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SciWiNet: Evaluating the Efficacy of a Mobile Virtual Network Operator for the Research Community

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Introduction

The United States government has been tremendously successful in funding exploration and development of infrastructure programs to stimulate research and development of computer networks and large scale systems. The Internet was originally motivated by the need to connect military sites and equipment in a robust manner. The Internet2 and the National Lambda Rail were motivated to facilitate large scale research in high performance computing. Large scale Internet testbeds such as PlanetLab, EmuLab, the Global Environment for Network Innovations (GENI) and CloudLab are exploring these and other advances to provide more versatile testbed platforms to better support large scale systems research [1-8]. These systems leverage the Internet or Internet2 to cost effectively expand the scale and consequently the impacts of the federal government investment. The economic models in the cellular industry are polar opposite to the economics surrounding the Internet. While the Internet was not designed to support mobile hosts, protocols and applications have adapted to support wireless. The economics behind wireless have made it very difficult for academic wireless testbeds such as Orbit, GENI/Wireless, PhantomNet to scale in terms of geographic footprint as well as in terms of diversity of radio access and device technology [9-10].

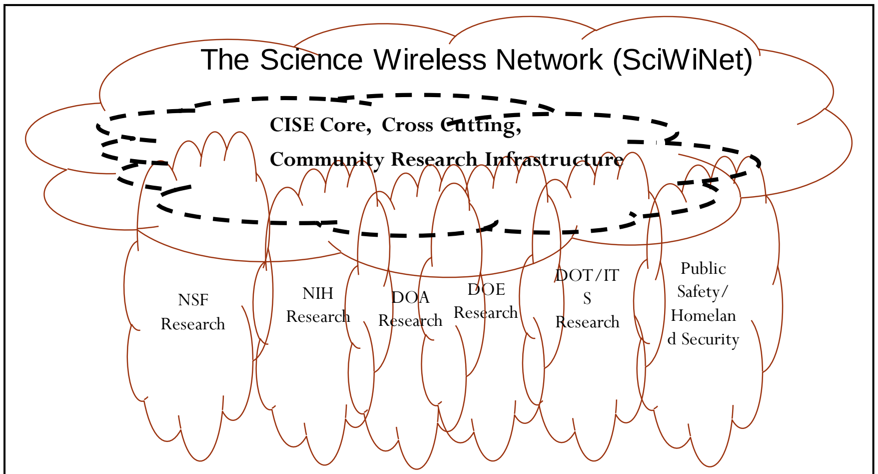

Figure 1. SciWiNet Concept

These issues in part have motivated the development of the Science Wireless Network (SciWiNet). Figure 1 illustrates the SciWiNet concept. The project was an exploratory engineering effort to evaluate a collaborative research wireless infrastructure that would facilitate research over a broad range of disciplines[1]. The dark dashed curve illustrates the broadening reach of fundamental CISE research including community wireless research infrastructure. Research in domains such as health, social sciences, SmartGrid, intelligent traffic systems, and public safety

[1] SciWiNet was funded by NSF CNS award number 1346632, "EAGER: Collaborative Research: SciWiNet: A Science Wireless Network for the Research Community".

are firmly intertwined with core CISE research and increasingly require wireless technology that frequently extends beyond just wireless access. The main objective of SciWiNet was to evaluate the efficacy of using an Mobile Virtual Network Operator (MVNO) as the anchor of community infrastructure to support academic research 'out in the wild'. In collaboration with Rutger's Orbit lab and the GENI project, the SciWiNet MVNO involved Clemson University and two companies in the cellular business, Arterra and Sprint . SciWiNet explored the concept of an MVNO and more specifically if an MVNO model might have the required level of flexibility that was anticipated to be required by the community. Another objective was to identify viable paths for SciWiNet to become a self-sustainable national resource.

