Software Defined Home Networking: Research Challenges and Innovation Opportunities

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Abstract— **The myriad of connected devices in today's households have greatly increased the complexity of home networks. Evolving use cases demand new networking capabilities in the home and call for new approaches to deal with the control requirements and quality of experience expectations of end users. OpenFlow/SDN represents a recent trend in open interfaces to network elements and new control plane abstractions that may change the landscape of home networking. In this paper, we discuss the challenges of home networking and discuss the concept of Software Defined Home Networking (SDHN). In addition, we present some of our related achievements and a number of open research questions.**

I. Introduction

Home networks have become part of our daily lives [1]. As the number and heterogeneity of devices connected to the Internet continues to grow [2] and given the pace of network operators broadband deployments, the network in the customer's house has become a critical factor to guarantee cost-effective operations and meet the end-user expectations.

Despite broadband investments and 10+ years of deploying home WiFi equipment, home networks suffer from a number of systemic challenges like (i) high deployment costs, (ii) hard to manage, and (iii) failure prone [7]. One root cause is that a common user does not have the skills required to operate and manage its own network due to the configuration complexity. With more family devices demanding connectivity, the complexity of the home network grows and turns very difficult for the common user to configure the multiple devices in a way that connectivity and performance are optimized. Trying to implement a policy to prioritize traffic from specific applications or users is also a non-trivial (if not impossible) task given today's network protocols and interfaces to the devices. One frustrating result is poor quality of experience when some user in the home becomes a bandwidth hogger (e.g., P2P, video streaming) in the already constraint wireless resource base of WiFi routers.

Another end-user pain is the bandwidth control performed by operators when the data consume exceeds a limit [5]. A common practice of ISPs is to throttle users after a monthly data quota has been reached. In such situations the user is often helpless in trying to monitor how much data the applications are consuming and also how the bandwidth consumption is distributed between applications, devices, and family members. Yet another source of pain is security. The home network has become a great target for attackers given the user's lack of ability (and capabilities/tools) to secure it [4].

The question becomes now how to change this landscape. The home network –as any multi-vendor Ethernet/IP architecture in operation– is hard to change and does not allow for much innovation other than via proprietary extensions or at the application level. We believe there is a need for configurable, maintainable and sustainable home networking approach that removes the barrier to adoption for new devices and networking services. This belief is motivated by the emergence of vendor-agnostic network control APIs introduced by the OpenFlow protocol [6] that allows to redefine the control logic via logically centralized software outside of the network devices themselves. The packet forwarding abstraction proposed with OpenFlow is the lower layer of an architectural approach referred to as Software Defined Networking (SDN). Such a layered and open architecture opens the opportunity to introduce innovative control services to tackle the hazards of current and future home networks by means of what can be called the Software Defined Home Network (SDHN). The idea of rethinking home network configuration and overall connectivity services is promising but not without challenges.

In the rest of this paper, we discuss issues with the current home networking scenario, including a number of challenging use cases (Section II). We then present the concept and early ideas on Software Defined Home Networks (Section III) and present our related research work (Section IV) before concluding (Section V).

II. Challenges of Home Networking

Up to recently home networks have been relatively simple to deploy and operate as the number of devices was small and the connectivity requirements rather simple. Figure 1 depicts a usual home network, where a single wireless router provides connectivity to small set of devices. Addresses are distributed via DHCP using the address space for private networks. The router performs also NAT to give Internet access to the connected hosts.

Consider now Figure 2 where the home network grows in terms of the number and type of connected devices. Providing all home devices not only with connectivity but also with some priority to the shared and constrained network resources means (at best) tedious configuration well over the network management capabilities of a common home user.

