LAID: Load-Adaptive Internet Gateway Discovery for Ubiquitous Wireless Internet Access Networks*

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Abstract. Ubiquitous wireless Internet access is to connect all devices to the Internet at any time and any place. To achieve this ubiquitous wireless Internet, we consider integrating the Internet and mobile ad-hoc networks. One of the most important issues in ubiquitous wireless Internet access is to find an efficient and reliable Internet gateway. We propose a load-adaptive hybrid Internet gateway discovery approach that can exploit network conditions. The load-adaptive hybrid Internet gateway discovery scheme dynamically adjusts a proactive area according to network traffic. Among the candidates, a serving gateway is selected based on offered load. The simulation results show that our discovery scheme can reduce discovery overheads and improve end-to-end delay and delivery ratio than existing discovery schemes.

1 Introduction

With the increase of potable devices as well as progress in wireless broadband communications, an integration of different heterogeneous wireless networks will be one of the areas for next generation wireless/mobile networks. To realize seamless heterogeneous wireless/mobile networks, we focus on ad-hoc networks providing Internet connection. This is referred as a ubiquitous wireless Internet access network or mobile ad-hoc wireless Internet access network. Ad-hoc networks are considered complementary to IP networks in a sense that Internet connectivity can be extended into the ad-hoc networks, making them part of the Internet. The mobile ad-hoc wireless Internet access network architecture is highly scalable and cost effective, offering a solution to the easy deployment of ubiquitous wireless Internet.

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Main issue in the ubiquitous wireless Internet access network is to discover an Internet gateway. When an ad-hoc mobile node wants to connect the Internet, it should be able to connect an appropriate Internet gateway. To achieve efficient integration and ubiquitous Internet access, we need efficient Internet gateway discovery scheme which determines the quality of the Internet connectivity. There have been three proposed approaches in the Internet gateway discovery: proactive, reactive, and hybrid schemes [6][7][8]. A proactive approach [10] enables good connectivity and low latency, but requires considerable overheads. In contrast, a reactive approach [9] achieves low routing overhead at the expense of increased latency. A hybrid approach [1][6][8] uses a proactive approach within a gateway's advertisement range, while it uses a reactive approach outside the coverage. One of primary challenges to design a hybrid scheme is to determine the optimal proactive area. However, existing hybrid schemes set their proactive area once and do not dynamically adjust it [7], which may not be an appropriate range any more for changing network conditions. To improve existing hybrid schemes, we propose a new ***L**oad-**A**daptive hybrid **I**nternet gateway **D**iscovery* (LAID) scheme that dynamically adjusts its proactive area according to changing network conditions. Once routes are discovered to Internet gateways, ad-hoc mobile nodes should be able to select one Internet gateway providing the best Internet connection. In the Internet gateway selection, our selection method distributes data packets into different Internet gateways while keeping low offered load. It decreases the average delay and the packet drop rate.

The rest of this paper is organized as follows. Section 2 discusses an overview of the Internet connectivity in ubiquitous wireless Internet access networks, and Section 3 proposes a load-adaptive hybrid Internet gateway discovery, and Section 4 presents our performance evaluation. Finally, we draw out conclusion in Section 5.

2 Overview of Ubiquitous Wireless Internet Access Networks

Ad-hoc networks can be applied anywhere with low cost and share data between device, where there is little or no communication infrastructure [5]. For access to ubiquitous Internet services, an *Internet gateway* (IG) in access networks provides Internet connectivity for *ad-hoc mobile nodes* (AMNs). AMNs are usually connected to the Internet through one or more IGs. This IG is part of both networks and acts as a bridge between an ad-hoc network and the Internet. First, packets from an AMN are forwarded to an IG and then transmitted to their destination in the Internet. IG is equipped with both interfaces: the first wired interface for the Internet and the second radio interface for ad-hoc networks. Thus, IGs run ad-hoc routing protocols to act as an AMN, and it operates as a member of a fixed subnet connected to the Internet. Fig. 1 shows an operation of ubiquitous wireless Internet access through ad-hoc networks. The IG provides ubiquitous Internet services to mobile users at any location without having to rewire or change hardware interfaces.

