A Wireless Intrusion Detection System for 802.11 WPA3 Networks

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Abstract—Wi-Fi (802.11) networks have become an essential part of our daily lives; hence, their security is of utmost importance. However, Wi-Fi Protected Access 3 (WPA3), the latest security certification for 802.11 standards, has recently been shown to be vulnerable to several attacks. In this paper, we first describe the attacks on WPA3 networks that have been reported in prior work; additionally, we show that a deauthentication attack and a beacon flood attack, known to be possible on a WPA2 network, are still possible with WPA3. We launch and test all the above (a total of nine) attacks using a testbed that contains an enterprise Access Point (AP) and Intrusion Detection System (IDS). Our experimental results show that the AP is vulnerable to eight out of the nine attacks and the IDS is unable to detect any of them. We propose a design for a signature-based IDS, which incorporates techniques to detect all the above attacks. Also, we implement these techniques on our testbed and verify that our IDS is able to successfully detect all the above attacks. We provide schemes for mitigating the impact of the above attacks once they are detected. We make the code to perform the above attacks as well as that of our IDS publicly available, so that it can be used for future work by the research community at large.

Keywords—WPA3, 802.11, Intrusion Detection System, Network Security

I. INTRODUCTION

Today, Wi-Fi has become an essential part of our daily lives. More than one billion Wi-Fi Access Points (APs) exist, which provide internet services to over a hundred billion consumer devices such as smartphones, tablets, laptops, desktops, IoT devices, etc. [1]. With such a large and growing number of users and devices, the security of Wi-Fi networks has become of utmost importance.

The Wi-Fi 802.11 standard has seen several revisions over the years since it was first defined in 1997 [2]. But most of these revisions have concentrated on performance improvements, and only a few were designed to enhance security. While the 802.11 protocols are standards defined by IEEE, the Wi-Fi Alliance issues security certifications based on IEEE’s work. Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA), and WPA2 are its previous security certifications, and now WPA3 is the latest one released in 2018 [3]. From June 2020 onwards, it has been mandatory for all new devices to support WPA3.

WPA2, which until recently was considered reasonably secure, has been shown to have a number of severe vulnerabilities and protocol loopholes [4]–[6]. Although WPA3 fixes these shortcomings of WPA2, some of the design and implementation flaws of WPA3 that allow denial-of-service (DoS), side-channel and downgrade attacks have been revealed in [7]–[9]. Even after carefully designing standards, there might be vulnerabilities present, which an attacker can exploit. Hence, there is a need for an Intrusion Detection System (IDS) to monitor the network as a second line of defense and raise alerts in real-time when an attacker is exploiting such vulnerabilities [10]. Once an attack alert is raised, a security expert can inspect it more closely and execute steps to locate and block the attacker. There has been plenty of research on building an IDS for 802.11 networks [6], [10]–[16], but none focuses specifically on WPA3. In this paper, we describe the design and implementation of an IDS that has been specifically designed for detecting attacks on WPA3 networks.

For performing various attacks on a wireless network, Aircrack-ng [17], MDK3 [18] and Metasploit [19] are popular publicly available tools that network researchers have long used. However, none of these provide support for performing attacks on WPA3 networks. A more recent work [20] demonstrates how advanced attacks on Wi-Fi networks can be carried out using cheap commodity hardware. In Section IV, we explain how we execute the known attacks on WPA3 networks, in order to test the efficacy of our IDS.

Our contributions are as follows:
1) We describe the attacks on WPA3 networks that have been reported in prior work. Additionally, we show that a deauthentication attack and a beacon flood attack (Sections IV-B8 and IV-B9), known to be possible on a WPA2 network, are still possible with WPA3.
2) We launch and test all the above (a total of nine) attacks using a testbed that contains an enterprise-grade AP supporting WPA3 and IDS that monitors our network for malicious behavior. Our experimental results show that the enterprise AP we use is vulnerable to eight out of the nine attacks and the enterprise IDS is unable to detect any of these nine attacks. We also provide the steps and code to perform each of the above attacks. The files are available in our GitHub repository [21], which can be used for future work by the research community at large.
3) We propose a design for a signature-based IDS [22], which incorporates techniques to detect all the above attacks. Also, we implement these techniques on our testbed and verify that our IDS is able to successfully detect all the above attacks. The code of our IDS is also available at [21].
4) Finally, we provide schemes for mitigating the impact of the above attacks once they are detected.

