Delivering Capacity for the Mobile Internet by Stitching Together Networks

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ABSTRACT

Despite of findings that only 5.2% of the spectrum from 30 MHz to 3 GHz is utilized, there is much talk of an impending spectrum crisis. This is no contradiction—spectrum is inefficiently utilized, with some part of the spectrum being heavily used while others barely used. In this paper, we explore a simple high-level approach to the problem: to enable user mobility across networks and exploit all the capacity available. By doing so, we can create a better mobile network by stitching together existing ones spanning multiple wireless technologies. We briefly outline our exploratory foray into radio agnostic handover and discuss the various challenges ahead.

Categories and Subject Descriptors

C.2.0 [**Computer Systems Organization**]: Computer-Communication Networks—*General*

General Terms

Experimentation, Measurement, Verification

Keywords

OpenFlow, Mobile Internet, Testbed

1. INTRODUCTION

A survey commissioned by NSF in 2005 concluded that radio spectrum is underutilized; they found only 5.2% of the spectrum occupied in the range from 30 MHz to 3000 MHz (averaged over six locations) [8]. In an attempt to use spectrum more efficiently, a flurry of research activities have sprouted in "cognitive radios" [13]. Cognitive radios allow for unlicensed use of an licensed band, as long as the secondary user does not affect the operation of the primary spectrum owner. This allows spectrum to be better utilized, opening spectrum access to unlicensed use. We applaud this movement to create more freedom in spectrum access, which is especially needed as the popular ISM bands become more cluttered.

Ironically, there is much talk of an impending *spectrum crisis* [1, 2, 7]—an alleged shortage of spectrum for cellular networks. But how can there be a spectrum shortage when only 5.2% is utilized? There is no contradiction—the problem at hand is not the lack of spectrum but because it is so inefficiently used. Pockets of spectrum are quite heavily used - for example, the cell phone and specialized mobile radio (SMR) band (a narrow band from 806 MHz to 902 MHz) is 46.3% utilized in New York city [8]; while other bands are barely used at all. Cognitive radios seem like one approach to provide more efficient usage of the spectrum.

In this paper we explore a simpler, higher-level (and perhaps more obvious) approach. We argue that there is, in fact, not really a shortage of capacity. It's simply off-limits to most users, most of the time. Switch on a cell-phone in most locations in the world and you can "see" 5-10 different cellular networks, and several WiFi networks. However, most users can only use *one* of the visible cellular networks, constrained by the contract they are locked into. Nearby WiFi networks are usually off-limits too, because they are secured by their owners.

If we really want to give users access to the abundant wireless capacity around them, why don't we make it easier—by design and by policy—for a mobile client to move freely between the spectrum, and networks, owned by different cellular and WiFi providers?

While this approach is clearly counter to current business practices—and would require cellular providers to exchange access to their networks more freely than they do today—we believe it is worth exploring because of the much greater efficiencies it would bring; and the much greater capacity that could be made available to end users. Interestingly, a several-fold increase in capacity could be made available for little or no additional infrastructure cost.

We highlight three main advantages of our approach:

- *Increased capacity through more efficient statistical sharing.* Cellular network operators tend to heavily overprovision their network in order to handle times of peak load and congestion. Most of the time, the network is lightly loaded. If instead they were able to hand off traffic to each other, or from cellular to WiFi networks, then their traffic load would be smoother, and their network more efficient. For example, what if AT&T could re-route traffic from their iPhone users to T-Mobile during an overload? Or T-Mobile could reroute their customers' flows to a nearby WiFi hotspot?

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- *Exploit differences in technologies and frequency bands.* Mobile technologies such as EVDO and HSPA provide wide area coverage with consistent bandwidth guarantees; while technologies like WiFi provide high bandwidth and low latency. Lower frequencies provides better coverage and penetration; while higher frequencies provides better spatial reuse. Being able to use the most appropriate technology for the application at hand would make best use of capacity available. For example, a backup where intermittent connectivity is tolerable can be done via WiFi where higher throughput is possible.

- *Open up new sources of capacity.* The ability to move between networks also open up new sources of capacity. For example, one can now use a network such as that of fon.com to supplement their main network, without having to deploy an extensive WiFi network. Such crowd-sourcing can be a powerful tool to cover dead spots and relieve congestion.

Through mobility across networks, we create a network with heterogeneous wireless technologies by "stitching together" the multitude of wireless networks available today. In the rest of this short paper, we summarizes our work in radio-agnostic handover. Towards the end, we describe other interesting questions that require further research.

