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Enhancing Security in 802.11 and 802.1 X Networks with Intrusion Detection

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ENHANCING SECURITY IN 802.11 AND 802.1 X NETWORKS WITH INTRUSION DETECTION

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ABSTRACT

The convenience and low cost of 802.11-based Wireless Local Area Networks (WLANs) complemented with 802.1 X authentication has led to widespread deployment in the consumer, industrial and military sectors. The combination of wireless signals radiating further than the intended coverage area, flaws in 802.11's basic security mechanisms and vulnerabilities found in 802.1 X have been widely publicized. Military bases and navy ships are open targets for wireless attacks.

Wireless Intrusion Detection System (WIDS), provides an additional (external) layer of security by combining intrusion detection, fire walling, packet filtering and determining the physical location of the intruder.

Chapter 1. INTRODUCTION

In today's fast changing world, management of information and communication infrastructure goes hand-in-hand. There has been tremendous growth in WLAN usage, a growth that is compared by many to be almost as that of the internet in the 90s.

The key factors driving this growth have been decreasing costs, increasing speeds and the general convenience of not having to run wires and not being limited to fixed network Access Points (APs). While WLANs are not likely to replace all wired Local Area Networks (LANs) any time soon (if ever), the two are already beginning to coexist almost seamlessly in several environments.

Another key factor in the growth of WLAN usage is the standardization of protocols and equipment. Access to a wired LAN is governed by access to an Ethernet port for that LAN. Therefore, access control for a wired LAN often is viewed in terms of physical access to LAN ports. Similarly, because data transmitted on a wired LAN is directed to a particular destination, privacy cannot be compromised unless someone uses specialized equipment to intercept transmissions on their way to their destination. In short, a security breach on a wired LAN is possible only if the LAN is physically compromised.

With a WLAN, transmitted data is broadcast over the air using Radio Frequency (RF) waves. Thus it can be received by any WLAN station (STA) in the area served by the data transmitter. Because RF waves travel through ceilings, floors, and walls, transmitted data may reach unintended recipients on different floors and even outside the building of the transmitter. Similarly, data privacy is a genuine concern with WLANs because there is no way to direct a WLAN transmission to only one recipient.

Security in the IEEE 802.11 standard has come under intense scrutiny. Researchers have exposed several vulnerabilities in the authentication, data-privacy, and message-integrity mechanisms defined in the standard. The 802.11 standard specifies Wired Equivalent Privacy (WEP), a link-layer security protocol. WEP is based on the RC4 stream cipher, a symmetric cipher (the same key is used for both encryption and decryption). These security mechanisms, intended to maintain the confidentiality, integrity, and availability of wireless communications are problematic. Several WEP flaws have been widely documented [3, 5, 6]. Each of these flaws allows passive or active attacks on wireless transmissions, by which attackers can decrypt information or inject forged information into the transmissions.

A lot has been written by various researchers in the past few years about the insecurity of wireless networks set up using 802.11 and 802.1 X standards. This paper presents an extension to a Wireless Intrusion Detection System (WIDS) designed to provide additional security not available in other intrusion detection systems.

WIDS provides an external layer of security around the perimeter of a wireless network and tracks and locates potential intruders using directional antennas before they connect to the internal network. The WIDS Access Points (APs) are special access points that operate on two wireless Network Interface Card (NIC) cards. One NIC functions in Master or HostAP [17] mode and the other NIC functions in Radio Frequency (RF) Monitor mode. The NIC running in HostAP mode intrudes stations, denies access, ignores frames and reacts promptly to applicable alerts. The NIC running in RF Monitor mode performs the function of passive scanning. It can monitor all frames in real time and also detect external/rogue access points. This feature of WIDS will extend its applicability not only on 802.11 [1] and 802.1 X [2] networks but also on 802.11 i [3] networks.

The WIDS APs report all findings to the Controller, which is connected to all WIDS APs through a wired connection. The Controller shows statistics of all WIDS APs, logs data and uses information from two or more WIDS APs to locate attackers. The advantage of WIDS over other wireless intrusion detection systems is that WIDS is an always live and active intrusion detection system. WIDS can actively respond to various threats and can track and locate potential attackers. WIDS can also detect, track and locate rogue external access points.

The following chapters present sections on IEEE 802.11 standard [1], security vulnerabilities, problems and attacks on IEEE 802.11 b networks, an introduction of IEEE 802.1 X [2], Extensible Authentication Protocol (EAP) [20], implementation of 802.1 X over 802.11, 802.1 X vulnerabilities, introduction to intrusion detection, tracking and location techniques, a detailed description of WIDS, an extension of WIDS AP implementation by using two NICs, one running (HostAP [17] mode and other running RF Monitor mode), defense mechanisms of WIDS and evaluation and testing of WIDS. The paper ends with a conclusion and suggestions for future work.

Chapter 2. BACKGROUND OF IEEE 802.11

2.1. IEEE 802.11 History

The IEEE 802.11 [1] was designed to support medium-range, higher data rate applications, such as Ethernet networks, and to address mobile and portable STAs. 802.11 is the original WLAN standard, designed for 1 Mbps to 2 Mbps wireless transmissions. It was followed in 1999 by 802.11a, which established a high-speed WLAN standard for the 5 GHz band and supported 54 Mbps. Also completed in 1999 was the 802.11b standard, which operates in the 2.4 - 2.48 GHz band and supports 11 Mbps.

The 802.11b standard is currently the dominant standard for WLANs and has been widely adopted. The 802.11 specifies a security protocol called WEP, which is a RC4 stream cipher. Another standard, 802.11g, operates in the 2.4 GHz waveband, where current WLAN products based on the 802.11b standard operate.

Two other important and related standards for WLANs are 802.1 X [2] and 802.11 i [3]. The 802.1 X, a port-level access control protocol, provides a security framework for IEEE networks, including Ethernet and WLANs. The 802.11 i standard, also still in draft, was created for wireless-specific security functions that operate with IEEE 802.1 X.

2.2. IEEE 802.11 Layers

2.2.1. Physical (PHY) Layer

The three physical layers originally defined in 802.11 included two spread-spectrum radio techniques and a diffuse infrared specification. The radio-based standards operate within the 2.4 GHz ISM band. The original 802.11 wireless standard defines data rates of 1 Mbps and 2 Mbps via radio waves using Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS).

Using the frequency hopping technique, the 2.4 GHz band is divided into 75 one-MHz sub channels. The sender and receiver agree on a hopping pattern, and data is sent over a sequence of the sub channels. Each conversation within the 802.11 network occurs over a different hopping pattern, and the patterns are designed to minimize the chance of two senders using the same sub channel simultaneously.

FHSS techniques allow for a relatively simple radio design, but are limited to speeds of no higher than 2 Mbps. This limitation is driven primarily by FCC regulations that restrict sub channel bandwidth to 1 MHz. These regulations force FHSS systems to spread their usage across the entire 2.4 GHz band, meaning they must hop often, which leads to a high amount of hopping overhead.

In contrast, DSSS divides the 2.4 GHz band into 14 twenty-two MHz channels. Adjacent channels overlap one another partially, with 3 of the 14 being completely non-overlapping. Data is sent across one of these 22 MHz channels without hopping to other channels. To compensate for noise on a given channel, a technique called chipping is used. Each bit of user data is converted into a series of redundant bit patterns called chips. The inherent redundancy of each chip combined with spreading the signal across the 22 MHz channel provides for a form of error checking and correction even if part of the signal is damaged, it can still be recovered in many cases, minimizing the need for retransmissions. The 802.11b standard uses just DSSS as the sole physical layer technique.

2.2.2. Data Link (DATA) Layer

The data link layer within 802.11 consists of two sub layers: Logical Link Control (LLC) and Media Access Control (MAC). 802.11 uses the same 802.2 LLC and 48-bit addressing as other 802 LANs, allowing for very simple bridging from wireless to IEEE wired networks, but the MAC is unique to WLANs.

The 802.11 standard specifies a common MAC Layer, which provides a variety of functions that support the operation of 802.11-based WLANs. In general, the MAC Layer manages and maintains communications between 802.11 STAs (wireless NICs and APs) by coordinating access to a shared channel and utilizing protocols that enhance communications over a wireless medium.

Before transmitting frames, a STA must first gain access to the medium, which is a channel that STAs share. The 802.11 standard defines two forms of medium access, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). DCF is mandatory and based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. With DCF, 802.11 STAs contend for access and attempt to send frames when there is no other STA transmitting. If another STA is sending a frame, STAs wait until the channel is free.

As a condition to accessing the medium, the MAC Layer checks the value of its Network Allocation Vector (NAV), which is a counter at each STA that represents the amount of time that the previous STA needs to

send its frame. The NAV must be zero before a STA can attempt to send a frame. Prior to transmitting a frame, a STA calculates the amount of time necessary to send the frame based on the frame's length and data rate. The STA places a value representing this time in the duration field in the header of the frame. When STAs receive the frame, they examine this duration field value and use it as the basis for setting their corresponding NAVs. This process reserves the medium for the sending STA.

An important aspect of the DCF is a random back off timer that a STA uses if it detects a busy medium. If the channel is in use, the STA must wait a random period of time before attempting to access the medium again. This helps to ensure that multiple STAs wanting to send data do not transmit at the same time. The random delay causes STAs to wait different periods of time and avoids all of them sensing the medium at exactly the same time, finding the channel idle, transmitting, and colliding with each other. The back off timer significantly reduces the number of collisions and corresponding retransmissions, especially when the number of active users increases.

With WLANs, a transmitting STA can not listen for collisions while sending data, mainly because the STA can not have it's receiver ON while transmitting the frame. As a result, the receiving STA needs to send an Acknowledgement (ACK) if it detects no errors in the received frame. If the sending STA doesn't receive an ACK after a specified period of time, the sending STA will assume that there was a collision (or RF interference) and retransmits the frame.

For supporting time-bounded delivery of data frames, the 802.11 standard defines PCF where the AP grants access to an individual STA to the medium by polling the STA during the contention free period. STAs can't transmit frames unless the AP polls them first. The period of time for PCF-based data traffic (if enabled) occurs alternately between contention (DCF) periods.

The AP polls STAs according to a polling list and then switches to a contention period when STAs use DCF. This process enables support for both synchronous (i.e., video applications) and asynchronous (i.e., e-mail and Web browsing applications) modes of operation.

2.2.3. MAC Layer Functions

2.2.3.1. Scanning

The 802.11 standard defines both Passive and Active scanning whereby, a wireless NIC searches for APs. Passive scanning is mandatory where each NIC scans individual channels to find the best AP signal. Periodically, APs broadcast a beacon, and the wireless NIC receives these beacons while scanning and takes note of the corresponding signal strengths. The beacons contain information about the AP, including Service Set IDentifier (SSID), supported data rates, etc. The wireless NIC can use this information along with the signal strength to compare APs and decide upon which one to use.

Optional active scanning is similar, except the wireless NIC initiates the process by broadcasting a probe frame and all APs within range respond with a probe response. Active scanning enables a wireless NIC to receive immediate response from APs, without waiting for a beacon transmission. The issue, however, is that active scanning imposes additional overhead on the network because of the transmission of probe and corresponding response frames.

2.2.3.2. Authentication

Authentication is the process of proving identity, and the basic 802.11 standard specifies two forms: Open system authentication and shared key authentication (Refer Figure. 1).

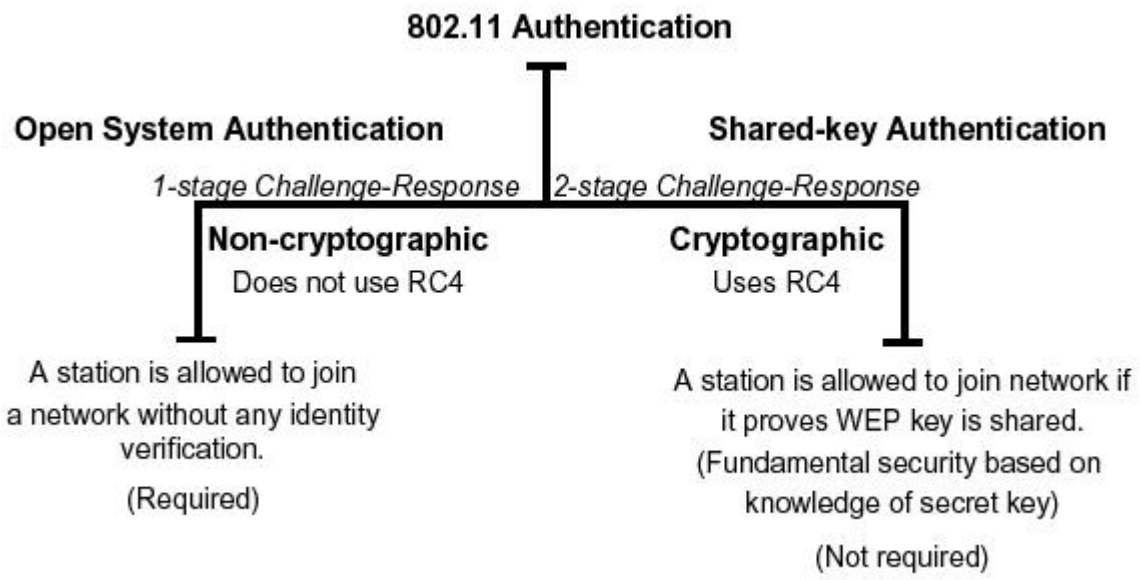


Figure 1: 802.11 Authentication

Open system authentication is mandatory, and it's a two step process. A wireless NIC first initiates the process by sending an authentication request frame to the AP. The AP replies with an authentication response frame containing approval or disapproval of authentication indicated in the Status Code field in the frame body.

Shared key authentication is an optional four step process that checks whether the authenticating device has the correct WEP key. The wireless NIC starts by sending an authentication request frame to the AP. The AP then places challenge text into the frame body of a response frame and sends it to the wireless NIC. The wireless NIC uses its WEP key to encrypt the challenge text and then sends it back to the AP in another authentication frame. The AP decrypts the challenge text and compares it to the initial text. If the text is equivalent, then the AP assumes that the wireless NIC has the correct key. The AP finishes the sequence by sending an authentication frame to the wireless NIC with the approval or disapproval.

2.2.3.3. Association

Once authenticated, the wireless NIC must associate with the AP before sending data frames. Association is necessary to synchronize the wireless NIC and AP with important information, such as supported data rates. The wireless NIC initiates the association by sending an association request frame containing elements such as SSID and supported data rates. The AP responds by sending an association response frame containing an

association ID along with other information regarding the AP. Once the wireless NIC and AP complete the association process, they can send data frames to each other.

2.2.3.4. Request-To-Send (RTS) /Clear-To-Send (CTS)

The optional RTS/CTS function allows the AP to control use of the medium for STAs activating RTS/CTS. With most wireless NICs, users can set a maximum frame length threshold whereby the wireless NIC will activate RTS/CTS. For example, a frame length of 2 Kb will trigger RTS/CTS for all frames larger than 2 Kb. The use of RTS/CTS alleviates hidden node problems, that is, where two or more wireless NICs can't hear each other and they are associated with the same AP.

If the wireless NIC activates RTS/CTS, it will first send a RTS frame to AP before sending a data frame. The AP will then respond with a CTS frame, indicating that the wireless NIC can send the data frame. With the CTS frame, the AP will provide a value in the duration field of the frame header that holds off other STAs from transmitting until after the wireless NIC initiating the RTS can send its data frame. This avoids collisions between hidden nodes. The RTS/CTS handshake continues for each frame, as long as the frame size exceeds the threshold set in the corresponding wireless NIC.

2.2.3.5. Power Save Mode

The optional power save mode enables the wireless NIC to conserve battery power when there is no need to send data. With power save mode ON, the wireless NIC indicates its desire to enter sleep state to the AP via a status bit located in the header of each frame. The AP takes note of each wireless NIC wishing to enter power save mode and buffers packets corresponding to the sleeping STA.

In order to still receive data frames, the sleeping NIC must wake up periodically (at the right time) to receive regular beacon transmissions coming from the AP. These beacons identify whether sleeping STAs have frames buffered at the AP and waiting for delivery to their respective destinations. The wireless NICs having awaiting frames will request them from the AP. After receiving the frames, the wireless NIC can go back to sleep.

2.2.3.6. Fragmentation

The optional fragmentation function enables an 802.11 STA to divide data packets into smaller frames. This is done to avoid the need to retransmit large frames in the presence of RF interference. The bit errors resulting from RF interference are likely to affect a single frame, and it requires less overhead to retransmit a smaller frame rather than a larger one. As with RTS/CTS, users can generally set a maximum frame length threshold whereby the wireless NIC will activate fragmentation. If the frame size is larger than the threshold, the wireless NIC will break the packet into multiple frames, with each frame no larger than the threshold value.

2.3. IEEE 802.11 Frame Types

The 802.11 standard defines various frame types that STAs and APs use for communication, as well as managing and controlling the wireless link. Every frame has a control field that depicts the 802.11 protocol version, frame type, and various indicators, such as whether WEP is on, power management is active, and so on. In addition all frames contain MAC addresses of the source and destination STA (and AP), a frame sequence number, frame body and frame check sequence (for error detection).

802.11 data frames carry protocols and data from higher layers within the frame body. Other frames that STAs use for management and control carry specific information regarding the wireless link in the frame body. For example, a beacon's frame body contains the SSID, timestamp, and other pertinent information regarding the AP.

2.3.1. 802.11 Management Frames

802.11 management frames enable STAs to establish and maintain communications.
The following are common 802.11 management frame subtypes:

Authentication Frame
802.11 authentication is a process where the AP either accepts or rejects the identity of a wireless NIC. The NIC begins the process by sending an authentication frame containing its identity to the AP. With open system authentication (the default), the wireless NIC sends only one authentication frame, and the AP responds with an authentication frame as a response indicating acceptance (or rejection). With the optional shared key authentication, the wireless NIC sends an initial authentication frame, and the AP responds with

an authentication frame containing challenge text. The wireless NIC must send an encrypted version of the challenge text (using its WEP key) in an authentication frame back to the AP.

The AP ensures that the wireless NIC has the correct WEP key (which is the basis for authentication) by seeing whether the challenge text recovered after decryption is the same that was sent previously. Based on the results of this comparison, the AP replies to the wireless NIC with an authentication frame.

Deauthentication Frame

A STA sends a deauthentication frame to an AP if it wishes to terminate secure communications.

Association Request Frame

An 802.11 association enables the AP to allocate resources for and synchronize with a wireless NIC. A NIC begins the association process by sending an association request to an AP. This frame carries information about the NIC and the SSID of the network it wishes to associate with. After receiving the association request, the AP considers associating with the NIC, and (if accepted) reserves memory space and establishes an association ID for the NIC.

Association Response Frame

An AP sends an association response frame containing an acceptance or rejection notice to the wireless NIC requesting association. If the AP accepts the radio NIC, the frame includes information regarding the association, such as association ID and supported data rates. If the outcome of the association is positive, the wireless NIC can utilize the AP to communicate with other NICs on the network and systems on the distribution (i.e., Ethernet) side of the AP.

Reassociation Request Frame

If a wireless NIC roams away from the currently associated AP and finds another AP having a stronger beacon signal, the wireless NIC will send a reassociation frame to the new AP. The new AP then coordinates the forwarding of data frames that may still be in the buffer of the previous AP waiting for transmission to the wireless NIC.

Reassociation Response Frame

An AP sends a reassociation response frame containing an acceptance or rejection notice to the wireless NIC requesting reassociation.

Similar to the association process, the frame includes information regarding the association, such as association ID and supported data rates.

Disassociation Frame

A STA sends a disassociation frame to another STA if it wishes to terminate the association. For example, a wireless NIC that is shut down gracefully can send a disassociation frame to alert the AP that the NIC is powering off. The AP can then relinquish memory allocations and remove the wireless NIC from the association table.

Beacon Frame

The AP periodically sends a beacon frame to announce its presence and relay information, such as timestamp, SSID, and other parameters regarding the AP to wireless NICs that are within range. Wireless NICs continually scan all 802.11 radio channels and listen to beacons as the basis for choosing which AP is best to associate with.

Probe Request Frame

A STA sends a probe request frame when it needs to obtain information from another STA. For example, a wireless NIC would send a probe request to determine which APs are within range.

Probe response frame

A STA will respond with a probe response frame, containing capability information, supported data rates, etc., when it receives a probe request frame.

2.3.2. 802.11 Control Frames

802.11 control frames assist in the delivery of data frames between STAs. The following are common 802.11 control frame subtypes:

RTS Frame

The RTS/CTS function is optional and reduces frame collisions present when hidden STAs have associations with the same AP. A STA sends a RTS frame to another STA as the first phase of a two-way handshake necessary before sending a data frame.

CTS Frame

A STA responds to a RTS with a CTS frame, providing clearance for the requesting STA to send a data frame. The CTS includes a time value that causes all other STAs (including hidden STAs) to hold off transmission of frames for a time period necessary for the requesting STA to send its frame. This minimizes collisions among hidden STAs, which can result in higher throughput if implemented properly.

ACK Frame

After receiving a data frame, the receiving STA will utilize an error checking processes to detect the presence of errors. The receiving STA will send an ACK frame to the sending STA if no errors are found. If the sending STA doesn't receive an ACK after a period of time, the sending STA will retransmit the frame.

A point worth noting is that RTS, CTS and ACK frames are not authenticated in the 802.11 standard.

2.3.3. 802.11 Data Frames

The main purpose of having a WLAN is to transport data. IEEE 802.11 defines a data frame type that carries packets from higher layers, such as web pages, printer control data, etc., within the body of the frame.

2.4. IEEE 802.11 Task Group i (TGi)

The IEEE is currently working on three separate initiatives for improving WLAN security. The first involves the IEEE 802.11 Task Group i (TGi) which has proposed significant modifications to the existing IEEE 802.11 standard as a long-term solution for security. The TGi is defining additional ciphers based on the newly released Advanced Encryption Standard (AES). The AES based solution will provide a highly robust solution for the future but will require new hardware and protocol changes. TGi currently has design requirements to address many of the known problems with WEP including the prevention of forgeries and detection of replay attacks.

The second initiative for improving WLAN security is the TGi’s short-term solution WiFi Protected Access (WPA) to address the problems of WEP. The group is defining the Temporal Key Integrity Protocol (TKIP) to address the problems without requiring hardware changes that is, requiring only changes to firmware and software drivers. The third initiative from IEEE is the introduction of a new standard, IEEE 802.1 X-2001, a

generic framework for port-based network access control and key distribution, approved in June 2001.

By defining the encapsulation of EAP (Extensible Authentication Protocol) [20] over IEEE 802 media, IEEE 802.1 X enables an AP and STA to mutually authenticate one another. Since IEEE 802.1 X was developed primarily for use with IEEE 802 LANs, not for use with WLANS, the IEEE 802.11 i draft standard defines additional capabilities required for secure implementation of IEEE 802.1 X on 802.11 networks. These include a requirement for use of an EAP method supporting mutual authentication, key management, and dictionary attack resistance. In addition, 802.11 i defines the hierarchy for use with the TKIP and AES ciphers and a four way key management handshake used to ensure that the STA is authenticated to the AP and a back-end authentication server.

2.5. IEEE 802.11 Security Vulnerabilities

IEEE 802.11 provides for security via two methods, which are authentication and encryption. The 802.11 standard provides for both MAC layer access control and encryption mechanisms, which is known as WEP, with the objective of providing WLANs with security equivalent to their wired counterparts. For the access control, the WLAN Service Area ID (ESSID) is programmed into each AP and is required knowledge in order for a STA to associate with an AP. In addition, there is provision for a table of MAC addresses called an Access Control List (ACL) to be included in the AP, restricting access to clients whose MAC addresses are on the list. For data encryption, the standard provides for optional encryption using a RC4 stream cipher. All data sent and received while the end STA and AP are associated can be encrypted using a shared key. In addition, when encryption is in use, the AP will issue an encrypted challenge packet to any client attempting to associate with it. The client must use its key to encrypt the correct response in order to authenticate itself and gain network access.

Security problems with WEP include the following [29]:

1. The use of static WEP keys—many users in a WLAN potentially sharing the identical key for long periods of time, is a well-known security vulnerability. This is in part due to the lack of any key management provisions in the WEP protocol. If a computer such as a laptop were to be lost or stolen, the key could become compromised along with all the other computers sharing that key. Moreover, if every STA uses the same key, a large amount of traffic may be rapidly available to an eavesdropper for analytic attacks, such as 2 and 3 below.

2. The Initialization Vector (IV) in WEP is a 24-bit field sent in the clear text portion of a message. This 24-bit string, used to initialize the key stream generated by the RC4 algorithm, is a relatively small field when used for cryptographic purposes. Reuse of the same IV produces identical key streams for the protection of data, and the short IV guarantees that they will repeat after a relatively short time in a busy network. Moreover, the 802.11 standard does not specify how the IVs are set or changed, and individual wireless NICs from the same vendor may all generate the same IV sequences, or some wireless NICs may possibly use a constant IV. As a result, hackers can record network traffic, determine the key stream, and use it to decrypt the cipher-text.

3. The IV is a part of the RC4 encryption key. The fact that an eavesdropper knows 24-bits of every packet key, combined with a weakness in the RC4 key schedule, leads to a successful analytic attack [6], which recovers the key, after intercepting and analyzing only a relatively small amount of traffic. This attack is publicly available as an attack script and open source code. Airsnort [11] and WEPCrack [12] perform this attack. The Federal Bureau of Investigation (FBI) recently demonstrated a method to crack the WEP key inside three minutes [26].

4. WEP provides no cryptographic integrity protection. However, the 802.11 MAC protocol uses a non-cryptographic Cyclic Redundancy Check (CRC) to check the integrity of packets, and acknowledge packets with the correct checksum. The combination of non-cryptographic checksums with stream ciphers is dangerous and often introduces vulnerabilities, as is the case for WEP [5]. There is an active attack that permits the attacker to decrypt any packet by systematically modifying the packet and CRC sending it to the AP and noting whether the packet is acknowledged. These kinds of attacks are often subtle, and it is now considered risky to design encryption protocols that do not include cryptographic integrity protection, because of the possibility of interactions with other protocol levels that can give away information about cipher text.

