Efficiency Evaluation of Air-defense Early-warning Detection Based on Communication Support

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Abstract. In order to quantitatively analyze the impact of communication support capability on early-warning detection efficiency under electronic jamming condition, based on the study of the air-raid targets searching process, this paper build the detection probability calculating model of target indicating radar by evaluating the jamming efficiency of the air intelligence informing communication. Combined with the typical combat scenario, analysis of examples simulation is done and the results show that the jamming effect of using airborne jamming is better than using subgrade jamming on communication and the target indicating error which is caused by early-warning information does not affect the improvement of early warning detection capability.

1. Introduction
Detection probability is the primary efficiency indicator of all radars and the important embodiment of air-defense early-warning detection capability. At present, a lot of research results are achieved of early-warning detection efficiency in complicated electromagnetic environment. [1-2] analyze the detection probability and detection efficiency from the aspect of energy loss when radar is jammed by different angles, modes and altitudes. [3] analyzes the impacts of environmental change on detection probability by critical radar cross section (CRCS) calculation. [4] gives the detection probability calculating method of Multi-radar detection system. However, little research has been done on the role of communication support in practical combat. [5-6] just theoretically introduce the impacts of communication supportability on early-warning detection efficiency in electronic jamming condition, so how to quantitatively analyze the impacts is the goal of this paper.

2. Efficiency evaluation model of jamming on air intelligence informing communication

2.1. Efficiency evaluation of jamming on microwave communication
Microwave communication is the primary means of intelligence transmission which transmits from the front early-warning radar to the operational command center. Here, we assume that the receiving antennas of microwave communication receiver system align the transmit antennas, and then the signal power of the receiver can be calculated as follows:

\[ P_r = \frac{P_t G_t G_r}{L_f L_{sr} L_{tr}} \]  

(1)
A subsubsection. The paragraph text follows on from the subsubsection heading but should no where $P_t$ denotes the transmitting power (w), $G_t$ denotes the transmitting gain, $G_r$ denotes receiving gain, $L_f$ denotes spatial propagation loss, $L_w$ denotes the atmospheric loss and $L_s$ denotes the line loss of receiver.

All above-mentioned factors are determined by the equipment performance except the spatial propagation loss and the atmospheric loss, whereas the mainly impacts of atmosphere on propagation are reflected in the atmospheric absorption loss and the rainfall loss.

Propagation path loss [7] in free-space is calculated by

$$L_f = 92.45 + 20\log r + 20\log f$$

(2)

where $r$ denotes the propagation distance (km) and $f$ denotes the microwave frequency (GHz).

The atmospheric absorption loss is extremely low when the wave frequency is below 12GHz, and that the usual operating frequency of microwave system is lower than 10GHz, so the atmosphere has little influence on the absorption loss of microwave communication. The atmospheric absorption loss is less than 1dB when the distance between two microwave communication stations is 50km, we assume that the atmospheric absorption loss is 1dB in this paper.

The rainfall loss can be calculated by (3), which is recommended by the International Telecommunication Union (ITU)

$$L_r = cR_p^d \cdot L_e$$

(3)

where $cR_p^d$ denotes the loss of unit length in rain zone (dB/km), $R_p$ denotes the rainfall (mm/h), $c$ and $d$ denote the coefficient which are related to the frequency, the rain size and the polarization (see [8]), $L_e$ denotes the path length of propagation (km), which is related to the rainfall thickness, the rainfall range and the ground station angle, etc. (see [9]).

Here, we assume that the jammer, the transmitter and the receiver of microwave communication are in the same horizontal or vertical plane, the distance between jammer and receiver is $R_j$ and the loss of jamming is $L_j$, so the jamming signal power that the receiver receives is calculated by

$$P_j = \frac{ERP_jG_r\gamma_pB_j}{(4\pi)^2 R_j^a L_s L_j}$$

(4)

where $G_r$ denotes the main lobe gain of receiver antenna, $ERP_j$ denotes the effective jamming power of jammer (w), $\gamma_p$ denotes the jamming polarization loss; $n$ denotes the propagation loss index and $B_j$ denotes the percentage of effective jamming power.

The signal-to-jamming ratio (SJR) of microwave receiver, which can be calculated by (5), is determined by the jamming signal power, the noise and other factors in battle environment.

$$\rho = \frac{G_r P_j}{P_j + P_n}$$

(5)

where $G_r$ denotes the signal processing gain and $P_n$ denotes the internal noise power of receiver.