The rest of the paper is organized as follows. Section II provides a review of related prior work. Section III describes the network model and objectives of this paper. Section IV describes and explains how to perform various attacks on WPA3 networks. Section V provides techniques to build an IDS to detect all of these attacks. Section VI provides some schemes for mitigating the impact of the above attacks. We present our experimental results in Section VII and provide conclusions and directions for future research in Section VIII.

II. RELATED WORK

IDSs have been used for a long time for detecting attacks on wired as well as wireless networks; see [23] for a survey. Depending on the type of detection technique used, an IDS can broadly be classified as either anomaly or signature (also called misuse) based [24]–[26].

There has been a lot of research on building a reliable high-performance anomaly-based IDS. In [14], the authors used deep learning methods for intrusion detection on the NSL-KDD and IDS-99 dataset. This dataset is an improved version of the KDD Cup ’99 dataset [27], which was compiled in 1998 by DARPA by launching various attacks on a simulated wired network. The authors in [16] used the GPRS database to train and test their IDS on. The GPRS database was built using an actual wireless network based on WEP. In [11]–[13], the...
more recent AWID2 dataset \[6\] was used to build an anomaly-based IDS using different machine learning techniques. This AWID2 dataset released in 2016 is also based on WEP, but is much more comprehensive than the GPRS dataset. Such machine learning based anomaly detection methods can detect previously unseen attacks, but they require a dataset (often labelled) to train their model on and have to deal with the problem of feature selection. Additionally, all the above mentioned datasets are outdated. They do not contain the attacks specific to WPA3, and most of the attacks they include are no longer a threat to WPA3 with its improved security. Even the latest AWID3 dataset \[23\] released in 2021 is based on WPA2. In this paper and our GitHub repository \[21\], we provide procedures and codes to perform the known attacks on WPA3. We believe that these will aid research in building a new and updated dataset based on WPA3, which in turn will help in developing improved IDSs.

While signature-based IDSs are not able to detect novel, zero-day attacks, they have the advantage that they provide a higher detection accuracy and lower false positive rate than anomaly-based ones \[29\]. Snort-Wireless \[30\], AirMagnet \[31\] and AirDefence \[32\] are some commercial signature-based IDSs for wireless networks. While these could be used to detect and prevent certain attacks in a WEP/ WPA/ WPA2 network, they are not updated to work with WPA3 networks. In Section \[IV\] we present a design for a signature-based IDS capable of detecting attacks on WPA3.

### III. Network Model and Objectives

We set up an 802.11 wireless network running in infrastructure mode. All the APs and clients in the network support the WPA3 security standard. An AP is configured to run either WPA3-Personal or WPA3-Personal Transition mode \[3\] as required for the analysis. We also set up an attack node capable of launching various attacks on this network. These attacks are known attacks specific to WPA3 (see Section \[IV\] for details). Lastly, we also set up an IDS at the link layer that monitors our network for any malicious behavior. We check whether this IDS can successfully detect any of the attacks launched on the network.

Our objectives are to perform the attacks, capture the packets exchanged during each attack, verify if they match the theoretically expected packet trace, and then identify the various attack signatures. Then, we seek to design a signature-based IDS capable of detecting all of these attacks. Next, our goal is to implement this design in code and test its performance on our 802.11 network setup.

### IV. Changes in WPA3 from WPA2 and Known Attacks on WPA3 Networks

First, in Section \[IV-A\], we present the main changes introduced in WPA3, relative to WPA2, for enhancing the security. Then in Section \[IV-B\] we describe all the currently known attacks on WPA3 and explain how to perform them.

#### A. Changes in WPA3 from WPA2

For authentication between the client and the AP, previous security standards (WEP, WPA, WPA2) allowed either Open System authentication or Shared Key authentication \[8\]. On the other hand, WPA3 makes it compulsory to use Simultaneous Authentication of Equals (SAE) \[38\]. It provides data integrity and replay protection for some of the management frames. Making SAE and MFP mandatory prevents most of the attacks that were previously possible on WPA2 networks. The deauthentication flood attack \[39\] is no longer possible as MFP protects the deauthentication frames and they cannot be spoofed. Fake authentication, offline dictionary attack, and other severe attacks \[4, 40, 41\] exploiting the vulnerabilities of Open System Authentication are also no longer possible as SAE is mandatory in WPA3. Still, there exist some known vulnerabilities in the WPA3 protocol, which an attacker can exploit \[7, 8\]. These attacks are described in Section \[IV-B\].

