Policy-Based Adaptive Routing in Mobile Ad Hoc Wireless Networks

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Abstract— **This paper investigates policy-based adaptive routing for *mobile ad hoc networks* (MANET's), in which routing metric, routing algorithm parameters and/or protocol selection can be controlled in response to observed performance and external service needs. We propose an adaptive routing framework which allows introduction of adjustable parameters and programmable routing modules. Control information is disseminated through the network to exchange state variables, and a global distributed policy manager is responsible for the adaptive operations at nodes of the network. The proposed architecture can support two types of adaptive mechanisms: the first involves switched selection between a set of routing protocols options or metrics, while the second is based on an integrated routing algorithm which incorporates adaptation of key network state parameters such as link speed or congestion. Example algorithms and simulation results are given, which show that adaptive routing help achieve the desired system performance under the dynamically changing network conditions.**

Index Terms — **Adaptive routing, mobile ad hoc wireless networks**

I. INTRODUCTION

In mobile ad hoc networks (MANET's), the topology may change frequently and unpredictably due to node movement and fluctuating wireless link quality. These characteristics make the development of dynamic routing protocols with good bandwidth and power efficiency an important design challenge. While there are many results on specific classes of ad hoc routing protocols such as Dynamic Source Routing (DSR) [1], Destination-Sequenced Distance-Vector (DSDV) [2], Ad hoc On-demand Distance Vector (AODV) [3] or Temporally-Ordered Routing Algorithm (TORA) [4], no single routing protocol performs well in a complex real-world environment. For example, previous work [5] shows that DSDV, as a proactive routing protocol, is preferable for latency-sensitive traffic; but DSR, as an on-demand routing protocol, outperforms DSDV in high mobility environment.

The above considerations motivate the use of adaptive routing for ad hoc networks such that routing can dynamically adapt to changing network topology and external service needs. One approach is to combine proactive and reactive strategies. For example, SHARP is a hybrid routing protocol that automatically finds the balance point between proactive dissemination and reactive discovery of routing information such that it can dynamically adapt to changing network characteristics and traffic behavior [6].

Tuning routing algorithm parameters can also help achieve adaptive behavior. The adaptive zone routing protocol (AZRP) [7] is an example which uses variable zone radius and controllable route update interval. In addition, using the number of hops as the routing metric may not achieve the desired performance under wireless environment. Some channel adaptive routing schemes have been proposed, which suggest to choose routes with high date rates [8].

Most prior work on this topic is specific to a certain routing protocol or approach. In this paper, we focus on system design and propose a unified adaptive routing framework which allows introduction of programmable routing modules and adjustable parameters. In this framework, protocol selection, routing algorithm parameters and/or routing metric can be controlled in response to observed performance and external service needs. We also investigate the use of adaptive routing policies in ad hoc networks to achieve improved routing performance over conventional methods. The proposed architecture is presented in Section II, and three kinds of adaptive mechanisms which can be deployed in the proposed framework are discussed in Section III. In Section IV, we present example adaptive algorithms and some simulation results. We conclude our work in Section V.

II. POLICY-BASED ADAPTIVE ROUTING FRAMEWORK

The architecture of the adaptive routing framework is shown in Fig.1.(a). The architecture implements self-adaptation by a control loop. This loop collects the information about routing states from the system, makes decisions and adjusts the system as necessary. The control loop consists of two parts: the controlling part and the controlled part. The Global Policy Manager (GPM) is the controlling part, which implements some particular adaptation operations such as selecting the routing module, tuning routing algorithm parameters and adjusting routing metric variables. The routing modules and routing metrics are the controlled elements.

Several routing modules are available in the system. The routing module which would produce the best desired performance is selected by the GPM. The parameters of the selected routing module can also be tuned by the GPM. According to service requirements and traffic behavior, the GPM decides a routing metric and its variables.