Note that only one of the four problems listed above depends on a weakness in the cryptographic algorithm. Therefore, these problems would not be improved by substituting a stronger stream cipher. For example, the third problem listed above is a consequence of a weakness in the implementation of the RC4 stream cipher that is exposed by a poorly designed protocol.

Key Problems with existing 802.11 WLAN Security [27] are as follows:

Security features in products are frequently not enabled**.** Security features are turned off not in 802.11 products when shipped, and novice users do not enable security during installation period. Bad security is generally better than no security.
IVs are short (or static). 24-bit IVs cause the generated key stream to repeat. Repetition allows easy decryption of data for a moderately sophisticated adversary.
Cryptographic keys are short.40-bit keys are inadequate for any system. It is generally accepted that key sizes should be greater than 80 bits in length. The longer the key, the less likely it is possible to comprise the key from a brute-force attack.
Cryptographic keys are shared. Keys that are shared can compromise a system. As the number of people sharing the key grows, the security risks also grow. A fundamental tenant of cryptography is that the security of a system is largely dependent on the secrecy of the keys.
Cryptographic keys cannot be updated automatically and frequently. Cryptographic keys should be changed often to prevent brute-force attacks.
RC4 has a weak key schedule and is inappropriately used in WEP. The combination of revealing 24 key bits in the IV and a weakness in the initial few bytes of the RC4 key stream leads to an efficient attack that recovers the key. Most other applications of RC4 do not expose the weaknesses of RC4 because they do not reveal key bits and do not restart the key schedule for every packet. This attack is available to moderately sophisticated adversaries.
Packet integrity is poor. CRC32 and other linear block codes are inadequate for providing cryptographic integrity. Message modification is possible. Linear codes are inadequate for the protection against advertent attacks on data integrity. Cryptographic protection is required to prevent deliberate attacks. Use of non cryptographic protocols often facilitates attacks against the cryptography.
No user authentication occurs. Only the device is authenticated. A device that is stolen can access the network.
Authentication is not enabled; only simple SSID identification occurs. Identity-based systems are highly vulnerable particularly in a wireless system because signals can be more easily intercepted.
Device authentication is simple shared-key challenge-response. One-way challenge-response authentication is subject to Man-in-Middle (MIM) attacks. Mutual authentication is required to provide verification that users and the network are legitimate.
The client does not authenticate the AP. The client needs to authenticate the AP to ensure that it is legitimate and prevent the introduction of rogue APs.

Table 1: Problems with existing 802.11 WLAN Security

2.6. Attacks on 802.11 Networks

2.6.1. Taxonomy of Attacks

Network security attacks are typically divided into passive and active attacks [27]. These two broad classes are then subdivided into other types of attacks. All are defined below (Refer Figure 2).

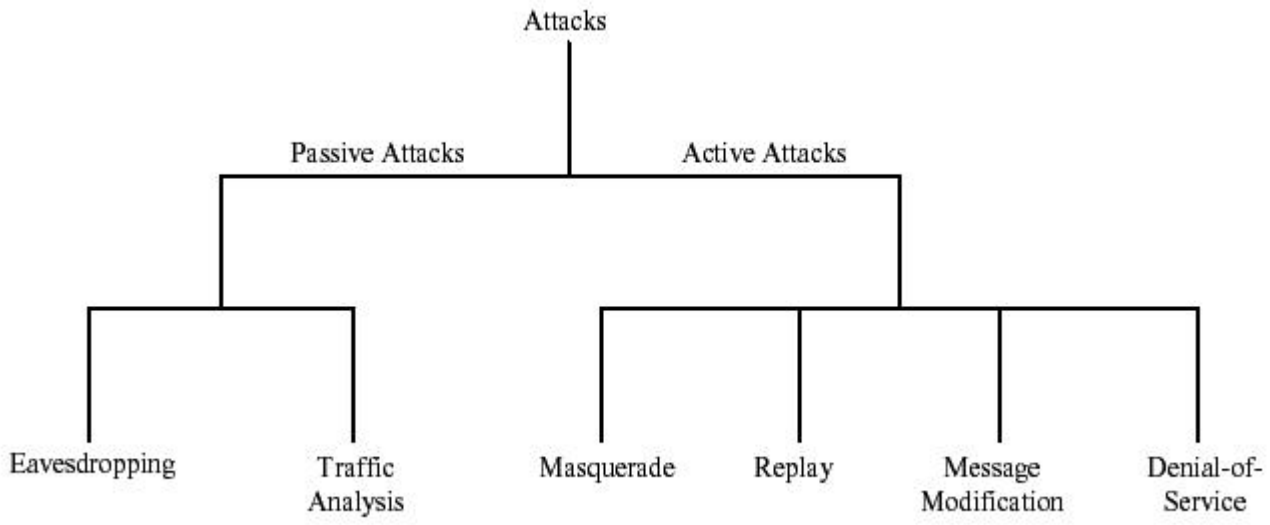


Figure 2: Taxonomy of Attacks

Passive Attack

A passive attack can be defined as one which involves an unauthorized user gaining access to a network and not modifying or altering the network. Passive attacks can be either eavesdropping or traffic analysis (sometimes called traffic flow analysis). These two passive attacks are described below.

Eavesdropping

The attacker monitors transmissions for message content. An example of this attack is a person listening into the transmissions on a LAN between two work stations or tuning into transmissions between a STA

and an AP.

Traffic Analysis

The attacker, in a more subtle way, gains intelligence by monitoring the transmissions for patterns of communication. A considerable amount of information is contained in the flow of messages between communicating parties.

Active Attack

An active attack can be defined as one which involves an unauthorized user making modifications to a message, data stream, or a file. It is possible to detect this type of attack but it may not be preventable. Active attacks may take the form of one of four types (or combination thereof): masquerading, replay, message modification, and Denial-of-Service. These attacks are defined below.

Masquerading

The attacker impersonates an authorized user and thereby gains certain unauthorized privileges.

Replay

The attacker monitors transmissions (passive attack) and retransmits messages as the legitimate user. Using a database of valid wireless traffic dumps from sources like Ethereal or Kismet, data can be replayed via packet injection.

Message modification

The attacker alters a legitimate message by deleting, adding to, changing, or reordering it.

Denial-of-Service (DoS)

The attacker prevents or prohibits the normal use or management of communications facilities. DoS attacks happen very frequently in the wired world but this class of attacks in the wireless world is damaging and can come from any direction. Microwave ovens, baby monitors, cordless telephones, and other commonly available consumer products can give attackers the tools for a simple and extremely damaging DoS attack. Unleashing large amounts of noise from these other devices can jam the airwaves and shut down a WLAN. Attackers can launch more sophisticated DoS attacks by configuring a station to operate as an AP. As an AP, the attacker can flood the airwaves with continuous deauthenticate/disassociate packets that force all STAs within range to disconnect from the WLAN. In another variation, the attacker's malicious AP broadcasts periodic deauthenticate/disassociate commands every few minutes that causes a situation where

stations are continually kicked off the network, reconnected, and kicked off again.

2.6.2. Malicious Association

The attacker can force unsuspecting STAs to connect to an undesired 802.11 network. As the victim's STA broadcasts a probe to associate with an AP, the attackers new malicious AP responds to the victim's request for association and begins a connection between the two. After providing an IP address to the victim's workstation (if needed), the malicious AP can begin its attacks. The attacker, acting as an AP, can use hacking tools that have been tested and proven in a wired environment. At this time, the attacker can exploit all vulnerabilities on the victim's laptop.

The malicious association attack shows that WLANs are subject to diversion and STAs do not always know which network or AP they connect to. STAs can be tricked or forced to connect to a malicious AP. Even WLANs that have deployed Virtual Private Networks (VPNs) are vulnerable to malicious associations. This attack does not try to break the VPN but takes over the client STA.

2.6.3. MAC Spoofing – Identity Theft

Software tools, such as Kismet [24] or Netstumbler [18], are available for attackers to easily pick off the MAC addresses of an authorized AP or STA. The attacker can then assume the identity of that AP or STA by asserting the stolen MAC address as his own. WLAN intrusion detection systems can also identify when a MAC address is spoofed by analyzing the vendor "fingerprints" of the WLAN card where by the IDS can see when, as an example, an Orinoco WLAN card connects to the network using MAC address of a Cisco WLAN card. (Refer Figure 3)

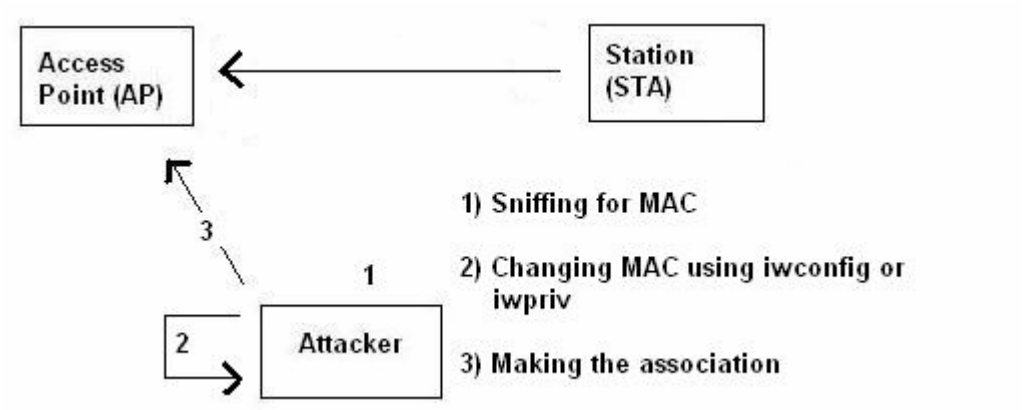


Figure 3: Mac Spoofing

2.6.4. Man-in-Middle (MIM) Attacks

A Man-in-Middle attack can break a secure VPN connection between an authorized STA and an AP. By inserting a malicious STA between the victim STA and the AP, the attacker becomes the man-in-middle as he tricks the STA into believing he is the AP and tricks the AP into believing he is the authorized STA.

To begin this attack, the attacker passively observes the station as it connects to the AP, and the attacker collects the authentication information, including the username, server name, client and server IP address, the ID used to compute the response, and the challenge and associate response. (Refer Figure 4)

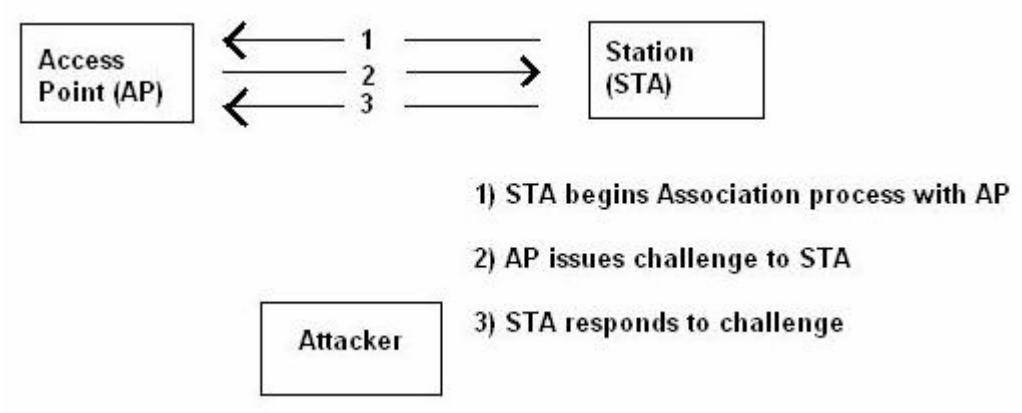


Figure 4: VPN Attack

The attacker then tries to associate with the AP by sending a request that appears to be coming from the authenticated STA. The AP sends the VPN challenge to the authenticated station, which computes the required authentic response, and sends the response to the AP. The attacker observes the valid response.

(Refer Figure 5)

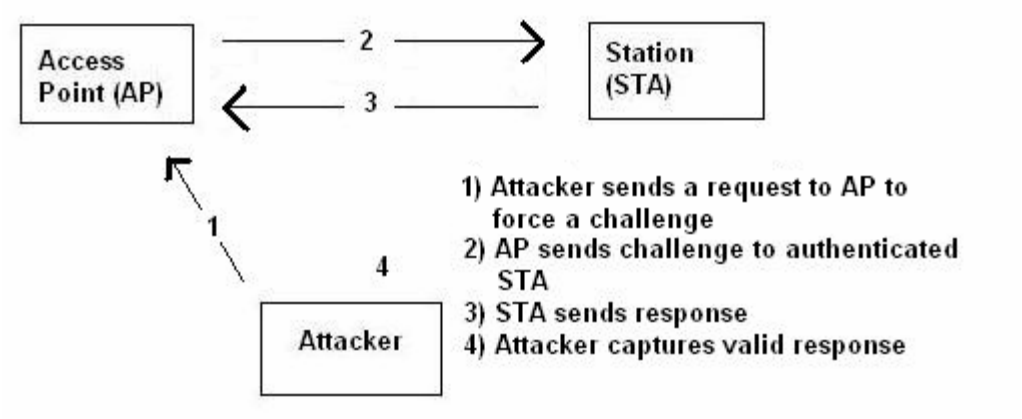


Figure 5: VPN Assault

The attacker then acts as the AP in presenting a challenge to the authorized STA. The STA computes the appropriate response, which is sent to the AP. The AP then sends the STA a success packet with an imbedded sequence number. Both are captured by the attacker. After capturing all this data, the attacker then has what he needs to complete the attack and defeat the VPN. The attacker sends a spoofed reply with large sequence number, which bumps the victim's station off the network and keeps it from re-associating. The attacker then enters the network as the authorized station.

2.6.5. Power Saving Vulnerabilities [8]

The Power Save mode in 802.11 allows STAs to enter into a sleep state during which they are unable to transmit or receive. Before entering the sleep state the STA sends its intention to the AP so that the AP can start buffering any inbound traffic. Periodically the STA polls the AP for any pending traffic. If there is any buffered data at this time, the AP delivers it and subsequently discards the contents of its buffer. By spoofing the polling message on behalf of the STA, an attacker may cause the AP to discard the STA's packets while it is asleep. It is also potentially possible to trick the STA node into thinking there are no buffered packets at the AP when in fact there are. The presence of buffered packets is indicated in a periodically broadcast packet called the Traffic Indication Map (TIM). If the TIM message itself is spoofed, an attacker may convince a STA that there is no pending data for it and the STA will immediately revert back to the sleep state. The power saving mechanism relies on time synchronization between the AP and its STAs so the STAs know when to awake. Key synchronization information, such as the period of TIM packets and a timestamp broadcast by the AP, are sent unauthenticated and in the clear. By forging these management packets, an attacker can cause a STA node to fall out of sync with the AP and fail to wake up

at the appropriate times.

2.6.6. Virtual Carrier Sense Attack [8]

The virtual carrier sense mechanism is used to mitigate collisions. Each 802.11 frame carries a duration field that indicates the number of microseconds that the channel is reserved. The duration field is used to program the Network Allocation Vector (NAV) on each node. Only when a node's NAV is zero is it allowed to transmit. This feature is used by RTS and CTS handshake that can be used to synchronize.

During the handshake the sending node sends a small RTS frame that includes the duration large enough to complete the RTS/CTS sequence, including the STS frame, the data frame and ACK frame. An attacker may assert a large duration field value preventing other STAs access to the channel. The maximum value of the NAV is 32767, approximately 32 milliseconds, so an attacker need only transmit 30 times in a second to jam all access to the channel.

2.6.7. PLME_DSSSTESTMODE (Jamming) Attack [13]

This is a PHY layer attack. It exploits a test mode in the IEEE 802.11b DSSS specification. It takes advantage of a test mode (PLME_DSSSTESTMODE) of operation present in 802.11b WLAN adapters (PCMCIA Cards/ APs) to continuously transmit a DSSS signal on a target channel. This continuous transmission effects all stations within range of the attacker (whether STAs or APs) using the target channel, resulting in the CSMA/CA reporting the media as busy for the duration of the attack.

The impact of this is that no station within range of the attacker will be able to seize the media for transmission, resulting in DoS of the target channel.

The flaws in 802.11's basic security mechanisms and vulnerabilities of 802.11 to the various above mentioned attacks have initiated the IEEE to propose 802.1 X as one of the initiatives to further secure 802.11 WLANs.

Chapter 3. BACKGROUND OF IEEE 802.1 X

3.1. What is IEEE 802.1 X?

Researchers have demonstrated basic flaws in 802.11 encryption mechanism and authentication protocols, which has led IEEE to create a series of protocol extensions and replacements. The IEEE 802.1 X standard defines a port-based network access control. It can be based on Extensible Authentication Protocol (EAP) [2], which provides a wide variety of authentication mechanisms. The access control is performed at the MAC level (it is PHY independent). 802.1 X provides network access control through the concept of a port. A port is any kind of controlled access, for example a router, switch or modem line for dial-up. 802.1 X was not initially designed for WLANs. The IEEE defines a virtual port as an association between a STA and an AP. To associate with an AP, the STA has to authenticate first (802.11 authentication). Once associated with a specific AP, the STA can go through 802.1 X authentication. 802.1 X provides per-station, per-session keys, and causes these keys to be changed often, solving reuse issues.

The 802.1 X framework provides the link layer with extensible authentication, normally seen in higher layers (Refer Figure 6).

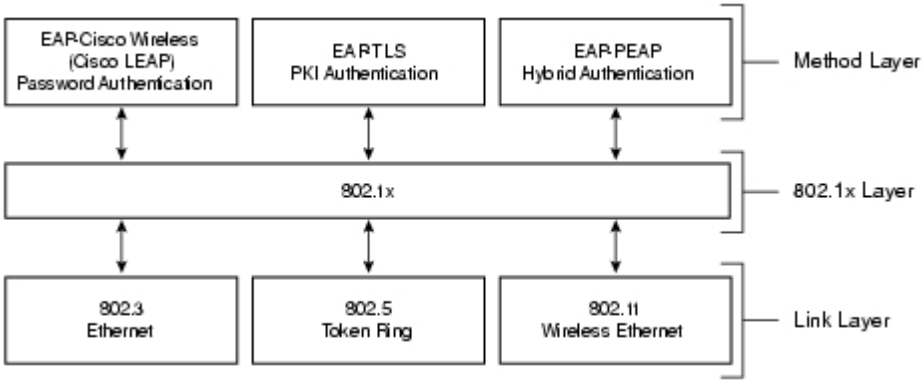


Figure 6: 802.1 X Layers

802.1 X requires two entities:

- The supplicant, which resides on the wireless STA
- The authenticator, which resides on the AP

The authentication server (optional) resides on the RADIUS (discussed in Section 3.2) server.

These entities are logical entities on the network devices. The authenticator creates a logical port per client, based on the client's Association ID (AID). This logical port has two data paths. The uncontrolled data path allows network traffic through to the network. The controlled data path requires successful authentication to allow network traffic through (Refer Figure 7).

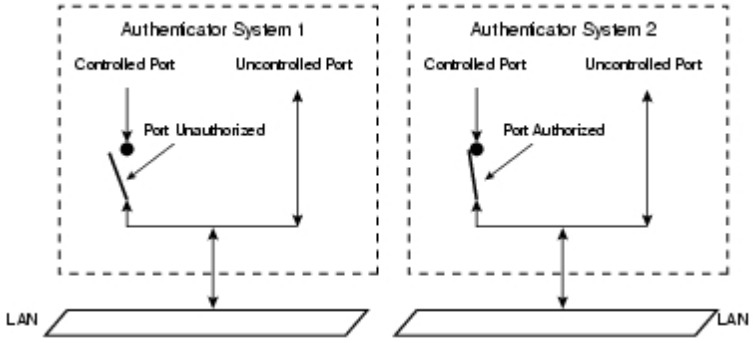


Figure 7: 802.1 X Ports

The supplicant becomes active on the medium and associates to the AP. The authenticator detects the client association and enables the supplicant's port. It forces the port into an unauthorized state so that only 802.1 X traffic is forwarded. All other traffic is blocked. The client may send an EAP Start message, although client initiation is not required (Refer Figure 8).

The authenticator replies with an EAP Request Identity message back to the supplicant to obtain the client's identity. The supplicant's EAP Response packet containing the client's identity is forwarded to the authentication server.

The authentication server is configured to authenticate clients with a specific authentication algorithm. Currently, 802.1 X for 802.11 LANs does not stipulate a specific algorithm to use thus allowing a variety of authentication algorithms to operate over it.

The end result is a RADIUS -ACCEPT or RADIUS-REJECT packet from the RADIUS server to the AP. Upon receiving the RADIUS ACCEPT packet, the authenticator transitions the client's port to an authorized state, and traffic may be forwarded.

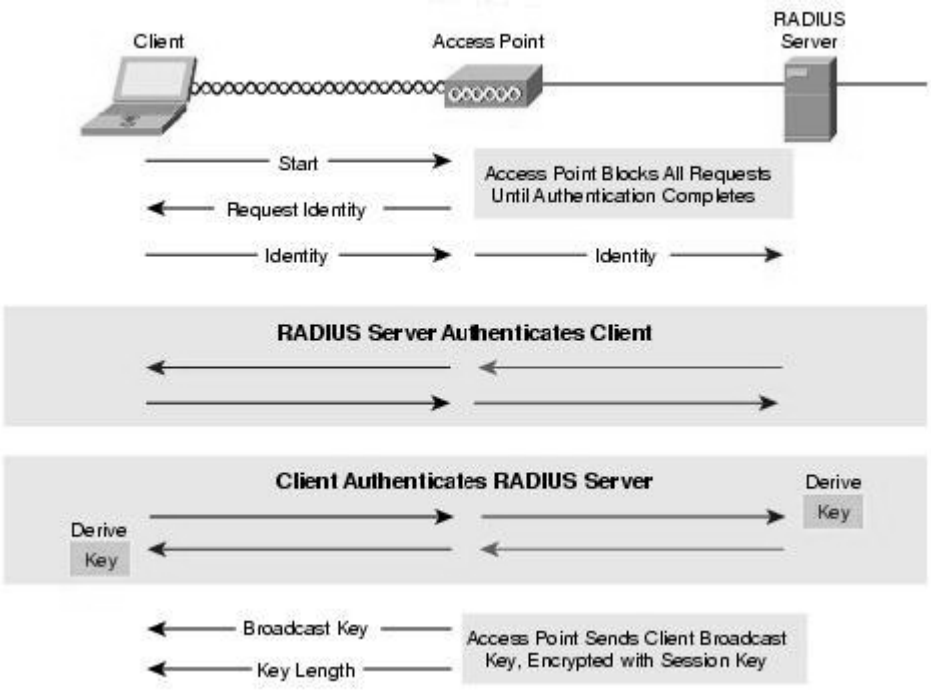


Figure 8: 802.1 X and EAP Message Flow

IEEE 802.1 X can be implemented entirely on the AP (by providing support for one or more EAP methods within the AP), or it can utilize a backend authentication server. The IEEE 802.1 X standard supports authentication protocols such as RADIUS, Diameter, and Kerberos. RADIUS [21] enables authentication, authorization, and accounting for Network Access Server (NAS) devices, including dial-up, xDSL, and 802.11. The 802.1 X standard can be implemented with different EAP types, including EAP-MD5 [20] (supports only one-way authentication without key exchange) for Ethernet LANs and EAP-TLS [22] (supports fast reconnect, mutual authentication and key management via certificate authentication). Currently new generations of EAP methods are being developed within the IETF, focused on addressing wireless authentication and key management issues. These methods support additional security features such as cryptographic protection of the EAP conversation, identity protection, secure ciphersuite negotiation, tunneling of other EAP methods, etc.

The use of EAP and RADIUS along with 802.1 X provides a user-based identification, a choice of authentication methods and a centralized user management as well as a dynamic key management. EAP and RADIUS are described in more detail later in this chapter.

3.2. RADIUS

RADIUS (Remote Authentication Dial-In User Service) [21] has been widely used by business and Internet Service Providers (ISPs) to control remote access.

A RADIUS client is a type of network access server (NAS), in our case this is an AP, and sends authentication and accounting requests to the RADIUS server (authentication server) in order to gain network access. Communications between the RADIUS server and the RADIUS client are authenticated through a shared secret. Each AP has its own shared secret with the RADIUS server. In general the transport protocol used is UDP and the RADIUS server listens on the port.

RADIUS supports a variety of authentication protocols like Challenge Handshake Authentication Protocol (CHAP), Microsoft Challenge Handshake Authentication Protocol (MS-CHAP) and EAP. The main advantage of EAP is that it supports different methods of authentication. The choice of EAP method is negotiated by the client and RADIUS server during the authentication phase.

3.3. EAP

EAP (Extensible Authentication Protocol) [20] is essentially a transport protocol. Its main advantage is that it provides an authentication framework and can be used by a variety of different authentication types known as EAP methods. It is supposed to head off proprietary authentication systems. It is designed to allow authentication methods to be deployed with no changes to the AP. EAP is used to pass the authentication information between the supplicant and the authentication server. The choice of authentication type is defined by the EAP type. The software supporting the EAP type resides on the authentication server and within the operating system of the client. The AP can be seen as a bridge between the supplicant and the authentication server. One of the goals of EAP is to enable development of new authentication methods without modifying the AP. One of the key points of 802.1 X is that the authenticator can be simple and dumb, all of the brains have to be in the supplicant and the authentication server. This makes 802.1 X ideal for wireless APs, which typically have little memory and processing power. Since the authentication mechanism is independent of the AP, we can specify any EAP methods without updating APs.

3.3.1. Overview of EAP Packets

EAP exchanges are composed of requests and responses. The authenticator (AP) sends requests to the supplicant (wireless STA that wants to access the network). The supplicant responds. Based on the credentials of the supplicant, the access will be granted or denied. There are two kinds of EAP packets (Refer Figure 9):

- EAP request and response
- EAP success and failure

The Data Type carried by the EAP request and response packets can be:
Data-type 1: The ID of the supplicant
Data-type 2: Notification: used to provide messages to the user
Data-type 3: NAK: used to suggest another authentication method
Data-type: 4-13 Kind of authentication type (EAP-MD5, EAP-TLS, EAP-TTLS, EAP-PEAP, LEAP etc...).

At the end of the EAP exchange, the authenticator grants access or not to the network. The EAP success and failure packets do not contain data. It only specifies if the user has been authenticated or not following the requests and responses. The Data Type carried by the EAP success and failure packets are either Data Type 3 in case of a success and Data Type 4 in case of a failure.