When an AMN needs a connection to the Internet, it should connect the nearest or best Internet gateway. Key issue for supporting Internet connectivity is IG discovery, for which three approaches have been proposed: proactive, reactive, and hybrid approaches [6][7][8]. According to the proactive approach, IGs advertise their presence

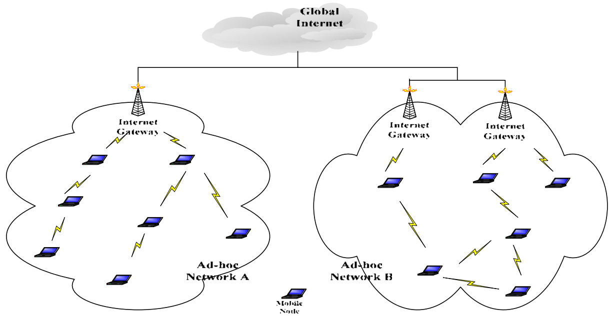


Fig. 1. Ubiquitous Internet connectivity through ad-hoc networks.

by sending an advertisement message on the ad-hoc network. It provides for good connectivity and low delay via frequent broadcasts of current IG information with the expense of high control message overheads. By the reactive approach, AMNs broadcast a route request message to discover IGs. On receipt of this request, IGs sends reply messages back to the requesters. Although it achieves low discovery overhead, the reactive scheme may increase route discovery delay. The hybrid approach combines the proactive and reactive schemes, reaping the best of both schemes: good connectivity and low delay. After finding multiple relay routes, AMNs select the best IG to communicate with Internet hosts outside the ad-hoc networks.

3 LAID: Load-Adaptive Hybrid Internet Gateway Discovery

In dynamic network environment, existing IG discovery schemes are only suitable for certain network configurations. Performance and scalability problems may come to the surface because of the fixed proactive areas in hybrid scheme that do not reflect dynamic network conditions [7]. The primary challenge in the design of a hybrid approach is how to determine the optimal proactive area. The loss rate and delay are decreased by increasing the area, but it will pay more in packet overhead to maintain routes in a larger area. The routing overhead is reduced by decreasing the area, but it may pay more in delay and experience higher loss rates [8]. Thus, fixed value of proactive area is not the best choice for all levels of network conditions. To achieve optimal performance, we propose a **L**oad-**A**daptive hybrid **I**G **D**iscovery (LAID) scheme which dynamically resizes the range of proactive IG advertisements. Our protocol adapts its behavior to current network situations such as the ad-hoc network size or the number of AMNs that need global communication. In this section, we compute the proactive area and describe IG selection method.

3.1 Proactive Area Measurement

Internet gateways (IGs) periodically announce their presence in an ad-hoc network by broadcasting Internet Gateway Advertisement Messages (IGAMs) with their information within periodic intervals. To prevent the flooding of the advertisements, these

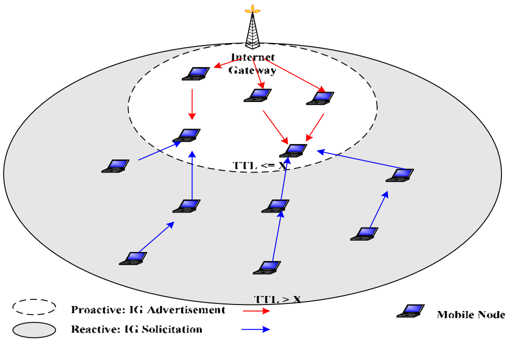


Fig. 2. Illustration of load-adaptive Internet gateway discovery.

advertisements are limited within n-hop neighborhood using a time-to-live (TTL) field. This range determines the IG's discovery scope, called a proactive area, which is dynamically adjusted by our adaptive Internet gateway discovery protocol. To decide the proactive area, we assume that the IGs can estimate the size of network and total number of node. The initial value of the proactive area is computed as follows:

$$Proactive\_area(\Psi) = \frac{A}{N \cdot 2P} \cdot \eta \tag{1}$$

where Ψ is a proactive area by *TTL*, *A* is network size defined as a rectangular area of a given length and width, *N* is the number of nodes, *P* is data packet size, and η is a constant 0.1. For example, if the bounded region of operation is 1000 × 1000 sq. m., and *P* is 512 bytes, and *N* is 50 nodes, *Proactive_area*(Ψ) is 2.

