A Hybrid Anycast Routing Protocol for Load Balancing in Heterogeneous Access Networks

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***Abstract*— The wireless multihop to an access point model appears to be a promising component of future network architectures, including multihop cellular networks and wireless access networks at the edges of mesh networks. Sophisticated software radios and core network protocols are being developed to support the integration of heterogeneous access networks. A challenge is managing diverse resources at access points (e.g., 3G, WiFi or WiMax), as well as the distributed interference among the mobiles within a heterogeneous access network. We propose the use of a new anycasting protocol to guide access point discovery and path selection for balancing access point resource and routing packets to access points (APs). In addition, a hybrid proactive/reactive approach is used to reduce overhead of AP discovery. We use theoretical analysis and extensive simulations, to study the tradeoff of our hybrid anycasting protocol. The simulation study indicates that the use of the hybrid anycasting protocol for AP discovery, load balancing and routing, results in consistent performance improvements.**

I. INTRODUCTION

The vision of future generation networks is evolving towards one that includes interoperable heterogeneous wireless access technologies to provide seamless access to core networks. Today's markets include a proliferation of cellular, WiFi and WiMax technologies for access to telecom, Internet and entertainment networks via mobile devices such as phones, PDAs, laptops and sensors. Mobile devices equipped with multiple interfaces are already available for commercial usage [1]. A number of approaches to combing multihop and cellular networks have been proposed. These include cellular overlay of ad hoc [4]–[7] and ad hoc overlay of cellular [8]–[14] approaches. An important aspect of such networks is the discover of an available access point. In this paper, we concentrate on an access network architecture formed by heterogeneous mobile devices, which rely on multihop connection to an access point. The mobiles attempt to locate the best access point (AP) for connection to the Internet, where the notion of best can be described as 'most willing' or 'optimum for communication' based on some selection criteria, as well as a route to the selected AP. We describe a new anycasting protocol for route discovery and maintenance from mobile nodes to the best AP available that integrates AP load balancing decisions with routing path selection.

Anycasting is originally an Internet service for best effort delivery of datagrams from a host to at least one, and preferably only one, receiver from the nearest 'group of receivers', where nearest is defined according to the routing system's measure of distance [2], [3]. All the servers in an anycast group share a single anycast address. Servers are configured with the same anycast address, and are located at different locations in the network. The routing protocol automatically delivers packets from the client to the closest destination with the anycast address. Anycasting has been applied to wireless ad hoc and sensor networks [15]–[20]. In [19], the authors proposed anycast routing protocol based on Ad Hoc On Demand Distance Vector (AODV) [21], which is a unicasting protocol for mobile ad hoc networks. Anycast routing is supported by introducing a 4-bit Anycast Group ID, which is contained in the Route Request (RREQ) message along with other flags for discovery of the nearest anycast service provider. This protocol is designed to work purely in ad hoc environments for evenly distributing the load on different available anycast server nodes. In [20], to support anycast service, Dynamic Source Routing Protocol [22] is extended with a similar idea as [19] for anycast ID or Anycast address. The RREQ packet does not contain a list of anycast servers, which reduces the packet size to some extent. However, the source routing mechanism introduces its own overhead. Both of the simulation results in [19], [20] show that, anycasting can bring better performance, especially with high traffic load.

Most existing anycast protocols for wireless networks (such as those in [19], [20]) are simply designed using reactive schemes, and utilize length of path as route selection criteria. In this paper, we study the designing of a hybrid anycast protocol for heterogeneous access networks, which can support any type of cost metric for path selection. Our hybrid mechanism divides the multihop portion of the access network into two regions. The proactive region enables APs to advertise their services by maintaining state information at mobiles or relays within close proximity of the APs. The reactive region enables mobiles to discover APs, as needed, by interrogating nodes in the proactive region. A combination of proactive and reactive routing reduces communication overhead and delay, while increasing throughput. We provide theoretical analysis on communication overhead of our method and derive the optimal radius of proactive region. Furthermore, instead of using hop count as path selection criteria, our protocol can support a generic load metric for AP selection to achieve load balancing among multiple heterogeneous APs. The efficiency of AP resource management with routing path selection is demonstrated using simulation. Since the load metric is a generic one, it is easy to extend our protocol to carry more complex path cost metrics (e.g., energy, processing, traffic patterns). We conduct extensive simulations in ns-2 [23] and the simulation results confirm the performance improvements of our new hybrid anycast protocol.