NAK is used to suggest another authentication method. That is the client and RADIUS server negotiate the choice of authentication during the authentication phase. Figure 10 shows a typical EAP exchange.

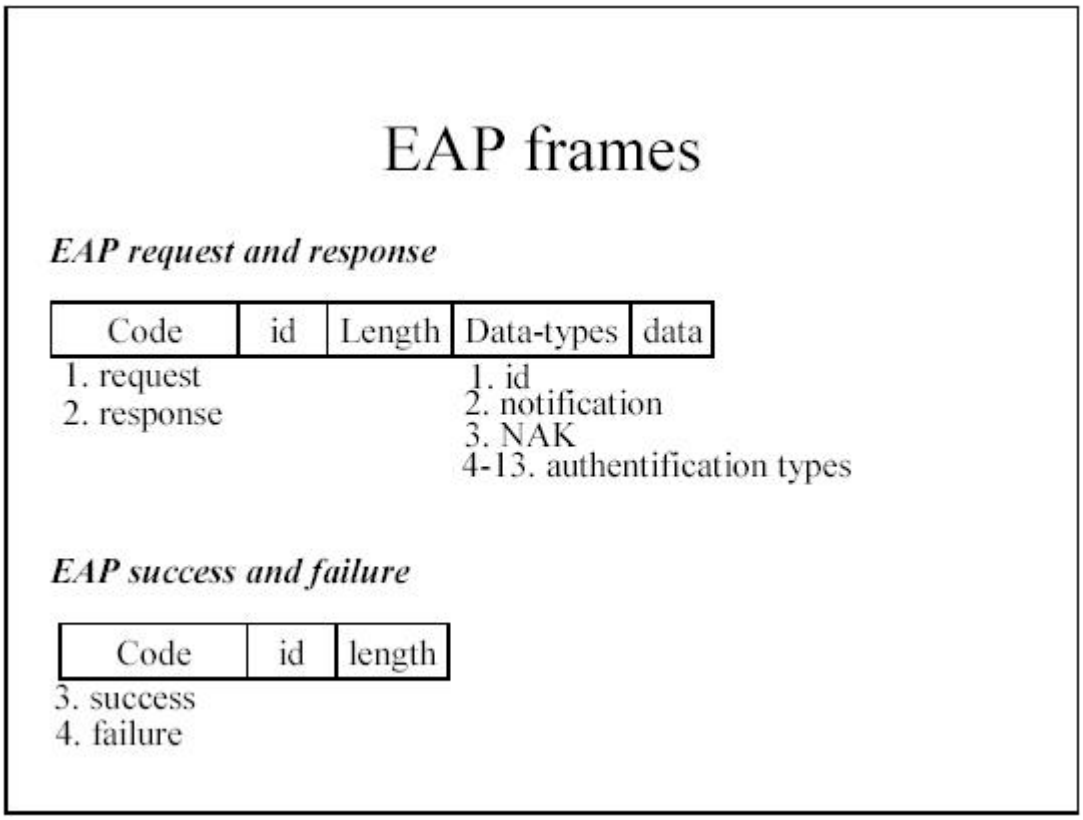


Figure 9: Kind of EAP Packets

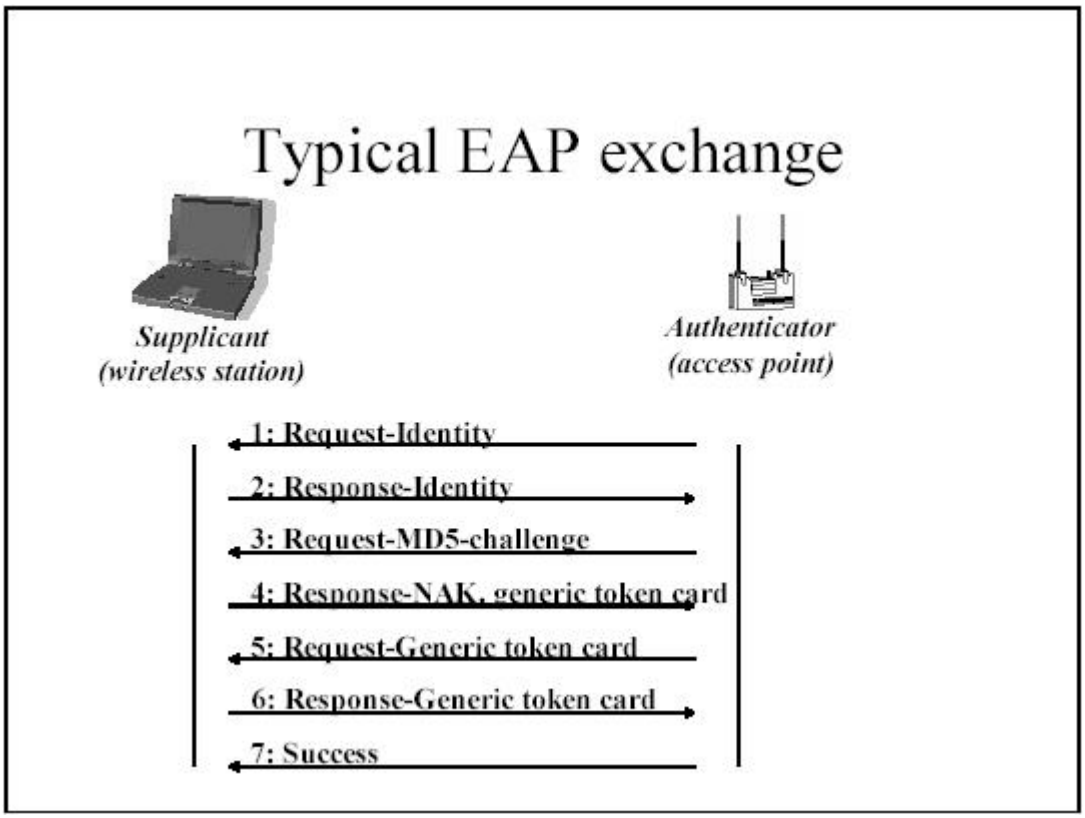


Figure 10: A typical EAP exchange

The protocol used between the supplicant and the AP is EAPOL. It is an encapsulation of EAP and it provides start messages, session logoff notification and key negotiation.

3.3.2. Choice of EAP methods

A common way of EAP authentication is certificates. Many EAP methods use certificates. The next section will describe what a certificate is and how a client can verify the certificate of the server.

Some EAP methods based on public-key certificates and Transport Layer Security (TLS) protocol: EAP-TLS, EAP-TTLS, and Protected EAP (PEAP).

3.3.2.1. EAP-TLS

It provides mutual authentication since both the client and the server use digital certificates signed by a certificate authority. It can provide user-based and session based WEP keys to encrypt the communication

channel between the client and the AP. This is a very secure authentication method. The certificates can be replaced by smart cards thus authenticating the user instead of the device. However, it requires all the user devices to have certificates. So, the cost of administration is high.

EAP-TLS is based on SSL v3.0. TLS is designed to provide secure authentication and encryption for a TCP/IP connection. To provide this functionality, TLS comprises three protocols:

- Handshake protocol: The handshake protocol negotiates the parameters for the SSL session. The SSL client and server negotiate the protocol version, encryption algorithms, authenticate each another, and derive encryption keys.
- Record protocol: The record protocol facilitates encrypted exchanges between the SSL client and the server. The negotiated encryption scheme and encryption keys are used to provide a secure tunnel for application data between the SSL endpoints.
- Alert protocol: The alert protocol is the mechanism used to notify the SSL client or server of errors as well as session termination.

TLS authentication is generally split into two methods: server-side authentication and client-side authentication. Server-side authentication uses public key infrastructure (PKI), namely PKI certificates. Client-side authentication can also use PKI certificates, but this is optional. EAP-TLS uses client-side certificates.

3.3.2.2. PKI and Digital Certificates

PKI encryption is based on asymmetric encryption keys. A PKI user has two keys: a public key and a private key. Any data encrypted with the public key can be decrypted only with the private key, and vice versa. For example: Mr. X gives Ms. Y his public key. Ms. Y then sends Mr. X an e-mail encrypted with his public key. For Mr. X to read the message, he has to decrypt the message with his private key. Because Mr. X is the only person with access to his private key, only he can decrypt the message (Refer Figure 11).

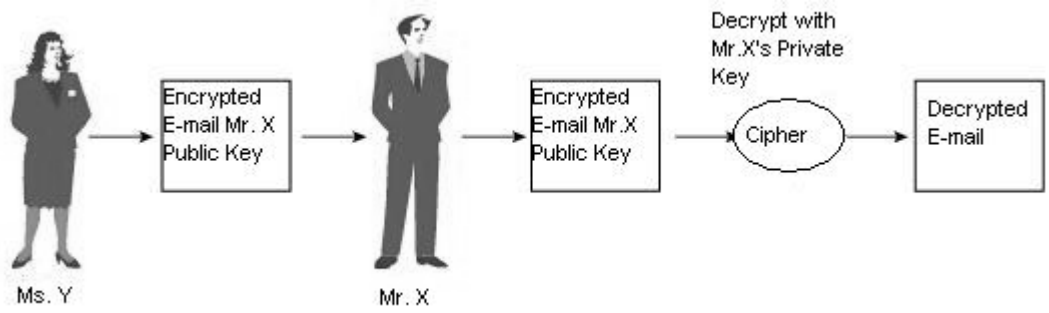


Figure 11: Public Key Encryption

Digital certificates are data structures distributed by a certificate authority that join a public key to a user. A digital certificate is generally made up of the following pieces of information:

- Certificate version
- Serial number
- Certificate issuer
- User
- User's public key
- Validity period
- Optional extensions
- Signature algorithm
- Signature

The digital signature is derived by combining the certificate version, serial number, issuer, user, user's public key, and validity period and running the values through a keyed hash function. The certificate authority keys the hash with its own private key (Refer Figure 12).

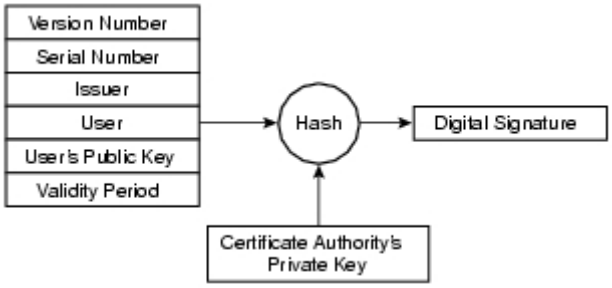


Figure 12: Digital Signature

3.3.2.3. TLS Authentication Process

The TLS process begins with the handshake process:

1. The SSL client connects to a server and makes an authentication request

2. The server sends its digital certificate to the client

3. The client verifies the certificate's validity and digital signature

4. The server requests client-side authentication

5. The client sends its digital certificate to the server

6. The server verifies the certificate's validity and digital signature

7. The encryption and message integrity schemes are negotiated

8. Application data is sent over the encrypted tunnel via the record protocol

3.3.2.4. EAP-TLS Authentication Process

The EAP-TLS authentication process is as follows (Refer Figure 13):

1. The client sends an EAP Start message to the AP

2. The AP replies with an EAP Request Identity message

3. The client sends its Network Access Identifier (NAI), which is its username, to the AP in an EAP Response message

4. The AP forwards the NAI to the RADIUS server encapsulated in a RADIUS Access Request message

5. The RADIUS server will respond to the client with its digital certificate

6. The client will validate the RADIUS server's digital certificate

7. The client will reply to the RADIUS server with its digital certificate

8. The RADIUS server will validate the client's credentials against the client digital certificate

9. The client and RADIUS server derive encryption keys

10. The RADIUS server sends the AP a RADIUS ACCEPT message, including the client's WEP key, indicating successful authentication

11. The AP sends the client an EAP Success message

12. The AP sends the broadcast key and key length to the client, encrypted with the client's WEP key.

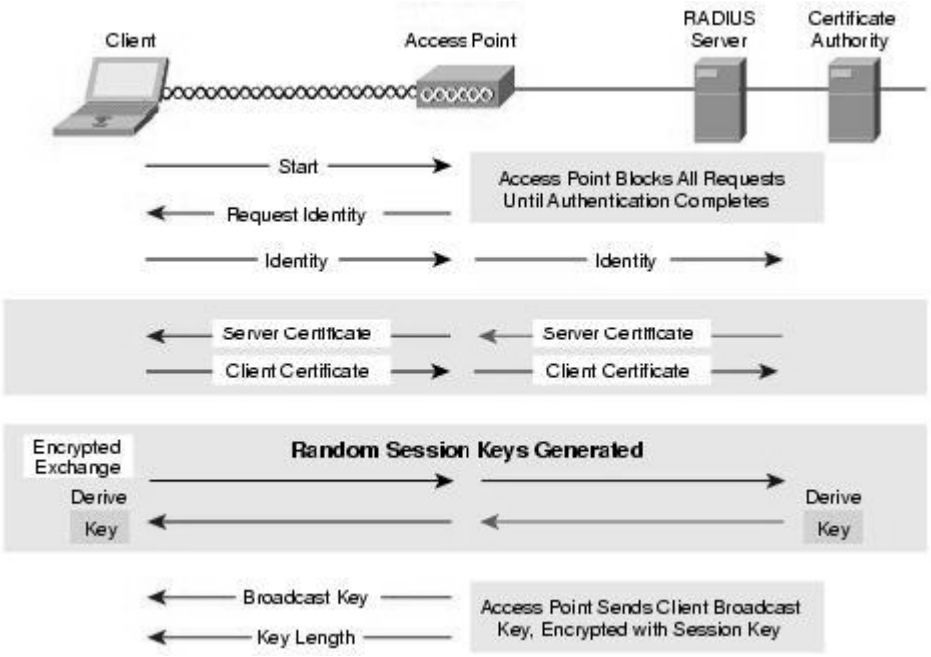


Figure 13: EAP-TLS Authentication Process [9]

3.3.2.5. EAP-TTLS / PEAP [9]

It is a hybrid method combining EAP-TLS and a traditional password-based method or another legacy method. This is to remove the burden of managing user certificates. Only the server needs a certificate. Like with EAP-TLS, encryption keys are generated during the authentication exchange.

For client-side authentication, Protected EAP (PEAP) can use any other EAP authentication type. Because PEAP establishes a secure tunnel via server-side authentication, non-mutually authenticating EAP types can be used for client-side authentication, such as EAP generic token card (GTC) for one-time passwords (OTP), and EAP MD5 for password based authentication.

PEAP is based on server-side EAP-TLS, and it addresses the manageability and scalability shortcomings of EAP-TLS. Organizations can avoid the issues associated with installing digital certificates on every client machine as required by EAP-TLS and select the method of client authentication that best suits them.

3.3.2.5.1. PEAP Authentication Process

PEAP authentication begins in the same way as EAP-TLS (Refer Figure 14):

1. The client sends an EAP Start message to the AP.

2. The AP replies with an EAP Request Identity message.

3. The client sends its Network Access Identifier (NAI), which is its username, to the AP in an EAP Response message.

4. The AP forwards the NAI to the RADIUS server encapsulated in a RADIUS Access Request message.

5. The RADIUS server will respond to the client with its digital certificate.

6. The client will validate the RADIUS server's digital certificate.

From this point on, the authentication process diverges from EAP-TLS.

7. The client and server negotiate and create an encrypted tunnel.

8. This tunnel provides a secure data path for client authentication.

9. Using the TLS Record protocol, a new EAP authentication is initiated by the RADIUS server.

10. The exchange will include the transactions specific to the EAP type used for client authentication.

11. The RADIUS server sends the AP a RADIUS ACCEPT message, including the client's WEP key, indicating successful authentication.

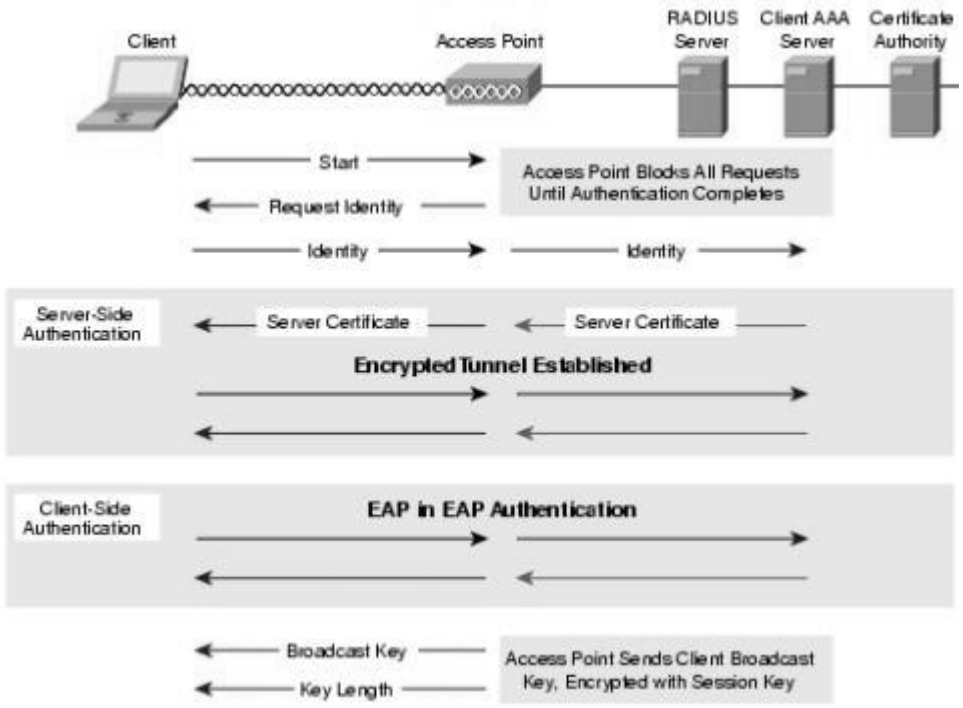


Figure 14: PEAP Authentication Process [9]

3.4. 802.1 X over 802.11

In this section, I show how 802.1 X can integrate with 802.11. (Refer Figure 15).

1) The STA must first associate with an AP. In 802.11, the association follows the authentication (Open-system or Shared-key). Once the association is made, the communication between the STA and the AP can start. The authentication server uses specific authentication techniques, to verify client's identity (Passwords, digital certificates).

2.a) The supplicant can trigger the authentication process by sending an EAPOL start message. The authenticator allows only EAP traffic and blocks all other traffic, such as HTTP, DHCP, and POP3 packets.

2.b) The authenticator sends an EAP-Request/Identity packet to the supplicant once it has associated with the AP.

3) The supplicant sends an EAP-Response/Identity packet to the authenticator to prove its identity. The

packet is then routed to the authentication server encapsulated in RADIUS protocol (an EAP-Message attribute is used to encapsulate EAP packets for transmission from the authenticator to the RADIUS server).

4) The authentication server sends back a challenge to the authenticator. The challenge depends on the EAP method chosen. The authenticator unpacks this from RADIUS and re-packs it into EAPOL and sends it to the supplicant. At this point, the number of exchanged messages will vary according to the EAP method. Only mutual authentication is considered appropriate for WLANs.

5) The supplicant replies to the challenge via the authenticator, which routes the response to the back-end server.

6) If the supplicant provides appropriate credentials, the authentication server responds with a success message -Access Accept-, which is then forwarded to the supplicant. The authenticator now unblocks the controlled port and allows normal traffic. However, RADIUS allows a per-user configuration. Certain users may have restricted access. In this case, the restrictions are specified in the RADIUS message Access-accept sent to the AP. For example, the authenticator might switch the supplicant to a particular VLAN or install a set of firewall rules. EAP supports dynamic keying. That happens when the authentication succeeds.

7) EAPOW-key is used to transport the global keys.

8) An EAPOL logoff notification can be sent to the authenticator to announce the end of the connection. 802.1 X also defines a re-authentication timer, which can be used to periodically require the Supplicant to re-authenticate.

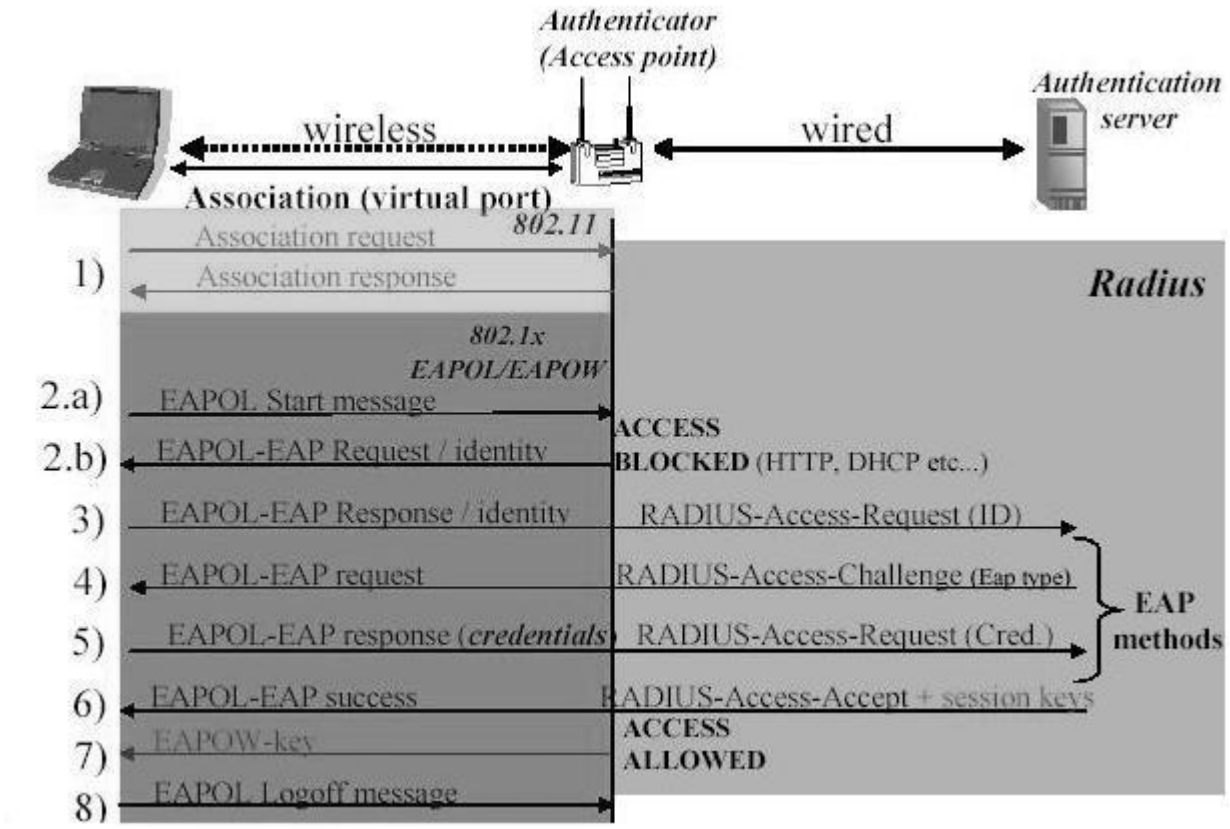


Figure 15: 802.1 X over 802.11

3.5. 802.1 X Vulnerabilities

In the paper [7]**,** the authors Arbaugh and Mishra, expose the fact that the 802.1 X protocol is severely flawed for a very simple reason, the authentication protocol is only one sided i.e. there is no mutual authentication. 802.1 X lets the AP make sure the user is authentic but it fails to provide a reciprocal method by which the user can guarantee the authenticity of the AP. This exposes the system to Man-In-Middle (MIM) Attacks and session hijacking. Other vulnerabilities in 802.1 X are carried out by Denial-Of-Service (DoS) attacks.

Session Hijacking [10]

Once the STA (Supplicant) authenticates with the AP (Authenticator), the attacker spoofs the MAC address of the AP and sends MAC disassociate requests. Once the STA sees the disassociate request it disassociates.

The RSN state machine (Refer Figure 16) goes to UNASSOCIATE and 802.1 X is still in AUTHENTICATED state.

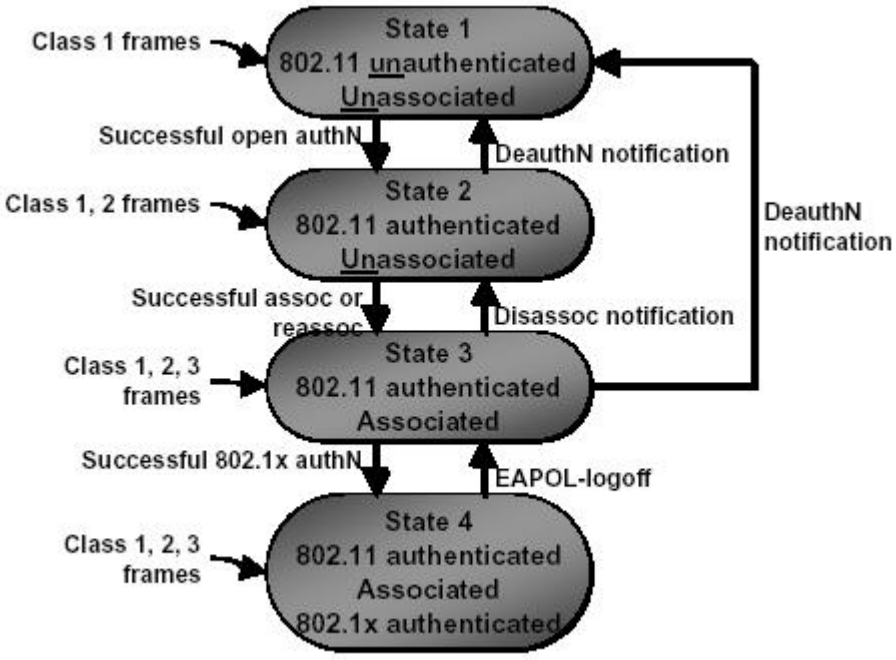


Figure 16: RSN State Machine

The attacker then gains access to the network spoofing the MAC address of the STA, 802.1 X state machine for AP is still in authenticated state. (Refer Figure 17).

