Vol.2011-SLDM-149 No.15
Vol.2011-EMB-20 No.15
2011/3/18

Organizing Ad Hoc Network Routing Protocols with Product Line Engineering

Yang Cao,[†1] Tsuneo Nakanishi,[†1,†2] Kenji Hisazumi[†2] and Akira Fukuda[†2]

So far, hundreds of ad hoc network routing protocols has been proposed in literatures. Although these protocols has a greater amount of commonality with a limited amount of variability, there is no comprehensive, intuitive, and integrated view. That makes it difficult for researchers and engineers to modify the protocols to resolve their focusing problems. In this paper, we introduce software product line engineering and organize existing ad hoc networking routing protocols by feature modeling, especially for AODV and DSR protocol families.

1. Introduction

The routing protocol has been a very hot research topic since mobile ad hoc network, or MANET, emerged. So far, almost hundreds of ad hoc network routing protocols has been proposed in literatures. Researchers and engineers who want to do research or use these routing protocols with some modification are required to comprehend the full definitions of the protocols and perform simulation to check if the protocols satisfy their needs. It is possible to cost much time but for only just a simple research goal. However, there are a greater amount of commonality among those routing protocols with a certain amount of variability. What we should do is to make variability among those routing protocols visible and intuitive for easier comprehension and modification. For this purpose, in this paper, we introduce key concepts of software product line engineering[1),2)].

Software product line engineering is a paradigm for software development of many variants with commonality and variability. So far, software product line engineering is applied to various product lines including cellular phones, electric home appliances, automotive devices, communication equipments, medical devices, *etc.* The key concepts of software product line engineering are: i) separation of commonality and variability, ii) separation of domain engineering and application engineering, and iii) architecture centric development of variants.

(1) *Separation of Commonality and Variability*: Variants in a product line should be clearly divided into common parts and variable parts. Variability among variants are described in terms of features that each variant equips. Feature modeling[3)] is an important activity that organizes features with relationships among them. The feature model composed as a result of feature modeling provides a comprehensive and intuitive view on commonality and variability among variants.

(2) *Separation of Domain Engineering and Application Engineering*: Domain engineering is a series of development activities that constructs core assets, assets shared among the variants in a product line. On the other hand, application engineering is a series of development activities that reuses core assets to derive a new variant. Both engineering activities should be distinguished but performed concurrently and cooperatively under management.

(3) *Architecture Centric Development of Variants*: In domain engineering, a software architecture supporting all the variants in a product line is constructed. Software components used in the architecture are also developed. In appilcation engineering, appropriate components are chosen according to the selected features for a new variant. The components are applied to the architecture in a prescribed process to derive a new variant.

In this paper, we perform feature modeling to provide a comprehensive and intuitive view on commonality and variability among representative ad hoc network routing protocols. Some UML models are created for each protocol to describe structural and behavioral aspects of the protocol. These models are integrated to define a software architecture. The models become core assets which will be reused to derive a new protocol.

This paper is organized as follows: Section 2 summarizes existing ad hoc network routing protocols used to form product lines in this paper. Section 3 describes our motivation of this work and proposes a design process of ad hoc net-

†1 Graduate School of Integrated Frontier Science, Kyushu University
†2 Faculty of Information Science and Electrical Engineering, Kyushu University

work routing protocol with software product line engineering. Section 4 shows feature modeling of ad hoc network routing protocols. Finally, Section 5 concludes this paper.

2. Ad Hoc Network Routing Protocols

In this work we need to investigate existing ad hoc network routing protocols to provide a comprehensive, intuitive, integrated view of them. The routing protocols that been chosen should be very popular and have sufficient technical materials. For such protocols, we chose two families of reactive protocols: AODV family and DSR family. Although there are rich commonality among the protocols in each family, there are less commonality between both families. Therefore, we form one product line for each family.

The AODV family includes the following protocols:

- AODV[4)]
- AODV-bis[5)]
- AODV-BR[6)], or backup route in AODV, is an algorithm that utilizes a mesh structure to provide multiple alternative paths to existing on-demand routing protocols. Compared to AODV, AODV-BR does not produce additional control packets.
- AOMDV[7)], or ad hoc on-demand multipath distance vector, is a multipath routing protocol similar to AODV. AOMDV computes multiple loop-free link disjoint paths during route discovery process.
- MAODV[8)], or multicast ad hoc on-demand distance vector, is a multicast routing algorithm by enhancing AODV.
- MRAODV[9)], or multiple-route ad hoc on-demand distance vector, is a multiple route function enhanced AODV.
- PRAODV[10)] is a routing protocol with features inherited from AODV. The main difference is that PRAODV includes its velocity and location information in its RREP packets.

