Research Article

Multiconstraint-Oriented Tactical Communication Network Planning Problem

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Received 9 March 2022; Revised 18 March 2022; Accepted 23 March 2022; Published 4 April 2022

Academic Editor: Mohammad Farukh Hashmi

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Based on the complex network theory, this paper comprehensively studies the equipment and its interrelationship in the tactical communication system and constructs a system networking model. Based on the analysis of the structure and organizational application of the tactical communication system, this paper provides an appropriate mathematical description of its net-electric attack strategy and evaluation. A network simulation test model of tactical communication system was established, and then, by changing the network structure of the tactical communication system, such as the number of nodes, the nature of links, and the conditions of the net-electric attack, changes in combat capabilities were observed, and the impact of equipment deployment and communication organization methods on the system was analyzed, and finally, reliability evaluation and optimization analysis were conducted.

1. Introduction

Currently, the warfare pattern is accelerating its evolution toward remote control, precision strike, intelligence and efficiency, and all-round and multidomain, especially the emergence of new operational concepts such as network-centric warfare and asymmetric warfare. Combat objectives have also changed from simple firepower killing and destruction to hindering the enemy’s strategic realization and paralyzing the enemy’s C4 system. Military information systems are the key support. In the face of the huge threat of cyberattacks, in order to ensure combat command, reconnaissance intelligence, firepower strikes, field air defense, electronic countermeasures, rear equipment security of the actual operational needs, the need to establish a comprehensive network of communications, timely, accurate, uninterrupted communications, and the formation of a safe, reliable, three-dimensional mobile integrated network are significant, to achieve a complex electromagnetic environment, “dynamic pass, all-dimensional pass, all the time pass, anti-central pass, anti-central pass, and the enemy’s C4 system. All-time pass, anticalentral pass, and disturbance pass were used in complex electromagnetic environment [1].

Our military tactical communication system is gradually developing in the direction of digitalization, broadband, grouping, integration, and mobility, and under the new requirements of this development trend, the research of tactical communication system has become more complicated [2]. At the same time, the network electric confrontation also brings new challenges to the reliability of tactical communication system. At present, the research of tactical communication systems is mainly based on individual techniques and experience, using mathematical models, supplemented by simulation experiments and mathematical calculations. This method is commonly used for smaller networks with simple structures, low traffic volumes, and single services. When the network is simpler, network testing and mathematical estimation is relatively easy, but it is often not feasible under new requirements and challenges to obtain reliable research conclusions. New technologies provide new ideas [1]. It integrates analysis methods, experimental methods, and simulation methods to build a simulated network in a real application environment and realize system performance prediction. At the same time, the application of emerging network technologies and intelligent algorithms also provides new solutions for the research of
tactical communication systems [3]. In order to better utilize the effectiveness of tactical communication systems, this military restructuring reform has established a new type of synthetic brigade, which adds a new generation of tactical communication equipment to the traditional army communication equipment, giving the army a stronger information warfare capability. This new tactical communication system will play an important role in future group operations of digital forces [4].

At present, there is little research on the operational application of this new tactical communication system under net-electric counter conditions. How to evaluate the reliability of the tactical communication system in the tactical corps’ dot confrontation and how to scientifically utilize the tactical communication system capability under the net-electric confrontation conditions has become a research hotspot [5].

Therefore, this paper studies the modeling and simulation of the tactical communication system under the enemy’s network attack conditions to provide reference for the development and improvement of the tactical communication system, provide support for the operational effectiveness and operational application of the new army tactical communication system, and contribute to the formation of combat effectiveness of the system as soon as possible.

2. Related Work

Tactical communication system models are to solve the problem of how to abstract the complex and actual physical communication networks into logical models that are easy to study. Most of the books, reports, and papers on communication networks or tactical communication systems in China and abroad present network structure models based on graph theory. Related books include "Analysis and System Integration of Military Communication Networks" [6], "Planning and Optimization of Military Communication Networks" [7], and "Introduction to Military Communication Equipment" [8]; related reports include "Communication Network Analysis" by Bruce [9, 10] proposed to analyze the connectivity of tactical communication systems from the perspective of military applications and defined “quasirandom” connectivity of tactical communication systems to assist in the design of the network. [11] used a graph theory-based network structure model to estimate the survivability of the network. The network structure model was used to analyze the effect of the topology of a data communication network on its security robustness, and the maximum cluster and cluster diameter in graph theory are used as network security indicators.

