Virtualization CPE template automatic recommendation algorithm based on fuzzy comprehensive evaluation method

Zheng Dong¹, Xiaohong Huang¹* and Tianle Yang²

¹ Network Information Center, Beijing University of Posts and Telecommunications, Beijing, 100876, China
² Tianle Yang, Government and Enterprise Service Company, ChinaMobile Group, Beijing, 100000 China

*Corresponding author’s e-mail: huangxh@bupt.edu.cn

Abstract. Research of virtualized Customer Premise Equipment (CPE) based on Network Function Virtualization (NFV) environment can replace existing physical CPE, thereby reducing the deployment cost. There are two main problems in research of existing virtualized CPE, one is that existing template configurations are manually configured, and configuration efficiency is low; the other is that the previous research on Virtualized Network Function (VNF) function templates for virtualized CPE mostly focuses on the research of a certain function or a specific scene, and lacks versatility. Aiming at these two problems, this paper presents a virtual CPE template automatic recommendation algorithm based on fuzzy comprehensive evaluation method. The automatic recommendation template is applicable to many different types of templates. Firstly, we classify the template parameters. Secondly, we build the index system. Thirdly, we calculate the weight assignment level of the membership index of the second-level index system based on the fuzzy comprehensive evaluation method. Finally, generate parameters. The model can automatically generate templates that are more suitable for current situation in real time according to changes in parameters such as traffic, user type, and device performance. Compared with manual configuration, there is a significant improvement in parameters generation accuracy and template configuration speed.

1. Introduction

Study has found that with the development of SDN [1]-[4], network equipment and functions have been greatly developed. With the development of SDN, NFV [5]-[7] is widely used in various network scenarios. The CPE is a high-speed wireless gateway located at the interface of the home/enterprise/government network and the external network, at the edge of the access network. Take the home user as an example. The CPE can provide voice, data, and video services for home users. When there is a problem in the network, because the IP address of the device in the home network is implemented by NAT (Network Address Translation), operators often need home maintenance to solve the problem, increasing the maintenance cost, and the network problems may have nothing to do with the operator. Therefore, if the network environment is opened to the operator, it is convenient for the operator to remotely diagnose and solve the problems in the network, and also reduce the operation and maintenance cost of the CPE. Besides, it is also provides the possibility of adding new value-added services in the future. In order to solve the above problems, we propose a...
scheme for virtualizing CPE. In the traditional carrier environment, the number of broadband users and broadband bandwidth are increasing, and various services are also developing rapidly. The existing architecture is more and more difficult to meet the requirements of fast service opening, efficient operation and maintenance, flexible and programmable, customer-oriented customization [8]. Virtualized CPE technology can provide ideas for solving such problems.

Some progresses have been made in the research of virtualized CPE. The current researches mainly focus on the improvement of the part of VNF function, the research of virtualization technology and the standardization of virtualization protocols. Firstly, for the virtualization CPE architecture, some improvements have been done on some of the VNF features, such as, improvements to VPNs in VNF function or improvements based on specific user types. One aspect is the study of virtualized CPE protocols:

Fufeng Chao et al. proposed three VPN technologies based on virtualized CPE, which are based on VxLAN, MPLS protocols and VPN technology based on IPSec protocol [9]; Fufeng Chao et al. proposed the method of establishing the connection between CPE and cloud platform in virtualized CPE, and the VxLAN and NvGRE technologies are adopted to realize the communication between the user-side CPE and the cloud platform while keeping the slight modification of the existing massive CPE [10]; Besides, the research on virtualization technology of virtualized CPE is also a research hotspot. Wang Wei and others proposed the virtualization research technology of enterprise network management, and proposed the realization of product functions and virtualization through NFV, thereby realizing the automatic and fast opening of the enterprise dedicated line business and the function of the user's self-service [11].

