Coping with Episodic Connectivity in Heterogeneous Networks

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Abstract—**In this paper, we present an efficient message delivery mechanism (MeDeHa - Message Delivery in Heterogeneous, Disruption-prone Networks) that enables message dissemination in an internet connecting heterogeneous networks and prone to disruptions in connectivity. MeDeHa also takes advantage of network heterogeneity (e.g., nodes supporting more than one network) to improve message delivery. For example, in the case of IEEE 802.11 networks, we use both infrastructure- and ad hoc modes to deliver data to unavailable destinations. Another important feature of MeDeHa is that there is no need to deploy special-purpose nodes such as message ferries or throwboxes in order to relay data to intended destinations, or to connect to the backbone network wherever infrastructure is available. We evaluate MeDeHa via simulations using indoor scenarios (e.g., convention centers, museums etc.) and show significant improvement in delivery ratio in the face of episodic connectivity. We also showcase MeDeHa's support for quality-of-service through traffic differentiation and message prioritization.**

I. INTRODUCTION

In this paper, we propose MeDeHa (Message Delivery in Heterogeneous, Disruption-prone Networks, pronounced ”medea”) - a general, yet efficient framework for data delivery in heterogeneous internets prone to disruptions in connectivity. To cope with arbitrarily long-lived connectivity disruptions, we use available storage within the network to save messages for destinations that are currently unreachable; once these destinations re-connect, messages destined to them will be delivered. With respect to using in-network storage, MeDeHa is complementary to the Bundle Architecture [1]. While the Bundle Architecture provides storage above the transport layer (to make networks, having different transport layers, interoperable), MeDeHa, stores data at the link layer (e.g., when intermediate nodes do not support higher-layer protocols). MeDeHa is also able to provide different levels of quality-of-service through traffic differentiation and message prioritization by controlling when messages are forwarded and for how long they are stored.

To-date, there are no comprehensive solutions targeting message delivery in heterogeneous networked environments prone to connectivity disruptions. Existing proposals either: (1) extend MANETs to handle episodic connectivity [2], (2) augment the coverage of access points in infrastructure based wireless networks by, for example, making use of multi-channel radios [3], (3) provide MANETs with Internet connectivity by using special-purpose gateway nodes [4], or (4) handle heterogeneity only at higher layers of the protocol stack (e.g., Bundle Architecture [1]). Unlike existing proposals such as message ferries [5] or throwboxes [6], MeDeHa does not require any special-purpose nodes. Furthermore, we take advantage of the underlying heterogeneity (e.g., in the context of IEEE 802.11 networks, the nodes' ability to operate in infrastructure or ad-hoc modes) to enable message delivery across different networks.

Our current implementation of MeDeHa performs message delivery in an internet comprised of an infrastructure-based wireless network where mobile nodes can roam freely among access points and can become temporarily disconnected from the network. Simulation results obtained with a variety of mobility, traffic and connectivity conditions show that MeDeHa is able to improve message delivery ratio significantly. We performed simulations to analyze the behavior of MeDeHa in terms of delivery ratio as a function of buffer sizes and disconnection times and observed class-wise behavior of traffic according to some quality-of-service.

II. MEDEHA OVERVIEW

MeDeHa's main functional components are:

Message relaying: Unlike several DTN solutions, which employ specialized nodes to aid with data delivery [5], [6], in MeDeHa any node in the network can relay messages under the store-carry-and-forward paradigm [1]. We thus avoid using any explicit discovery mechanism for finding specialized nodes (e.g., gateway to the backbone). Nodes may also take advantage of network heterogeneity to improve message delivery. For example, 802.11-capable nodes may periodically switch between infrastructure- and ad-hoc modes to get messages delivered across both networks.

Buffering: An important question is where to buffer these messages. In MeDeHa, any node can relay messages and therefore will need to store messages whose destination(s) is (are) not available. However, we again try to take advantage of network heterogeneity. For example, Access Points (APs) in infrastructure-based wireless networks are perfect candidates to serve as temporary storage for undelivered messages as they usually exhibit higher resource availability. Note that in the Bundle Architecture [1], buffering is performed above the transport layer; which in itself restricts the types of nodes that can perform this functionality. For instance, it rules out APs as buffering nodes, as APs usually run only the two lower protocol layers. In MeDeHa, buffering is done at layer 2 which enables almost any network-enabled device to relay and buffer messages.

