

# A Heterogeneous Ship Formation Network Selection Algorithm Based on Service Level and Load Balance

Xubin Yang, Wenqiang Zhang, Xinrong Wu, Lei Zhu  
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**Abstract** Future ship formation tactical wireless communication networks will be heterogeneous and integrate several communication methods. To guarantee the end-to-end Quality of Service (QoS) for users in the heterogeneous ship formation network, one of the key problems is to design a proper network selection algorithm depending upon the QoS requirements of the service together with the network QoS parameters. In this paper, we propose a network selection algorithm based on service level and load balance. Analytic Hierarchy Process (AHP) method and entropy method are applied to compute the subjective weights and objective weights, respectively, and the final weights are determined by the combination weight process. The algorithm then adapts Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method to rank the optional subnets. Taking the service level and load balance into consideration, the suboptimal subnet is also probably to be selected and service with high service level has better chance to access to the optimal subnet. Simulation results verify the validity as well as the load balance performance of the algorithm.

**Keywords** Heterogeneous ship formation network · Network selection · Service level · Load balance

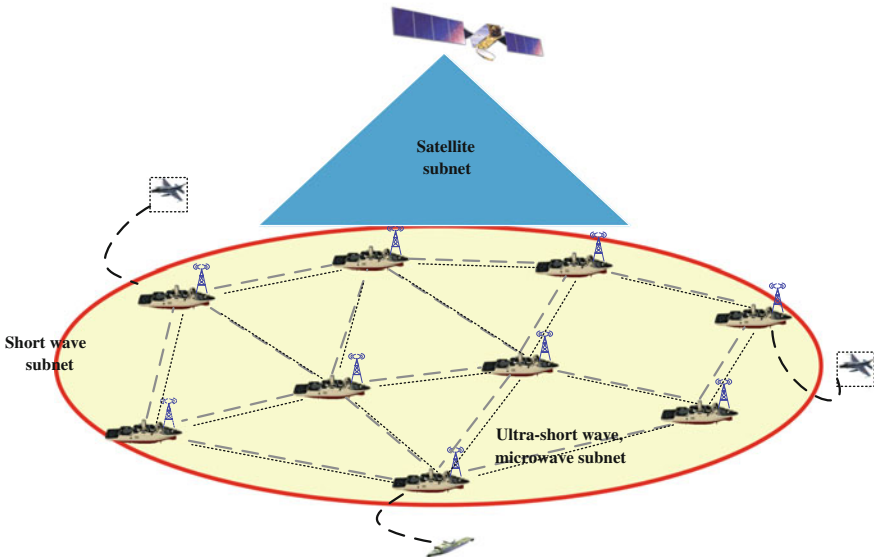
## 1 Introduction

With the wireless communication technology and the network technology developing rapidly, future ship formation tactical wireless communication network (hereinafter referred to as ship formation network) will be a high-speed self-organized

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**Fig. 1** The heterogeneous ship formation network

network center which is expected to integrate multiple communication methods. As shown in Fig. 1, nodes in the ship formation network all support server communication methods and each communication method forms a communication subnet. The network center should achieve the effective access of users which are flexible platforms composed of aircraft, submarines, and so on. Therefore in the environment of the heterogeneous ship formation network, how users select the Always Best Connected [1] network according to their own needs together with the network QoS parameters has become a new research points.

In recent years, numerous network selection algorithms have been proposed, among which multi-attribute decision-making (MADM) [2] algorithm has been used widely because of its comprehensive consideration of network attributes. In [3–5], TOPSIS method has been used to rank the alternative networks by computing the relative closeness coefficient of each alternative network to the ideal network. In [6], an improved AHP method is applied to solve the weights consistent problem in network selection. In [7], depending on the QoS requirements, a network selection algorithm based on the signal strength is proposed. To make the network selection more accurately, fuzzy AHP is used in [8] to assign the attribute weight. However, the above network selection algorithms are in the background of civil heterogeneous convergence networks. For a specific tactical communication network, to fully exert combat effectiveness only important users' communication

(e.g., the commander's communication) is guaranteed. Besides, to make the full use of the ship formation network, load balance among the multiple hosted networks also need to be taken into consideration.