Existing virtualized CPE research has also been proposed with relevant standards. Currently, the existing standards mainly include: The BBF organization, the TR-317 proposal [12] issued in June 2016, is mainly to regulate the technical and management requirements of virtualized CPE and this standard uses the NFV which is based on virtualized CPE scheme; the ETSI organization also publishes standards that briefly introduce the NFV-based virtualized CPE scheme [13]; Cisco has proposed a draft standard on virtualized CPE deployment scheme.

It is not difficult to see from the current research that the current research on virtualized CPE mainly has the following two problems. One is that the configuration of the virtualized CPE is manually configured. Manual configuration of the template will result in inefficiency and is not suitable for large-scale configuration. The other is that the current research has a single applicability, mostly concentrated in a specified user type or a template, and is not universal.

Based on the above research, this paper will design a virtualized CPE template automatic recommendation algorithm based on fuzzy comprehensive evaluation method which is universal. By obtaining the user type, network status, equipment information and other parameters, the method classifies the parameters of the VNF template, and then constructs the second-level fuzzy evaluation structure by the fuzzy comprehensive rating method of the analytic hierarchy process, and calculates each based on the membership function. Rating the classification parameters and give the final template configuration rating.

The organizational structure of this article is as follows. Section 1 introduces the development of virtualized CPE and the problems of current research. Section 2 introduces the specific methods and key steps of the algorithm, especially the key parts different from traditional fuzzy comprehensive evaluation method. Section 3 does the experiment and analyses the result. Section 4 summarizes the algorithm and gives the conclusion.

2. Virtualization CPE template recommendation algorithm based on fuzzy comprehensive evaluation method

The membership theory of fuzzy mathematics is to link the influencing factors that are not easy to objective quantitative analysis with fuzzy concepts and precise mathematical models. Based on this idea, the fuzzy comprehensive evaluation method quantifies the non-deterministic factors that are not easy to objective, and then gives an overall evaluation method. In this paper, the fuzzy comprehensive
evaluation method is a method to combine the AHP method and the fuzzy comprehensive evaluation method for comprehensive evaluation. The main reason for recommending VNF function templates is that, firstly, the parameter configuration of the template has certain ambiguity. If only qualitative analysis is performed, it is not easy to be objective and accurate. If quantitative analysis is used, these indicators are not easy to do quantitative analysis. The specific steps of the fuzzy comprehensive evaluation method are as follows.

- Identify goals and evaluation factors
  P evaluation indicators, $u = \{u_1, u_2, ..., u_p\}$.

- Construct judgment matrix
  This paper judges the value of the matrix element reflects people's understanding of the relative importance of each element, generally using the scale method of 1-9 and its reciprocal. The value is the importance of the two elements of the same layer to the upper layer. When the importance of the mutual comparison factor can be explained by the ratio of the actual meaning, the value of the corresponding element of the judgment matrix is taken as the ratio. Judging the maximum eigenvalue of the matrix $S$ by programming $\lambda_{\text{max}}$ and its corresponding feature vector, then do the normalization. This eigenvector is the order of importance of each evaluation factor, that is, the distribution of weight coefficients.

- Consistency test
  In order to check the consistency of the judgment matrix, it is necessary to calculate the consistency index $CI = \frac{\lambda_{\text{max}}-n}{n-1}$, and the average random consistency indicator $RI$. When the random consistency ratio $R = \frac{CI}{RI} < 0.10$, it is considered that the results of the hierarchical analysis ranking have satisfactory consistency, that is, the distribution of the weight coefficients is reasonable; otherwise, the element values of the judgment matrix are adjusted, and the weight coefficients are re-allocated. The consistency index $RI$ value is the value given by Satty, as shown in the following table. When the consistency ratio is less than 0.1, the matrix passes the consistency test.

| N  | 2   | 3   | 4   | 5   | 6   | 7   |
|----|-----|-----|-----|-----|-----|-----|
| RI | 0.52| 0.90| 1.12| 1.26| 1.36|     |

- Determine the rating domain and Establish fuzzy relation matrix $R$
  The $V$ set, which is level set. Each level can correspond to a fuzzy matrix. Determining the fuzzy relation matrix using binary comparison ordering. The i-th row and j-th column element $r$ in the matrix $R$ indicates the membership degree of the vi-level fuzzy subset from a factor $u$.