In summary, it is common to abstract the network into a graph consisting of nodes and links describing the link relationships between nodes, and most scholars abstract the network into three elements consisting of nodes, links, and terminals, with the nodes corresponding to the switching and routing control class devices in the physical network, the links corresponding to the transmission class devices in the physical network, and the terminals corresponding to the various service terminal class devices in the physical network. The current research mainly classifies networks into simple networks and complex networks in terms of network topology, the former including star networks, ring networks, tree networks, and cellular networks and the latter mainly constructed for studying the behavior and characteristics of real network performance, including ER random network models, small world models (SW (small worlds)) [12], and scale-free network models (SF (scale-free)) [13].

The real research of tactical communication system reliability is developed with the research of network system dependability, which is a crossover hotspot between reliability field and complex networks, and the high reliability of tactical communication system is often related to whether the battle can be won. The current research mainly refines the “three provisions and one capability” defined in the reliability terminology based on different research purposes and priorities, and its definition is still not unified in the industry. The reliability of network systems can be summarized into two aspects. One is the ability of a network system to remain connected under specified conditions and for a specified period of time from a graph theory perspective [12]. The other is from the perspective of the functions undertaken by various networks, and the network system task reliability is the ability to accomplish the specified task of transmitting material, information, energy, and logical flows under the specified conditions and within the specified time. It is important to emphasize that the study of reliability definition should be clarified in the context of actual networks and assessment needs and in accordance with the general requirements of reliability [13].

3. Tactical Communication

System Components

3.1. System Architecture. The tactical communication system consists of tactical Internet, data chain, satellite communication system, military integrated mobile communication system, unmanned aircraft relay communication system, network management system, security protection system, etc., mainly using the communication vehicle as the carrier platform.

Tactical Internet is based on wireless communication and Internet technology, interconnecting tactical radio, field transmission equipment, switching and routing equipment and information terminals, etc. [14]. It is an integrated battle/tactical communication system for digital battlefield and network-centric warfare and is the main body of our new generation of field communication equipment. Tactical Internet is the main body of the joint tactical communication system, which consists of the organic fusion of the integrated field service digital network and tactical radio Internet, and extends the coverage through satellite communication system and unmanned aircraft relay communication system, constituting a multidimensional battlefield public information transmission platform for joint warfare, as shown in Figure 1.

The joint tactical communication system integrates mobile satellite FDMA/MF-TDMA dual-mode terminals in user node vehicles, radio access node vehicles, and integrated
3.2. Basic Model of Tactical Communication System. Tactical communication systems are primarily used to support the transmission of information such as battlefield posture, command and control, weapon control, and combat support during movement operations within the operational territory. For a tactical communication system, the service performance of the service is its most important measure [16].

Consider a tactical communication system with an arbitrary topology consisting of links and network nodes, as shown in Figure 2. Since the processing speed of the network devices is constantly accelerating and the reception processing speed is much faster than the bandwidth of the network links, the switching nodes are assumed to be nonblocking; i.e., packet data arriving at the input ports of the switching nodes do not experience switching conflicts and are immediately switched to the appropriate output ports, ignoring the switching processing delay therein. The packet data on different output ports do not interfere with each other, and only the packet data need to be queued on the output port [17].

Below the data link layer, especially for physically shared transport media, links are usually considered to be undirected. In contrast, at the network layer, the path established for each data stream is related to the direction of data transmission, and the transmission can be considered directional. The route established between the source-destination node represents a logical path from the source node to the destination node, which is even more clearly directional. Based on the above considerations, we can use directed graphs to model and analyze the end-to-end service performance of the tactical communication system for the service.