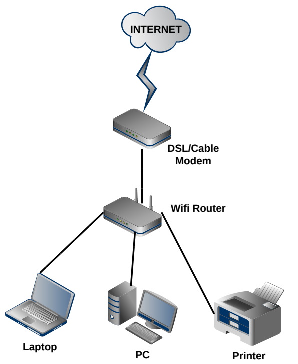

Fig. 1. Traditional Home Network

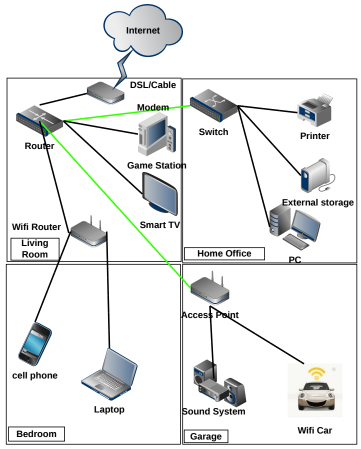

Fig. 2. Future Typical Home Network

A. *Use Cases*

Web navigation, online gaming, P2P content sharing, and especially IP streaming [9] are the main applications responsible for the vast majority of the home traffic. The emerging type of services that challenge current home networks are not restricted to traditional well-known use cases but do actually define a new problem space [3]. Bandwidth control is only one of the issues when looking forward. In the following, we present a number of use cases that shall become part of the (not so future) home network and which are not well supported using the traditional networking model and protocols:

Separation of guest users from home users. Users want to keep their data and bandwidth isolated from guests, so it becomes interesting to think about two separate networks so that guests can be in quarantine – very much like corporate networks. It is possible to create other networks using WiFi routers based on OpenWrt [10] or buying expensive enterprise-grade equipment that allows to create virtual wireless interfaces. While the latter is a costly proposition and often lacks of bandwidth control [11], the problem with OpenWrt lies in the difficulty that a common user is likely to face when installing and configuring a Linux-based system.

Smart grid. Smart grid is a technology that brings intelligence to the house electric network by collecting information, enabling better statistics about energy usage, and taking actions according to determined state [12]. Home routers will be responsible (or certainly involved) in the connectivity with the smart grid utility. The problem here is that a specific gateway is expected to be required to connect these smart devices, adding one more layer of complexity and cost to the home network.

Multi-homing. A future home network may have two distinct connectivity options to the Internet for instance to increase the speed and reliability or just to benefit from the combo offers of different providers. Multihomed networks are hard to configure and there is a common routing problem to be solved. Since the user will have two IP addresses obtained from the ISPs, load balancing to ensure the best performance becomes a non-trivial exercise. Recent proposals to handle the problem (e.g., [13], [14]) involve complicated configurations and protocols. Multipath-TCP proposes to solve this issue by changing the end-device networking stack, something not always possible in every device.

Video content sharing and streaming. This kind of services is becoming common in home networks. Technologies, like the Samsung AllShare,[1] enable the user to share content only between devices of a given brand or installed software. The DNLA protocol promises seamless and effortless sharing of digital content, but it has limitations on the type of media that can be shared [15]. The question remains unsolved, how to effectively provide a high capacity, reliable and easy to setup network connectivity service between any device?

Heterogeneous link layer technologies. Devices can present different link layer technologies (e.g., Zigbee, WiFi, 4G/LTE)) which need to interwork nicely in the home. Heterogeneous link technologies add more complexity to the network due to the need of specific networking gear and bridging or gateway solutions. Moreover, it would be desirable that wireless could be effectively shared whatever link technology is used [18]. Recently, WiFi Direct has appeared as a new option to allow wireless connectivity directly between the devices without involved the access point. How could the control plane of a multi-layer/technology/vendor home network look like?

Bandwidth control. QoS configuration is not an easy task for the normal user. Ensuring or limiting bandwidth for applications should be quick and easy to perform, just like changing the fire temperature in a stove. Another problem is that most users do not want to know details about the required bandwidth required by the applications. A user desires applications to run with (relative) good performance, may be just expressed by chain of priority among applications, users and/or devices. This calls for new network control abstractions and new user-friendly interfaces to allow users expressing their desire on how bandwidth should be shared.

The use cases presented above highlight a number of challenges involving their implementation and has motivated related work to question the way a home network should be structured and controlled [8], [17], [16]. Getting the home network "right" for whatever combination of use cases one may think of is really hard. Following the same rationale that has lead to the SDN thinking, the reason behind this challenging networking scenario is its distributed nature and the low-level and mostly vendor-specific configuration interfaces.