On the other hand, the DSR family includes the following protocols:

- DSR[11)]
- DSRFLOW[12)]
- BSR[13)], or backup source routing, is an enhanced source routing that enable backup route switching when main route breaks. The key advantage of BSR is the reduction of the frequency of route discovery flooding.

3. Motivation

Routing protocols for ad hoc network has attracted lots of researchers for their impact to performance. So far, more than hundreds of variants of two famous routing protocols, AODV and DSR, has been developed after their emergence in early 90s. Researchers and engineers follow the path shown below to present a new protocol by modifying these protocols to resolve a certain problem:

(1) Learn about one or some existing routing protocols and identify advantages and disadvantages of them.
(2) Modify existing routing protocols to resolve identified disadvantages.
(3) Define a working principle of the modified protocol.
(4) Define the details of route discovery and route maintenance.
(5) Define the details of control packets.
(6) Verify the modified protocol with network simulation or experiment.

However, due to absence of the comprehensive view describing difference among routing protocols, it is required for researchers and engineers to understand existing routing protocols completely although they have interested in limited aspects of the protocols. In fact, most of newly proposed routing protocols are enhanced variants of existing routing protocols with some new features that resolve a certain problem.

Considering the above, we propose to introduce software product line engineering and define a design and implementation process of ad hoc network routing protocols.

The works that should be achieved in domain engineering are as follows:

(1) Commonality and variability analysis, namely feature modeling, of existing ad hoc network routing protocols
(2) Construction of integrated structure and behavior models for ad hoc network routing families.
(3) Realization of traceability from the feature model to the integrated structure and behavior models.

These works can be large scaled and complicated, thus requires more investment.

Vol.2011-SLDM-149 No.15
Vol.2011-EMB-20 No.15
2011/3/18

The investment should be return in application engineering. The process of application engineering are as follows:

(1) Selection of desirable features for a new routing protocol
(2) Extraction of the models required to realize the selected features based on traceability information.
(3) Model based generation of codes and scenarios for the protocol simulator
(4) Evaluation of the routing protocols by the protocol simulator
(5) Improvement of the routing protocol

4. Features Modeling of Ad Hoc Network Routing Protocol

In this section we perform feature modeling to provide a comprehensive view of commonality and variability among ad hoc network routing protocols. We construct models describing the following aspects:

- Inter node communication with UML sequence diagrams
- Node behaviors with UML activity diagrams
- Packet structure with UML class diagrams

for each protocol and integrate them with making common parts and variable parts visible. The variable parts in those models are identified and named as features. The identified features are organized as a feature model.

The feature model help researchers and engineers comprehend commonality and variability among routing protocols. At the same time, the integrated models help researchers and engineers understand design and implementation of the protocols easier than the code and contribute the base for model based generation of simulator codes and scenarios.

4.1 Describing Node Behaviors

There are three types of nodes in ad hoc network, namely the source node sending a packet, the intermediate node relaying the packet, and the destination node receiving the packet. For each routing protocol, node behaviors of these three types of the nodes are described with UML activity diagrams. These protocol specific models of node behaviors are integrated finally.

Fig. 1 shows the integrated activity diagram describing the source node behaviors in AODV and AODV-bis. In this diagram we adopt AODV and AODV-bis for page limitation, while the full version of this activity diagram integrates the source node behaviors in other protocols. The white and gray modeling elements in this activity diagram are common and variable parts, respectively. Since this activity diagram shows the behaviors only in AODV and AODV-bis, variable parts show the behaviors specific to AODV-bis. One or more features can be identified from these variable parts. Any identified feature should have an appropriate name representing its partial behavior well. If necessary, we should define multiple features even for one variable part. Sometimes we should one feature for multiple variable parts because behaviors relating to one feature can be scattered. In this example, we identified two features, *Forward RREP with Path Information Contained in RREP* and *Using APL to Enhance Normal Route Table*, for two variable parts.