The topology of the tactical communication system is represented by graph $G(V, E)$ to distinguish it, as shown in Figure 2, where $V$ is the set of nodes, which can represent communication vehicles with switching and routing functions, or a network, and $E$ is the set of edges, which represents communication links. Let the communication bandwidth of each edge be $e_{ij} = (v_i, v_j)$, which represents a directly connected link from node $v_i$ to $v_j$, representing the channel set, such that a path on the directed graph $G$

$$P = (v_1, v_2, \cdots, v_k), \quad k \leq n,$$

$$= V \Theta (e_{i_2} \cdots e_{(k-1)k}),$$

(1)

where $v_1$ is the source node, $v_k$ is the destination node, and the number of hops from the source node to the destination node is the number of links passed by the path $P$: $H(P) = k - 1$. $(e_{i_2} \cdots e_{(k-1)k})$ denote the edges of the route selected by the routing algorithm. $V \Theta$ denotes the nodes through which the edges of the path are sequentially taken out [18].

Let there be a service source $S(t)$ on source node $v_1$, $t$ is the time when the service is generated, the destination node is $v_k$, and the service received is $D(t')$; then, the maximum bandwidth, delay, and data loss rate on the relevant path can be found as a function.

The end-to-end maximum throughput is the minimum value of the communication bandwidth of all edges (links) on the path $P$.

Let the communication bandwidth of each edge be $C(e_{i(i+1)})$, so there is end-to-end throughput:

$$R(P) = \min \left\{ C(e_{i(i+1)}) \mid i = 1, 2, \cdots, H(P) \right\}.$$  

(2)

It can be seen that the communication bandwidth between nodes of a tactical communication system depends on the minimum bandwidth in the path selected by the routing algorithm, and ignoring some minor factors, the end-to-end throughput $R(P)$ of the visible service is closely related
to the channel bandwidth of the nodes and the channel allocation method. For the end-to-end delay between nodes $D(P)$, it is the sum of the delays caused by all nodes and edges on the path $P$.

Let $D_n(v_i)$ denote the delay caused by the service processing in node $v_i$ and $D_{ij}(v_i, v_{i+1})$ denote the delay caused by the service transmission at the edge after processing from node $v_i$, so there is an end-to-end delay $D(P)$:

$$D(P) = \sum_{i=1}^{k-1} D_n(v_i) + \sum_{i=1}^{k-1} D_{ij}(v_i, v_{i+1}),$$  \hspace{1cm} (3)$$

where $D_n(v_i) = \text{size}(S(t))/\lambda_{v_i}$ represents the queuing delay caused by the node sending the service, including the sum of the delay caused by the network layer traffic control and the link layer media access to queue the packets. $\text{size}(S(t))$ represents the packet size of $S(t)$ and represents the average equivalent service rate of node $v_i$ to the service, related to the network layer traffic control algorithm and the link layer media access protocol. $D_{ij}(v_i, v_{i+1})$ represents the delay of service delivery in the channel and the delay of over-the-air propagation. $C_{ij}(v_i, v_{i+1})$ represents the communication bandwidth of the node, which is closely related to the channel bandwidth of the node and the channel allocation method. $l_{ij}$ denotes the distance between nodes $v_i$ and $v_{i+1}$, and $t_{ij}$ denotes the speed of channel airwave transmission. The service loss rate $L(P)$ depends on the queuing loss rate of the node and the transmission loss rate of the channel. Burst service flows that are larger than the free buffer space for network layer traffic control will overflow, thus increasing the packet loss rate; also, the uncorrectable BER of the channel transmission will affect the correct data delivery.

