RC24558 (W0805-082) May 13, 2008
Computer Science

IBM Research Report

How to Enable Policy-based Interactions in Dynamic Wireless Networks?

Chi-Kin Chau, Jon Crowcroft
Computer Laboratory
University of Cambridge
United Kingdom

Kang-Won Lee, Starsky H. Y. Wong
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 704
Yorktown Heights, NY 10598
USA

Research Division
Almaden - Austin - Beijing - Cambridge - Haifa - India - T. J. Watson - Tokyo - Zurich

How to Enable Policy-based Interactions in Dynamic Wireless Networks?

Chi-Kin Chau, Jon Crowcroft
Computer Laboratory
University of Cambridge, UK
Email: chi-kin.chau,jon.crowcroft@cl.cam.ac.uk

Kang-Won Lee, Starsky H.Y. Wong
IBM T.J. Watson Research Center
Hawthorne, NY, USA
Email: kangwon,hwong@us.ibm.com

Abstract

Policy is a key component in the interoperations among multiple heterogeneous domains of networks with different routing metrics and preferences. IDRM is a recent protocol that enables policy-based inter-domain routing over mobile ad hoc networks (MANETs), supporting dynamic network topology and diverse intra-domain routing protocols. Notwithstanding a protocol to interoperate multi-domain MANETs, there are fundamental challenges to support dynamic networks - how can network administrators formulate practical inter-domain routing policies considering MANET-specific characteristics. This paper studies this issue with illustrating examples, and discusses potential solutions.

1 Introduction

Policy makes the internetworking possible. In order for multiple heterogeneous networks to interoperate together they must agree on a common policy mechanism and allow network administrators to specify policies for routing, data forwarding and other services and the quality of such services. In the Internet, connected gateways of different domains exchange route announcements of reachable destinations in the network. Inter-domain routing policies will be translated as the decisions for filtering and route selection operations at the gateways of each domain. Typically, different domains usually have distinct local policy considerations related to security and performance concerns. The study of policy-based interactions among heterogeneous domains has been an active research area in the networking research community [1, 2].

IDRM [3] is a recent protocol to enable inter-domain routing over mobile ad hoc networks (MANETs), with careful considerations of the dynamic network topology and diverse intra-domain routing protocols in MANETs. IDRM is based on a path vector protocol, which can support policy-based interaction among domains; however, the policy aspect has not been studied at length previously. Complementary to [3] this paper presents a discussion on the fundamental challenges of supporting policy-based inter-domain routing over MANETs, i.e., how can network administrators formulate practical inter-domain routing policies considering MANET-specific characteristics? We study this issue with illustrating examples, and discuss potential solutions.

2 Policy-based Interactions in MANETs

Mobile ad hoc networks (MANETs) can enable effective communications in dynamic operation environments such as a coalition military operation, emergency operation for disaster recovery, and on-the-fly team formation for a common mission, e.g. search and rescue. In these situations, multiple groups and organizations need to come together, communicate, and collaborate to achieve a common goal. For example, in a disaster recovery scenario, the local police force may need to coordinate with fire fighters, military forces, and medical crews by sharing information and communicating with each other regardless of the particular networking technologies that each group uses. Such application scenarios call for development of a technology to enable end-to-end communications over heterogeneous MANETs governed by distinct administrative domains. However, different domains are usually mandated by distinct policies, such as security and performance concerns. Therefore, facilitating policy-based interactions among multiple heterogeneous domains is a very important and practical problem in dynamic wireless networks.

In the Internet, the Border Gateway Protocol (BGP) [4] provides a standard mechanism for policy-based inter-domain routing among heterogeneous domains, called autonomous systems (AS). The basic idea that we borrow from the Internet is that they enable opaque interoperation, where each domain has the administrative control over its intra-domain routing protocol and inter-domain routing policy, which is not known (or *opaque*) to the other domains. However, the dynamic and wireless nature of MANETs introduces two major challenges. First, in MANETs, the network connectivity changes frequently, thus a policy-based inter-domain routing protocol must be able to cope with such changes as network partitions and merges and connectivity changes. Second, MANET environment has spawned out a new breed of routing protocols [5] that are specialized for dynamic networks, and they require special handling to participate in inter-domain routing. In order to cope with these challenges, a novel inter-domain routing protocol for MANETs called IDRM has been proposed [3]. In the following, we briefly review the main components of IDRM, and discuss the policy issues using the framework of IDRM.

