

# 9. SECURITY FOR WIRELESS NETWORKS

## 1. Introduction

While unlicensed spectrum provides a huge cost savings to the user, it has the unfortunate side effect that Denial of Service (DoS) attacks are trivially simple. By simply turning on a high powered access point, cordless phone, video transmitter, or other 2.4GHz device, a malicious person could cause significant problems on the network. Many network devices are vulnerable to other forms of denial of service attacks as well, such as disassociation flooding and ARP table overflows.

There are several categories of individuals who may cause problems on a wireless network:

### **Unintentional users.**

Densely populated areas such as city centres and university campuses can lead to a density of wireless access points. In these populated areas, it is common for laptop users to accidentally associate to the wrong network. Most wireless clients will simply choose any available wireless network, often the one with the strongest signal, when their preferred network is unavailable.

The user may then make use of this network as usual, completely unaware that they may be transmitting sensitive data on someone else's network.

Malicious people may even take advantage of this by setting up access points in strategic locations, to try to attract unwitting users and capture their data.

The first step in avoiding this problem is educating your users, and stressing the importance of connecting only to known and trusted networks.

Many wireless clients can be configured to only connect to trusted networks, or to ask permission before joining a new network.

As we will see later in this chapter, users can safely connect to open public networks by using strong encryption.

**War drivers.**

The “war driving” phenomenon draws its name from the popular 1983 hacker film, “War Games”.

War drivers are interested in finding the physical location of wireless networks.

They typically drive around with a laptop, GPS, and omnidirectional antenna, logging the name and location of any networks they find. These logs are then combined with logs from other war drivers, and are turned into graphical maps depicting the wireless “footprint” of a particular city.

The vast majority of war drivers likely pose no direct threat to networks, but the data they collect might be of interest to a network cracker. For example, it might be obvious that an unprotected access point detected by a war driver is located inside a sensitive building, such as a government or corporate office.

A malicious person could use this information to illegally access the network there. Arguably, such an AP should never have been set up in the first place, but war driving makes the problem all the more urgent. As we will see later in this chapter, war drivers who use the popular program NetStumbler can be detected with programs such as Kismet.

For more information about war driving, see sites such as:

<http://wagle.net/>,

<http://www.nodedb.com/>, or <http://www.stumbler.net/>.

**Rogue access points.**

There are two general classes of rogue access points:

Those incorrectly installed by legitimate users, and those installed by malicious people who intend to collect data or do harm to the network. In the simplest case, a legitimate network user may want better wireless coverage in their office, or they might find security restrictions on the corporate wireless network too difficult to comply with.

By installing an inexpensive consumer access point without permission, the user opens the entire network up to potential attacks from the inside. While it is possible to scan for unauthorized access points on your wired network, setting a clear policy that prohibits them is a very important first step.

The second class of rogue access point can be very difficult to deal with. By installing a high powered AP that uses the same ESSID as an existing network, a malicious person can trick people into using their equipment, and log or even manipulate all data that passes through it. Again, if your users are trained to use strong encryption, this problem is significantly reduced.

### **Eavesdroppers.**

As mentioned earlier, eavesdropping is a very difficult problem to deal with on wireless networks. By using a passive monitoring tool (such as Kismet), an eavesdropper can log all network data from a great distance away, without ever making their presence known.

Poorly encrypted data can simply be logged and cracked later, while unencrypted data can be easily read in real time.

If you have difficulty convincing others of this problem, you might want to demonstrate tools such as

Driftnet (<http://www.ex-parrot.com/~chris/driftnet/>).

Driftnet watches a wireless network for graphical data, such as GIF and JPEG files. While other users are browsing the Internet, these tools simply display all graphics found in a graphical collage. While you can tell a user that their email is vulnerable without encryption, nothing drives the message home like showing them the pictures they are looking at in their web browser. Again, while it cannot be completely prevented, proper application of strong encryption will discourage eavesdropping.

## **2. Protecting the wireless network**

In a traditional wired network, access control is relatively straightforward: If a person has physical access to a computer or network hub, they can use (or abuse) the network resources. While software mechanisms are an important component of network security, limiting physical access to the network devices is the ultimate access control mechanism. Simply put, if all terminals and network components are physically only accessible to trusted individuals, the network can likely be trusted. The rules change significantly with wireless networks. While the apparent range of your access point may seem to be just a few hundred metres, a user with a high gain antenna may be able to make use of the network from several blocks away.

Should an unauthorised user be detected, is impossible to simply “trace the cable” back to the users location.

Without transmitting a single packet, a sufficiently talented nefarious user can capture and log traffic on a wireless network to disk.

This data can later be used to launch a more sophisticated attack against the network. Never assume that radio waves simply “stop” at the edge of your property line, or inside your building. Physical security in wireless networks is limited to preventing compromise of the active components, cables and power supply.

Where physical access to the network cannot be prevented we have to rely on electronic means for controlling access to the wireless infrastructure in order to only allow authorised persons and systems to use the wireless network. But remember, while a certain amount of access control and authentication is necessary in any network, you have failed in your job if legitimate users find it difficult to use the network to communicate. Lastly, it is usually unreasonable to completely trust all users of the network, also on wired networks. Disgruntled employees, uneducated network users, and simple mistakes on the part of honest users can cause significant harm to network operations. As the network architect, your goal is to facilitate private communication between legitimate users of the network and between legitimate users and services.

There's an old saying that the only way to completely secure a computer is to unplug it, lock it in a safe, destroy the key, and bury the whole thing in concrete. While such a system might be completely “secure”, it is useless for communication. When you make security decisions for your network, remember that above all else, the network exists so that its users can communicate with each other. Security considerations are important, but should not get in the way of the network's users.

A simple rule-of-thumb as to whether or not the network is getting in the way of its users is to look at how much time you or other staff spend on helping people get on the network.

If regular users are repeatedly having problems simply gaining access to the network, even after they have been provided instruction and training on how to do so, it's possible that the access procedures are too cumbersome and a review of them is in order.

Taking all of this into account, our goal is to provide adequate physical security, control access protect the communication without sacrificing ease

of use.

### 3. Physical security for wireless networks

When installing a network, you are building an infrastructure that people depend on. Security measures exist to ensure that the network is reliable. Wireless networks have physical components, such as wires and boxes, which are easily disturbed. In many installations, people will not understand the purpose of the installed equipment, or curiosity may lead them to experiment.