The proactive range expands or shirks according to network traffic which is estimated by IGs during the time interval (Δ_{t1}, Δ_{t2}). To compute the offered load, we suppose that the average traffic arrival rate is λ and the average traffic duration is τ per time interval, and we consider a periodic time interval of length $\Delta_t\{>1\}$ between two successive estimations. The number of path connected to the IG over this interval is $n(\Delta_t)$ and the amounts to be generated are $\lambda_1 \cdot \tau_1$, $\lambda_2 \cdot \tau_2$, …, $\lambda_n(\Delta_t) \cdot \tau_n(\Delta_t)$. For simplicity, let us also assume that the packet sizes are independent. Then over the interval Δ_{t1}, Δ_{t2}, the offered load is given by

$$\rho = \sum_{i=1}^{n(\Delta_t)} \lambda_i \cdot \sum_{i=1}^{n(\Delta_t)} \tau_i = \sum_{i=1}^{n(\Delta_{t1}, \Delta_{t2})} \lambda_i \tau_i \tag{2}$$

To obtain an up-to-date route from IGs, it is desirable to reduce the time interval. However, short interval will increase the overhead of the protocol in terms of bandwidth waste and battery power consumption at AMNs [8]. We dynamically adjust the beacon interval according to the network conditions, e.g., node mobility and traffic. It allows our LAID protocol to react to the changes in the network on time.

To avoid unnecessarily frequent resizing of the proactive area, we introduce two threshold: max threshold ($\gamma_{\max}$) and min threshold ($\gamma_{\min}$), which are based on the traffic load given by (2) and always $\gamma_{\max} > \gamma_{\min}$. If the estimated value is larger than the max threshold ($\rho > \gamma_{\max}$), the area size is incremented by 1. Similarly, if the estimation is less than the min threshold ($\rho < \gamma_{\min}$), the area size is decremented by 1. In other words, if $\Psi(now)$ is the current proactive range, the next proactive area becomes $\Psi(now + \Delta_t) = \Psi(now)$ or $\Psi(now + \Delta_t) = \Psi(now) \pm 1$. The $\gamma_{\max}$ and $\gamma_{\min}$ are $\rho + \rho \cdot 0.05$ and $\rho + \rho \cdot (-0.05)$, respectively.

As shown in Fig. 2, AMNs within the TTL (e.g. the proactive range) receive the periodic IGAM messages from IGs. If they are out of the range, the AMNs broadcast Internet gateway Request messages (IGRQ). AMNs inside the proactive area of an IG respond with Internet gateway Response messages (IGRP) to the soliciting AMNs or relay to IGs. On receipt of IGRQ messages, IGs send an IGRP message which has the IGs' prefix and information back to the soliciting AMNs. Data packets within the proactive area are routed by means of proactive routing protocols. Routes from a source node to the edge of the proactive area are reactively maintained. The load-adaptive hybrid IG discovery scheme provides efficient and fast discovery of IGs by the integration of three traditional Internet gateway discovery schemes.

3.2 Internet Gateway Selection Method

After finding multiple IGs, AMNs should select the best IG to communicate with Internet hosts outside the ad-hoc networks. The selection of the IG can be categorized into two cases: when an ad-hoc node is entered into the ad-hoc network at the first time and when a node performs a handover to new IG. The handover occurs when a moving ad-hoc node receives the IGAMs or when the ad-hoc node is disconnected from the previously registered IG. Although there exist several IG discovery schemes providing ad-hoc networks with Internet connection, most of them regard the shortest path with minimum hop counts as a major IG selection metric. Also, they did hardly concern multiple IGs. When AMNs are available some IGs and the selection of IG is only based on the shortest-path, the shortest-path algorithm does not perform very well. The poor performance of the shortest-path algorithm is not surprising, since the metric do not consider load of IGs and/or quality of a path during route setup. Hence they cannot fairly distribute the load on the different IGs and may lead to higher packet dropping rate. That is because the ad-hoc nodes want to get the qualified various services from the Internet. To reach this goal, we consider load of IG to guarantee the quality of network connection for user. This information is used by the source node to select the proper IGs. In our proposed load-adaptive discovery approach, Internet gateway selection is regulated by a distributed redirecting selection mechanism based on load of IG, which redirects the selected IG with heavy offered load into different IGs with less offered load to reduce and distribute data traffic over the network.