$$L(P) = 1 - \prod_{i=1}^{k-1} [1 - L_n(v_i)][1 - \text{er}(v_i, v_{i+1})],$$ \hspace{1cm} (4)$$

where $L_n(v_i)$ is the loss rate due to insufficient remaining buffer, where packet drop occurs when the size of the service packet exceeds the remaining buffer space and is a deterministic value for a node $v_i$, $L_n(v_i)$ at a deterministic moment. The remaining buffer space is

$$F(P) = \min \{F_k(v_i)|i = 1, 2, \cdots, k-1\}. $$ \hspace{1cm} (5)$$

The remaining buffer space can be used to predict the maximum traffic that the path can sustain at the next moment and can be used in algorithms for traffic control. $(1 - \text{er}(v_i, v_{i+1}))$ denotes the loss rate of channel $ii(i+1)$ between nodes $(v_i, v_{i+1})$, which is closely related to the channel and communication environment used between nodes. Since the radios of tactical communication systems generally have strong coding and error correction capabilities, in the actual calculation, $(1 - \text{er}(v_i, v_{i+1}))$ denotes the channel loss rate after error correction is performed, which is closely related to the propagation environment of the physical channel.

In the comprehensive analysis of equations (2)–(5), in ignoring some minor factors, only from the consideration of the performance provided by the tactical communication system to the service, the impact on the overall performance of the system and the tactical communication system can be reduced to a directed graph parameterized by the properties of node, and edge, and the performance of the network is a function of the properties of nodes and edges.

4. Network Switching Model

4.1. Model Description. The network switching model mainly performs packet pathfinding and forwarding functions. Packet pathfinding is mainly related to the routing algorithm model of the network, while packet forwarding is mainly related to the queuing or traffic control model of the packets. Let the graph consist of a nonempty set $V$ of nodes and a set $E$ of edges between nodes, which can be written as $G = (V, E)$, where the edges can be undirected or directed; if they are directed, the graph is called a directional graph; otherwise, it is called an undirected graph.

In the assignment graph, the weight of an edge is called the length of the edge, and the length of a path is the sum of the lengths of the paths in this path. Suppose there are $j$ basic paths between nodes $m$ and $n$, and the length of each path is $W_1, W_2, \cdots, W_j$, respectively, and the shortest path $D_{\min}$, which is the path with the smallest length, can be expressed by the following equation:

$$D_{\min} = \min \{W_1, W_2, \cdots, W_j\}. $$ \hspace{1cm} (6)$$

The tactical communication system can be abstracted as a graph, and the network devices in the network (such as routers, switches, and terminal devices) can be abstracted as nodes in the graph, and the communication links between the network devices can be abstracted as edges in the graph.

In addition, in tactical communication systems, each node has a limited storage capacity and processing capability, so when packet forwarding is performed, node congestion occurs when the storage and processing capabilities of the nodes are exceeded. The analysis of the tactical communication system leads to the conclusion that the main cause of congestion is the burstiness of the service, and if the network nodes send the service at a uniform rate, the frequency of congestion will be greatly reduced. Therefore, the token funnel algorithm is modeled and analyzed here as the traffic control model in the tactical communication system.

4.2. Routing Algorithm Model. Assume that in a network, any node pair $w = (S, D)$ (S is the source node and D is the destination node) can deliver the service flow $r_w$ input to the source node to the destination node via multiple paths simultaneously. Let the set of all paths between any node pair $w$ be denoted by $P_w$, i.e., $P_w = \{P_1, P_2, \cdots, P_m\}$, and the flows on each path be denoted by $X_w$, then, the set of these flows is denoted by $X_w$, i.e., $X_w = \{x_1, x_2, \cdots, x_n\}$; then, let the set of all node pairs in the network be denoted by $W$. 
By definition, it is clear that there is
\[ \sum_{p \in P_w} x_p = r_w, \quad w \in W, \]
\[ x_p \geq 0, \quad p \in P_w, \quad w \in W. \tag{7} \]

That is, the sum of the traffic on each path is equal to the input traffic, and the traffic on each link must be greater than or equal to zero. Let the traffic on link \((i,j)\) be denoted by \(F_{ij}\); then
\[ F_{ij} = \sum_{p \in P_w} x_p. \tag{8} \]

The purpose of finding the best route is to minimize the cost in the network; i.e., equation (9) minimizes
\[ \sum_{(i,j)} D_{ij}(F_{ij}), \tag{9} \]
where \(D_{ij}\) is a monotonic function of the cost per link, and the larger the \(F_{ij}\) the higher the cost. A commonly used cost function is
\[ D_{ij}(F_{ij}) = \frac{F_{ij}}{C_{ij} - F_{ij}} + d_{ij}F_{ij} = \left( \frac{1}{C_{ij} - F_{ij}} + d_{ij} \right)F_{ij}, \tag{10} \]
where \(C_{ij}\) is the capacity of link \((i,j)\) and \(d_{ij}\) is the delay of the link (including propagation delay and processing delay). Routing optimization is the search for the best that minimizes the cost function.

