Enhancing Rural Connectivity with Software Defined Networks

Shaddi Hasan
UC Berkeley

Yahel Ben-David
UC Berkeley and AirJaldi

Colin Scott
UC Berkeley

Eric Brewer
UC Berkeley and Google

Scott Shenker
UC Berkeley and ICSI

ABSTRACT

Software-defined networks (SDNs) have simplified management of complex data center and enterprise networks. We argue that SDNs can play a similar role in rural wireless networks, especially those in developing regions. Operating a rural network in the developing world means coping with unpredictability, low profit margins, and resource constraints; the increased flexibility and simplified management that software-defined networks provide are a major benefit in this context. Network virtualization, also enabled by SDN, could allow rural networks to operate as infrastructure providers to existing ISPs, thus enabling cooperation rather than competition with powerful incumbent providers.

1. INTRODUCTION

Poor and rural areas are fundamentally difficult for Internet service providers to profitably serve: sparse population densities reduce opportunities for oversubscription, low purchasing power of potential customers implies small profit margins, and resource constraints make providing acceptable service quality hard. The history of rural wireless networks is rife with "pilot projects" that never reached meaningful scale or slowly fell apart when the (often US-university-affiliated) team who installed them left the area. Realizing the benefits of Internet access requires profitable Internet service providers whose customers trust them to provide reliable service over the long term. This requires innovation to drive down the costs of network operation and enable service providers to operate sustainable businesses, even in the most rural and poor areas. Recent technical innovations such as long-distance WiFi have reduced costs at the physical layer, as have regulatory decisions to allocate microwave spectrum for unlicensed use. A new class of Internet service providers has developed as a result, which utilize point-to-point, "fixed wireless" access technology to provide service to remote, sparsely populated areas. We refer to such an organization as a *rural wireless network operator* (RWNO), also known as "wireless ISPs" (WISPs) or "fixed wireless broadband providers".

Yet infrastructure cost is only one component of the cost structure for rural ISPs; profitable operation depends on controlling management and support costs. In this respect, a fundamental problem remains: rural wireless networks are highly variable, heterogeneous environments that are difficult to manage, yet RWNOs operate while understaffed and under severe resource constraints.

Software-defined networking (SDN) offers a principled approach to managing rural wireless networks, providing opportunities for making their operation simpler and more efficient and potentially enabling new business models. SDNs decouple the control and data forwarding tasks of a network, placing control and management functionality into a logically centralized controller which configures and monitors the state of the network's forwarding elements (e.g., switches and access points) [3]. In doing so, SDNs enable a RWNO to decouple *construction* of physical infrastructure, which must be done locally, from *configuration* of their network, which can be done remotely. Going further, this decoupling enables the infrastructure deployment business and the ISP business to be operated by *completely separate entities*. As a result, software-defined rural wireless networks can decrease costs and lower technical and business barriers to entry, thereby enabling profitable operation of RWNOs and expanding access to the Internet.

2. OPPORTUNITIES FOR SDN

Decoupling skills. Rural wireless network operators perform two core operational tasks: construction of physical wireless infrastructure and configuration of that infrastructure. The skill sets required for each have little overlap, and thus a RWNO must either maintain separate staff for each or provide training in both areas to all their staff, both expensive options. Yet for today's rural wireless operators, adjusting configuration parameters on individual routers and access points is commonplace, and troubleshooting link failures requires understanding the full networking stack. Learning how to design and manage a robust and scalable data network often comes after initial mistakes and their associated costs.

Software-defined networking enables network virtualization [1], which allows network operators to treat their physical network as an abstract pool of resource, specify management policy against this abstraction, and let the SDN controller handle the configuration of individual network components. In doing so they decouple the physical network from network policy. Decoupling these tasks also enables a rural network operator to decouple the staff responsible for each and increase specialization among their employees.

Decoupling these tasks also enables a novel solution to this training and staffing challenge: outsourcing network management. Specifically, given a complete global view of network state and an abstract, logical model for the underlying physical network, control plane management can be conducted from anywhere. Architecturally, rural wireless network operators would run one or more SDN controllers within their own network, but the policy descrip-

DEV'13, January 11–12, 2013, Bangalore, India.

tion for those controllers would be crafted by the operator's own network administrators or by a third-party network management consultancy to translate business needs and service agreements into a logical network configuration. This decoupling also simplifies the deployment of novel network services, such as limited "free" tiers of connectivity or support for local, non-Internet-based services, since only logical network elements must be configured to support them.

Standardization of tools. A second opportunity for software-defined networking in RWNOs arises from the fragmented ecosystem of currently available tools. RWNOs require a suite of tools for network monitoring, configuration, billing, and user authentication. Complicating the situation, tools from different vendors do not necessarily interoperate or expose common configuration interfaces. A similar situation exists for debugging and troubleshooting: with no unified or automated mechanisms for reasoning about the status of the whole network, operators are forced to rely on ad-hoc techniques for identifying and fixing faults. Individual RWNOs develop institutional knowledge to cope with this situation over time through experience, often learned the hard way.