Assuming that $m$ times microwave relay are needed when early-warning intelligence transfers to the command center, so the transmission rate of communication path can be calculated by

$$P_{mct} = \prod_{i=1}^{m} P_{cti}$$

(6)

where $P_{mct}$ denotes the transmission rate of communication system and $P_{cti}$ denotes the transmission rate of segment $i$ relay path, which can be calculated by empirical formula [10]...
\[ P_{cl} = 1 - A_n Q F_r B_{mw} d_i C_{mw} 10^{-\rho_i/10} \]  

where \( d_i \) denotes the length of segment \( i \) relay path (km), \( \rho_i \) denotes the SJR of segment \( i \) relay path, \( A_n \) denotes the climate factor, \( Q \) denotes the terrain factor, \( B_{mw}, C_{mw} \) denote the constant, we take \( A_n = 1\times10^6, B_{mw} = 1, C_{mw} = 3, Q = 1 \) in China.

2.2. Efficiency evaluation of jamming on V(U)HF communication

V(U)HF communication is the main wireless communication means between operational command center and air-defense fire unit, which runs automatically when the optical fiber communication is interrupted. In order to enhance the reliability of communication, the radio will work with frequency hopping mode.

The signal power that the communication receiver receives is calculated by

\[ P_r = \frac{P_G G_n}{(4\pi)^2 R^i L_L} \]  

where \( G_n \) denotes the gain of transmitter antenna in the direction of receiver, \( G_n \) denotes the gain of receiver antenna in the direction of transmitter and \( R^i \) denotes the communication distance.

When the microwave communication receiver is jammed by the airborne jammers, the jamming signal power that the communication receiver receives can be calculated by

\[ P_{jrt} = \frac{ERP G_j \gamma_j B_j}{(4\pi)^2 R^j L_L} \]  

where \( G_j \) denotes the gain of receiver antenna in the direction of jamming, \( \gamma_j \) denotes the jamming polarization loss and \( R^j \) denotes the jamming distance (m).

The current jamming methods on frequency hopping communication include the blocking jamming and the tracking jamming, we take 2FSK modulation, non-coherent demodulation signal for example to calculate the bit error rate (BER).

When the radio is jammed by the blocking jamming \([11]\), the BER can be calculated by

\[ P_e = \frac{1}{2} \exp\left(-\frac{1}{2} \frac{P_r}{P_{jrt} + P_n}\right) \]  

When the radio is jammed by the tracking jamming \([11]\), the BER can be calculated by

\[ P_e = \frac{P_n}{P_{jrt} + 2P_n} \exp\left(-\frac{P_{jrt}}{P_{jrt} + 2P_n}\right) \]  

The transmission rate of V(U)HF communication is calculated by

\[ P_{tr} = \begin{cases} 1 & P_e < \alpha \\ 0 & P_e \geq \alpha \end{cases} \]  

where \( \alpha \) denotes the threshold of BER, we take \( \alpha = 30\% \) in calculation.

3. Detection probability calculation model of target indication radar

3.1. Probability of the target falling into the searching area

It’s impossible to indicate the position of target accurately due to the measurement error and the random perturbation, so the probability of falling into the search area \( P_l \) will be less than 1 under target indication condition.
We assume that the searching area is formed by extending $\alpha$ alone the indication direction and the target indication error is normally distributed, thus the probability of target falling into the indicated searching area can be calculated by

$$P_I = \frac{1}{\sqrt{2\pi}\sigma_0} \int_{-\alpha}^{\alpha} e^{-\frac{t^2}{2\sigma_0^2}} dt$$  \hspace{1cm} (13)

3.2. Detection probability of target indication radar

Assuming the target discovery probability of the front warning radar is $P_f$, the early-warning probability of the warning radar is calculated by

$$P_{fy} = \left[1 - (1 - P_f)(1 - P_{wb})\right] P_f$$  \hspace{1cm} (14)

where $P_f$ denotes the transmission probability of the fiber optic communication and $P_{wb}$ denotes the transmission probability of the microwave communication.

The target indication radar do call search with target indication intelligence and do regular search without indication intelligence, so the detection probability of indication radar is calculated by

$$P_{zi} = P_{fy} \left[ P_{com} \cdot P_I \cdot (1 - P_{com}) P_{cg} \right] + (1 - P_{fy}) P_{cg}$$  \hspace{1cm} (15)

where $P_{com}$ denotes the transmission probability of communication between the target indication radar and the operational command center, $P_{zi}$ denotes the detection probability of call search and $P_{zcg}$ denotes the detection probability of regular search.

