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Deadline-constrained content upload from multihomed devices: Formulations and algorithms

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ABSTRACT

This work originates from the practical requirements of video surveillance in public transport systems, where security cameras store video onboard, and a central operator occasionally needs to access portions of the recordings. When this happens, the selected video portions must be uploaded within a given deadline, using (multiple) wireless interfaces, with different costs (which correspond to, e.g., tariffs). We study this video upload problem as a scheduling problem with deadline, where our goal is to choose which interfaces to use and when, so as to minimize the cost of the upload while meeting the given deadline. Our study gives rise to adaptive schedulers that require only a very coarse knowledge of the wireless interfaces bandwidth.

In this paper, we first assume an oracle has the perfect knowledge about the available bandwidth of wireless interfaces at each time, and we formulate an optimization problem to minimize the upload cost within the given deadline. Second, we propose greedy oracle-based heuristics that perform very close to optimal, and that can provide a simple baseline for performance. Third, we formulate a stochastic optimization problem, assuming only the knowledge of the distribution of available bandwidth, and, fourth, we propose adaptive schedulers, that we simulate and also implement and test in a real testbed.

Simulation results demonstrate that the proposed adaptive solutions can effectively leverage the fundamental trade-off between upload cost and completion time, despite unpredictable variations in the available bandwidth of wireless interfaces. Experiments with real mobile nodes provided by the MONROE platform confirm the findings.

1. Introduction

Wireless technologies such as WiFi, 3G, 4G, and soon-to-come 5G, provide access capacities up to hundreds of Mb/s. Multihomed devices are commonly available, offering the chance to transmit over different technologies and networks at the same time. Yet, there are scenarios in which the amount of data being produced and consumed challenges the bandwidth offered by wireless networks.

In this paper, we look at one of those scenarios. Our interest is motivated and inspired by the real needs of public transport operators. Public transport vehicles (like buses or trains) are equipped with multiple Mobile BroadBand (MBB) [1] interfaces, and several onboard security cameras that record videos. Those must be uploaded to a security center where an operator occasionally requests to watch selected portions of the videos. In this scenario, continuous real-time video uploading is too expensive. Even if current MBB networks can offer capacities up to 100 Mb/s, the number of vehicles and videos, the limited data quota, the performance variability along the route, and the need to check only parts of the videos, call for ingenious upload strategies. Hence, videos are stored onboard, and, only when an alarm is triggered, the security operator on duty requests the specific portion of the video that must be uploaded before a specified short deadline. The deadline normally is of the order of a few minutes, depending on the urgency of the incident. For instance, pickpocketing events can wait till the vehicle returns to deposit. Instead, in case of health problems of passengers, the security officer needs to access the video within a short time, after obtaining all the required authorizations.

We model this problem as the scheduling of content upload from multihomed mobile devices, where the content must be delivered within a given deadline, while the total cost must be min-

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imized. The cost associated with each interface is defined according to the nature of the problem. For example cost can correspond to tariffs, energy consumption, data quota, or system load. In our problem definition, cost is related to the monetary cost of the data transmission on each technology.

Our problem differs from the classic problem of content upload using multihomed devices [2,3], where upload delay has typically to be minimized, i.e., throughput maximized. Also, no real time constraint exists in our case, thus making our problem different from video streaming, and somehow similar to a delay tolerant scenario, albeit the hard deadline for delivery of the entire content (rather than individual packets) must be met [4].

We assume that the mobile node is equipped with several MBB interfaces, with different technologies, e.g., cheap but occasionally available WiFi, more ubiquitous, but more expensive, 3G, 4G, and soon-to-come 5G subscriptions, possibly offered by different operators. The system has to decide (i) which interface(s) to use, (ii) when to upload from such interface(s), and (iii) at which rate to upload (if there is available bandwidth). The goal is to minimize the total cost of the upload, while meeting the deadline. A greedy solution that immediately starts uploading from all interfaces minimizes the upload time, ignoring opportunities for cheap interfaces to become available in the future, thus increasing upload cost. A trade-off clearly exists between minimizing the total transmission cost or minimizing the upload completion time.

In this paper, we propose and analyze a family of adaptive schedulers that require only a very coarse knowledge of the available bandwidth on wireless interfaces. We extend our work in [5] by defining a more refined scheduler, and evaluating our solution using a larger and recently collected dataset to evaluate the dynamic algorithm proposed in [6]. In addition, We discuss how to carefully tune the dynamic algorithm parameters, we provide a more extensive evaluation, and we compare the proposed algorithm with MP-DASH [7], one of the advanced deadline-aware scheduler. Finally, we implement and test the algorithms in a real testbed, provided by the MONROE[1] platform [8].