2.1 Design of IDRM

IDRM (Inter-Domain Routing Protocol for Mobile Ad Hoc Networks) is an inter-domain routing protocol that has specifically designed to enable interoperation among multiple MANETs. It employs a path vector routing protocol, where each domain enumerates the entire domain level path to a destination. Using a path vector routing protocol, IDRM can potentially support a policy-based routing in a similar manner to BGP if the network topology is relatively stable. In this paper, we are mainly interested in the issue of supporting policies for inter-domain routing when the inter-domain and intra-domain network topology changes dynamically. We refer the reader to [3] for detailed operations of IDRM.

3 Supporting Policy Routing in MANETs

IDRM provides a basic mechanism for inter-domain routing, and the specification of inter-domain routing policy by network administrators is a key component in the policy-based interactions. In this section, we first review different approaches that are used in practice for specifying routing policies, and discuss how we can accommodate these specifications in dynamic networks.

In the network community, the common approaches to specify inter-domain routing policies have been as follows.

Next-hop Specification: A simple approach to specify inter-domain routing policies is based on the next-hop domains in the routes to a specific destination, and ignored the rest of downstream domains. The next hop specification is widely used in practice to denote the mutual commercial relations among Internet service providers, which are coarsely classified as customer-provider or peering relations. A common practice by the Internet service providers is that the routes from customers are preferred to peers and providers, and routes from peers are preferred to providers.

Enumerative Specification: A more sophisticated approach that enumerates all possible routes of the domains in the network, and ranks those routes by a complete order of preference. For example, domain A may specify the following ordered list ($A \to D$, $A \to B \to D$, $A \to C \to D$, $A \to C \to B \to D$) for a destination domain D. Routes with a higher rank will be selected if available, and backup routes will be given a lower rank, which will only be selected when no other routes are available. This approach is feasible when only simple routes are considered.

Cost-based Specification: A more practical and flexible approach is to assign a numerical cost, which is subjective to a local domain, to all other domains. The subjective cost captures the local evaluation of the reward or penalty of forwarding packets through the respective domain, such as hop counts, available bandwidth, reliability of the path. In this case, the routes with the minimum total subjective cost of all the downstream domains will be selected.

Forbidden-set Specification: Another practical approach is to specify local policies is to identify a set of forbidden domains to traverse. The forbidden set captures the security concerns as to traversing insecure domains. Only the routes consisting of domains that are not from the forbidden set will be selected among available ones. Usually, an additional tie-breaking mechanism (e.g. random tie-breaking or lexicographical tie-breaking) is required for selecting a route among multiple candidates.

It is important to address the issue of heterogeneous inter-domain routing policies, because the policies of different domains may not be consistent. For example, consider a route $A \to B \to C$. Domains A and B may treat domain C differently in their local routing policies.

In this framework, inter-domain routing policies are described by an abstract formalism called *path algebra* [6], and one can reason the properties and behaviors of policy-based interactions. In particular, it is known that earlier policy algebras (e.g. [7, 8]) can be subsumed by path algebra.

The basic idea of path algebra is that the inter-domain routing process can be captured by two operations:

1, Translation process of potential routes, represented by operator $\otimes$.

2, Selection process of potential routes, represented by operator $\oplus$.

For example, consider the network topology of Fig. 1. There are two potential routes to destination D from domain C; one direct path (represented as $C \otimes D$) and another via domain B (represented algebraically as $C \otimes B \otimes D$). The selection process of domain C is represented algebraically as $(C \otimes B \otimes D) \oplus (C \otimes D)$.

We provide some concrete instances of policy specifications in the formalism of path algebra as follows:

Next-hop Specification: Define translation operator $\otimes$ as retaining only the next-hop domain ID of a route (i.e., $C \otimes B \otimes D = C \otimes B, C \otimes D = D$), and selection operator $\oplus$ as picking the most preferable route according to a prespecified preference with respect to only next-hop domain ID.

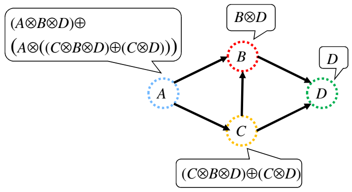

Figure 1. An example of path algebra.

