Optimization-Based Atomic Capability Routing Model for Flexible Architecture of Reconfigurable Infrastructure

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Abstract. There are more and more emerging problems in today's Internet, indicating today's Internet architecture can not meet the quality requirement of various applications and service. With conventional Internet under mounting pressure, a new future Internet architecture named as Flexible Architecture of Reconfigurable Infrastructure (FARI) has been developed and implemented in China. Aiming at designing a routing mechanism which is one of the most essential issue in any Internet architecture, this paper explores to establish an optimization-based atomic capability routing model that is able to optimally select or generate a routing protocol based on the current network quality of service (QoS) requirement. In experiments, the feasibility of this routing model is verified and results of complexity analysis are satisfying.

Keywords: Combinatorial Optimization · FARI · Atomic Capability · Routing Protocol

1 Introduction

The transmission capacity becomes increasingly crucial under the rapid development of today's Internet. Specifically, the transmission capability usually does not match the certain service requirement, which leads to terrible user experience. Moreover, the IP/TCP based Internet can not give sufficient support to mobility, security, quality of service (QoS), network convergence etc, indicating that conventional Internet is no longer suitable for our various service nowadays.

Dedicated to solving the existing various problems and improving QoS, Flexible Architecture of Reconfigurable Infrastructure (FARI) has benn proposed by the 973 program [1,2]. To be simple, FARI is no longer a static Internet architecture but a dynamic self-adaptive one. The novelty of this brand new Internet architecture lies in its reconfigurable and extensible transmission ability that can automatically match the service requirement. That is to say, there is nearly no transmission capability that is wasted by unreasonable resource allocation.

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There two importance concepts in the routing model of FARI that need to be explained in detail. One is the basic routing state and the other is the polymorphic routing state. To be specific, the basic routing state refers to the protocol library which contains all the existing routing protocols and its extension. It is like a combination of all existing routing mechanism. The polymorphic routing state is a specific routing protocol or routing mechanism generated from the basic state, namely the protocol library. Both the basic routing state and the polymorphic routing state constitute the two aspects of the routing model of FARI.

One of the most essential part of FARI is the routing architecture, or routing mechanism. In the light of optimization theory and atomic capability theory, we proposed the optimization-based routing model for FARI in this paper. The outline of this paper is as follows. Section 2 comprehensively introduces the atomic capability theory. Section 3 presents the optimization-based atomic capability routing model for FARI. Experiments is discussed in Section 4, followed by concluding remarks given in Section 5.

2 Atomic Capability

2.1 Introduction of Atomic Capability

Atomic capabilities, which are defined as the smallest and undecomposable functionality in a routing protocol, are essential for the optimization-based routing model. For now, we have already defined the basic state as a set of every routing protocol and routing forwarding mechanism and the polymorphic state as many possible subsets containing one specific routing protocol. This definition is far away from satisfying for us because it is hard to be described in mathematical form and therefore difficult to be applied to build a routing model. So we need to give mathematical expression for atomic capabilities and also describe the way atomic capabilities are generated.

Similar to the relation between atoms and material, atomic capabilities are the smallest functional components for any routing protocols. That is to say, if the decomposition of the atomic capability is proceeded anyway, we will not obtain any component with a complete function. As a result, it is why we call them the smallest functional components. Atomic capabilities consists of the basic atomic capabilities and the extra atomic capabilities. Simply speaking, the basic atomic capabilities are the necessary and indispensable functions which are shared by all routing protocols, and the extra atomic capabilities are the special and optional functions that just a few routing protocols have.

2.2 Generation of Atomic Capability

The atomic capability is abstracted from similarities that are shared by existing routing protocols such as RIP [4], OSPF [5] etc. Existing routing protocols constitute a library-like basic routing state. Atomic capabilities stand for the smallest

