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MORA routing and capacity building in disruption-tolerant networks

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Abstract

Disruption-tolerant networks (DTNs) differ from other types of networks in that capacity is created by the movements of network participants. This implies that understanding and influencing the participants' motions can have a significant impact on network performance. In this paper, we introduce the routing protocol MORA, which learns structure in the movement patterns of network participants and uses it to enable informed message passing. We also propose the introduction of autonomous agents as additional participants in DTNs. These agents adapt their movements in response to variations in network capacity and demand. We use multi-objective control methods from robotics to generate motions capable of optimizing multiple network performance metrics simultaneously. We present experimental evidence that these strategies, individually and in conjunction, result in significant performance improvements in DTNs.

Keywords: Autonomous agents; Disruption-tolerant networks; Multi-objective control; Routing

1. Introduction

Many routing protocols exist to support end-to-end messaging in mobile ad hoc wireless networks. Such protocols assume an end-to-end connection through a contemporaneous set of links through intermediary peers [19,27]. As a result, if a path between two peers in a network does not exist, communication is not possible, and the route creation process fails.

A growing body of work is exploring techniques for routing network traffic over asynchronous paths to adapt to situations where routes cannot be created from contemporaneous links. Such networks have varied names: highly partitioned networks [10,17], message ferrying [41,42], delay-tolerant networks [12], and disruption-tolerant networks (DTNs) [11]. To enable end-to-end routing in a DTN (the term we choose for this paper), network participants are relied upon to carry and deliver messages of others. Whenever two participants pass, they negotiate the exchange of messages. A message may be passed between a number of network participants before reaching its destination.

There are many scenarios in which DTNs are the most viable routing solution for several reasons. First, it is challenging to deploy an unpartitioned network using mobile nodes that roam a large

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geographic area. This can be the result of relatively short radio ranges; obstructions can also curtail the reach of devices, including buildings, trees, mountains, or water for amphibious devices (as can happen in wildlife monitoring [32]). Our own DTN, DieselNet [4] which is deployed using 802.11 on 30 buses, spans an area of 150 sq. miles, beyond the range of WiMax and our area's cellular phone coverage. In underwater acoustic networks [1,26], DTNs are more critical as no fixed infrastructure exists and less than ten expensive autonomous underwater vehicles may roam an area hundreds of km in diameter carrying acoustics transducers that reach only 2–5 km. Second, battery-powered devices may adhere to energy management schemes that power down radios [31,2], effectively decreasing the population of the network. Finally, DTNs can arise naturally from dense, infrastructure-based deployments. For example, a municipal mesh that is deployed to support radios on vehicles can provide robust, unpartitioned coverage. However, vehicles may leave the geographic coverage of the mesh; a DTN can extend networking to an area beyond the municipality's mesh by taking advantage of opportunities for transfer between vehicular nodes that arise intermittently.

The performance of disruption-tolerant networks depends on many factors, including the number of network participants, their storage capacity, communication capabilities, and movement patterns. In this paper, we focus on a performance factor unique to DTNs, namely the movement patterns of participants. We examine how movements can be exploited or controlled to improve performance in DTNs. We classify movements of network participants according to two independent properties: their inherent structure and their adaptiveness to the demand in the network (see Fig. 1). In this context, structure refers to periodic patterns in peers' movements that can be exploited to estimate the probability of delivery for a specific message and peer.

For purposes of illustration, we relate this classification of participant's motion and associated routing protocols to everyday experience. The lower-left of the classification shown in Fig. 1 corresponds to hitchhikers being picked up by randomly moving cars. In this scenario, cars move without periodicity and do not adapt to the route of the hitchhiker. The lower-right of the figure corresponds to public transport with fixed schedules. Independently operating taxicabs that pick up passengers in the street are represented in the top-left of the diagram.

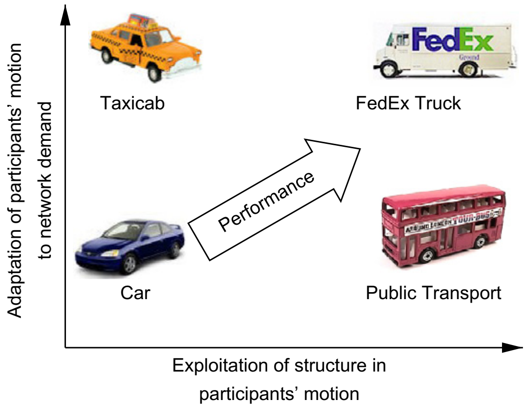

Fig. 1. Classification of routing methods for DTNs based on characteristics of participants' movement patterns.

Finally, FedEx trucks are situated in the top-right corner. (Here, packages are transported, rather than people but the analogy holds.) FedEx trucks travel on structured daily routes, but only stop for scheduled pickups and deliveries, i.e., their coordinated routes are adjusted in response to demand.

From this description, it is clear that performance metrics, such as bandwidth and latency, can be expected to improve for scenarios that can be classified towards the top-right of the diagram. To achieve these performance improvements, an increased amount of coordination among the network participants is required. Such coordination can exploit structure present in participant's motion patters to improve the efficiency of routing. A coordination of network participants that adapts the motion to the network's demands enables a better usage of the participants' capacity and thus can lead to increased bandwidth and reduced latency. The contribution of this paper lies in algorithms that take advantage of these insights to improve the performance of disruption-tolerant networks.

1.1. Contributions

To address the incongruence between the movement of network participants and traffic flow that may arise when movement pattern of participants do not match bandwidth requirements, we propose the introduction of autonomous agents as participants into the network. These agents can be ground-based [36] (see Fig. 2), airborne [8], or underwater mobile robots [13,14,38,34].

We propose methods for adapting the motion of such agents to bandwidth and latency requirements