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All-to-all data dissemination with network coding in dynamic MANETs

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ABSTRACT

This paper investigates the problem of efficient data dissemination in Mobile Ad hoc NETwork (MANETs). A testbed is presented; which provides a realistic degree of mobility in experiments. The testbed consists of ten autonomous robots with mobile phones mounted on them. The mobile phones form an IEEE 802.11g ad hoc network to communicate with each other. A dynamic network topology is assumed, where the mobile devices form a cooperative cluster in order to communicate directly with each other. In the investigated scenario, the initial state is that each device carries a unique fragment of the full data set, and the goal is to exchange this data set among all devices. Several alternative strategies are presented that use UDP broadcast transmissions and Random Linear Network Coding (RLNC) to facilitate the efficient exchange of information in the wireless network. An application is introduced; which implements these strategies on Nokia phones. Results collected during an extensive measurement campaign are presented, and the performance of several strategies is compared using numerous metrics. We observe that network coding can substantially reduce the completion time in our scenario, which also leads to significant energy savings.

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1. Introduction

The recent proliferation of mobile phones portends that Mobile Ad hoc NETwork (MANETs) are going to be ubiquitous in the near future. There were around 6 billion mobile phone subscribers [1] in the world at the end of 2011. These mobile devices are rapidly evolving, and they have become a convergent programmable platform with sensing, computing and communication capabilities.

First of all, these devices are equipped with a myriad of sensors (i.e., cameras, microphones, GPS receivers, accelerometers, compasses, and many others under industrial development), therefore they can be used to capture information and produce content that may be of interest to others. Additionally, mobile phones have multiple communication air-interfaces, such as 3G or WiMAX accessing wide-area networks, 802.11b/g/n-based WiFi for local-area networks and Bluetooth for personal-area networks. Furthermore, mobile phones have powerful computing capabilities that are comparable to those of desktop and laptop computers. It is reasonable to anticipate that mobile phones will serve as a primary local computing device for millions of users.

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Even though the client–server paradigm is still prevalent on the Internet, and users are mostly consuming content generated by a relatively small number of central entities known as content providers, there is a clear new trend that more and more users contribute content to the cloud. For example, users upload images, audio and video content to sites like YouTube or Facebook. Mobile phones can upload various sensor data to the cloud in various participatory sensing applications. Thereby information flows from multiple individuals to the central cloud through the existing wireless communication infrastructure.

The advanced sensing, communication and computing capabilities of mobile phones bring about a paradigm shift to omni-directional information flow. There are a variety of potential applications such as local content sharing, Internet connection sharing, social media, augmented reality, sensor data aggregation, group-oriented military networks and many others that can benefit from local data dissemination via short-range communication. This technology can also be used for opportunistic networking to disseminate applications, which has a huge potential in mobile data off-loading [2]. Another good example is a collaborative sensing and video recording system, VUPoints, developed at Duke University [3]. The basic idea of this system is that when multiple phones at a social gathering use VUPoint, short video-highlights of the event can be created without human intervention. According to the current design, each mobile phone has to upload the recorded audio or video content to a central server. But with a smart data dissemination method, the content can be shared among individual mobile phones without any pre-existing infrastructure. The motivation of this work is to enable mobile phones to efficiently exchange information with each other within a local cooperative cluster.

The focus of this paper is the evaluation of different coding schemes and strategies for all-to-all data dissemination in MANETs. The main objective is to minimize the completion time and the overall energy consumption. Network coding is applied in several configurations within the framework of the same cooperative protocol.

This paper is organized as follows. Related work is discussed in Section 2. The investigated scenario is presented in Section 3. Our testbed is introduced in Section 4. The features of the proposed protocol are discussed in Section 5. The scenario is analyzed from a theoretical perspective in Section 6. Section 7 presents measurement results collected from our testbed, and the final conclusions are drawn in Section 9.

2. Related work

The problem of data dissemination in MANETs is a particularly interesting research topic. Typically we intend to share multimedia content or mobile applications with other users in the vicinity. This content may originate from a single source or from multiple devices in the network. The content is always divided into numerous packets due to the limitations of the underlying communication systems. The goal is to ensure reliable delivery for the content as a whole, and not only for the individual packets.

Supporting reliability in MANETs is very challenging due to node mobility and the unstable nature of the wireless channel: a significant number of packets can be lost during transmission. To improve reliability in packet erasure networks, Automatic Repeat-reQuest (ARQ) has been employed in unicast communications. On the other hand, ARQ is not always useful in multicast due to the feedback implosion problem [4] (too many network nodes sending feedback at the same time).

Since the same data set should be delivered to all receivers, the broadcast nature of the wireless channel allows for an efficient delivery of innovative information. The existing reliable broadcasting protocols for mobile ad hoc networks [5–7] generally focus on the delivery of individual packets, which is an inherent limitation of these protocols that results in significant control overhead. It is more efficient to consider the entire data set as a unit, and apply some coding scheme on top of it. With a rateless erasure code, a single coded packet can convey useful information about the whole data set. Thus it suffices for a receiver to retrieve any subset of coded packets of size slightly larger than the set of source packets.

Network Coding (NC) [8,9] is well-suited for this task because of its clear advantages for mobile multi-hop communication systems [10–12]. From the theoretical aspect, Lun et al. [13] proved that Random Linear Network Coding (RLNC) is able to approach the multicast and broadcast capacity in lossy multi-hop wireless networks.

Fujimura et al. [14] compared NC and Erasure Coding (EC) in wireless multicast scenarios over mobile ad hoc networks. The simulation results and the theoretical analysis demonstrated that NC can significantly save network resources whilst achieving the same reliability as EC. Dynamic random topologies with 50 nodes were also simulated with different settings for node density and node mobility, and it was shown that NC always reaches the achievable delivery ratio earlier than EC.

In [15], the authors investigated a few simple network coding techniques to increase the bandwidth efficiency of reliable broadcast in wireless networks. The advantages of the proposed schemes over the traditional wireless broadcast were shown through simulations and theoretical analysis.

Several researchers [16–18] applied network coding in peer-to-peer (P2P) systems where the data distribution (or streaming) occurs over the Internet. It was demonstrated that RLNC makes it possible for multiple seeds to collaboratively serve a peer, which is a great advantage in streaming applications. The possibility for local cooperation is limited in P2P systems where the spatial properties of the network can be ignored and any peer can connect to any other peer. Moreover, the protocols designed for P2P systems cannot exploit broadcast or multicast, since this type of communication is not available over the Internet.

The authors in [12] introduced R-Code, a network coding-based reliable broadcast protocol for Wireless Mesh Network (WMNs) that achieves 100% packet delivery ratio with low transmission overhead and relatively short broadcast latency. R-Code relies on a link quality-based minimum spanning tree, therefore it is not suitable in networks with high mobility.

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