III. Software Defined Home Networks

A Software Defined Network (SDN) is an architecture where the control plane is separated from the forwarding plane, which is programmable through a common API (e.g. OpenFlow). SDN provides a centralized view of the entire network and allows to define the control logic to interconnect all devices from a single point. This design is very interesting to solve the issues of home networks because it gives deep and fine granular control and allows to dynamically handle

[1] http://www.samsung.com/global/allshare/pcsw/

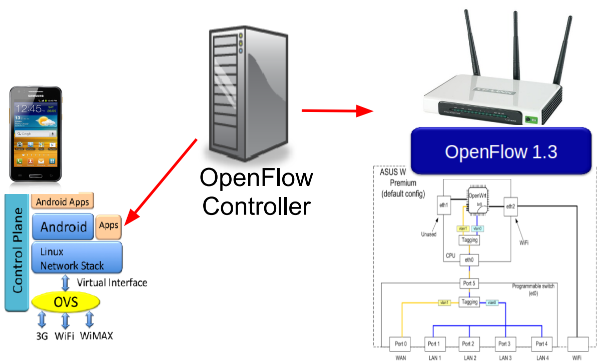

Fig. 3. OpenFlow control in the home.

changes in the network. Tools developed for monitoring and bandwidth control [16], [17] have already demonstrated the promising potential of SDN for home networks. A broader approach for home networks should comprehend utilities for the cited tasks along with a complete set of tools to achieve network resiliency and security yielding a superior control over the connectivity between devices and the rest of the Internet. This vision is what we refer to as a Software Defined Home Network (SDHN).

Figure 3 shows a straw man example of an OpenFlow controller controlling two home network devices, namely, a Linux-based mobile device and a wireless router. The router acts as an access point and implements the OpenFlow protocol to control both the wired and wireless interfaces. The mobile phone (or any Linux-based system like a modern TV) runs the Android operating system and features the Open vSwitch software switch,[2] which in addition to act as a Linux bridge it also implements the OpenFlow protocol (cf.[18]).

A. Towards Control Abstractions for the Home

Figure 3 only shows how OpenFlow control logic could be run in some server (running in the home or the Cloud) but does not help alone to address the complexity of managing and controlling the home network. One initial approximation to present the control application with a simplified view is depicted in Figure 4, which abstracts the connectivity details of the home network. Devices can be named with user-friendly identifiers hiding low-level details like IPs or MAC addresses.

This would be one way to present the user with a view of all devices in the network as if they were directly connected. From this view, the user could determine connectivity rules, for instance, to isolate devices or to rank them by some priority.

Note that the controller does not necessarily need to be located in the home network as a separate device or inside the OS of the router or TV. The control application could be a cloud-based management service, accessible via a Web interface from any device. The options are open to whether future home networks will have a new box with the control

[2]OVS is now part of the Linux kernel since version 3.3. See http://kernelnewbies.org/Linux_3.3

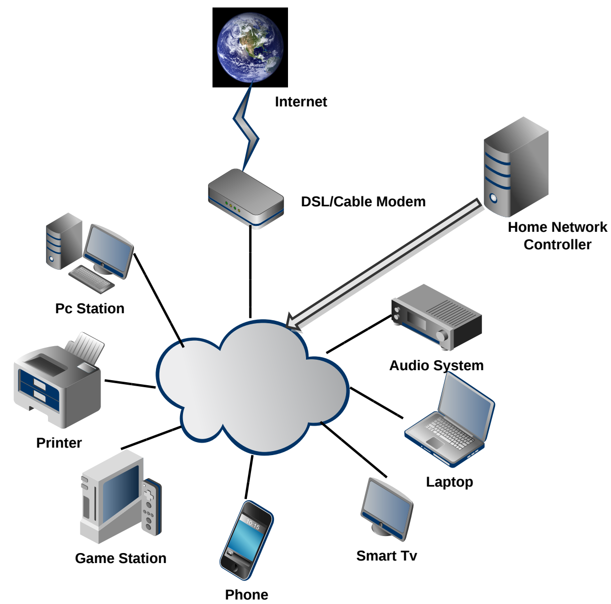

Fig. 4. Device connectivity abstraction in the SDHN.

functionality required by the user, or whether the control application could be offered as a service by the ISP or a third-party (potentially outsourced) network management entity.