The main contributions of this paper are:

- Devising mathematical formulations of the deadline constrained content upload problem from multihomed devices, under different assumptions.
- Reporting extensive evaluations of the proposed solutions, based on trace-driven simulations using recently collected traces.
- Designing, implementing, and testing a real implementation of the proposed dynamic algorithm on deployed mobile multihomed nodes.

The rest of this paper is structured as follows. We first overview related works and we position our work with respect to state-of-the-art solutions for similar problems (Section 2). Then, we report on the collection of traces of content upload data rates from mobile multihomed terminals, showing the unpredictability of short-term variations in available bandwidth (Section 3) to gain insight about the trade-off between cost and delivery time over wireless channels. Next, we formulate and solve an idealized version of the problem, where an oracle has perfect knowledge of the upload rate on each interface at each time. The oracle can then schedule the upload in those time slots when cheap connectivity is (expected to be) available, thus minimizing total cost (Section 4.1). We also introduce three simple greedy heuristics, to show the effectiveness of intuitive approaches to solve this problem (Section 4.2). Then, we formulate the video upload problem as a centralized scheduling problem, where the upload rates of the available interfaces are random variables with known distributions. Solving such problem is computationally impractical (Section 4.3). Thus, we aim for a practical solution that requires only a coarse knowledge of the available bandwidth, and we design online, adaptive schedulers to explore the trade-off between cost and delivery time (Section 4.4). Afterwards, we show results obtained in a working prototype of the proposed algorithms in the real MBB platform provided by the MONROE H2020 project (Section 6). Finally, we conclude the paper (Section 7).

2. Related work

Mobile devices allow users to connect to multiple wireless networks with possibly different technologies [9–11], obtaining throughput values which depend on the terminal position, the network coverage, the traffic load, the weather conditions, etc. This makes the problem of scheduling transmissions over multihomed [12] wireless interfaces both relevant and challenging. This family of problems has been studied by many researchers, but none of them target the same problem as we define in this paper. Two of these prior studies consider a rather similar problem to ours. Higgins et al. [13] consider a multihomed scenario, and face the problem of choosing when each interfaces should be used. They propose a framework – called intentional networking – that lets the application opportunistically choose the interface, based on a label that expresses the application requirements. Their goal is to offer the application layer a clear and simple interface to control the bottom layers. Their solution does not consider deadline to finish the content upload and their focus is mostly on the system design. We instead consider the scheduling problem, i.e., which interface to use and when. The second closest work is from Zaharia and Keshav [14]. They present an optimal scheduler over multiple network interfaces, and propose approximations which can be implemented with limited resources in mobile phones, or PDAs. They make an unrealistic assumption that the cost and bandwidth of each interface is constant and known a priori. Here, we do not assume any a priori knowledge of available capacity. However, we consider a similar solution, assuming perfect knowledge of available bandwidth, but only use this to derive the bounds on performance.

We group the remaining prior studies based on the following three main focus that they pursue: predictability of wireless network performance, multipath TCP, and delay tolerant networks.

Predictability of MBB performance: The performance of wireless network services under uncertain network availability has been previously investigated by several authors. Deng et al. [15] investigate the characterization of multihomed systems considering WiFi vs. LTE in a controlled experiment. They show that LTE can provide better performance than WiFi, also exhibiting large variability on both short and long time scales. Rahmati and Zhong [16] present a technique for estimating and learning the WiFi network conditions from a fixed node. Rathnayake et al. [17] demonstrate how a prediction engine can be capable of forecasting future network and bandwidth availability, and propose a utility-based scheduling algorithm which uses the predicted throughput to schedule the data transfer over multiple interfaces from fixed nodes. These works heavily rely on channel performance predictions, and consider scheduling at the packet-level, i.e., choosing which packet to send through which interface, to maximize the total throughput.

Our work differs from these studies since we deal with moving vehicles. This exacerbates the unpredictability of the network performance, as shown by several authors. For instance, Riiser et al. [18] collected 3G mobile network traces from terminals onboard public transport vehicles around the city of Oslo (Norway). Similarly, Chen et al. [19] measured the throughput of both single-path and multipath data transport in 3G, 4G, and WiFi networks.

[1] https://www.monroe-project.eu/.