In tactical communication systems, distance vector routing and link state routing algorithms are often used to find the optimal path between end-to-ends under specific conditions.

4.2.1. Distance Vector Routing Algorithm Model. The distance vector routing algorithm is a concrete implementation of the B-F algorithm, which is a method for finding the shortest path. The definition of B-F algorithm is as follows: the shortest path is the shortest path from a given node \(i\) to the destination node \(j\) with the following constraints. (i) The path includes at most \(h\) edges; (ii) the path passes through the destination node once; (iii) if \((i,j)\) is not an edge in the graph, then let its weight \(d_{ij} = \infty\).

The shortest path is denoted by \(D^h_i\), and for all \(h\), let \(D^0_i = 0\). The B-F algorithm for finding the shortest path from the \(h\)-step path is given below:
\[ D^{h+1}_i = \min \left[ d_{ij} + D^h_j \right], \quad i \neq 0, \tag{11} \]
where \(d_{ij}\) denotes the path length of edge \((i,j)\) and \(D^h_j\) denotes the shortest route to the destination node from node \(j\) (including the source node) in the graph.

In distance vector routing, each node maintains a routing table, which includes information items arriving at all nodes in the network, and the item has two parts: the output link to the destination node and the distance estimate to the destination node. The distance metric can be chosen from hop count, delay, etc. Every \(T\) seconds, each network node sends a packet containing the contents of its own routing table to its neighboring nodes, which update their own routing table contents based on this packet.

Dijkstra’s algorithm is described as follows:

1. Initialization: let obtain the \(p\)-label, \(L(v) = 0\), \(P = \{ v \}\), \(T = V - P\), and \(v, j \in (T)\) with the \(t\)-label
\[ L(v) = \left\{ W(v, j) \mid (v, j) \in E \right\} \tag{12} \]

2. Find the \(p\)-label of the next node: let the \(t\)-label of node \(v\) be the minimum of the \(p\)-label of all nodes in \(T\). Change the \(t\)-label of \(v\) to the \(p\)-label, so \(v\) obtains the \(p\)-label and modifies the permanent label set \(P\) and the temporary label set \(T\), so that \(P = P \cup \{ v \}\) and \(T = T - \{ v \}\)

3. Modify the value of \(t\) marker of each node in \(T\) For any \(v \in T\)
\[ L(v) = \min \{ L(v), L(v) + W(v, j) \} \tag{13} \]

Repeat steps (2) and (3) until \(v_n\) obtains the \(p\) mark.

4.3. Flow Control Model. The tactical communication system is a bandwidth-constrained communication system, so the main role of the traffic control model is to queue the services at this node as well as the forwarding services according to the link bandwidth limitation. The tactical communication system has to support services with priority, so the token funnel algorithm model is used here.

It is assumed that the packet length is fixed, the packet arrival process is a Poisson process with rate \(\lambda\), the interval of token generation \(\Delta T = 1/r\), \(r\) is the frequency of token generation, and the capacity of the token funnel is \(C\). When the funnel is full, the generated tokens will be lost.

Based on the above assumptions, the funnel system can be regarded as a discrete-time Markov chain with state \(i\) and \(i\) denotes the usage of tokens. When \(i = 0, 1\), it means that there are \(C - i\) tokens available in the funnel and no untokenized groups are waiting, which is equivalent to the remaining space in the funnel; when \(i = C + 1, C + 2\), it means that there are \(i - C\) untokenized groups waiting and no tokens. The state transfer occurs at \(0, \Delta T, 2\Delta T, \ldots, \) i.e., just after the arrival of the token.

