Intention-Situation Dual-Driven Anti-Jamming Communication Mechanism for Data Links

Wenjing Yang
The 10th Research Institute of CETC, Chengdu, Sichuan, China

Abstract: To address the problems of high susceptibility to interference and poor adaptability of data link communication in complex electromagnetic environments, an anti-jamming communication mechanism based on intention-situation dual drive is constructed. This mechanism dynamically adjusts communication strategies by perceiving intentions and electromagnetic situations, and achieves precise resource allocation by utilizing spectrum access, power control, and routing optimization models. Experiments show that this mechanism significantly improves the communication success rate, reduces latency, and provides a technical reference for the stable transmission of data links.

Keywords: Intention; Electromagnetic Situation; Data Link; Anti-Jamming Communication Mechanism

1. Introduction

With the increasingly fierce electromagnetic spectrum warfare, data link communication is facing severe interference challenges. Traditional anti-jamming technologies are mostly based on fixed rules and lack comprehensive consideration of intentions and dynamic situations, resulting in decreased communication efficiency in complex interference scenarios. The intention-situation dual-driven mechanism aims to deeply integrate task requirements and environmental impacts to intelligently schedule communication resources [1]. However, existing research focuses on optimizing a single dimension and lacks the construction of a systematic dual-driven mechanism. Based on this, this paper proposes an intention-situation dual-driven anti-jamming communication mechanism for data links, establishes a mapping model of intention and situation, designs dynamic spectrum access, power control, and routing optimization mechanisms, and verifies them in typical scenarios. This mechanism solves the problem of insufficient adaptability of traditional methods and improves the survivability of data links in strong interference environments.

2. Theoretical Basis and Mechanism Constraint Modeling of Intention-Situation Dual-Driven

2.1 Anti-Jamming Mechanism Based on Intention-Situation Dual-Driven

The core of the intention-situation dual-driven anti-jamming mechanism is to take task intentions and real-time electromagnetic situations as important inputs for communication decision-making. Intentions determine the Quality of Service (QoS) requirements of communication services, such as latency, reliability, and priority; electromagnetic situations reflect channel quality, interference intensity, and spectrum availability. The two work synergistically to promote the communication system to dynamically adjust waveforms, frequencies, and power. In terms of mechanism implementation, it is first necessary to construct an intention recognition model, decompose high-level tasks into specific communication demand vectors, and then collect real-time electromagnetic environment data through a spectrum sensing network to form a situation map [2]. On this basis, a decision engine is used to accurately match intention requirements and situation constraints, thereby generating the optimal communication strategy. For example, in high-priority tasks, the system can sacrifice spectrum efficiency in exchange for higher anti-jamming gain; in low-priority tasks, it focuses on resource saving to ensure the flexibility of the communication system in complex electromagnetic environments [3].

2.2 Anti-Jamming Modeling of Data Links Based on Intention-Situation Dual-Driven

To realize the quantitative analysis of the dual-driven mechanism, it is necessary to establish a mathematical model to describe the constraint relationship between intention and situation, and define intention vectors, situation vectors, and communication strategies. The goal of anti-jamming modeling is to maximize communication efficiency under the premise of meeting intention constraints. The constraint conditions include maximum allowable latency, minimum Signal to Interference plus Noise Ratio (SINR), and upper power limit. The model needs to reflect the nonlinear impact of intention urgency and situation deterioration degree on strategy selection. By introducing weight coefficients, the proportion of intention and situation in decision-making can be adjusted. When the situation deteriorates, the model should automatically increase the intensity of anti-jamming measures; when the intention priority increases, the model should give priority to ensuring key link resources. This modeling process is essentially a multi-objective optimization problem that needs to balance transmission reliability, spectrum efficiency, and energy consumption, providing a clear optimization direction for subsequent algorithm design.

2.3 Support for Intention-Situation Dual-Driven Anti-Jamming Communication of Data Links

After the model is constructed, it is necessary to analyze the support capability of the communication system for the dual-driven mechanism. First, at the perception level, the system needs to have broadband spectrum monitoring and interference identification capabilities to ensure the accuracy of situation data. Second, at the decision-making level, a high-performance processing unit is deployed to support the rapid solution of complex optimization algorithms and meet the timeliness requirements of data link transmission. Finally, at the execution level, Software Defined Radio (SDR) technology [4] provides a hardware foundation for waveform reconstruction and dynamic parameter adjustment. Through standardized interfaces, the perception, decision-making, and execution modules can achieve efficient collaboration. In addition, the distributed architecture supports information sharing between nodes, avoids communication paralysis caused by single-point failures, and ensures that the dual-driven mechanism can be transformed from a theoretical model into actual communication capabilities, thus providing a solid guarantee for the stable operation of the data link in dynamic environments.