The project started in August 2013. The MVNO went into service in December of 2013 and was taken offline December 2015. Through a series of phased project work items that involved different forms of interaction with diverse sets of researchers, we obtained feedback on the system allowing us to address the motivating questions. The results suggest that an MVNO might not offer the range of versatility required by the wireless network community. However, the details of our experiences with the design, implementation and operation of an MVNO provides a unique, albeit limited, glimpse inside the normally closed world of commercial cellular operators. Further, disseminating the lessons learned from the SciWiNet project might provide useful guidance for future research projects. This paper begins with a brief background discussion relevant to the project. This is followed by a summary of the project methodology and then a description of the system. The next section presents results primarily in the form of summaries of how different research groups used the system. This section also includes a summary of results from a survey we conducted of participating researchers as to their current and future needs for wireless infrastructure. We end the paper with a summary of our conclusions including lessons learned.

Background

The idea of a community research infrastructure to support large scale wireless research is certainly not new. PhoneLab engaged students and faculty to use a smartphone with data and voice service in return for allowing researchers to obtain sensing data from the device and in some cases to place install additional experimental software on the device [11]. Due to funding limits the concept was evaluated only at a single campus but the concept could scale to any level. Researchers from the wireless measurement community noted at a recent AIMs Workshop the need for community wireless measurement infrastructure [12]. The idea of an MVNO for the academic community has been explored by the community at least one other time prior to SciWiNet. NSF organized the Wireless National Scale Test Bed (WiNTeB) Workshop in 2010 to explore the community needs[2]. Feedback from the Workshop was a confirmation that the infrastructure could broadly help the academic community. However, the attendees recognized the potential diversity of users. They identified at least three targeted populations: (non-CISE) domain specific, networking specific, and cellular network specific. The feedback also suggested that the intellectual merit of an NSF project to fund the testbed would likely derive from what was learned about wireless networking and applications in setting up the testbed and through the results learned by each specific research project utilizing the shared

[22] The award abstract summarizing the funded WiNTeB Workshop can be found at NSF's site https://www.nsf.gov/awardsearch/showAward?AWD_ID=1029079. An unofficial copy of the workshop summary report is available at https://people.cs.clemson.edu/~jmarty/projects/docs/WiNTeB_Workshop_Report_v1.4-1.pdf

resource. To the best of our knowledge, a funded project did not emerge as a direct result of this workshop. However, the workshop represents the seeds leading to SciWiNet.

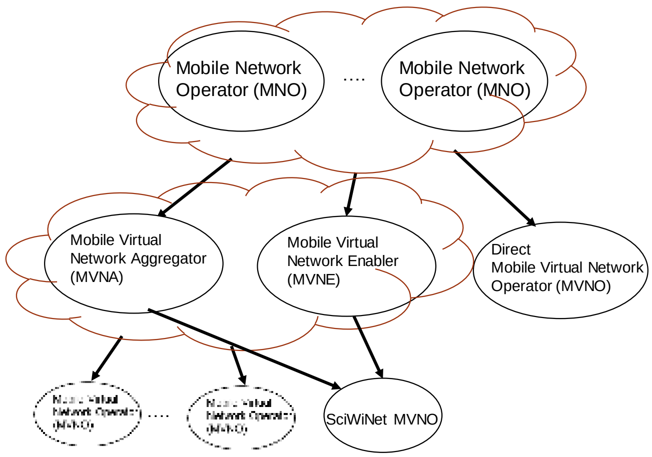

Figure 2. Defining System Concepts and Terminology

The cellular industry terminology and concepts applicable to SciWiNet are illustrated in Figure 2. Mobile Network Operators such as AT&T, Verizon, Sprint, T-Mobile all offered direct support for MVNOs. A direct MVNO would need to be sufficiently large to justify the upfront investment required to support all aspects of running a commercial cellular services company. MNO's sell wireless access to MVNOs in bulk, typically with incentives to purchase large quantities (thousands of GBytes) rather than smaller amounts. MVNOs cater to niche markets that are likely not of high interest to the MNO which tends to make MVNOs small. A Mobile Virtual Network Aggregator is a company that represents multiple MVNOs in order to acquire data at lower cost by aggregating demand across MVNOs. A Mobile Virtual Network Enabler that provides other services on behalf of MVNOs such as device provisioning or management, customer billing or service.