![Figure 1: (a) Open System Authentication, (b) Shared Key Authentication, (c) Simultaneous Authentication of Equals (SAE)](image)

As shown in Figure \[1\] after authentication and association, a 4-way handshake takes place using Extensible Authentication Protocol Over LAN (EAPOL)-Key frames \[8\]. This handshake is used to derive a Pairwise Transient Key (PTK) \[8\]. Particularly in the third message of the handshake (EAPOL Key Message 3), using the information from the Robust Security Network Element (RSNE) \[8\] the parties verify if both of them have the same security parameters of the network. RSNE contains information about the security protocols and parameters supported by the AP and is also shared within its beacons. If there is any mismatch between the RSNE held by the two parties, then the handshake is aborted.

#### B. Known Attacks on WPA3 Networks

Table \[I\] lists the currently known attacks on WPA3. It comprises a total of nine attacks, of which the first seven are specific to WPA3 only. The last two attacks existed in WPA2 networks and we show that it is still possible to execute them on a WPA3 network. The table also includes two columns showing the results of our testing. It can be seen that the APs we used for this experiment are vulnerable to eight out of the nine attacks, and the IDS system was unable to detect any
Our test result: AP vulnerable and IDS does not detect it.

Source: This attack is from [7].

Impact: It causes clients to connect to the network using the less secure WPA2 instead of WPA3. This makes the AP vulnerable to some of the attacks that were possible with WPA2.

4) SAE Commit Values out of Range Attack:

Source: This attack is from [8].

Impact: Causes DoS – prevents clients from connecting to the network.

Our test result: AP vulnerable and IDS does not detect it.

Short Description: Once the client sends the first SAE commit message (see Figure 2), the attacker can spoof the AP MAC address and in a race condition, reply with a “commit value out of range rejection” message before the legitimate AP replies. The client will abort the handshake on receiving the rejection message. Repeatedly sending such rejection messages before the legitimate AP can cause DoS for the client. This attack is explained in detail in [8].

How to launch: We modify the source code of hostapd-2.9 in such a way that the attacker’s AP replies to the supplicant’s commit message with a commit reply that contains the rejection status code 0x0001 – “Unspecified failure”. We found that our attacker was able to send the rejection message before the legitimate AP’s reply in every test conducted and successfully cause DoS to the clients.

5) SAE Unsupported Group Attack:

Source: This attack is from [8].

Impact: Causes DoS – prevents clients from connecting to the network.

Our test result: AP vulnerable and IDS does not detect it.

Short Description: Once the client sends the first SAE commit message using a particular cryptographic group, similar to the commit out of range attack, an attacker can reply with a “group unsupported” message. The client will then abort the handshake and will have to resend its commit message using a different group. The attacker can again reply with a “group unsupported” message and keep doing this repeatedly causing DoS to the client. This attack is explained in detail in [8].

How to launch: We again modify the source code of hostapd-2.9 in such a way that the attacker’s AP replies to the supplicant’s commit message with a commit reply that contains the rejection status code 0x0001 – “Unspecified failure”. We found that our attacker was able to send the rejection message before the legitimate AP’s reply in every test conducted and successfully cause DoS to the clients.

6) Downgrade Group Attack:

Source: This attack is from [7].

Impact: It makes a connection less secure by making use of a weaker cryptographic group in the SAE handshake.

Our test result: AP vulnerable and IDS does not detect it.

Short Description: The SAE mechanism can be carried out with a range of different cryptographic groups. For this attack, rather than repeatedly replying to all client commit messages...
with “group unsupported” error codes, the attacker replies to only those commit messages that use strong groups and allows only weaker groups to pass. Hence, after starting with the strongest group, which gets rejected, the client eventually ends up using a weaker group for establishing its connection. This attack is explained in detail in [7].

How to launch: This attack can be launched in a similar way as the previous one (Section IV-B5). The only difference is that we need to modify the source code such that the rejection message is sent only when certain strong groups are being used, while allowing requests using weaker groups to pass.

7) Timing Side Channel Attack:

Source: This attack is from [7].

Impact: It leaks information about the password. If the password is weak, it is possible for an attacker to recover it.

Our test result: AP is not vulnerable and IDS doesn’t detect it.

