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Wireless LAN Security : IEEE 802.11g & VPN

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Abstract: 802.11g is an exciting new technology that offers additional performance, while providing investment protection for 802.11b clients through backward compatibility. By using previous technologies and economies of scale, 802.11g devices are available at little or no additional cost relative to 802.11b. As such, there are many reasons to begin migrating from 802.11b to 802.11g.802.11g is not, however, a panacea for WLAN capacity issues. As WLAN capacity needs increase, network professionals are well-advised to begin deploying a dual-band infrastructure to access the far greater capacity available with 802.11a. As such, 802.11g should be viewed as a portion of an overall WLAN architecture, not a substitute for 802.11a. 802.11g is a "bridge" technology and an ideal means for migrating from low-capacity 802.11b networks to the high-capacity, dual-band WLANs of the very near future. The evolution of wireless networking in recent years has raised many serious security issues. These security issues are of great concern for this technology as it is being subjected to numerous attacks. Because of the free-space radio transmission in wireless networks, eavesdropping becomes easy and consequently a security breach may result in unauthorized access, information theft, interference and service degradation. Virtual Private Networks (VPNs) have emerged as an important solution to security threats surrounding the use of public networks for private communications. This paper presents an approach to secure IEEE 802.11g WLAN using OpenVPN, a transport layer VPN solution and its impact on performance of IEEE 802.11g WLAN.

Keywords: WLAN, IEEE 802.11g, VPN, OpenVPV, Security.

1. INTRODUCTION

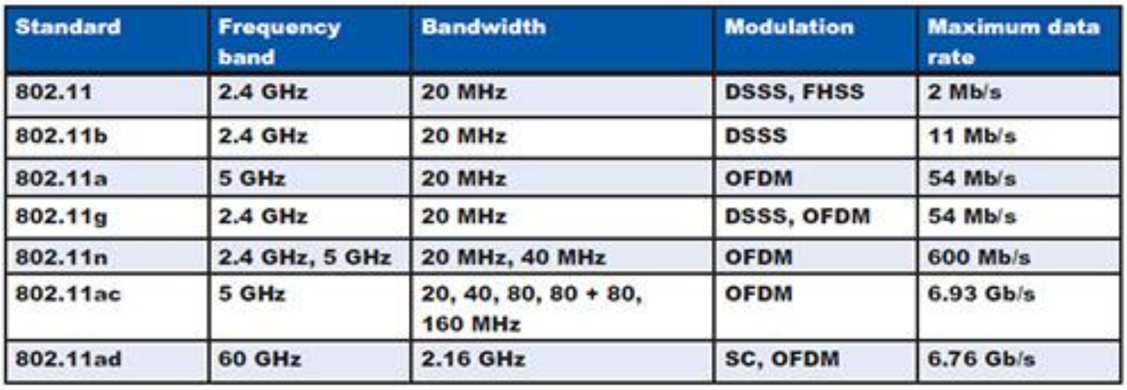
The IEEE 802.11g WLAN standard can be thought of as an intersection between the 802.11b and 802.11a standards. Like 802.11b, 802.11g operates in the same 2.4-GHz portion of the radio frequency spectrum that allows for license-free operation on a nearly worldwide basis. 802.11g is also limited to the same three non-overlapping channels as 802.11b. An important mandatory requirement of 802.11g is full backward compatibility with 802.11b, which both provides investment protection for the installed base of 802.11b clients and extracts a substantial performance penalty when operating in this mode. Like 802.11a, 802.11g uses Orthogonal Frequency Division Multiplexing (OFDM) for transmitting data. OFDM is a more efficient means of transmission than Direct Sequence Spread Spectrum (DSSS) transmission, which is used by 802.11b. When coupled with various modulation types, 802.11g (like 802.11a) is capable of supporting much higher data rates than 802.11b. As noted in Table 1, 802.11g uses a combination of OFDM and DSSS transmission to support a large set of data rates-in fact, all of the data rates supported by both 802.11a and 802.11b. These security issues are of great concern for this technology as it is being subjected to numerous attacks [3], [4], and [5]. The most common attacks on wireless LANs are unwanted or automatic connection to the wrong network, man-in-the-middle attack with a fake Access Point (AP), theft of information by illegal tapping of the network, intrusion from open air, scrambling of the WLAN and consumption of device batteries. The Wired Equivalent Privacy (WEP) is a standard security mechanism for IEEE 802.11g WLAN. When it was introduced, it was considered as a secured algorithm. But later it was found that it can be cracked easily [3], [6], [7], and [8]. VPN technology has been used successfully to securely transmit data in wired networks especially when using Internet as the medium. This success of VPN in wired networks and the inherent security limitations of wireless networks have prompted developers and administrators to deploy it in case of wireless networks. A VPN works by creating a tunnel, on top of a protocol such as IP. In this paper we evaluated the impact of OpenVPN [9], transport layer VPN solution, on performance of IEEE 802.11g WLAN.

