmatrix} U_{11}^V & U_{12}^V & U_{13}^V & U_{14}^V \\ U_{21}^V & U_{22}^V & U_{23}^V & U_{24}^V \\ U_{31}^V & U_{32}^V & U_{33}^V & U_{34}^V \\ U_{41}^V & U_{42}^V & U_{43}^V & U_{44}^V \end{bmatrix} \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \\ -1 \end{pmatrix} = 0 \tag{12}$$

$$\begin{aligned} &c_{11} \stackrel{\text{def}}{=} (U_{11}^V - U_{14}^V) - (U_{41}^V - U_{44}^V) \quad c_{12} \stackrel{\text{def}}{=} (U_{21}^V - U_{24}^V) - (U_{41}^V - U_{44}^V) \\ &c_{13} \stackrel{\text{def}}{=} (U_{31}^V - U_{34}^V) - (U_{41}^V - U_{44}^V) \quad d_1 \stackrel{\text{def}}{=} U_{44}^V - U_{41}^V \end{aligned} \tag{13}$$

$$\begin{aligned} &c_{21} \stackrel{\text{def}}{=} (U_{12}^V - U_{14}^V) - (U_{42}^V - U_{44}^V) \quad c_{22} \stackrel{\text{def}}{=} (U_{22}^V - U_{24}^V) - (U_{42}^V - U_{44}^V) \\ &c_{23} \stackrel{\text{def}}{=} (U_{32}^V - U_{34}^V) - (U_{42}^V - U_{44}^V) \quad d_2 \stackrel{\text{def}}{=} U_{44}^V - U_{42}^V \end{aligned} \tag{14}$$

$$c_{31} \stackrel{\text{def}}{=} (U^V_{13} - U^V_{14}) - (U^V_{43} - U^V_{44}) \quad c_{32} \stackrel{\text{def}}{=} (U^V_{23} - U^V_{24}) - (U^V_{43} - U^V_{44})$$
$$c_{33} \stackrel{\text{def}}{=} (U^V_{33} - U^V_{34}) - (U^V_{43} - U^V_{44}) \quad d_3 \stackrel{\text{def}}{=} U^V_{44} - U^V_{43} \tag{15}$$

Following the above substitutions, we obtain solutions for the perfect Bayesian equilibrium of the dynamic game with incomplete information based on determinants [4, 5]:

$$\begin{cases} \dfrac{\partial U^W}{\partial p_1} = a_{11}\cdot q_1 + a_{12}\cdot q_2 + a_{13}\cdot q_3 = b_1 \\ \dfrac{\partial U^W}{\partial p_2} = a_{21}\cdot q_1 + a_{22}\cdot q_2 + a_{23}\cdot q_3 = b_2 \\ \dfrac{\partial U^W}{\partial p_3} = a_{31}\cdot q_1 + a_{32}\cdot q_2 + a_{33}\cdot q_3 = b_3 \end{cases} \tag{16}$$

$$\Delta_q = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{12} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \quad \Delta_{q1} = \begin{vmatrix} b_1 & a_{12} & a_{13} \\ b_2 & a_{22} & a_{23} \\ b_3 & a_{32} & a_{33} \end{vmatrix}$$
$$\Delta_{q2} = \begin{vmatrix} a_{11} & b_1 & a_{13} \\ a_{12} & b_2 & a_{23} \\ a_{31} & b_3 & a_{33} \end{vmatrix} \quad \Delta_{q3} = \begin{vmatrix} a_{11} & a_{12} & b_1 \\ a_{12} & a_{22} & b_2 \\ a_{31} & a_{32} & b_3 \end{vmatrix}$$

$$\begin{cases} \dfrac{\partial U^V}{\partial q_1} = c_{11}\cdot p_1 + c_{12}\cdot p_2 + c_{13}\cdot p_3 = d_1 \\ \dfrac{\partial U^V}{\partial q_2} = c_{21}\cdot p_1 + c_{22}\cdot p_2 + c_{23}\cdot p_3 = d_2 \\ \dfrac{\partial U^V}{\partial q_3} = c_{31}\cdot p_1 + c_{32}\cdot p_2 + c_{33}\cdot p_3 = d_3 \end{cases} \tag{17}$$

$$\Delta_p = \begin{vmatrix} c_{11} & c_{12} & c_{13} \\ c_{12} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{vmatrix} \quad \Delta_{p1} = \begin{vmatrix} d_1 & c_{12} & c_{13} \\ d_2 & c_{22} & c_{23} \\ d_3 & c_{32} & c_{33} \end{vmatrix}$$
$$\Delta_{p2} = \begin{vmatrix} c_{11} & d_1 & c_{13} \\ c_{12} & d_2 & c_{23} \\ c_{31} & d_3 & c_{33} \end{vmatrix} \quad \Delta_{p3} = \begin{vmatrix} c_{11} & c_{12} & d_1 \\ c_{12} & c_{22} & d_2 \\ c_{31} & c_{32} & d_3 \end{vmatrix}$$

Computing the probabilities (18) and (19) will get the perfect Bayesian equilibrium solution for the transition of strategies followed by actor V with expression (20) and (21) [4, 5].

$$\begin{cases} q_{01} = \dfrac{\Delta_{q1}}{\Delta_q} \\ q_{02} = \dfrac{\Delta_{q2}}{\Delta_q}, \Delta_q \neq 0 \\ q_{03} = \dfrac{\Delta_{q3}}{\Delta_q} \end{cases} \tag{18}$$

$$\begin{cases} p_{01} = \dfrac{\Delta_{p1}}{\Delta_p} \\ p_{02} = \dfrac{\Delta_{p2}}{\Delta_p}, \Delta_p \neq 0 \\ p_{03} = \dfrac{\Delta_{p3}}{\Delta_p} \end{cases} \tag{19}$$

$$U_0^W = (p_{01}, p_{02}, p_{03}, 1 - p_{01} - p_{02} - p_{03}) \cdot \begin{bmatrix} U^W_{11} & U^W_{12} & U^W_{13} & U^W_{14} \\ U^W_{21} & U^W_{22} & U^W_{23} & U^W_{24} \\ U^W_{31} & U^W_{32} & U^W_{33} & U^W_{34} \\ U^W_{41} & U^W_{42} & U^W_{43} & U^W_{44} \end{bmatrix} \cdot \begin{pmatrix} q_{01} \\ q_{02} \\ q_{03} \\ 1 - q_{01} - q_{02} - q_{03} \end{pmatrix} \tag{20}$$

$$U_0^V = (p_{01}, p_{02}, p_{03}, 1 - p_{01} - p_{02} - p_{03}) \cdot \begin{bmatrix} U^V_{11} & U^V_{12} & U^V_{13} & U^V_{14} \\ U^V_{21} & U^V_{22} & U^V_{23} & U^V_{24} \\ U^V_{31} & U^V_{32} & U^V_{33} & U^V_{34} \\ U^V_{41} & U^V_{42} & U^V_{43} & U^V_{44} \end{bmatrix} \cdot \begin{pmatrix} q_{01} \\ q_{02} \\ q_{03} \\ 1 - q_{01} - q_{02} - q_{03} \end{pmatrix} \tag{21}$$

CONCLUSIONS AND FUTURE WORKS

Computing the perfect Bayesian equilibrium in this paper research proves that anti-jamming solutions for the best results in protecting one's team is more efficient nowadays in comparison to the jamming solution offered. While one searches and „jamms", another becomes vulnerable due to the fact that he must expose himself to do so. This research proves that the wideband anti-jamming solution still has an Achilles foot, more exactly the follower jammer and of course a wideband equipment at end of the line that works in the same frequency range as him.

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