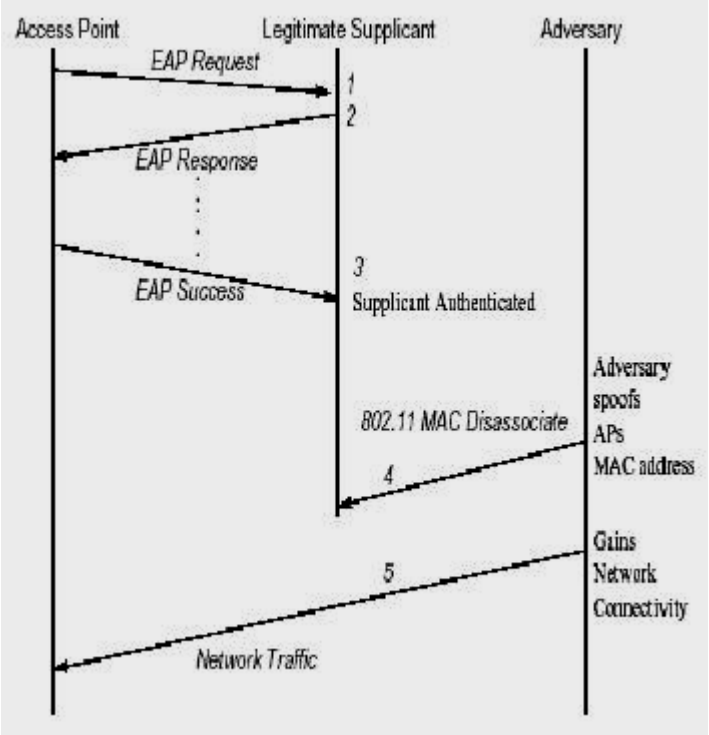


Figure 17: Session Hijack Flow [10]

Denial Of Service attacks [10]

DoS attacks can be performed in many ways. One way a DoS attack is performed is by 802.11 Management frame spoofing. Since the AP sends de-authenticate messages, the STA gets logged off. 802.11 management messages include beacon, probe request/response, association request/response, reassociation request/response, disassociation, and deauthentication. Without authenticating these management messages, denial of service attacks are possible.

Another DoS attack is to send a flood of associate requests [8]. After the 802.11 association phase and during 802.1 X authentication phase, the AP can hold only a set limit of state information and if a lot of requests are flooded, the AP can not accept these requests.

Lucent, Cisco, Funk Software have come up with separate replies for 802.1 X vulnerabilities. Their solutions perform mutual authentication between STA and AP. The dynamic keys are created locally on the client and server.

Cisco's LEAP, which is also called Light EAP uses dynamic WEP keys, mutual authentication and the AP rejects packets that are not encrypted.

Lucent's CHAP performs client authentication with AP and there is a TLS tunnel between client and server. The client authenticates a digital certificate from the server, then the client sends a hashed password, name and challenge.

Kerberos and LEAP are vulnerable to dictionary attacks [15] and there are lots of LEAP cracking tools available like ASLEAP , THC LEAP and ANWRAP LEAP.

Most of the problems in 802.1 X seem to be addressed with 802.11 i but there will still be a need for change of hardware and firmware. IEEE 802.11 i does not have any defense mechanisms for some of the Denial-of-Service attacks like PLME_DSSSTESTMODE (Jamming) attack since it protects MAC layer Protocol Data Units (PDUs) and PLME_DSSSTESMODE attack operates at the Physical Layer Convergence Protocol (PLCP) layer. Hence there is still a need for security on 802.11, 802.1 X or 802.11 i network based systems. Any unprotected 802.11, 802.1 X or 802.11 i network is vulnerable to many attacks and WIDS can provide an external layer of security to protect these networks.

Chapter 4. INTRUSION DETECTION

Intrusion detection is a process that detects rogue users attempting to access, have already accessed, or have compromised the WLAN. Intrusion Detection System (IDS) for WLANs can be host-based, network-based, or hybrid, the hybrid combining features of host- and network-based IDS [27].

A host-based IDS includes a host-based program, which is installed on a system and monitors it for suspicious behavior. The agent could halt an attack on a system but its primary function is to log and analyze events and send alerts.

A network-based IDS monitors network traffic (each packet) in real time and determines whether traffic conforms to predetermined attack signatures (activities that match known attack patterns). For example, a DoS attack sends packets that are fragmented in such a way as to crash the target system. The network monitor will recognize packets that conform to this pattern and take action such as killing the network session, sending an e-mail alert to the administrator, or other action specified.

Host-based IDS has an advantage over network-based IDS when encrypted connections such as SSL Web sessions or VPN connections are involved, since the agent resides on the component itself, the host-based system is able to examine the data after it has been decrypted. In contrast, a network-based IDS is not able to decrypt data therefore, encrypted network traffic is passed through without investigation.

IDS on wired networks cannot be directly applied to WLANs. A Network-based IDS component on a wired network behind the AP will not detect attacks directed from one STA to another STA (peer to peer) on the same subnet. The wireless AP switches traffic directly between STAs. The traffic does not enter the wired network, it is WEP encrypted, and the IDS component does not have an opportunity to capture clear-text packets for analysis. IDS components on the wired network usually will not detect attempts to de-associate a legitimate STA from the WLAN and will not detect the association of an unauthorized STA with the WLAN.

Flooding, jamming, and other DOS attacks against wireless devices use physical and data-link layer techniques that are not visible to the IDS components at a packet level. IDS on wired networks will not identify the physical location of rogue APs within the building. These rogue APs can act as entry points for unauthorized wireless access from remote locations.

IDS components will not detect an authorized STA communicating peer-to-peer with an unauthorized STA. This scenario can create a bridge into the wired network by allowing a rogue user to connect to a STA that is operating in “ad hoc” mode. The ad hoc mode allows a STA to be used to relay traffic to the network and creates a number of potential attack scenarios.

There is a need to architect a wireless IDS, that is capable to handle all the shortcomings of a wired IDS. Hence a wireless IDS should be capable of detecting unauthorized peer-to-peer communications within the WLAN. It should be able to track and physically locate the unauthorized APs/STAs, analyze wireless traffic and monitor 802.11 RF space and generate an alarm upon detection of unauthorized configuration changes to wireless devices that violate security policy, detect flooding and de-association attempts before they successfully compromise the WLAN and provide centralized monitoring and management features.

WIDS is an intrusion detection system that is capable of providing perimeter security to an internal WLAN. WIDS is capable of detecting, tracking and locating intruders using directional antenna. WIDS also has the capability to sniff passively in RF Monitor mode and analyze wireless traffic and detect outside perimeter rogue APs.

Chapter 5. TRACKING AND LOCATION

While detection of rogue APs and unauthorized ad-hoc networks is certainly useful, physically tracking the offender is more interesting.

Most triangulation today uses directional techniques. A dish or other directional antenna with a narrow range is attached to a receiver and then an area is scanned for the strongest signal. The STA is moved some distance away, the area is scanned again, and then the position is found using simple trigonometry. (Refer Figure 18)

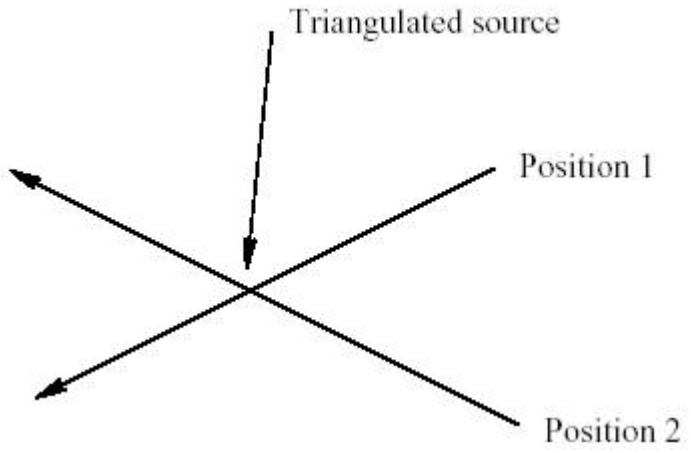


Figure 18: Tracking by triangulation.

In practice, there is usually more involved than this. Terrain, obstructions, heat and atmospheric effects, reflections, refraction, antenna design, and many other factors that could affect the apparent location of the transmitter affect radio propagation. The apparent location of the strongest signal may not actually be the location of the transmitter. A full discussion of these effects is beyond the scope of this paper.

Regardless, the basic theory is sound and can be a very effective technique to locate a transmitter. Another technique, not quite as common today, is to locate the transmitter using only the relative signal strength at various well-placed locations around the area, and if known, the free-space propagation losses and the power of the transmitter.

If we know the output power of the transmitter, the gain of the receiving and transmitting antennas, power drop-off, and the received signal strength, location of transmitter to two possible locations should be

possible with only two samples.

At point A, from the signal strength and power drop-off equation, we would be able to determine the distance from the transmitter (Refer Figure 19). At point B, we would also know that, so the location of the transmitter will be found at the point(s) where both dA and dB meet:

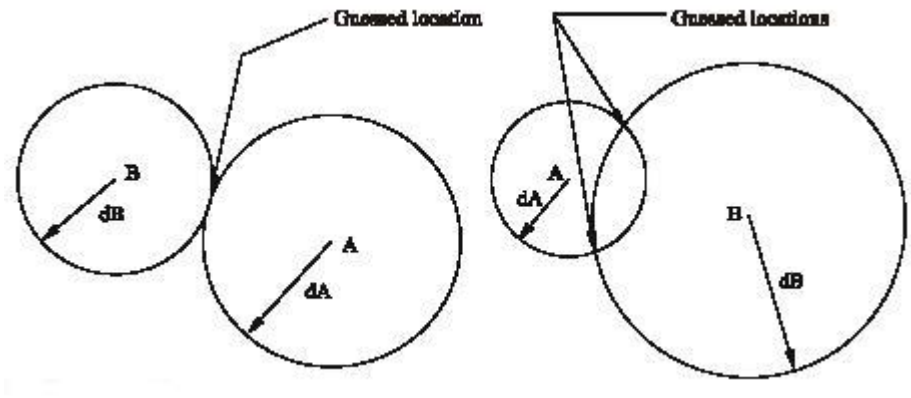


Figure 19: Tracking by signal strength.

If we do not know the strength of the transmitter or the gain of any of the antennas involved, we just have to introduce one more unknown, a signal strength ratio, so the problem turns into a simultaneous equation with three unknowns. Thus, a minimum of three data points is needed. If these data points are well placed, there should only be one or two realistic solutions to the equations.

A paper by Frank Adelstein, Prasanth Alla, Rob Joyce and Golden G. Richard III [23] related to WIDS documents attempts to locate an intruding wireless station. In this paper the authors locate an intruder's position by rotating a directional antenna 360 degree's while monitoring signal strength. An antenna's signature is computed ahead of time and the intruder's location is computed by comparing the intruder's data to the signature data.

Experiments were done with three different types of directional antennas. The test antenna was mounted on a telescope tripod and connected to a portable AP consisting of a laptop running Linux and HostAP [17]. The antenna's signature was computed by placing an intruder machine a few hundred feet away from the AP. The intruder associated with the AP and the directional antenna was rotated in fixed increments and the signal strength value was recorded. Readings were taken over a 360 degree range.

In order to compute the location of an intruder, several readings of the intruder's signal strength data were made at different angles of the AP antenna. The intruder's data was correlated with the signature data and the computed angle is the angle with the best fit to the known signature data. Two different locations of the AP were used. The results of the tests computed the location of the intruder within 2 to 4 degrees. The intruder's location was computed using triangulation with the computed angles and access point locations.

The research showed that it is possible to determine the intruder's location with reasonable accuracy using low priced off the shelf hardware and free software. A Wireless Intrusion Detection System (WIDS) could be implemented through the knowledge gained from the research to locate intruder's and also provide an external layer of security to a WLAN.

Chapter 6. WIDS

6.1. General Description

Wireless Intrusion Detection System (WIDS) is designed to keep an internal wireless network secure around the physical perimeter of the network with special access points to detect and locate intruders. Radio waves from a wireless network extend out past the physical perimeter of the network and can be received by anyone with the correct equipment. A potential intruder could gain access to the WLAN and possibly a wired network behind the WLAN.

Authorized users connect to the internal network APs from within the perimeter. WIDS assumes that internal security procedures handle authentication inside the perimeter. Using the assumption that a station will associate with the access point from which it receives the strongest signal, a potential intruder outside the perimeter would associate with a WIDS access point (WIDS AP) on the perimeter and not with an access point in the internal network. The WIDS system would then locate the intruder using the directional antennas on two or more WIDS access points. Even if an intruder was able to associate with the internal access point from beyond the perimeter, the WIDS AP system directional antennas should still be able to locate the intruder, because WIDS can work with signals it picks up and association with a WIDS AP is not necessary.

WIDS is designed to give the user control over how it is applied. The user can decide that all stations outside the perimeter are intruders or that some stations outside the perimeter are authorized to connect to the WIDS APs or the internal network APs. Another possibility is for the WIDS APs to be used as honeypots that allow intruders to associate so that an intruder's activities can be monitored or the intruder can be given false or misleading data. The honeypot scenario is not implemented as part of this paper.

WIDS APs use a set of rules to identify potential intruders. The rules can search for known attack fingerprints or search according to user defined criteria based on the data in the signal (MAC address, IP header information, application data, etc.). Each WIDS AP is equipped with a directional antenna which points outward and sweeps in a preconfigured arc searching for wireless users. The WIDS AP determines if the remote station is an intruder and it contacts a controlling computer. Other nearby WIDS APs are reconfigured by the controller to modify their areas of coverage. Bearings from multiple WIDS APs are used by the controller to pinpoint the location of the intruder. The rules can trigger actions to interact with the intruder such as denying access, ignoring frames, reacting to IP

header data, etc.

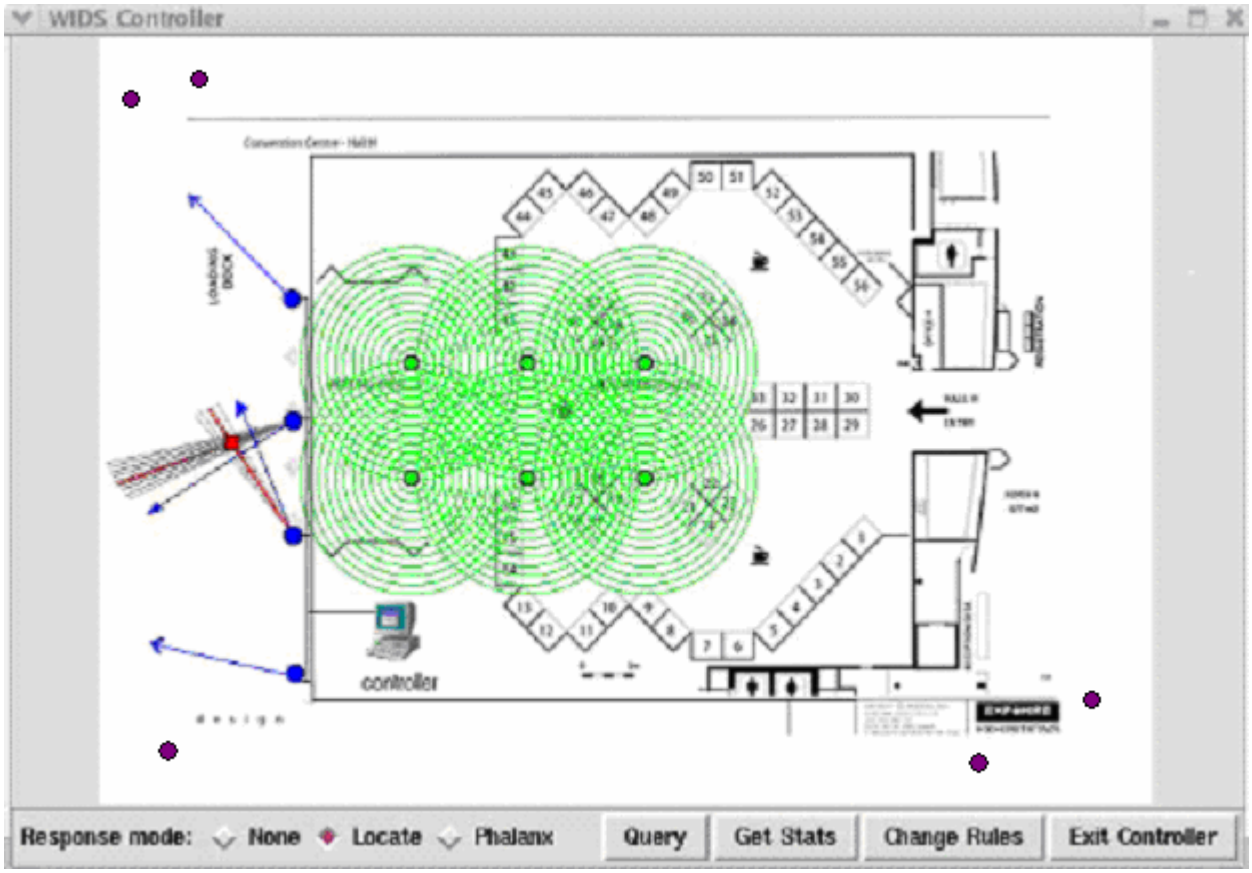
6.2. WIDS Architecture and Design

WIDS is an intrusion detection system that is classified as a network based IDS [27]. The WIDS architecture consists of one or more WIDS access points connected to a centralized controller via a standard wired network. The wired network provides a more secure management of the WIDS AP's than a wireless network.

WIDS APs use an open-source access point code, HostAP [17] and Linux. HostAP allows an 802.11b wireless Prism 2/2.5 Ethernet card to be used as an access point instead of a remote station. HostAP has been extended to include the additional functions needed by WIDS. The controller is a personal computer running Linux. The controller software is written in Perl using Perl-TK to construct the graphical interface.

We investigated several designs and configurations for the WIDS AP hardware and decided that it should be an embedded computer equipped with a rotating directional antenna. The WIDS AP would be built from components including an X-Scale single board computer and wireless networking platform, a directional antenna, a stepper motor to rotate the antenna, and a stepper motor controller. A list of the components is presented in the Appendix of this paper. Unfortunately, we were not able to obtain financing to build a fully functional WIDS AP equipped with the rotating antenna. A laptop computer without a rotating directional antenna was used in our implementation and directional antenna components were simulated in the software, for example the antenna readings file was generated by hand.

Since some 802.11 frames that are handled by the Prism 2/2.5's firmware when in hostAP can only be captured by a wireless card in monitor mode, a configuration with two Prism 2/2.5 cards, one in hostAP mode and one in monitor mode provides WIDS with more intrusion detection capabilities. The card in the monitor mode can capture data, control, and the management frames that are handled by the card's firmware and pass them to the modified HostAP software for processing and testing. The card in the monitor mode can also receive the HFA384x (refer section 6.7) transaction frames that show time, signal, silence and rate.



WIDS access point
Internal access point
Station (possible intruder)
Orientation of a WIDS AP attached directional antenna
Estimates of an intruder's location
External/Rogue access point

Figure 20: WIDS Architecture

Figure 20 depicts four WIDS access points, arranged vertically on the left, protecting an internal wireless network installed in an arena. Only one side of a WIDS installation is shown in order to keep the picture simple. (A complete WIDS installation would include WIDS AP's on all four sides of the arena.) The WIDS access points connect to a controller computer via a wired network. The controller can be located inside the perimeter. The arena contains six internal access points. The signals transmitted by the internal AP's extend outside of the perimeter of the arena. The arrows originating from each WIDS access point show the current orientation of an attached directional antenna. The other dotted lines extending from two of the WIDS access points represent station signals picked up by the directional antennas. The triangulation lines

represent bearings on the station and a square indicates the location of a station. The outer dotted circles are external APs detected by WIDS. Hence, WIDS is designed to strengthen the security of an internal wireless network by surrounding physical perimeter of the network with special access points to detect and locate intruder signals from a wireless network extended out past the physical perimeter of the network received by anyone with the correct equipment.

6.3. Typical WIDS Installation with 802.1 X

A typical WIDS installation (Refer Figure 21) consists of a normal omni-directional AP located in the center of the physical facility and WIDS APs located around the perimeter and directional antennas pointing outward. (Note that there could be multiple omni, or directional, APs inside the perimeter, I do not show them in the figure to keep the explanation at the basic level.) The WIDS APs sweep their directional antennae in preconfigured arcs, searching for wireless users. Authorized users connect to the omni AP from within the perimeter. I also assume that internal security procedures handle authentication inside the perimeter. The problem is that the omni AP's coverage extends beyond the physical perimeter. WIDS addresses this problem because an intruder attempting to break into the WLAN from the outside will contact the WIDS APs before coming within range of the omni AP. The WIDS APs will detect intrusions based on both known attack signatures (such as network probes from NetStumbler [18] or other non-passive "war-driving" programs [19]) and behavior based signatures (such as an internal MAC address suddenly appearing in an external location on a machine with different OS characteristics than it had previously).

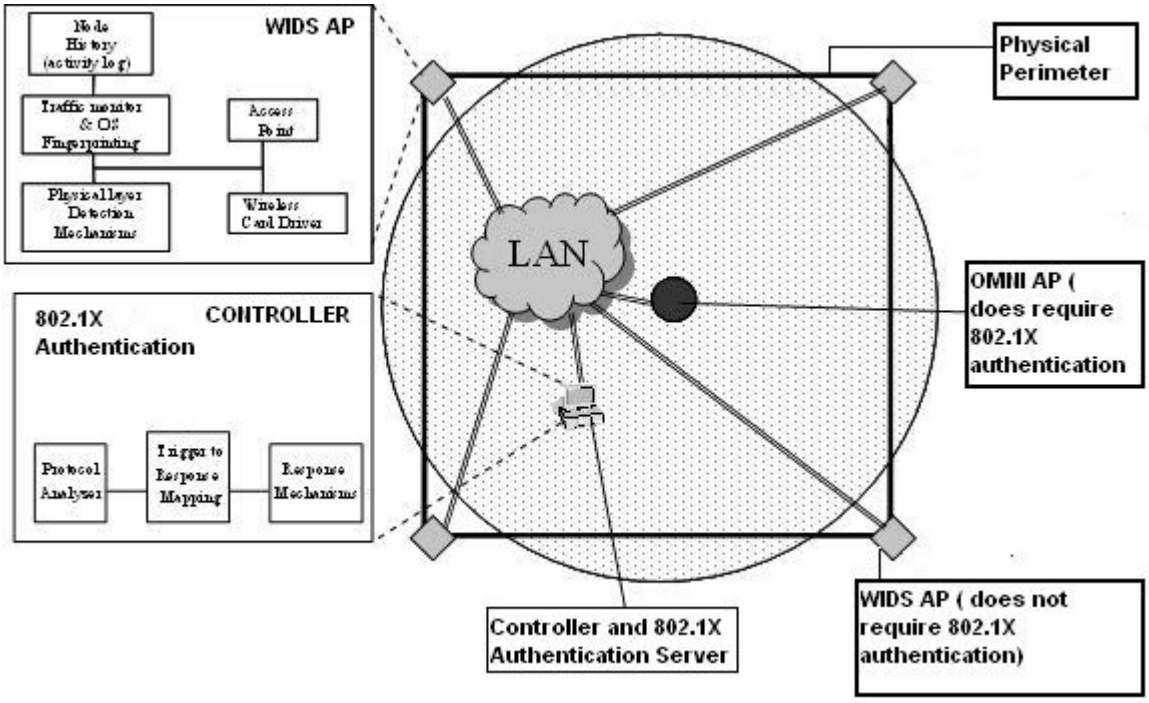


Figure 21: Typical WIDS installation with 802.1 X.

WIDS detects anomalous behavior by tying the signature data into a behavior-based intrusion detection system [9, 10]. When a WIDS AP detects an unauthorized wireless user, the controller is contacted and other nearby WIDS APs are reconfigured (by the controller) to modify their areas of coverage (i.e., the arc that their directional antennae travel through are modified appropriately). Information from multiple WIDS APs is used by the controller in order to pinpoint the physical location of unauthorized users.

6.4. WIDS Access Point/Controller Protocol

The WIDS access points and the controller communicate over TCP, using the WIDS Access Point/Controller Protocol (WCP). This section presents a summary of the communications between access points and the controller. Access Point/Controller Protocol message types are printed in upper case letters.

An access point starts up and attempts to connect to the controller using sockets. If the access point is unable to connect, it retries every 5 seconds. When a connection is made, the access point sends a HELLO message to the controller and waits for a response. The HELLO message contains the name of the access

point and its location. The controller replies with a CONFIG message containing the beginning and ending sweep positions for the antenna, the report rate for sending data to the controller and the intrusion detection rules to be used by the access point. The antenna begins sweeping and listening for signals. The report rate specifies how often the access point sends REPORT messages to the controller. The REPORT message contains the access point name, the position (angle) of the antenna, the sweep direction, the time, the signal strength received at that position, and the MAC address of the station sending the signal.

When a signal is received which has the maximum signal strength in a specified number of readings, the access point sends a POSITION message to the controller. The POSITION message contains the access point name, the position of the antenna when the maximum signal strength was received, the MAC address of the station sending the signal and whether or not the station is associated with the reporting access point.

The controller maintains a hash of POSITIONS received. The keys are the MAC addresses of the stations and the values are strings containing the name of the access point that sent the POSITION message, an integer indicating whether or not the access point and the station are associated, and another integer indicating whether or not the station has been located.

When a POSITION message is received by the controller, the controller checks the hash for the MAC address. If it is not found, the controller adds it to the hash, and checks if the station is associated with the reporting access point. If it is associated, the controller determines which neighboring access point needs to be reconfigured and sends a RECONFIG message with reconfigured antenna sweep information to the applicable access point.

If the MAC address is in the hash, the controller checks the hash value to determine if the station has already been located or if a POSITION message from the same access point with the same information has been previously received. If so, the controller does nothing. If the MAC is in the hash with a different access point and has not been located, the controller will use the information from both access points to compute the station's location. The hash is updated to show that this station has been located.

The controller will display a warning message if the same MAC address is associated with more than one access point. This may be an indication that MAC address spoofing has occurred.

When an access point receives a RECONFIG message, it changes the starting sweep position or the ending sweep position in accordance with the RECONFIG message. The antenna sweeps to the new position

twice and then returns to its original sweep configuration.

