

SCIFI – A Software-Based Controller for Efficient Wireless Networks

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Abstract

SCIFI is an open source software wireless controller. Large scale wireless networks that use low cost (SOHO) Access Points are hard to install and run due to the complexity of configuring and monitoring many APs with a distributed interface, coupled with the difficulty of creating a good network configuration with no help from the system. On the other hand, hardware controllers and their compatible APs are too expensive, proprietary and ultimately tie the buyer to a single vendor. SCIFI allows the use of inexpensive hardware to create large scale wireless installations. This paper describes the SCIFI algorithms, its interface, the current deployment at UFF and the future work planned for SCIFI.

Keywords

IEEE 802.11, wireless network deployment, AP controller, scifi.

1. Introduction

SCIFI is an acronym in Portuguese for intelligent control system for wireless networks (Sistema de Controle Inteligente para redes sem Fio). SCIFI is open source, and uses as hardware off-the-shelf, low cost SOHO routers compatible with OpenWRT or any other Linux-like OS to build medium and large scale wireless networks. The project was developed at the Fluminense Federal University (UFF) and funded by Brazilian NREN (RNP). SCIFI intends to be an extensible platform, including all the tools needed for installing, operating, securing and managing wireless networks using low cost hardware and free software.

In order to cover large areas, network administrators have to install a significant number of Access Points (APs) which makes the configuration and administration of the wireless environment a complex task. Also, using several APs can lead to a low spectral efficiency if their channel utilization is not coordinated and, as the medium is shared, other sources can also interfere in the same frequency. Therefore, a using a centralized algorithm for channel allocation

can be an interesting choice to reduce interference and, consequently, achieve better network performance.

The goals of centralized configuration management and coordinated usage may be achieved by the use of proprietary solutions that cater to events or institutions with high usage and high user density. These solutions typically use expensive hardware and tie customers to a single vendor, as there is no inter-operation between different brands. SCIFI is able to fulfill both goals with an open source solution, replacing the expensive single vendor APs with multi-vendor SOHO APs.

The SCIFI controller is extensible and allows customization, but it already provides channel selection and power control algorithms to maximize spectrum usage and allows the use of large numbers of APs. The SCIFI architecture consists of a software controller that can be run in any Linux box, requiring low processing power, and software running in the APs. The controller coordinates data collection from APs, which feeds the channel selection and power control algorithms, stores the information needed to run the system and provides a web interface where a system administrator can configure parameters of the SCIFI system (such as the frequency of dynamic channel allocation) and monitor the wireless network elements. Due to its use of auto-configuration, site surveys are no longer needed. The rule of thumb for installing APs is to divide the number of users by 20, and install the corresponding number of APs in each area. Experience at large events and public venues has shown that a single AP is able to handle larger number of users (up to 100) if the bandwidth requirements are low - twenty is a good number for heavy users. The full system also includes customized monitoring software using SNMP (NAGIOS and MRTG), and uses EDUROAM for user authentication.

SCIFI networks are already in use at UFF, the Federal University of Ouro Preto and the Brazilian Navy, as well as at a number of different events, and have proven to be a stable, low-cost and easy-to-install solution for controlling wireless APs.

This paper is divided in six sections. The next section describes the evolution of wireless usage, the requirements that led to the creation of SCIFI and the other players in the field. The third section describes the core SCIFI functions. The fourth section describes the parts that compose SCIFI. The fifth explains the current deployment at UFF, which can be used as the paradigm for other deployments, and the article ends with conclusions and the next steps for SCIFI.

2. Large Scale Wireless Deployments

Wireless devices are becoming increasingly inexpensive and ubiquitous. This lead to changes in the requirements for wireless installations. First there was the move from isolated hotspots to the current complete coverage model. In this model, the previous practise was to focus on coverage, and minimize the number of Access Points (APs) used for that. The technique used to guarantee coverage is called a site-survey. Using floor plans, an initial distribution is planned. Then, one AP is placed and measurements are made to guarantee that it is possible to connect to the network at several points around the AP. This is repeated until no area is left without coverage. After installation, another pass is done to validate the architecture. Site surveys are complex and work intensive, and may not give accurate results if the distribution of people is not taken into account.

