A Novel Intelligent Radar Detection Network

Junhua Zhang
Nanjing Glarun Defense System Co., Ltd, Nanjing, Jiangsu Province, 210039, China
tombrain@163.com

Abstract. A novel Intelligent Radar Detection Network (IRDN) is proposed to be able to flexibly decompose and re-aggregate all functional elements in OODA cycle, so as to establish a new kind of all-domain kill web featuring on-demand service, flexibility, scalability and optimal kill channel, which can obtain and maintain asymmetric air defense superiority with benefits from all-domain sensing, all-domain C2 and all-domain strike capabilities.

1. Introduction
Introduction of mosaic warfare theory into the construction of Intelligent Radar Detection Network (IRDN) will greatly improve the operational flexibility and dynamic responsiveness. However, at present, there is no unified and clear understanding of the theoretical concept and system construction, so it is very necessary to study on it.

2. Demand Analysis
Nowadays, operation system of systems is usually a complex system composed of geographically dispersed and complementary combat element such as detection systems, command systems, communication systems and weapon systems.
Under the condition of modern informatization, the encountering battlefield environment is becoming more complex. Air threats have evolved from a single threat to SoS threats. Air attack platforms have expanded from conventional threats to stealthy, high-speed/hypersonic, unmanned, swarms, tactical ballistic missiles and other targets. Air attack modes have been evolving from stand-in attack to long-range with guided missiles. And, electromagnetic countermeasures during air raid have evolved from on-site confrontation to being running through the whole process of air raid.
In order to achieve efficient defense operations, the air defense system needs to obtain air information from multiple sources such as land-based, maritime, airborne or spaceborne platforms, so as to find as farther as possible, respond as earlier as possible and intercept as soon as possible.

3. IRDN Network
Fully-Adaptive Sensing Network (IRDN) proposed in this paper adopts “Cloud-Terminal” network information architecture. "All are Resources and All are Services" can be realized by intelligently managing and controlling all kinds of battlefield resources according to the decomposition of the “Observe-Orient-Decision-Act” loop.
In accordance with specific requirements of different tasks, different stages and different targets,
killing loops are formed with flexible, dynamic, diversified and adaptive combination, and a highly decentralized and flexible distributed killing network and optimal killing channel are formed, so as to achieve the expected operation efficiency and deal with dynamic and diversified threats.

3.1. IRDN Composition

According to actual operational requirements, IRDN architecture can be divided into six layers: Equipment Layer, Supplier Layer, Algorithm Layer, Management Layer, Service Layer and Application Layer.

Equipment Layer consists of traditional equipment for air defense tasks, such as AWACS aircrafts, floating balloons, fighters, air surveillance radars, SAMs and ground command stations.

The supplier layer abstracts and aggregates various heterogeneous and decentralized air defense elements through virtualization technology to form mosaic components and element suppliers, including detection suppliers, network suppliers, shooter suppliers, weapon suppliers, data suppliers and computing suppliers, which are combined into a "Capability Supermarket".

Algorithm Layer is the algorithm set supporting the function execution, including intelligent resource management and scheduling algorithm, real-time task planning algorithm, intelligent data fusion algorithm, collaborative control algorithm, etc.

Figure 1. Composition of IRDN Network
Management Layer refers to the management of various element resources, including detection resource management, shooter resource management, data resource management, storage resource management, etc.

Service Layer carries out real-time and high-speed resource management and scheduling based on various combat resources provided by the supplier layer to form the services necessary for specific operation, including detection services, tracking services, fire control solution services, guidance services, etc.

Application Layer dynamically combines various services according to the type of combat task to form different application modules, including counter-stealth application, counter-hypersonic application, counter-cruise-missile application, counter-UAV etc.