The academic literature reflects at least two research areas of interest related to MVNOs. The majority of work has been from the economics community [13-14]. The main interest has been to develop a theory to explore the self-imposed competition an MNO creates by launching MVNOs that share the resources managed by the MNO's subscribers. Recent work from the wireless measurement community has assessed if MVNO traffic might be treated differently, possibly with a lower priority, than MNO subscriber traffic [15-16]. The published results are quite varied making it difficult to draw concrete conclusions.

Methods

After an initial evaluation of possible approaches we opted to partner with Arterra Corporation to serve as the MVNA and MVNE. The main reasons for this decision were: 1)It was the fastest path to become operational as it avoided having to develop software to interact with an MSOs provisioning and device management subsystems; 2)Arterra provided a rudimentary online payment method to allow participants to purchase data; 3)Arterra was working towards an innovative direction that involved access to multiple MNOs (at the time, they were a Sprint partner but were working towards similar partnerships with T-Mobile and Verizon).

The project was organized into two main phases. First, with the assistance of Sprint and Arterra, the MVNO capabilities were identified and the system was made operational. Once operational, SciWiNet staff could order devices, provision devices with specific service plans, and manage devices and user accounts.

The second phase involved working with the MVNO 'customers' to learn community requirements. The 'customers' were academic researchers that volunteered to participate in the trial and subsequent evaluation. The researchers ranged from individual researchers from the NSF CISE research community who simply wanted a set of smartphones with cellular access for a limited time, to GENI wireless researchers who were interested in better understanding how they could utilize the network control framework provided by the MVNO, and finally to academic researchers outside of the engineering community who wanted to know how an MVNO might facilitate domain specific research 'out in the wild'.

Summary of the SciWiNet System

Figure 3 illustrates a simplified diagram of the SciWiNet system. From one perspective, the system was a cellular operator that provided cellular access including devices to customers. From another perspective, it was a project that purchased a pool of mobile devices and data access credit, made these resources available to researchers who wanted access, and interacted with the users and industry partners. The central research perspective of the project was to make available to researchers a cellular network and to investigate the design space of an MVNO and to explore how such a system could benefit the research community. In the remainder of this paper we refer to the principle investigators of the project as the system administrators and to the researchers who participated in the trial of the system as SciWiNet users.

Mobile devices that have been provisioned for SciWiNet are treated by Sprint's cellular network no differently from any of Arterra's other customers. Sprint's network forwards all Arterra traffic to an Arterra network location through an MPLS circuit. Arterra allows MVNOs to select from a number of service plans that Sprint supports. The set of plans does include an adaptive service rate plan that allows the MVNO to define the details of the adaptation including the specific set of available services rates and the thresholds in terms of subscriber byte consumption when a subscriber's rate is throttled.

The Arterra system provides the traffic and user management capabilities based on specific MVNO policies[3]. The specific capabilities and administrative interfaces are customized for each of their MVNO customers. To keep costs low, we utilized a bare bones system that did not include customer billing or online device purchase and provisioning. We created a simple script based mechanism to automate provisioning a new device. Once provisioned, we had access to a subscriber management system that allowed us to manage the devices as well as the traffic associated with devices. The management system provided a web interface (the Admin Portal shown in Figure 3). We summarize the capabilities of the system Arterra put in place for us to manage SciWiNet users.