When the number of APs used in one installation increased, the distributed mode of control became too complex. Complexity leads to fragility, where errors in configuration become more common, and to inefficiencies, where the wireless network is not configured to the optimal state. This led to the adoption of centralized control, instantiated in hardware controllers. Several vendors sell wireless controllers, which normally look like switches but have additional functions. Those are usually very expensive, and because there is no interoperability between vendors, once a controller is bought, the client cannot go to other brand without giving up a substantial investment.

Another approach is to use a software controller. The best known solution is Unifi (Ubiquiti (2013), from Ubiquiti, but other vendors, like EnGenious (2013) also have a software controller. They are free, and can be downloaded or come bundled with their hardware. Unfortunately, like their hardware counterpart, they only work with hardware from the specific vendor that distributes them, and no source code is provided to adapt to other hardware.

There are several nice characteristics associated with wireless controllers. The ability to control the network from a single point. The possibility of automating some tasks, such as the wireless channel selection. The added security to be able to scan the network looking for anomalies. But as no single solution had all desired characteristics, or was too expensive for large deployments, we decided to build an open source software controller. The tasks was simplified by the previous work done with the open-source firmware for APs called OpenWRT. (OpenWRT,2013)

OpenWRT is a linux distribution for embedded systems. We knew we could make a control framework and change commands and data easily and securely on APs running OpenWRT. Besides this makes the project hardware independent, as any AP that runs OpenWRT is compatible with the project. A mix of ssh (Ylonen and Lonvick, eds. 2006) and SNMP (Case, Fedor, Schoffstall and Davin,1990) is used to gather information from and configure APs in SCIFI, and in fact, even OpenWRT is not a requirement, as many other OS have ssh and SNMP (such as AirOS,(2013) from Ubiquiti, RouterOS from Mikrotik, (2013), DDWRT (2013) and others), and to be compatible requires little work.

One of the hardest steps of installing a wireless network is the planning and site survey. The best practice should be to do away with site survey and minimize the difficulty of planning. This calls for a self-configurable network, and some easy rules-of-thumb for spatially distributing the APs. If access points are expensive, this is not easy, because each additional Access Point in a non-optimal configuration (that which uses more than the minimal number of APs) means a significant amount of money. On the other hand, if APs are not expensive, the problem becomes easy. A single AP running OpenWRT can handle 60 users with some head-room. At UFF, to allow for future growth we have planned for 20 users at each AP, or one AP for each room. A good rule of thumb is to put one AP for each 30 users, and enough APs to cover the important areas. This may mean one AP for each room, or one AP each 30 meters. Overlaps are ok, because the system adapts to them, as we will describe later. Overlaps also allow for equipment failures without compromising the network.

For wireless networks, self-configuration means choosing which channel and at what power level to operate. Current software controllers let the user choose the channel and power level, but without extensive information. It also has an automatic mode, but with local information (no

global, centralized state). Hardware controllers use global information for minimizing interference and maximizing throughput. In SCIFI we implemented a centralized state to get optimal channel and power configuration, and also created mechanisms for dynamic reconfiguration.

It is not a very well known fact that the optimal configuration changes with time. People are very good absorbers of radio energy at WIFI frequencies. The radio environment changes as spaces get filled and emptied of people. Interference from sources such as other WIFI devices or any radio-emitting equipment come and go. Some of the interferences are of short duration, but long term interferences should be dealt with by reconfiguring the network. This requires a dynamic reconfiguration scheme. Of the software controllers available today, only SCIFI implements dynamic reconfiguration.