3.2. IRDN Features

Compared with traditional sensing network, IRDN network is a huge and complex SoS, which has the characteristics and advantages that traditional sensing network does not have.

a) Multi-Domain Integration: all sensing resources existing in land, sea, air and space domains are integrated with the aid of high-speed data transmission network into an organic all-domain sensing network featuring wide-area coverage, ubiquitous access and deep integration, so that wide-area detection and accurate detection can be achieved.

b) Dynamic SoS Reconfiguration: based on ad-hoc and open architecture design, various sensing elements can be accessed at any time for plug-and-play, generating one service-oriented detection system, which has changed from centralized resource aggregation to mission-driven resource intensity with flexible survivability. Even if some elements in IRDN network are degraded or damaged, the whole network can still be quickly reconstructed and responded as needed to obtain expected operation efficiency.

c) Cloud-Terminal Collaboration: Based on Cloud-Terminal network information architecture, Cloud is responsible for big data storage, computation, training and distributed cloud node management, while small-scale local computation, storage and control sink into Terminals. Moreover, various mosaic components are accessed whenever they encounter, showing decentralized and dynamic self-organizing networking, forming an intelligent, general-purpose and service-oriented network information system, changing from centralized and pipeline resource concentration to task driven, intelligent and autonomous resource concentration, so as to realize real-time, high-speed and autonomous battlefield resource management and control. So, distributed collaboration is vital to solve low network latency and high data traffic restricting rapid detection data acquisition, processing and situation decision-making, which becomes the cornerstone of Sense-to-Decision-Making.

d) Intelligent Real-Time Processing: Based on artificial intelligence, real-time processing, deep integration and intelligent analysis of big data generated by IRDN network are conducted to achieve real-time response, situation consistency, sharing on demand, dynamic adjustment and rapid decision-making.

e) Menu-style Solution Matching: Traditional operations pursue huge systems, centralized resources and complex single platform design, resulting in bloated system, resource waste and huge cost. IRDN network is pursuing "not for me, but for me" on battlefield resources, so as to achieve a high degree of resource intensification and functional modularization. Based on the high resource intensity and functional modularization, detection node resources in IRDN network can be coordinated and scheduled in accordance with operational objectives, mission scenarios, battlefield electromagnetic environment, resource situation etc. Consequently, a flexible, optimal and cheapest menu-style solution is generated, matching specific task, specific scenario and specific resources.

f) Iterative Evolution: IRDN network is new emerging things, and its architecture, form and capability are in continuously iterative evolution. At present, IRDN network is mainly used to execute netting detection in large airspace and in large scale for information sharing and multi-source data fusion. In the future, IRDN can work in consistency with a specific mission scenario, carry out unified
decision-making and collaborative resource scheduling of radar frequency modes, transmitting energy, signal parameters and back-end processing of radars with different frequency bands, systems, functions and platforms in IRDN, executing real-time fusion and sharing of radar detection signals.

3.3. IRDN Operation Mechanism

The traditional winning mechanism pursues the energy advantage based on linear accumulation, while IRDN pursues the knowledge advantage driven by artificial intelligence, software and hardware integration and the advantage of information-fire integration. Based on the millisecond or even microsecond evaluation and decision planning of multi-domain rapid acquire, distributed high-speed processing and human-machine interaction, it greatly reduces the OODA loop time and achieves on-demand, fast and accurate strike effect.

In scenario of air defense operations, IRDN adopts the Cloud-Terminal architecture, and the whole system is divided into two parts: Supplier Cloud and Function Client. The Supplier Cloud is distributed in the ground-based air defense command posts or AWACS aircrafts, responsible for the control and scheduling of various battlefield resources and completing the air defense battle command process. Function Client no longer refers to an independent combat platform, but refers to various functional elements for air defense tasks. Each element may be concentrated on a single platform or widely dispersed in geospatial space, including detection clients, command clients, shooter clients, weapon clients, etc., constantly providing corresponding data, resources and services to Supplier Cloud and requesting for data, resources and services from the cloud according to specific combat mission requirements.

![Figure 2. IRDN Operation Mechanism in Air Defense Scenario](image)

Compared with the traditional air defense system, the decoupling degree of air defense elements in IRDN network has reached to a new level, which is no longer limited to the limitations of each platform, but dynamically optimizes and combines the operational functional elements of the whole system to launch weapons from any shooter platform based on the data of any sensor, forming a freely reconfigurable and robustly enabled distributed air defense network.

