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The challenges of disconnected delay-tolerant MANETs

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ABSTRACT

This article is concerned with the challenges associated with supporting communication in disconnected MANETs with such a sparse population of nodes and so little (or no) fixed infrastructure that the network graph is rarely, if ever, connected. The networks considered are autonomous and do not depend on established infrastructure. The disconnected nature and the lack of end-to-end connectivity between nodes mean that the communication must be delay-tolerant. We refer to such a networks as Disconnected Delay-Tolerant MANETs (DDTMs). In general the challenges associated with mobile computing are not new. However, issues in wireless communication such as low bandwidth, disconnections and high bandwidth variability are problematic and further exacerbated in DDTMs by little or no infrastructure, variable node population and lossy links. DDTMs additionally face challenges of mobility which is frequent and uncontrolled resulting in a highly dynamic topology and disconnected network graph. In addition, portability remains a challenge, where battery power, memory and processing power are limited. The challenges are presented using a two-tier classification scheme that allows their causes and inter-dependencies to be mapped.

1. Introduction

The increased popularity of mobile computing and communication devices, such as cell phones, laptops and handheld digital devices such as Personal Digital Assistants (PDAs), means that wireless networks are increasingly the most convenient solution for interconnection in many usage scenarios. Since the early 2000s mobile devices have been getting smaller, cheaper and more convenient to carry, with the ability to run applications and connect to network services [20]. Currently, most of the connections among wireless devices are achieved through fixed infrastructure service providers or private networks. For example, since the 1980s mobile phones have been connected by cellular networks, and the connection of laptops to the Internet via wireless access points has grown rapidly in popularity in the early 2000s [20]. Current developments, such as 3G and 4G phones, show little signs of change in this trend. While infrastructure-based networks provide an effective mechanism for mobile devices to get network connectivity, setting up the necessary infrastructure can be time consuming and incurs potentially high costs. There are situations where networking connections are not available in a given geographic area, and providing connectivity and network services in these situations becomes a real challenge. Examples range from wildlife tracking and habitat monitoring sensor networks, military networks, inter-vehicle communication, disaster response networks, inter-planetary networks to nomadic community networks. For this reason, alternative ways to deliver services in disconnected environments have been emerging. Two such areas include MANETs which arose in the 1990s, and more recently Delay-Tolerant Networks (DTNs) which were first introduced in 2001.

2. Background

2.1. MANETs

MANETs were traditionally developed for tactical networks related to improving battlefield communication where the network cannot rely on access to a fixed

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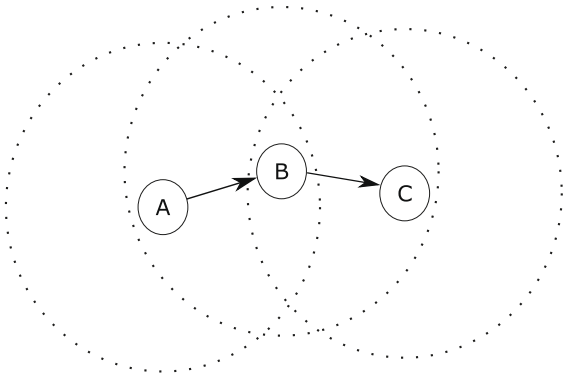

Fig. 1. Multi-hop routing in MANETs.

communication infrastructure. A MANET is a dynamic wireless network with or without fixed infrastructure. Nodes may move freely and organise themselves arbitrarily; thus the network's wireless topology may change rapidly and unpredictably [9]. Each node may communicate directly with any node within transmission range. Communication beyond that range is achieved by using intermediate nodes to relay messages hop by hop. Such a route may include multiple hops, and therefore, the resulting network may or may not be a multi-hop network. MANETs do not depend on centralised administration, rather each node acts as an independent router and typically also as an application node, generating and receiving application data. As such, network management is distributed across the nodes. Fig. 1 on page 3 shows an example of multi-hop routing. In the scenario, node A is out of direct communication range with node C, but can communicate with node C by using node B as an intermediary.

MANET routing protocols can be classified into two main categories: *proactive* routing protocols and *reactive* routing protocols. Proactive routing protocols attempt to maintain routing information for every pair of network nodes by actively propagating route updates. Reactive protocols establish a route to a destination only when needed. The source node initiates a route discovery process when the route is required, and once a route has been established it is maintained until either the destination becomes inaccessible or until the route is no longer used. Both categories of MANET routing protocols assume the existence of a full (possibly, multi-hop) route from source to destination at the time of sending, and if one is not available routing fails. This assumption makes MANET routing protocols unsuitable for environments where disconnections are frequent and potentially long-term.

2.2. Delay-Tolerant Networks (DTN)

A Delay-Tolerant Network (DTN) provides 'interoperable communications with and among challenged environments' [10]. A challenged network is defined as a network that has one or more of the following characteristics: high end-to-end path latency; end-to-end disconnection meaning a path between a node pair my never exist; limited resources or limited life expectancy either due to lack of battery power, such as in sensor networks, or node damage as may occur in battlefield deployments. Such networks may never have an end-to-end path from source to destination at a given time. The routing problem in DTNs can be described as 'where messages are to be moved end-to-end across a connectivity graph that is time-varying but whose dynamics may be known in advance' [16].

DTNs stemmed from research to develop an Inter-Planetary Internet (IPN). The Delay-Tolerant Network Research Group (DTNRG) have proposed an architecture to support messaging in delay-tolerant applications. The architecture presented by Fall [10] consists of an overlay, called the bundle layer. A bundle is defined as a number of messages to be delivered together. DTN nodes implement the bundle layer which forms an overlay that employs persistent storage to overcome network interruptions. The bundle layer stores and forwards bundles between DTN nodes. The bundle layer is situated below the application layer and above the transport layer, thus allowing environment-specific underlying protocols.

Fig. 2 on page 4 shows an example of a DTN configuration consisting of three regions. Region A is an intranet which is running TCP/IP and region B consists of a bus carrying a DTN Gateway node (DTN GW). Region C is running a non-TCP/IP environment-specific transport protocol. In order for the DTN Gateway to carry bundles between region A and region C, the DTN GW of region B must run multiple lower-layer protocols to allow the gateway to span two regions using different lower-layer protocols.

The key contribution of the architecture is the bundle layer, which facilitates hop-by-hop reliability and retransmission. It also implements a naming scheme that uses late binding, which means that the name is not mapped to an address until topologically near the target of communication. Each DTN node has a two-part name, consisting of a region ID which is known among all regions of the DTN and an entity ID which has a regional scope. Routing between regions is based only on region IDs, which are bound to their corresponding addresses throughout the DTN. Routing within regions is based only on entity IDs, which are bound to their corresponding address only within that region.

The bundle layer provides an overlay to hide disconnections and delays from the application layer and also provides transparent communication between different regions. However, the problem of how to route within, and among the regions is still an open issue.

2.3. Disconnected Delay-Tolerant MANETs (DDTM)

This article is concerned with disconnected MANETs with such a sparse population of nodes and so little (or no) fixed infrastructure that the network graph is rarely, if ever, connected. The networks considered are autonomous and do not depend on established infrastructure. Each node acts a router, forwarding messages to other nodes. Due to the disconnected network graph, a full end-to-end path to nodes may not exist at any given point in time. However, an end-to-end connectivity graph that is time-varying may exist to forward messages. The challenge for routing protocols in this type of environment is