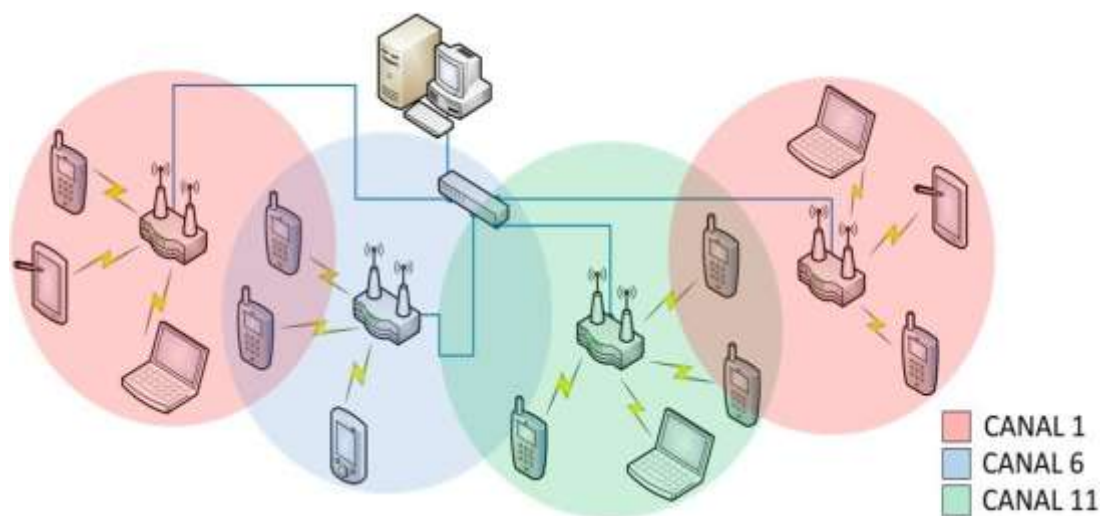


Figure 1: Orthogonal channels.

3. SCIFI Algorithms

According to the requirements, we need auto-configuration of channel and power levels, and dynamic configuration so the system can adapt to changes in the environment and also to equipment failures, by increasing coverage areas of the AP surrounding the failure. SCIFI models the network as a graph, and the problem becomes a graph coloring with three colors (in 2.4GHz used in most inexpensive IEEE 802.11g and n). The algorithm has been described in Postgres (2013), and experiments have shown that it not only increases throughput for SCIFI APs, but by being a “good neighbor” and minimizing interference, it also increases throughput to other neighbor wireless networks. In a nutshell, the algorithm starts by collecting data at each AP by listening to beacons from other APs. The APs are either controllable or not. The APs that are

not under the control are already “colored”, that is, their channel is fixed, and are mapped to one of the three colors available (channels 1, 6 and 11 - Figure 1) if they are not already using these channels. The controlled APs start with no color and are then assigned to the colors starting with the AP which has the greatest number of neighbors of different colors. When a color is assigned, the number of neighbors of the unassigned APs change to reflect that. The process repeats always selecting the AP with greatest number of neighbors of different colors until all APs have been configured.

After channel selection, the set of APs is divided in subsets with “orthogonal” (non-interfering) frequencies. In the case of 2.4GHz, three subsets. In each of these subsets, the power configuration algorithm is run. The power on the APs radio can be set in discrete steps, given by the firmware. Each hardware has a specific number of power levels, and the network administrator can choose which levels will be used in the configuration interface, shown below on section 4.

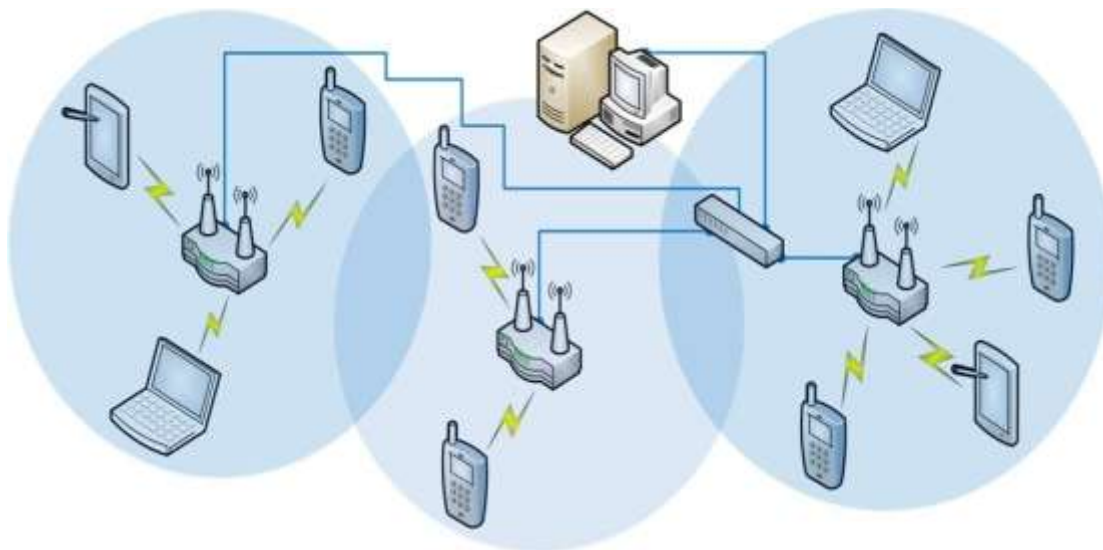


Figure 2: Power level.