The paper is organized as follows. Section II describes the details of our proposed hybrid anycast protocol. Theoretical analysis on the optimal radius of proactive region for proposed protocol is also provided. Section III presents our simulation results and Section IV gives a brief conclusion and points out our future work.

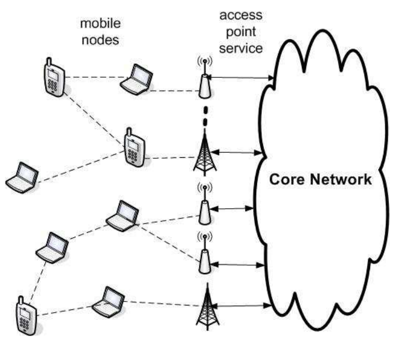


Fig. 1. Network Architecture.

II. Hybrid Anycast Routing Protocol

A. Network Architecture

In this paper, we assume a general heterogeneous network architecture as shown in Figure 1. There are two basic entities in the system: mobile nodes (MNs) and access points (APs). MNs are mobile devices which may have multiple interfaces (e.g., 3G, 802.11, or 802.16) as well as the capability to relay traffic between interfaces. APs are physical access points that connect MNs to the core network and terminate the wireless portion of the network. Different APs can use various technologies. We assume existing protocols or system designs are available to integrate heterogeneous access technologies into the core network. We will only focus on AP discovery and path selection in the multihop part of the architecture. We also assume that all nodes have prior information about anycast group memberships, using protocols available in literature.

B. Hybrid Protocol Design

This hybrid anycast routing protocol is primarily based on AODV architecture; with major modifications to support anycasting and distributed regions. The routing protocol combines both proactive and reactive mechanisms. The network is divided into two regions:

- **Proactive Region:** APs and MNs within an m hop radius of an AP are in the proactive region. All MNs maintain active information about AP in this region through periodic Hello packets sent by AP. Hereafter, we call m as *proactive radius*.
- **Reactive Region:** All MNs more than m hops away from an AP are part of the reactive region, and use a reactive anycast routing protocol to discover routes to an AP.

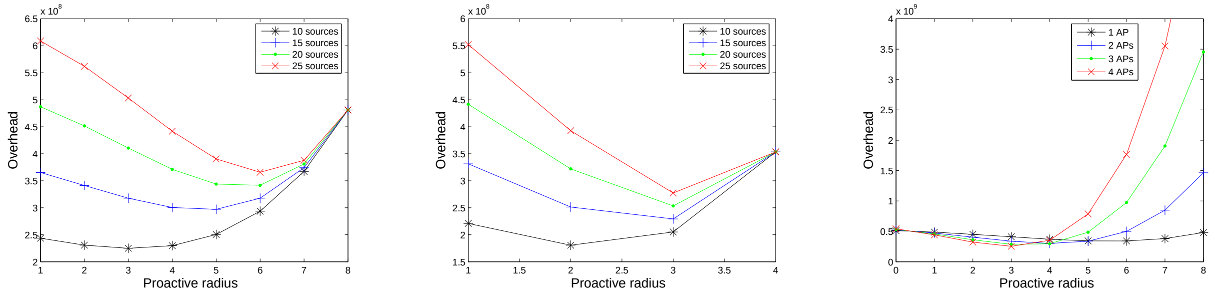
The objective of our hybrid anycast protocol is for a mobile node to establish communication with an AP in an anycast group so that the selected AP can forward packets to the destination in the core network. The route to destination for all data packets is selected through any of the AP based on a decision metric. APs are entry points for MNs to access the Internet and are part of one or more anycast group(s).