In this paper, combined with the actual characteristics of the heterogeneous ship formation network, we proposed a network selection algorithm based on service level and load balance. The algorithm adapts a combination weight process to make each attribute assigned more accurately and TOPSIS is used to rank the alternative subnets. By classifying the service level and setting the relative closeness coefficient difference threshold, the suboptimal subnet is also probably to be chosen to balance the global traffic, and high level service is more likely to be guaranteed better QoS.

## 2 Service Classification

Based on users' perceived QoS of the service, 3GPP classifies next generation network service into four primary types, respectively are conversational service, streaming service, interactive service, and background service. However, the services in ship formation network are of specific military application background and are not suitable to be classified exactly according to the standard of the civil network service. Considering the actual QoS requirements of the services in the ship formation network, we sort them into voice service, messages service, data service, and streaming service, as described in Table 1, where B denotes bandwidth, D denotes delay, DJ denotes delay jitter, PLR denotes packet loss rate, BER denotes bit error rate.

Ship formation network contains different kinds of users, and the users' levels are diverse. In battlefield environment, users' service importance may also change according to mission's importance and urgency. Hence, we sort the service level (SL) into three classes based on the importance of the user and the service, as is shown in Table 2.

**Table 1** Service classification in ship formation network

Service type	QoS requirements					Including service
	B	D	DJ	PLR	BER	
Voice	Low	Strict	Strict	Moderate	Moderate	Voice of different security classifications
Messages	Low	High	Low	Strict	Strict	Messages commands
Data	High	Low	Low	High	High	Mainly refer to large-capacity data
Streaming	Strict	Low	Moderate	High	High	Videos images

**Table 2** Service level classification

SL	Service description	Importance degree
1	Important service of key users	Extremely
2	General service of key users or important service of normal users	Quite
3	General service of normal users	Moderate

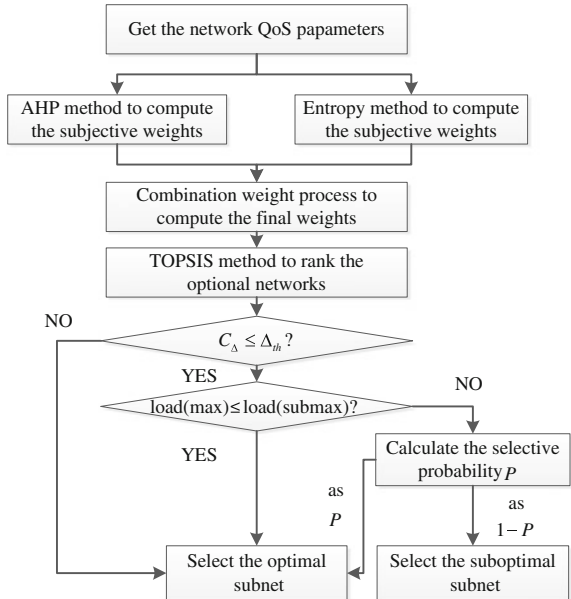
### 3 Network Selection Algorithm

In heterogeneous ship formation network, due to the characteristics of the high delay in the satellite subnet and the low bandwidth in the short wave subnet, large-capacity service is mainly transmitted over ultra-short wave subnet and microwave subnet by multiple relay transmission. Satellite subnet and short wave subnet are normally for signaling channels or backup networks solely. Hence, we take user preference (UP) as one of the target attributes in the proposed algorithm, and the proposed algorithm process is shown as Fig. 2.

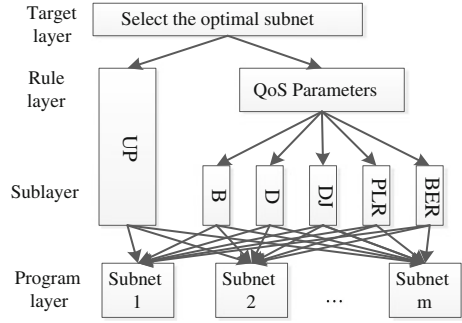
#### 3.1 Combination Weight Process to Compute the Weights

In ship formation network, the QoS requirements between different types of service are greatly different, so we adapt AHP method to compute the subjective weights of

**Fig. 2** The proposed algorithm process



**Fig. 3** The hierarchical structure of network selection



the target attributes. Besides, some QoS parameters are also distinct between each subnet, e.g., bandwidth in short wave subnet is quite low. Considering that sole AHP method is too subjective and does not take the network objective conditions into account. Hence, we adapt entropy method to compute the objective weights of the target attributes and the final weights is calculated by combination weight process. The hierarchical structure of network selection in AHP method is shown as Fig. 3.