The connectivity abstraction is however only the first step towards enabling user-friendly rich control services for the home. At the end of the day, the user is interested in being in control of *when*, *what* applications and *who* should have preferential network usage, considering both the wireless medium and the wired link to the Internet. A natural step forward would be to be able to define new abstractions of the devices, users, and applications so that a user-friendly control logic can be presented to the end-user. As a result of processing users' preferences, the controller application would translate the resulting policies into OpenFlow rules (flow match fields

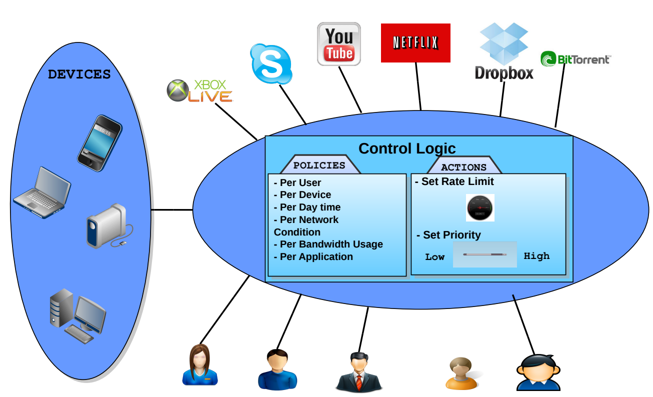

Fig. 5. Device, user, and application abstractions in the SDHN that could allow an end-user to define its preferences for traffic control by means of high-level and flexible policies.

and actions) to enforce the desired control logic. Figure 5 aims at illustrating this next step towards a SDHN.

How to turn this into reality for any combination of devices and applications is one of many open research questions, including whether OpenFlow control over L1-L4 suffices (e.g. is there a need for application level IDs?) and how to design a user-friendly graphical interface that is simple and capable of capturing the users' intention in a generalized way. A web interface for the control application needs to be clean and intuitive, where users can perform actions such as choosing applications to be prioritized or applying parental control. Network statistics shall be shown in a readable way for the common user and shall warn about current data usage, trying to prevent users from exceeding bandwidth caps.

IV. Related Research at CPqD

We now present some of the R&D threads that bring us closer to materialize SDHN.

OpenFlow 1.3. The open-source OpenFlow 1.3 software switch implementation [19] has been ported to a wireless router running OpenWrt. This is a great step towards the prototype of a SDHN. OpenFlow 1.3 brought key features to enable innovative control applications for home networks. Noteworthy, flow meters can be applied to implement QoS mechanisms, i.e. to balance the bandwidth consumed by the home devices or users. Traffic monitoring and filtering are also made simple, as we only need to create flows that match the field value we want to block or monitor. Another advantage of having an OpenFlow 1.3 router in home networks is a low cost dual stack solution, since it has support to both IPv4/v6.

Cloud networking. We are investing on infrastructure to create an experimental testbed for SDHN. We are gaining experience with the Open Stack framework to deploy a private cloud. This shall provide the basis to allow network controllers run as service. In addition, control applications shall apply flow rate limiting based not only on static policies but also considering a feedback control loop based on networking monitoring and historical usage statistics. On another sub-thread, we will investigate how content sharing could be facilitated by the cloud. One approach is to pass all the shared traffic to the controller and retransmit it to the target device, adding the possibility to keep a cached copy of content objects. Hybrid home and cloud network services is yet another opportunity to innovate on the end-to-end transport service of the future.

IP routing. We expect to address the problem of routing and allocation of address prefixes shall be addressed by the experiences with IP routing over OpenFlow networks as pursued within the RouteFlow project [20]. Software-defined IP routing allows to offer routing services located in the cloud and opens more research topics worth to explore. Manual tasks on the current implementation, e.g virtual routers auto-configuration and on demand network topologies need to be automated in order to reduced operational costs. A worth to mention trend in refactoring network functionality to be vitualized and run on commodity server technology is being discussed within the Network Functions Virtualisation (NFV) group.

V. Conclusion

Home networks have grown in complexity given the myriad of connected devices that are common in households. Home network gateways are the portal to Cloud provided services and thus the edge of the future Internet. We expect an increasing role of home networks to allow new end-to-end services in addition to becoming the center of attention as intra-home networking hazards continue to pop up. New control abstractions and open APIs to the networking stacks of devices allow thinking about a software-defined approach to home networking, promising new levels of user control, reliability, security, and service innovation.

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