2. WIRELESS LAN STANDARDS

The IEEE 802.11 is a set of standards for wireless local area network (WLAN) computer communications in the 2.4, 3.6 and 5 GHz frequency bands [11]. The 802.11a, b, and g standards are the most common for home wireless access points and large business wireless systems. The 802.11a is faster than 802.11b with a data transfer rates up to 54Mbps. As compare to 802.11b it can support more simultaneous connections and suffers less interference as it operates in 5GHz frequency band. However, among the three standards 802.11a has shortest range. The 802.11b works in 2.4 GHz frequency band and support maximum transfer rate of 11Mbps. As compare to 802.11a it uses less expensive hardware and better in penetrating physical barriers. It is more susceptible to interference as its working frequency is used by many electronic appliances. The 802.11g operates in 2.4GHz frequency band with maximum transfer rate of 54Mbps and have backward compatibility with 802.11b. Being operated in the 2.4GHz it also susceptible to interference. In practical scenario distance coverage by 802.11g is better than 802.11a but slightly less than 802.11b.

These WLAN standards are summarized in the Table 1.

Table 1: IEEE 802.11 Standards



Standard	Frequency band	Bandwidth	Modulation	Maximum data rate
802.11	2.4 GHz	20 MHz	DSSS, FHSS	2 Mb/s
802.11b	2.4 GHz	20 MHz	DSSS	11 Mb/s
802.11a	5 GHz	20 MHz	OFDM	54 Mb/s
802.11g	2.4 GHz	20 MHz	DSSS, OFDM	54 Mb/s
802.11n	2.4 GHz, 5 GHz	20 MHz, 40 MHz	OFDM	600 Mb/s
802.11ac	5 GHz	20, 40, 80, 80 + 80, 160 MHz	OFDM	6.93 Gb/s
802.11ad	60 GHz	2.16 GHz	SC, OFDM	6.76 Gb/s

3. WIRED EQUIVALENT PRIVACY (WEP)

The WEP is a privacy protocol specified in IEEE 802.11 to protect the link data transmitted in WLAN. It refers to the intent to provide a privacy service to wireless LAN users similar to that provided by the physical security inherent in a wired LAN. The WEP encryption uses the RC4 symmetric stream cipher with 40-bit and 104-bit encryption keys. Although 104-bit encryption keys are not specified in the 802.11 standard, many wireless AP vendors support them.

3.1. Security Issues with WEP

Security researchers have discovered potential attacks that let malicious users compromise the security of WLAN that use WEP [5], [7]. The following is a list of such attacks:

- Passive attacks to decrypt traffic, based on statistical analysis.
- Active attacks to inject new traffic from unauthorized mobile stations, based on known plaintext.
- Active attacks to decrypt traffic, based on tricking the access point.
- Dictionary-building attacks, after analyzing enough traffic on a busy network.

