# Towards Crowd-Shared Home Networks


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***Abstract*—**


## I. Introduction

The Internet has evolved into a critical infrastructure for education, employment, e-governance, remote health care, digital economy, and social media. However, Internet today is facing the challenge of a growing digital divide, i.e., an increasing disparity between those with and without Internet access. Access problems often stem from sparsely spread populations living in physically remote locations, since it is simply not cost-effective for Internet Service Providers (ISPs) to deploy the required infrastructure for broadband Internet access in these areas. Coupled with physical limitations of terrestrial infrastructures (mainly due to distance) to provide last mile access, remote communities also incur higher costs for connection between the exchange and backbone network when using wired technologies, because the distances are longer. A large exchange may accommodate many users and allow for competition between service operators; in contrast, a rural/remote broadband connection does not usually offer economies of scale, increasing the costs per user.

This problem is widely and publicly recognized. For example, in 2012 9.1 million homes in Europe still did not have fixed broadband coverage, more than 90% of which are in rural areas [4]. Achieving ubiquitous mobile broadband coverage is also currently seen as not feasible by major operators as direct investment in local infrastructure may be uneconomic.

Addressing digital exclusion due to socio-economic barriers is also important. The United Nations revealed the global disparity in fixed broadband access, showing that access to fixed broadband in some countries costs almost 40 times their national average income [5]. This problem is also applicable to developed countries where many individuals find themselves unable to pass a necessary credit check or living in circumstances that are too unstable to commit to lengthy broadband contracts [1]. A recent survey in Nottingham, UK [7] revealed that affordability is cited as the primary barrier, explicitly so by over 22.7% of digitally excluded in the age of 16-44 years.

We see enabling benevolence in the Internet (act of sharing resources) as a potential solution to solve the problem of digital exclusion caused due to socio-economic barriers. Lowest Cost Denominator Networking (LCDNet) [1] is a new Internet paradigm that architects multi-layer resource pooling Internet technologies to support new low-cost access methods that could greatly reduce a network operator's direct investment in local infrastructure to support wider Internet access. LCDNet proposes to bring together several existing resource pooling Internet technologies to ensure that donors (users and network operators), who share their resources, are not affected and at the same time are incentivized for sharing their resources.

Public Access WiFi Service (PAWS) [3] is based on LCDNet using a set of techniques that make use of the available unused capacity in home broadband networks and allowing Less-than-Best Effort (LBE) access to these resources [1]. PAWS adopts an approach of community-wide participation, where broadband customers are enabled to donate controlled but free use of their high-speed broadband Internet by fellow citizens. Other initiatives have already explored sharing a user's broadband Internet connection via wireless (e.g., FON [6]). Although these methods are gaining worldwide acceptance, they are usually viewed as an extension of a user's paid service which is accessible only by other customers of the same service. In contrast, PAWS offers free access to essential services to all.

To protect the consumer's paid service and the service provider revenue, it is essential to ensure that the guest user traffic does not impact perceived performance of the bandwidth donor (customer). The PAWS service is therefore constrained to offer a LBE access to network resources (lower quality compared to the standard Internet service offered to paying users). Various methods are being considered, including enabling LBE QoS (both in layers 2 and 3) in the network.

PAWS is currently under deployment with 20 custom-made PAWS routers placed in a deprived community in Nottingham and another 10 routers in rural Scotland (Fig. 1). The testbed currently serves as a small-scale open network measurement

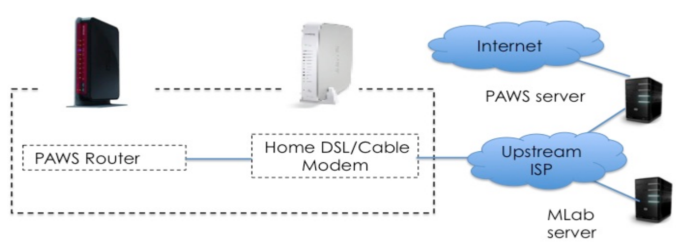


Fig. 1. PAWS network.

observatory in the UK that will allow researchers to gather data about network availability, reachability, topology, security, and broadband performance from distributed vantage points in socio-economically deprived urban and rural areas. A significant contribution of the PAWS deployment is that it currently serves as a crowd-shared access network (like FON) for under-privileged users in urban and rural communities. This provides the research community with a wealth of information on the needs of under-privileged users in terms of their access patterns and what do they use Internet access for. The testbed also provides researchers the opportunity to understand behavioral patterns of home broadband users in terms of how do they share their home broadband networks with the public, e.g., how often do they switch off their home access points and when (day/time) do they switch it off.