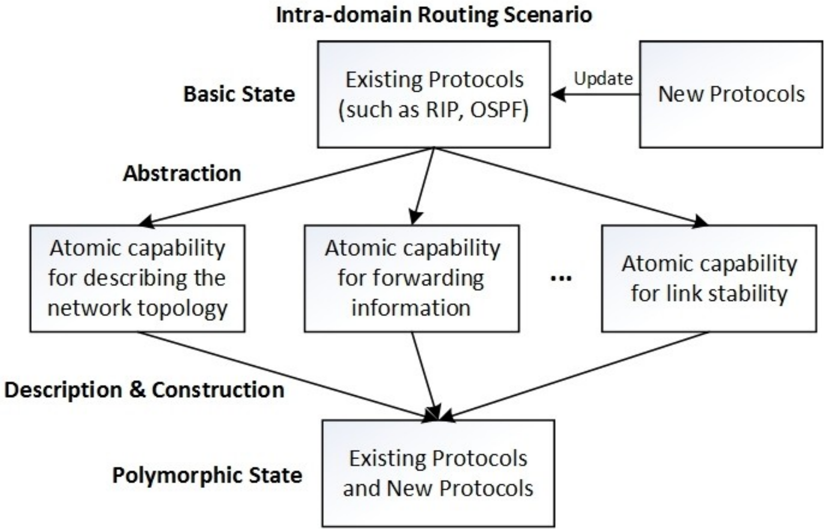

Fig. 1. Generation of Atomic Capability

functionality of the routing protocol and are abstracted and generated from the existing routing protocols. As mentioned above, the atomic capability contains the basic atomic capability and the extended atomic capability. The basic atomic capabilities are the necessary components of a routing protocol and represent the similarities among routing protocols while the extended atomic capabilities are the extra functionalities of a routing protocol and stand for the difference among routing protocols. The brief generation process of the atomic capabilities is shown in Fig.1.

2.3 Mathematical Expression of Atomic Capability

We divide the atomic capabilities into two general categories. One is the basic atomic capabilities and the other is the extended atomic capabilities. The basic atomic capabilities derive from the similarities among all the routing protocols while the extended atomic capabilities come from the difference and particular characteristics among all the routing protocols. In conclusion, basic atomic capabilities are essential to a routing protocol while extended atomic capabilities are selectable.

We depute the set of all basic atomic capabilities as the matrix S_{BAC} and the set of all extended atomic capabilities as the matrix S_{EAC}.

$$S_{BAC} = (S_1, S_2, \cdots, S_n) \tag{1}$$

where $S_i, 1 \leq i \leq n$ stands for the ith basic atomic capability. Similarly, the extended atomic capability is defined as follows.

$$S_{EAC} = (S_{E1}, S_{E2}, \cdots, S_{Ep}) \tag{2}$$

where $S_{Ei}, 1 \leq i \leq p$ represents the ith extended atomic capability.

As for the specific atomic capability, we define it as a vector containing its feasible multiple schemes. Taking the basic atomic capability S_i as an example, we show the constitution of the vector S_i.

$$S_i = (s_{i1}, s_{i2}, \cdots, s_{im})^T \tag{3}$$

And the extended atomic capability shown as follows is similar to S_i.

$$S_{Ei} = (s_{Ei1}, s_{Ei2}, \cdots, s_{Eim})^T \tag{4}$$

To show the optionality of the extended atomic capability, we should modify S_{Ei} by assigning $s_{Ei1} \equiv 0$, which will turn (4) into the following equation.

$$S_{Ei} = (0, s_{Ei2}, \cdots, s_{Eim})^T \tag{5}$$

There is another important issue that has been brought up above. It is the determination of the value of m. In order to take all the schemes in every atomic capability into account, we should let m exceed the maximum of the number of schemes in the atomic capabilities. So we assign m as follows.

$$m = \max_{1 \leq i \leq n, 1 \leq r \leq p} \{row(S_i), row(S_{Er})\} \tag{6}$$

where $row(.)$ is the row of this matrix. Therefore, after defining all the atomic capabilities, we can obtain three large matrixes, namely the basic atomic capability matrix, the extended atomic capability matrix and the general atomic capability matrix

$$\begin{aligned} S_{GAC} &= (S_{BAC} \mid S_{EAC}) \\ &= (S_1, S_2, \cdots, S_n \mid S_{E1}, S_{E2}, \cdots, S_{Ep}) \\ &= \begin{pmatrix} s_{11} & \cdots & s_{n1} & s_{E11} & \cdots & s_{Ep1} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ s_{1m} & \cdots & s_{nm} & s_{E1m} & \cdots & s_{Epm} \end{pmatrix} \end{aligned} \tag{7}$$

2.4 Mathematical Expression of Protocol Based on Atomic Capability

In the light of atomic capability theory, we know that all the routing protocols are turned into the combination of several atomic capabilities and some constraint conditions among these atomic capabilities just like Fig.2.

Assume X be the scheme selection matrix which stands for the chosen protocol. X is the following form:

$$X = [\delta(x_1), \cdots, \delta(x_n) \mid \delta(x_{n+1}), \cdots, \delta(x_{n+p})] \tag{8}$$

where $\delta(x)$ is a m dimensions row vector with xth element equal to 1 and others equal to 0. In particular, $\delta(x)$ is a zero row vector when $x = 0$.