The controller operator can send messages to an access point to change the intrusion detection rules or to collect statistics related to a station associated with the access point. A CHANGERULES message is sent to change the intrusion detection rules. When the access point receives a CHANGERULES message, it destroys its current rule tree and processes the new rules sent by the controller. A STATS message is sent to gather statistics from an access point. The access point returns a STATS message containing a list of stations associated with it in response to the controller's STATS message. The controller operator selects a station and sends a MAC message with the station's MAC address. The access point reads the applicable /proc/net/hostap/wlan0/MAC address file (it is a file that contains real time statistics like signal strength, transmitted packets, bytes etc sent from the NIC firmware) and sends the stats information back to the controller in a MACST message. The controller receives the MACST message, opens a new window and displays the stats.

The access point can send a LOGDATA message to the controller. When the controller receives a LOGDATA message, it writes the message to the controller's log file.

6.5. WIDS Intrusion Detection Rules

Each 802.11b frame received by a HostAP access point which is not handled by the wireless card's firmware can be tested with a set of intrusion detection rules. If the access point also has a wireless card operating in the monitor mode, all 802.11b frames received can be tested with the rules. The results of the rules tests are intended to identify potential intruders.

A rule has the format type-subtype, a test list consisting of one or more pairs of test and test data, and one pair of action and action data. The type-subtype is the 802.11 frame type-subtype, the test is one of the tests defined in the WIDS AP software, the test data is data used in the test, the action is one is one of the actions defined in the WIDS AP software, and the action data gives more information about the action. The action is performed only if all of the tests in the rule are true.

The type-subtype, test list, and action are separated by ','. The test list is enclosed by '(' and ')'. The test keyword and test data are separated by a ':'. The end of a test keyword test data pair is designated by an '!'. An action consists of an action keyword and action data pair. The action keyword

is separated from the action data by a ‘:’.

The test keyword generally describes an operation on a field in the 802.11 or the IP frame, such as SOURCE_MAC_EQUALS for source MAC address equals, TTL_LESS_THAN for time to live is less than, or FLAG_PWRMGMT for power management is on or off. The value to be tested is given by the rule’s test data. Sample test data for test keywords are 00022D2E5C6a for SOURCE_MAC_EQUALS, 64 for TTL_LESS_THAN and OFF for FLAG_PWRMGMT.

An example of a rule is:

> "MGMT_ASREQ, (SOURCE_MAC_EQUALS:00022D2E5C6a! FLAG_WEP:OFF!), LOG, assoc request from 00:02:2D:2E:5D:6a flag wep off"

This rule is testing an association request. It is true if the source MAC address is 00:02:2D:2E:5C:6a and the wep flag is 0. If the rule is true, the WIDS AP will send a message to the controller, which displays the message in a terminal window and logs the message in a file. The message includes the WIDS AP name, date and time of message, and the action data “assoc request from 00:02:2D:2E:5D:6a flag wep off.”.

6.6. Tools

WIDS is based on open-source access point, HostAP [17], using Prism 2/2.5/3 wireless card drivers. The capabilities of WIDS include user specifiable, trigger based intrusion detection, allowing the user running the WIDS Controller to tailor the criteria that trigger alarms. Triggers are based on both packet/frame data and historical/behavioral data including typical signal strength levels, locations, time-to-live (TTL) values, IPIDs, etc. for particular MAC addresses. For example, I could specify that packets from MAC 00:20:E0:8C:92:88 must have a TTL of 30 and a signal strength greater than 10, any packets from this MAC address not meeting those criteria will raise an alert. This is similar to a honeypot or honeynet [16], but allows more detailed control. HostAP is publicly available software and consists of a set of loadable kernel modules and a user-space daemon (HOSTAPD), under Linux, for interacting with and configuring the module that make an 802.11b wireless NIC become an AP (instead of a remote STA).

6.6.1. Host AP

Host AP is an open source implementation of Linux drivers for Intersil Prism 2/2.5/3 chipset based 802.11b

network cards. It supports operation in a variety of modes such as:

- Managed – client connected to an AP
- Master – serves as an AP
- Monitor – passive RF monitoring

The most interesting aspect of Host AP drivers is operation in Master mode where a standard 802.11b NIC can be used as an AP. Host AP accomplishes this by configuring the card to operate in a mode which is specific to Prism chipsets – the Host AP mode.

In Host AP mode, the firmware performs all time critical tasks of APs like the periodic transmission of beacon frames and the transmission of probe response frames in response to probe requests. Other AP related tasks are left to the host driver to accomplish. It essentially provides hooks in the firmware that call host level handlers while passing the packet that was received up to the kernel. It completely implements all AP functionality like association/disassociation, authentication/deauthentication, and bridging (wired to WLANs). The drivers can also be compiled with the HOSTAPD option, which will transfer all AP handling tasks from the driver level to a user level daemon and there is no need to recompile and reinitialize the kernel to apply code changes.

Host AP also supports Linux Wireless Tools. It provides a unified configuration interface (iwconfig) for all wireless cards on the system. It also implements a set of wireless ioctls that can be used to reconfigure the wireless adapter directly in a program.

6.6.2. Kismet

Kismet [24] is an 802.11 layer2 wireless network detector, sniffer, and intrusion detection system. Kismet will work with any wireless card which supports raw monitoring (rfmon or RF Monitor) mode, and can sniff 802.11b, 802.11a, and 802.11g traffic.

Kismet identifies networks by passively collecting packets and detecting standard named networks, detecting (and given time, de-cloaking) hidden networks, and infering the presence of non-beaconing networks via data traffic.

6.6.2.1. Kismet.conf

I faced many issues before I got Kismet to work properly using Lucent Technologies Orinoco card. Kismet requires the version 14 of Wireless Tools for Linux [30] containing iwconfig, iwpriv and ioctl's. Kismet uses ioctl on the firmware of Orinoco card to function in RF Monitor mode.

One of the important files to get Kismet to work properly is the configuration file (Kismet.conf). The settings in the configuration have been set up to specifically be compatible with the Lucent Technologies Orinoco Silver 11mb Card and configured to run on the interface eth0. The configuration file contains information like source, which in this case is Orinoco, the name of the interface, which in this case is eth0. It also contains information on setting up the format type for the output .network file that Kismet creates with respect to the networks and stations that it finds. The configuration file is as follows :

```
# Kismet config file
# Most of the "static" configs have been moved to here -- the command line
# config was getting way too crowded and cryptic.  We want functionality,
# not continually reading --help!

# Version of Kismet config
version=2.8.1

# Name of server (Purely for organizational purposes)
servername=Kismet

# MAC addresses to filter, comma seperated.
#macfilter=DE:AD:BE:EF:00:00

# Known WEP keys to decrypt, bssid,hexkey.  This is only for networks where
# the keys are already known, and it may impact throughput on slower hardware.
# Multiple wepkey lines may be used for multiple BSSIDs.
# wepkey=00:DE:AD:C0:DE:00,FEEDFACEDEADBEEF0102030405060708090O

# Is transmission of the keys to the client allowed?  This may be a security
# risk for some.  If you disable this, you will not be able to query keys from
# a client.
allowkeytransmit=true

# User to setid to (should be your normal user)
suiduser=jvigo

# Port to serve GUI data
tcpport=2501
# People allowed to connect, comma seperated IP addresses or network/mask
```

```
# blocks.  Netmasks can be expressed as dotted quad (/255.255.255.0) or as
# numbers (/24)
allowedhosts=127.0.0.1
# Maximum number of concurrent GUI's
maxclients=5

# Packet sources:
# source=capture_cardtype,capture_interface,capture_name
# Card type - Specifies the type of device. It can be one of:
#     cisco         - Cisco card with Linux Kernel drivers
#     cisco_cvs     - Cisco card with CVS Linux drivers
#     cisco_bsd     - Cisco on *BSD
#     prism2        - Prism2 using wlan-ng drivers with pcap support (all
#                     current versions support pcap)
#     prism2_hostap - Prism2 using hostap drivers
#     prism2_legacy - Prism2 using wlan-ng drivers without pcap support (0.1.9)
#     prism2_bsd    - Prism2 on *BSD
#     orinoco       - Orinoco cards using Snax's patched driers
#     generic       - Generic card with no specific support.  You will have
#                     to put this into monitor mode yourself!
#     wsp100        - WSP100 embedded remote sensor.
#     wtapfile      - Saved file of packets readable by libwiretap
#     ar5k          - ar5k 802.11a using the vt_ar5k drivers
# Capture interface - Specifies the network interface Kismet will watch for
#  packets to come in on.  Typically "ethX" or "wlanX".  For the WSP100 capture
#  engine, the WSP100 device sends packets via a UDP stream, so the capture
#  interface should be in the form of host:port where 'host' is the WSP100 and
#  'port' is the local UDP port that it will send data to.
# Capture Name      - The name Kismet uses for this capture source.  This is
the
#   name used to specify what sources to enable.
#
# To enable multiple sources, specify a source line for each and then use the
# enablesources line to enable them.  For example:
# source=prism2,wlan0,prism
# source=cisco,eth0,cisco

#source=cisco,eth0,Kismet
source=orinoco,eth0,Kismet
#source=prism2_hostap,wlan0,Kismet

# Comma-separated list of sources to enable.  This is only needed if you wish
# to selectively enable multiple sources.
# enablesources=prism,cisco

# Do we have a GPS?
gps=false
# Host:port that GPSD is running on.  This can be localhost OR remote!
gpshost=localhost:2947

# How often (in seconds) do we write all our data files (0 to disable)
writeinterval=300

# Do we use sound?
# Not to be confused with GUI sound parameter, this controls wether or not the
# server itself will play sound.  Primarily for headless or automated systems.
sound=false
```

```
# Path to sound player
soundplay=/usr/bin/play
# Optional parameters to pass to the player
# soundopts=--volume=.3
# New network found
sound_new=/usr/local/share/kismet/wav/new_network.wav
# Network traffic sound
sound_traffic=/usr/local/share/kismet/wav/traffic.wav
# Network junk traffic found
sound_junktraffic=/usr/local/share/kismet/wav/junk_traffic.wav
# GPS lock aquired sound
# sound_gpslock=/usr/local/share/kismet/wav/foo.wav
# GPS lock lost sound
# sound_gpslost=/usr/local/share/kismet/wav/bar.wav
# Alert sound
sound_alert=/usr/local/share/kismet/wav/alert.wav

# Does the server have speech? (Again, not to be confused with the GUI's
speech)
speech=false
# Server's path to Festival
festival=/usr/bin/festival
# How do we speak?  Valid options:
# speech    Normal speech
# nato      NATO spellings (alpha, bravo, charlie)
# spell     Spell the letters out (aye, bee, sea)
speech_type=nato
# speech_encrypted and speech_unencrypted - Speech templates
# Similar to the logtemplate option, this lets you customize the speech output.
# speech_encrypted is used for an encrypted network spoken string
# speech_unencrypted is used for an unencrypted network spoken string
#
# %b is replaced by the BSSID (MAC) of the network
# %s is replaced by the SSID (name) of the network
# %c is replaced by the CHANNEL of the network
# %r is replaced by the MAX RATE of the network
speech_encrypted=New network detected, s.s.i.d. %s, channel %c, network
encrypted.
speech_unencrypted=New network detected, s.s.i.d. %s, channel %c, network open.

# Where do we get our manufacturer fingerprints from?  Assumed to be in the
# default config directory if an absolute path is not given.
ap_manuf=ap_manuf
client_manuf=client_manuf

# Use metric measurements in the output?
metric=false

# Do we write waypoints for gpsdrive to load?  Note:  This is NOT related to
# recent versions of GPSDrive's native support of Kismet.
waypoints=false
# GPSMap waypoint file.  This WILL be truncated.
waypointdata=%h/.gpsdrive/way_kismet.txt

# How many alerts do we backlog for new clients?  Only change this if you have
# a -very- low memory system and need those extra bytes, or if you have a high
# memory system and a huge number of alert conditions.
```

```
alertbacklog=50

# File types to log, comma seperated
# dump    - raw packet dump
# network - plaintext detected networks
# csv     - plaintext detected networks in CSV format
# xml     - XML formatted network and cisco log
# weak    - weak packets (in airsnort format)
# cisco   - cisco equipment CDP broadcasts
# gps     - gps coordinates
#logtypes=dump,network,csv,xml,weak,cisco,gps
logtypes=dump,network

# Do we log "noise" packets that we can't decipher?  I tend to not, since
# they don't have anything interesting at all in them.
noiselog=false

# Do we log beacon packets or do we filter them out of the dumpfile
beaconlog=false

# Do we log PHY layer packets or do we filter them out of the dumpfile
phylog=true

# Do we do "fuzzy" crypt detection?  (byte-based detection instead of 802.11
# frame headers)
# valid option: Comma seperated list of card types to perform fuzzy detection
#  on, or 'all'
fuzzycrypt=prism2_legacy,wtapfile

# What type of dump do we generate?
# valid option: "wiretap"
dumptype=wiretap
# Do we limit the size of dump logs?  Sometimes ethereal can't handle big ones.
# 0 = No limit
# Anything else = Max number of packets to log to a single file before closing
# and opening a new one.
dumplimit=0

# Default log title
logdefault=Kismet

# logtemplate - Filename logging template.
# This is, at first glance, really nasty and ugly, but you'll hardly ever
# have to touch it so don't complain too much.
#
# %n is replaced by the logging instance name
# %d is replaced by the current date
# %t is replaced by the starting log time
# %i is replaced by the increment log in the case of multiple logs
# %l is replaced by the log type (dump, status, crypt, etc)
# %h is replaced by the home directory
# ie, "netlogs/%n-%d-%i.dump" called with a logging name of "Pok" could expand
# to something like "netlogs/Pok-Dec-20-01-1.dump" for the first instance and
# "netlogs/Pok-Dec-20-01-2.%l" for the second logfile generated.
# %h/netlots/%n-%d-%i.dump could expand to
# /home/foo/netlogs/Pok-Dec-20-01-2.dump
#
```

```
# Other possibilities:  Sorting by directory
# logtemplate=%l/%n-%d-%i
# Would expand to, for example,
# dump/Pok-Dec-20-01-1
# crypt/Pok-Dec-20-01-1
# and so on.  The "dump", "crypt", etc, dirs must exist before kismet is run
# in this case.
#logtemplate=%n-%d-%i.%l
logtemplate=%h/kismet-logs/%n-%d-%i.%l
#logtemplate=%h/kismet-logs/%n.%l

# Where state info, etc, is stored.  You shouldnt ever need to change this.
# This is a directory.
configdir=%h/.kismet/

# cloaked SSID file.  You shouldn't ever need to change this.
ssidmap=ssid_map

# Group map file.  You shouldn't ever need to change this.
groupmap=group_map

# IP range map file.  You shouldn't ever need to change this.
ipmap=ip_map
```

To get Kismet started we need to run the “kismet_monitor –H” command on the terminal window. This starts Kismet Hopper, which hops through different channels to find networks and then run “Kismet” command on the terminal window.

To keep acquiring data in the passive RF Monitor mode we need to run a script every 5 seconds containing the command iwpriv eth0 force_reset which forces a reset of the wireless card to RF Monitor mode.

6.6.2.2. Kismet.pl

The output data from Kismet is stored in two formats (.dump) and (.network). The .network file is used by a perl script called Kismet.pl to communicate with WIDS Controller about all external/rogue access points that were found by Kismet. Kismet also de-cloaks hidden networks. Only external access points that have an SSID show up on the controller.

The .dump file can be opened using Ethereal (next section) and we can gather more information about networks by static filtering.

The Kismet.pl file is as follows :

```
#! /usr/bin/perl

#system ("for files in `ps -ef| grep perl | awk '{print $2}'`; do kill -9
$files ; done");

$cwd = "/home/jvigo/kismet-logs";
chomp $cwd ;
$debug = 1;
print "Now running script in $cwd\n" if $debug;
$date = `date +"%b-%d-%Y"`;
chomp $date;
print "Current date is $date \n" if $debug;
#@logfiles =  glob ("Kismet-May-25-2005-*\.network");
#@logfiles =  glob ("$cwd/Kismet-May-25-2005-*\.network");
@logfiles =  glob ("$cwd/Kismet-${date}-*\.network");
foreach $logfiles (@logfiles){
if ($logfiles =~ /Kismet-\w+-\d+-\d+-(\d+)/){
      $number = $1;
}
push @latest, $number;
}
print "Latest array is @latest \n" if $debug;
@descending = sort { $b <=> $a } @latest;
#$uselog="$cwd/Kismet-May-25-2005-${descending[0]}.network";
$uselog="$cwd/Kismet-${date}-${descending[0]}.network";
print "This is the log file used $uselog\n" if $debug;
open (LOG, "$uselog")|| die "Can't open: $!\n";
$x = 1;
while ( $line = <LOG>){
  if ($line =~ /Network\s\d:\s"(.*)"\sBSSID/){
    $network=1;
    if (( $1 eq "jv.cs.uno.edu" ) || ( $1 eq "<no ssid>")){
          $network=0;
        next;
    }
  $accesspt= $1;
  #$accesspt = "OutAP".$x;
  $x = $x + 1;
  }
  if ($line =~ /Type\s+:\s+infrastructure/ && $network == "1"){
    push @accesspt, $accesspt;
  }

}

print "These are the available access points: @accesspt\n" if $debug;
#$port=2000;
#$xdata=10;
#$ydata=400;
$xx = 0;
$yy = 0;
foreach $accesspt (@accesspt){
$pid = fork;
```

```
die "fork:$!" unless defined $pid;
if($pid){#parent
} else {
#system ("perl -w wids.pl -accesspt configfile 192.168.1.4 7777 $accesspt $port
0 $xdata $ydata data8 1 &");

$port = random(2000,6000);

if ($xx eq 0){
$xdata = random(10,50);
} else {
$xdata = random(450,530);
}


if ($yy eq 0){
$ydata = random(450,530);
} else {
$ydata = random(10,50);
}

$test = open(TEST,"perl -w wids.pl -accesspt configfile 192.168.1.4 7777
$accesspt $port 0.08 $xdata $ydata data8 1 |");
print "command is perl -w wids.pl -accesspt configfile 192.168.1.4 7777
$accesspt $port 0.0 $xdata $ydata\n" if $debug;
close (TEST);
exit 0;
}

if ($xx eq 0){
$xx = 1;
} else {
$xx = 0;
}

if ($yy eq 0){
$yy = 1;
} else {
$yy = 0;
}

#print "command is perl -w wids.pl -accesspt configfile 192.168.1.4 7777
$accesspt $port 0.0 $xdata $ydata\n" if $debug;
#$port = $port+100;
#$xdata = $xdata+5;
#$ydata = $ydata+10;
}

sub random($$){
   $lower = $_[0];
   $upper = $_[1];
   $random = int(rand($upper));
   #Keep generating until number falls within range
   while ($random < $lower)
   {
      $random = int(rand($upper));
   }
```

```
    # then print
    return $random;
}
```

6.6.3. Ethereal

Ethereal [25] is a network packet analyzer. A network packet analyzer will try to capture network packets and try to display that packet data as detailed as possible. Ethereal can capture live packet data from a network interface (Refer Figure 22). One of the main reasons for using Ethereal is that it allows the Open and Save of packet data that is captured.

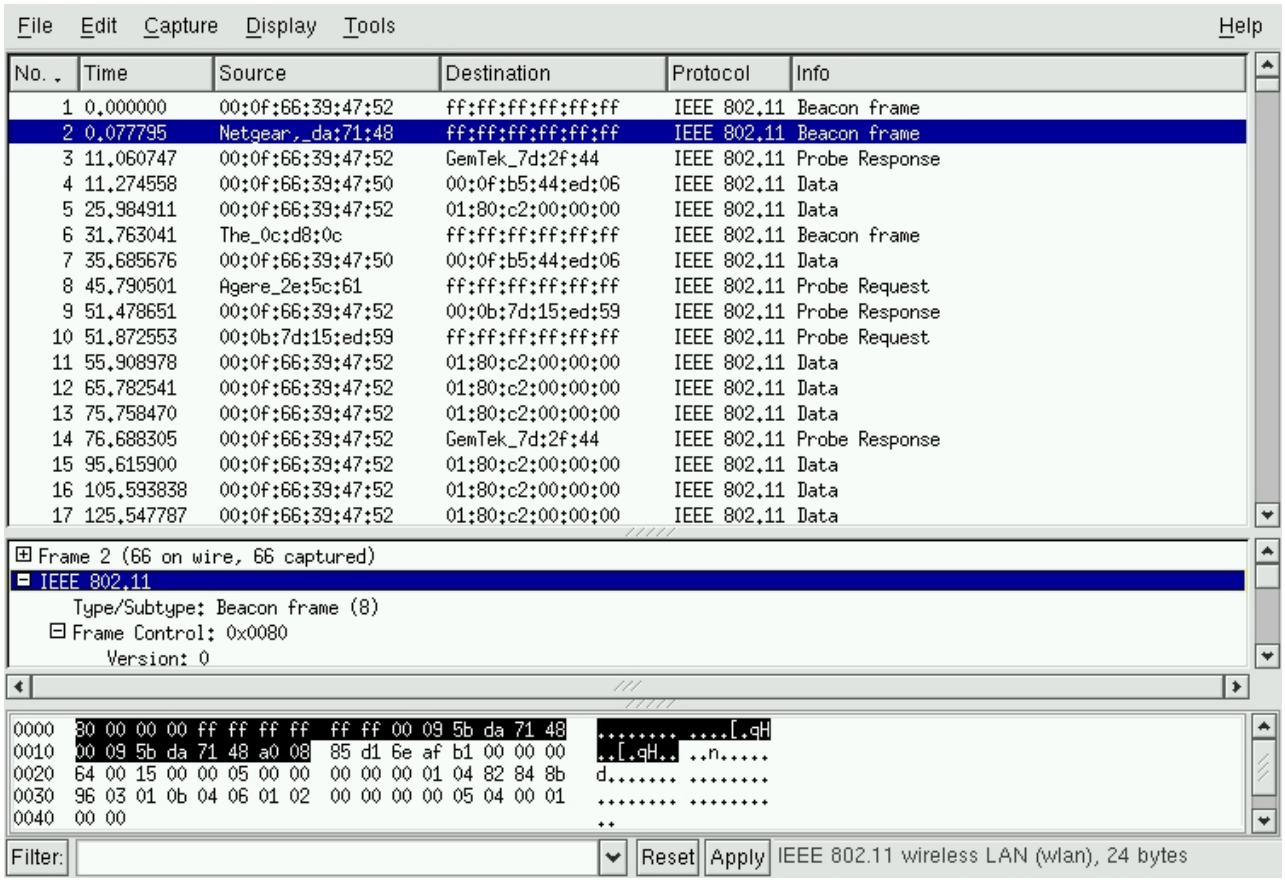


Figure 22: Example of a .dump file from Kismet analyzed using Ethereal

6.6.4. FakeAP

Fakeap [25] creates fake 802.11b access points. It can be used as a rule action. Fakeap was modified to read MAC addresses and vendors from file that contains authorized OUI values for MAC address. Fakeap sends out an unlimited number of fake access points. When the fakeap action is triggered, a window pops up on the controller's screen that has a button that is used to stop sending fake access points and to restore the WIDS AP original essid and MAC address.

6.6.5. Scoop

Scoop [14] is written by Mike D. Schiffman. Scoop is a program which captures and decodes IP frames. Some changes were made to scoop to enable it use the intrusion detection rules.

If an intrusion detection rule needs information from an IP packet such as the time to live (TTL), HostAP forks a new process and runs a program scoop.c that listens for IP packets on wlan0. The IP listener program is based on libpcap and communicates with HostAP via shared memory. When an IP packet meeting the rule criteria is received, the IP listener signals HostAP and HostAP takes the action that is described in the intrusion detection rule.

The shared memory is initialized when the access point starts up. Semaphores are used to control access to the shared memory. The shared memory and semaphore id's are stored in the hostapd struct. The new process that listens for IP packets needs to know the shared memory and semaphore id's. They are passed to the new process as command line arguments in the execl command. The IP listener process for scooping, is started as follows:

```
sprintf(filter,"%s%s","ip[8] > ", rule->test_data1);
execl("/home/jvigo/BOSNST/Scoopshared/scoop","scoop", "-i", "wlan0","-a",ascshmid,"-
m",ascsemid,"-x",filter,(char*)0);
```

On termination scoop detaches from shared memory segment and removes the shared memory segment and semaphore.

6.7. WIDS Implementation

All the code modifications to Host AP were done in the HOSTAPD module. Before I explain the implementation part of WIDS, I would like to discuss some of the issues that I faced. One of my main findings with Host AP mode was that not all packets were being received by HOSTAPD. Packets like probe requests and control frames were being absorbed by the firmware. I also did not receive any packets that were not destined for the MAC address of my NIC. Critical tasks like probe request handling and beacon broadcasts were handled by the firmware. One of the main reasons why I wanted to get a handle on probe Requests and beacon broadcasts was to detect NetStumbler but I shall discuss that later in the NetStumbler detection section.

The Monitor mode, also known as the RF Monitor mode, is used by network sniffing tools like Ethereal [25], Airsnort [11], and Kismet [24] to analyze all packets on the network. I looked into wlansniff.c file which was provided in the Host AP distribution and was able to listen to all packets but AP functionality was no longer enabled in this mode. The firmware just left the receiver on and sent all packets through the protocol stack without processing. Hence I decided to have two network interfaces, one set up in Host AP mode (wlan0) and the other set up in Monitor mode (eth0) and start communication between both networks (eth0, wlan0) and WIDS controller.

Firstly, I shall discuss code implementation in the WIDS Module. The rules engine is based of a tree structure where the root is the rule and its children are Control Frames (CONT), Data Frames (DATA) and Management Frames (MGMT). These three types of frames have a number of sub-types. I also have actions that are defined as Alert, Log, Pass, Suspicious, Other and Deny. The rules for each WIDS AP are stored in a hash and any rule can be added, changed or deleted from the Controller. Once a WIDS AP detects a malicious NIC or AP it sends the signal strength , mac address and position of the intruder to the controller and the controller responds to neighboring WIDS AP depending on the position, to change its sweep angle and try to locate the intruder. Once the neighboring WIDS AP sends its information about the intruder to the controller, it can triangulate and locate the intruder. The WIDS Simulator provides a live view of the intrusion detection process.