However, PAWS has faced ongoing deployment challenges such as limited coverage and most importantly due to home user sharing patterns. We have noticed that the PAWS routers were always not available mainly due to home users plugging off the PAWS router from the Ethernet socket of the home router and reusing the socket for their own use or because they did not want to share their Internet connection with the others for certain periods of the day or for other reasons such as economic constraints placed on home users in underprivileged areas where they are forced to conserve energy by turning off the routers at nights. Figure 2 presents a six-month view of the PAWS routers status (available/unavailable) logs demonstrating that not a single router was available continuously over the entire duration. These observed user behaviors have become serious challenges for the successful adoption of PAWS.

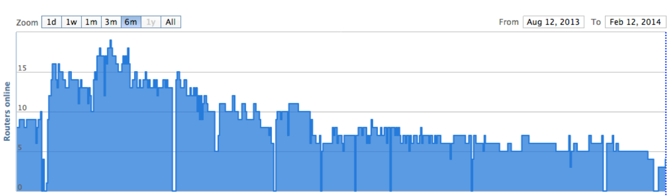


Fig. 2. PAWS routers availability.

The underlying problem with PAWS or any crowd-shared network (such as FON) is that they serve as single point of Internet access to users within the coverage of the wireless router and hence have no provision to extend the coverage or to provide any redundancy during unavailability of the routers which is mainly due to the sharers sharing tendencies or policies. A potential solution to these problems would be to extend the PAWS network as a crowd-shared mesh network. Such a network would allow home broadband users to share part of their own broadband connection to the public for free while also connected to each other as a wireless mesh providing extended coverage. This also offers network redundancy to the Internet backhaul even when some sharers decide not to share their backhaul Internet connection for certain periods of time.

In this paper, we explore the potential benefits of enabling PAWS or any crowd-shared wireless network as a crowd-shared wireless mesh network. Our paper provides the following contributions:

The rest of the paper is structured as follows: In Section II, we discuss the architecture of the simulated mesh network. Section **??** presents the simulation methodology. In Section III, we evaluate the benefits using simulations and discuss the results, while in Section **??** we provide a discussion. Finally we conclude in Section IV.

## II. Architecture

## III. Evaluation

In this section, we quantify the benefits of using a wireless mesh in crowd-shared home networks for public Internet access. In Section III-A, we present the simulation environment, the modeling of router on/off periods, and the metrics used to evaluate the efficiency of the wireless mesh. Section III-B provides a comparative study of crowd-shared home networks with and without a wireless mesh based on our simulation results.

### A. Simulation Environment

Using python, we developed a simulator that models the behaviour of guests flows in a crowd-shared network connected through a wireless mesh network. The simulator uses TFA wireless mesh topology [] which consists of 21 nodes. In our simulator, each TFA node represents an access home router which shares 8 Mbps of its internet access capacity, whereas each mesh link has the capacity a IEEE 802.11ac wireless link with 40 Mhz bandwidth and 200 Mbps data rate.

To model the sharing policy of the access routers owners, the simulator switches the router ON and OFF for different time periods during the simulation lifetime. The length of the ON and OFF period are randomly generated out of an exponential distribution with two different mean values (555 mintues for OFF period and 106 minutes for the ON period). The mean values are driven from real world data of home routers owners behaviour. To keep track of the ON and OFF period, the simulator equips each router with a timer which expires at the end of an ON/OFF period. The simulator distinguishes between ON and OFF status of a router by using a flag for each router which is true when the router is ON and False when the router is OFF.