The management system was based on a 'bucket' model to manage data usage. SciWiNet users were assigned '*data*' and '*points*'. The term '*data*' represents an allocation of SciWiNet pre-purchased access to the network in units of Mbytes. If a researcher was allocated 1 GByte of data, the researcher could have any of his/her devices access the network collectively consuming data from the allocation. A '*point*' is

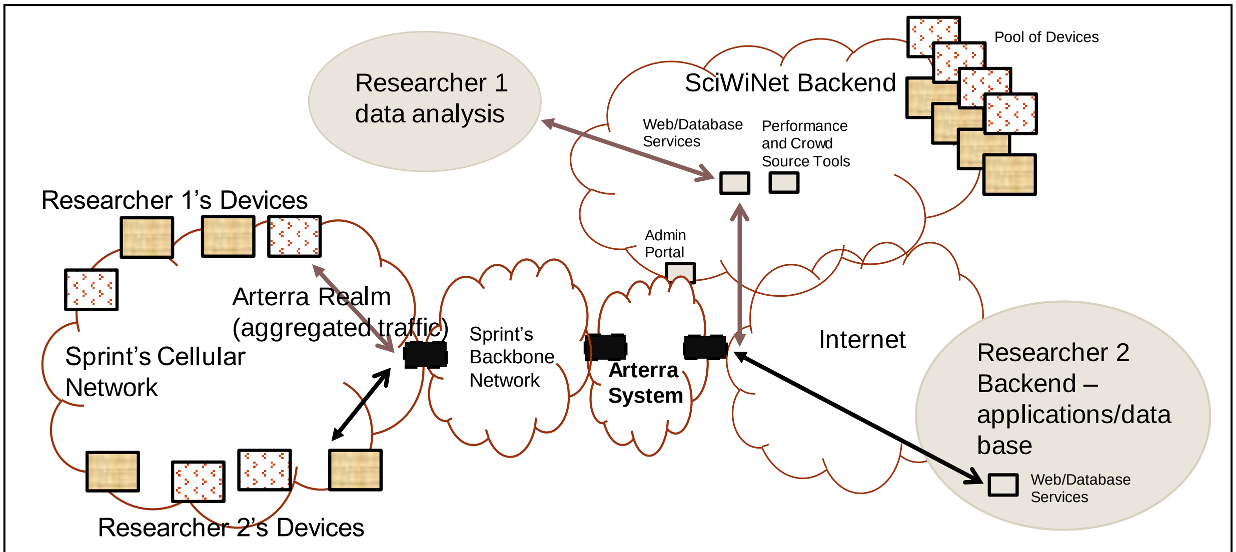

Figure 3. SciWiNet System Model

the mechanism used by Arterra to charge for the number of active devices. A '*wallet*' is an abstraction to manage the payment for data and points by users. To simplify the trial, we had a single wallet that the project used to purchase data and points for the set of SciWinet users throughout the trial. We allocated this data across all participants of the trial. If a researcher required more data or points, they could purchase this directly from Arterra as our service contract included a simple billing mechanism. As a University we could not accept payment for services from another University. To purchase more data, a researcher would issue a purchase order to Arterra who would add the data to the researcher's bucket. Only the GENI project purchased additional data.

The management system provided a hierarchical approach to classifying and grouping sets of users. A hierarchy can have its own 'bucket' of data and its own 'wallet'. More importantly, we could create administrative accounts for users to manage devices and traffic assigned to their hierarchy. We created a top level administrative hierarch for the SciWiNet project. called SciWiNet. The next level included a

[3] Please refer to http://www.arterramobility.com/arterra/ for further information on Arterra's service.

hierarchy for the PIs (Rutgers and Clemson) and also a hierarchy referred to as RESEARCH. This hierarchy included the initial set of collaborators participating in the trial. We wanted to see if a relatively small number of different research projects could be served through a single bucket. The problem was how to ensure specific users did not consume the majority of the data allocation. These users were not give administrative rights to the system. They were given devices that had a maximum allowed data 'allowance' that was a fraction of the total data in the RESEARCH bucket. Given the scope of SciWiNet, we were wary of completely opening up the system to large numbers due to the potential support issues and also liability issues if users violated contract agreements such as rooting SciWiNet provided devices. Later in the project, we added an additional hierarchy for the GENI community. Administrative access to devices in this hierarchy was provided to GENI administrators.