4. IRDN Efficiency Evaluation

To evaluate the sensing efficiency of IRDN network, a efficiency evaluation model is established with four dimensions including Sensing Service, Sensing Characteristics and Technology Maturity. Sensing Service (S) includes search service (S1), tracking service (S2), guidance service (S3) and assessment service (S4). Sensing Characteristics (C) includes four elements: SoS scale, SoS flexibility, sensing accuracy and sensing implementation, which are expressed as C1, C2, C3 and C4 respectively. Technology Maturity are expressed as M1~M5 respectively.

Based on AHP, the evaluation matrix of evaluation indexes at all levels is established according to the scale of 1-9. According to \( Cr=(\lambda_{max}-m)/(m-1) \) * R1 test the consistency of evaluation and calculate the weight of indicators at all levels.

Among them, the primary indicator set is set as \( A_{IRDN} = \{S, C, M\} \), the respective weight vectors are \( \omega = \{ \omega_S, \omega_C, \omega_M \} \). For the primary indicator s, the secondary indicator set is \( S_s = \{S_1, S_2, S_3, S_4\} \), the
weight vector is set to $\omega_i=\{\omega_{S1}, \omega_{S2}, \omega_{S3}, \omega_{S4}\}$. Then the comprehensive operational effectiveness coefficient of S is $E_S=E_{S1}\times\omega_{S1}+E_{S2}\times\omega_{S2}+E_{S3}\times\omega_{S3}+E_{S4}\times\omega_{S4}$. Other secondary indicators are analogized.

Finally, the comprehensive detection efficiency index of sagirn is $E_{IRDN}=E_S\times\omega_S+E_C\times\omega_C+E_M\times\omega_M$. Taking the traditional network as the reference, the capability index of IRDN is about 1.95, showing that the sensing efficiency of IRDN is about twice that of traditional sensing network.

5. Conclusions
With the continuous development of machine learning, deep learning, knowledge reasoning, cloud computing and other technologies, IRDN network will continue to realize knowledge empowerment and intelligent empowerment.

However, due to the different technical systems of all sensing elements and diverse standards, it is difficult to realize efficient inter-connection among different elements and create one common sensing network with globally coverage. Therefore, it is necessary to strengthen in-depth integration of network architecture, technical systems and support systems.

References

[1] Xing, W. (2018) New requirements of joint operations for the development of naval battlefield early warning system and equipment. Modern Radar., 11: 103 – 107.

[2] Qiao Y., Zhang X. (2016) Research on theory and method of missile weapon strike chain construction. Journal of China Academy of Electronic Sciences., 40: 1-5.

[3] Deng, D.S., Sun, J., Yang, Y.H. (2020) Establishment of Homeland Air Defense SoS. Journal of China Academy of Electronics and Information Technology. 15: 105-109.

[4] Eli, B. (2019) Cognitive Adaptive Array Processing (Caap) - Adaptivity Made Easy. In 2019 IEEE International Symposium on Phased Array System & Technology (PAST. Waltham, USA.

[5] Xing, W.G. (2019) A Study on Self-organizing Ubiquitous Wireless Network Architecture of Radar Communication. Modern Radar. 41: 1-7.

[6] Griffiths, H. (2011) Developments in bistatic and networked radar. In Proceedings of 2011 IEEE CIE International Conference on Radar. Chengdu, China.

[7] Mirjalily,G., Aref, M.R., Nayebi, M.M.(2000) Optimal design of multibit radar detection networks. Record of the IEEE 2000 International Radar Conference. VA, USA.

[8] Hugh, D.G, Baker, C.J., Baubert, J., Kitchen, N., Treagust, M. (2002) Bistatic radar using satellite-borne illuminators. In IET Radar Conference 2002. Edinburgh.

[9] Baker, C.J., Hume, A.L. (2003) Netted Radar Sensing. IEEE Aerospace and Electronic Systems Magazine., 18: 3-6.

[10] Bath, W.G. (2002) Tradeoffs in radar networking. In IET Radar Conference 2002. Edinburgh.

[11] Hugh, G. (2010) Multistatic, MIMO and networked radar: The future of radar sensors?. In The 7th European Radar Conference. Paris.