Short Description: The time taken by an AP to respond to the authentication commit message sent by a client is a function of the password of the network and the MAC address of the client. This exposes it to a side channel timing attack, in which the attacker sends numerous first messages to the AP and records the average time it takes for the AP to respond. This timing information reveals certain information about the password. An AP is vulnerable to this attack only if it uses the weak groups 22-24 (MOPD groups) and 27-30 (Brainpool groups) during SAE authentication [33]. Our AP does not support these groups and hence is not vulnerable to this attack. This attack is explained in detail in [7].

How to launch: In [42], a tool and detailed steps to perform this attack are provided. It is important to note that this tool only tests if the AP implementation is vulnerable to it or not. We set up and configured wpa_supplicant-2.9 [44] on our attack node to make it run as a WPA3 client. We sent several SAE Authentication requests to the target AP using different cryptographic groups from 22-24 and 27-30. Each time we received a response from the AP rejecting the request with the reason “group unsupported” (0x004d). Our AP did not support the use of any of these weak groups, and hence was not vulnerable to this timing attack.

8) Deauthentication Attack:

Source: This attack was possible with WPA2 [39]. Below we show that a similar variant is still possible on a WPA3 network.

Impact: Causes DoS– prevents clients from connecting to the network.

Our test result: AP vulnerable and IDS does not detect it.

Short Description: Management Frame Protection (MFP) introduced in 802.11w [38] and made mandatory with WPA3 prevents an attacker from spoofing a deauthentication frame after the 4-way handshake has taken place. However, an attacker can still spoof a deauthentication packet before this handshake and can cause DoS to a client trying to connect to the network. As shown in Figure 3(a), just after the client sends an association request to the AP, the attacker sends a deauthentication packet to the client. The client now goes back to State 1 of its state machine as shown in Figure 3(b) and expects frames only of type Class 1 as defined by the 802.11 protocol [33]. The AP is unaware of this and continues to respond to the association request with an association response followed by the EAPOL message 1 of the 4-way handshake as it would normally do. The client in State 1 does not expect to receive these messages and replies to them with a deauthentication packet with reason code 7– “Class 3 frame received from nonassociated STA”. The AP accepts this deauthentication packet and aborts the handshake. The attacker keeps doing this every time a client tries to establish a connection with the AP, thus causing DoS to the client.

How to launch: To implement this attack, we again modify the source code of hostapd-2.9 in a way that the attacker’s AP sends a deauthentication packet to the client right after the client completes authentication and sends an association request to the legitimate AP. We found that our attacker was able to send the deauthentication packet before the legitimate AP’s reply in every test conducted and successfully cause DoS to the clients. Figure 4 shows the packets captured during the attack, which match with the packet sequence we expect theoretically from Figure 3(a).

Figure 3: (a) The figure shows that by sending a deauthentication packet at the right time, an attacker can prevent new clients from joining the network. (b) The figure shows the state machine of a node running the 802.11 protocol during the establishment of a connection.

9) Beacon/ Probe frames Flood Attack:

Source: This attack was possible with WPA2. In this paper, we show that it is still possible on a WPA3 network.

Impact: Confuses new clients trying to find the legitimate AP.

Our test result: AP vulnerable and IDS does not detect it.

Short Description: Since the beacons are not protected, an attacker can flood the network with beacons advertising similar or different SSIDs compared to the legitimate AP. Likewise, when a client sends Probe request frame, the attacker can flood the network with Probe response frames from similar or different SSIDs. Similar SSIDs can confuse a user, while a huge list of different (say 200) SSIDs can make it time consuming for clients to find the correct one. This is illustrated in Figure 5.
Figure 4: In this figure, the attacker AP, which spoofs the MAC address of the legitimate AP, sends a deauthentication packet (no. 635) to the client, which eventually leads to a mismatch of states between the client and legitimate AP and abortion of the handshake.

**How to launch:** This attack can be easily launched with the MDK3 tool [18], which comes pre-installed with Kali Linux.

![Figure 5](image1.png)  ![Figure 6](image2.png)

Figure 5: (a) Beacon flood with random SSIDs, (b) Beacon flood with confusing SSIDs

Figure 6: High level design of the IDS

V. SIGNATURE BASED IDS TECHNIQUES

A. High Level Design and Overview

Our IDS sensor monitors and captures the packets being exchanged in the network into a `.pcap` file. The IDS then processes this `.pcap` file. It extracts the necessary attributes for each type of packet and then converts it into a `.csv` file. Then, each packet (row) is read from this `.csv` file one by one, and appropriate conclusions are drawn. Each of the logic blocks (A-F) in Figure 6 analyses the packet received, applies some logic, updates the state of the IDS, and if there is any attack detected, prints the same along with the packet timestamp. We look at how we implement each of these blocks in Section V-C.