It should be said that IEEE 802.11 does not have automatic gain control, unlike cellular telephony networks. Cell phones are constantly measuring the “radio distance” between them and the radio tower, and both the infrastructure and the phone change the power level used according to the distance, using a lower power level if they are near and higher power level if they are far apart. On IEEE 802.11 networks, the way to cope with variations on the signal to noise ratio (S/N) is to change the data encoding, using a more efficient encoding if the station is near and a more robust (and therefore less efficient) encoding if the station is far. The frame header, which has to be received by all stations (and not only those exchanging data) is always sent at the base encoding so it can be decoded at all meaningful distances. On the other hand, it is

possible to set the power level used by each AP, which will be used by every frame sent. The algorithm to find a good power level for each AP lowers the power step by step, until it is no longer “seem” (that is, their beacons are no longer received) by its neighbors, and then goes up one power level step. This minimizes interference and guarantees good coverage (Figure 2).

4. Installing and Operating SCIFI

SCIFI begin as a java implementation of the core algorithms, but grew by receiving new features that are somewhat isolated from the core. In fact, once the core became stable it has not changed much. The last update to the core algorithm happened more than four months ago. But system configuration using command line and configuration files please only hard core unix hackers, so a graphic interface was created that allow APs to be added using a google maps API (which makes it easier to give the AP location, which is a requirement for EDUROAM, see below). As the pilot grew to from 20 APs to the 240 installed as of last week (500 APs are already bought and being installed), the need for tools to help operation became apparent, and with new deployments the need of an automated installation interface was clear.

The general architecture for the system can be seen on Figure 3. Part of the system runs on the controller. Four modules comprise the core functions, implementing the algorithms described above in section 3, the communication with the APs, data collection (which gets the data from the APs) and database interfacing. Two modules compose the application server, the web interface for monitoring and management, and the database communication module. The last two pieces are a Database module (Postgres2013) and a monitoring platform, composed of Nagios(2013) MRTG(2013) and Monitorix(2013)

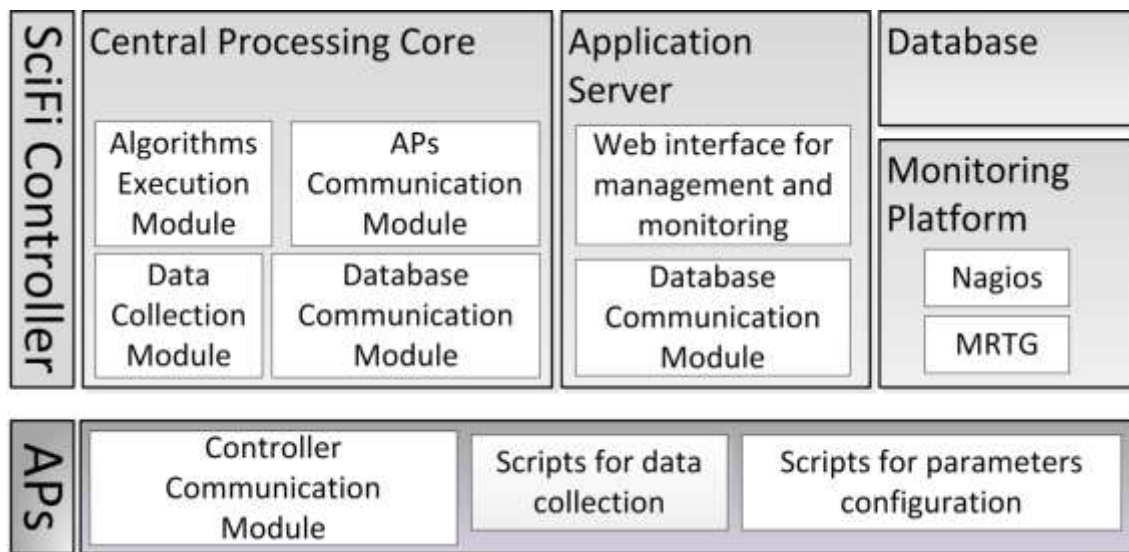


Figure 3: System architecture.