They may not realise the importance of a cable connected to a port. Someone may unplug an Ethernet cable so that they can connect their laptop for 5 minutes, or move a switch because it is in their way. A plug might be removed from a power bar because someone needs that receptacle. Assuring the physical security of an installation is paramount. Signs and labels will only be useful to those who can read your language. Putting things out of the way and limiting access is the best means to assure that accidents and tinkering do not occur. In your locality, proper fasteners, ties, or boxes may not be easy to find.

You should be able to find electrical supplies that will work just as well. Custom enclosures are also easy to manufacture and should be considered essential to any installation. It is often economical to pay a mason to make holes and install conduit. PVC can be embedded in cement walls for passing cable from room to room. This avoids the need to smash new holes every time a cable needs to be passed. Plastic bags can be stuffed into the conduit around the cables for insulation. Small equipment should be mounted on the wall and larger equipment should be put in a closet or in a cabinet.

#### Switches

Switches, hubs or interior access points can be screwed directly onto a wall with a wall plug. It is best to put this equipment as high as possible to reduce the chance that someone will be able to touch the device or its cables without significant effort.

#### Cables

At the very least, cables should be hidden and fastened. It is possible to find plastic cable conduit that can be used in buildings. If you cannot find it, simple cable attachments can be nailed into the wall to secure the cable.

This will make sure that the cable doesn't hang where it can be snagged, pinched or cut.

When fastening cable to the wall, it is important to not nail or screw into the cable itself. The cable contains many tiny wires that the network data travels over. Nailing through the cable will damage it and make it useless for transmitting data. Take care also to not overly bend or twist the cable as this will damage it as well.

It is preferable to bury cables, rather than to leave them hanging across a yard. Hanging wires might be used for drying clothes, or be snagged by a ladder, etc. To avoid vermin and insects, use plastic electrical conduit. The marginal expense will be well worth the trouble. The conduit should be buried about 30 cm deep, or below the frost level in cold climates. It is worth the extra investment of buying larger conduit than is presently required, so that future cables can be run through the same tubing. Consider labeling buried cable with a "call before you dig" sign to avoid future accidental outages.

### **Power**

It is best to have power bars locked in a cabinet. If that is not possible, mount the power bar under a desk, or on the wall and use duct tape (or gaffer tape, a strong adhesive tape) to secure the plug into the receptacle. On the UPS and power bar, do not leave any empty receptacles. Tape them if necessary. People will have the tendency to use the easiest receptacle, so make these critical ones difficult to use. If you do not, you might find a fan or light plugged into your UPS; though it is nice to have light, it is nicer to keep your server running!

### **Water**

Protect your equipment from water and moisture. In all cases make sure that your equipment, including your UPS is at least 30 cm from the ground, to avoid damage from flooding. Also try to have a roof over your equipment, so that water and moisture will not fall onto it. In moist climates, it is important that the equipment has proper ventilation to assure that moisture can be exhausted. Small closets need to have ventilation, or moisture and heat can degrade or destroy your gear.

### **Masts**

Equipment installed on a mast is often safe from thieves. Nevertheless, to

deter thieves and to keep your equipment safe from winds, it is good to over-engineer mounts.

Painting equipment a dull white or grey colour reflects the sun and makes it look plain and uninteresting. Panel antennas are often preferred because they are much more subtle and less interesting than dishes. Any installation on walls should be high enough to require a ladder to reach. Try choosing well-lit but not prominent places to put equipment. Also avoid antennae that resemble television antennae, as those are items that will attract interest by thieves, whereas a wifi antenna will be useless to the average thief.

#### **4. Authentication and access control**

Talking about authentication a number of related terms like (digital) identity, authorisation, privacy etc. pop up. So before we get into authentication proper we need to introduce some terminology, without trying to be exhaustive.

Digital identity is the electronic entity that is a representation of a physical entity, like a person or a device. Authentication is the process of verifying the claim that an (electronic) entity is allowed to act on behalf of a given known (physical) entity. In other words, authentication is the process of proving that the physical entity corresponds to a certain electronic one. Authorisation in turn is the process of establishing the rights of the identity to access certain resources or to perform certain tasks. Privacy, finally, is a complex issue but has to do with the right of a person not to have their personal data and behaviour be known to parties that do not strictly need it to provide the service the users request. So for example, it is reasonable for a liquor shop to know that a customer is above a certain age before selling alcoholic drinks, but not to know the name of the customer, and third parties should not have any knowledge of the transaction at all. Privacy is of particular concern in a world in which users increasingly use networks and services outside their home environment. Without proper attention to privacy aspects it is too easy to trace a users behaviour and movement.

It is worth mentioning that there is a trade-off between authentication and privacy. Verifying the identity of a user in itself invades the user's privacy, the authenticating party knows who is using what resource at a particular time and location, but the challenge is to minimise the amount of

information about a user and the number of parties that are privy to that information.

In the context of this book we are mainly interested in techniques for controlling access to the network. In other words, we want to be able to decide who (authenticated identity) gets to access what (authorisation) without sacrificing privacy.

Authentication is typically done by proof of knowledge of a secret (a password, a signature), possession of a token or characteristic (a certificate, a fingerprint) or both. Access control is often needed to make sure that only authorised users can use the network, to prevent exhaustion of scarce resources and/or compliance with rules and regulations. In addition to access controlled networks there may also be open networks with limited access or for a limited time, but due to the need for organisations to control access to their scarce resources and also anti-terrorist laws they become less ubiquitous. Over the years a number of techniques have been employed to control access to wireless networks. Subsequently they have been mostly abandoned due to security or scalability issues as WiFi became increasingly popular.

### **Mac filtering**

Access to a WiFi network can be based on the MAC address. This is the 48-bit number assigned by the manufacturer to every wireless and Ethernet device, and that is supposed to be unique and persistent. By employing mac filtering on our access points, we can authenticate users based on their MAC address.

With this feature, the access point keeps an internal table of approved MAC addresses.