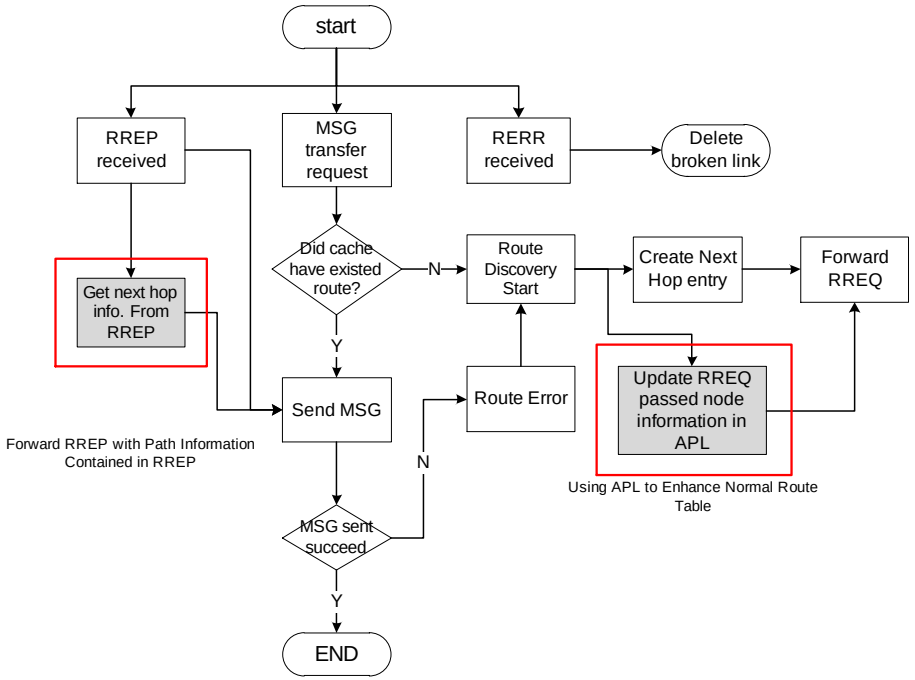

Fig. 1 Source Node Behaviors of AODV Family (partial)

The behaviors of intermediate and destination nodes are similarly described in activity diagrams.

4.2 Feature Modeling

We can identify features from variable parts of UML diagrams describing inter node communication, node behaviors, and packet structures. We organize the identified features as a feature model.

Fig. 2 shows the feature model we constructed. The feature model includes only features relating to AODV and AODV-bis due to page limitation. We define the abstracted concept generalizing common properties among identified features or other abstracted concepts if necessary. Moreover, we categorize features into *mandatory*, *optional*, and *alternative* according to their reuse categories and append dependency on feature selection.

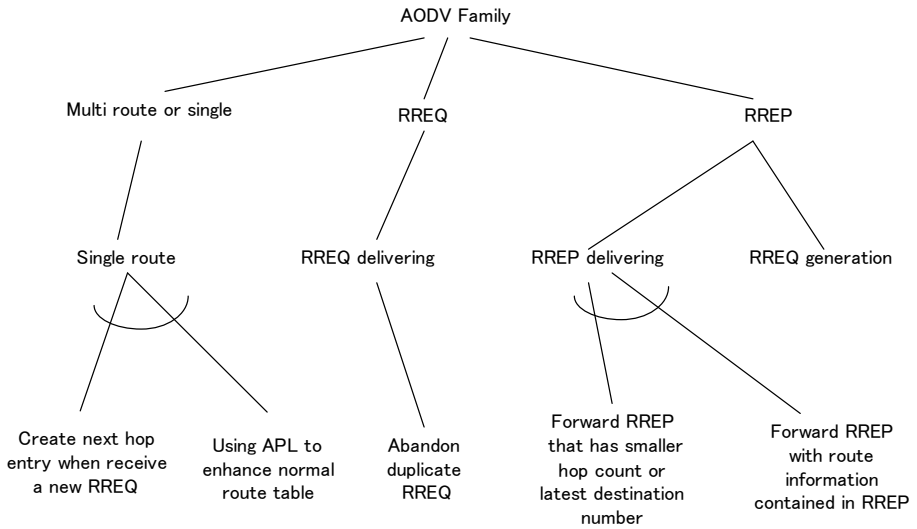

Fig. 2 Feature Model for AODV Family (partial)

Each routing protocol can be represented in terms of its equipping features. For example, AODV equips features *Create next hop entry when receive a new RREQ* and *Forward RREP that has smaller hop count or latest destination number*, while AODV-bis equips features *Using APL to enhance normal route table* and *Forward RREP with route information contained in RREP*.