Enumerative Specification: Define translation operator $\otimes$ as a dummy operator with no translation, and selection operator $\oplus$ as picking the most preferable route according to a pre-specified preference with respect to all routes from every node.

Cost-based Specification: Associate with every route with a subjective cost. Define translation operator $\otimes$ as translating a route to its subjective cost defined by the left domain in the operation, and selection operator $\oplus$ as picking the minimum cost route.

Forbidden-set Specification: Define translation operator $\otimes$ as filtering routes that contain a domain in the forbidden set of the left domain in the operation, and selection operator $\oplus$ as picking a unfiltered route.

While the above definitions and instances are introduced in an informally manner, the formal definitions of path algebra and concrete construction of instances from inter-domain routing policies can be found at [6–8].

Useful theorems about policy-based interactions can be proven by considering suitable algebraic properties of path algebra. For instance, one of the most important property is the existence of consistent interactions without oscillating behaviour, which can be proven under suitable algebraic properties known as monotonicity or positivity [6, 7].

4 Dynamic Policy Refinement

Inter-domain routing policies will be long lived compared to the dynamics of MANET topology changes. Therefore network administrators will need to specify the inter-domain routing policies a priori to the operations of MANETs (although on demand policy modification will be supported). As discussed earlier, a salient characteristic of MANETs is the dynamic nature of network topology due to node moiblity. Thus we need to examine how the aforementioned approaches of policy specifications can be supported in the dynamic MANET environments.

The path vector routing protocol relies on the uniqueness of domain IDs[1] to specify policy-based inter-domain routes and identify the existence of cyclic paths. To cope with the challenge of dynamics in MANETs, IDRM gateways generate new MANET IDs for a partitioned network when a topology change is detected. Now the question is how we can translate the static policy that administrator defined for the original network configuration when such network change occurs. In other words, we need to address the *policy refinement* problem where a static routing policy must be dynamically translated into a more specific policy for the new network configuration. As presented earlier, when IDRM generates a new domain ID, it retains the original domain ID, and this characteristics is useful when writing a meta-rule for the policy refinement. We now explain the necessary policy refinement procedures using a simple illustrative example.

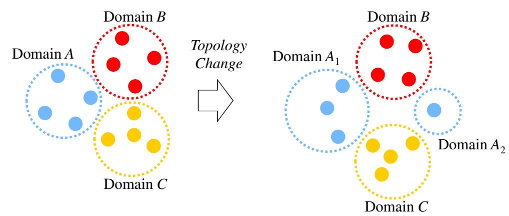

Figure 2. A network partition in MANETs of three domains.

Consider Fig. 2 with MANETs consisting of three domains A, B, C. Because of ad hoc mobility, there is a change in the underlying network topology, such that nodes in domain A are partitioned into two sets, each of which falls outside the wireless communication range of each other. However, by traversing the nodes in domains B, C, nodes in domain A_1 and domain A_2 can still communicate with each other.

After the partition, the use of inter-domain connectivity (e.g. through domains B, C) to enable intra-domain communications (e.g. between two partitions of domain A) may be necessary. Inter-domain routing policies for MANETs, therefore, also need to specify the actions for this situation.

Firstly, let us consider the next-hop policy specification. Assume that domain B had a next-hop policy for domain C that reads $C \prec A \prec$ *others*, where $x \prec y$ means x is more preferable to y. Now after the partition of A, it can refine the original policy into $C \prec A_1 \sim A_2 \prec$ *others*, where $\sim$ denotes a equivalent relation. This is a straightforward translation and one can specify this rule using a standard policy refinement logic, e.g. [10]. In other words, for the next-hop policy, we can specify a meta-rule that simply replaces the original domain with new subdomains. We present this meta-rule in a pseudo code format below. Note that it is not straightforward to specify the preference between A_1 and

[1]Although we use domain ID and MANET ID interchangeably in this paper, by domain ID we refer to an ID assigned to a logical group, whereas by MANET ID we refer to an ID assigned to a group of network devices the same network.

A_2 in the next-hop policy because their preferences cannot be determined a priori.

