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Exploiting content centric networking to develop topic-based, publish–subscribe MANET systems

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ABSTRACT

Mobile Ad-hoc NETworks (MANETs) connect mobile wireless devices without an underlying communication infrastructure. Communications occur in a multi-hop fashion, using mobile devices as routers. Several MANET distributed applications require to exchange data (GPS position, messages, pictures, etc.) by using a topic-based publish–subscribe interaction. Participants of these applications can publish information items on a given topic (identified by a name) and can subscribe to a topic to receive the related published information. An efficient dissemination of publish–subscribe data in MANET environments demands for robust systems, able to face radio resource scarcity, network partitioning, frequent topology changes. Many MANET publish–subscribe systems have been proposed so far in the literature assuming an underlying TCP/IP network.

In this paper, we discuss the benefits of building a MANET publish–subscribe system exploiting Content Centric Networking (CCN) technology, rather than TCP/IP. We show how CCN functionality, such as in-network caching and multicasting can be used to achieve an efficient and reliable data dissemination in MANET environments, including the support of delay tolerant delivery. We present different design approaches, describe our topic-based publish–subscribe CCN system, and report the results of a performance evaluation study carried out with real software in an emulated environment. The emulation environment is based on Linux virtual machines. The performance evaluation required also a CCN MANET routing engine, which we developed as a plug-in of the OLSR Linux daemon.

1. Introduction

The TCP/IP protocol suite is designed to *push* data to a remote host identified by an *address*. This host-centric service is not perfectly tailored for information-centric applications (e.g. web browsing) that require to *pull* information identified by *names*, regardless of the source of information. Users are interested in receiving "what" they requested, and do not care "who" provides it.

Nowadays, information-centric applications are the most used in the Internet, as well as in sensor and ad-hoc networks. The need of efficiently support them on top of a host-centric TCP/IP network has given rise to the introduction of many incompatible proprietary content-oriented services (name-based routing, caching, multicasting, data replication, and so on) offered, e.g., by Content Delivery Networks [1].

Information Centric Network (ICN) is an emerging paradigm aimed at supporting content-oriented services in any kind of network: wide and local area networks [5],

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mobile ad-hoc or mesh networks [15], delay tolerant networks, sensor networks [35], etc. ICN rethinks network services by putting information dissemination at the center of the network-layer design. Rather than creating network pipes between hosts identified by addresses, ICN delivers information (or contents) identified by names. A user expresses an interest for a content to the ICN Application Programming Interface (API) and the underlying ICN functionality takes care of routing-by-name the content request towards the best source (be it the original one, a replica server, or an in-network cache) and of sending back the related data.

The ICN concept dates back to 1999, when the TRIAD architecture was proposed [3]. However, the interest in ICN has been rather limited until 2009, with few contributions from the research community. In 2009, Jacobson et al. presented an ICN architecture named Content-Centric Network (CCN) [4], aka Named Data Network (NDN), supported by an open-source implementation, named CCNx [7]. This work quickly renewed the interest in ICN research and most of current ICN work uses or is related to the CCN architecture.

CCN research mostly applies to wide area static network scenarios. However, CCN functionalities are deemed to be effective also in Mobile Ad-hoc NETworks (MANETs). In fact, many MANET applications require to exchange data (GPS position, messages, pictures, etc.) by using a publish–subscribe interaction scheme [9], which is information-centric in nature. Publishers characterize their information items with a set of attributes, and subscribers register their interests in receiving only those information items whose attribute match a given criterion, regardless of who is the publisher. Publishers and subscribers are decoupled in space (they do not need to know of each other), and in time (they do not need to be active at the same time). Such decoupling simplifies mobility and disconnected operations, which are typical of MANETs. Moreover, one-to-many delivery can exploit intrinsic broadcast properties of the wireless channel.

The simplest publish–subscribe scheme is the so called "topic-based" one, in which the only attribute of an information item is its being part of a given topic. Participants of a topic-based publish–subscribe system can publish information items on a topic and can subscribe to a topic to receive the related published information items. Topics are identified by a name (e.g. "foo.news"), and publishing an information on a topic T implies its distribution to the users subscribed to T.

A more complex publish–subscribe scheme is the "content-based" one, in which publishers can characterize the information items with many attributes and subscribers can express complex conditions of interest. For instance a subscriber could be interested in information items regarding all cars with price less than 20 k€. Content-based publish–subscribe systems are more complex than topic-based ones and their design is rather different.

The main contribution of this paper is to show how CCN functionality can be exploited to easily setup an efficient and resilient topic-based publish–subscribe system for MANETs. As shown in Fig. 1, we propose a topic-based publish–subscribe system that uses the service of a CCN. We

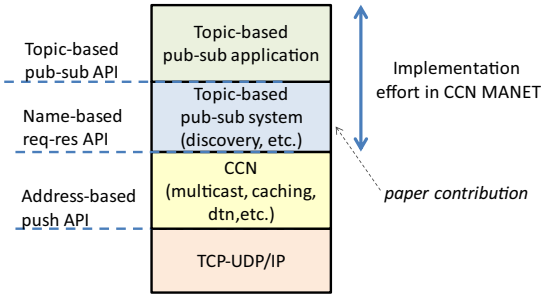

Fig. 1. Functional architecture of a topic-based publish–subscribe system over CCN.

use hierarchical names to address topic information items and this makes it possible to exploit the in-network caching and multicast functionality offered by CCN to achieve low delay and delivery efficiency. Moreover, through a dynamic configuration of CCN forwarding tables, we carry out a data muling functionality. Moving devices can use this functionality to transport information items among disconnected part of the networks, thus realizing the delay tolerant delivery [26] typical of Delay Tolerant Networks (DTNs).

Our findings are based on the practical development experience that we gained by using CCN as the underlying layer of the BEE DDS middleware [13], which is a specific implementation of the Object Management Group (OMG) specification of the Data Distribution Service for Real Time System [8]. We discuss design approaches, present some details of our pull-based system and report the results of a performance evaluation study carried out in an emulated environment, based on Linux virtual machines.

To evaluate the system performance, we had to develop our own CCN routing engine for MANET, since available CCN routing software tools, e.g. [6,34], are designed for fixed networks. The routing engine is developed as an open-source OLSR plug-in [23], which configures CCN routing tables according to a shortest path strategy. The plug-in may be of interest to other researchers, independently from the specific results presented in this paper.

As for the organization of the paper, in Section 2 we describe the CCN architecture and briefly revise some publish–subscribe literature works. In Section 3 we motivate the use of CCN to realize publish–subscribe systems over MANETs and discuss the related research challenges. In Section 4 we discuss several approaches to build a publish–subscribe system over CCN. In Section 5 and 6 we describe our publish–subscribe system and routing engine, respectively. In Section 7 we report a performance evaluation study and in Section 8 we draw our conclusions. Finally we present some additional performance results in an Appendix A.

2. Related work

2.1. Information Centric Networking

Information Centric Networking (ICN) is a networking approach that addresses content by names, instead of locations, at the network layer, and combines in-network