Solving Routing Problem in Multicast Delay Tolerant Networks using Hybrid Routing

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Abstract

Mobile devices gain increasing importance, both in private and professional sectors. 7.1 billion mobile-connected devices are estimated to exist by 2015, equalling the world's population. Traffic volume generated by these devices shows exponential growth with an expected 26-fold increase between 2010 and 2015, reaching over 6 Exabyte per month in 2015. Already today, such traffic volumes put heavy load on wireless networks, resulting in high cost, and network unavailability. This trend is expected to continue, especially as the fraction of users accessing Internet resources solely through mobile devices grows steadily, reaching an estimated 788 million by 2015—a 25-fold increase compared to 2010. In strong contrast to ubiquitous Internet access in the developed world, only 21% of the population in developing countries have access to Internet resources Out of those, 48 million mobile phone users—138 million estimated by 2015—have no electricity in their homes; underlining the importance and people's desire for information access. Still, technical availability of Internet infrastructure does not guarantee free access to information: Repressing regimes censor, shut down, and destroy infrastructure-based networks, with countermeasures being taken, e. g., through deployment of infrastructure-less ad hoc networks.

Keywords: *Multicast capacity, delay tradeoffs, Mobile Ad Hoc Networks (MANETs), Mobility models, hybrid random walk mobility models, capacity achieving schemes, Hybrid routing.*

Objective

Objective of this thesis is the integration of infrastructure-based networks, and infrastructure-less delay into hybrid networks. Distributed overlay networks have in the past proven beneficial for developing and deploying novel routing schemes and are to be explored in this thesis for hybrid networks. While development of new routing protocols for MANETs is no objective of this thesis, focus is on generic applicability for integration of existing routing protocols. Two important use cases are focus in this thesis and are to be supported by the developed system: 1) Providing communication if infrastructure access is sparse, and 2) Offloading traffic from infrastructure networks if infrastructure access is widely available.

I. Introduction

Wireless technology has provided an infrastructure-free and fast-deployable method to establish communication, and has inspired many emerging networks including mobile ad hoc networks (MANETs), which has broad potential applications in personal area networks, emergency/rescue operations, and military battlefield applications. For example, the ZebraNet [1] is an MANET used to monitor and study animal migrations and inter-species interactions, where each zebra is equipped with a wireless antenna and pair-wise communication is used to transmit data when two zebras are close to each other. Another example is the mobile-phone mesh network proposed by TerraNet AB (a Swedish company) [2], where the participated mobile phones form a mesh network and can talk to each other without using the cell infrastructure.

II. Existing System

In a mobile ad hoc network where *n* nodes move within a unit square. Among them, *ns* nodes are selected as sources, and each node has *nd* distinct destinations. We group each source and its *nd* destinations as a multicast session. Note that a particular node may serves as both a source and a destination in different multicast sessions.

A. Homogeneous Networks

Mobile ad hoc network model: Consider an ad hoc network where n wireless mobile nodes are randomly distributed in a unit square. The unit square is assumed to be a torus to avoid the border effect. We will study the following mobility models

1) Two-dimensional i.i.d. mobility model:

a) At the beginning of each time slot, nodes will be uniformly and randomly distributed in the unit square.

b) The node positions are independent of each other, and independent from time slot to time slot.

2) Two-dimensional hybrid random walk model:

Consider a unit square which is further divided into 1/B2 squares of equal size. Each of the smaller square is called a RW-cell (random walk cell), and indexed by (Ux, Uy) where Ux, Uy ∈ {1,..., 1/B}. A node which is in one RW-cell at a time slot moves to one of its eight adjacent RW-cells or stays in the same RW-cell in the next time-slot with a same probability. Two RW-cells are said to be adjacent if they share a common point. The node position within the RW-cell is randomly and uniformly selected.

3) One-dimensional i.i.d. mobility model:

a) Reasonably, we assume the number of mobile nodes *n* and source nodes *ns* are both eve numbers. Among the mobile nodes, *n/*2 nodes including *ns/*2 source nodes), named Hnodes, move horizontally; and the other *n/*2 nodes (including the other *ns/*2 source nodes), named V-nodes, move vertically.

b) Let (*xi, yi*) denote the position of node *i*. If node *i* is a H-node, *yi* is fixed and *xi* is randomly and uniformly chosen from [0*,* 1]. We also assume that H-nodes are evenly distributed vertically, so *yi* takes values 2*/n,* 4*/n, . . . ,* 1. V-nodes have similar properties.

c) Assume that source and destinations in the same multicast session are the same type of nodes. Also assume that node *i* is a H-node if *i* is odd, and a V-node if *i* is even.

d) The orbit distance of two H(V)-nodes is de-fined to be the vertical (horizontal) distance of the two nodes.

