A Marketplace for Mobile Applications Supporting Rich Multimedia Feeds

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1. Introduction

Mobile devices are pervasive today; multimedia applications executing on smartphones and tablets are also commonplace. Rich content involving images, voice, audio, video, graphics, and animations is a part and parcel of the mobile experience for a wide range of applications ranging from entertainment to crisis response. The large volumes of information being captured, exchanged, disseminated through wired and wireless networks result in network congestion, packet drops and consequently low Quality of Service/ Experience for end-users. Often a single network alone is incapable of supporting a large number of rich feeds.

For example, current cellular providers are not able to support massive live video broadcast of popular sporting events (such as World Cup Soccer games) to a large number of diverse devices. Recent efforts have indicated that combining cellular infrastructures with ad hoc network capabilities offer additional scalability [1]. Similarly, in a disaster situation, surge loads and damages to infrastructure often cause a loss in network capacity when it is critically needed. Multimodal citizen reports through participatory sensing on mobile phones, social media and the Internet can aid situational awareness. The use of multiple networks concurrently has also been shown to help fast dissemination of rich alerts in that situation [2]. The ability to share mobile Internet access, that may be spotty, unavailable or expensive, is critical in each of these cases.

Mobile Internet usage is also influenced by the fact that a large fraction of mobile operators, today, only offer tiered data plans. It is therefore tricky for mobile users to "select" contracts, e.g., (1) light mobile users may want to avoid data plans all together, (2) heavy mobile users may accidently exceed the monthly quotas and be charged at higher rates, and (3) most mobile users may waste their residue quotas every month. Volume-based access plans are generally unsuitable for rich multimedia feeds; the ability to share network access across devices offers additional flexibility to users. However, mobile devices are limited in resources; one such key consumable resource that impacts the desire and ability to share access is the available battery capacity on the mobile host offering the shared access.

While users may be motivated to share mobile Internet access and utilize their local resources in dire situations (e.g., emergencies), users need to be incentivized to share access in more general scenarios. We envision a *marketplace* where mobile users trade their residual data plan quotas over short-range networks, such as Bluetooth and WiFi Direct to enable a more flexible data plan quota usage [3]. Such a marketplace also allows cellular operators to: (1) extend the cellular network coverage and (2) offload some of the traffic load from the crowded cellular networks – the latter is possible because the short-range networks run on different frequency bands causing virtually no interference to the cellular networks and providing additional access networks (which are not managed by cellular operators).

There are multiple challenges in creating the basic functionality to enable such a marketplace that we will discuss in this short article. Firstly, we will highlight a generalized system architecture that spans multiple providers, network types and entities. The entities of this ecosystem include mobile devices, mobile hotspots (those mobile devices providing connectivity to a backbone network for Internet access), brokers, service and content providers. We argue that a control framework that controls low level information flow reliably is required to enable shared access – we believe that Lyapunov based control theoretic framework can provide a good basis for this. In this short article, we also discuss non-functional challenges that dictate the viability of the proposed scheme – security, pricing and payment are some key issues.

2. An Architecture and Control Framework for Enabling Shared Mobile Internet Access

Figure 1 illustrates the high-level architecture of the considered marketplace, in which mobile users who need Internet access, called *mobile clients*, hire nearby mobile users, called *mobile hotspots*, to transport mobile data for a small fee. As an illustrative example, mobile clients C1 and C2 hire mobile hotspots H1 and H2 for Internet access. To join the system, mobile users register at a proxy and billing server, which is managed by cellular operators or third party companies. The mobile clients make a monetary deposit to the proxy and billing server before they can gain Internet access from mobile hotspots. They are charged for their data usage transferred through the mobile hotspot's data connection. For each request from a mobile client, the mobile hotspot may charge the client three fees: (1) data plan fee: for the used cellular quota, (2) resource fee: for the local resources, such as energy and storage, and (3) SLA fee: for setting up a Service-Level Agreement (SLA) with the cellular operators for transferring data plan quotas. The considered marketplace works for various mobile applications, e.g., video upload/download, video streaming, Web browsing, and Online Social Network (OSN) updates.

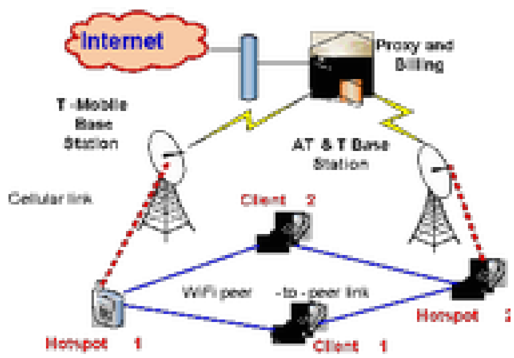

Figure 1 The proposed marketplace.