When a wireless user tries to associate to the access point, the MAC address of the client must be on the approved list, or the association will be denied. Alternatively, the AP may keep a table of known “bad” MAC addresses, and permit all devices that are not on the list. Unfortunately, this is not an ideal security mechanism. Maintaining MAC tables on every device can be cumbersome, requiring all client devices to have their MAC addresses recorded and uploaded to the APs. Even worse, MAC addresses can often be changed in software. By observing MAC addresses in use on a wireless network, a determined attacker can spoof (impersonate) an approved MAC address and successfully associate to the AP.

While MAC filtering will prevent unintentional users and even most

curious individuals from accessing the network, MAC filtering alone cannot prevent attacks from determined attackers.

MAC filters are useful for temporarily limiting access from misbehaving clients. For example, if a laptop has a virus that sends large amounts of spam or other traffic, its MAC address can be added to the filter table to stop the traffic immediately. This will buy you time to track down the user and fix the problem.

### Closed networks

Another at one time popular "authentication feature" of WiFi networks is the so-called closed network mode. In a typical network, APs will broadcast their ESSID many times per second, allowing wireless clients (as well as tools such as NetStumbler) to find the network and display its presence to the user. In a closed network, the AP does not beacon the ESSID ("hidden ESSID"), and users must know the full name of the network before the AP will allow association. This prevents casual users from discovering the network and selecting it in their wireless client. There are a number of drawbacks to this feature. Forcing users to type in the full ESSID before connecting to the network is error prone and often leads to support calls and complaints. Since the network isn't obviously present in site survey tools like NetStumbler, this can prevent your networks from showing up on war driving maps. But it also means that other network builders cannot easily find your network either, and specifically won't know that you are already using a given channel.

A conscientious neighbour may perform a site survey, see no nearby networks, and install their own network on the same channel you are using. This will cause interference problems for both you and your neighbour.

Finally, using closed networks ultimately adds little to your overall network security. By using passive monitoring tools (such as Kismet), a malicious user can detect frames sent from your legitimate clients to the AP. These frames necessarily contain the network name. The malicious user can then use this name to associate to the access point, just like a normal user would. Encryption is probably the best tool we have for authenticating wireless users. Through strong encryption, we can uniquely identify a user in a manner that is very difficult to spoof, and use that identity to determine further network access. Encryption also has the benefit of adding a layer of privacy by preventing eavesdroppers from easily watching network traffic. Encryption is the technique that is used

for authenticating users in most current deployments.

## WEP

The first widely employed encryption method on WiFi networks was WEP encryption. WEP stands for Wired Equivalent Privacy, and is supported by virtually all 802.11a/b/g equipment. Incidentally, this is a complete misnomer as the privacy that WEP provides is in no way equivalent to that of wired connections. WEP uses a shared 40-bit key to encrypt data between the access point and client. The key must be entered on the APs as well as on each of the clients.

With WEP enabled, wireless clients cannot associate with the AP until they use the correct key. An eavesdropper listening to a WEP-enabled network will still see traffic and MAC addresses, but the data payload of each packet is encrypted.

This provided an authentication mechanism while also adding a bit of privacy to the network. WEP is definitely not the strongest encryption solution available.

For one thing, the WEP key is shared between all users. If the key is compromised (say, if one user tells a friend what the password is, or if an employee is let go) then changing the password can be prohibitively difficult, since all APs and client devices need to be changed.

This also means that legitimate users of the network can still eavesdrop on each others' traffic, since they all know the shared key.

The key itself is often poorly chosen, making offline cracking attempts feasible. But most importantly, WEP itself is broken, making it very easy to gain illegal access the network.

So WEP should not be used anymore.

For more details about the state of WEP encryption, see these papers:

<http://www.isaac.cs.berkeley.edu/isaac/wep-faq.html>

<http://www.cs.umd.edu/~waa/wireless.pdf>

## "Switched" wireless networks

One critical difference between modern switched Ethernet networks and wireless is that wireless networks are built on a shared medium.

They more closely resemble the old network hubs than modern switches, in that every computer connected to the network can "see" the traffic of

every other user.

To monitor all network traffic on an access point, one can simply tune to the channel being used, put the network card into monitor mode, and log every frame.

This data might be directly valuable to an eavesdropper (including data such as email, voice data, or online chat logs). It may also provide passwords and other sensitive data, making it possible to compromise the network even further. WPA and 802.1X are designed to make the wireless network behave like a switched rather than a shared network.

## WPA

Another data-link layer authentication protocol is Wi-Fi Protected Access, or WPA. WPA was created specifically to deal with the known problems with WEP mentioned earlier. WPA was intended to be a backwards compatible interim solution while the full standard 802.11i (WPA2) was developed.

WPA and WPA2 can operate in combination with the 802.1X umbrella standard for wireless authentication (see below) but also much in the same mode as WEP, with a shared secret between all clients and the AP, the so-called Pre Shared Key (PSK) mode (the WiFi Alliance calls WPA-PSK "WPA Personal", as opposed to "WPA Enterprise" that is used in combination with 802.1X).

Overall, WPA provides significantly better authentication and privacy than standard WEP, mainly by leveraging the Temporary Key Integrity Protocol (TKIP) that continuously and automatically changes the keying material between clients and access points.

Unfortunately precisely the backwards compatibility of TKIP has given rise to some attack vectors against TKIP that allow for decrypting certain encrypted packets, that in turn can be manipulated for further attacks.

More information can be found in the following articles:

<http://dl.aircrack-ng.org/breakingwepandwpa.pdf>

[http://download.aircrack-ng.org/wiki-files/doc/enhanced\\_tkip\\_michael.pdf](http://download.aircrack-ng.org/wiki-files/doc/enhanced_tkip_michael.pdf)

The consequence of these discoveries is that it is wise to move to the next generation of secure WiFi access protocols: WPA2.

## WPA2-PSK

WPA2 is the full IEEE 802.11i standard.

The main difference with WPA is the use of the Advanced Encryption System (AES) instead of TKIP a (so far) not broken encryption standard.

So the use of WPA2 with AES can be considered secure for now!

## 5. Summary

The major downside of any of these last three authentication methods is that, regardless of the strength of the encryption, they are still built upon the notion of a common shared secret between all clients and the access point.

They don't allow for identifying individual users and frankly, a secret shared by potentially tens of thousands of users can hardly be called a secret.

Another serious problem with wireless networks to which access is controlled by any of the methods mentioned, is that its users are relatively anonymous.