In entropy method, we construct the original target decision-making matrix  $\mathbf{A}$  by combining the user preference parameters with the QoS parameters:

$$\mathbf{A} = \begin{matrix} & \begin{matrix} UP & B & D & DJ & PLR & BER \end{matrix} \\ \begin{matrix} N_1 \\ N_2 \\ \vdots \\ N_m \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & a_{m4} & a_{m5} & a_{m6} \end{bmatrix} \end{matrix} \quad (1)$$

Assume  $\mathbf{W}' = [w'_1, w'_2, w'_3, w'_4, w'_5, w'_6]$  is the subjective weight vector obtained by AHP method, and  $\mathbf{W}'' = [w''_1, w''_2, w''_3, w''_4, w''_5, w''_6]$  is the objective weight vector obtained by entropy method. The final weight of  $i$ th target attribute  $w_i$  can be denoted as the linear combination of  $w'_i$  and  $w''_i$ . That is:

$$w_i = \lambda w'_i + (1 - \lambda)w''_i \quad (i = 1, 2, 3, 4, 5, 6) \quad (2)$$

where  $0 < \lambda < 1$ , denotes the proportional coefficient of the subjective weight. To get the optimal combination weights, make a game equilibrium between the subjective weights and the objective weights by minimizing the deviation to optimal weights, namely:

$$\min z = \sum \left[ (w_i - w'_i)^2 + (w_i - w''_i)^2 \right] \quad (3)$$

Combine (3) with (2), the optimal proportional coefficient  $\lambda$  and the final combination weight vector can be obtained:  $\mathbf{W} = [w_1, w_2, w_3, w_4, w_5, w_6]$ .  $\mathbf{W}$  will be used to construct the weighted target decision-making matrix in later TOPSIS method.

### 3.2 TOPSIS Method to Rank the Optional Subnets

TOPSIS method is a widely used ranking algorithm to conduct network selection scheme. Its basic idea is to rank the optional networks by computing the relative closeness coefficient of each alternative network to the ideal network. Suppose  $D_i^+$  and  $D_i^-$  respectively denotes the Euclidean distance of each optional subnet to the positive ideal solution and negative ideal solution calculated by TOPSIS method. Then the relative closeness coefficient to the negative ideal solution can be given by

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (i = 1, 2, \dots, m) \quad (4)$$

where  $C_i$  reflects the deviate degree between optional subnet  $N_i$  and the negative ideal solution. TOPSIS method generally selects the subnet whose  $C_i$  is the highest.

### 3.3 Network Selection Scheme Based on Service Level and Load Balance

As in Fig. 2, the proposed algorithm does not directly choose the subnet whose  $C_i$  is the highest to access. Instead, the algorithm calculates the relative closeness coefficient difference between the optimal subnet and the suboptimal subnet, defined as  $C_\Delta$ :

$$C_\Delta = \max_i(C_i) - \text{sub}_i \max(C_i) \quad (5)$$

Then set a threshold of  $C_\Delta$  in advance, denoted as  $\Delta_{th}$ . The network selection scheme will be determined depending on the value of  $C_\Delta$  and  $\Delta_{th}$ . In the proposed scheme, the optimal subnet selective probability  $P$  is given by:

$$P = \alpha \frac{L(\text{sub}_i \max(C_i))}{L(\max_i(C_i))} \quad (6)$$

where  $\alpha$  is a factor related to service level.  $0 \leq \alpha \leq 1$ , and the higher the service level, the smaller the  $\alpha$ . That is to say service with high service level has better chance to receive the best QoS guarantee.  $L(\text{sub}_i \max(C_i))$  denotes the load of the

suboptimal subnet and  $L(\max_i(C_i))$  denotes the load of the optimal subnet. Denoted the ratio as  $\beta, 0 < \beta < 1$ , it indicates the load balance degree between the optimal subnet and the suboptimal subnet. From (6), we can see  $P$  is proportional with  $\beta$ . That is to say, the less balance of the load between the optimal subnet and the suboptimal subnet, the higher probability to access to the suboptimal subnet. On this account, the global traffic of the ship formation network can be balanced.