The following details were applicable to SciWiNet:

- Coverage was available wherever Sprint provided service. There were areas, especially rural locations, where coverage was poor or non-existent[4].
- Depending on the area, the access technology includes 3G, 4G based on WiMAX, 4G based on LTE.
- Users could use their own device as long as it was on the Sprint approved list. The procedure was manual – users contacted SciWiNet who submitted a porting request. The device would be provisioned within roughly 24 hours.
- SciWiNet service was limited to data. We could have included voice and text services, however this would have increased the cost and was consequently not considered.
- WiFi Hotspot was possible but required additional cost to setup. We chose not to offer this feature.

[4] Please refer to http://coverage.sprint.com/IMPACT.jsp? for detailed coverage information.

- The costs of the system included a one-time startup fee, an initial purchase of data and points, the purchase of roughly 20 devices for the pool, and then a monthly service charge representing Arterra software license and costs for providing necessary services and support.

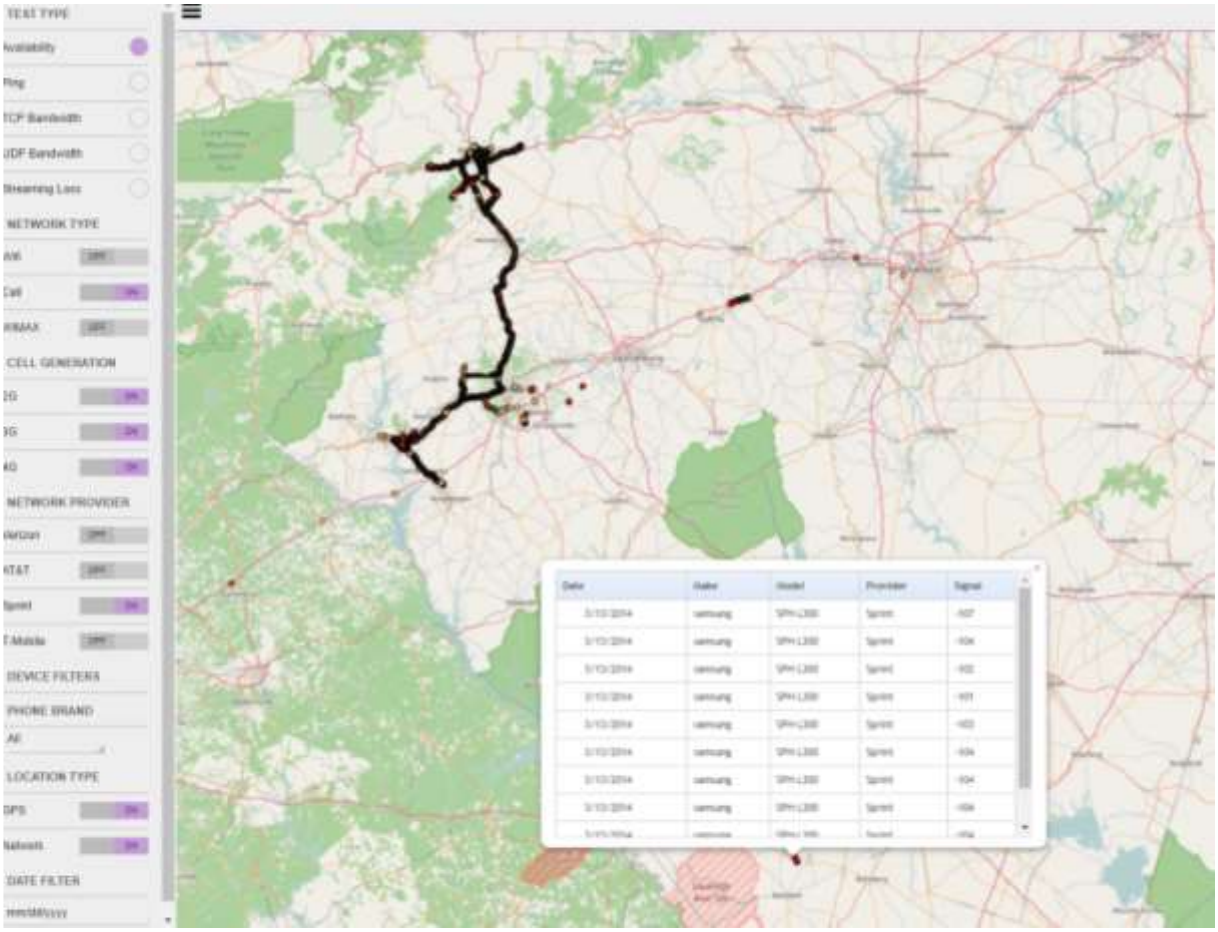

Figure 4. SciWiNet Coverage Data

Figure 3 identifies a number of components in the SciWiNet backend. These provide services that would likely be required by a subset of the user community[5]. The database services represents an open database that several projects used. The Performance and Cloud Source Tools was a tool made available to users for network assessment purposes. The performance service was open to any device that ran the client side of the tool and therefore collected data from any cellular operator. In addition to basic RF coverage information, the tool could obtain path throughput and loss assessments. Figure 4 illustrates data collected in the Upstate area of South Carolina that assesses the SciWiNet LTE coverage. The data table in the figure show several specific data points from the Aiken SC area. A REST API was developed allowing users to query the database for data.

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[5] We could have a version of Figure 2 that is specific to the GENI community. The SciWiNet backend is replaced by an equivalent system model of GENI.