Meta-rule 1 Refinement for Next-hop Specification

event: $X \xrightarrow{partition} X_1, ..., X_n$
replace X with $(X_1 \sim ... \sim X_n)$, $\forall$ policies with X

One can see that the same type of policy translation is possible in the forbidden set specification. For example, if domain A was forbidden in the original policy of domain B then both A_1 and A_2 will be forbidden in the new topology. However, we conjecture that the forbidden set may be relaxed in order to establish intra-domain connectivity in certain situations. This can be implemented by dividing the forbidden set into a *weak* forbidden set and an *strict* forbidden set. The domains in weak forbidden set may be allowed to traverse if there is no other way to connect the network partitions, whereas the domains in absolute forbidden set are disallowed to traverse under any condition.

Furthermore, we note that dynamic network topology has an impact on the network performance. Considering Fig. 2, the network partition of domain A will create two transit points for other domains. Hence, domains B, C will need to re-evaluate the subjective costs for domain A in the cost-based specification, which may be attained by advertisement or revelation from domain A about its network topology [2]. Hence, it requires an operational evaluation mechanism to convert the information of dynamic network topology into subjective costs from time to time. For example, if the cost is based on the number of hop counts, then smaller domains are favorable and the cost for A_1 and A_2 will likely be lower than that of A. Thus policy rules involving A should be modified accordingly. On the other hand if the cost is based on the availability of alternate paths then it is likely that the cost of A_1 and A_2 will be higher than that of A. This refinement is presented in meta-rule 2.

Meta-rule 2 Refinement for Cost-based Specification

event: $X \xrightarrow{partition} X_1, ..., X_n$
modify $\forall$ policies with X using $cost(X_1), ..., cost(X_n)$

We can see that similar translation techniques can be used for the case when a network merge happens. The only difference in this case is that the merge may happen among only a subset of partitions (i.e. not all sub-networks of a domain are connected). When multiple topology changes have been detected by the gateway this policy refinement rules can be applied sequentially. In order to ensure the correctness of policy refinement in this case, the meta-policy rules should be defined as declarative rules and there should not be any dependencies among them.

[2]Note that the default setting of inter-domain routing is not to reveal the internal topology of a domain to other domains, and the new cost may be advertised by the newly created domains

5 Conclusion

In this paper, we have studied the problem of policy-based inter-domain routing over MANETs, with particular attention to policy specifications in dynamic wireless environments with frequent network partition and merging. To address the issues of dynamic wireless environments, various ideas for policy refinement have been proposed for common policy specifications that are widely used in inter-networking. We believe future studies of policy semantics (e.g. extending path algebra), with the interactions between policy and MANET dynamics, are important to the practical deployment of inter-domain routing in MANETs.

References

[1] T. G. Griffin, F. B. Shepherd, and G. Wilfong, “Policy Disputes in Path-Vector Protocols,” in *Proc. Inter. Conf. on Network Protocols*, November 1999.

[2] C.-K. Chau, “Policy-based Routing with Non-strict Preferences,” in *Proc. ACM SIGCOMM*, 2006.

[3] C.-K. Chau, J. Crowcroft, K.-W. Lee, S. H.Y. Wong, “IDRM: Inter-domain Routing Protocol for Mobile Ad Hoc Networks,” Computer Lab, University of Cambridge. Technical Report UCAM-CL-TR-708, 2007, http://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-708.html.

[4] Y. Rekhter and T. Li, “RFC 1771: a Border Gateway Protocol 4 (BGP-4),” March 1995.

[5] M. Abolhasan, T. Wysocki, and E. Dutkiewicz, “A Review of Routing Protocols for Mobile Ad Hoc Networks,” *Ad Hoc Networks*, vol. 2, pp. 1–22, 2004.

[6] C.-K. Chau, “Networks and Disputes,” Ph.D. dissertation, University of Cambridge, 2007.

[7] J. Sobrinho, “An algebraic theory of dynamic network routing,” *IEEE/ACM Trans. Networking*, vol. 13, no. 5, pp. 1160–1173, October 2005.

[8] T. G. Griffin and J. Sobrinho, “Metarouting,” in *Proc. ACM SIGCOMM*, September 2005.

[9] T. G. Griffin and G. Huston, “RFC 4264: BGP wedgies,” November 2005.

[10] A. K Bandara, E. C Lupu, J. Moffett and A. Russo, “A Goal-based Approach to Policy Refinement,” in *Proc. IEEE Policy Workshop*, June 2004.