To reflect real world traffic, we consider dynamic communication pattern where guests flows arrive to and departure from the network at certain time points. Flows arrival rates and durations are generated randomly based on Poisson and exponential distribution, respectively. Each flow has constant bit rate which is sampled out of a uniform distribution. Since in reality the flows load across the home routers may differ due to the number of guests connected to each router, we use geometric distribution to randomly choose at which router the next flow will arrive.

To grant internet access to the flows, the simulator implements two methods. The first method only give access to flows through the router at which they arrive given that there is enough internet access capacity. This method ignores the mesh network. On the other hand, the second method considers the mesh network by redirecting flows which does not fit in the local access routers to other routers through the mesh network. The router to which the flow is redirected are selected using worst-fit decreasing algorithm. The algorithm starts by sorting the flows to be redirected in non-decreasing order of their rates. Then, for each flow (starting with the flow with the highest rate), the algorithm selects the router with the highest available internet access capacity which fits the flow rate. The shortest path between the router is chosen based on the number of hops. The worst-fit decreasing algorithm is also used to redirect flows when a router goes OFF. This sustains as much as possible flows in the network and reduce disruption by the routers owners sharing policy.

The simulation proceeds in discrete time ticks. At each time tick, the simulator updates the ON/OFF timer of the access routers and subsequently switches the routers with expired timer ON or OFF depending on their current status. It also removes flows which expires and generates new flows if required. Furthermore, it assigns flows to home access routers either without considering the mesh network (method 1) or with the mesh network (method 2). When the mesh network is considered, the simulator also updates the available capacity of the mesh links through which the flows are redirected.

To evaluate the benefits of mesh network, we measure the average shared bandwidth utilization of the access router as well as the accumulated acceptance rate of the network at each time tick. At time tick $t$, we define *the accumulated acceptance rate= the total rates of flows finished up to* $t$ */ (the total rates of flows finished up to* $t$ *+ total rates of flows rejected up to* $t$*)*. From the acceptance rate, we exclude the flows which are still running and may finish in the future.

Due to the large mean values of the ON and OFF period (8 hours OFF and 1.5 hours ON), we run each simulation for 60 hours with time scale of 20 minutes. We perform 20 runs and report the average.

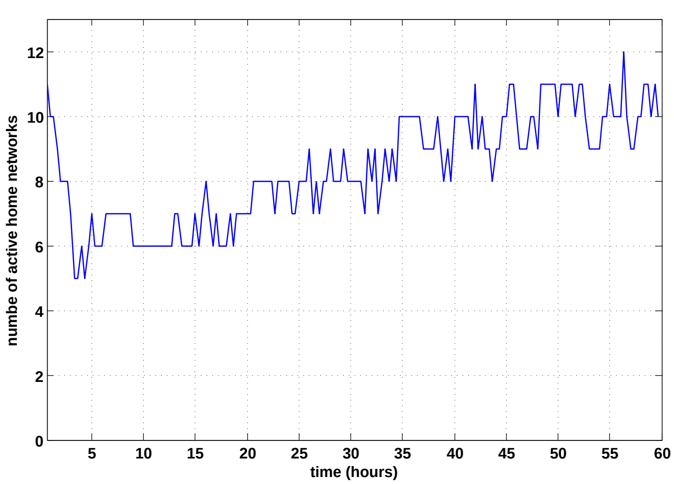


Fig. 3. Number of active home routers.

### B. Simulation Results

Initially, we measure the shared bandwidth utilization and request acceptance rate with an arrival rate of 50 flows per minute over a 60-hour period. Fig. 4 illustrates a low utilization of the shared bandwidth without a wireles mesh during the whole period, although there is high demand for Internet access by guest users attached to the various home networks. In contrast, a wireless mesh allows to capitilize the unused capacity and accommodate a larger volume of guest user traffic. More precisely, according to Fig. 4 guest user traffic redirection through the wireless mesh results in the full utilization of the bandwidth shared by home network users. Furthermore, crowd-shared home networks with a wireless mesh can accommodate substantially higher guest user traffic, as depicted in Fig. 5. This stems from the high utilization of the shared bandwidth.