## 4 Simulation and Analysis

We consider a heterogeneous ship formation network integrating four different subnets, respectively are broadband short ground wave subnet with a total bandwidth of 76.8 Kbps, denoted as  $N_1$ , high-speed ultra-short wave subnet with a total bandwidth of 40 Mbps, denoted as  $N_2$ , high-speed microwave subnet with a total bandwidth of 20 Mbps, denoted as  $N_3$ , and the second generation communication satellite subnet with a total bandwidth of 34 Mbps, denoted as  $N_4$ .

The value of user preference is depending on the type of the service,  $\Delta_{th}$  is set to 0.2, and  $\alpha = 1/\sqrt{SL}$ . To verify the validity as well as the load balance performance of the algorithm, we set the following three simulation scenarios:

### 4.1 Simulation Scenario 1

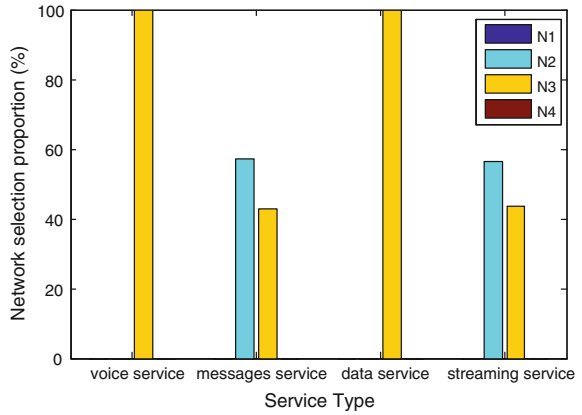
Scenario1 denotes the normal environment (without any electromagnetic interference). When the service comes, the network QoS parameters are set as Table 3, where B denotes the available bandwidth. 1000 times simulation is performed for each type of service and the service level is random. The network selection results are shown as in Figs. 4 and 5.

Figure 4 depicts the network selection proportion for each type of service in scenario 1. It is shown that the voice service and the messages service all select the microwave subnet whose bandwidth is relatively high and the delay, day jitter, packet loss rate, and bitter error rate are quite low as the optimal access network. Streaming service has strict requirements on bandwidth and messages service has strict requirements on delay, as a result, these two types of service select the

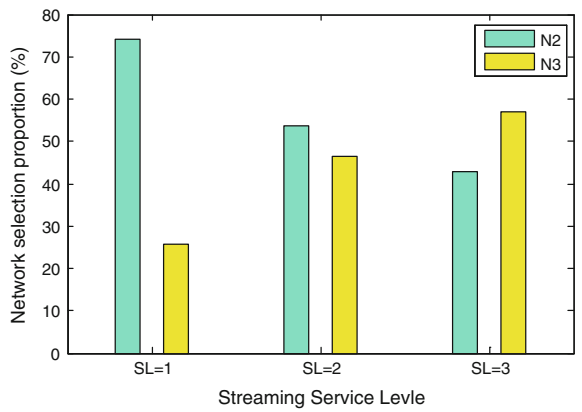
**Table 3** The network QoS parameters in scenario 1

	B (Mbps)	D (ms)	DJ (ms)	PLR (%)	BER ( $10^{-4}$ )	Load
$N_1$	0.06	40	10	0.4	0.5	0.2
$N_2$	24	20	6	0.5	0.2	0.4
$N_3$	14	24	6	0.3	0.05/10	0.3
$N_4$	27.2	270	40	0.5	1	0.2

**Fig. 4** The network selection proportion in scenario 1



**Fig. 5** The network selection proportion for streaming service



ultra-short wave subnet whose bandwidth is the highest, meanwhile the delay is the lowest as the optimal subnet. Besides, because of the high traffic load of the ultra-short wave subnet, streaming service and messages service partly select the suboptimal subnet (microwave subnet) to balance the global traffic. From the simulation result, we can dawn that in the normal environment, service transmission mainly depend on ultra-short wave subnet and microwave subnet, satellite subnet and short wave subnet are normally used solely as backup networks. The results are coincided with the fact.

Figure 5 depicts the network selection proportion for steaming service of different service level in scenario 1. The simulation results show that the higher the service level, the higher proportion for the service to select the optimal subnet. It indicates the proposed network selection algorithm can provide service of high service level with better chance to achieve the better QoS guarantee based on load balance.