While it is true that every wireless device includes a unique MAC address that is supplied by the manufacturer, as mentioned these addresses can often be changed with software.

And even when the MAC address is known, it can be very difficult to judge where a wireless user is physically located.

Multi-path effects, high-gain antennas, and widely varying radio transmitter characteristics can make it impossible to determine if a wireless user is sitting in the next room or is in an apartment building a mile away.

The concerns about security, accountability and scalability have led to the rise of what is commonly called identity-based networking.

### Identity-based networking

In identity based networking individual users are being authenticated

rather than secrets shared between many users.

Typically the authentication system verifies user credentials against some sort of enterprise database or directory.

Commonly by using the RADIUS protocol, a protocol originally designed for controlling access to dial-in modem pools but sufficiently versatile to serve as generic access control protocol for network access.

### **Captive portals**

One common authentication tool used on wireless networks is the captive portal. A captive portal uses a standard web browser to give a wireless user the opportunity to present login credentials.

It can also be used to present information (such as an Acceptable Use Policy) to the user before granting further access.

By using a web browser instead of a custom program for authentication, captive portals work with virtually all laptops and operating systems. Captive portals are typically used on open networks with no other authentication methods (such as WEP or MAC filters).

To begin, a wireless user opens their laptop browser and is directed to the portal.

They will then be asked to accept the use policy or answer other questions such as entering a user name and password, and click on a “login” button, or perhaps type in numbers from a pre-paid ticket.

The user enters their credentials, which are checked by the access point or another server on the network.

All other network access is blocked until these credentials are verified.

After verification their computer will receive a DHCP lease.

They can then use their web browser to go to any site on the Internet.

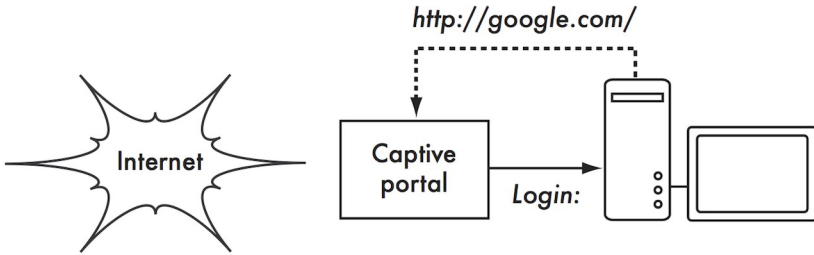


Figure SWN 1: The user requests a web page and is redirected.

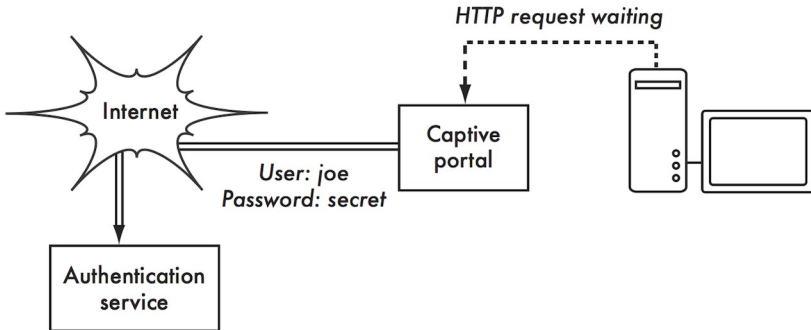
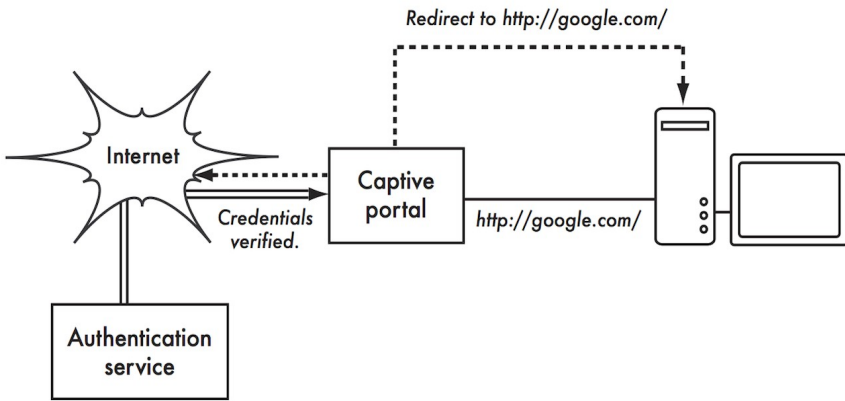


Figure SWN 2: The user's credentials are verified before further network access is granted. The authentication server can be the access point itself, another machine on the local network, or a server anywhere on the Internet.



*Figure SWN 3: After authenticating, the user is permitted to access the rest of the network and is typically redirected to the original site requested - in this case Google.*

Captive portals provide no encryption for the wireless users, instead relying on the MAC and IP address of the client as a unique identifier, which can be spoofed easily, many implementations will therefore require the user to keep a connection window open. Since they, just like MAC- or WEP-based, do not provide protection against eavesdropping (they use a shared medium) and are vulnerable to session hijacking, captive portals are not a very good choice for networks that need to be locked down to only allow access from trusted users.

They are much more suited to cafes, hotels, and other public access locations where casual network users are expected. Another downside of captive portals is that they rely on the use of a browser for authentication, which can be very counterintuitive for users that just try to check their e-mail or send an instant message, not to mention the fact that many wireless devices like sensors, printers and cameras don't have a builtin browser.

In public or semi-public network settings, encryption techniques such as WEP and WPA are effectively useless. There is simply no way to distribute public or shared keys to members of the general public without compromising the security of those keys.

In these settings, a simple application such as a captive portal provides a level of service somewhere between completely open and completely closed. Many vendors and open source projects exist that provide captive portal capability, to name a few:

- CoovaChilli, CoovaAP (<http://coova.org/CoovaChilli/>), Coova is the successor of the no longer actively maintained Chillispot project. Coova allows for the use of a RADIUS authentication backend.
- WiFidog (<http://www.wifidog.org/>), WiFi Dog provides a very complete captive portal authentication package in very little space (typically under 30kb). From a user's perspective, it requires no pop-up or javascript support, allowing it to work on a wider variety of wireless devices.
- M0n0wall, pfSense (<http://m0n0.ch/wall/>), m0n0wall is a complete embedded operating system based on FreeBSD. It includes a captive portal with RADIUS support, as well as a PHP web server.