B. Packet Attributes Extracted for Each Type of Packet

- **All frames in general**
  - Serial number of the frame (frame.number)
  - Timestamp of the frame (frame.time)
  - Source address (wlan.sa)
  - Receiver address (wlan.ra)
  - BSSID of the frame (wlan.bssid)
  - Sequence number (wlan.seq)
  - Type of frame (wlan.fc.type)
  - Subtype of frame (wlan.fc.subtype)

- **Beacon/Probe frame**
  - Beacon interval (wlan.fixed.beacon)
  - Beacon timestamp (wlan.fixed.timestamp)
  - SSID advertised (wlan.ssid)
  - Number of authentication protocols supported (wlan.rsn.akms.count)
  - Type of authentication protocol supported (wlan.rsn.akms.type)

- **Authentication frame**
  - Type of authentication algorithm used (wlan.fixed.auth.alg)
  - Authentication sequence number (wlan.fixed.auth_seq)
  - Status code of the event (wlan.fixed.status_code)
  - SAE message type (wlan.fixed.sae_message_type)
  - Cryptographic group used for authentication (wlan.fixed.finite_cyclic_group)

- **Association frame**
  - SSID advertised (wlan.ssid)
  - Number of authentication protocols supported (wlan.rsn.akms.count)
  - Type of authentication protocol supported (wlan.rsn.akms.type)
  - Association ID (wlan.fixed.aid)

- **Deauthentication frame**
  - Reason for Deauthentication (wlan.fixed.reason_code)
C. Detailed Design of the IDS to Detect Specific Attacks

1) Design to Detect SAE Authentication Flood Attacks: We keep track of the last eight authentication frames sent to the AP at any given point of time. That is, we maintain a buffer of size eight containing the timestamps of the last eight authentication frames exchanged in the network (and so it will be updated using the FIFO rule when a new authentication frame is received). If at any point, the time difference between the first and last frames of the buffer is less than 500 ms, then we note that an abnormal event has occurred. A rate of 8 frames per 500 ms (= 16 frames/sec) is actually low and an attacker would always have to send packets at a higher rate for the attack to be successful [7]. But keeping our detection threshold at this low rate helps increase the detection accuracy. Then to lower the false positive rate, we wait to see if such an abnormal event is detected at least 10 times in the next 3 minutes. If it is, only then we say that an authentication flood attack is detected. (We use the fact that the attacker would have to keep flooding the network continuously to successfully cause a DoS attack. On the other hand, in any normal scenario, there would not be such a high rate of authentication frames being consistently present in the network for such a long time. Even in a case where an AP restarts and all its clients try to connect to the network simultaneously, they would end up doing so within the first minute itself. Hence this case will not be falsely detected as an attack.)

Remark 1: 1) We only count the authentication frames sent towards the AP and not the ones sent by the AP as replies. 2) We also do not count the second authentication frame (confirm message) sent by the client. So effectively, we are only keeping track of the number of connection requests received by the AP. 3) We also incorporate an additional check to reduce false positives. When an abnormal event is detected, we store the eight MAC addresses of the clients from which the eight addresses turn out to be successful. If they do, then we do not consider that as an abnormal event. We use the fact that only legitimate clients, having possession of the network password, would be able to establish a successful authentication. In other words, we only count the unsuccessful authentication connection requests and ignore the successful ones. We consider a connection successful if the AP replies to the client with a confirm message containing the status code as successful.

We add the above detection logic to block B (see Figure 6).

2) Design to Detect WPA2 Downgrade Attacks: We keep track of the last two beacon frames having the same SSID and BSSID as that of our AP. In particular, we maintain a FIFO buffer of size two containing all the necessary information of the last two beacons. If at any time we see that there is a mismatch in the RSNE information of these two beacon frames, then we note that an abnormal event has occurred. In particular, if between the two beacons the number of authentication protocols (wlan.rsn.akms.count) differs or the types of authentication protocols supported (wlan.rsn.akms.type) change from WPA3 to anything lower, then that is an abnormal event. If such an abnormal event is detected at least 4 times in a span of 5 seconds, then we conclude that a WPA2 downgrade attack is being executed. This logic is able to detect the attacks in both Sections IV-B2 and IV-B3.