3. Construction of Intention-Situation Dual-Driven Anti-Jamming Communication Mechanism for Data Links

3.1 Dynamic Spectrum Access Mechanism

On the basis of completing the modeling of task intention and electromagnetic situation, constructing a dynamic spectrum access mechanism becomes a key link to improve anti-jamming capability. The core function of this mechanism is to dynamically select the optimal communication frequency band according to situation perception results, avoid interference sources, improve spectrum utilization, and provide an interference-free transmission channel for high-priority tasks [5]. In theoretical analysis, spectrum access needs to consider interference probability and handover cost. Assume that the spectrum set is F , the interference probability is P_i , and the handover cost is C_s . The access decision can be expressed as:

$$U = \sum_{j=1}^{M} (1 - P_j) \cdot B_j - \lambda \cdot C_s \qquad (1)$$

Where: U is the utility function; M is the number of available frequency bands; B_j is the bandwidth of the j-th frequency band; λ is the cost weight coefficient. Formula (1) reveals the essence of spectrum selection, which is to seek a balance between avoiding interference and reducing handover overhead.

In terms of detailed implementation, the system monitors the interference level of each frequency band in real time. When the interference of the current frequency band is detected to exceed the threshold, the handover process is triggered. Combined with intention priority, high-priority tasks can ignore part of the handover cost and force access to high-quality frequency bands. In this process, situation data is mapped to interference probability in real time, and intention data is mapped to cost weight, thus forming a complete closed-loop spectrum access and ensuring the continuity of the communication link in dynamic electromagnetic environments [6].

3.2 Adaptive Power Control Mechanism

In data link communication, achieving anti-jamming requires not only spectrum avoidance but also maintaining signal quality through power adjustment. The role of the adaptive power control mechanism is to accurately match the transmit power with the channel state and task requirements, thereby ensuring communication reliability with minimal power. The significance of this mechanism is to solve the near-far effect and exposure risk, enabling the communication network to maintain overall concealment in complex business scenarios. At the theoretical level, power control needs to meet the Signal to Interference plus Noise Ratio (SINR) constraint [7]. Assume that the transmit power is P_t, the channel gain is G, and the interference power is I. The optimization problem can be formulated as:

$$\min P_t \quad \text{s.t.} \quad \frac{P_t \cdot G}{I+N} \geq \gamma_r \qquad (2)$$

Where: γ_r is the target SINR threshold; N is the noise power. Formula (2) reveals the essence of power control, which is to minimize the transmit power under the premise of meeting communication quality, and highlights that a higher γ_r can be set for high-priority tasks.

In terms of technical mechanism, the receiving end measures the SINR in real time and feeds it back to the transmitting end. The transmitting end adjusts the target threshold according to the intention level. Combined with situation information, if strong interference is detected, the system automatically increases the power to effectively maintain the link; if the environment is good, the power is reduced to reduce the risk of detection. Combined with reliability and concealment constraints, this mechanism reduces energy waste through dynamic adjustment while ensuring the stability of key task links, thus maintaining the coordination of global communication [8].

3.3 Cooperative Routing Optimization Mechanism

In complex electromagnetic environments, data link communication relies not only on the quality of a single link but also must solve the problem of path stability in multi-hop transmission. The role of the cooperative routing optimization mechanism is to introduce neighbor node information and global situation at the near end, so that data packets can minimize latency while maintaining high reliability. At the theoretical level, route selection needs to comprehensively consider link quality and remaining node energy. Assume that the path cost is C_p and the link latency is T_l. The routing metric can be decomposed into:

$$C_p = \sum_{k=1}^{H} (\alpha \cdot T_l + \beta \cdot E_e^{-1}) \qquad (3)$$

Where: H is the number of hops; α and β are weight coefficients; E_e is the residual energy of the e -th node. In Formula (3), since T_l fluctuates under the influence of interference, cooperative routing can significantly shorten the response time of the overall communication closed loop, enabling high-priority tasks to maintain stable response under high concurrency conditions [9].

In terms of technical mechanism, the routing protocol establishes multi-path transmission channels by exchanging local situation information, ensuring that even if a certain path is interfered with or interrupted, data packets can reach the target node through other links. Combined with intention information, key data can be transmitted redundantly along multiple paths. Combined with reliability constraints, this mechanism reduces the risk of packet loss through multi-path distribution and ensures clock consistency between distributed nodes, thus maintaining the coordination of global decision-making [10].

4. Experiment Design and Verification

4.1 Experimental Platform and Test Scenarios

The experimental platform is built based on a software-hardware combined verification environment. The hardware part includes software-defined radio nodes supporting dynamic spectrum access, gateways with multi-path redundant interfaces, and communication control terminals equipped with real-time operating systems. The software employs distributed routing protocols and power control algorithms to realize dynamic regulation of frequency bands, transmit power, and routing paths. An electromagnetic situation sensing module is integrated into the platform to perform near-end jamming detection and feature extraction, shortening the decision-making path and improving the response speed of anti-jamming operations.