Many general networking vendors offer some form of integrated captive portals, e.g. Mikrotik, Cisco, Aruba, Atilo.

## 6. 802.1X

In enterprise and campus deployments, the most common wireless network authentication framework is that based on IEEE 802.1X. 802.1X is a layer 2 protocol that can be used both for wired and wireless network authentication and in fact comprises a number of technologies. 802.1X describes the interaction between the client device (supplicant in 802.1X) and the Access Point or Switch (Authenticator) as well as that between the Access Point or Switch and a backend RADIUS server (Authentication Server) that in turn verifies user credentials against an enterprise directory (or flat file for that matter). Finally, 802.1X describes how to transport user credentials from the supplicant to the authentication server transparently to the authenticator or any other device in the path by leveraging the Extensible Authentication Protocol (EAP).

The encryption between the supplicant and the authenticator can be done using rotating WEP-keys, WPA with TKIP or WPA2 with AES. For the reasons mentioned in the paragraph on WEP, WPA-PSK and WPA2-PSK, WPA2 with AES is highly recommended.

Probably the most interesting feature of the 802.1X is the use of EAP. EAP defines a generic way of encapsulating credentials and transporting them from a supplicant (client software) to an authentication server (RADIUS server). So-called EAP-methods define how specific authentication methods can be encapsulated into EAP. There are EAP-methods for all common types of authentication methods like certificates, SIM-cards, username/password, one-time passwords and hardware tokens. Due to key or token distribution problems with handing out tokens or certificates and revocation the vast majority of large scale deployments use what are called tunnelled EAP- methods: username/password based authentication using a TLS tunnel to the authentication server through which the actual username and password are transmitted. The user identity used for the TLS-envelope is typically of the form anonymous@domain (this is called the outer identity) whereas the inner identity (inside the TLS tunnel) is of the form username@domain. This distinction is particularly interesting for roaming to other organisations networks. It is possible to transport the authentication credentials of a user over the Internet while only revealing the home organisation of the user (the domain part), but that is the topic of the next paragraph. So what happens in a typical 802.1X authentication with a tunnelled EAP-method is the following:

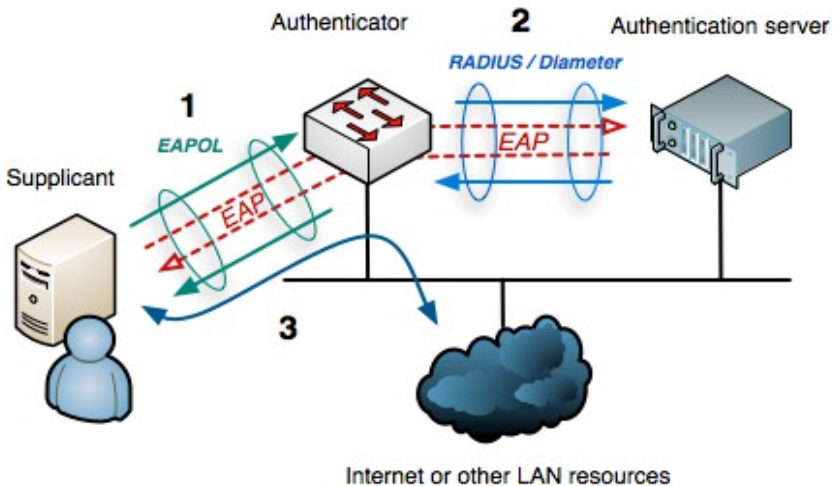


Figure SWN 4: The use of 802.1X with tunnelled EAP for network access (courtesy SURFnet)

The client associates with the Access Point (authenticator).

The Access Point requests the client (supplicant) to authenticate.

The client sends an EAP message containing a TLS packet with an outer identity `anonymous@domain` and inside the TLS packet `username@domain` and the password to the access point over the 802.11 link (EAP over LAN or EAPoL).

The Access point receives the EAP-message, encapsulates it in RADIUS and sends it to the organisational RADIUS server (authentication server).

The RADIUS server decapsulates the EAP-message and verifies the user credentials against some sort of backend like a flat file, an LDAP directory, Active Directory or something else.

If the credentials are valid the RADIUS server sends back a RADIUS Access Accept message to the Access Point. The Access Point gives the client access to the wireless LAN.

The client performs a DHCP request, gets an IP-address and is connected to the network.

There are a number of tunnelled EAP-methods that essentially work the same, the differences are in the support in common operating systems, the vulnerability to dictionary and man-in-the-middle attacks and whether they require storage of clear-text passwords in the backend.

The most widely deployed tunnelled EAP-methods nowadays are EAP-TTLS (EAP Tunnelled Transport Layer Security) and PEAP (Protected EAP).

There have been incompatible implementations of PEAP due to disagreements between the proponents of PEAP (Apple, Cisco and Microsoft) resulting in a large uptake of TTLS. The fact that these incompatibilities are largely solved and the lack of native support for TTLS in a number of common OSes (Apple iOS and MS Windows variants) have resulted in an increase in uptake of PEAP. A newer EAP-method that is gaining traction is EAP-FAST due to its security properties. EAP-FAST has also been chosen as the basis for the new to be developed tunnelled EAP-method (TEAP) that the IETF expects to be the single endorsed one.

## 7. Inter-organisational roaming

RADIUS has the interesting property that RADIUS messages can be proxied to other RADIUS servers.

That means it is possible for an organisation to allow for each others users to gain access to the network by authenticating to their home organisation's RADIUS server.

When the RADIUS server of organisation A receives an authentication request from `anonymous@organisationB.org` it can forward the request to organisation B's RADIUS-server instead of verifying the credentials locally. Organisation B's RADIUS server in turn can verify the credentials and send the access accept back to organisation A's RADIUS server, that then tells the Access Point to allow the user access. This so-called federated access allows for the creation of very scalable and large deployments while at the same time allowing the individual organisations to apply their own authentication policies to their users.

While RADIUS proxying is certainly possible in captive portal deployments it definitely shines in an 802.1X/EAP environment.

By using EAP the user credentials can be protected so that only the home organisation of the user is able to see them.