4 Simulation Model and Performance Evaluation

In this section, we evaluate the proposed scheme, compare it with existing IG discovery schemes, and analyze the analytical overhead of the discovery approaches.

4.1 Simulation Model

The simulations were performed using ns-2 [4]. In order to support wireless LAN in the simulator, the Distributed Coordination Function (DCF) of IEEE 802.11 is adopted as MAC layer protocol. As a mobility model, we use the random waypoint model in rectangular field where a node starts its journey from a random location to a random destination with a randomly chosen speed. The size of network is 700 m × 700 m and the number of mobile nodes is 50 in simulations. Constant bit rate (CBR) traffic with four packets per second and packet size of 512 bytes are used. We use the number of source nodes of 10 and 20. Simulations are run for 300 seconds. For fair comparisons, all discovery protocols use the same set of mobility and traffic. On stationary, Internet gateway is located in the middle of the grid [i.e., coordinate (400, 400)] for the first three simulation scenarios. In the second simulation scenario, two Internet gateways are located in the coordinates (1, 400) and (799, 400), respectively. An AMN uses modified AODV protocol [2] to communicate with its peers and to access wired networks through an Internet gateway. To manage AMNs' mobility between ad-hoc networks, AMNs as well as Internet gateways run MIP [3], where MIP FA and HA are hosted in the Internet gateway.

4.2 Simulation Results

To compare IG discovery approaches in the case of a single IG, a set of simulations has been performed in terms of three metrics: packet delivery fraction, average end-to-end delay, and normalized routing overhead. Various mobility scenarios have been simulated to understand their effects. Fig. 3 shows the simulation results for the proactive, reactive, hybrid, and load-adaptive approaches. Both proactive and reactive approaches have specific advantages and disadvantages that make them suitable for certain types of scenarios. In the proactive approach, the overhead for Internet connectivity increases as IGs broadcast periodic IGAM messages during the intervals that are flooded through the whole. The proactive scheme costs more overhead, but allows for good connections and low delay because it instantly knows better paths to IGs. In contrast, the reactive scheme incurs fewer overhead than the proactive approach, because AMNs request IG information by sending out IGRQ messages only when necessary. However, whenever there is a need for sending a packet, AMNs must find IGs if the IGs are not already known. This IG discovery process may result in considerable delay. Thus, it causes longer packet delay and lower packet delivery fraction. Fig. 3 shows that the hybrid and load-adaptive schemes are a compromise of proactive and reactive schemes. The hybrid and load-adaptive approaches minimized the disadvantages, and maximized the advantages of the two combined approaches.

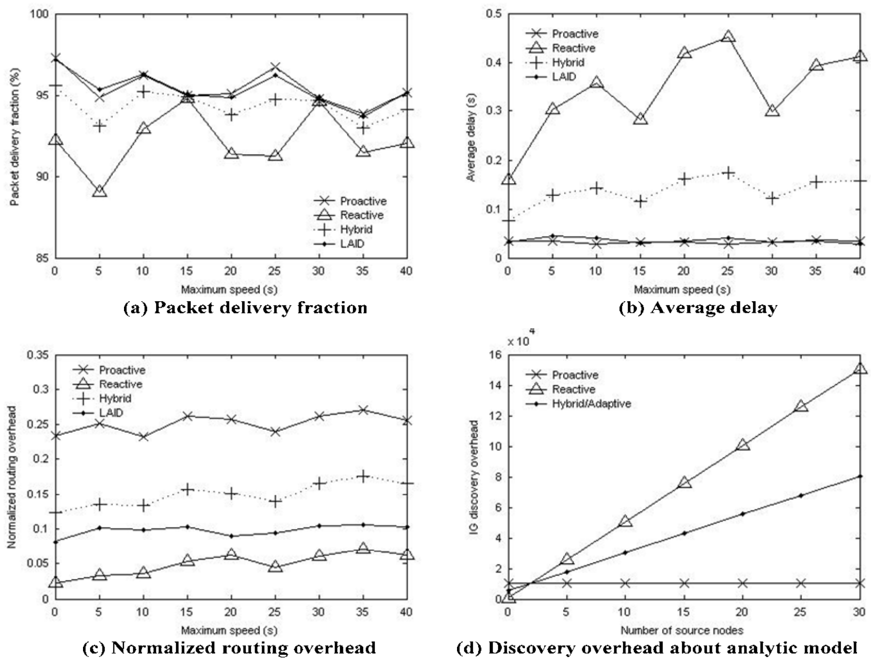
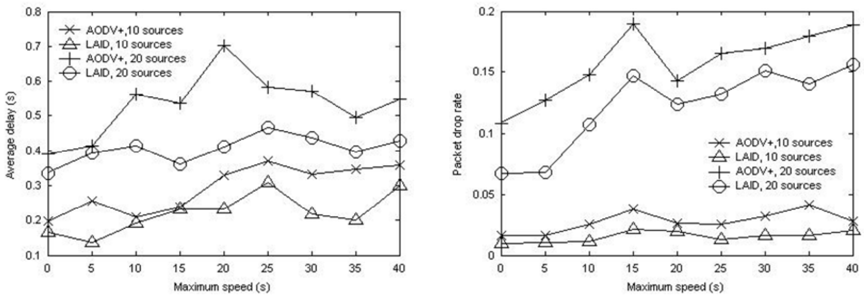