- Calculation evaluation vector
  Faced with the concept that some connotations and extensions are relatively vague, the binary contrast ranking method determines the order of certain features by comparing pairs of objects to determine the degree of membership of the corresponding features, and obtains the membership matrix $R$. The evaluation vector is obtained by the membership matrix.

- Calculate the comprehensive score for rating
  Judging the maximum eigenvalue of the matrix $S$ by programming $\lambda_{\text{max}}$ and its corresponding feature. The comprehensive evaluation score is obtained, according to the evaluation vector and the comment level domain and the rating is judged according to the rating, and the rating of the template is judged.

3. Experiment and Analysis
Based on the second part’s steps, this paper takes the probe template as an example and apply the algorithm to experiment.

- Calculate the comprehensive score for rating
  The NFV-based probe template mainly has these parameters, and each parameter corresponds to a different configuration content.
Table 2. Probe template parameters description table.

| Variable name     | Variable description                                                                                                                                                                                                 |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| probe type        | Specify the packet and protocol contents of a probe.                                                                                                                                                                   |
| Target            | Specify the destination address or URL used for the probes.                                                                                                                                                             |
| test_interval     | Specify the time to wait between tests, in seconds. A test interval of 0 seconds causes the RPM test to stop after one iteration.                                                                                      |
| history_size      | Specify the number of stored history entries.                                                                                                                                                                          |
| moving_average_size| Enable statistical calculation operations to be performed across a configurable number of the most recent samples.                                                                                                     |
| probe count       | Specify the number of probes within a test.                                                                                                                                                                             |
| probe_interval    | Specify the time to wait between sending packets, in seconds.                                                                                                                                                         |
| source_address    | Specify the source IP address used for probes. If the source IP address is not one of the router’s or switch’s assigned addresses, the packet use the outgoing interface’s address as its source. |
| source-address    | Enable time stamping of RPM probe messages in the Packet Forwarding Engine host processor. This feature is supported only with icmp-ping, icmp-ping-timestamp, and Transmission Control Protocol (TCP) port to which a probe is sent. This statement is used only for TCP or UDP probe types. The value for the destination-port can be only 7 when you configure the destination port along with hardware time stamping. A constraint check prevents you for configuring any other value for the destination port in this case. This constraint does not apply when you are using one-way hardware timestamping along with destination-port and either probe-type udp-ping or probe-type udp-ping-timestamp. |

It is not difficult to see from the introduction of the above table, some of them will have certain similarities in the required data types, the goals of the specified configuration, and so on. Therefore, the parameters of the associated fixed configuration in the variable can be configured in advance, reducing the number of parameters to be configured, and improving the accuracy of the recommendation. After that, we can get the following form.

Table 3. Variable combination description table.

| Variables          | Description                                                                                                                                                                                                 |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| probe type &       | After configuring the probe type associated with HW_timestamp Need to consider storage capacity The variable is a fixed value when specified Both are used to specify the waiting time |
| HW_timestamp       |                                                                                                                                                                                                             |
| History_size       |                                                                                                                                                                                                             |
| destination_port   |                                                                                                                                                                                                             |
| test_interval &    |                                                                                                                                                                                                             |
| probe_interval     |                                                                                                                                                                                                             |
between sending data, the difference is the content of the sent data. Filling in fixed content can be configured according to the user's different security requirements.

source_address & target

Filling in fixed content can be configured according to the user's different security requirements.

moving_average_size & probe_count

Filling in fixed content can be configured according to the user's different security requirements.

