Research on precise organization of operational network based on "Chains in Network" model

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Abstract. Aiming at the network organization requirements of precise operation, this paper proposes a precise network organization method based on the "network in the chain" model: starting from the command perspective, setting the intelligence chain, C2 chain, strike chain and service chain as the entry points, the organizing and planning of operation network is classified and carried out. The model of "chain in net" is formally described, and the evaluation index system of "chain" to "net" is established. This kind of precise network organization based on command perspective is of great significance to improve the ability of joint operation based on network information system.

1. Introduction

As an important material basis of informationized warfare, military information network is the information center linking operation elements, operation platform and operation power, a key element for the generation of new quality combat effectiveness of the army, and an important pillar for joint operation based on network information system. Precise network organization is an important basis for giving full play to the network operational effectiveness.

Precise operation, precise command and precise service are the important characteristics of future joint operation. As an important material basis to support joint operation, the precise organization of network greatly affects the operation efficiency, which urgently requires network organization to make a breakthrough in fine calculation, actuarial calculation and deep calculation, to transform from rough organization to precise organization and from qualitative organization to quantitative organization, and constantly expand scientific organization methods, so as to improve service efficiency and support joint operation. The study of network organization from the perspective of command can enable commanders to have a comprehensive, rapid and clear understanding of battlefield network deployment, providing more powerful information support for decision-making actions, which will have a strong practical significance for realizing the transformation of information advantages into operation advantages. Therefore, the problem of precise network organization is an urgent problem to be solved.

2. Element analysis of operation network

Operation network is the basic platform of C4IKSR, which mainly realizes the transmission of intelligence information, C2 information, strike information and service information. Under the condition of informationized countermeasures, the comprehensive influence of various countermeasures on operation network determines the effect of information countermeasures. The traditional operation network models are relatively mature and widely used in command information
system and operation system simulation. Generally, combined with the characteristics of joint operation command, the elements involved in operation network models can be classified into entity node, basic link, data and data link routing. And the transmission of information in operation network is mainly represented by data link route.

2.1. Element Description

2.1.1. Entity nodes
Entity node is the intermediate node or terminal node that communicates in the network. It can be the producer of data information, the repeater of data information, and the actor of data information. In addition, the state of the node determines the state in which the information is produced, transmitted, and used. Entity nodes are represented by the following binary groups:

\[ \text{Node}::=\langle \text{Node\_ID, Node\_Attribute} \rangle \]

- \text{Node\_ID}-- entity identification, defining the entity name having global uniqueness.
- \text{Node\_Attribute}-- entity attribute, explaining the attribute that distinguishes the entity from other entities.

2.1.2. Basic link
In the operation network, the basic link is formed by the connection of entity nodes, which mainly refers to the communication link. It can be the wired link connected by optical fiber, twisted pair, etc., or the wireless link connected by shortwave, satellite, etc. The state of entity node has direct or indirect influence on the state of link. The basic link is defined as follows:

\[ \text{Link}::=\langle \text{StartNode, EndNode, Link\_Type, Link\_State} \rangle \]

- \text{StartNode}-- source node.
- \text{EndNode}-- terminal node.
- \text{Link\_Type}-- link types including inter-satellite link, wired link, wireless link, etc.
- \text{Link\_State}-- link state. The wired link is determined by its own state of the link and the communication working state of the associated nodes, and the wireless link is determined by its own state of the node (such as SNR, etc.).

2.1.3. Data
The data on the nodes and links is the data transmitted by operation network, and the data transmission is carried out on the basis that the link state meets certain requirements. The definition of data is as follows:

\[ \text{DataStruct}::=\langle \text{Data\_Name, Data\_ID, Data\_Src, Data\_Des} \rangle \]

- \text{Data\_Name}-- data name.
- \text{Data\_ID}-- data ID.
- \text{Data\_Src}-- data source.
- \text{Data\_Des}-- data destination.