From any feature in the feature model we should be traceable to the models or their fragements relating to the feature. For example, the behavior *Update RREQ passed node information in APL* in the activity diagram in Fig.**??** is traceable from its relating feature *Using APL to Enhance Normal Route Table* in Fig.2.

We can derive a new routing protocol with a legal selection of features listed in the feature model. The models describing inter node communication, node behaviors, and packet structures are also derived. We review the models, generate codes and scenarios for protocol simulation, and make preliminary evaluation of the protocol on the simulator. In case we found that the routing protocol does not satisfy functional and non-functional requirements by simulation, we change the selection and follow the similar process. If it is impossible to satisfy requirements with existing features, we have to evolve the protocol family. That means we have to invent and introduce new features to resolve the problem in an integrated manner.

5. Conclusion

In this paper we proposed to introduce software product line engineering for design and implementation of ad hoc network routing protocols and define its process. As a first step for the introduction, we performed feature modeling of existing ad hoc network routing protocols for AODV and DSR families. Features are identified from the models describing inter node communication, node behaviors, and packet structures and organized later as a feature model. Moreover, we make the models traceable from the feature model so that we can extract the models or their portions relating to the selected features.

The future work will be enabling model based generation of simulation codes and scenarios based on feature selection on the feature model.

Acknowledgments

This work was supported by Grant-in-Aid for Scientific Research (B) (No. 21700035).

Vol.2011-SLDM-149 No.15
Vol.2011-EMB-20 No.15
2011/3/18

References

1) Paul Clements and Linda Northrop, *Software Product Lines: Practices and Patterns*, Addison-Wesley, 2001.
2) Klaus Pohl, Günter Böckle, and Frank v. d. Linden, *Software Product Line Engineering: Foundations, Principles and Techniques*, Springer, 2005.
3) K. C. Kang, S. G. Cohen, J. A. Hess, W. E. Novak, and A. S. Peterson, "Feature-Oriented Domain Analysis (FODA) Feasibility Study," Technical Report CMU/SEI-90-TR-21, SEI/CMU, Nov. 1990.
4) Charles E. Perkins, Elizabeth M. Belding-Royer, and Samir R. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing Protocol," RFC 3561, Jul. 2003.
5) Chia-Ching Ooi and N. Fisal, "Implementation of Geocast-Enhanced AODVbis Routing Protocol in MANET," *Proc. TENCON 2004*, p.660, Nov. 2004.
6) Sung-Ju Lee and Mario Gerla, "AODV-BR: Backup Routing in Ad hoc Networks," *IEEE Wireless Communications and Networking Conf. 2000 (WCNC 2000)*, Vol.3, pp.1311–1316, Sep. 2000.
7) M. K. Marina and S. R. Das, "On-Demand Multipath Distance Vector Routing in Ad Hoc Networks," *Proc. 9th Int. Conf. on Network Protocols*, p.14, Nov. 2001.
8) Dr. Ayman Abdel-Hamid, "Multicast Operation of AODV," *Mobile Computing, Report, Virginia Tech.*, Spring 2006.
9) Sayaka Hatsuta, Kazuki Morita, and Hiroaki Higaki, "Route Switching Protocol in MRAODV," *Proc. Int. Symp. 18th Parallel and Distributed*, p.237, Apr. 2004.
10) Vinod Namboodiri, Manish Agarwal, and Lixin Gao, "A Study on the Feasibility of Mobile Gateways for Vehicular Ad-hoc Networks," *Proc. 1st ACM Int. Workshop on Vehicular Ad Hoc Networks (VANET '04)*, pp.65–75, Oct. 2004.
11) David B. Johnson, David A. Maltz, and Josh Broch, "DSR: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks," *Proc. Ad Hoc Networking 2000*, pp.139–172, Dec. 2000.
12) Yih-Chun Hu and David B. Johnson, "Implicit Source Routes for On-Demand Ad Hoc Network Routing," *Proc. 2nd ACM Int. Symp. on Mobile Ad Hoc Networking and Computing (MobiHoc '01)*, pp.1–10, Dec. 2001.
13) Song Guo, Oliver Yang, and Yantai Shu, "Improving Source Routing Reliability in Mobile Ad Hoc Networks," *IEEE Trans. on Parallel and Distributed Systems*, Vol.16, No.4, p.362, Apr. 2005.