Determine the combination of variables that need to be configured, and determine the primary evaluation index of the evaluation index. The primary evaluation index determines the parameters of the designated VNF template from various angles. For the first-level evaluation indicators, use the AHP method to analyze the characteristics of each level of indicators and construct a secondary evaluation index.

- Probe type and HW_timestamp

When determining the Probe type parameter, we set the corresponding configuration parameters according to the ratio of each protocol in different bandwidth situations. When the users of different bandwidths use it, the corresponding HTTP, TCP and UDP protocols will have different proportions. Therefore, the ratios of HTTP, TCP and UDP in Table are first normalized. Get the following table.

Table 4. Proportion of Broadband Network protocol (Normalized).

| Broadband user type | HTTP | TCP | UDP |
|---------------------|------|-----|-----|
| 2M                  | 0.40 | 0.23| 0.37|
| 4M                  | 0.37 | 0.23| 0.40|
| 8M                  | 0.37 | 0.26| 0.37|
| 20M                 | 0.37 | 0.26| 0.37|
| 100M                | 0.43 | 0.26| 0.31|

According to the different proportions of the protocols in the table, we can get the configuration parameter weight vector of the Probe type variable under different bandwidth conditions.

- History size

This variable is used to specify the number of stored history entries. Therefore, it is necessary to consider the storage capacity of the current device, the amount of storage space that can be allocated, and the weighting of the information that the service needs to record information. The number of entries in the info, warning, and error levels varies greatly. To consider different levels of entries, it is necessary to consider the difference in security requirements between different user types.

- Destination port

The choice of port should match the security policy, and also consider the type of user and other information.

- Test interval and probe interval

It is used to specify the waiting time between tests. If the waiting time is too long, the template will be too inefficient and the waiting time will be too short, which will increase the burden on the device. Consider the device's CPU performance, memory size, and the level of testing required to determine latency.

- Source address and target

This set of variables is associated with the IP address and is used to detect and monitor the source and destination IP addresses. In order to more accurately monitor the source and destination IP addresses, you need to consider the user type and security level.
Moving average size and probe count
This variable is used to determine the number of probes in the statistical calculation operation and the test on the configurable sample. This always depends on the number of probes and the size, so the user needs and the actual configuration of the device are mainly considered. Mainly types are user types, device storage space, and device CPU performance.

Calculate the comprehensive score for rating
After determining the content of the secondary evaluation indicators corresponding to each level of indicators, the environmental indicator system is as shown in the following figure.

Figure 1. Ladder hierarchy mode.

Determining the rating level
To facilitate the calculation, we quantify the semantic scale of the subjective evaluation and assign the values to 4, 3, 2, and 1. Subjective measurements use semantic scales, and the evaluation criteria for evaluation are shown in the table below.

Table 5. Comment level domain standard table

| Evaluation range | Level   | Description                                           |
|------------------|---------|-------------------------------------------------------|
| X > 3            | Great   | Template parameters are very suitable for the current situation |
| 2 < X ≤ 3        | Good    | Template parameters are suitable for the current situation |
| 1 < X ≤ 2        | Average | Template parameters are not recommended               |
| X ≤ 1            | Poor    | Do not use template parameters                       |

Computational Comprehensive Evaluation Vector
Faced with the concept that some connotations and extensions are relatively vague, the binary contrast ranking method determines the order of a certain feature by comparing two objects to
determine the degree of membership of the corresponding features. It is not difficult to derive the corresponding membership vector matrix $R$ for each:

$$R_1 = \begin{pmatrix} 0.404 & 0.410 & 0.154 & 0.032 \\ 0.756 & 0.191 & 0.053 & 0 \\ 0.368 & 0.354 & 0.170 & 0.107 \end{pmatrix}$$

(1)

$$R_2 = \begin{pmatrix} 0.313 & 0.436 & 0.164 & 0.087 \\ 0.373 & 0.408 & 0.189 & 0.030 \\ 0.272 & 0.500 & 0.122370 & 0.006 \\ 0.312 & 0.459 & 0.150 & 0.279 \end{pmatrix}$$