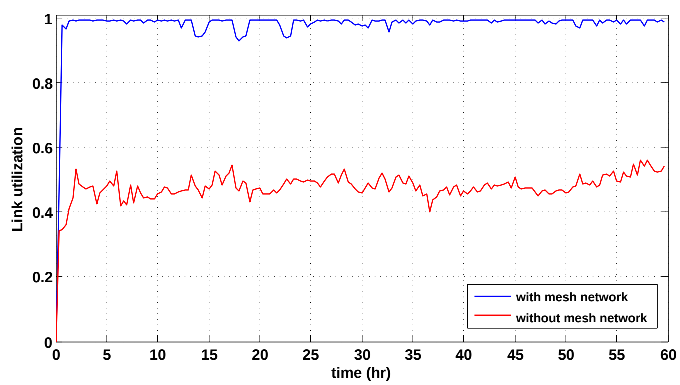


Fig. 4. Shared bandwidth utilization.

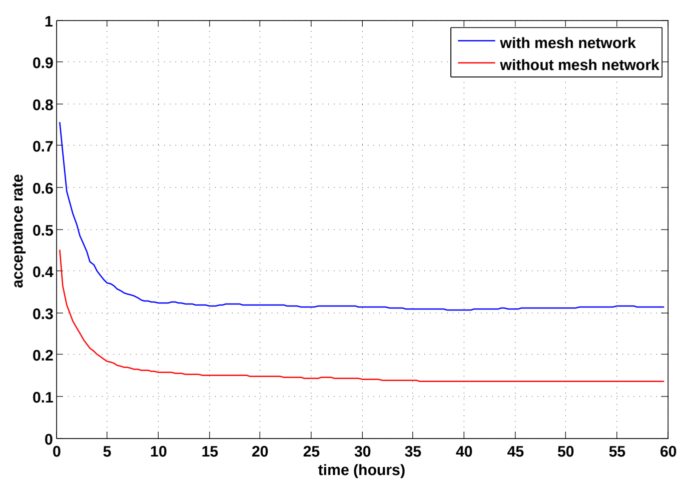


Fig. 5. Guest user traffic acceptance rate.

We further measure the shared bandwidth utilization with a wide range of guest user traffic demands. In this respect, Fig. 5 illustrates the shared bandwidth utilization with diverse flow arrival rates, ranging from 10 to 100 flows per minute. This simulation result corroborates the efficiency of the wireless mesh for various traffic loads, as the shared bandwidth utilization always remains very high. Without the presence of a wireless mesh, Fig. 5 shows poor bandwidth utilization, especially with low guest user traffic demand. In this particular case, the inability to redirect guest user traffic to home networks with available bandwidth results in wasting most of the shared bandwidth. Eventually, our simulation results show the significant benefit that a wireless mesh can bring in crowd-shared home networks, by effectively pooling shared resources across the interconnected home networks.

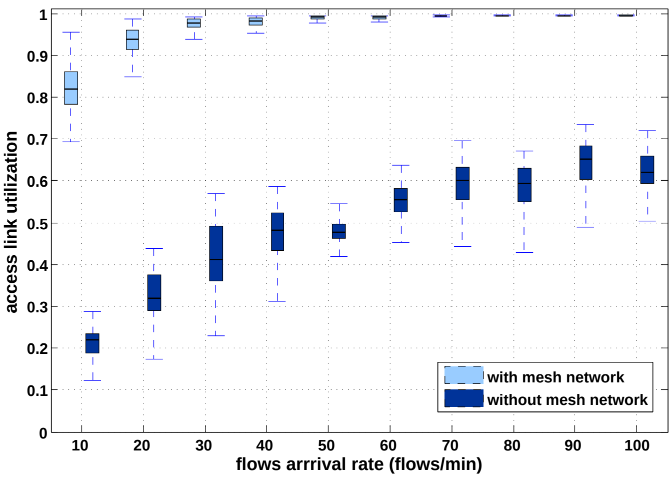


Fig. 6. Shared bandwidth utilization vs. flow arrival rate.

## IV. Conclusions

## V. Acknowledgments

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