This way large deployments can be created without the leakage of credentials and without teaching users to enter their secret credentials in every website that is thrown up in front of them. As an example, eduroam, the roaming wireless access federation in education, that extends the above concept slightly by instead of having direct RADIUS connections between organisations, it builds a hierarchical system of national and international RADIUS servers, allowing millions of students to gain access to over 5000 campus networks in many countries in all continents with the exception of Antarctica.

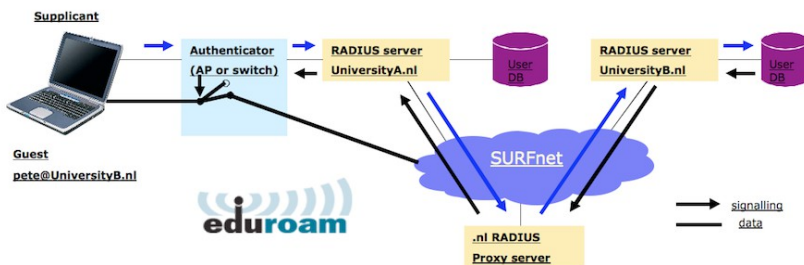


Figure SWN 5: The eduroam infrastructure for world-wide roaming in academia

## 8. End to end encryption

It should be noted that whereas WEP, WPA-PSK and WPA2-PSK are using encryption techniques to provide access control and protect against eavesdropping, they only protect the wireless traffic between client and access point, not on the wired part of the communication path. In order to protect the communication against unauthorised tampering or eavesdropping end to end encryption is needed.

Most users are blissfully unaware that their private email, chat conversations, and even passwords are often sent “in the clear” over dozens of untrusted networks before arriving at their ultimate destination on the Internet. However mistaken they may be, users still typically have some expectation of privacy when using computer networks. Privacy can be achieved, even on untrusted networks such as public access points and the Internet. The only proven effective method for protecting privacy is the use of strong end-to-end encryption. These techniques work well even on untrusted public networks, where eavesdroppers are listening and possibly even manipulating data coming from an access point.

To ensure data privacy, good end-to-end encryption should provide the following features:

### **Verified authentication of the remote end.**

The user should be able to know without a doubt that the remote end is who it claims to be. Without authentication, a user could give sensitive data to anyone claiming to be the legitimate service.

### **Strong encryption methods.**

The encryption algorithm should stand up to public scrutiny, and not be easily decrypted by a third party. There is no security in obscurity, and strong encryption is even stronger when the algorithm is widely known and subject to peer review.

A good algorithm with a suitably large and protected key can provide encryption that is unlikely to be broken by any effort in our lifetimes using current technology. Beware of product vendors who assure you that their proprietary encryption using trade-secret algorithms are better than open, peer-reviewed ones.

### **Public key cryptography.**

While not an absolute requirement for end-to-end encryption, the use of public key cryptography instead of a shared key can ensure that an individual's data remains private, even if the key of another user of the service is compromised. It also solves certain problems with distributing keys to users over untrusted networks.

### **Data encapsulation.**

A good end-to-end encryption mechanism protects as much data as possible. This can range from encrypting a single email transaction to encapsulation of all IP traffic, including DNS lookups and other supporting protocols. Some encryption tools simply provide a secure channel that other applications can use. This allows users to run any program they like and still have the protection of strong encryption, even if the programs themselves don't support it.

Be aware that laws regarding the use of encryption vary widely from place to place.

Some countries treat encryption as munitions, and may require a permit, escrow of private keys, or even prohibit its use altogether.

Before implementing any solution that involves encryption, be sure to verify that use of this technology is permitted in your local area.

In the following sections, we'll take a look at some specific tools that can provide good protection for your user's data.

### **TLS**

The most widely available end-to-end encryption technology is Transport Layer Security, known simply as TLS (or its predecessor SSL: Secure Sockets Layer).

Built into virtually all web browsers and many other applications, TLS uses public key cryptography and a trusted public key infrastructure (PKI) to secure data communications on the web.

Whenever you visit a web URL that starts with https, you are using TLS.

The TLS implementation built into web browsers includes a collection of certificates from organisations called Certificate Authorities (CA).

A CA validates the identity of network users and/or providers and ensures that they are who they say they are and issues a certificate saying so.

Rather than doing this by a signed fancy document suitable for framing, this is done through the exchange of cryptographic keys.

As an example, someone wanting a certificate for their website submits a Certificate Request (CR), encoded ("signed") with a cryptographic key created specifically for signing the certificate request.

They submit this request to the CA, who then "signs" the request with their own key. These are encoded in the certificate along with the exact name of the website that the requester wants the certificate to be valid for.

For example, WWW.AIPOTU.GOV, from a certificate perspective, is not the same as AIPOTU.GOV. Each site would require its own certificate to present to a browser to do authenticated HTTPS transactions.

If the owner of AIPOTU.GOV domain only has their certificate issued for AIPOTU.GOV and not also WWW.AIPOTU.GOV, a user accessing the "WWW" address will see a warning for an invalid certificate for that site. This can be confusing to some users and, over time, lead them to just expect TLS Certificate warnings from their browser as normal when the truth is completely the opposite case.

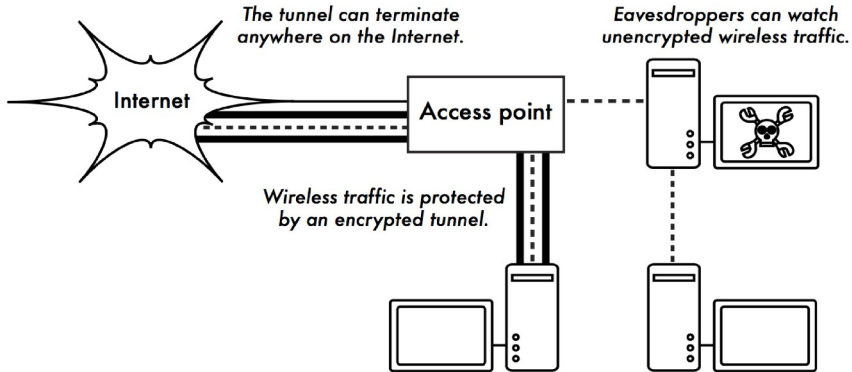
When you browse to a website that uses TLS, the browser and the server first exchange certificates.