SciWiNet Supported Devices

SciWiNet supported all devices that were on Sprint's 'approved list' for MVNOs[6]. Devices included USB-based dongles and Android smartphones. At the time we designed SciWiNet, Sprint MVNOs were not allowed to support iPhones. The LTE dongle and handset of choice was the Netgear 341U and the Google Nexus 5 and 6 models as both devices supported all three of Sprint's spectrum bands (800 MHz, 1.9 GHz, and 2.5 GHz). The GENI community used WiMAX devices such as the Samsung Galaxy SII and the Teltonika UM6223 dongle. These devices would also work with GENI/Wireless WiMAX equipment. If a SciWiNet device was outside the range of 4G, it would fall back to 3G if possible.

An issue of high interest by the wireless research community was device customization. As we had a legal contract with Arterra and Sprint, we were required to conform to Sprint's required usage rules. Extensive customization requires OEM approval which is expensive, consequently behind the scope of this project. However, smaller levels of customization for Android smartphones (that starts with an existing Sprint approved device) is feasible although it would incur cost to have Sprint to re-certify the device. It is likely that users were using rooted devices on SciWiNet. We followed the standard practice of indemnifying Clemson from legal recourse by having users accept terms and conditions before they could access the network.

Results

Project outcomes that address the core research issues derive primarily from feedback from SciWiNet's trial participants. The first year of the project focused on getting the network operational and then on carrying out a small scale trial of the network. In the second year, we opened the network to the GENI community. During peak time periods, we would see up to 20 active devices on the network however over longer timescales the network was lightly used. Feedback was obtained through an online survey involving thirty-six researchers representing 20 different universities. Most of the survey participants were also involved in the trial of SciWiNet. The questions were designed to learn current wireless needs, to obtain feedback specific to the SciWiNet trial including on possible future use and potential ideas for long term sustainability.