2. FIRST STEP: RADIO AGNOSTICISM

To allow for mobility across networks that utilize a multitude of wireless technologies, the natural first step is to enable radio agnostic handover. Many handover mechanisms today are specific to wireless technologies, e.g., WiMAX forum recommends how handover can be achieved in a mobile WiMAX network where GRE tunneling is commonly employed. These mechanisms often make assumptions about the specific wireless technologies and are not directly applicable to other wireless technologies.

To reconcile the differences, we reduce handover to the lowest common denominator for popular wireless technologies, i.e., *re-routing flows.* To advocate flow-based management to the mobile industry is to preach to the choir. The concept of managing the network at the flow or terminal granularity is well-established in the mobile industry. However, Ethernet-IP based networks tend to manage with granularity of packets. To introduce the idea of flows in these networks, we exploit a growing movement, namely OpenFlow [5, 6].

OpenFlow brings the concept of a flow to switches, routers and WiFi APs, which can then manage packets identified to be a flow from a 12-tuple that spans from Ethernet addresses to TCP/UDP ports. This allows a flexible definition of flows, which in turn provide a powerful way to manage the network using the idea of flows. Such flows can be handled at line-rate in these devices using flow tables, originally introduced to provide the access control list functionality. This allows OpenFlow to be readily integrated into commercial switches, routers and WiFi APs.

By extending the simple and yet powerful abstraction of flows to Ethernet-based technologies, we were able to demonstrate how a flow can be routed between WiFi APs and WiMAX base-stations. In a demonstration [10], we n-cast a H264 encoded UDP video stream across multiple wireless technologies to a single client equipped with two WiFi interfaces and a single WiMAX interface. We show that network impairments—specifically 3% packet loss—can be overcome through sheer dumb replication across multiple wireless networks exploiting the multiple radio interfaces on the mobile client. Here, we do not advocate repetition coding but aim to show the power of simple control of routing in mobile networks.

Through the demonstration, we show how flow-based control can be used to handover between networks of different wireless technologies. While we advocate the use of simple dumb base-stations for other wireless technologies akin to what LWAPP advocated for WiFi [11, 12], this is not a requirement for radio agnostic handover—the critical piece of technology that enables us to stitch networks together. On and above the benefits of building a better network, our approach allows for flexible slicing/virtualization of the wireless networks which in turn provide ease of management, as we detailed in [12].

While we can argue for an uniform method for handover in different networks, we are clearly aware of the technical feasibility of employing different handover mechanisms in different networks while relying on radio agnostic handover to cross the boundaries of networks. By developing the technology, we expand the spectrum of possible solutions. Through this, we allow other non-technical reasons to settle on the most appropriate operating point within this enlarged solution space.

3. CHALLENGES AHEAD

While we believe radio agnosticism is a key component of stitching together networks, there are many other research problems to be solved. Due to space constraints, we outline three that are close to heart in the following:

- *Client networking stack is restrictive.* For example, it continues to be uncommon to have multiple interfaces being used simultaneously. This is because such complex network management has to be manually configured by users today. We contend that a more powerful and flexible client networking stack would be instrumental in changing the way networks are used today. Maybe one day we would not need to turn off the WiFi interface in Android when Skype is started.

- *Network today provides only a single service, i.e., connectivity.* Application developers expect little more than a connection to the Internet from network providers. For example, a delay-tolerant application would not be able to query the congestion state of the network today. Sophisticated developers might even perform network probing, which in turn affects the network state itself. We argue that more can be done [4, 9]. From our discussion with telcos, we are seeing changes in the right direction—i.e., there have been talks about providing QoS services as supported by 4G wireless technologies. The willingness of telcos to introduce new network services poises a great opportunity for researchers. We can propose and research on new network services that would help better tomorrow's mobile networks.

- *IP management has to change.* As we stitch together different networks, we have to reconsider the management of IP addresses used in these networks. Some networks might be NAT-ed while others provide a publicly addressable IP. Users might have a single IP address or multiple given the increasing number of network interfaces in mobile devices. Under these dynamics, session continuity is an interesting and hard problem.

Even for a single service provider, they might use another's network to serve their customers, much like Sprint using Clear's WiMAX network shared with Comcast and Time Warner. What IP address would a customer be given in Clear's network? Some might advocate the use of mobile IP, which would then require a scalable directory service from which the home agent of the client can be located. All these problems have to be resolved as we move towards the next generation of mobile technologies.

Our point here is that the solution space is large and much research is needed to find the right solutions for these problems and others issues. To seed the process, we have created OpenFlow Wireless [12]—a platform that allows innovation of mobile wireless networks—for researchers to test and verify their ideas. We are not alone. Similar efforts, like GENI's WiMAX [3], will also provide researchers access to 4G wireless technologies for ideas to be verified in realistic ways. With these, we hope other researchers would also be encouraged to think about the many problems associated with building a better mobile network.

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