Three modules run on the APs: the communication module, which talks to the server; the data collection scripts; and the parameters configuration scripts. Those use SSH and SNMP to communicate with the server. There is an API that allows the controller to ask for specific data from the AP. Data is collected using commands like iwconfig and the required information is

selected using UNIX commands like grep and awk. Scripts have been made for different models: Ubiquiti's Bullet, nanoStation and picoStation, TP-Link TL-WR740nd and TL-WR743d, D-Link DIR 600. To add a new model to SCIFI means porting the scripts.



Figure 4: Controller interface.

The interface for the controller can be seen in Figure 4. There are four buttons on the left side, and they are AP, AREA, COMMANDS, CONFIGURATION and MONITORING. Respectively, they allow: adding, editing and listing APs; adding and deleting AREAS; executing controller COMMANDS such as forcing the execution of the algorithms, or to restart the controller (Figure 5 shows the new page); finally, the last two buttons allow access to the controller CONFIGURATION and to the MONITORING interface.



Figure 5: Commands page.

The monitoring interface uses Nagios, Monitorix and MRTG. The MRTG user page can be seen in Figure 6. The menu on the left has three buttons. The first allows choosing to view by type

(bandwidth, users, wireless, memory and CPU usage). The second allows choosing to view by device. The third is the access to the graph of disk usage on the controller.

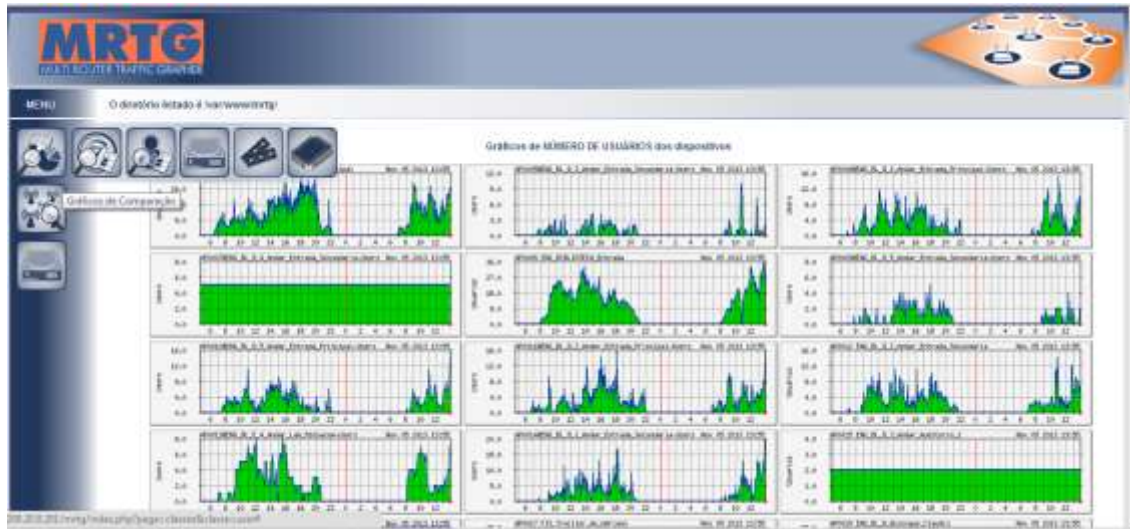


Figure 6: MRTG user page.

The server installation is done by a script called Easy Life for SCIFI (EL-SCIFI). It is currently a simple, albeit long, shell script that install all needed packages and creates an initial configuration. The AP installation is done by a script that copies the needed files and updates some configuration files. Help can be found at the [gtscfi-community](#) in googlegroups.