Year 1 controlled trial:

During the first year of the trial, we interacted a number of researchers individually. We summarize seven specific research, referred to as Project1 through Project7, projects all funded in part by NSF/CISE. Projects 1 through 5 all benefit from the cost and usage model provided by SciWiNet. Projects 6 and 7 benefit as devices from the SciWiNet pool could be multi-purposed and used for these projects. In addition, aspects of the SciWiNet services would be useful for both projects 6 and 7. While project is an example of a wireless research project that is focused on radio technology and might not immediately take advantage of SciWiNet's connectivity. Projects 4, 5 and 6 represent large wireless infrastructure projects. Projects 1, 5 and 6 indicate an interest in the use of multiple wireless networks

[6] Please refer to SciWiNet's discussion of supported (and not supported) devices at http://sciwinet.org/SciWiNet-Devices.html

possibly in use concurrently. Based on these direct project interactions, we draw the following conclusions:

- Research that requires cellular access involving a small number of devices with low bandwidth usage requirements would benefit from SciWiNet's device pool and low cost. However, research projects that involve a large number of users and over long time periods might benefit by brokering a direct deal with a cellular operator.
- Research that involves instrumented android devices could benefit from the SciWiNet community.
- Research that requires a cloud that offers storage and basic shared access and analytic capabilities would benefit.
- Research that involves radio specific details would not benefit as the intent of SciWiNet is to enable research out in the wild, but with limited access to the cellular network internals. Network researchers would benefit from SciWiNet's middleware box located at the cellular network egress/ingress – extending that box to support containers with researcher developed code would be an interesting direction.

Community Survey Results:

In 2014 we conducted an online survey in 2014 that was designed to provide feedback on the requirements of the academic research community for wireless infrastructure. There were 36 participants from 20 universities. All participants were academic researchers (faculty or post-docs). The survey was approved by Clemson's Internet Research Board (IRB) to ensure standard privacy procedures. Highlights of the survey include:

- Usage of wireless for research and education: 82% WiFi, 50% 50% Cellular data 3G/4G service
- Current devices: 70% Android, 36% iPhone, 33% embedded/custom, 50% use more than 2 devices
- Project duration requiring active devices: mean/median: 3.17/3.0 months, 44% <= 1month, expected usage for future projects will be greater than current usage
- Current data consumption: mean/median: 118/2 GBytes, expected usage in future similar
- Biggest complaint with current wireless: Only answer that was observed >3 times was related to poor coverage, high data costs, or limited plan flexibility
- Sustainability plan options for SciWiNet: 61% for a model that offers reduced wireless access cost if added to research proposal budgets; 42% for a model that offers reduced wireless access cost if agree to contribute devices to a 'shared' pool of devices managed by SciWiNet; 38% for a model that offers reduced wireless access cost if devices can be used by other researchers while in use by your project.

More detailed results are noted below (with the survey question number listed as a reference):

1. (Q6) Participant academic discipline: 78% Engineering, 8% Education
2. (Q7) Participant research areas: 55% Computer Science, 33% ECE, 2%CE, 2%ME
3. (Q8) Research areas: 47% Networking systems, 33% wireless networking, 25% sensing/M2M, 22% Algorithms, 25% Mobile apps
4. (Q9) What technologies were used for research/education: 82% WiFi on campus/home, 50%