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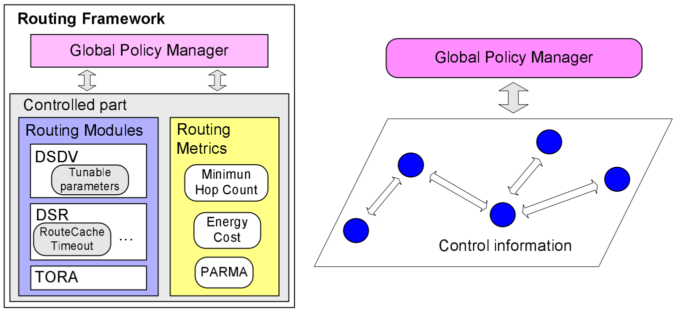

(a) (b)

Fig. 1. (a) Adaptive routing framework; (b) Distributed global policy manager.

In order to achieve global optimization, the GPM, when making decisions, needs not only local information but also information from other nodes of the network. The control information, including state variables and management information, is disseminated through the network. Thus the GPM entities of all the nodes in the network construct a distributed system and perform the global controlling functionalities, instead of being isolated, as shown in Fig.1.(b).

A. Global Policy Manager (GPM)

Achieving global optimization in a distributed system is a complicated goal, especially when the system conditions are under changes. As shown in Fig.2, in the GPM of each node, the controller monitors the local environmental conditions, interacts with information from other nodes (e.g. via control messages), analyzes data based on routing policies, and decides control actions. Control instructions are sent to the controlled part to complete the adaptation function of the loop.

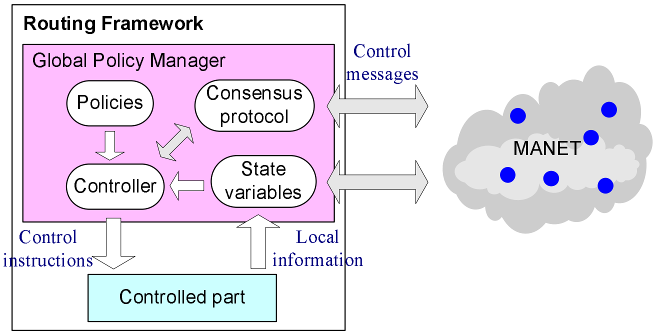

Fig. 2. The Global Policy Manager (GPM).

In particular, the control information needed for forming the global information at nodes could be sent either explicitly or implicitly. If they are sent explicitly, extra control messages are necessary. In addition, the consensus protocol, which is used to achieve consensus over nodes of the network on how to adjust their settings in order to more globally adapt to network conditions, provides a way to transfer control information. If the control information is sent implicitly, it can be piggybacked on the existing routing messages to reduce the overhead.

B. Routing policy

A routing policy specifies the criteria that GPM uses to accomplish a definite goal. Each policy corresponds to a particular adaptation operation. Based on the policy, data (e.g. routing state variables and service needs) are analyzed and control processes are driven.

C. Routing state variables

The routing state variables are state variables needed by routing, including link information. The state variables can be categorized as follows:

1) Traffic behavior: The dynamically changing traffic behavior can be described by wireless medium access delay and/or packet dropped rate. Medium access delay or channel busy degree can be estimated by measuring the occupancy of the channel [8]. Packet dropped rate is the fraction of packets dropped due to full queues at nodes.

2) Link characteristics: Link characteristics can be represented by link quality and link data rate. Link quality can be measured as the expected number of transmissions using probes [9]. Link data rate can be obtained from the link layer [8]. Note that cross-layer design is involved.

3) Mobility metrics: The mobility metrics evaluate the relative difficulty of routing due to mobility in ad hoc networks. The routing difficulty due to mobility is related to many factors such as the mobility pattern, movement speed, and thus is not easy to evaluate. The example mobility metrics are *Geometric Mobility Metric* and *Minimal Route-change Metric* [10].

4) Service needs: The variables on service needs can be obtained from the application profile, for example, latency-sensitive and/or burst traffic.

5) Other known network conditions: They could be network size, stationary or moving nodes, power sensitive requirement etc.

III. ADAPTIVE MECHANISMS

The proposed architecture can support three adaptive mechanisms: (1) selecting routing module; (2) tuning routing algorithm parameters; and (3) adjusting routing metric. These mechanisms are based on specified adaptive routing policies, and can be used either individually or together with any routing algorithm. Based on the collected information and routing policies, GPM performs one or more adaptive mechanisms. In this section, after describing each mechanism, we also review some existing adaptive techniques and discuss how they can be supported by the proposed adaptive routing framework.