Protocol functionality of our proposed anycast protocol can be divided into the following different phases.

1) **Hello Message Transmission:** All APs periodically transmit *Hello* packets (denoted by HELLO), which only traverse m hops (i.e., inside the proactive region), as defined by using the TTL value in the IP header. Upon receiving a Hello packet, the node first determines whether it is within m-hop distance from the AP. If so, the route to the AP is created or updated. Only nodes $m-1$ hops away from the AP decrease the TTL value and rebroadcast the packet. The *Hello* packets include anycast group identifier number and a generic *load metric* which represents the load/avaiability of the AP. This metric value may be updated before broadcasting.
2) **Route Discovery (Proactive Region):** A node determines that it is in the proactive region if it has received a *Hello* packet from any AP that belongs to the destination anycast group in the previous *Route Expiration* time interval. Then, it can start sending data using the information in the routing table without performing route discovery phase.
3) **Route Discovery (Reactive Region):** RREQ and RREP packets are similar to AODV specifications, but have additional fields to include anycast group ID and load metric. If a node does not have any valid route available to any member of the anycast group in its routing table, it broadcasts a RREQ. Most of the RREQ processing is the same as that described in [21]. RREP can only be generated by AP members of the anycast group or MNs in proactive area that have an active path to any member of the anycast group.
4) **Route Selection:** Route selection is related to the cost metric used in the protocol, i.e., AODV selects the path with the first RREP. While using load metric included in the RREQ, our anycast protocol selects the route with the best load value out of the available destinations in the anycast group. If two or more APs have the same load value, then the route with maximum life time (similar to AODV) is selected to forward the packets.
5) **Route Maintenance:** Route maintenance is the same as for classical AODV.

C. Analysis of Optimal Proactive Radius

Notice that the hybrid proactive/reactive approach in our hybrid anycast protocol can reduce overhead of AP discovery. However, the radius m of proactive region is an important



(a) 1 access point (b) 4 access points (c) 20 sources

Fig. 2. Overhead vs proactive radius: plot of $f(m)$.

TABLE I

PARAMETERS IN OUR ANALYSIS AND THEIR VALUES IN THE PLOTS.

Symbols	Meaning	Values
R	Network radius	2000m
r	Transmission range of an AP or MN	250m
m	Radius of proactive region of an AP	various
s	Number of traffic sources in the network	various
l	Number of APs in the anycast group	various
d	MNs distribution density	4 per m^2
t	Total time of operation	500 seconds
η	HELLO broadcast interval	20 seconds

parameter, which can greatly influence the network performance. Therefore, in this subsection, we focus on analysis of the optimal m value in terms of overhead.

Before giving our theoretical analysis, we list the assumptions of our models:

1) APs and MNs have the same transmission range r;
2) All APs belong to the same anycast group and their coverage does not overlap with each other;
3) MNs only rebroadcast a RREQ message once;
4) Both MNs and traffic sources are uniformly distributed in the network;
5) The network is distributed in a disk area with radius R.

Table I presents all the parameters we use in our analysis.

The total overhead of AP discovery can be divided into two parts: Hello messages from APs inside the proactive region and RREQ messages from MNs inside the reactive region. Here, we ignore the RREP messages, since they are sent along unicast routes which leads to a much lower number as compared to the number of HELLO and RREQ messages which are sent by flooding.