4) **One-dimensional hybrid random walk model:**

Each orbit is divided into 1*/B* RW-intervals (random walk interval). At each time slot, a node moves into one of two adjacent RW-intervals or stays at the current RW-interval. The node position in the RW-interval is randomly, uniformly selected.

We further assume that at each time slot, at most *W* bits can be transmitted in a successful transmission.

Mobility time scales: Two time scales of mobility are considered in this paper:

Fast mobility: The mobility of nodes is at the same time scale as the transmission of packets, i.e., in each time-slot, only one transmission is allowed.

Slow mobility: The mobility of nodes is much slower than the transmission of packets, i.e., multiple transmissions may happen within one time-slot.

Scheduling Policies: We assume that there exists a scheduler that has all the information about the current and past status of the network, and can schedule any radio transmission in the current and future time slots, similar to [4]. We say a packet *p* is successfully delivered if and only if all destinations within the multicast session have received the packet. In each time slot, for each packet *p* that has not been successfully delivered and each of its unreached destination *k*, the scheduler needs to perform the following two functions:

Capture: The scheduler needs to decide whether to deliver packet *p* to destination *k* in the current time slot. If yes, the scheduler then needs to choose one relay node (possibly the source node itself) that has a copy of the packet *p* at the beginning of the timeslot, and schedules radio transmissions to forward this packet to destination *k* within the same timeslot, using possibly multi-hop transmissions. When this happens successfully, we say that the chosen relay node has successfully *captured* the destination *k* of packet *p*. We call this chosen relay node the *last mobile relay* for packet *p* and destination *k*. And we call the distance between the last mobile relay and the destination as the *capture range*.

Duplication: For a packet *p* that has not been successfully delivered, the scheduler needs to decide whether to *duplicate* packet *p* to other nodes that do not have the packet at the beginning of the time-slot. The scheduler also needs to decide which nodes to relay from and relay to, and how.

B. Heterogeneous Networks

We introduce *m* regularly placed base stations (connected with each other via wires) into the mobile ad-hoc networks and generate a heterogeneous network. All transmissions can be carried out either in *ad hoc mode* or in *infrastructure mode*. We assume that the base stations have a same transmission bandwidth, denoted by *Wi* for each. The bandwidth for each mobile ad hoc node is denoted by *Wa*. Further, we evenly divide the bandwidth *Wi* into two parts, one for uplink transmissions and the other for downlink transmissions, so that these different kinds of transmissions will not interfere with each other.

A transmission in infrastructure mode is carried out in the following steps:

1) *Uplink:* A mobile node holding packet *p* is selected, and transmits this packet to the nearest base station.

2) *Infrastructure relay:* Once a base station receives a packet from a mobile node, all the other $m - 1$ base stations share this packet immediately, (i.e., the delay is considered to be zero) since all base stations are connected by wires.

3) *Downlink:* Each base station searches for all the packets needed in its own sub-region, and transmit all of them to their destined mobile nodes. At this step, every base station will adopt TDMA schemes to deliver different packets for different multicast sessions.

Example

- If node Nsend contains packet P in its relaying pool to be sent to Nreceive, and Nsend is in the same cell as Nreceive, we call Nsend and Nreceive a R-D pair.
- If node Nsend does not contain packet P in its relaying pool to be sent to Nreceive, while node Nreceive does not contain packet P in its relaying pool to be sent to Nsend, and Nsend is in the same cell as Nreceive, we call Nsend and Nreceive a S-R pair.

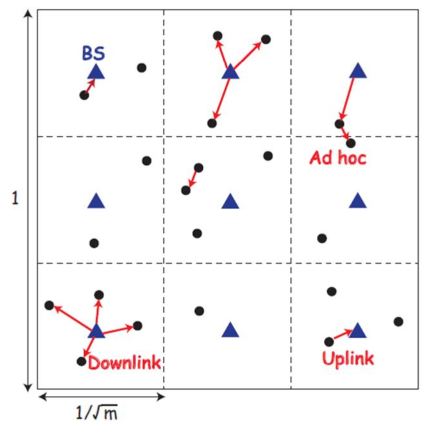

Figure 1

Heterogeneous Network with Infrastructure Support

III. Proposed System

A. Random Walks

In the random mobility model a device selects its next destination uniformly at random over the complete network area, i.e., an (x,y) coordinate that is uniformly at random with x,y € [0km, 2km] each. Based on the selected coordinate, a graph vertex is chosen that is close to the geographic point in euclidean distance. Length-shortest paths are calculated over the graph towards the next destination, and movement speed selected uniformly at random out of the aforementioned 1-3$\frac{m}{s}$. selection of the next destination vertex based on the network area is performed to prevent bias in case a larger number of graph vertices lie spatially close. This is e.g. the case for rounded streets that are modelled through several small edges which are connected by a larger number of vertices.