The probability of arriving \(k\) groupings in \(\Delta T\) is
\[ a_k = \frac{e^{-\lambda r} (\lambda r)^k}{k!}. \tag{14} \]
The state transfer probability is
\[ P_{0i} = \begin{cases} a_{i+1}, & i \geq 1, \\ a_0 + a_1, & i = 0. \end{cases} \]  
(15)

Equation (15) represents the state transfer probability for the current state of 0, where the first term is the probability of arriving at \( i + 1 \) groups in \( \Delta T \) and the second term corresponds to the probability of no group arriving or arriving at 1 group in \( \Delta T \). For \( j \geq 1 \), the state transfer probability is
\[ P_{ji} = \begin{cases} a_{i-j+1}, & j \leq i - 1, \\ 0. \end{cases} \]  
(16)

The global equilibrium equation is
\[ p_i = \sum_{j=0}^{\infty} a_{i-j+1} p_j, \quad j \geq 0, \]  
(17)
where \( p_i \) is the probability of state \( i \).

5. Simulation Modeling

In order to examine whether the information transmission of this network is timely and reliable under different formation and usage conditions, three experimental indicators are initially selected here to test, namely, average network delay, network load, and network throughput. Now, the ministry intends to deploy 120 groups in this region; after researching these 120 groups, if they are deployed by 3 subnets, the number of nodes in the subnets will be 50, 40, and 30 in order; if they are deployed by 4 subnets, the number of nodes in the subnets will be 30. In addition, there is the following information: there are 3 options for the transmission power of communication nodes, namely, 20 MW, 30 MW, and 50 MW; it is assumed that the data is sent in the form of packets. The packet size is fixed, depending on the type of information transmitted, and there are roughly 4 types of transmitting rates, which are 1, 2, 5, and 10 per second although there are 120 user nodes in the whole network, but not all user nodes are sending and receiving information, so here the size of the network is used to describe these nodes used online, and the online rate is defined as the ratio of the communication nodes used during the simulation time to the total. The ratio of the number of nodes used during the simulation time can be taken as 100%, 80%, 60%, and 40% in order. Since this is a two-level network, i.e., there is not only intrasubnet communication but also some intersubnet communication, and all the intersubnet communication needs to be forwarded through the cluster head router, when this intersubnet communication is more frequent, the load of the whole network will increase, so a factor is defined here as the intercommunication ratio, that is, the ratio of the number of intergroup communication node pairs to the number of all network node pairs; generally, three ratios can be considered according to the busy degree, 5%, 10%, and 20%; nodes within each subnet are free to move within a specified area. Here, still use the widely used random waypoint movement model, and mainly consider the impact of node movement speed on network performance. According to the patrol fast and slow, the node movement speed can be considered as 20, 30, and 40 (km/h). According to the idea, two different network scenarios need to be created here due to the different number of subnets. The scenario is based on the idea that two different network scenarios need to be built here due to the different number of subnets. The scenario has 3 subnets and scenario two has 4 subnets [19, 20].

As shown in Figure 3, there are 3 subnets in scenario 1, which are subnet 0, subnet 1, and subnet 3. The subnets are wired together and forward information between them through a large relay station center bridge. The number of nodes in the three subnets is set to 0, 40, and 30 according to the geographical size in turn, and each node represents a dolly, which can send and receive data freely and has information forwarding function within the same subnet. The routing protocol of the whole network adopts the commonly used AODV protocol.

Figure 4 is the structure of the subnet 0, and the intermediate node \( ap0 \) acts as the cluster head node; in addition, it has the function of sending and receiving data, mainly responsible for the communication between the car inside this subnet and other subnet workshops; the whole subnet is wireless communication inside.

In the formulation of the initial experimental factor level table according to the simulation thought and model...
The suggested method of the auxiliary system and combining the factor characteristics was used. The final factor level table is shown in Table 2.

The experimental design method used was an orthogonal design, and the experimental design table was $L_4(2 \times 3)^3$. The experimental protocol design table was obtained as shown in Table 3, where the last 3 columns are the experimental index values.