2.1.4. Data routing link
During the transmission of intelligence, C2, strike and service data in the network, the link node the data packet passing through is fixed or relatively fixed, which requires the path of the link routing to be clear. The routing of data packet in the link is defined as follows:

\[ \text{DataRoute}::=\langle \text{Data\_ID, StartNode, EndNode, RouteNodes, RouteLinks, Priority} \rangle \]

- \text{Data\_ID}-- data ID.
- \text{StartNode}-- source node.
- \text{EndNode}-- terminal node.
- \text{RouteNodes}-- set of routing nodes.
- \text{RouteLinks}-- set of routing link
- \text{Priority}-- Priority level.
2.2. Network Elements Relationship

Based on the analysis of the above network elements, the relationship of the elements can be obtained, and the ER diagram of the network elements relationship can be constructed, as shown in figure 1.

![Fig.1. Network Elements Relationship](image)

As can be seen from figure 1, each network node can produce, store and transmit data packets. The link is the transmission path of data packets, and data routing link is composed of network node and basic link, reflecting the transmission path of data packets in the network. It can be also concluded that the essence of network organization is orderly integration of network elements to achieve high-speed and accurate transmission of data packets in the network.

3. "Chains in Network" model

3.1. Design ideas

As can be seen from the above, the information network supporting precise operation is a physical network built based on various nodes and links. In different perspectives, the network has an entirely different structure. From the perspective of organization, operation network can be classified into basic (backbone) network, access network and user network. From the perspective of transmission, it can be classified into optical cable communication network, satellite communication network and short-wave communication network. From the perspective of operation, it can be classified into intelligence network, C2 network, strike network and service network. In the operation process, the commander pays more attention to the closed loop of the intelligence chain, the C2 chain, the strike chain and the service link than the topological structure of the organization perspective and the application of the transmission perspective. These logical information links built by "command activity" can more accurately and truly reflect the information interaction in operation process. In the process of information network organization, with "command activity" as the center, professional information system users, information network nodes and various transmission links are connected in series to form virtual subnets covering the information network. The establishment of the covering network is helpful to further enhance the information link and network situation presentation ability and improve the assistant decision-making level.

3.2. "Chains in Network" model

The "Chains in Network" model distributes resources for logical links with resource constraints in the shared underlying network. The requirements for these logical links based on "command activities" include not only link resource constraints, but also node resource constraints (for example, node computing power and location requirements, etc.). The underlying network allows different logical links to share the same underlying node resources.
3.2.1. Description of the Underlying Network

The underlying network topology can be marked as the weighted undirected graph \( G_s = (N_s, L_s, A_{s,n}, A_{s,l}) \), in which \( N_s \) represents the set of the underlying nodes, \( L_s \) represents the set of the underlying links, while \( A_{s,n} \) and \( A_{s,l} \) respectively represent the attribute of the underlying node \( n_s \) (\( n_s \in N_s \)) and the underlying link \( l_s \) (\( l_s \in L_s \)). And the attributes of the underlying node \( n_s \) can be the current available computing power and physical location of the node, while the attributes of the underlying link \( L_s \) can be the current available bandwidth resources of the link, etc. The loopless paths of all the underlying networks can be marked as \( P_s \). Figure 2 depicts an underlying network in which the number in the rectangle near the node represents the available computing resources for that node, and the number near the link represents the available bandwidth resources for that link.

![Fig.2. Underlying Network Topology](image)

3.2.2. Description of Upper Link

Similar to the description method of the underlying network topology, the topological structure of the upper logical link can also be marked as a weighted undirected graph \( G_v = (N_v, L_v, C_{v,n}, C_{v,l}) \), in which \( N_v \) is the set of upper virtual nodes, \( L_v \) is the set of virtual links, \( C_{v,n} \) and \( C_{v,l} \) respectively represent resource constraints of virtual node \( n_v \) (\( n_v \in N_v \)) and virtual link \( l_v \) (\( l_v \in L_v \)). Generally speaking, the resource constraint of virtual node mainly considers the computing power demand of the virtual node, while the resource constraint of virtual link mainly considers the bandwidth resource demand of the virtual link. For a virtual network request, it can be represented by a triple group \( VNR{(i)}(G_v, t_a, t_d) \), in which \( t_a \) represents the arrival time of the virtual network request, and \( t_d \) represents the duration of the virtual network in the underlying network. Figure 3 depicts a virtual network request of node and link resource constraints.