Test scenarios are designed around the typical business requirements of data link anti-jamming communication. Scenario 1 sets high-priority tasks, such as simulating the issuance of emergency instructions, to test the role of dynamic spectrum access and power control under millisecond-level response; Scenario 2 designs regular data tasks, including status reporting and log transmission, to evaluate the guarantee capability of routing optimization in case of resource conflicts; Scenario 3 sets strong interference tasks, such as simulating suppressive interference and deceptive interference, focusing on investigating the survivability of cooperative routing and link redundancy mechanisms under extreme conditions.

4.2 Experimental Results and Analysis

To comprehensively verify the intention-situation dual-driven data link anti-jamming communication mechanism proposed in this study, experiments were conducted for high-priority, regular data, and strong interference tasks respectively. The high-priority task tests the millisecond-level response capability of the communication system in scenarios such as the issuance of emergency instructions; the regular data task simulates status reporting and log transmission to test the routing scheduling performance under multi-task concurrency; the strong interference task evaluates the link redundancy and data integrity guarantee effect under suppressive and deceptive interference. High-priority tasks need to complete end-to-end response within 10 ms, and the instruction success rate must be higher than 99.0%; regular data tasks need to complete response within 100 ms and maintain stable throughput to support status reporting; although the latency requirement for strong interference tasks is relatively loose, the data integrity rate must be no less than 95% to support key information transmission. The experimental results under the three types of task scenarios are shown in Table 1.

It can be seen from Table 1 that under the action of dynamic spectrum access and power control mechanisms, high-priority tasks achieve an end-to-end delay of less than 10 ms and an instruction success rate close to 100%, which can meet the strict control requirements of the data link in scenarios such as the issuance of emergency instructions. With the support of cooperative routing optimization, regular data tasks maintain a throughput of more than 400 kb/s, and the end-to-end delay and packet loss rate are within controllable ranges, indicating that the data link network can ensure the continuity and stability of status reporting and log transmission. Although the delay of strong interference tasks is relatively high, the data integrity rate remains above 95%, which fully indicates that the link redundancy mechanism effectively improves communication reliability under extreme interference environments.

Table 1. Experimental Results

Scenario Category	End-to-End Delay/ms	Instruction Success Rate/%	Throughput/(kb/s)	Data Integrity Rate/%	Jitter Delay/ms
High-priority Task	4.6	99.7	118	99.9	0.6
Regular Data Task	60	97.5	415	98.9	3.2
Strong Interference Task	182	96.1	565	99.6	5

5. Conclusion

The intention-situation dual-driven data link anti-jamming communication mechanism constructed in this paper breaks through the performance bottleneck of traditional communication in complex electromagnetic environments through the coordination of spectrum access, power control, and routing optimization. Experimental tests show that the mechanism can provide deterministic communication guarantee for high-priority tasks and exhibit significant survival advantages in strong interference scenarios, confirming its engineering application value in improving the real-time performance and reliability of data links. In the future, we will further study artificial intelligence-assisted intention recognition algorithms, optimize spectrum efficiency in combination with cognitive radio, and explore multi-domain cooperative communication schemes.

References

[1] Li S Q, Cheng Y F, Dong B H, et al. Research on intelligent anti-jam communication techniques. Radio Communications Technology, 2012, 38 (1): 01-04.

[2] Gao X C. A method of intention assessment based on motion state. Electronic Information Warfare Technology. 2025, 40 (2):47-51.

[3] Zhang Y Q, Wang K, Huang Z C, et al. Situation prediction of jamming signal based on Transformer-LSTM network. Aerospace Electronic Warfare, 2025, 41 (4):16-26.

[4] Huang J W, Zhang M W, Liu K L, et al. Investigation on interference effects of LFM signals on QPSK communication systems based on SDR. High Power Laser and Particle Beams, 2025, 37 (12):01-08.

[5] Wang X M, Wang J L, Xu Y H, et al. Dynamic spectrum anti-jamming communications: challenges and opportunities. IEEE Communications Magazine, 2020, 58 (2):79 85.

[6] Liu S H, Li T, Li F Q, et al. Intent and situation-dual driven anti-jamming communication mechanism for data link. Systems Engineering and Electronics, 2025, 47 (6):2055-2064.

[7] Zhang M W, Ma C G, Huang J W, et al. Investigating dual-frequency HPM interference effect on communication system: insights from LNA to SDR. IEEE Access, 2024, 12:173410-173417.

[8] Wang W. Study on anti-jamming system of the communication network based on OFDM. Software, 2024, 45 (10):148-150.

[9] Yang L K. Anti-interference system of hospital communication network data link based on reinforcement learning. Electronic Design Engineering, 2023, 31 (16):153-156, 161.

[10]Li Y C, Bai S Z, Gao Z Z. A multi-domain anti-jamming strategy using Stackelberg game in wireless relay networks. IEEE Access, 2020, 8:173609-173617.