A. Selecting routing module

When the routing service is initialized, the routing module is selected by GPM according to the application requirements (e.g. latency sensitive or real-time service) and the observed network conditions. The routing module may be re-selected accordingly if the environmental conditions are changed during run time; this is dynamic selection. In order to accomplish routing module selection, an additional distributed mechanism is required to reach a consensus.

Switching routing module requires resetting and reconfiguring the routing service and may cause service discontinuity, so it is preferred for long-time changes. Another approach is to use a hybrid routing protocol combining several routing strategies into one protocol and dynamically balancing the tradeoff among these parameters corresponding to the environment. The SHARP protocol is an example [6].

B. Tuning routing algorithm parameters

Tuning of key routing algorithm parameters is another step towards designing an adaptive system. The system performance would degrade when these parameters are not set appropriately. When the optimal values of the parameters are related to the network conditions such as node movement speeds, it is preferred that these parameters can be dynamically adjusted according to the observed network conditions, rather than fixed to the predetermined values.

An example parameter is the cache timeout of DSR [11]. In DSR, the routing information stored in the cache can be used to avoid route rediscovery for each individual packet. However, it may be out-of-date information. To overcome this potential drawback, each link in the cache has a timeout associated with it, to allow that link to be deleted if not used within this timeout. The simulation studies in [10] show that this timeout value is closely related to the performance metrics, but the relationship is not straightforward, which depends on not only the mobility scenario but also the contents of the cache and the routing protocol's reaction on it. Also the optimal static timeout on the same mobility scenario is different for different node movement speeds. The paper proposed several cache timeout algorithms, among which the adaptive *Link-MaxLife* algorithm has the best performance.

When employing the cache timeout, *link caches* are used, where each node has a graph data structure of its current view of the network topology. The global view at nodes can be obtained by adding each link in the routes in the original routing messages to the graph of the link cache. Thus link cache structure can be implemented in the adaptive routing framework without explicitly adding extra control messages.

C. Adjusting routing metric

The routing metric consists of path selection criteria such as minimum hop count. The minimum hop count metric is a carry-over from the wired network, which might not be suitable for wireless networks when bandwidth, medium congestion or power usage are concerned. In wireless networks, different routing metrics can be used to trade off among system performance metrics such as throughput, latency and power. For example, when power is considered, the energy cost can be used as the link metric [12]. The study shows that the energy cost metric helps reduce power consumption at nodes at the expense of lower throughput and higher delay. According to the performance requirements, GPM can decide the routing metric for the routing module to be used.

The routing metric can switch between available metrics when network service needs change. As in re-selection of the routing module, a metric switch requires explicit control messages (e.g. by the consensus protocol) and may cause service discontinuity. Adaptive routing metrics represent a different approach, which can provide adaptive features via routing metric variables that adjust to the dynamically changing environment and traffic load. In particular, the adaptive routing metric incorporates the parameters which reflect observed network state changes such that the routes which would produce the best system performance are chosen. PARMA (PHY/MAC Aware Routing Metric for Ad hoc networks) is an adaptive cross-layer routing metric which includes parameters reflecting MAC congestion and link speed [8]. Therefore, PARMA can be used as a candidate metric in the framework.

D. Implementation issues

The above adaptive routing mechanisms under consideration can also be classified into two classes: one switches between available routing modules or metrics, and the other implements a single adaptive algorithm to control a particular routing element, such as a routing parameter or a routing metric.

In the second class, the controlled and controlling parts in the framework are combined and implemented in the adaptive algorithm, and control information (e.g. time-varying state variables) is propagated over the network by routing messages. Each node makes decision based on its local information and the information from other nodes without a consensus protocol. Therefore, the second class is practically easier to implement, and does not involve service interruptions in the network. In the next section, we give example algorithms for the first class and simulation results for the second one.

IV. EXAMPLE ALGORITHMS

Using the defined routing state variables, we give some examples on routing policies and adaptive algorithms, which can be deployed in the adaptive routing framework.