experimental WiFi system, 50% Cellular 3G/4G service, 11%/17% voice/text service

5. (Q12) What network operators are used: 40% AT&T, 26% Sprint, 23% T-Mobile, 20% Verizon, 13% GENI, 33% None
6. (Q13) What devices have been used: 70% Android smartphone, 36% iPhone, 33% Android tablet, 33% embedded/custom device
7. (Q14) How many devices active at the same time: 50% use more than 2 devices, 30% used more than 10
8. (Q15) Monthly data limit on current plans: 36% unlimited, 16% have a plan providing 1 GByte or less.
9. (Q17) What services did were used: 60% 3G, 56% 4G, 20% text, 16% voice
10. (Q18) How much time the device needed to be active: The mean was 3.17 months, the median was 3 months. 44% of the participants that responded said 1 month or less was needed.
11. (Q19) How much data did was actually consumed over the entire project: The mean was 118 GBytes, the median was 2 GBytes.
12. (Q20) What is your biggest complaint: Only answer that was observed >3 times was related to poor coverage, high data costs, or limited plan flexibility.
13. (Q21) When might they need cellular data services in the future: 41% currently using or will use within 1 month, 20% will use within the next 12 months, 13% will use in the future but not sure when, 27% will probably not require cellular.
14. (Q22) How much time will be needed service for future use: Highly variable from 1 month to 60 months. The mean is 13.4 months, the median is 6 months.
15. (Q23) How many devices will be needed: the mean is 15, the median is 5.
16. (Q24) What type of devices will be needed: 72% Android smart phone, 20% Android tablet, 24% iPhone, 17% USB dongle, 17% embedded/customized
17. (Q25) Estimate of total data required by all devices per month: mean 64 Gbytes, median 2 Gbytes.
18. (Q26): What is the most important requirement: quite diverse, 34% speed not an issue but ubiquitous coverage important, 27% said LTE rather than 3G.
19. (Q27) : What is the most important service plan requirement: 50% said bucket model with shared use by all devices, 19% plan with no contract, 11% unlimited data
20. (Q28) Which seems to be the most effective incentive plan
    a. (61%) A model that offers reduced wireless access cost if added to research proposal budgets.
    b. (42%) A model that offers reduced wireless access cost if agree to contribute devices to a 'shared' pool of devices managed by SciWiNet (and made available to other researchers).
    c. (38%) A model that offers reduced wireless access cost if devices can be used by other researchers while in use by your project (the devices would run SciWiNet software that allows users to timeshare your devices in a controlled and secure manner).
21. (Q29) Ranking of requirements in the context of cellular needs identified device flexibility, support for multiple devices, reuse of devices, cost as the most important requirements.
22. (Q30) SciWiNet does not support Apple devices. 88% said this is OK.
23. (Q32) If SciWiNet were to meet your requirements would you use it for education or research: 84% for research, 53% for education, and 7% said it does not.

Conclusions

The needs of the academic community are very diverse. The majority of our participants (including survey participants) are from the wireless networking community. Therefore, are results are biased towards this community. Even within the wireless community, there are clearly visible sub-communities, each with their own specific requirements. However, in general, our findings suggest that the infrastructure required by the wireless research community includes at least the following : 1)customized cellular devices; 2)access to internal wireless information (from the base stations); 3)control of wireless network at least to support experimentation.

Over the course of the project we became familiar with Sprint's design space for an MVNO. The first step for Arterra when they design a solution for a new MVNO is to find the set of service plans that might be appropriate for the MVNO's anticipated customers. Of particular interest was a dynamic rate control plan that allowed the MVNO to define the set of reduced rates and the consumption threshold levels that could be used to throttle subscriber traffic. It would be possible to extend SciWiNet to allow researchers to conduct experiments involving specific services plans. A further extension would be to develop a SciWiNet middleware box at Arterra facilities that not only supports traffic management and measurement capabilities but that could support microservices allowing researcher provided filters or control to be applied to traffic. Sprint maintains quite a bit of data related to subscriber usage that is, in some cases, correlated with location and use of specific cellular resources. With minor extensions SciWiNet could have made available subsets of this information to researchers, although not in real-time. Sprint has a mechanism to push out network usage data at a particular frequency.

While it is unlikely that an MVNO would be helpful to the software define radio or even wireless MAC layer researchers, it does open up interesting possibilities for measurement, middleware, and cellular systems research. The economic benefits of an MVNO that caters to the broader academic community are more difficult to precisely know. The cost of a bulk purchase of data can change on a weekly basis. Based on our experience, the bulk cost is likely to provide at least a 50% savings compared to the lowest price available direct with the MNO. The SciWiNet bucket model was of interest to the participants in our study. However, most cellular operators now use bucket models for IoT-oriented service plans. The motivations driving SciWiNet are likely to grow as technology, and in particular wireless technology, is fundamental to any new infrastructure projects funded by federal research or economic stimulus programs.

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