![Fig.3. Upper Chain Topology](image)

When the virtual network request arrives, the underlying network should distribute resources that meet its node and link resource requirements. When the virtual network leaves the underlying network,
the resources allocated for it are released. In addition, when the underlying network resources are insufficient, the request should be deferred mapped or rejected directly.

3.2.3. Description of "Chains in Network" mapping

"Chains in Network" mapping can be defined as $M: C_P(V, L) \rightarrow G_S(N'_S, P'_S)$, in which $N'_S \in N_S, P'_S \in P_S$. The mapping process of "Chains in Network" can be decomposed into the following two steps: firstly, map the virtual link node to the underlying network node that satisfies its resource constraints; then the virtual link is mapped to the underlying loopless path that satisfies its bandwidth resource constraints.

Figures 2 and 3 describe a reliable mapping scheme. For example, the node mapping is $\{a \rightarrow A, b \rightarrow B, c \rightarrow C, d \rightarrow D\}$, and the link mapping is $\{(a, b) \rightarrow (A, E, B), (a, c) \rightarrow (A, F, C), (c, d) \rightarrow (C, I, D), (b, d) \rightarrow (B, H, D)\}$. In the same upper virtual link, a virtual node can only be mapped to a lower physical node, while a virtual link can be mapped to multiple physical links. In addition, different virtual links can be mapped to the same underlying node, but different nodes belonging to the same virtual link cannot share the same underlying physical node.

4. Evaluation Index System

The main goal of "Chains in Network" mapping is to express the network resource requirements of all kinds of information from the command perspective, so as to improve the accuracy of network organization. The corresponding evaluation indexes include the underlying network benefits, the successful establishment rate of the upper virtual link and benefit rate of underlying network. The following is a formal description of the above three indexes on the basis of defining the benefits and costs of the upper link mapping.

At the time $t'$, the benefit of the lower network accepting the upper link mapping can be defined as:

$$R(G, t) = \alpha \sum_{n \in N} CPU(n) + (1 - \alpha) \sum_{l \in L} BW(l)$$

In which $CPU(n)$ represents the computing power demand value of virtual node $n$, and $CPU(n)$ represents the bandwidth capacity demand value of virtual link $l$. Parameter $\alpha$ and parameter $1 - \alpha$ can be used to adjust the relative weights of CPU and bandwidth resources. For "Chains in Network" mapping, benefit generally refers to benefit of building chains.

At the time $t'$, the cost of accepting a chain establishment requirement is defined as the sum of resources allocated by the underlying network to the upper link:

$$C(G, t) = \alpha \sum_{n \in N} CPU + (1 - \alpha) \sum_{l \in L} BW(l)$$

In which $f(l)$ assigns bandwidth resources to the upper logical link $l$. When the underlying physical link $l$ assigns bandwidth resources to the upper logical link $l$, $f(l)$ is $1$; otherwise $f(l)$ is $0$. $BW(f(l))$ represents the value of bandwidth allocated by $l$.

The underlying network needs an efficient mapping algorithm to maximize its benefits. The benefits of the underlying network can be defined as:

$$\lim_{t \to \infty} \frac{\sum_{t=0}^{T} R(G, t)}{T}$$

With the same underlying network resources, an efficient "Chains in Network" mapping algorithm can accept more link-building requirements. The chain-building rate to the upper can be defined as:

$$\lim_{T \to \infty} \frac{\sum_{t=0}^{T} VNR}{\sum_{t=0}^{T} VNR}$$

The benefit rate of chain-building of the underlying network can reflect the utilization rate of resources in the underlying network to some extent. It is defined as the ratio between the benefit of chain-building in a period of time and the open source of resources, which can be defined as follows:

$$\lim_{T \to \infty} \frac{\sum_{t=0}^{T} R(G, t)}{\sum_{t=0}^{T} C(G, t)}$$
5. Conclusions

From the perspective of precise operation service, this paper studies the precise organization mode of operation network. The traditional network organization usually starts from the network structure planning and resource channel configuration of operation area. However, this paper starts from the command activity and the command process, and it precisely plans the information link around operation's information chain, C2 chain, strike chain and service chain. In this paper, the mapping model of "Chains in Network" is established and the basic mapping evaluation index system is established. The next step is to carry out in-depth research on the mapping of logical information link to physical network.

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