### 4.2 Simulation Scenario 2

In the real combat environment, every band of the ship formation network is likely to be affected by enemy electromagnetic interference. Assuming the microwave band is affected by electromagnetic interference, the BER of the microwave subnet changes from  $0.05 \times 10^{-4}$  to  $10 \times 10^{-4}$  and the left network QoS parameters remain the same as Table 4. Then the network selection results are shown as in Fig. 6.

Figure 6 depicts the network selection proportion for each type of service in scenario 2. The simulation results show when the microwave subnet is affected by electromagnetic interference, large-capacity service can partly transfer to satellite subnet for service transmission and the voice service partly select the short wave subnet because of its low requirements on bandwidth. The results verify the backup role of the short wave subnet and the satellite subnet.

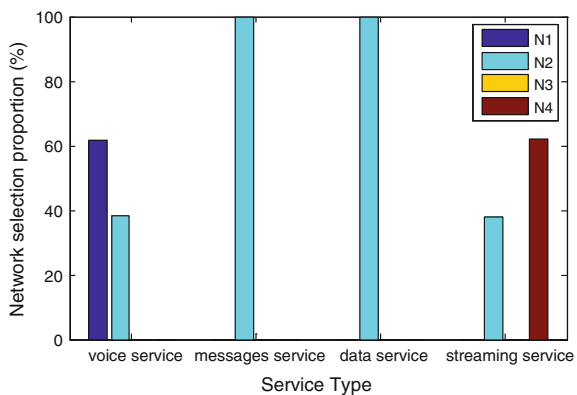
### 4.3 Simulation Scenario 3

In a period of time, assume the four types of service arrive at an independent Poisson process and the duration of the service obeys exponential distribution. The service level is assumed to be random. The network QoS parameters will change

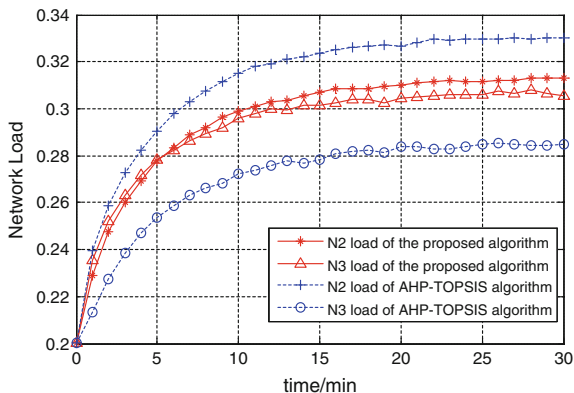
**Table 4** The initial network QoS parameters in scenario 2

	B (Mbps)	D (ms)	DJ (ms)	PLR (%)	BER ( $10^{-4}$ )	Load
$N_1$	0.06	40	10	0.4	0.5	0.2
$N_2$	32	18	5	0.4	0.2	0.2
$N_3$	16	23	6	0.28	0.05	0.2
$N_4$	27.2	270	40	0.5	1	0.2

**Fig. 6** The network selection proportion in scenario 2



**Fig. 7** The network load of  $N_1$  and  $N_2$  in scenario 3



correspondingly after the service successfully access to the ship formation network. The initial network QoS parameters are set as Table 4. The average of 1000 times simulation results is shown as in Fig. 6.

Figure 7 depicts the load of ultra-short wave subnet and the microwave subnet versus the time in scenario 3. The proposed algorithm is compared with the algorithm simply based on AHP-TOPSIS method, where AHP method is used to determine the target attribute weight while TOPSIS method is used to select the optimal subnet. It is clear that the load of the ultra-short wave subnet is always higher than the microwave subnet's in both of the two algorithms. It is because that the total bandwidth of the ultra-short wave is higher, hence the ultra-short wave can provide more available bandwidth under the same load. Simulation results show that the proposed algorithm achieves better load balance than the AHP-TOPSIS one in the steady state, thus the load balance performance of the proposed algorithm is verified.

## 5 Conclusion

To guarantee the end-to-end QoS and maximize the utilization of the resources in heterogeneous ship formation network, the proper network selection scheme is the one of the key technologies. Considering the actual characteristics, the proposed algorithm sorts the service level into three classes and the load balance is the key point to be concerned. The simulation results show that the proposed algorithm can select the suitable subnet based on the QoS requirements of the service, where the service with high service level has better chance to access to the optimal subnet, and the performance of load balance is verified in the end.

**Acknowledgements** This work is supported by National Natural Science Foundation of Jiangsu Province BK20140065.

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