Each HELLO message floods the proactive region and it can reach m hops with $m-1$ re-broadcasts. Therefore, the total number of HELLO messages broadcast per AP is

$$\pi((m-1)r)^2 d, \tag{1}$$

where d is the node density and $\pi((m-1)r)^2$ is the area of the proactive region of this AP. Then, the total number of HELLO messages from all l APs during the whole operation is

$$l[\pi((m-1)r)^2 d]\frac{t}{\eta}. \tag{2}$$

On the other side, we calculate the total number of RREQ messages. If the source node is located in the proactive region, there should be no RREQ overhead; otherwise, the number of RREQ messages per flooding for one route discovery is

$$\pi(R^2 - lm^2r^2)d. \tag{3}$$

Here $\pi(R^2 - lm^2r^2)$ is the area of the reactive area. Notice that when a RREQ reaches the proactive region of any AP in the anycast group, it will not be rebroadcast anymore. Since we assume s sources are uniformly distributed in the network, the number of traffic sources located in the reactive area is

$$s\frac{R^2 - lm^2r^2}{R^2}. \tag{4}$$

Thus, the total number of RREQ messages of all the s sources can be calculated by multiplying Equations (3) and (4):

$$s\frac{R^2 - lm^2r^2}{R^2} \times \pi(R^2 - lm^2r^2)d = \pi sd\frac{(R^2 - lm^2r^2)^2}{R^2}. \tag{5}$$

Therefore, the total number of overhead can be expressed as a function of m, (if HELLO and RREQ packets have the same size)

$$f(m) = l[\pi((m-1)r)^2 d]\frac{t}{\eta} + \pi sd\frac{(R^2 - lm^2r^2)^2}{R^2}. \tag{6}$$

If HELLO and RREQ are not of the same size, we can modify the above equation to:

$$f(m) = \alpha l[\pi((m-1)r)^2 d]\frac{t}{\eta} + \beta\pi sd\frac{(R^2 - lm^2r^2)^2}{R^2}, \tag{7}$$

where α and β are the HELLO and RREQ packet size, respectively. In following experiments, HELLO and RREQ packets have the same size.

Using a common setting of the parameters, as shown in Table I, we plot the overhead function of $f(m)$ with different combinations of l and s. Figure 2(a) shows the plot of $f(m)$ with various numbers of sources when only a single AP is inside the anycast group. The following observations are summarized: (1) total overhead increases with the number of traffic source increases, since the number of RREQ messages increases; (2) all curves follow the same trend, first decreasing to the lowest point, then increasing, and merging together when $r = 8$, where it is completely proactive; (3) the optimal value of m (where $f(m)$ is minimized) increases as the source number increases, i.e., 3 for 10 sources, 5 for 15 sources, 6 for 20 and 25 sources; this has been confirmed later in our simulation. Figure 2(b) shows a similar scenario with 4 APs. The trend of all curves is the same as that with single AP. Notice that the merge point of all curves shifts to 4, since $m = 4$ can guarantee the proactive region covers most of the network. To observe how the quantity of AP affects the overhead function, we fix $s = 20$ and plot the set of curves with different l values in Figure 2(c). The curves follow the similar trend (first decreasing then increasing) as shown in Figures 2(a)(b). It is interesting that the optimal value of m decreases as the number of AP increases. In other words, as more APs belong to the same anycast group, each AP can reduce its proactive radius.

D. Load Balancing Schemes

Since the traffic sources and relaying MNs (or even APs) are not evenly distributed in the real access networks, simply using the nearest AP for access may lead to unbalanced load among APs (i.e., some APs may be overloaded while some APs are always idle). Due to wide diversity of access techniques in heterogeneous access networks, different APs may also have various capacity to serve MNs. Thus, load balancing among multiple heterogeneous APs is an important and challenging task. Anycast mechanism has the potential to achieve better load balancing, because multiple APs in the same anycast group can all provide same access services. In this subsection, we use a simple load metric plus several load balancing policies at APs to demonstrate the power of combining load balancing with anycast route selection.

