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Virtualizing vehicular node resources: Feasibility study of virtual machine migration

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ABSTRACT

With emerging geo-distributed services, there is a need to coordinate the use of resources offered by field-area networks. In the case of vehicular networks, such resources include the processing, sensing, and storage capabilities offered to service providers for urban sensing or intelligent transportation. In this paper, we propose to virtualize the resources embedded on the vehicular nodes to allow multiple tenants to coexist and deploy their services on the same underlying mobile substrate. Virtualization is the task of an infrastructure provider that controls the mobile substrate and allocates sliced resources to the tenants. A service results from a collection of virtual machines hosted on the mobile nodes allocated by the infrastructure provider. Efficient utilization of the node resources may trigger virtual machine migrations. We study the problem of virtual machine migrations through V2V communications between mobile nodes. To evaluate the impact of such migrations on the resource allocation process, we use the real traces of a bus transit system to simulate a vehicular network where virtual machines migrate via V2V communications. Our results show that virtual machines of several hundreds of Megabytes can migrate between moving buses. We then discuss design principles and research issues toward the full virtualization of opportunistic networks.

1. Introduction

New services and network usages have emerged with the recent networking paradigm of the Internet of Things, like context-based sensing or crowdsensing [1]. The applications and services require very low and predictable bandwidth and target geo-distributed (*e.g.*, sensor-based monitoring), fast mobile (*e.g.*, connected vehicles and rail), and large-scale platforms (*e.g.*, Smart Grid and Smart City). These services rely on field-area networks with greater capacities in terms of processing, storage, and bandwidth. Thus, associated services depend on a large collection of distributed mobile nodes to collect, process, and aggregate data to perform real-time analytics and make fast operational decisions [2]. Vehicles will definitely play a major role in such a scenario. Enabling virtualization on top of these mobile nodes, and in particular on top of vehicles, would offer service providers immediate access to these new emerging paradigms; in return, they bill their services to their end users, leaving the maintenance of such highly mobile and intermittently-connected networks to infrastructure providers.

Most of the existing work on network virtualization focuses on fixed network infrastructures [3]. In the literature, the traditional Internet Service Provider (ISP) is divided into two independent entities with distinct roles: (i) Infrastructure Providers, which manage the fixed infrastructure, and (ii) Service Providers, which form virtual networks from the resources allocated by possibly multiple Infrastructure Providers to offer end-to-end services to their customers. Recently, SDN (Software-Defined Networking) has facilitated the virtualization of wired networks with network hypervisors such as FlowVisor [4] or OpenVirteX [5]. Conversely, the existing work on mobile network virtualization focuses on the virtualization of mobile infrastructure networks, such as cellular or local wireless networks [6,7]. To our knowledge, our work is the first one that proposes to virtualize the resources hosted on mobile nodes.

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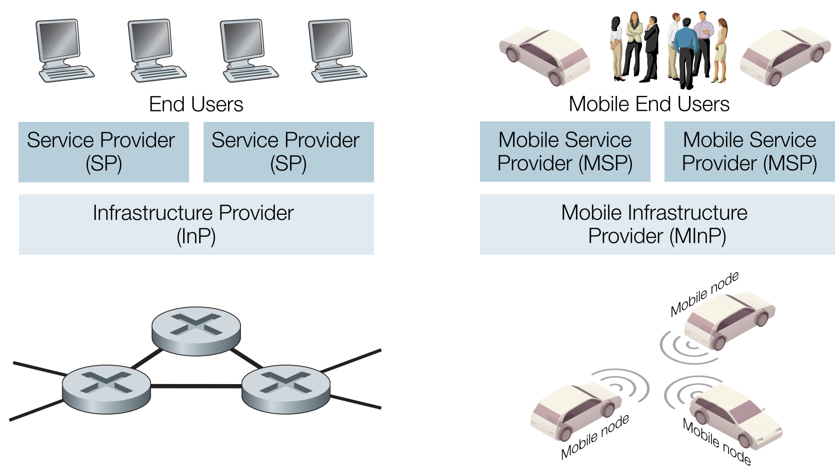

(a) Fixed infrastructure network model. (b) Mobile network model.