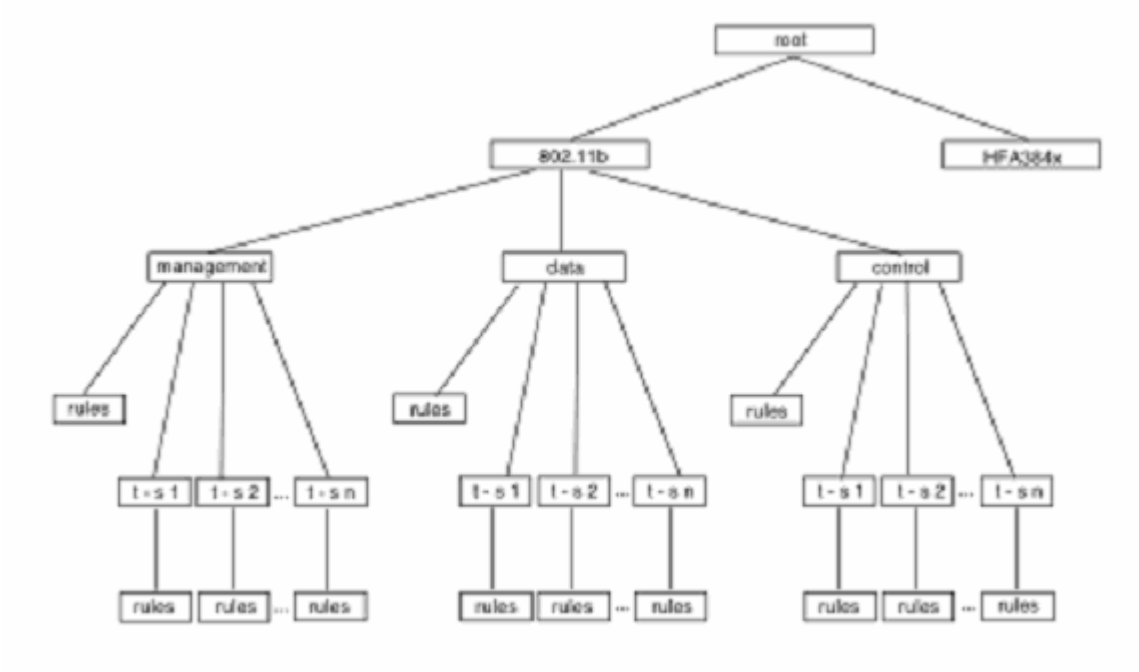


Figure 23: Rules Tree

The tree contains the intrusion detection rules used by WIDS (Refer Figure 23). There are two branches under the root. The 802.11b branch can be used for wireless cards running in either the hostAP mode or monitor mode. The HFA384x branch requires a wireless card to be in monitor mode and needs the two card implementation of WIDS. Rules were implemented only for the 802.11b branch. Rules for HFA384x can be built into Kismet.pl since Kismet does report all information from HFA384x transaction frames.

The code implementation in the Controller Module is to deal with the communication between WIDS AP and controller using WCP and triangulating with the help of information received from at least two WIDS APs to locate an intruder.

The code implementation of the WIDS Simulator was done in Perl using Perl-TK for constructing graphical interface. It is an user interface that shows real time analysis to intrusion detection and also allows users to change rules and get statistics.

6.7.1. Kismet related files, Kismet.pl

The Kismet.pl file scans through the chronologically latest Kismet.network file, for example (Kismet-Jun-26-2005-1.network) and communicates with the WIDS Controller by sending it a message that a new virtual access point exists. The Kismet.pl excludes SSID's, jv.cs.uno.edu and <no ssid> since jv.cs.uno.edu is a

WIDS AP and Kismet finds it and <no ssid> is a cloaked AP and there is a need to wait for Kismet to de-cloak it. It only reports access points running in infrastructure mode. The WIDS Controller graphical interface is a simple X and Y axis grid with a minimum value of 0 and maximum value of 540 for both X and Y axis. The X and Y locations of the access points are created through a random function that keeps the numbers created with in the max range of the WIDS GUI which is 540 on X and Y directions and outside of the inner perimeter. These locations are generated randomly since I did not use directional antenna to calculate the locations. The ports on which the access points connect to the WIDS controller are also generated randomly.

The Kismet.pl can be run on a scheduled Cron job every five minutes.

6.8. WIDS Controller Module

This module performs all the core central functions with respect to detecting intruders by communicating with other WIDS APs to change angle or direction of sweep and also the controller consists of a real time analysis user interface that shows all the WIDS APs and also the current sweep routines performed by WIDS APs. The controller module is written in Perl and uses Perl-TK for constructing the graphical interface.

Two of the controller's responsibilities are to provide the access points with information needed to configure/reconfigure the directional antenna and to provide the intrusion detection rules for the access point. The controller reads a configuration file at startup. The configuration file contains a hash of HostAP/WIDS AP names and their beginning sweep positions, ending sweep positions, and report rates, a hash of internal (non-WIDS) access points and their locations, the size of the grid for specifying access point locations and a hash of the HostAP/WIDS AP names and their related locations, a numerical ID, and the midpoint of the beginning and ending sweep positions. The access points ID's are numbers starting with 1 for left bottom corner of the perimeter and proceeding in a counterclockwise direction, 2 for the next access point, 3 for the next access point, etc. until all access points have a number. Numbering in this matter eliminates the need to consider x and y position values when comparing the location of one access point compared to the location of another.

After the controller configuration is completed, the controller displays a GUI containing an image of the area to be protected and the internal non-WIDS access points. The controller opens a socket on a specified port and listens for messages from the access points. Messages are handled by the WIDS Communication

Protocol (WCP) (Refer section 6.5). WIDS APs are displayed on the GUI as they are connected to the controller. The position of the antenna of each access point is designated by a sweeping line. The controller assumes that a station associates with the access point closest to it.

The controller operator can change the rules file, display statistics about the stations connected to the WIDS AP or query the log file. Screen shots of those operations are shown below.

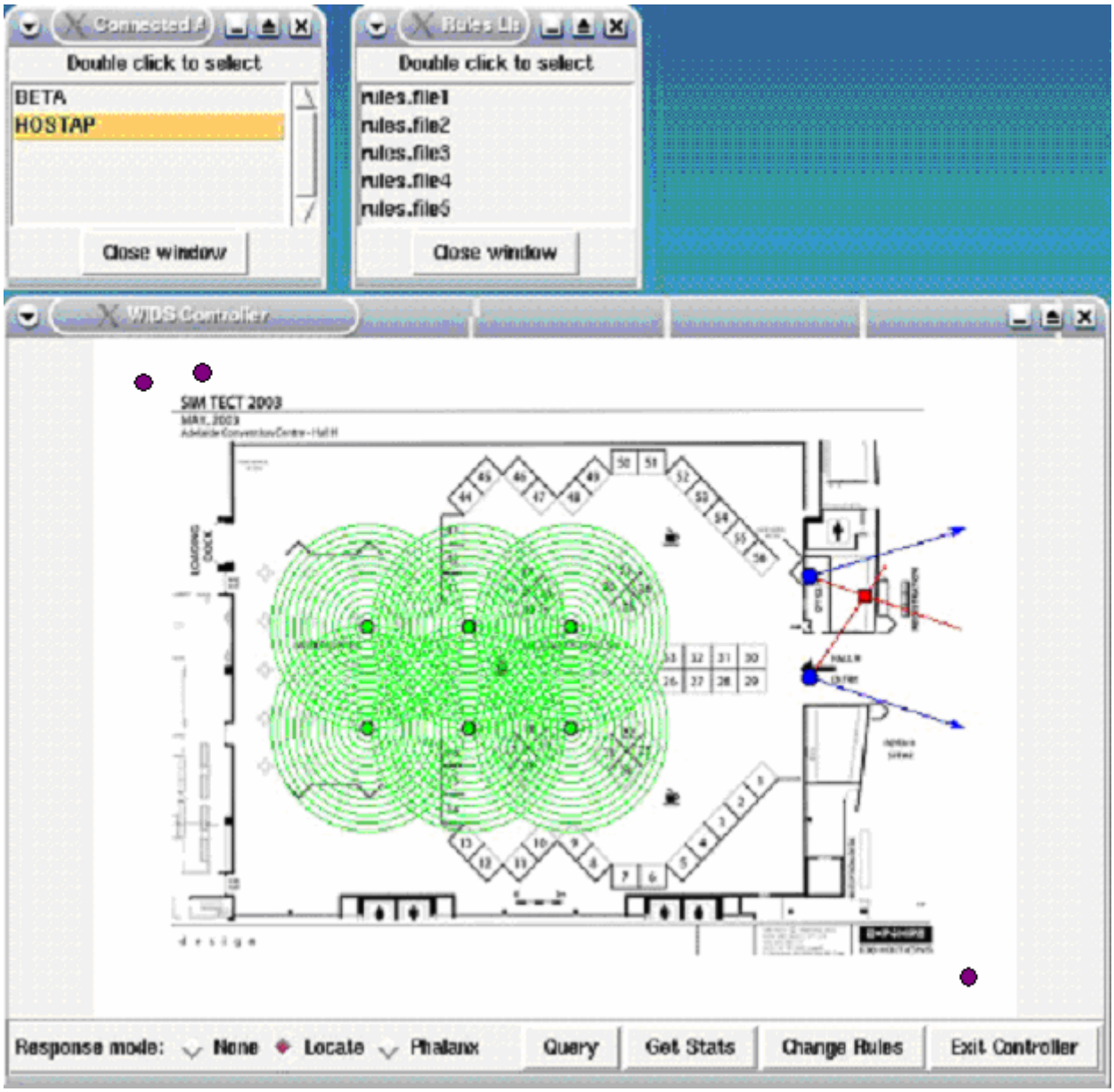


Figure 24: Change rules file

Figure 24 shows the WIDS Controller user select the WIDS AP, HOSTAP and then select the rule files for that WIDS AP.

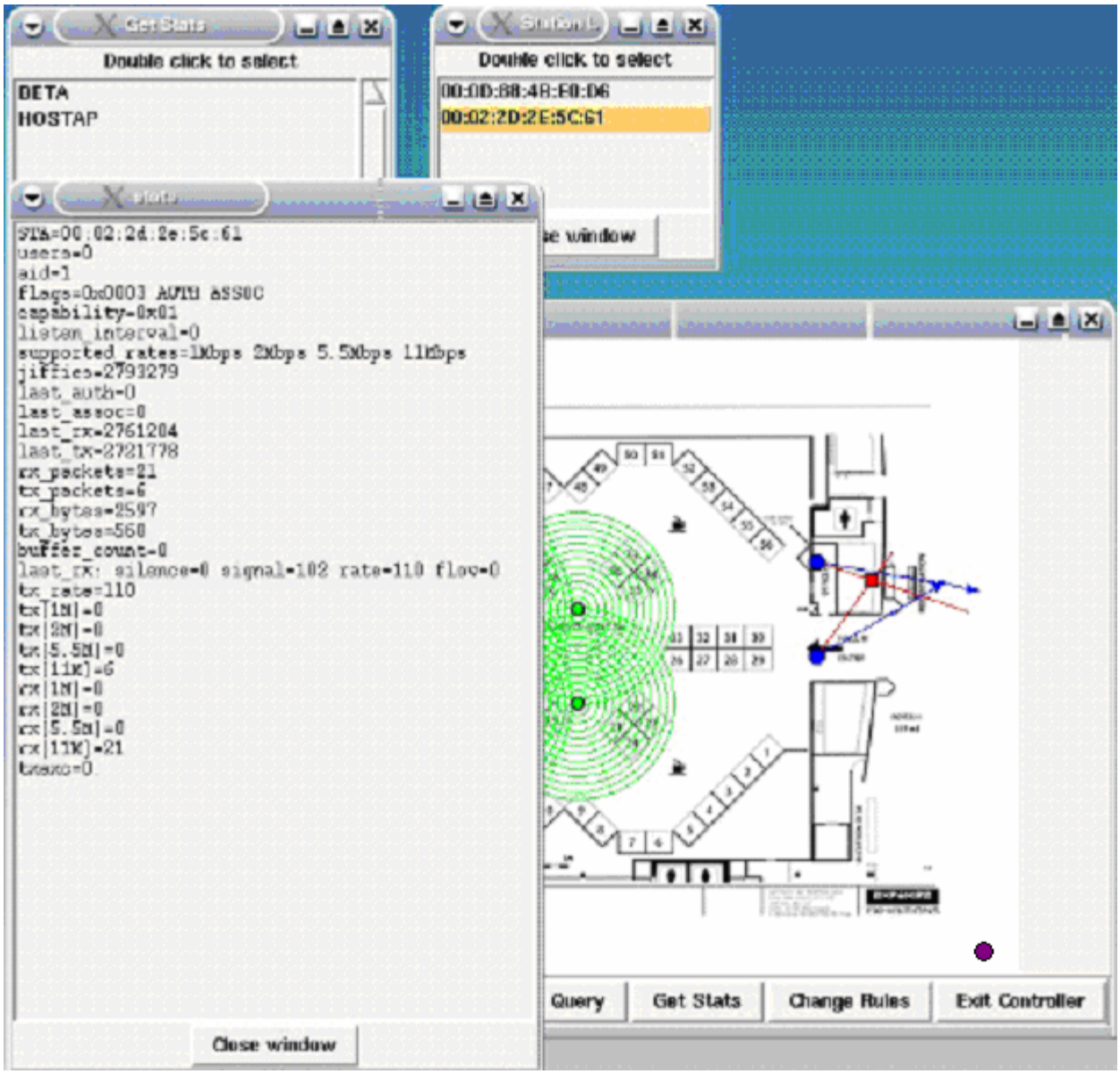


Figure 25: Show Stats

Figure 25 shows the WIDS Controller user click the Get Stats button on the graphical interface and then select a WIDS AP with a MAC address ’00:02:2D:2E:5C:61’ and then double click it to see all the statistics of the WIDS AP.

The controller uses a simple algorithm to determine which access point to reconfigure when a maximum signal strength position has been received from an access point. If the position is greater than the access point's sweep midpoint, then the access point with the next highest ID number is reconfigured. If the position is less than the sweep midpoint, the access point with the next lowest ID number is

reconfigured. When maximum signal strength positions for a MAC address are received from two WIDS access points, the controller can locate the access point's position using trigonometry (the law of sines and Pythagoras' theorem). The graphical interface draws a square (red) at the calculated location of the intruder.

6.9. WIDS Simulator Module

The WIDS system can be run with simulated access points and simulated stations for testing or presentation purposes (Refer figures 26 and 27). The simulation handles up to sixteen WIDS access points. The WIDS access points can be either real (non-simulated) WIDS/HostAP access points, simulated access points or a combination of the two. If real WIDS/HostAP access points are used in the simulation, real stations can associate with them. The simulation does not handle simulated stations associating with a non-simulated WIDS/HostAP access point.

The simulation is written in Perl using Perl-TK for creating the graphical interface. The simulation can be run on the same computer as the controller, the same computer as a real WIDS/HostAP access point, or a separate computer. It can be run from a command line or from a GUI. Use of the GUI requires a configuration file giving geometry for locating windows and a hash of commands for starting access points, controller, and virtual station. Other information in the simulation configuration file is controller IP and port for listening, access point name, access point port, delay per degree value, location, name of file containing simulated antenna readings, and an association allowed value. The delay per degree value determines the sweep speed of the simulated antenna. The association allowed determines if clients can associate with the access point.

If the simulation is run on the same computer as the controller or a real WIDS/HostAP access points, the performance of the WIDS system may decline significantly.

Figure 26: WIDS Simulation Control GUI

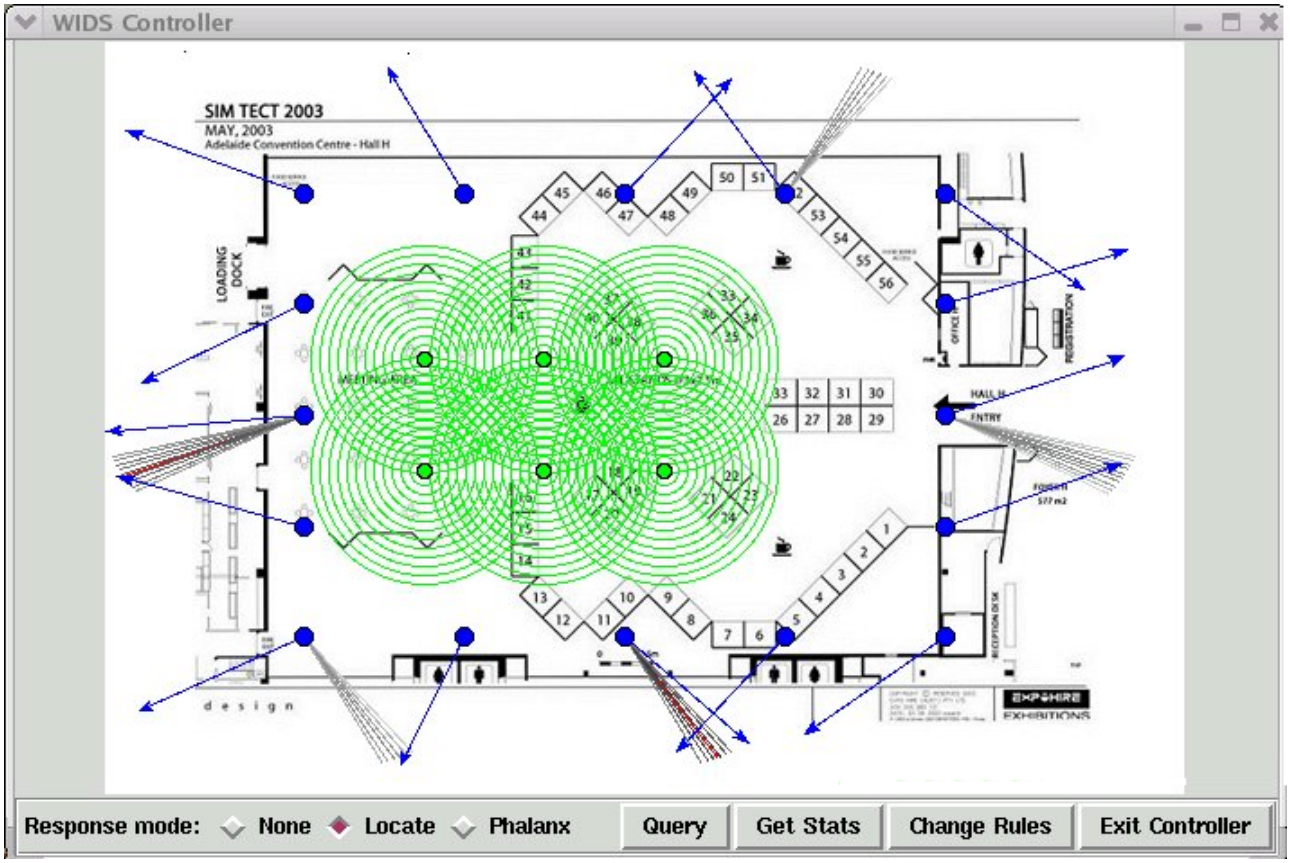


Figure 27: WIDS simulation with sixteen simulated access points

6.9.1. WIDS Simulated Access Point

A WIDS simulated access point associates with a real (non-simulated) controller and receives no 802.11b frames. A simulated access point has all the functionality of a real WIDS/HostAP access point except it doesn't process or test rules, the only 802.11b type/subtypes implemented are associate and disassociate, and it doesn't compute the maximum signal strength location using least squares regression [28]. It just picks the position of the maximum value signal strength as a position with POINTS/2 increasing trend on one side and POINTS/2 decreasing trend on other side [28].

6.9.2. WIDS Simulated Station

The simulated station configuration file contains a hash of MAC addresses, locations, show up begin time in seconds and show up end time in seconds, a list of IP:port pairs representing simulated

access points, the time between associates, and the timeframe that a station attempts to associate. The timeframe is designated by BEGIN and END in the configuration file. A station appears at BEGIN seconds after the virtual station simulation is started and ends END seconds after the virtual station simulation is started. The simulation sends ASSOCIATE messages to the list of IP:port pairs for simulated stations whose timeframe is in effect. The rate of sending the ASSOCIATE messages is determined by the time between associates value in the configuration file.

6.9.3. WIDS Simulation

The WIDS Simulation was written by Dr. Richard Golden III and the Hostap code changes and additions were done by John Louis Vigo Jr [28]. I have implemented the extension of WIDS to include Kismet [24] compatibility and allow WIDS Access Points to also be able to work in RF Monitor mode without affecting any functionality of the basic HostAP mode by having two separate NICs, one in HostAP mode and the other in RF Monitor mode. Since the WIDS Access points work in RF Monitor mode also, I am able to extend WIDS functionality to 802 1.X and 802.11 i networks.

I have referred to a number of experiments with directional antennae [23] in order to characterize the locations of wireless STAs based on signal strength and antenna bearing. In addition, I have created a simulation of the WIDS system, written entirely in portable Perl using Perl-TK for graphical interfaces. The WIDS simulator (Refer Figure 28), where four WIDS APs (arranged vertically, on the right, blue in the simulator) are protecting an internal WLAN installed in an arena (depicted as a set of six APs in the center of the diagram). Arrows originating from each WIDS AP show the current orientation of an attached directional antenna. The other lines emanating from each WIDS AP are estimates of an intruder's location; intruders are squares (in red in the simulator) on the exterior of the arena. The external dots (in purple in the simulator) are external/rogue access points that have surfaced in the outside perimeter. These external access points are detected by the wireless card running Kismet in RF Monitor mode.

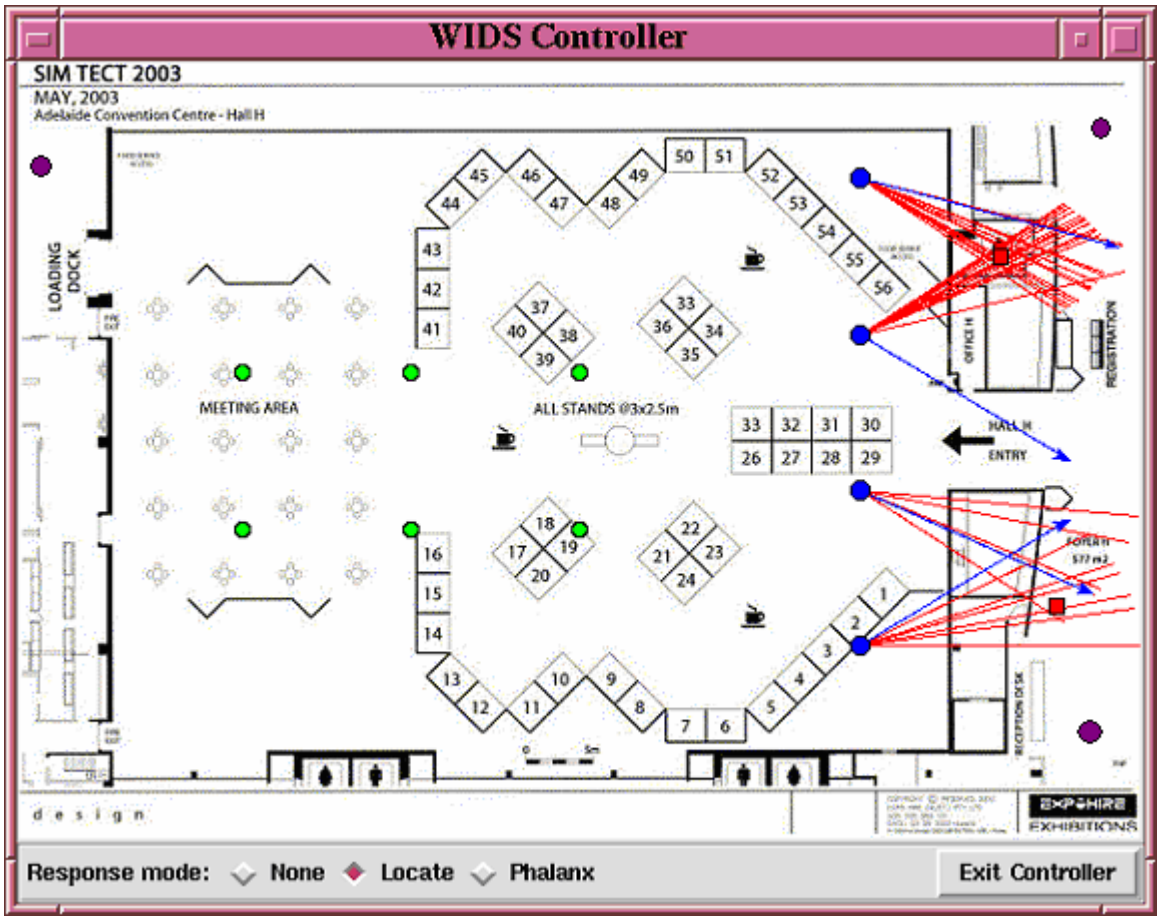


Figure 28: The WIDS simulator.

The WIDS simulator communicates over TCP, implementing a subset of our WIDS AP/Controller Protocol (WCP) discussed in the next section. WCP is a standard client/server protocol built specifically to handle communication between WIDS APs and Controller. Individual components can be started and stopped independently, and other components react accordingly. For example, WIDS AP components depend on the controller for configuration information, if the WIDS controller is taken down, the AP will wait and then reconnect automatically when the controller comes back online. Rules can also be changed on individual WIDS APs from the Controller.

Chapter 7. DEFENSE MECHANISMS OF WIDS

I have discussed various attacks on 802.11 and 802.1 X networks in previous chapters. This chapter discusses how WIDS detects and handles those attacks. As mentioned earlier I have not implemented WIDS as a HoneyPot [16], so all STAs and APs outside the perimeter are considered a threat to the internal network. WIDS tracks and locates attackers, even if they are ineffective.

Taking advantage of the two NICs (one running in HostAP mode and other in RF Monitor mode) implementation, the WIDS AP transforms into a very powerful intrusion detection tool. The HostAP mode permits WIDS AP to perform a plethora of functions for example logging data, deny access, apply specific rules and produce alerts. The RF Monitor mode permits WIDS AP to work as a stealthy passive sniffer. WIDS AP in conjunction with Kismet [24] helps gather raw real time data and analyze using Ethereal [25] and also detect rogue APs outside of the perimeter.

7.1. NetStumbler Detection (Eavesdropping)

One of the most commonly used tool for war driving is NetStumbler. There are two ways of detecting NetStumbler. One way uses the wireless NIC in HostAP mode and the other uses the wireless NIC in RF Monitor mode. The quickest way to detect NetStumbler is through the RF Monitor mode and Kismet has an in built NetStumbler detection rule.