The browser then verifies that the hostname in the certificate provided by the server matches the DNS hostname that the browser knows the server by, that the certificate has not expired or been revoked and that it has been signed by a trusted certificate authority.

The server optionally verifies the validity of the browser's certificate. If the certificates are approved, both sides then negotiate a master session key using the previously exchanged certificates to protect the session that is being established.

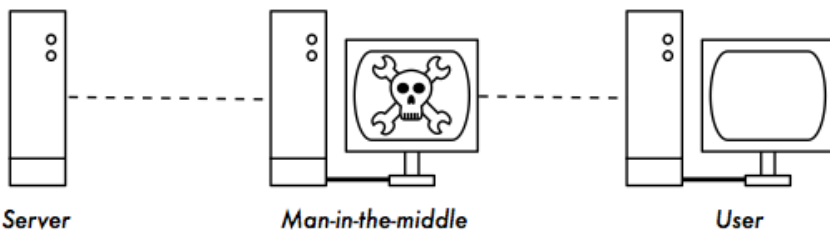
That key is then used to encrypt all communications until the browser disconnects.

This kind of data encapsulation is known as a tunnel.



*Figure SWN 6: Eavesdroppers must break strong encryption to monitor traffic over an encrypted tunnel. The conversation inside the tunnel is identical to any other unencrypted conversation.*

The use of certificates with a PKI not only protects communication against eavesdroppers but is also used to prevent the so-called Man-in-the-Middle (MitM) attack. In a MitM attack, a malicious user intercepts all communication between a client and a server. By presenting counterfeit certificates to both the client and the server, a malicious user could carry on two simultaneous encrypted sessions. Since this user knows the secret on both connections, it is trivial to observe and manipulate the data being passed between the client and the server.



*Figure SWN 7: The man-in-the-middle effectively controls everything the user sees, and can record and manipulate all traffic. Without a public key infrastructure to verify the authenticity of keys, strong encryption alone cannot protect against this kind of attack.*

Use of a good PKI can significantly reduce the chances of this kind of attack. In order to be successful, the malicious user would have to be in possession of a certificate signed by a trusted CA that it can present to the client to accept as authentic.

This is only possible if they can trick the end-user into accepting it or if the CA is compromised.

Certificate Authorities bear a special burden to protect their systems and network from unauthorised access and malicious users.

If a CA were to be compromised, the attacker who performed the compromise could conduct MiTM attacks on any of the users trying to connect to systems with a certificate issued by that CA.

They could also issue counterfeit certificates in response to legitimate certificate requests, ensuring their ability to intercept or interfere with encrypted communications between browser users and servers.

While CA compromise was once held to be very unlikely to happen, there have been a number of incidents at the time of this writing proving this is no longer the case.

Companies whose primary activity was in acting as a commercial CA have gone out of business as a result of having their systems compromised and counterfeit certificates issued under their name.

In September 2011, the certificate authority DigiNotar was found to have been subverted by crackers, forcing all its certificates to be revoked and sending it into bankruptcy.

These compromises were not the result of sophisticated computer criminals employing exotic sophisticated attacks but simply lapses in the security of their overall infrastructure and security policies and procedures. Finally, it is good to point out that TLS is not only used for web browsing. Insecure email protocols such as IMAP, POP, and SMTP can be secured by wrapping them in an TLS tunnel.

Most modern email clients support IMAPS and POPS (secure IMAP and POP) as well as TLS protected SMTP. If your email server does not provide TLS support, you can still secure it with TLS using a package like Stunnel (<http://www.stunnel.org/>). TLS can be used to effectively secure just about any service that runs over TCP.

## SSH

Most people think of SSH as a secure replacement for telnet, just as SCP and SFTP are the secure counterparts of RCP and FTP.

But SSH is much more than an encrypted remote shell. For example, it can also act as a general purpose encrypting tunnel, or even an encrypting web proxy.

By first establishing an SSH connection to a trusted location near (or even on) a remote server, insecure protocols can be protected from eavesdropping and attack.

Like TLS, it uses strong public key cryptography to verify the remote server and encrypt data. Instead of a PKI, it uses a key fingerprint cache that is checked before a connection is permitted.

It can use passwords and public keys for user authentication, and, through its support for the Pluggable Authentication Modules (PAM) system, it can also support other methods of authentication.

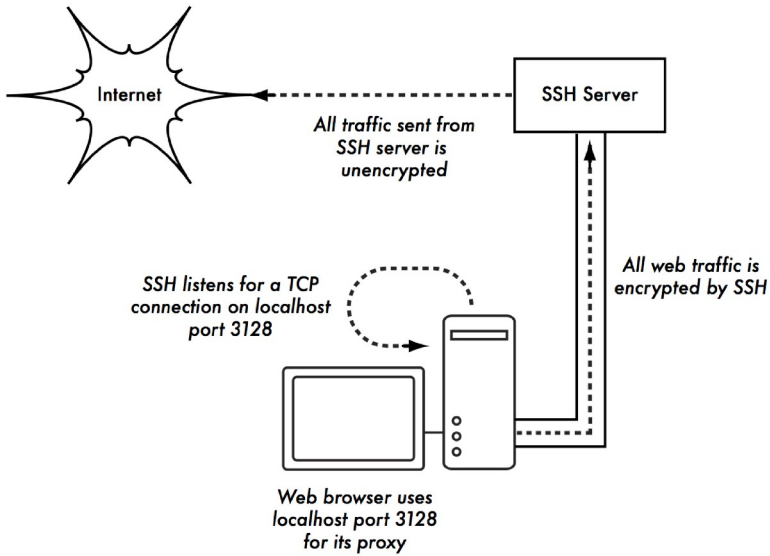
While this technique may be a bit advanced for many users, network architects can use SSH to encrypt traffic across untrusted links, such as wireless point-to-point links.

Since the tools are freely available and run over standard TCP, any educated user can implement SSH connections for themselves, providing their own end-to-end encryption without administrator intervention.

OpenSSH (<http://openssh.org/>) is probably the most popular implementation on Unix-like platforms.

Free implementations such as Putty (<http://www.putty.nl/>) and WinSCP (<http://winscp.net/>) are available for Windows.

OpenSSH will also run on Windows under the Cygwin package (<http://www.cygwin.com/>) These examples will assume that you are using a recent version of OpenSSH.