Fig. 3**.** Simulation results in IG discovery scenario: a) Packet delivery fraction, b) Average delay, c) Normalized routing overhead, and d) IG discovery overhead about analytic model.

The load-adaptive IG discovery (LAID) scheme enables lower packet delay compared to the reactive and hybrid approaches, and less overhead compared to the proactive and hybrid approaches. The dynamic resizing of proactive ranges can help to reduce excessive traffic otherwise by proactive approach during low mobility and traffic periods, by confining the advertisement traffic to a limited area. Under high traffic and mobility, our LAID will extend the proactive area to farther disseminate information about available IGs. Increased proactive area ends up with reduced route acquisition time and bandwidth loss. The LAID will scale well with network size and mobility.

For IG selection, we compare the performance of proposed LAID using load-based selection scheme and the AODV+ [1] using shortest-path selection algorithm in terms of average end-to-end delay and packet drop probability. For a scenario involving burst traffic, we assume a set of AMNs is initially requesting connections to IGs. The second experiment (Fig. 4) reports average delay and packet drop rate under various speeds. The average delay is defined by delay from the source node to the IG. Fig. 4(a) shows that our LAID using load-based selection achieves lower average delay than AODV+. Under higher traffic load, the average delay is further improved compared to the AODV+ using shortest path selection algorithm. A new connection is blocked, if there is no IG bandwidth available when it is needed. Fig. 4(b) plots the packet drop probability versus mobility at IGs. As the number of source nodes increases, the AODV+ and the LAID drop a large fraction of the packets. The reason is that there are more collisions in the air and congestion in IG when the number of



(a) Average delay **(b) Packet drop rate**

Fig. 4. Effects of varying mobility in IG selection: a) Average delay and b) Packet drop rate.

source nodes increases. Simulation result has shown that the LAID gives a lower packet drop rate than AODV+. That is because our redirecting selection mechanism in LAID can redirect the IG with heavy traffic to the IGs with light traffic. When the number of source nodes increase, the AODV+ does not perform well, since the metric simply selects an IG with shortest-path without regard to their density. The LAID using load-based selection method considers offered load of IG, and uses redirecting selection mechanism. Thus, it performs better performance than AODV+ using shortest path selection method. Our selection method might increase the throughput because of redirecting the requests originated by the AMNs at the boundary of radius through the neighborhood IGs.

4.3 Comparison of Internet Gateway Discovery Approaches by Analytic Model

We analyze the three IG discovery approaches: proactive, reactive, and hybrid/adaptive. Our analysis model assumes that new traffic generated by the hosts connected to mobile nodes follows Poisson distribution and is generated independently of each other. All hosts have the same traffic generation pattern.