A. Switching routing module

As an on-demand routing protocol, TORA can quickly create and maintain loop-free multipath routing for packets, while reducing routing overhead [4]. However, it has been shown that TORA would fail to converge because of congestion collapse when the number of communication pairs increases, while DSDV has approximately consistent performance regardless of the number of communication pairs [5]. Based on these characteristics, we could switch the routing protocol from TORA to DSDV when the number of communication pairs increases such that network congestion occurs. Here we assume that the offered traffic at each source node does not change over time.

We use the channel busy degree, d, as the monitored state variable. Earlier work showed that the network begins to saturate when the channel busy degree approaches 0.6 [8]. Since switching routing module is worth the overhead it brings when the change is long-term, we need to observe the channel busy degree for some period of time. The routing policy is: when the measured channel busy degree $d \geq 0.6$ for some period of time, the routing module is switched to DSDV; when

$d \leq 0.4$, it switches back to TORA. The consensus protocol is used to reach an agreement for the switch.

The algorithm is shown in Table I, which can be used to trigger a transition from one protocol to another.

TABLE I

ALGORITHM 1: SWITCHING ROUTING MODULE

```
Check channel busy degree $d$ during run time
    if $d \geq 0.6$ && TORA then
        Trigger Consensus Protocol for switching to DSDV
    else if $d \leq 0.4$ && DSDV then
        Trigger Consensus Protocol for switching to TORA
```

B. Selecting routing metric

Simulation results have shown that the energy cost routing metric [12] helps reduce power consumption at nodes which trades off against the throughput. Table II gives the algorithm for routing metric selection. The decision is based on the network conditions. All the nodes at the network have to achieve consensus on the routing metric.

TABLE II

ALGORITHM 2: CHOOSING ROUTING METRIC

```
Check network conditions when initializing the application
    if power sensitive then
        Choose energy cost as the routing metric
    else
        Choose minimum hop count as the routing metric
```

C. Adaptive routing metric

As we have discussed, both routing module and metric switches require extra control messages and may cause service discontinuities. Compared to switching, single adaptive algorithms, including adaptive routing protocols (i.e. combining several strategies into one protocol such as SHARP), adaptive routing parameters and adaptive routing metrics, have the advantages of reduced adaptation overhead and flexibility.

We take the PARMA routing metric as the example of an integrated adaptive routing algorithm. PARMA incorporates two adaptive state variables, wireless link data rate and channel busy degree, and has been implemented with DSDV using the *ns*-2 simulator [13] in earlier work [8]. Simulation results are displayed in Fig.3. Fig.3.(a) shows that PARMA helps packets choose high speed links thus improves system performance. Fig.3.(b) shows that PARMA helps avoid congested area in the network, and thus further improves system throughput. The simulation parameters are not given due to space limitations, and are similar to those in [8].

V. CONCLUSIONS

This paper is a preliminary investigation of policy-based adaptive routing for ad hoc networks. We propose an adaptive routing framework which is controlled by a global distributed policy manager. Control information can be disseminated over the network by flooding of control messages, or piggybacking on routing messages. The state variables which can be monitored and used in the adaptive framework are also discussed. We further discuss three adaptive mechanisms and give example algorithms which can be deployed in the adaptive routing framework. It has been shown that adaptive routing helps achieve the desired system performance under the dynamically changing network conditions.

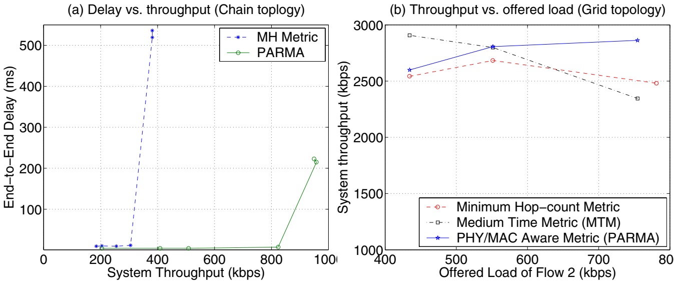

Fig. 3. Simulation results for PARMA and other routing metrics.

While switching of routing protocols and routing metrics results in extra overhead and service discontinuity, introducing an integrated adaptive algorithm to a particular routing element such as routing metric is a more practical alternative which can be implemented more easily with smaller overhead. In future work, we will consider more detailed comparisons between the proposed methods including an evaluation of protocol overheads.

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