5. Deployment at UFF

SCIFI has been deployed as a pilot in many institutions. As it is open-source, available at [github.org/sci-fi](https://github.com/sci-fi), we do not control or know all deployments, but besides UFF, UFOP (Universidade Federal de Ouro Preto) has adopted SCIFI as the main component of its institutional wireless network. MidiaCom also has helped deployment at CASNAV (a research laboratory of the Brazilian Navy), at FISL (the International Forum for Open Source Software at Porto Alegre, Brazil), Niteroi Digital (free access at the city of Niteroi public squares) and at SPOLM (the Brazilian Navy Symposium for Operational Research).



Figure 7: Map of deployment at UFF, Niteroi.

The deployment at UFF has currently 240 APs (Figure 7). It will ultimately have four thousand nodes. UFF is a large university, and has 92 buildings in separate campi at the city of Niteroi (they are interconnected by dark fiber that belongs to the University), besides campi at other cities in the state of Rio de Janeiro (Volta Redonda, Campos, Rio das Ostras) and a campus in the state of Pará (Oriximiná).



Figure 8: Deployment at the Engineering Campus.

In Figure 8 we see the details of the deployment at the engineering campus. Each square is an AP. APs in red are turned off at the control interface. APs in green are working, and APs in orange are not responding.

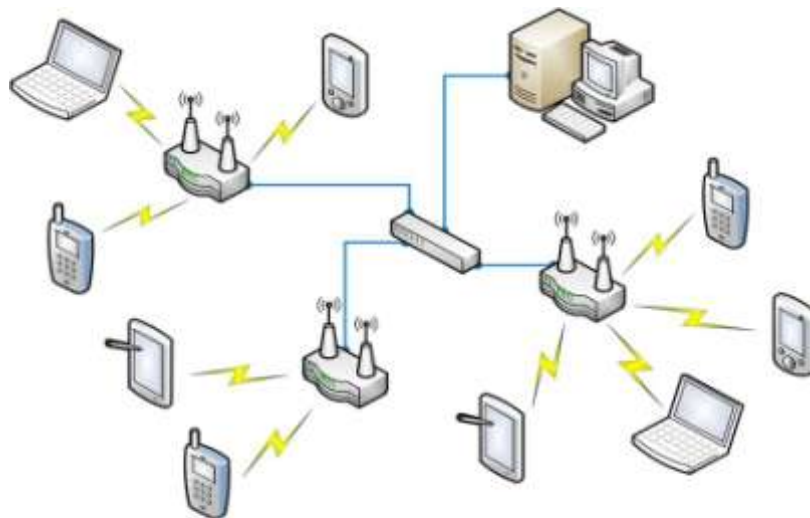


Figure 9: Architecture.

One of the constraints we had on our networks architecture is that we wanted to have seamless handoff between the APs. This allows some applications, like IP-phones (which are easily implemented with SIP clients and Asterisk (Asterisk, 2013)), to work with mobile users. Therefore, it is planned that for each campus we have a single DHCP server for all wireless clients, and a VLAN interconnecting all access points. Currently we have a single SCIFI controller, which is also the NAT (Egevang, and Francis, (1994) and DHCP (Droms, 1997) server, and a VLAN connecting all APs. The SCIFI controller was designed to work with areas, which are sets of APs that interfere with each other, and normally map to a campus. This is still not a requirement, as the workload is still small with two hundred APs, but will be when all four thousand APs are installed. It is in our development wishlist to be able to “federate” controllers, which for us means to distribute monitoring information so University staff responsible for operations can have an unified view of the wireless network, even if multiple instances of the SCIFI controller are installed.

The model of the network can be seen in Figure 9. It is the standard model, where the distribution system is represented by a switch (in our case it is a VLAN, but does the same job to interconnect the different APs). We use a model of three SSIDs for each AP. There is an SSID EDUROAM, which allows all students and staff at the University to access the wireless network, as well as visitors belonging to institutions federated to EDUROAM (2013) It uses IEEE 802.11i and IEEE 802.1x, with a Radius server and and LDAP backend. UFF is the uff.br radius realm. We also wanted visitors to be able to self-register on the network. The scheme to do that uses two other SSIDs. The SSID CADASTRO-CONFIGURAÇÃO (sign-in/setup) is an open network that allows visitors to create an account and new EDUROAM users to configure their device. As in Brazil all cell phones require the user to be identified, we send an SMS message with the login and password to new users (visitors), and tie the account to the cell phone number and document number. Both visitors and EDUROAM users use the same authentication method, and this is not very easy to setup. The web site and helper applications make this process less painful. The only difference between regular users and visitors is that visitors use the VISITANTES SSID, while students and faculty (both from UFF and federated institutions) use the EDUROAM SSID. The SMS is sent using an android smartphone and the SMS GATEWAY application (SMS Gateway, 2013). The helper applications use software from EDUROAM CAT (Winter, 2013)