Each AP keeps track of its load information and broadcasts it to MNs within the proactive area via Hello messages. Here, we use the number of packets received per second as a simple load metric, which can be easily extended to other complicated load metrics. This load metric is included in both HELLO and RREP messages and used during the route selection. Beside the load metric, APs can actively take actions to balance load by changing its attitude towards RREQ and HELLO messages. Our load balancing approach classified the status of APs into three zones based on their load information:

- Green Zone: When traffic load is below the threshold Th_{green}, AP is in normal state. Therefore, AP keeps broadcasting HELLO messages and also corresponding to normal RREQ it receives.
- Red Zone: When traffic load is between thresholds Th_{green} and Th_{red}, AP is in overload-avoidance state. APs stop broadcasting HELLO message when they enter this state, moreover, they only correspond RREQs from MNs inside its proactive region, which limits connection requests to avoid overload situation.
- Black Zone: When traffic load is above Th_{red}, AP is in overload state. APs stop corresponding to any RREQs and decline any new connections. If the traffic load keeps increasing even though there are no new connections coming in, APs can explicitly send a message to the sending source to announce the overload status. Then, the source node can switch to another available AP or start a new round of RREQ if no other entries are available in its routing table.

These threshold values can be configured by network administrators based on equipment properties, network deployment, traffic load or other factors.

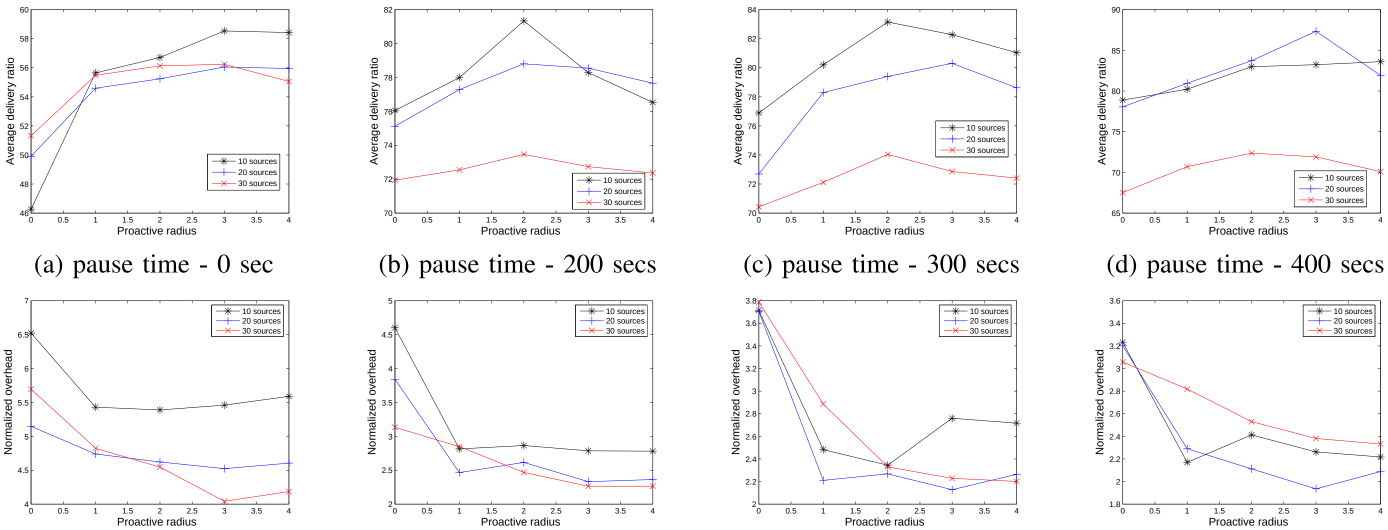
III. Simulation Results

In this section, we conduct two sets of simulations with ns-2 to evaluate our proposed hybrid anycast protocol. Comparison of the proposed anycast approach to existing reactive anycast schemes could not be done, because we were unable to replicate their implementations completely. Our simulations use the IEEE 802.11 distributed coordination function (DCF) MAC protocol.