When an ad-hoc source tries to discover a route towards a fixed node, it should find an IG. In a proactive approach, IGs will periodically broadcast IGAM messages to an ad-hoc network to advertise their presence. Therefore, the overhead of proactive schemes includes hello messages for route update plus the messages sent out by IGs themselves. Total overhead in the number of messages required by the proactive approach can be expressed as follows:

$$\Theta_P = N\left(N_{IG} \cdot \lambda_{IGAM} \cdot \Delta_t + P_{Ph}(\Delta_t) + {}^{1}\!/\!_{\mu}\,\alpha_N \right) \tag{3}$$

where Θ_p is the overhead of proactive approach, N is the number of nodes, N_{IG} is the number of IGs, λ_{IGAM} is the rate at which IGAM messages are emitted by IGs, $P_{Ph}(\Delta_t)$ is the number of the hellos packets by a AMN per a time interval, and ${}^{1}\!/\!_{\mu}\,\alpha_N$ is a route maintenance cost which is called $\hat{\beta}_P$, where μ is average communication link lifetime and α_N is the number of active neighbor nodes. We assume that link lifetime is independent of each other and are exponentially distributed. The discovery overhead of the proactive approach is independent of the number of sources sending data packets to the same IG.

Similarly, in the reactive approach a source willing to communicate with a host in the fixed network will first attempt to contact it within the ad-hoc network. If no answer is received after a network-wide search, then the source tries to find a route towards the Internet. The source wants to reactively discover an IG there is an overhead which includes the IGRQ broadcast messages, plus IGRP reply messages from every IG to the source. The overhead of the reactive IG discovery by one source can be computed as follows:

$$\Theta_R = N\left(N_S \cdot \lambda_{IGRQ} \cdot \Delta_t(R) + P_{Rh}(\Delta_t(R)) + {}^{1}\!/_{\mu}\,\alpha_L h \right) \tag{4}$$

where Θ_R is the overhead by the reactive approach, N_S is the number of source nodes communicating with a host in the Internet, λ_{IGRQ} is the sum of route requests and replies during the time interval ($\Delta_t(R)$) for reactive requests, $P_{Rh}(\Delta_t(R))$ is the number of hello packets emitted by a AMN for $\Delta_t(R)$ second, and ${}^{1}\!/_{\mu}\,\alpha_L h$ is route maintenance overhead which is called $\hat{\beta}_R$, where α_L is the number of active links and h is a hop count. If link layer is used to detect link failures, P_{Rh} is 0. Route lifetime follows an exponential distribution with a mean route lifetime of μ/h. The average rate of route failures is given by h/μ. The discovery overhead of the reactive approach is proportional to the number of active routes in the network. Therefore, reactive overhead increases with the number of sources and destinations in the network.

By a hybrid/adaptive approach, IGs periodically send IGAM messages within a certain range which is determined by a proactive area. Sources in that range behave as in a proactive approach, and those beyond that range behave as in a reactive approach. The hybrid/adaptive IG discovery scheme has the constituent overhead of proactive and reactive approaches. For sources outside the area covered by the IGAM messages, the overhead will be similar to that of the reactive approach. Thus, the overhead of the hybrid/adaptive approach is computed as follows:

$$\begin{aligned}\Theta_H &= N_{TTL}^{IG}\left(N_{IG} \cdot \lambda_{IGAM} \cdot \Delta_t + P_{Ph}(\Delta_t) + \hat{\beta}_P\right) + \\ &\quad N_{N-TTL}\left(N_S \cdot \lambda_{IGRQ} \cdot \Delta_t(R) + P_{Rh}(\Delta_t(R)) + \hat{\beta}_R\right)\end{aligned} \tag{5}$$

where Θ_H is the overhead of hybrid/adaptive approach, N_{TTL}^{IG} is the number of nodes in the TTL range from an IG, and N_{N-TTL} is the number of nodes for each source outside the proactive area. Hence only $N-TTL$ nodes in the path revert to reactive discovery. In this scheme, used hello packets are not part of the discovery overhead. That is because update packets are generated, transmitted, and received by the link layer (in that case, P_{Ph} = 0 and P_{Rh} = 0). Fig. 3(d) shows a graph for this analytic model. We note that different proactive range leads to different performance of the hybrid/adaptive scheme, and the optimal TTL is dependent on several network conditions. As our analytical model has estimated, our adaptive approach can achieve a good trade-off between the efficiency of the protocol in terms of signaling overhead.

5 Conclusions

We have proposed a load-adaptive hybrid Internet gateway discovery approach named LAID. Our load-adaptive hybrid Internet gateway discovery approach dynamically adjusts the proactive area based on the offered load. We investigate the performance of LAID under various network conditions. Our simulation study shows that the proposed load-adaptive discovery approach outperforms other existing approaches. Also, the load-based redirecting selection scheme provides load-balancing and reduces average delay and packet drop rate.

Acknowledgment

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