B. Simulation Setup

Category	Value
Mobile Devices	n = 40
Movement speed	Uniformly in [1,3]$\frac{m}{s}$
Ad hoc comm. range	R = 50m
Network area size	City and grid based graphs A = 2x2km
Seeds per scenario	30

Table 1

From these combinations are simulated each with 30 statically independent seeds using a wireless communication range of 50m and the random mobility model reaches steady state distribution of devices on the graph.

C. Hybrid Routing System

The Hybrid Routing System developed in this thesis provides seamless and transparent routing over infrastructure-based, and infrastructure-less networks. Its design is based on a novel probabilistic extension of distributed overlay networks into Delay Tolerant Networks. Mobile devices act as opportunistic gateways to provide routing towards infrastructure, and register at a distributed announcement system according to their applicability for routing in the Delay Tolerant Network towards other mobile devices. Addressing is based on flat identifiers alone, without requiring knowledge of geographic locations or current network attachment of devices. Using a novel categorization, existing Delay Tolerant Network routing Protocols can be integrated into the Hybrid Routing System. This Categorization is built upon how routing information is structured, and used. The framework for overlay-based services is used as enabling platform for the announcement system that is built up in the infrastructure-based part of the hybrid network. General steps for the integration of existing Delay Tolerant Network routing protocols are explained, and three exemplary protocols integrated. Two use cases are implemented using the Hybrid Routing System: Providing communication in face of few infrastructure-capable devices, and offloading infrastructure-based networks in case of a large number of infrastructure-capable devices. Extensive simulations provide insight into performance and cost metrics. For example, equipping 40% of mobile devices in a Delay Tolerant Network with infrastructure access boosts the message delivery probability compared to a pure Delay Tolerant Network, even when only routing a single copy of a message and resigning from replication. For infrastructure offloading, over 30% of traffic can be relieved from infrastructure by accepting a maximal delay of 5 h, and over 50% by accepting maximal delay of 10 h. Compared to the state of the art, the Hybrid Routing Systems does not require dedicated systems, does not require information about geographic location or current network access of devices, and can integrate existing Delay Tolerant Network routing protocols.

1) Categorization of Hybrid Routing

The categorization presented in our work for hybrid routing is based on two main ideas: first, the structure of routing information that the protocol maintains, how this routing information is employed in this protocol categorized as:

- Destination-aware
- Self-aware
- Unaware

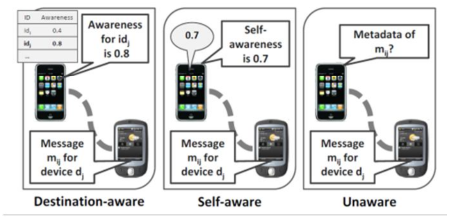

Figure 2

2) Illustration

Destination-aware: Every device $d_i \in D$ manages a table

$T_i = \{(id_j, p_i(d_j)), (id_k, p_i(d_k)). (id_l, p_i(d_l)),....\}$

for devices d_j, d_k,d_l,.... it has come into direct or transitive contact. The *destination-awareness* $p_i(d_j) \in [0,1]$ reflects the applicability if d_i for forwarding a message to d_j, with $d_i \neq d_j$. For $d_i = d_j$ the destination awareness for a device itself is complete and therewith 1.

Self-aware: Each device $d_i \in D$ locally manages the *self-awareness* p_i that reflects the general applicability of d_i for forwarding messages, irrespective of the message's destination.

Unaware: Each message m_{ij} with sender d_i and destination d_j stores a counter c that reflects the number of replicas allowed for m. Forwarding is based on metadata in m, e.g. replication counter c or TTL counter, irrespective of any awareness.

IV. Conclusion

The strong growing number of mobile devices results in exponential growth of traffic volumes in infrastructure-based mobile networks. On the other hand this large number of mobile devices is an enabled for infrastructure-less opportunistic networks made up solely by mobile devices and exploit opportunistic device contacts for store-carry-forward routing. While MANETs on their own have limited applicability due to probabilistic message delivery and long delay, their integration with infrastructure-based networks is promising. In this paper we propose flawless hybrid-routing system that can provide end-to-end communication.

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