A. Hybrid Anycasting: Study on Proactive Radius

In the first set of simulations, we test the performance of hybrid anycasting with different proactive radii. 100 nodes are randomly distributed in a $2200m \times 1000m$ rectangular region. While 4 APs are fixed around the four corners, MNs move freely with a maximum speed of 20 m/s using Random Way Point (RWP) mobility model. Each round of simulation runs for 500 seconds. We generate various mobility degrees with different pause time values (0, 100, 200, 300, 400 seconds), varying from high mobility (low pause time) to very low mobility (high pause time and almost static). Constant bit rate (CBR) sources are used, and the communication pairs are randomly chosen over the network. 10, 20 and 30 sources are used to represent different load degrees, each sending 4 packets per second with size 512 bytes.

Figure 3 shows the simulation result for the first set of simulations, comparing the performance of our hybrid protocol with different proactive radii (0, 1, 2, 3 and 4). Due to space limitation, here we only present the delivery ratio and overhead measurements for four types of mobility. It is clear that average delivery ratio increases as pause time increases, also as the number of traffic sources decreases. In Figure 3(d), the delivery ratio of 10 traffic sources are lower than that of 20. This is because the network is nearly static when the pause time is 400 seconds, and there might be a partition which causes lower delivery ratio in the network. Although there are fluctuations in the plots, the main trend is coherent, increasing to a peak point, then decreasing, which means that the proper proactive radius selection can improve the performance, i.e., in Figure 3(b), the optimal proactive radius is 2. Figures in the lower row of Figure 3 compare the normalized routing overhead of the same scenarios, which also increases as the pause time increases. This set of curves also show a rough trend, decreasing to the lowest point, then increasing, similar to the observation in the theoretical analysis in Section II-C. For example, in Figure 3(d), with 10 traffic sources, overhead achieves the lowest point when the proactive radius is 1, 20 sources with 3, and 30 sources with 4. This also confirms one of our conclusions from the theoretical analysis: optimal



(a) pause time - 0 sec (b) pause time - 200 secs (c) pause time - 300 secs (d) pause time - 400 secs

(e) pause time - 0 sec (f) pause time - 200 secs (g) pause time - 300 secs (h) pause time - 400 secs

Fig. 3. Average delivery ratio (upper row) and normalized overhead (lower row) with different proactive radii, number of sources, and pause time values.

proactive radius increases as the number of traffic sources increase. It is not possible to determine a particular radius value, as it varies for different situations. One of our future work is to devise algorithms for optimal radius determination at run time based on network parameters.

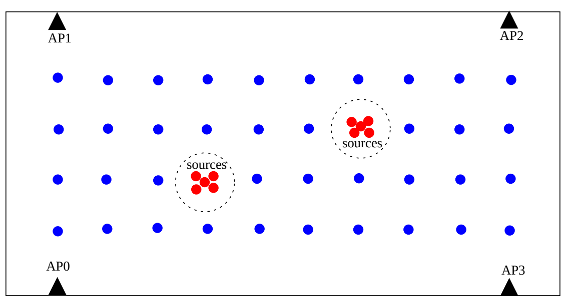
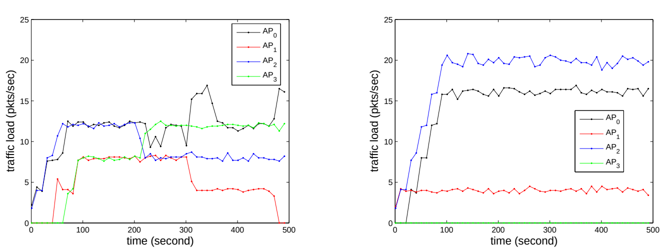


Fig. 4. Fixed network deployment: black triangles are APs, blue circles represent MNs, and red circles represent traffic sources.