NetStumbler is detected through Host AP mode since it queries the AP by issuing a data frame with the protocol, Organizationally Unique Identifier (OUI) value of 0x00601d and protocol id of 0x0001. This packet also contains a payload string of size 58 bytes that can be put into the NetStumbler detection rule to identify the version of NetStumbler:

NetStumbler Version Payload String

- 3.2.0 -- Flurble gronk bloopit, bnip Frundletrune
- 3.2.3 -- All your 802.11b are belong to us
- 3.3.0 -- intentionally blank

7.2. Denial of Service Attacks

The most common DoS attack is to send continuous disassociation messages. WIDS can keep a track of the continuous flow of disassociation frames from a particular MAC address and a rule can be set up to send a disassociate message to the malicious NIC or AP after N number of continuous disassociation attempts (Refer Figure 29).

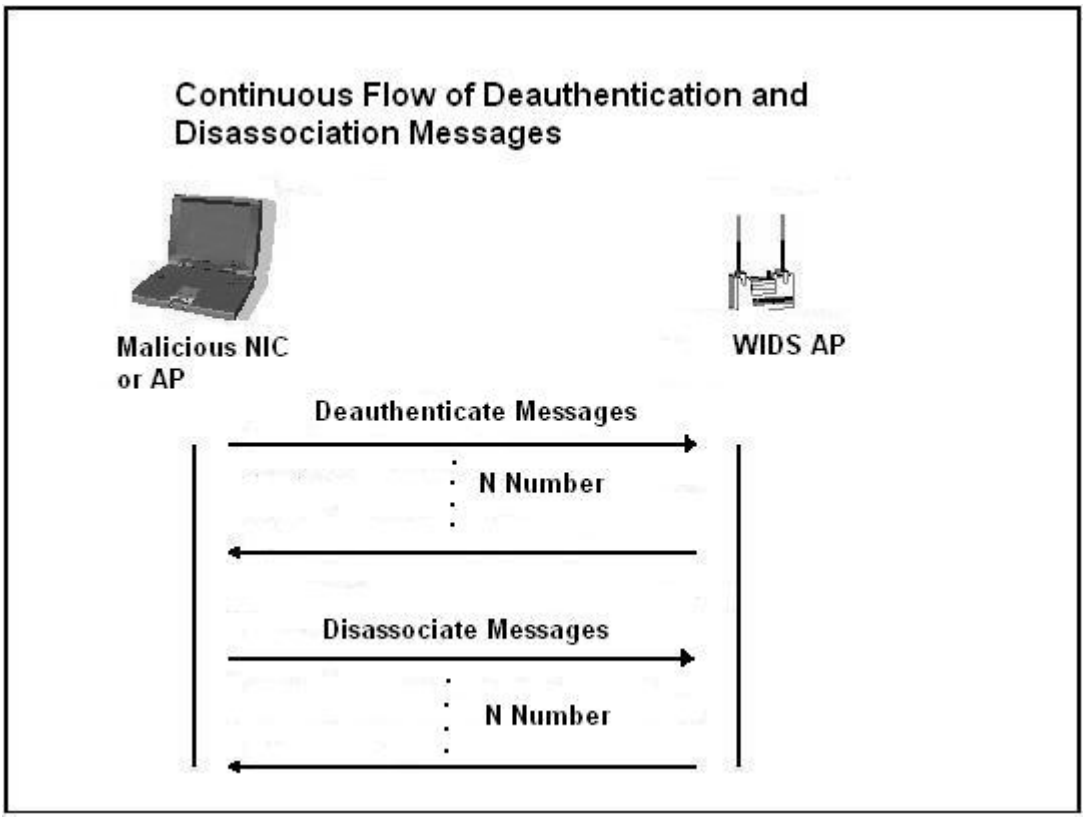


Figure 29: Continuous Flow of Deauthentiction/Disassociation Messages

WIDS cannot provide a detection mechanism for Virtual Carrier Sense Attack and PLME_DSSSTESTMODE (Jamming) Attack. Both of the above attacks make the wireless medium act busy and thus not available to any STA or AP within range. The WIDS AP and Controller communicate with one another through a wired medium and the attack does not cause any interference to the wired medium but since the wireless medium is rendered busy the WIDS AP can not calculate the location of the intruder.

7.3. MAC Spoofing – Identity Theft

I am aware that MAC addresses can very easily be spoofed. Let me give you an example. The MAC address of a NIC can be changed using the 'iwconfig' utility from wireless utilities. WIDS has a list of vendor names that manufacture NIC's and each manufacturer is allowed to assign a MAC address between a certain range of MAC addresses.

WIDS logs every MAC address and cross checks the MAC address with the above list and raises an alert if the rule fails. If an attacker spoofs the MAC address of a NIC with another MAC address which is in the same range as required for the manufacturer we can still detect by noticing the change in sequence on Sequence Numbers in MAC frame.

7.4. Session Hijacking

WIDS is an external layer of protection and WIDS AP's face the first line of attack with respect to a session hijack attempt. The WIDS AP is able to address the issue of spoofed MAC addresses and is able to quickly detect such an attempt (Refer to previous section). Since the disassociate request comes from an AP with spoofed MAC address the WIDS AP immediately issues a return request to the malicious AP to disassociate. Hence it will prevent the session hijack attempt.

WIDS is a very useful active intrusion detection system and I have extended the implementation of WIDS AP from a single NIC running in HostAP mode to use two NICs (one running HostAP mode and the other running RF Monitor mode). This work and merging of Kismet into the WIDS family was a comprehensive part of my thesis. Other intrusion detection systems either work in the Master mode or in RF Monitor mode at a given point of time but WIDS always runs in dual mode.

Chapter 8. TESTING AND RESULTS

WIDS has been tested at various stages of development and I have devised a thorough and complete test for WIDS to track and locate unauthorized STAs and external/rogue APs.

8.1 Test - Locating Intruders and External/Rogue Access Points

8.1.1 Test Description

There are two neighboring access points connected to the controller. One is a real (non-simulated) WIDS AP access point, named HOSTAP, and the other is a simulated access point, named BETA, running on the same computer as the WIDS AP access point.

The real station with MAC address 00:02:2D:2E:5C:61 associates with the real WIDS AP access point. This is a real association and not simulated. The rules are applied to the 802.11 frames received from the real station. The WIDS AP access point computes the position of the station 00:02:2D:2E:5C:61 maximum signal strength using the data in its simulated antenna readings file and sends it to the controller. The WIDS controller reconfigures the simulated access point sweep arch.

The simulated access point computes the position of the station 00:02:2D:2E:5C:61 maximum signal strength using the data in its simulated antenna readings file and sends it to the controller.

The controller computes the position of the station 00:02:2D:2E:5C:61 from the data received from the two access points.

In order to test the IP packet reading rule, the station 00:02:2D:2E:5C:61 pings the WIDS/HostAP access point. Four pings were sent from the station.

The controller should also show two networks outside the perimeter. These are external/rogue access points detected by Kismet running in passive monitor mode on the HostAP machine.

8.1.2 Hardware Used for the Test

One IBM ThinkPad Pentium III 450 MHz, 128 Mb memory laptop with a Linksys Instant Wireless WPC11 wireless card (MAC address 00:04:5a:0c:d8:0c) running Linux and HostAP used for a WIDS/HostAP access point and a Lucent Technologies Orinoco Silver 11 Mbits/s wireless card (MAC address 00:02:2d:2e:5b:f6) running Kismet in Monitor mode.

One generic Pentium 4 266 GHz, 512 Mb memory laptop with an Lucent Technologies Orinoco Silver 11 Mbits/s wireless card (MAC address 00:02:2D:2E:5C:61) address running WindowsXP used for a station connecting to the WIDS/HostAP access point.

One IBM ThinkPad Pentium III 450 MHz, 128 Mb memory laptop running Linux used for the controller.

One Laplink Cable (Parallel Port connection cable) connecting the WIDS/HostAP access point and the controller (A Laplink cable was used instead of an Ethernet hub to connect the WIDS/HostAP access point and the controller since I wanted to free the second PCMCIA slot used by the PCMCIA Ethernet card and use it for a Wireless Card to run Kismet in RF Monitor mode).

8.1.3 Expected Results for the Test

The rule
"MGMT_ASREQ,(FLAG_RETRY:OFF!SOURCE_MAC_EQUALS:00022D2E5C61!), LOG,FLAG RETRY Off" should be true. The controller log should show an entry for HOSTAP with a message including the date and time and "FLAG RETRY Off, Association Req.". Logging the association request attempt is very useful to keep track of STAs trying to associate with an AP.

The rule "MGMT_AUTH,(SOURCE_MAC_EQUALS:00022D2E5C61!TTL_EQUALS:64! FLAG_RETRY:OFF!),LOG, 02 2d 2e 5c 61 authenticated with ttl = 64" should be true. The controller log should show an entry for HOSTAP with a message including the date and time and "02 2d 2e 5c 61 authenticated with ttl = 64, Authentication." Since four pings are sent with TTL= 64, the log should show four messages.

All other rules are false and no action should be taken.

The controller log should show association messages with dates and times for station 00:02:2d:2e:5c:61 with an Agere Systems wireless card.

The WIDS/HostAP log should show messages sent to the controller as a result of the rules. HostAP logs all authentications and associations in the /var/log/messages log. There should be messages with times and dates for authentication and association for station 00:02:2D:2E:5C:61.

Simulated antenna position of simulated access point BETA antenna when maximum signal received from station 00:02:2D:2E:5C:61 is 63 degrees. Simulated antenna position of HostAP access point HOSTAP antenna when maximum signal received from station 00:02:2D:2E:5C:61 is -25 degrees. The station is located at (452.94, 334.64).

Pings will be sent from 00:02:2D:2E:5C:61 with TTL = 64. HostAP and controller logs should show test results for IP headers from 00:02:2D:2E:5C:61.

Kismet should find three rogue networks ‘Mine’, ‘My Home’ and ‘LASSI’ outside of the perimeter.

8.1.4 Results of the Test

The controller log shows only the two lines expected as results of the intrusion detection rules (times are gm time):

```
HOSTAP Sun June 26 02:48:13 2005 FLAG RETRY Off Association Req
HOSTAP Sun June 26 02:51:56 2005  02 2d 2e 5c 61 authenticated with ttl = 64
Authentication
```

The controller log shows the expected association messages from the two stations:

```
HOSTAP Sun June 26 02:48:16 2005 associated with  00:02:2d:2e:5c:61
wireless card Agere Systems
```

The WIDS/HostAP log shows messages:

```
Sat June 25 21:48:13 2005
,FLAG RETRY Off,Association Req
```

```
Sat June 25 21:51:57 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
```

The HostAP access point /var/log/messages log shows authentication and association of station

00:02:2d:2e:5c:61.

```
June 25 21:48:13 localhost hostapd: wlan0: STA 00:02:2d:2e:5c:61 IEEE
802.11:
authenticated
June 25 21:48:13 localhost hostapd: wlan0: STA 00:02:2d:2e:5c:61 IEEE
802.11:
associated (aid 1)
```

The controller received the antenna position of 63 degrees for simulated access point BETA antenna when the maximum signal message was received from station 00:02:2D:2E:5C:61 and the antenna position of -25 degrees for HostAP access point HOSTAP antenna when maximum signal received message was received from station 00:02:2D:2E:5C:61:

```
WIDS controller received client located at -25 (angle) from
HOSTAP WIDS controller received client located at 63 (angle)
from BETA
```

The controller is an (X, Y) grid and shows the computed station's location rounded to two decimals as (452.94, 334.64):

```
ALERT client found at x = 452.936474021111 y = 334.641469930032
```

HostAP and Controller logs show test results for IP headers from 00:02:2D:2E:5C:61. As additional testing on the IP packets, Scoop was run with the print hex option to dump the Ethernet and IP headers. The hostAP terminal window displayed the following for pings from 00:02:2D:2E:5C:61. Only the ping from 00:02:2D:2E:5C:61 shows a test result as expected.

```
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15773 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
10     003c 3d9d 0000 4001 bb48 c0a8 0045 c0a8
20     0046 0000 535c 0100 0100 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing packet
test  result  is  ....
Wed  June 25  21:51:56  2005
,  02  2d  2e  5c  61  authenticated  with  ttl  =  64,Authentication
 log action  02 2d 2e 5c 61 authenticated with ttl = 64
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15774 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
10     003c 3d9e 0000 4001 bb47 c0a8 0045 c0a8 …
```

Kismet finds three rogue networks. Kismet does also find the networks, jv.cs.uno.edu and <no ssid> but does not report it to the controller since jv.cs.uno.edu is a WIDS AP and <no ssid> is a hidden network with the SSID 'LASSI' which after a certain time is de-cloaked by Kismet (Refer Figure 30).

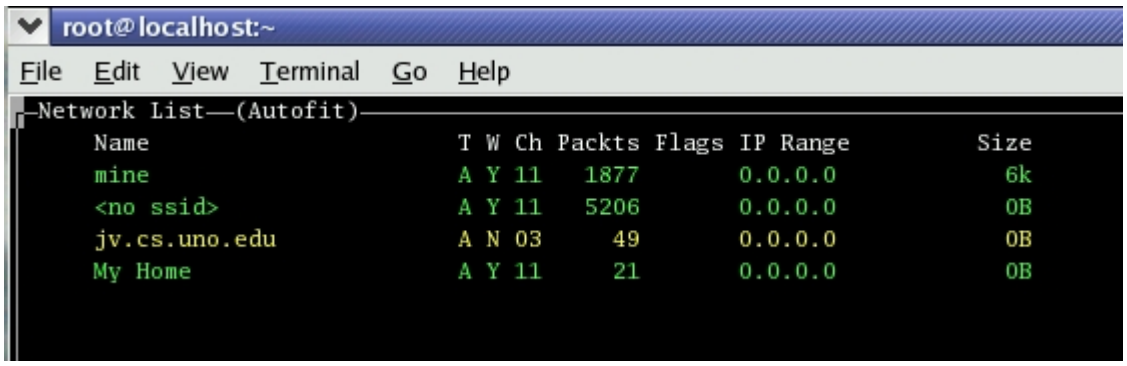


Figure 30: Networks found by Kismet.

The following are other screen shots of Kismet :

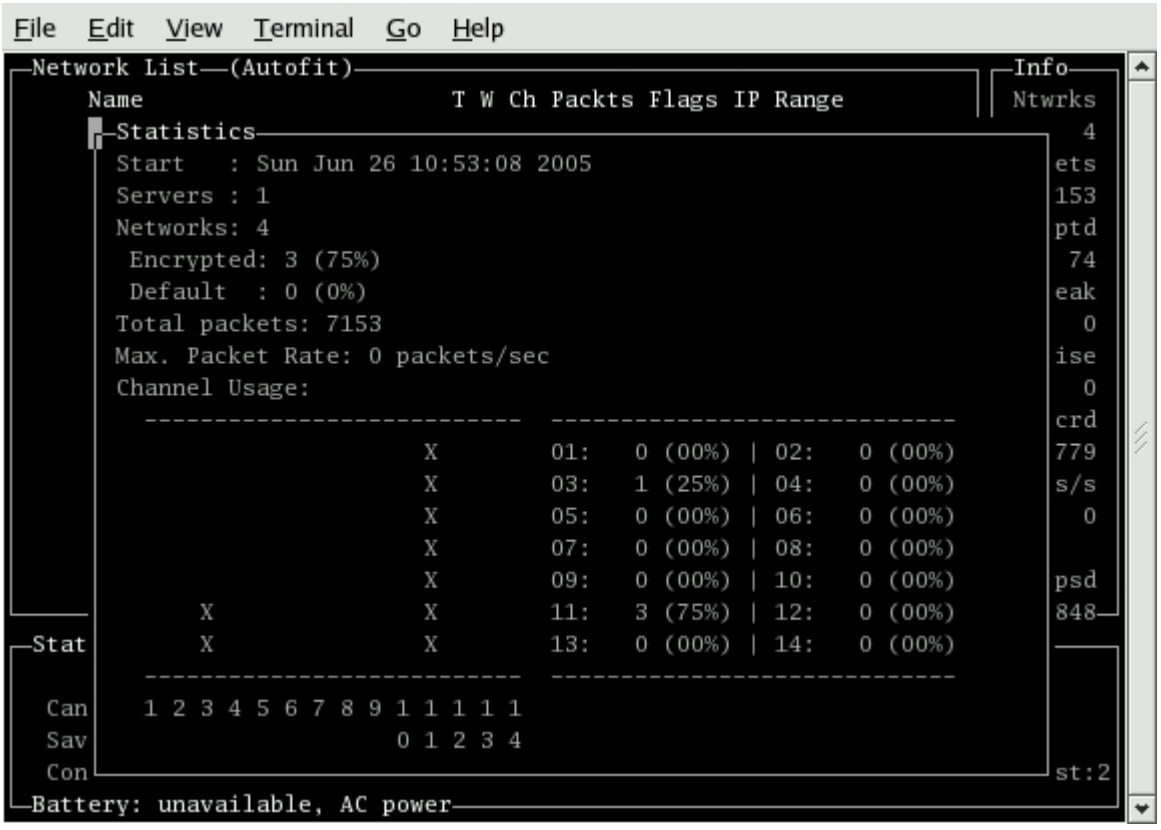


Figure 31: Kismet found networks with statistics.

Kismet provides statistics with respect to the networks that were found. It shows how many APs that were have WEP enabled, channel usage of each AP and total number of packets collected (Refer

Figure 31).

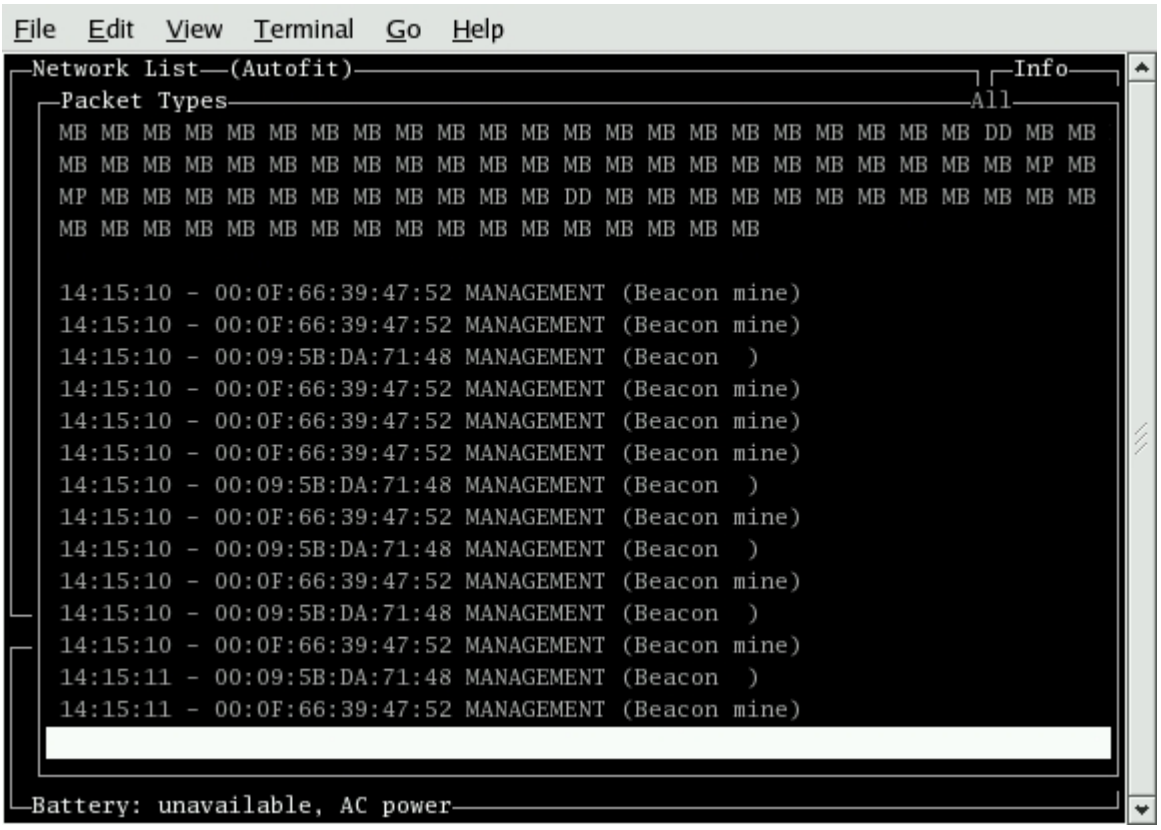


Figure 32: Kismet found networks with Packet Types.

Kismet also provides a screen to see different packet types associated with name of the AP and MAC address (Refer Figure 32).

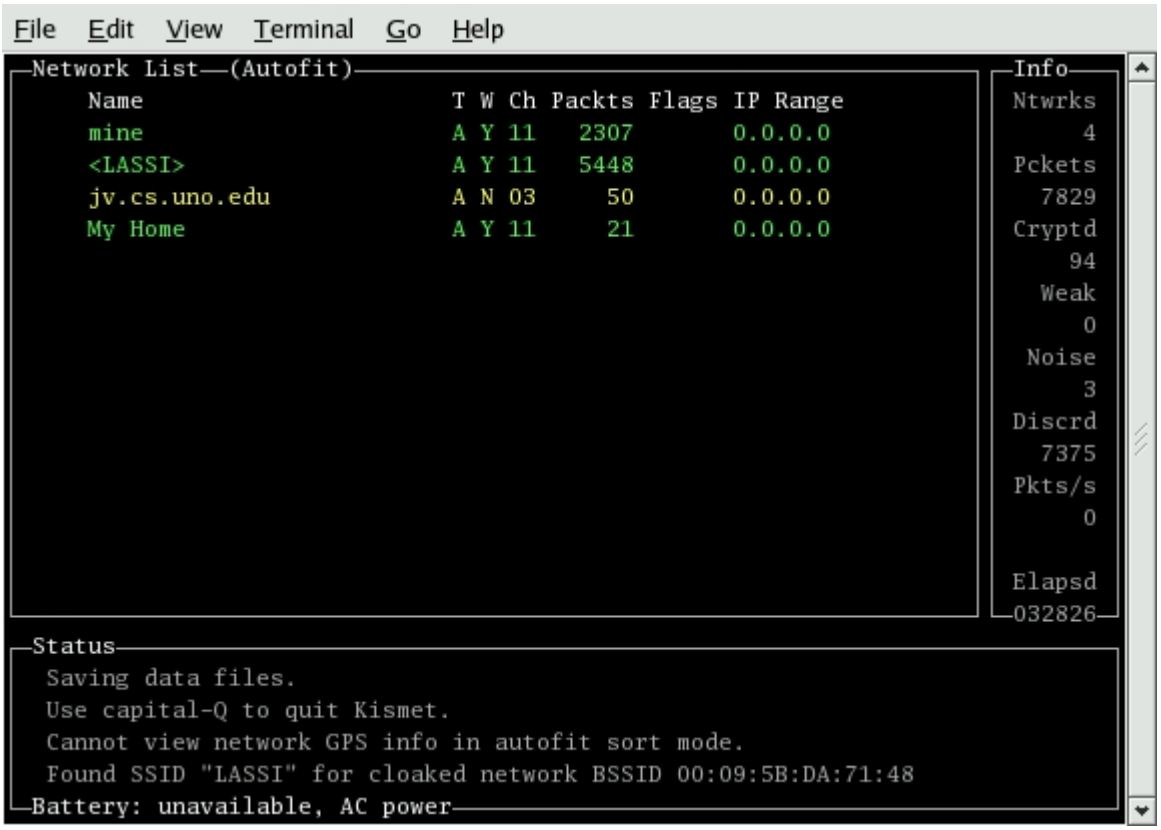


Figure 33: Kismet found Networks with one de-cloaked network 'LASSI'.

Finally Kismet has found three rogue APs and all the three rogue APs have WEP enabled (Refer Figure 33).