A Potential Solution using the Lyapunov Framework. To realize the proposed marketplace, a control mechanism that allows for reliable exchange of content between devices is essential. We present high-level software architecture in Figure 2 to enable the content exchange. To illustrate the flow of information in a concrete scenario, we consider video upload applications, in which each video is divided into multiple segments to better adapt to the network dynamics (the intuition here is similar to that of Dynamic Adaptive Streaming over HTTP (DASH) [4]). When a mobile client wants to upload a video, it first sends a request for each video segment and hires a mobile hotspot to transfer the segment to the Internet. A mobile hotspot invokes the *Client Request Admission* module to decide if it would admit the request based on the mobile hotspot's current workload and optimization objectives (revenue maximization for example). Then the mobile hotspot sends a reply to the client with a segment transfer delay and a cost/price to serve the request. The client may receive multiple replies from surrounding mobile hotspots. The client uses the *Hotspot Selection* module to choose the hotspot with the most preferred trade-off between segment transfer delay and cost, and transmits the video segment to the mobile hotspot. The incoming video segments transmitted via the *Data Transfer* module at both mobile hotspot and client. The mobile hotspot and client also employ the AAA (Authentication, Authorization and Accounting) module for secured connection establishment and payment.

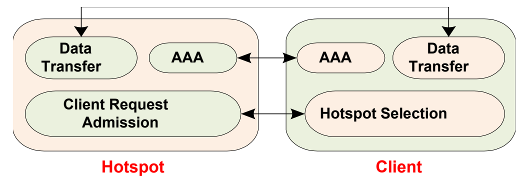

Figure 2 Software components.

One of the key functionalities in the system is provided by the Client Request Admission module running on each mobile hotspot, which admits or rejects the incoming requests from multiple mobile clients in order to: (a) maximizing the long term revenue (measured as average revenue over time), (b) ensuring overall stability of the system (implying no buffer overflow instances), and (c) providing a distributed and practical implementation. We develop the admission control algorithm using a Lyapunov optimization framework. It makes admission decisions based on the characteristics of the incoming requests, their potential to generate increased revenue, and the current set of ongoing commitments made by the mobile hotspot. The Lyapunov approach provides a meaningful theoretical underpinning for stability analysis of the dynamic execution environment [5].

3. Potential Research Challenges

There are plenty of other challenges to make the data plan marketplaces into reality. We briefly discuss some of them in the following.

Multihoming support for multimedia applications. Multimedia applications require low delay and high bandwidth; a difficult challenge for cellular networks. One promising approach is allowing mobile devices to hire multiple nearby mobile APs and WiFi APs for higher aggregate bandwidth, more stable connectivity, and lower latency. Concurrently leveraging multiple access networks is known as multihoming in the literature, e.g., for high-quality video streaming [6]. However, further study is required to efficiently apply the multihoming techniques in data plan marketplaces. Moreover, for real-time multimedia applications, it is desired to have a comprehensive control framework for timely exchanges of delay-sensitive multimedia feeds.

Dynamic pricing. Instead of assuming that each mobile hotspot owner will manually set a price, a possible approach is to have a dynamic pricing mechanism based on residual traffic quotas, battery levels, network congestion levels, and degree of competition. For example, when a mobile AP's residual traffic quota is high, the owner may be willing to sell the service at a lower rate, compared to another mobile AP that has almost used up its dataplan quota. A dynamic pricing mechanism, perhaps based on game theory, will allow mobile hotspots to adapt prices based on their conditions. Note that embedding the game theoretic solution within a real system is not necessarily straightforward. Additionally, the lack of popular micro-payment mechanisms may slow down the deployment of data plan marketplaces. We believe that a credit-based solution may be employed initially, and virtual currency mechanisms such as BitCoin [7] and Square [8] should be explored in the longer run.

Mobility support. Mobile clients and hotspots are often moving, the ability to support continued service in spite of this movement is essential in a mobile service marketplace. One possibility is to leverage mobile host trajectories in order to: (i) improve the reliability of mobile Internet access by reducing the number of likely disconnections during data transfers and (ii) increase the performance of mobile Internet access by performing proactive handoff operations. We envision a distributed technique for achieving these two goals: (i) a lightweight client that runs on individual mobile devices to collect local device conditions and the neighboring network environment and (ii) optimization logics that run on a broker for optimal decisions to adapt to device mobility.

Security support. Several practical security mechanisms, such as encryption and digital signatures [9], can be applied in the data plan marketplaces to avoid data manipulation by malicious mobile APs. Integrating these security mechanisms is no easy task as mobile devices are resource-constrained, and the overhead of adding potentially complex security mechanisms must be taken into consideration. A scalable mechanism that allows users to choose the most appropriate security level depending on their residual resources and the nature of the data transfers is desirable. Another key open issue is that concerning user privacy. For example, a mobile device may not want to reveal its geographical location, but selecting a mobile AP inherently indicates that this mobile device is very close to that mobile AP. Mechanisms to keep mobile devices (and mobile APs) anonymous for better privacy is an interesting direction of research.

In this short article, we present our vision of building up a marketplace where mobile devices trade their resources and residual data plan quotas. Other types of resources may also be traded among resource-constrained mobile devices, and more complex ecosystems can be gradually built up. For example, a mobile device with abundant battery level may sell computational power to near-by mobile devices, or even provide them a wireless charging service for a small fee. Similarly, public spaces (e.g., malls, airports) today deploy expensive WiFi network infrastructures to provide the temporary occupants with Internet access; one can envision offering incentives (e.g., coupons, discounts) to those mobile devices that volunteer to serve as mobile hotspots in this case. In general, we see a great potential in creating mobile marketplaces–however, there are many challenges that need to be addressed before such ecosystems can be widely deployed and accepted.

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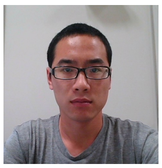

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