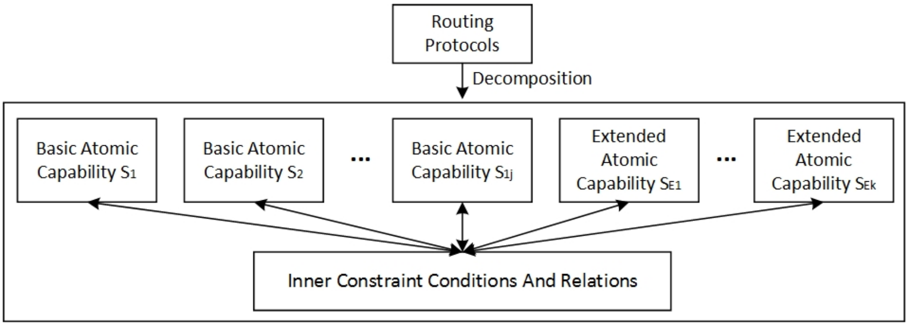

Fig. 2. Decomposition of a Routing Protocol

We have given a mathematical expression for protocol which is

$$pr = diag\left({S_{GAC}}^{T} \cdot X\right) \tag{9}$$

Protocols can also be represented by the following form.

$$pr = \left[pr_1, \cdots, pr_n \;\middle|\; pr_{n+1}, \cdots, pr_{n+p}\right] \tag{10}$$

3 Routing Model

3.1 General Framework

The fundamental idea of this framework is to regard the process of the construction from the basic state to the derived state as an optimization process. The abstract form of the routing architecture selection model is shown as follows.

$$\begin{aligned} \min \quad & res\,(protocol) \\ \text{subj. to} & \begin{cases} TimeDelay > a_1 \\ BandWidth > a_2 \\ \qquad \vdots \\ Reliability > a_n \end{cases} \end{aligned} \tag{11}$$

where, $res(\cdot)$ stands for the hardware resource that the generated protocol will consume and the constraint conditions in (11) represent the quantitative description of the communication service that users need. This optimization target can be replaced by the other feasible target such as the $TimeDelay$ ($TimeDelay$ denotes -1 times the allowable time delay) and so on. The constraint conditions may be much more than we have listed and the evaluation index may also be different. However, it will not affect how our model works. For illustrative purposes, we can summarize all the constraint conditions shown in (11) as the service requirements.

The optimization model can be written in a more specific form. Before further explaining this part, we first introduce the atomic capabilities partition model.

3.2 Mathematical Form of the Optimization-Based Model

We can turn the minimum consumed hardware resource into the following optimization target by adding the inner requirements and relation conditions to the constraint conditions in the optimization expression.

$$\begin{aligned} &\min\nolimits_X \quad C \cdot X \\ &\text{subj. to} \begin{cases} diag({S_{GAC}}^T \cdot X) \in P \\ constraint\,(S_{GAC}) \\ SR - A > 0 \end{cases} \end{aligned} \tag{12}$$

$$\text{where, } SR = \begin{bmatrix} TimeDelay \\ BandWidth \\ \vdots \\ Reliability \end{bmatrix}, \; A = [a_1, a_2, \cdots, a_2]^T \tag{13}$$

and C represents a cost vector, denoting the resource cost of the system and P is the universal set of all possible protocols. $constraint(\cdot)$ denotes the inner constraint of atomic capabilities in a routing protocol. To sum up, the purpose of this model is to select a optimal routing protocol for the different QoS requirements, which can be also summarized as ”service-adaptive”.

4 Experiments and Results

This section is to simulate the optimization-based routing model. There are 2 experiments containing the scenario simulation and the complexity experiment.

4.1 Specific Optimization Model in Experiments

The specific optimization model shown as follows has been simplified from the previous one.

$$\begin{aligned} &\min\nolimits_X \quad C \cdot X \\ &\text{subj. to} \begin{cases} diag({S_{GAC}}^T \cdot X) \in P \\ SR - A > 0 \end{cases} \end{aligned} \tag{14}$$

$$\text{where, } SR = \begin{bmatrix} TimeDelay \\ BandWidth \end{bmatrix}, \; A = [a_1, a_2, \cdots, a_2]^T \tag{15}$$

4.2 Scenario Simulation

Considering there are three available routing protocols: RIP, OSPF and IS-IS [6], we only take Interior Gateway Protocol (IGP) into consideration. The basic idea is to determine which protocol is optimal under different QoS requirements. All links in this topology have 20ms delay.

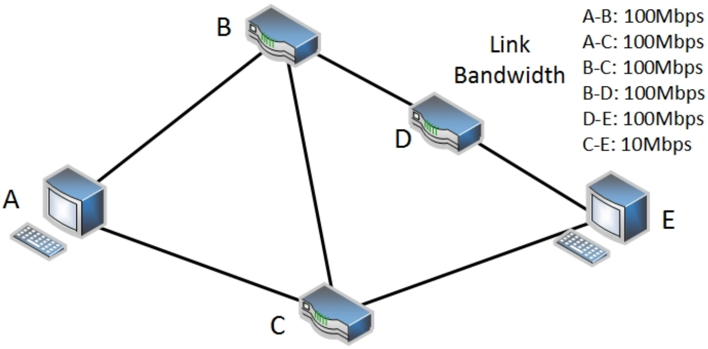

Fig. 3. Process of Atomic Capability Abstraction from Existing Protocols

We apply the optimization-based atomic capability routing model to find the optimal routing protocol under different QoS guarantee. First we let the bandwidth guarantee be the independent variable and find the proper routing protocol to meet the bandwidth requirement. Results are shown in Fig.4, in which the blue bar represents this protocol is available under the bandwidth requirement. Then we change the bandwidth guarantee to the time delay guarantee and proceed the similar experiment whose results are shown in Fig.5.