6. Conclusions and Future Work

The development of SCIFI has been going on for three years. It has grown from a very small core that allowed for efficient use of the spectrum by low-cost Access Points to a system composed of many open-source package and a medium code-base. As every open-source system, it needs to keep on evolving or die. Because SCIFI is being used in the institutional wireless network of two large public institutions in Brazil means that some resources will be available for its maintenance, but the creation of a larger user base will ease the burden for all as problems will be found faster and solutions can be shared. One Brazilian maker of access points is studying the addition of SCIFI to its products, which also bodes well for the continuation of the project.

As a wireless controller, SCIFI works better than other free offerings, and has the added advantage of being hardware agnostic. Compared to hardware implementation, it has a significantly lower cost. In Brazil, the price of a SCIFI system with the same number of APs is

1/30 of the price of the hardware implementation. This allows the creation of much larger networks for the same budget. It is true that the hardware of major vendors is better than the SOHO APs used in SCIFI, but because of the cost advantage is so great, more access points can be installed, which null that disadvantage.

In fact, SCIFI calls for a paradigm shift. Instead of trying to minimize the number of APs used to make the budget feasible, use as many APs as possible. Ultimately, this gives better coverage, makes more bandwidth available to users and give more resiliency to the network than the old approach. The self-configuration approach allows the dense use of APs while maintaining low interference.

The characteristics of an open-source project means that SCIFI is highly configurable. There is a long wish list of characteristics that we want to add to SCIFI. Two of them are better heuristics for starting self-configuration, and algorithms to use the wireless scan already done to identify possible security risks or attacks to the wireless network. At UFF, the APs are being adapted to do access control (by connecting them to RFID readers and electric locks) and for security (by using wireless IP cameras for surveillance).

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Biographies

Luiz Claudio Schara Magalhães has a PhD in Computer Science from the University of Illinois at Urbana-Champaign. He has been a professor at the Telecommunications Department at Universidade Federal Fluminense since 1994, instructor at UIUC, Visiting Scholar at HP-Labs in Palo Alto and is currently working on the creation of wired and wireless testbeds for Future Internet research and free software for large scale wireless deployments. His main research interests lie in the area of wireless, mobility, large scale infrastructure to support mobile nodes, hiperconnectivity (high redundancy last mile access) and device environment awareness and cooperation.

Helga Dolorico Balbi graduated in Production Recording at Estacio de Sá University (2007), degree in Telecommunications Engineering at Federal Fluminense University (2009) and MSc in Telecommunications Engineering at the Federal Fluminense University (2012). Currently pursuing a PhD in Computer Science at Federal Fluminense University.

Cosme Corrêa has a BS in Computer Science from UFF, Post-grad work both in Business Management at FGV-SP and Theology at UniLaSalle, MS in Production Engineering at UFF. Currently works at UFF in the deployment of SCIFI. His research interests are in the area of computer security, network management and user support.

Rafael De Tommaso do Valle is Coordinator of Research and Development at RNP. Rafael has graduation and M.S. degrees in Telecommunications Engineering at Federal Fluminense University (UFF) in 2008 and 2011, respectively. He works at RNP since 2011 and currently has been coordinating R&D projects involving advanced internet, wireless networks, dynamic circuits, video applications and accessibility.

Michael Stanton is Director of Research and Development at RNP. After a PhD in mathematics at Cambridge University in 1971, he has taught at several universities in Brazil, since 1994 as professor of computer networking at the Universidade Federal Fluminense (UFF) in Niterói, Rio de Janeiro state. Between 1986 and 2003, he helped to kick-start research and education networking in Brazil, including the setting-up and running of both a regional network in Rio de Janeiro state (Rede-Rio) and RNP. He returned to RNP in 2001, with responsibility for R&D and RNP involvement in new networking and large-scale collaboration projects.