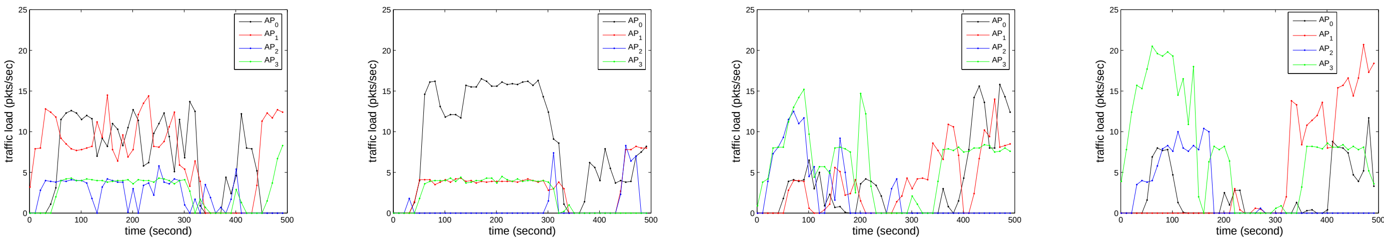
(a) with load balancing (b) without load balancing

Fig. 5. Load distribution of APs in the fixed network (as shown in Figure 4) with or without our load balancing schemes.

B. Load Balancing via Simple Load Metric

To give a simple illustration of our load balancing scheme, we conduct the second set of simulations first with a fixed network deployment as shown in Figure 4, where black triangles are APs, blue circles represent relaying MNs, and red circles represent MNs who are traffic sources. The proactive radius is fixed to two hops for all APs. There are 10 CBR traffic sources divided equally into two groups. In each group, the sources start generating traffic one by one, and the beginning point is (5, 20, 50, 70, 90) seconds, respectively. We use number of packets received per second as a simple load metric for each AP and set the load threshold parameters as follows: $Th_{green} = 8$, $Th_{red} = 16$, $Th_{black} = 18$. We run the simulation both with and without load balancing schemes. The load distributions at each AP are plotted in Figure 5. We can observe that, with load balancing, the traffic load is distributed more evenly among access points as compared to without-load balancing technique. Note that we deliberately place the two groups of traffic sources near to AP_0 and AP_2 respectively. Thus, without our load balancing schemes, all traffic is directed towards these two APs and their loads are very high, as shown in Figure 5(b). But with the information of load metric, our scheme can redirect some traffic to the other two APs, such that, the load among APs is more balanced (Figure 5(a)). The crests and turfs in the plots can be attributed to MAC layer callbacks due to which routing protocol may generate Route Error messages for sources, resulting in new route discovery processes.

We also conduct load balancing simulations in a mobile environment. To increase the confidence level, we run each simulation multiple times and average out the result. The network setup is similar as that used in hybrid anycasting simulations, and the proactive radius is fixed to 2 hops. Figure 6 depicts data processed at each AP. As the mobility and communication patterns are random, more fluctuations are observed as compared to the static topology. Close observations reveal that load distribution among APs is better when



(a) pause time - 300 secs with load balancing (b) pause time - 300 secs without load balancing (c) pause time - 100 secs with load balancing (d) pause time - 100 secs without load balancing

Fig. 6. Load distribution of APs in a mobile enviroment with or without our load balancing schemes.

our load balancing technique is used. The upper bound of load per AP is significantly reduced and new connections are forced to find other closer APs. We expect more complex load metric and dynamically adjusting proactive radius techniques can lead to better load balancing in a dynamic network. These issues will be addressed in the future work.

IV. Conclusion

We presented an anycast protocol for heterogeneous access networks to enable MNs to select one of multiple eligible access points. We further integrated a hybrid proactive and reactive approach to AP discovery, which significantly reduces the communication overhead. The theoretical analysis shows that the selection of the proactive radius can affect the network performance and thus an optimal proactive radius is derived. We also conducted a set of simulations to evaluate the performance of the protocol, and as an extension, we utilize traffic load as the cost metric for AP selection, and let APs dynamically adjust their attitudes for dissemination of HELLOs and acceptance of RREQs regarding their load states. The simulation results show that our protocol effectively improves the performance and provides the provision for load balancing and high service availability. Further research work is in progress for building of a dynamic algorithm to increase and decrease AP flooding radius, based on network conditions, using complex cost metrics. Also, further analysis can be done on the effect of heterogeneous transmission ranges of devices, as well as coverage overlapping of APs.

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