Fig. 1. In the fixed-infrastructure network model, the InP manages a network of fixed nodes and virtualizes their resources to SPs, which in turn offer services to end users. In the mobile network model, the MInP must manage the mobility nodes to virtualize the resources they embed and provide guarantees to the MSPs.

In this paper, we address the problem of virtualizing the resources hosted on the mobile nodes. In our solution, we propose a centralized architecture where a Mobile Infrastructure Provider (MInP) manages the physical substrate mobile network and virtualizes the resources of the mobile nodes. We consider the case of a large-scale mobile network such as a vehicular network (VANET) or a vehicular delay-tolerant network (V-DTN). As depicted in Fig. 1, virtualizing vehicles allows multiple tenants, here denoted as Mobile Service Providers (MSP), to coexist and deploy their services on the same underlying physical substrate. The MInP slices resources of the vehicles (CPU, memory, storage, forwarding, onboard sensors) into virtual machines and allocates the virtual machines to the MSP so as to match their demands.

More specifically, the MInP leverages a centralized architecture with a controller that runs the allocation procedure with the MSPs' requirements as input. The allocation procedure allocates a set of virtual machines hosted on different mobile nodes so as to accommodate the MSPs' requirements. We consider that the central controller is always on-line (*e.g.*, connected via a cellular network); thus, re-allocations of the MSPs' demands result in *virtual machine migrations* from one vehicle to another. In this paper, we focus specifically on this problem as it is central to the feasibility study we conduct. Virtual machine migrations also happen when the current set of allocated virtual machines does not satisfy the requirements of the MSPs' demands (*e.g.*, the mobile node hosting the virtual machine leaves an area to be sensed and needs to be moved to the original area), or just before the node hosting the virtual machine becomes inactive.

Our main contributions are in the following three areas:

Mobile node resource virtualization. We propose a novel architecture to virtualize the resources embedded in mobile nodes. The MInP slices and allocates the resources to tenants, or MSPs, that will in turn aggregate the virtual resources to form virtual networks.

V2V Virtual machine migration. Changes in the physical topology trigger reallocations of the virtual resources and virtual machine migrations. Instead of using cellular connectivity to migrate the virtual machines, we leverage the V2V communications between vehicles.

System capacity. We evaluate the feasibility of V2V virtual machine migrations using real traces of a bus transit system. The results show that it is feasible to trigger virtual machine migrations at specific locations where the mobile nodes are most likely to encounter each other.

This paper is organized as follows. In Section 2, we overview the existing work on fixed and mobile network virtualization. In Section 3, we discuss the business model and design requirements involved with the virtualization of mobile node resources. In Section 4, we evaluate our proposal with real traces of a bus transit system under different scenarios and show that a vehicular network can serve as a communication substrate to be shared among multiple tenants. Finally, in Section 5, we overview some of the challenges and open issues involved with virtualizing mobile opportunistic networks as a perspective to our work.

2. Virtualization platforms

Let us first recall design principles of virtualization and review related work.

Wired network virtualization. Network virtualization refers to the decoupling of the physical routers (line card and CPU) from the forwarding functions. Multiple virtual router instances are then created on top of a single physical router. The collection of virtual nodes connected together by a set of virtual links forms a virtual network, whose topology is a subset of the underlying physical topology [3,8]. Each virtual node is hosted on a physical node, although a virtual link spans over a physical path in the underlying network topology. The dynamics of virtual networks are different from those of the underlying physical networks on which they rely, as it is possible to turn the virtual routers on and off, and to migrate them. Virtual router migration consists in moving both the control and data plane states and processes from the hosting physical router to a target physical router [9].

Works on software-defined networking facilitate the deployment of network virtualization by capitalizing on the decoupling of the control plane from the data plane [10]. A central controller manages the control plane of software-defined networks and modifies the forwarding states of the networking devices. FlowVisor [4] and more recently OpenVirteX [5] define network hypervisors capable of mapping the forwarding states corresponding to the control logic of the virtual networks belonging to the tenants onto the physical networking equipment. In an SDN network, migration then consists in copying the flow tables from the host router to the target router, as SDN provides packet-forwarding abstraction [11]. Keller et al. propose LIME to migrate an entire network composed of virtual machines to a different collection of physical