(2)

$$R_3 = \begin{pmatrix} 0.315 & 0.460 & 0.055 & 0.170 \\ 0.230 & 0.488 & 0.218 & 0.064 \end{pmatrix}$$

(3)

$$R_4 = \begin{pmatrix} 0.180 & 0.403 & 0.256 & 0.161 \\ 0.600 & 0.161 & 0.052393 & 0 \\ 0.207 & 0.285 & 0.311 & 0.197 \end{pmatrix}$$

(4)

$$R_5 = \begin{pmatrix} 0.556 & 0.277 & 0.058 & 0.110 \\ 0.489 & 0.310 & 0.160 & 0.041 \end{pmatrix}$$

(5)

$$R_6 = \begin{pmatrix} 0.328 & 0.466 & 0.167 & 0.040 \\ 0.499 & 0.225 & 0.052363 & 0.041 \\ 0.296 & 0.543 & 0.137 & 0.025 \end{pmatrix}$$

(6)

Then, this paper calculate the evaluation vector from the calculated membership vector matrix $R$.

$$A_1 = \alpha \cdot R_1 = (0.4300 \ 0.2600 \ 0.3100) \cdot \begin{pmatrix} 0.404 & 0.410 & 0.154 & 0.032 \\ 0.756 & 0.191 & 0.053 & 0 \\ 0.368 & 0.354 & 0.170 & 0.107 \end{pmatrix}$$

$$= (0.48436 \ 0.3357 \ 0.1327 \ 0.0469)$$

(7)

After normalization, the evaluation vector is obtained as

$$A_1 = (0.4845 \ 0.3358 \ 0.1327 \ 0.0469)$$

(8)

Similarly, we can get other evaluation vectors.

$$A_2 = (0.3159 \ 0.4435 \ 0.1763 \ 0.0643)$$

(9)

$$A_3 = (0.2938 \ 0.4670 \ 0.0957 \ 0.1435)$$

(10)

$$A_4 = (0.2840 \ 0.2873 \ 0.2823 \ 0.1464)$$

(11)

$$A_5 = (0.5330 \ 0.2880 \ 0.0920 \ 0.0870)$$

(12)

$$A_6 = (0.3750 \ 0.4051 \ 0.1826 \ 0.0374)$$

(13)

So as comprehensive evaluation vector

$$A = (0.3953 \ 0.3704 \ 0.1614 \ 0.0739)$$

(14)

Grade the Comprehensive Score

$$V_1 = 4 \times 0.4845 + 3 \times 0.3358 + 2 \times 0.1327 + 1 \times 0.0469 = 3.2577$$

(15)

$$V_2 = 4 \times 0.3159 + 3 \times 0.4435 + 2 \times 0.1763 + 1 \times 0.0643 = 3.011$$

(16)
\[ V_3 = 4 \times 0.2938 + 3 \times 0.4670 + 2 \times 0.0957 + 1 \times 0.1435 = 2.911 \quad (17) \]

\[ V_4 = 4 \times 0.2840 + 3 \times 0.2873 + 2 \times 0.2823 + 1 \times 0.1464 = 2.709 \quad (18) \]

\[ V_5 = 4 \times 0.5330 + 3 \times 0.2880 + 2 \times 0.0920 + 1 \times 0.0870 = 3.267 \quad (19) \]

\[ V_6 = 4 \times 0.375 + 3 \times 0.4051 + 2 \times 0.1826 + 1 \times 0.0374 = 3.1179 \quad (20) \]

\[ V = 4 \times 0.3953 + 3 \times 0.3704 + 2 \times 0.1614 + 1 \times 0.0729 = 3.0881 \quad (21) \]

Known by Table 6 before, the comprehensive evaluation index result \( V > 3 \) indicates that the overall quality of the recommended template calculated by the recommended algorithm in the probe template under this condition is good. It is recommended to use this template for configuration.