8.1.5 Data Files used for Test

8.1.5.1 Rules File for the Test

The rules file contains a set of rules that need to be tested for a WIDS AP. The rules files I have used for the test is as follows:

```
MGMT_ASREQ,(FLAG_RETRY:OFF!SOURCE_MAC_EQUALS:00022D2E5C61!),LOG,FLAG RETRY
Off MGMT_ASREQ,(FLAG_RETRY:ON!SOURCE_MAC_EQUALS:00022D2E5C61!),LOG,FLAG
RETRY On MGMT_ASREQ,(DEST_MAC_EQUALS:00022D2E5C61!),LOG,assoc request dest
mac 00 02 2d
2e 5c 61
MGMT_AUTH,(SOURCE_MAC_EQUALS:00022D2E5C61!TTL_EQUALS:64!FLAG_RETRY:OFF!),LOG
,
02 2d 2e 5c 61 authenticated with ttl = 64
```

8.1.5.2 Access Point MAC Address 00:02:2D:2E:5C:61 Antenna Readings File

WIDS does not have rotational directional antenna capability, hence I used an antenna readings file for WIDS AP HOSTAP to perform the test. The antenna readings file is as follows:

filename "angle4"

```
# format for a reading is degrees,signal strength;mac address,
# first number represents the angle in degrees. The second number represents
# the signal strength.
# next 6 numbers represent mac address. Each reading must be separated by
','
# or '/n' and there must be a '\n' before the EOF character
# comments start with '#' and the '#' is allowed only at start of line
-35,10;00:02:2D:2E:5C:61,-34,12;00:02:2D:2E:5C:61,-33,16;00:02:2D:2E:5C:61,-
32,20;00:02:2D:2E:5C:61,-31,23;00:02:2D:2E:5C:61,-30,25;00:02:2D:2E:5C:61,-
29,27;00:02:2D:2E:5C:61,-28,24;00:02:2D:2E:5C:61,-27,27;00:02:2D:2E:5C:61,-
26,28;00:02:2D:2E:5C:61,-25,29;00:02:2D:2E:5C:61,-24,26;00:02:2D:2E:5C:61,-
23,27;00:02:2D:2E:5C:61,-22,25;00:02:2D:2E:5C:61,-21,23;00:02:2D:2E:5C:61,-
20,20;00:02:2D:2E:5C:61,-19,16;00:02:2D:2E:5C:61,-18,14;00:02:2D:2E:5C:61,-
17,12;00:02:2D:2E:5C:61
```

8.1.5.3 Simulated Access Point (BETA) Antenna Readings File

WIDS does not have rotational directional antenna capability, hence I used an antenna readings file for WIDS AP BETA to perform the test. The antenna readings file is as follows:

filename "data8"

```
57,32;00:02:2D:2E:5C:61
58,33;00:02:2D:2E:5C:61
59,38;00:02:2D:2E:5C:61
60,40;00:02:2D:2E:5C:61
61,44;00:02:2D:2E:5C:61
62,45;00:02:2D:2E:5C:61
63,47;00:02:2D:2E:5C:61
64,44;00:02:2D:2E:5C:61
65,43;00:02:2D:2E:5C:61
66,41;00:02:2D:2E:5C:61
67,30;00:02:2D:2E:5C:61
68,29;00:02:2D:2E:5C:61
```

8.1.5.4 Kismet Output Network File

The output file from Kismet will be used by Kimset.pl to report to the Controller information about all the external/rogue access points found by Kismet. The sample file is as follows :

```
Network 1: "mine" BSSID: "00:0F:66:39:47:52"
    Type     : infrastructure
    Carrier  : 802.11b
    Info     : "None"
    Channel  : 11
    WEP      : "Yes"
    Maxrate  : 54.0
    LLC      : 2213
    Data     : 94
    Crypt    : 94
    Weak     : 0
    Total    : 2307
    First    : "Sun Jun 26 10:54:48 2005"
    Last     : "Sun Jun 26 14:16:50 2005"

Network 2: "LASSI" BSSID: "00:09:5B:DA:71:48"
    Type     : infrastructure
    Carrier  : 802.11b
    Info     : "None"
    Channel  : 11
    WEP      : "Yes"
    Maxrate  : 11.0
    LLC      : 5448
    Data     : 0
    Crypt    : 0
    Weak     : 0
    Total    : 5448
    First    : "Sun Jun 26 10:54:48 2005"
    Last     : "Sun Jun 26 14:16:51 2005"

Network 3: "jv.cs.uno.edu" BSSID: "00:04:5A:0C:D8:0C"
    Type     : infrastructure
    Carrier  : 802.11b
    Info     : "None"
    Channel  : 03
    WEP      : "No"
    Maxrate  : 11.0
    LLC      : 50
    Data     : 0
    Crypt    : 0
    Weak     : 0
    Total    : 50
    First    : "Sun Jun 26 10:55:20 2005"
    Last     : "Sun Jun 26 14:15:15 2005"

Network 4: "My Home" BSSID: "00:09:5B:EB:3A:94"
    Type     : infrastructure
    Carrier  : 802.11b
```

```
    Info     : "None"
    Channel  : 11
    WEP      : "Yes"
    Maxrate  : 36.0
    LLC      : 21
    Data     : 0
    Crypt    : 0
    Weak     : 0
    Total    : 21
    First    : "Sun Jun 26 11:02:45 2005"
    Last     : "Sun Jun 26 11:22:09 2005"
```

8.1.6 Details of Test Results

8.1.6.1 HostAP log

```
log opened log.new Sat June 25 21:47:24 2005

Sat June 25 21:48:13 2005
,FLAG RETRY Off,Association Req
 HOSTAPHOSTAPSat June 25 21:51:56 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 Sat June 25 21:51:57 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 Sat June 25 21:51:58 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 Sat June 25 21:51:59 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
```

8.1.6.2 Controller log

```
hostap.log opened gmtime Sun June 26 03:21:49 2005
HOSTAP Sun June 26 02:48:13 2005 FLAG RETRY Off Association Req
HOSTAP Sun June 26 02:48:16 2005 associated with  00:02:2d:2e:5c:61
wireless card Agere Systems

HOSTAP Sun June 26 02:51:56 2005  02 2d 2e 5c 61 authenticated with ttl = 64
Authentication
HOSTAP Sun June 26 02:51:57 2005  02 2d 2e 5c 61 authenticated with ttl = 64
Authentication
HOSTAP Sun June 26 02:51:58 2005  02 2d 2e 5c 61 authenticated with ttl = 64
Authentication
HOSTAP Sun June 26 02:51:59 2005  02 2d 2e 5c 61 authenticated with ttl = 64
Authentication
```

8.1.6.3 Controller Terminal Display

```
Script started on Sat June 25 22:14:54 2005
dashipushi:/home/shobanp/widsfinal1 # ./controllernet
WIDS controller initializing using file "CONFIG.controllerhap".
KNOWN ACCESS POINT LIST:
```

```
CTR
CBR
PINK
Y
CTL
CBL
LAP1
BAP1
BAP3
ALPH
A
BAP2
BETA
HOSTA
P
TAP2
LAP3
LAP2
TAP1
WIDS controller configuration
complete. WIDS controller bringing up
GUI.
WIDS controller: Image is 600 x 416.
WIDS controller listening on port
7777. WIDS controller got connection.
WIDS controller sending CONFIG to BETA.
WIDS controller configured BETA, located @ (420,270).
WIDS controller got connection.
WIDS controller sending CONFIG to HOSTAP.
WIDS controller configured HOSTAP, located @ (420,350).
WIDS controller logging HOSTAP Sun June 26 02:48:13 2005 FLAG RETRY Off
Association Req
WIDS controller logging HOSTAP Sun June 26 02:48:16 2005 associated with
00:02:2d:2e:5c:61 wireless card Agere Systems

WIDS controller received client located at -25 (angle) from HOSTAP
adding to hash 00:02:2D:2E:5C:61 HOSTAP;-25;1
SENDING RECONFIG  to BETA POS = -25 -45 90 2
WIDS controller received client located at 63 (angle) from BETA
locating ap
name1= BETA,position1= 63, name2 =HOSTAP, position2= -25, ap1x=420 ap1y=270
ALERT client found at x = 452.936474021111 y = 334.641469930032
WIDS controller received client located at -25 (angle) from HOSTAP
WIDS controller logging HOSTAP Sun June 26 02:51:56 2005  02 2d 2e 5c 61
authenticated with ttl = 64 Authentication
WIDS controller logging HOSTAP Sun June 26 02:51:57 2005  02 2d 2e 5c 61
authenticated with ttl = 64 Authentication
WIDS controller logging HOSTAP Sun June 26 02:51:58 2005  02 2d 2e 5c 61
authenticated with ttl = 64 Authentication
WIDS controller logging HOSTAP Sun June 26 02:51:59 2005  02 2d 2e 5c 61
authenticated with ttl = 64 Authentication
WIDS controller received client located at -25 (angle) from HOSTAP
Use of uninitialized value in concatenation (.) or string at wids.pl line
466,
```

```
<RULES> line 6.
mesg not defined type =
** OTHER SIDE HUNG UP 11111 **
WIDS controller received client located at -25 (angle) from HOSTAP
Use of uninitialized value in concatenation (.) or string at wids.pl line
466,
<RULES> line 6.
mesg not defined type =
** OTHER SIDE HUNG UP 11111 **

Script done on Sat June 25 22:41:27 2005
```

The “use of unitialized value …” and “mesg not defined type = “ comments are results of the access points shutting down

8.1.6.4 HostAP terminal

```
Script started on Sat June 25 21:25:54
2005]0;root@localhost:/home/jvigo/hostap-0.0.3/hostapd2new_shared4_clean1

[root@localhost hostapd2new_shared4_clean1]# ./hostapd
hostapddashipushi.conf
Configuration file:
hostapddashipushi.conf table_alloc
done
table_alloc rule done
could not insert in table: key exists and no overwrite,key=00:01:C8, c=
915 could not insert in table: key exists and no overwrite,key=08:00:30,
c= 14393 could not insert in table: key exists and no
overwrite,key=08:00:30, c= 14395

log opened log.new Sat June 25 21:47:24 2005

HOSTAP;17;log opened ;Sun June 26 02:47:24 2005
ip add= 192.168.1.4, port 7777
WIDS AP HOSTAP connecting to CONTROLLER @
192.168.1.4:7777. controller registered sockfd= 4
hostap AP HOSTAP sending initial HELLO to WIDS
controller. WIDS hostap HOSTAP waiting for CONFIG
message.
message = CONTROLLER;2;-
45;45;2;MGMT_ASREQ,(FLAG_RETRY:OFF!SOURCE_MAC_EQUALS:00022D2E5C61!),LOG,F
LAG RETRY Off
MGMT_ASREQ,(FLAG_RETRY:ON!SOURCE_MAC_EQUALS:00022D2E5C61!),LOG,FLAG RETRY
On
MGMT_ASREQ,(DEST_MAC_EQUALS:00022D2E5C61!),LOG,assoc request dest mac 00 02
2d
2e 5c 61
MGMT_AUTH,(SOURCE_MAC_EQUALS:00022D2E5C61!TTL_EQUALS:64!FLAG_RETRY:OFF!),LOG
,
02 2d 2e 5c 61 authenticated with ttl = 64
#MGMT_AUTH,(SOURCE_MAC_EQUALS:000D884BE0D6!TTL_EQUALS:64!FLAG_RETRY:OFF!),LO
G,
00:0d:88:4b:e0:d6 authenticated with ttl = 64
```

```
#MGMT_AUTH,(SOURCE_MAC_EQUALS:00022D2E5C61!TTL_EQUALS:64!FLAG_RETRY:OFF!),D
ISA SSOC, 02 2d 2e 5c 61 disassociated with ttl = 64

hostap AP HOSTAP received CONFIG: sweep -45 - 45, report rate 2
processing rules
Using interface wlan0ap with hwaddr 00:04:5a:0c:d8:0c and ssid
'jv.cs.uno.edu' Flushing old station entries
Deauthenticate all stations
ieee802_11.c 10 /nieee802_11.c auth failed
wlan0: STA 00:02:2d:2e:5c:61 IEEE 802.11:
authenticated do auth stuff here
Sat June 25 21:48:13 2005
,FLAG RETRY Off,Association Req
 log action FLAG RETRY Off
wlan0: STA 00:02:2d:2e:5c:61 IEEE 802.11: associated (aid 1)
do associate stuff
here get ant
readings
simulated antenna readings ok
Modified Scoop 1.0 [IP packet sniffing tool]
<ctrl-c> to
quit scoop
pid = 1304
HOSTAP AP HOSTAP got ASSOCIATE from 00:02:2d:2e:5c:61, signal=120 @
position unknown
HOSTAPieee802_11.c 10 /nieee802_11.c auth failed
wlan0: STA 00:0d:88:4b:e0:d6 IEEE 802.11:
authenticated do auth stuff here
ieee802_11.c 10 /nieee802_11.c auth failed
wlan0: STA 00:0d:88:4b:e0:d6 IEEE 802.11:
authenticated do auth stuff here
wlan0: STA 00:0d:88:4b:e0:d6 IEEE 802.11: associated (aid 2)
do associate stuff
here get ant
readings
simulated antenna readings ok
HOSTAP AP HOSTAP got ASSOCIATE from 00:0d:88:4b:e0:d6, signal=0 @
position unknown
HOSTAPmax signal is at -25.6176 sig= 29
max signal is at -25.6176 sig= 29
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15773 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
10     003c 3d9d 0000 4001 bb48 c0a8 0045 c0a8
20     0046 0000 535c 0100 0100 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing
packet test result
is ....
Sat June 25 21:51:56 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 log action  02 2d 2e 5c 61 authenticated with ttl = 64
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15774 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
```

```
10     003c 3d9e 0000 4001 bb47 c0a8 0045 c0a8
20     0046 0000 525c 0100 0200 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing
packet test result
is ....
Sat June 25 21:51:57 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 log action  02 2d 2e 5c 61 authenticated with ttl = 64
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15775 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
10     003c 3d9f 0000 4001 bb46 c0a8 0045 c0a8
20     0046 0000 515c 0100 0300 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing
packet test result
is ....
Sat June 25 21:51:58 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 log action  02 2d 2e 5c 61 authenticated with ttl = 64
IP: 192.168.0.69 -> 192.168.0.70 (60) id: 15776 ICMP: echo reply
00     0002 2d2e 5c61 0004 5a0c d80c 0800 4500
10     003c 3da0 0000 4001 bb45 c0a8 0045 c0a8
20     0046 0000 505c 0100 0400 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing
packet test result
is ....
Sat June 25 21:51:59 2005
, 02 2d 2e 5c 61 authenticated with ttl = 64,Authentication
 log action  02 2d 2e 5c 61 authenticated with ttl = 64
IP: 192.168.0.69 -> 192.168.0.71 (60) id: 3257 ICMP: echo reply
00     000d 884b e0d6 0004 5a0c d80c 0800 4500
10     003c 0cb9 0000 4001 ec2b c0a8 0045 c0a8
20     0047 0000 535c 0100 0100 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing packet
IP: 192.168.0.69 -> 192.168.0.71 (60) id: 3258 ICMP: echo reply
00     000d 884b e0d6 0004 5a0c d80c 0800 4500
10     003c 0cba 0000 4001 ec2a c0a8 0045 c0a8
20     0047 0000 525c 0100 0200 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869scoop testing packet
IP: 192.168.0.69 -> 192.168.0.71 (60) id: 3259 ICMP: echo reply
00     000d 884b e0d6 0004 5a0c d80c 0800 4500
10     003c 0cbb 0000 4001 ec29 c0a8 0045 c0a8
20     0047 0000 515c 0100 0300 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing packet
```

```
IP: 192.168.0.69 -> 192.168.0.71 (60) id: 3260 ICMP: echo reply
00     000d 884b e0d6 0004 5a0c d80c 0800 4500
10     003c 0cbc 0000 4001 ec28 c0a8 0045 c0a8
20     0047 0000 505c 0100 0400 6162 6364 6566
30     6768 696a 6b6c 6d6e 6f70 7172 7374 7576
40     7761 6263 6465 6667 6869
scoop testing packet
max signal is at -25.6176 sig=
29 max signal is at -25.6176
sig= 29 handle term
killing 1304
cleaning up shared memory
struct eloop.c after loop
Removing station 00:0d:88:4b:e0:d6
Removing station 00:02:2d:2e:5c:61
Flushing old station entries
Deauthenticate all stations
]0;root@localhost:/home/jvigo/hostap-0.0.3/hostapd2new_shared4_clean1

[root@localhost hostapd2new_shared4_clean1]#
[root@localhost hostapd2new_shared4_clean1]# Script done on Wed June 25
21:54:12 2005
```

8.1.6.5 BETA AP terminal

```
[root@localhost root]# cd /root/wids
[root@localhost wids]# perl accesspt2net
WIDS AP BETA connecting to controller @ 192.168.1.4:7777.
WIDS AP BETA sending initial HELLO to WIDS controller.
WIDS AP BETA waiting for CONFIG message.
57,32;00:02:2D:2E:5C:61
adding to allowed mac hash 00:02:2D:2E:5C:61 associate allowed = 1
58,33;00:02:2D:2E:5C:61
59,38;00:02:2D:2E:5C:61
60,40;00:02:2D:2E:5C:61
61,44;00:02:2D:2E:5C:61
62,45;00:02:2D:2E:5C:61
63,47;00:02:2D:2E:5C:61
64,44;00:02:2D:2E:5C:61
65,43;00:02:2D:2E:5C:61
66,41;00:02:2D:2E:5C:61
67,30;00:02:2D:2E:5C:61
68,29;00:02:2D:2E:5C:61
WIDS AP BETA received CONFIG: sweep -45 - 45, report rate 2.WIDS AP BETA
listening on port 7001 for virtual client. reconfig message -45 90 2
ap got
reconfig
vcexists 0
 reconf received
position -11, begin -45, end 90 at receive reconf in
nfound sending position  63,  00:02:2D:2E:5C:61, 0
pos =-45 end = 90 beg = -45
back to original config BETA count = 2 end =45 begin = -45 pos =-45, dir= 1
mac
```

```
0
[root@localhost wids]#
```

8.1.6.6 Kismet terminal

```
root@localhost root]# kismet_monitor -H
Will launch kismet_hopper
Using /usr/local/etc/kismet.conf sources...
Enabling monitor mode for an orinoco card on eth0 channel 6
Launching kismet_hopper in the background.
/usr/local/bin/kismet_monitor: line 238: test: : integer expression
expected
[root@localhost root]# Hopping 3 channels per second (333333 microseconds
per channel)
NOTICE:  No enable sources specified, all sources will be enabled.
kismet_hopper - Source 0 - Channel hopping (United States) on interface
eth0

[root@localhost root]# kismet
Server options:  none
Client options:  none
Starting server...
Will drop privs to jvigo (500)
No enable sources specified, all sources will be enabled.
Source 0 (Kismet): Using pcap to capture packets from eth0
Dropped privs to jvigo (500)
Allowing clients to fetch WEP keys.
Logging networks to /home/jvigo/kismet-logs/Kismet-Jun-26-2005-2.network
Logging data to /home/jvigo/kismet-logs/Kismet-Jun-26-2005-2.dump
Writing data files to disk every 300 seconds.
Filtering beacon packets.
Reading AP manufacturer data and defaults from /usr/local/etc/ap_manuf
Reading client manufacturer data and defaults from
/usr/local/etc/client_manuf
Dump file format: wiretap (local code) dump
Kismet 2.8.1 (Kismet)
Source 0 (Kismet): Capturing packets from libpcap device eth0
Logging data networks
Listening on port 2501.
Allowing connections from 127.0.0.1/255.255.255.255
Registering builtin client/server protocols...
Starting UI...
```

8.1.7 Commands to Run Test

On HostAP access point laptop:

1. Start simulated access point

/root/wids # perl accesspt2net

2. In another terminal window - start hostapd

/home/jvigo/hostap-0.0.3/hostapd2new_sharedclean1 # ./hostapd
hostapddashipushi.conf

3. Start Kismet Hopper

/root# kismet_monitor –H

4. Start Kismet

/root# kismet

5. Run iwpriv every 5 secs to get data through monitor mode on eth0

/root# csh
/root~ while 1
> while 5
> iwpriv eth0 force_reset
> end

6. Run Kismet.pl

/root/wids # perl Kismet.pl

On controller pc:

1. Start controller

/home/shobanp/widsfinal1# ./controllernet

8.2 Test Results and Final Comments

The test was designed to track and locate an intruder and also detect rogue access points on the outer perimeter. I used two WIDS APs, a real WIDS AP (HOSTAP) and a simulated WIDS AP (BETA) and a controller which handles both real and simulated WIDS access points. Antenna information was simulated by using two antenna readings files for HOSTAP and BETA APs. WIDS was able to track and locate the intruder and also locate three rogue APs.(Refer Figure 34).

The test produced the expected results and shows that the WIDS software successfully implements parts of the complete WIDS package. Kismet also detected rogue external/rogue networks. However, the software needs to be extended to handle the rotating directional antennas and tests of the location calculations and antenna reconfiguration need to be performed with the actual hardware.

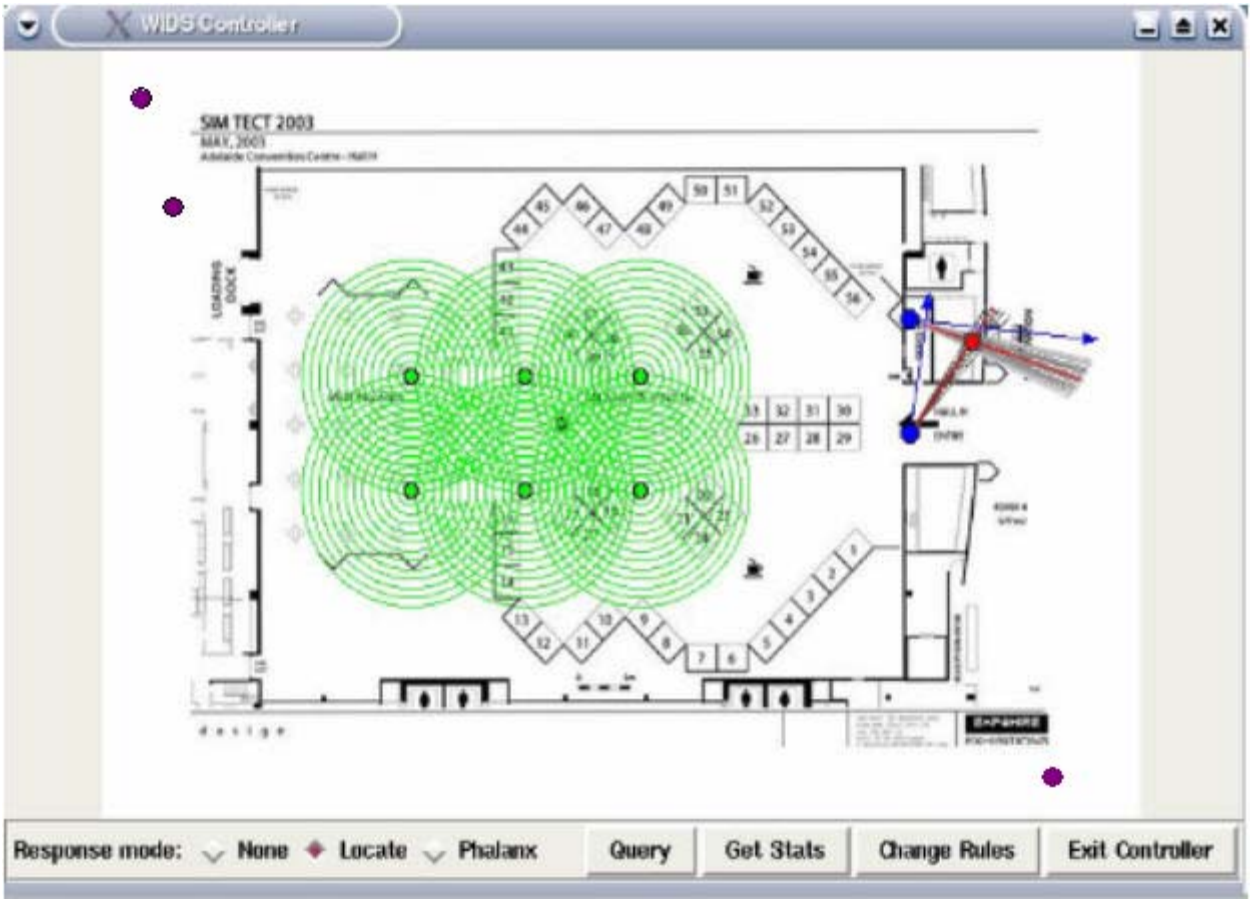


Figure 34: Reconfigured BETA AP and HOSTAP locating station.

Chapter 9. CONCLUSIONS

9.1. Conclusions

WIDS system will work very successfully in environments where WLANs requires perimeter intrusion detection. WIDS is well suited for military environment, navy shipyards and navy ships. The WIDS system contains three modules, which are WIDS Module, Controller Module and WIDS Simulator.

The WIDS Module scans actively for malicious NICs or APs with the help of directional antennas. The WIDS Module has a rules engine and specific rules are stored in a hash so real-time data can be compared and alerts can be sent as required to the Controller. The Controller Module is a vital part in the WIDS system. It manages all the WIDS APs and coordinates WIDS APs to triangulate intruders. The WIDS Simulator is an user interface which allows users to add, edit or delete rules, get statistics and also has all the WIDS APs visible showing their individual antenna sweeps.

WIDS is able to detect and defend a WLAN from the most commonly known attacks. Denial of Service attacks on 802.11 and 802.1 X networks are more frequently used by intruders since these attacks cause the most inconvenience to the WLAN with respect to basic functionality. WIDS AP's are connected to the Controller through wire and when the wireless medium is acting busy due a DoS (deauthentication/disassociation/jamming) attack, the controller is triggered about the attack and recognizes that an attack is in progress. The controller then can basically shutdown the wireless medium. There is no defensive procedure for such DoS attacks yet but the WIDS Simulator can graphically show which WIDS AP's are acting busy and the controller can collect further information from the various WIDS AP's about time of attack, period the wireless medium is busy etc

WIDS, is one of the few WLAN intrusion detection systems which is built with off-the-shelf components and also has the functionality to physically locate intruders. All that remains to complete a WIDS prototype is to build a WIDS AP with an embedded computer and a rotational antenna and to modify the WIDS HostAP software to control the movement of the antenna.

Even though IEEE802.11 i improves security of wireless networks, there is still a need for additional security provided by WIDS. Installed wireless networks will not be immediately updated. New

hardware is needed for CCMP, which could be expensive for large networks. Since IEEE 802.11 i is new technology, there can be configuration or implementation errors. Authentication mechanisms can be compromised by human errors or by lost or stolen equipment.

9.2. Future Research

One of the main topics for future research is the development of a hardware embedded prototype of the WIDS APs, with moveable directional antennae accompanied with motor control. Other improvements would be to expand rule processing, implement combination of AND and OR logic, implement more rule cases and test them.

The controller needs to check for access points that are down and refresh the GUI. It would be beneficial to implement an Agent Service that is able to perform log data clean up, send email on the rise of an alert etc.

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APPENDIX

WIDS Access Point components

Stepper Motor Controller (STP 100)
http link : www.pontech.com/products/stp100/index.htm
Price : $159.00

Stepper Motor (Vexta PK268-01A)
http link : www.pontech.com/products/vexta/index.htm
Price : $99.00

Netgate Prism Card (NL-2511 CD PLUS EXT2)
http link : www.netgate.com/NL2511.html
Price : $75.00

Pigtail for the wireless card to allow connection of directional antenna
Price : $25.00

Celestron 93499 heavy duty tripod
http link : www.digitalfotoclub.com/products2/Celestron_Heavy_Duty_Tripod_93499.html
Price : $325.00

X-Scale Single Board Computer and Wireless Networking Platform (SP-KIT400, SPB400CA, SDC400CA)
http link : www.xbox.com/Products/Xscale.htm
Price : $795.00 (SP-KIT400)
$575.00 (SPB400CA)
$159.00 (SDC400CA)

Power supply +5V/15A, +12V/4A, -12V/1A, 24V/3A Supply, stock number 14066 PS
http link : www.powersupplydepot.com/14066-PS.htm
Price : $29.95

Directional antenna with mounting hardware
Price : $150.00

Additional supplies, including aluminum poles for mounting directional antennas, enclosures for the electronics, cables, solder, and electrical connectors
Price : $300.00

VITA

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