Remark 2: 1) APs generally have a beacon interval set to 102.4 ms. Even if an AP sets the beacon interval to as high as 1024 ms, it will still broadcast 4 beacons in any 5-second window. Hence still, 4 abnormal events will be raised in a 5-second window, and our IDS will be able to detect the attack successfully. 2) If the time difference between the last two beacons is greater than 10 seconds, then we do not check for the abnormal event condition; we ignore it. This is done to avoid a false positive resulting from the restarting or reconfiguration of the AP. However, if a secure communication channel between the AP and the IDS is available, then when the AP has restarted, an ‘AP restarted’ signal can be shared with the IDS by the AP. We can then use this signal to conclude that the AP has restarted and possibly reconfigured. In such a case, we discard any abnormal events detected just before and just after such a signal is received. This would again help in avoiding any false positives. 3) When our AP was configured to run in Transition Mode (supporting both WPA2 and WPA3), it advertised itself using just one beacon, and not two separate beacons, per beacon interval. The RSNE of the beacon carried information that the AP supported both SAE and PSK type of authentication.

We add the above detection logic to block A (see Figure 6).

3) Design to Detect Deauthentication Attacks: Once we detect that a deauthentication packet is exchanged between a client (victim) and our AP, there should be no packet of type Association or EAPOL being exchanged between these two parties for the next short interval of time (say 3 seconds). If such a packet is detected within the short interval, then we conclude that an attack is being executed.

It can happen that the deauthentication packet sent by the attacker to the victim client is not sniffed by our IDS sensor, which is located close to the AP and far from the client. In this case, the attack will pass undetected. So we incorporate an additional signature to detect this attack. We look for the condition where a client has sent an association request, the AP has replied with a successful association response and then the client has sent a deauthentication packet to the AP with reason code 7– “Class 3 frame received from nonassociated STA”. When we detect such a sequence of packets being exchanged, then we say that an abnormal event has happened. This is because once a client has sent an association request, it cannot reply to a successful association response with a deauthentication packet with reason code 7. This can only take place if before receiving the association response, the client itself was deauthenticated and is now expecting frames of only Class 1 type as defined by the 802.11 protocol. If such an abnormal event repeats in a short time interval, then we conclude that a deauthentication attack is taking place. We add this detection logic to blocks D, C, and F.

Logic Block D (Deauthentication frame)
Store the victim client’s MAC address (say in ‘deauth_client’ array) and the time at which the deauthentication packet is sent (say in ‘deauth_time’ array).

Logic Block C (Association frame)
Check if source or destination address of the current packet lies in the ‘deauth_client’ array. If it does not, then do nothing and move on to read the next packet. If it does, then note down the index at which that address is present in ‘deauth_client’. Check the time difference between the time the association packet is received and the corresponding time stored at the same index in ‘deauth_time’ array. If this time difference is less than 3 seconds, then count it as an abnormal event.

Logic Block F (EAPOL frame)
Same as logic block C.

4) Design to Detect Group Downgrade and Commit Value out of Range Attacks: At any instant if we see that an
authentication rejection packet is sent by the AP to a particular client, we then monitor the channel for the next 500 ms to see if a successful authentication packet is sent by the AP to the same client. If such a packet is found, then we conclude that the group unsupported or commit value out of range attack is being performed. The authentication rejection packet should have status code “group unsupported” (0x004d) or “commit value out of range” (0x0001) and the successful authentication packet should have status code “successful” (0x0000).

Remark 3: It can happen that the authentication packet sent by the attacker (masquerading as AP) to the victim client is not sniffed by our IDS sensor, which is located at the AP; far from the client. In this case, the attack will pass undetected. One way to solve this issue is by having multiple sensors at different locations, so that every packet is sniffed by at least one IDS.

We add the above detection logic to block B (see Figure 6).

5) Design to Detect Timing Side-Channel Attacks: Similar to the detection of the SAE Authentication flood attack (see Section IV-B), we keep a count of the number of unsuccessful authentication requests received by the AP. In this case, these requests may not be flooded in a short time period but could be spread out across a longer duration. Hence, we do not use the request transmission times, and, instead, conclude that a timing side channel attack is being performed when the detected count of these unsuccessful authentication requests reaches a very high value, say 500.