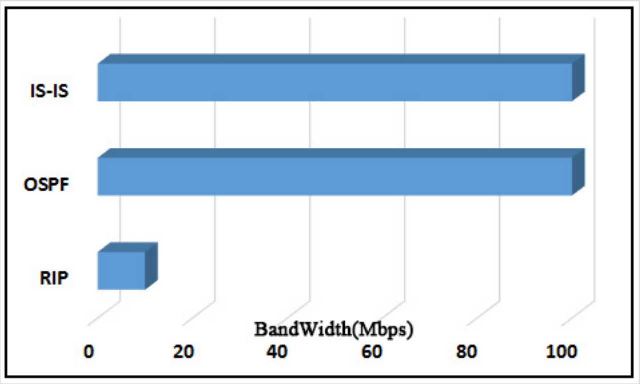

Fig. 4. Available Routing Protocols under Bandwidth Guarantee

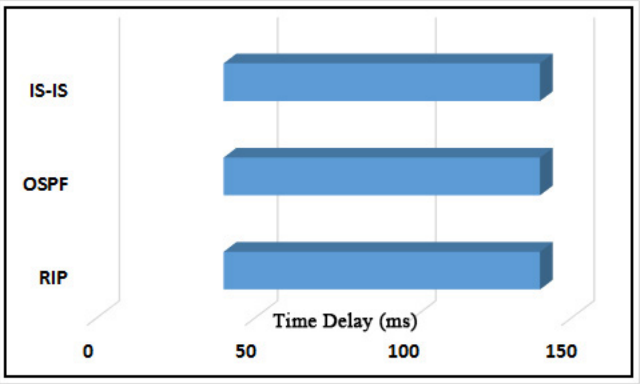

Fig. 5. Available Routing Protocols under Time Delay Guarantee

From Fig.4 and Fig.5, we can see that this model can effectively select a proper routing protocol to meet the current network QoS requirement.

4.3 Complexity Analysis

In the complexity experiment, we assume there are total 50 available routing protocols and the number of atomic capabilities is set as 10. For simplification, we regard all the atomic capabilities as the basic ones. Binary search and exhaustion are both adopted to solve the atomic capability routing model, and we also

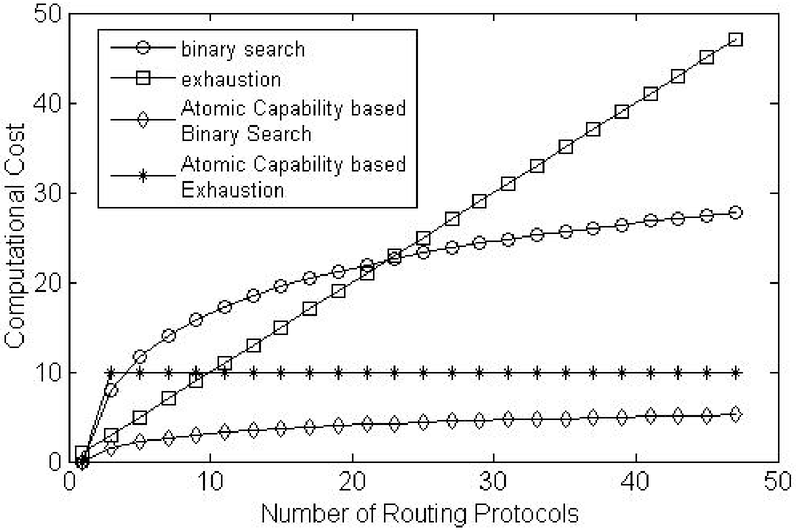

Fig. 6. Comparison of Computational Cost

apply binary search and exhaustion algorithm to optimally find routing protocol directly for comparison. Results are shown in Fig.6.

5 Conclusions

Concentrating on the development of the novel routing mechanism for FARI, this paper explores to establish a optimization-based atomic capability routing model in order to achieve the reconfigurable property in routing mechanism of FARI. This model is expressed in a general form and could be specified under different QoS guarantee. Experimental results show that this routing model is feasible and flexible to some extent. Most importantly, the computational cost of the optimization-based atomic capability routing model is also affordable.

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