*Figure SWN 8: The SSH tunnel protects web traffic up to the SSH server itself.*

To establish an encrypted tunnel from a port on the local machine to a port on the remote side, use the `-L` switch. For example, suppose you want to forward web proxy traffic over an encrypted link to the squid server at `squid.example.net`. Forward port 3128 (the default proxy port) using this command:

```
ssh -fN -g -L3128:squid.example.net:3128 squid.example.net
```

The `-fN` switches instruct `ssh` to fork into the background after connecting.

The `-g` switch allows other users on your local segment to connect to the local machine and use it for encryption over the untrusted link.

OpenSSH will use a public key for authentication if you have set one up, or it will prompt you for your password on the remote side. You can then configure your web browser to connect to localhost port 3128 as its web proxy service.

All web traffic will then be encrypted before transmission to the remote side. SSH can also act as a dynamic SOCKS4 or SOCKS5 proxy. This allows you to create an encrypting web proxy, without the need to set up squid. Note that this is not a caching proxy; it simply encrypts all traffic:

```
ssh -fN -D 8080 remote.example.net
```

Configure your web browser to use SOCKS4 or SOCKS5 on local port 8080, and away you go.

SSH can encrypt data on any TCP port, including ports used for email. It can even compress the data along the way, which can decrease latency on low capacity links:

```
ssh -fNCg -L110:localhost:110 -L25:localhost:25 mailhost.example.net
```

The `-C` switch turns on compression.

You can add as many port forwarding rules as you like by specifying the `-L` switch multiple times.

Note that in order to bind to a local port less than 1024, you must have root privileges on the local machine. These are just a few examples of the flexibility of SSH. By implementing public keys and using the ssh forwarding agent, you can automate the creation of encrypted tunnels throughout your wireless network, and protect your communications with strong encryption and authentication.

## OpenVPN

OpenVPN is a VPN implementation built on SSL encryption with both a commercially-licensed and an Open Source "community" edition.

There are OpenVPN client implementations for a wide range of operating systems including Linux, Window 2000/XP and higher, OpenBSD, FreeBSD, NetBSD, and Mac OS X. Many users find it easier to understand and configure than IPSEC VPNs. OpenVPN has some disadvantages though, such as fairly high latency of traffic over the VPN tunnel. Some amount of latency is unavoidable since all encryption/decryption is done in user space, but using relatively new computers on either end of the tunnel can minimise this.

While it can use traditional shared keys for authentication, OpenVPN really shines when used with SSL certificates and a certificate authority. OpenVPN has many advantages that make it a good option for providing end-to-end security. Some of these reasons include:

- it is based on proven, robust, encryption protocols (SSL and RSA)
- it is relatively easy to configure. It functions across many different platforms
- it is well-documented. An Open-Source "Community" version is maintained in addition to a for-pay commercial version.

OpenVPN needs to connect to a single TCP or UDP port on the remote side. Once established, it can encapsulate all data down to the Networking layer, or even down to the Data-Link layer, if your solution requires it. You can use it to create robust VPN connections between individual machines, or simply use it to connect network routers over untrusted wireless networks. VPN technology is a complex field, and is a bit beyond the scope of this section to go into more detail. It is important to understand how VPNs fit into the structure of your network in order to provide the best possible protection without opening up your organisation to unintentional problems.

There are many good online resources that deal with installing OpenVPN on a server and client, we recommend this article from Linux Journal:

<http://www.linuxjournal.com/article/7949>

as well as the official HOWTO:

<http://openvpn.net/howto.html>

## 9. Tor & Anonymizers

The Internet is basically an open network based on trust.

When you connect to a web server across the Internet, your traffic passes through many different routers, owned by a great variety of institutions, corporations and individuals.

In principle, any one of these routers has the ability to look closely at your data, seeing the source and destination addresses, and quite often also the actual content of the data.

Even if your data is encrypted using a secure protocol, it is possible for your Internet provider to monitor the amount of data transferred, as well as the source and destination of that data.

Often this is enough to piece together a fairly complete picture of your activities on-line. Privacy and anonymity are important, and closely linked to each other. There are many valid reasons to consider protecting your privacy by anonymizing your network traffic.

Suppose you want to offer Internet connectivity to your local community by setting up a number of access points for people to connect to.

Whether you charge them for their access or not, there is always the risk that people use the network for something that is not legal in your country or region.

You could plead with the legal system that this particular illegal action was not performed by yourself, but could have been performed by anyone connecting to your network. The problem is neatly sidestepped if it were technically infeasible to determine where your traffic was actually headed.

And what about on-line censorship?

Publishing web pages anonymously may also be necessary to avoid government censorship. There are tools that allow you to anonymize your traffic in relatively easy ways.

The combination of Tor (<http://www.torproject.org>) and Privoxy (<http://www.privoxy.org>) is a powerful way to run a local proxy server that will pass your Internet traffic through a number of servers all across the net, making it very difficult to follow the trail of information.

Tor can be run on a local PC, under Microsoft Windows, Mac OSX, Linux and a variety of BSD's, where it anonymizes traffic from the browser on that particular machine.

Tor and Privoxy can also be installed on a gateway server, or even a small embedded access point (such as a Linksys WRT54G) where it provides anonymity to all network users automatically.

Tor works by repeatedly bouncing your TCP connections across a number of servers spread throughout the Internet, and by wrapping routing information in a number of encrypted layers (hence the term onion routing), that get peeled off as the packet moves across the network.

This means that, at any given point in the network, the source and destination addresses cannot be linked together.

This makes traffic analysis extremely difficult.

The need for the Privoxy privacy proxy in connection with Tor is due to

the fact that name server queries (DNS queries) in most cases are not passed through the proxy server, and someone analysing your traffic would easily be able to see that you were trying to reach a specific site (say google.com) by the fact that you sent a DNS query to translate google.com to the appropriate IP address.

Privoxy connects to Tor as a SOCKS4a proxy, which uses hostnames (not IP addresses) to get your packets to the intended destination. In other words, using Privoxy with Tor is a simple and effective way to prevent traffic analysis from linking your IP address with the services you use online.

**Combined with secure, encrypted protocols (such as those we have seen in this chapter), Tor and Privoxy provide a high level of anonymity on the Internet.**