In order to not have false positives, this count value is reset to zero every 24 or 48 hours. Also, it should be reset to zero after an authentication flood attack is detected (as the signature we defined for the authentication flood attack is also a signature for the timing attack).

We add the above detection logic to block B (see Figure 6).

6) Design to Detect Beacon Flood Attacks: When the IDS is first booted, we put it into a learning phase where it stores the MAC addresses and SSIDs of the APs in its neighborhood. Thus it builds and maintains an authorised APs list. After a short period (say 2-3 minutes), we change the IDS mode into detection phase where it monitors the network and marks an abnormal event when it receives beacons for which either MAC address or SSID does not lie in the authorized APs list. When a number of such abnormal events are detected in a short time interval, then we conclude that a beacon flood attack is in progress. Specifically, we draw this conclusion when 5 such different abnormal events occur in a span of 10 seconds. The manufacturer of our AP provides a Wireless Cloud Manager server that stores the current state of all our APs. When an AP restarts or a new AP is added to the network, this information gets updated on the server. At the IDS, using the Application Programming Interfaces (APIs) provided by the manufacturer of the AP, we poll our APs’ Wireless Manager server to check for this information. Whenever we see that an AP is restarted or a new AP is added to the network recently, we put the IDS back into the learning phase for a short period. This helps in reducing false positives.

We add the above detection logic to block A (see Figure 6). We can use this same logic with probe frames instead of beacons to detect Probe frames Flood attack.

Remark 4: It is important to note that the particular values and thresholds chosen in the design of our IDS are based on our experimental observations. They can be easily changed if found sub-optimal.

VI. MITIGATION OF IMPACT OF DETECTED ATTACKS

Except for the SAE flood and timing side-channel attacks (Sections IV-B1 and IV-B7), in all the other attacks described in Section IV-B, the attacker sends some malicious packets to the clients. So once we detect any of these attacks, we record the MAC addresses of the affected clients. We then send them a notification. These affected clients can later take appropriate actions from their side.

Also, we can track down any rogue transmitters in the vicinity. We do this by maintaining a list of authorized APs. Using the APIs provided by the manufacturer of our AP, we poll our APs’ Network Management System (NMS) to get information about the authorized APs set up in our location and maintain this list. If there is any AP not present in this list but present in the vicinity, then it is marked as rogue and may be banned.

Also, if we have multiple IDSs set up in a region, then once an attack is detected, we can find the approximate physical location of the attacker. We do this by first identifying which packets are sent by the attacker. We mark those packets and measure their received signal strength (RSSI value) at each of the IDSs. We then try to find the location of the transmitter of those packets using signal triangulation [45].
detect this flood attack. We also re-perform the attack with
the authentication flood rate reduced to as low as 20 frames/sec. Even at this rate, our AP was still vulnerable. It either was
unable to accept new connections or only accepted them after
a considerable delay. For our IDS, we had set the detection
threshold to 16 frames/sec. Hence, as expected, our IDS was
able to detect the attack even at the above low rate.

Figure 9: The figure shows the packet capture of the SAE
unsupported group DoS attack. The highlighted packet 43 with
status code 0x004d is sent by the attacker, which spoofs the
MAC address of the AP.

VIII. CONCLUSIONS AND FUTURE WORK

We launched and tested all the attacks on WPA3 networks
that have been reported in prior work and two additional
attacks using a testbed that contains an enterprise AP and an
IDS. Our experimental results show that the AP is vulnerable
to eight out of the above nine attacks and the IDS is unable to
detect any of them. We proposed a design for a signature-
based IDS, which incorporates techniques to detect all the
above attacks. Also, we implemented these techniques on our
testbed and verified that our IDS is able to successfully detect
all the above attacks. We provided schemes for mitigating the
impact of the above attacks once they are detected. We have
made the code to perform the above attacks as well as that of
our IDS publicly available, so that it can be used for future
work by the research community at large. In particular, we
believe that it will aid research in building a new and updated
dataset based on WPA3, which in turn will help in developing
improved IDSs.

Figure 8: The figure shows the packet capture of the SAE
authentication flood attack. We can see that seven authentication
frames are received by the AP in 1.3 ms.

Figure 10: The figure shows the response of the IDS when the
packet capture of (a) the SAE authentication flood attack, (b)
the SAE unsupported group DoS attack, is given as input.

was stopped, all clients were able to successfully connect to
the network.