For the NFV environment, the VNF function template configuration in the virtualized CPE cannot automate the recommendation parameter configuration. This paper constructed the virtualized VNF function template based on the NFV environment, and gave the virtualization CPE template recommendation algorithm based on the fuzzy comprehensive evaluation method. Firstly, the template parameters are classified according to the content of the parameter indicators; then the index system is constructed according to the analytic hierarchy process; the membership level of the second-level index system based on the fuzzy comprehensive evaluation method is calculated and analysed, and the recommended parameters are generated. The algorithm automatically generates a VNF function template that is more adaptive to the current situation by automatically changing the parameters such as traffic, user type, and device performance. Compared with the traditional manual configuration, there is a significant improvement in parameter generation accuracy and VNF function template configuration speed.

The device status is automatically obtained every 30s through the program call, and the recommendation template is automatically generated according to the information such as the login user type. The average score of the generated template is 2.868. Using the recommendation algorithm, the average time taken to generate a template is about 253ms. If you consider further improving the efficiency of the algorithm, you can consider the more efficient C++ instead of the Python language. You can also consider refining the user's classification and increasing the accuracy of the recommendation.

Then, this paper’s algorithm is compared with the final applied template which is totally correct seen as the standard template and compared with the accuracy of manually configuring the template for the first time. After generating 100 templates in different situations on the four templates. The accuracy is shown in the following table. The standard templates have already applied to the network online.

| Template type | Number of parameters | Algorithm Accuracy | First Manual Accuracy |
|---------------|----------------------|--------------------|----------------------|
| Probe         | 10                   | 95%                | 25%                  |
| VPN           | 11                   | 95%                | 27%                  |
| UTM           | 17                   | 93%                | 19%                  |
| IDP           | 7                    | 97%                | 35%                  |

Since the algorithm was designed to use only the first generated configuration as a judgment to confirm the accuracy of the configuration, we also compared the first-time accuracy of the manual configuration template. It can be seen that the first-time accuracy of the manual configuration template
is much lower. Besides, it can be seen that the accuracy of the application template is proportional to the complexity of the parameters of the template, and the overall accuracy is high.

In addition to accuracy, the algorithm designed in this paper has a significant improvement in time consumption compared to manual configuration, especially for large-scale deployment. Applying the algorithm, this paper simulated the scale of template deployment at 10, 100, 1000 and 10,000 units respectively, which is order of index increase. The time automatically configured a template with the algorithm is at milliseconds level, while manually a template is at the minute level. It can be obtained that the average time taken by the algorithm for each template configuration is as shown in the following figure, and can be seen that the application algorithm is not sensitive to the deployment scale and is suitable for large-scale deployment, which is much too faster than manual configuration. In addition, there is another advantage that the template generated by the recommendation algorithm is generated for the actual situation of each device, and the template is more specific than the manually configured template.

![Figure 2. Time cost of applying templates.](image1)

![Figure 3. Time cost of manual and algorithm.](image2)

Since the average time for manually configuring templates is minute level and cannot be performed in parallel, as the number of configuration templates increases, the time spent on configuration increases linearly. When the magnitude of the number of devices changes, the magnitude of the configuration time also changes. It can be clearly seen from the figure that manual configuration is not suitable for larger template configurations. The time-consuming algorithm designed in this paper is not sensitive to the change of the number of devices, which is very suitable for large-scale application configuration templates.

### 4. Conclusion

This paper presented a virtual CPE template automatic recommendation algorithm based on fuzzy comprehensive evaluation method, which solved the problem that the existing manual configuration template is too slow, and solved the problem of single application scenario existing in the current research. The algorithm proposed in this paper can automatically generate VNF function templates that are more suitable for the current situation based on changes in parameters such as traffic, user type, and device performance. Compared with the traditional manual configuration, there is a significant improvement in parameter generation accuracy and VNF function template configuration speed.

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