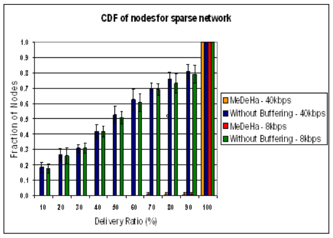

Fig. 1. CDF of nodes vs. PDR for non-uniform APs deployment

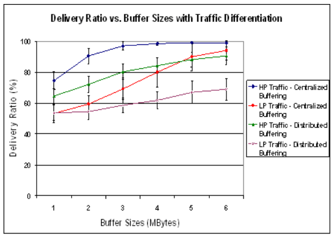

Fig. 2. Buffer Size Impact on PDR (Non-uniform APs deployment)

***Topology and content information exchange*:** Nodes periodically exchange information in order to build their routing tables. This information includes a node's knowledge about the topology (e.g., its own neighborhood as well as what it knows about other nodes). Nodes can also exchange a summary of their message buffer, their current state in terms of resources (e.g., storage, battery lifetime, etc.). This information can be used by relay selection [7]. Note that if neighborhood information is already made available by the underlying layer-2 protocol (e.g., beaconing, AP association/disassociation), MeDeHa will simply make use of it.

***Traffic differentiation*:** In order to satisfy application-specific requirements, MeDeHa uses message tags to carry information such as message priority, time-to-live (or TTL, the maximum amount of time the message should remain in the network) etc. Besides performing traffic differentiation and supporting quality-of-service, message tags are also used for buffer management purposes.

III. DESIGN ISSUES

MeDeHa raises a number of interesting design issues that are critical to the correct and efficient operation of the protocol. We discuss some of them here.

***Relay node selection*:** Several heuristics can be considered when choosing a suitable relay node. These include time since a node last saw a destination, encountering frequency, total meeting time, node's mobility pattern, node's social behavior, resources including battery, storage etc. Some of these heuristics have already been reviewed in the literature [7], but their application is highly dependent upon the target environment. Wherever an infrastructure is available, MeDeHa gives preference to an infrastructure-based node (e.g. AP) over other relay nodes, if the destination is not directly reachable.

***Buffer Management*:** Another important design decision is how to perform buffer management including storage space to be utilized at relay nodes, when to discard stored messages, etc. The storage space parameter depends upon a relay node's storage capacity (i.e., its storage and energy capabilities), as we can have heterogeneous devices in the system.

***Switching Between Networks*:** For nodes that participate in more than one network (e.g., infrastructure and ad-hoc modes in IEEE 802.11), deciding when to switch between different networks is important. Switching can be periodic by default (specific time for each mode), forced by an event (urgency to deliver a message), or adaptive according to traffic.

IV. RESULTS

We use packet delivery ratio (PDR) to show how MeDeHa improves message delivery in heterogeneous internets subject to connectivity disruptions. We used a museum environment where exhibit rooms/halls are equipped with APs. Visitors carrying portable devices move from one room to another to visit the museum and roam around in between regions of coverage of the APs. When no destination information is available, messages are stored using centralized (at a central storage station) and distributed (use APs to store messages) buffering mechanism. To have results close to a realistic scenario, we have used Random Waypoint (RWP) mobility model with attraction points. The nodes move in between attraction points at a speed between 1 and 2.5 m/s and pause time is between 10 and 90 seconds. We have chosen a network of 9 APs and define 28 attraction points with an effective radius of 10 meters for each, indicating its region of influence. There are 60 nodes in the network and we have run the simulations for a duration of 40 minutes. The CDF of nodes in case of non-uniform APs deployment and the impact of varying buffer sizes are shown is Figure 1 and 2 respectively.

V. CONCLUSION AND FUTURE WORK

This work is a building stone for heterogeneous internets, where late delivery of data is preferred over loss of data. Besides the ability to deliver the data to temporarily unavailable destination, our contributions are two fold. First, we extend the concept of heterogeneous networks to support frequent and/or long-lived disruptions in connectivity. Proposals targeting network heterogeneity don't deal with arbitrarily long connectivity interruptions. Second, with our scheme, there is no need to introduce special-purpose nodes in order to connect to the backbone network, or to support network heterogeneity. This is significant, as there is no overhead of having extra, more resourceful entities in the network. We can rely on more resourceful entities like APs to store messages but these entities are already part of our system. We are currently extending MeDeHa to support participating ad hoc networks. We believe that this would not only increase packet delivery ratio, but also would be helpful in reducing overall delay for messages.

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