The status quo for RWNOs today is that best practices are encoded in their employees, and the implementation of a best practice in a network is specific to its particular environment, precluding sharing hard-earned wisdom between organizations. A solution naturally arises in an SDN: the controller presents a global view of network state, a well-defined API and programming model for accessing and modifying that state, and implicitly a standard abstraction for monitoring and managing equipment from multiple providers. Any applications built against such a controller could be easily shared among RWNOs.

3. VIRTUAL RWNOS

The opportunities for SDN described in Section 2 are each practical innovations that would directly impact rural wireless network operators as they build and manage their networks today. Yet the decoupling between construction and configuration that SDN provides also enables new business models for RWNOs. In particular, these two tasks can be conducted by *completely separate entities*.

The logical extension of this idea is that RWNOs would, rather than acting as an ISP themselves, "rent out" their network to an established ISP. The task of the RWNO, then, becomes simply one of building wireless infrastructure and ensuring it can be managed by an SDN controller. This model radically changes the way RWNOs interact with existing telecoms. Rather than competing with incumbent telecoms, which often have monopoly status, government subsidy, or other strong competitive advantages, RWNOs are able to cooperate with an incumbent provider. In this arrangement, the RWNO provides an incumbent telecom access to new customers outside their existing service range. In return, the incumbent telecom brings their business expertise and, if applicable, regulatory licenses to the rural market. For example, billing customers with small and irregular incomes is challenging, but large cellular service providers that serve remote areas have already developed payment infrastructures that cope with this reality [2]. The RWNO can allow such a cellular service provider to offer Internet service over the RWNO's infrastructure and thus take advantage of the payment infrastructure the telecom may already have in place. The RWNO itself only needs to bill and interact with its ISP "customer".

In the long term, we envision *virtual rural wireless network operators* which rent their infrastructure to multiple ISPs rather than only a single one. A fully virtualized RWNO would be an *infrastructure service provider*, analogous to the role that cloud providers such as Amazon's EC2 plays in the server hosting market. Rather than directly providing service to subscribers, the rural network operator would provide infrastructure to existing telecom and Internet service providers, its "client ISPs". The RWNO would present these service providers, its clients, with a virtualized abstraction of its network as presented by the SDN controller. Crucially, these ISP clients would be able to modify their slice's configuration without (non-programmatic) interaction with the RWNO, just as users of cloud-hosted virtual machines require no interaction with their hosting provider to deploy new services. While the RWNO would still be responsible for building the physical infrastructure to connect their own network to potential clients, the subscriber would interact directly with the client ISP for billing and support. This model of service provision is also beneficial to consumers as it enables multiple Internet service providers to utilize the same physical infrastructure, thus increasing competition.

We acknowledge that the RWNO environment also poses new challenges for software-defined networks, which have historically been designed for datacenter and enterprise environments. In particular, production SDNs often use physically separate networks for control and data plane traffic, and datacenter and enterprise environments have few resource constraints. The loosely-coupled, unreliable, and resource-constrained nature of an RWNO, coupled with the impracticality of building separate control networks, complicates the SDN controller's task of maintaining a consistent global view of network state. Addressing this issue is a substantial research challenge and is beyond the scope of this paper. However, this need not be a fatal flaw for SDN in a RWNO; indeed, it suggests a tradeoff space between the quality of the RWNO's network and the richness of the global state the SDN controller has to work with. If the only changes to global state occur when a RWNO's tenant ISPs add, remove, or change a customer's configuration, it may be acceptable for such changes to require seconds or even minutes before being reflected in both the controller and the affected network data plane elements.

4. CONCLUSION

Just like operators of large data center networks in which SDN has traditionally been applied, RWNOs are not well served by the status quo for network management. Consolidating control and management of a rural wireless network will simplify their operation, as will decoupling the tasks of infrastructure construction and network configuration. This decoupling further enables new cooperative business models for rural wireless networks. Taken together, we believe SDN has an important role to play in spreading sustainable, reliable Internet access to people worldwide.

5. REFERENCES

[1] M. Casado, T. Koponen, R. Ramanathan, and S. Shenker. Virtualizing the network forwarding plane. In *Proceedings of the Workshop on Programmable Routers for Extensible Services of Tomorrow*, PRESTO '10, pages 8:1–8:6, New York, NY, USA, 2010. ACM.

[2] N. Hughes and S. Lonie. M-PESA: mobile money for the "unbanked" turning cellphones into 24-hour tellers in kenya. *Innovations: Technology, Governance, Globalization*, 2(1-2):63–81, 2007.

[3] T. Koponen, M. Casado, N. Gude, J. Stribling, L. Poutievski, M. Zhu, R. Ramanathan, Y. Iwata, H. Inoue, T. Hama, et al. Onix: A distributed control platform for large-scale production networks. *OSDI, Oct*, 2010.