A total of 3 experimental indicators were examined in the experiment, of which network latency directly reflects the timeliness of network transmission information, and the lower the latency, the better the network performance. A total of 3 experimental metrics are examined in experiment A. Among them, network latency directly responds to the timeliness of network transmission information, and the lower the latency, the better the network performance. If the network throughput is examined separately, it will lose the significance of the study because it is within the processing capacity of each node. The greater the load, the greater the network throughput; however, if the load is too large beyond the processing capacity of the nodes, it will lead to a decrease in throughput instead. This is just like a traffic jam occurs when a car on the road over. Therefore, before analyzing the results of these two experimental indicators, we redefine a new indicator a payload ratio; the calculation method is to use the throughput than the network load on the same period; the definition of network load and throughput is not difficult to know; the higher the payload ratio network performance the better. Tables 4 and 5 are the experimental results of network delay and network payload ratio analysis.

It must be noted that because of the different number of factor levels, the number of level-hidden replicates is unequal and the range of levels taken may vary widely. Therefore, there is a certain influence on the extreme difference $R$. Usually, in order to eliminate this effect, $R$ is used to compare the factors, where $R = d_1 d$ is the correction factor of $R$, which can be obtained by looking up the table. Here, the table is $d_2 = 0.71$ and $d_3 = 0.52$.

The experimental results in Tables 4 and 5 show that the order of the experimental factors affecting the network delay and payload ratio is basically the same, one is $E$, $A$, $F$, $B$, $C$, and $D$ and the other is $E$, $A$, $F$, $B$, $D$, and $C$. In terms of the value of the corrected polarity $R$, the three experimental factors in the top order (the transmission rate of node data, the number of subnets in the network topology, and the user

| Number | Factor                       | Level                      | Horizontal number |
|--------|------------------------------|----------------------------|-------------------|
| 1      | Number of subnets (PCs)      | 3, 4                       | 2                 |
| 2      | Node transmit power (MW)     | 20, 30, and 50             | 3                 |
| 3      | Node moving speed (km/h)     | 30, 30, and 40             | 3                 |
| 4      | Inter network communication ratio | 5%, 10%, and 15% | 3                 |
| 5      | Data transmission rate (packets/s) | 1, 2, 5, and 10 | 4                 |
| 6      | Online rate                  | 20%, 40%, 60%, 80%, and 10% | 5                 |

Table 1: Experimental results.

| Number | Factor                       | Level                      | Horizontal number |
|--------|------------------------------|----------------------------|-------------------|
| A      | Number of subnets (PCs)      | 3, 4                       | 2                 |
| B      | Node transmit power (MW)     | 20, 30, and 50             | 3                 |
| C      | Node moving speed (km/h)     | 30, 30, and 40             | 3                 |
| D      | Inter network communication ratio | 5%, 10%, and 15% | 3                 |
| E      | Data transmission rate (packets/s) | 2, 5, and 8  | 3                 |
| F      | Online rate                  | 40%, 60%, and 80%          | 3                 |

Table 2: Experimental results.
online ratio) have a significantly better effect on the two indicators significantly better than the last three factors (node transmitting power, node movement speed, and inter-network communication ratio). The consistency between the two experimental indicators and the factor relationships also verifies the reasonableness of the experimental results, and there is no inconsistency between the two network performance indicators and the factor relationships.

### 6. Conclusions

In this paper, a model of tactical communication system is established. Firstly, based on complex network theory, a three-layer network architecture of physical, relational, and interactive networks applicable to the establishment of tactical communication systems is designed. Secondly, based on the nested relationships and network functions between each layer of network architecture, the relevant model descriptions required to establish each layer of network are established.

A complex network-based tactical communication system operational experiment is designed, and the simulation experiment and result analysis are carried out for a typical tactical communication system application style from the perspective of network congestion.

### Data Availability

The datasets used in this paper are available from the corresponding author upon request.

### Conflicts of Interest

The authors declared that they have no conflicts of interest regarding this work.

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