4. Analysis of example

Assuming the transmission power of the microwave communication transmitter is 4w, the antenna gain is 40dB and its frequency is 1.5GHz, the distance between receiver and transmitter is 50km, the main lobe gain of the receiver antenna is 30dB, the average side lobe gain is 15dB, the noise figure is 7dB and its signal processing gain is 20dB, sunny weather, the transmission probability of the fiber optic communication is 0.5, the detection probability of call search is 0.95 and the detection probability of regular search is 0.6.

When the jamming signal enters into receiver from the main lobe and the side lobe respectively, the relationship between transmission probability and different jamming distance is shown in Figure 1.
Figure 1. Relationship between the transmission probability and the jamming distance

The relationship between the early-warning probability of warning radar and the transmission probability when the microwave relay times are 2, 3, and 4 respective is shown in Figure 2.

Assuming the target indication error is normal distributed and $\sigma$ is $18^\circ$, the call search area from $-30^\circ$ to $30^\circ$, the probability of the target falling into the searching area is 0.8667 by (13). The relationship between the detection probability and the early-warning probability under the V(U)HF communication support condition is shown in Figure 3.

Figure 2. Relationship between the early-warning probability and the transmission probability

Figure 3. Relationship between the detection probability and the early-warning probability

Through the analysis of the simulation results, this paper draws the following conclusions:

(1) The shorter distance and the higher power can enhance the jamming degree on microwave communication. The jamming effect of using airborne jamming is better than using subgrade jamming on communication; even the lower jamming power which enters into the receiver from side lobe can also make the communication be interrupted.

(2) The early-warning ability improves with the increase of the transmission probability of microwave communication, and the transmission probability has relationship with its relay times, less relay times means small energy loss during the transmission, so the transmission probability is higher. In the district air-defense combat, it can shorten the distance between warning radar and operational command center, by reducing the relay times to increase the transmission probability.

(3) When V(U)HF communication is interrupted, as the target indication radar do regular search without target indication intelligence, which agrees with the practical situation. Although the target indication intelligence will bring an indication error, it still can increase the detection probability.

5. Conclusion

Based on the study of the air-raid targets searching process, this paper sets up the evaluation model of jamming efficiency on microwave communication and V(U)HF communication. In the typical combat scenario, analysis of example is taken to test the feasibility of the air-defense early-warning detection efficiency model. To improve the evaluation model of jamming efficiency on air intelligence informing communication, the jamming efficiency of short-wave communication and microwave communication network will be studied in the further study.
References

[1] Huang Hao, Lu Jianwei, Zhou Pu, et al. Quantitative algorithm of detection probability single shipborne radar and the functional simulation [J]. Electronics Optics and Control. 2007,14 (6) :68-70

[2] Xie Chengfeng, Wang Hong, Tan Yinsi, et al. Analysis of the influence of blanket jamming on ground-based PD radar’s detectability to small target [J]. Fire Control and Command Control. 2010,35 (7) :70-72

[3] Luo Xun, Ma Dongli. Detection probability calculation of low pulse repetition frequency PD radar on low altitude aircraft [J]. Systems Engineering and Electronics. 2007,29 (7) :1066-1069

[4] Wang Xu, Song Bifeng, Guo Xiaohui. Research on the approach for calculating the probability of detecting an aircraft by radar system [J]. Systems Engineering-Theory and Practice. 2006,6:130-134

[5] Zhou Hui, Shi Zhijun, Liu Litian. The resolved strategy of battlefield communication support in complex electromagnetic environment [J]. Journal of Academy of Equipment Command and Technical. 2008,19 (6) :1-5

[6] Chen Nanyang. Early warning and detection of external electromagnetic fields interfering wired communication equipments [J]. Communication Technology. 2007,2:44-46

[7] Song Zheng, Zhang Jianhua, Huang Ye. Antenna and wave propagation [M]. Xi’an: Xidian University Press. 2003

[8] Joe Nader. Modeling and Performance of microwave radio links in rain [D]. McGill University. Montreal, Canada. 1998

[9] Yao Lianxing, Yu Menglong, Li Jianbing. Missile motor plume and the radiation characteristics of Earth atmosphere background [J]. Research on Target and Environmental Characteristic. 1998,2

[10] Xia Peng, Lv Donglei, Wang Yafu. Effective model of microwave communication jamming [J]. Ship Electronic Engineering, 2008,172 (10) :97-100

[11] Shao Guopei, Cao Zhiyao, et al. EW operational effectiveness analysis [M]. Beijing: The Publishing House of PLA. 1998:33