WEP has been widely criticized for a number of weaknesses [6], [8]:

- WEP is vulnerable because of relatively short IVs and keys.
- Authentication messages can be easily forged.
- Reuse Problem: Stream ciphers are vulnerable to analysis when the key stream is reused. Integrity Check value Insecurity: WEP uses a CRC for the integrity check. Although the value of the integrity check is encrypted by the RC4 key stream, CRCs are not cryptographically secure. Use of a weak integrity check does not prevent determined attackers from transparently modifying frames.
- Key Management: The WEP standard does not define any key-management protocol and resumes that secret keys are distributed to the wireless nodes by an external key management service.

3.2. Tools available for attacking WLAN

The various popular tools for attacking the WLAN are listed in Table 2.

Table 2. Tools for Attacking WLAN.

TOOLS	Operating System	Description
Aircrack [13]	Linux/Windows	It is a WEP key cracking program for use on 802.11 networks. The primary purpose for the program is to recover the unknown WEP key once enough data is captured.
Airpwn [14]	Linux	It is a tool for generic packet injection on an 802.11 network.
Airsnarf [15]	Linux	It is a simple rogue wireless access point setup utility to steal usernames and passwords from public Wi-Fi hotspots.
BSD-Airtools [16]	Linux	It contains a bsd-based wep cracking application, called dweputils. It also contains a AP detection application similar to netstumbler (dstumbler) that can be used to detect wireless access points and connected nodes, view signal to noise graphs *etc*.
Dsniff [17]	Linux	It is counterpart of NetStumbler
Dstumbler [18]	FreeBSD	It is counterpart of NetStumbler
Fake AP [19]	Linux	It generates thousands of counterfeit WLAN access points.
KisMAC [20]	MacOS	It is a free stumble application for MacOS X. It puts network card into the monitor mode, completely invisible and send no probe requests.

Kismet [21]	Linux	It passively monitors wireless traffic and dissects frames to identify SSIDs, MAC addresses, channels and connection speeds.
MacIdChanger [22]	Windows	It is a MAC address spoofing tool. This is generally used to conceal the unique MAC id that is on every network adapter.
MacStumbler [23]	MacOS	It is a utility to display information about nearby 802.11b and 802.11g wireless access points.
Netstumbler [24]	Windows	It is a wireless access point identifier running on Windows.
Wep0ff [25]	Linux/Windows	It is a tool to crack WEP-key without access to AP by mount fake access point attack against WEP-based wireless clients.
WEPCrack [26]	Linux	It is a tool that cracks 802.11 WEP encryption keys by exploiting the weaknesses of RC4 key scheduling.
WEPWedgie [27]	Linux	It is a toolkit for determining 802.11 WEP keystreams and injecting traffic with known keystreams. The toolkit also includes logic for firewall rule mapping, ping scanning, and port scanning via the injection channel and a cellular modem.
Wifitap [28]	Linux	It allows users to connect to wifi networks using traffic injection.

4. VIRTUAL PRIVATE NETWORK (VPN)

VPN technology provides the means to securely transmit data between two network devices over an insecure data transport medium.VPN technology has been used successfully in wired networks especially when using Internet as the medium. This success of VPN in wired networks and the inherent security limitations of wireless networks have prompted developers and administrators to deploy it in case of wireless networks. A VPN works by creating a tunnel, on top of a protocol such as IP. VPN technology provides three levels of security:

- **Confidentiality**: To provide the security against the loss of confidentiality, VPN provides a secure tunnel on top of inherently un-secure medium like the Internet. The data is encrypted before passing through the tunnel which provides another level of data confidentiality. If an attacker manages to get into the tunnel and intercepts the data, that attacker will only get encrypted data.
- **Integrity**: VPN uses integrity check mechanism such as hashing, message authentication code or digital signature to protect against the modification of data. It guarantees that all traffic is from authenticated devices thus implying data integrity.
- **Origin Authentication**: VPN provides mechanism for origin authentication by using cryptographic mechanism such as message authentication code or digital signature.
- **Replay Protection**: VPN also provides security against replay attack by using sliding window mechanism.

4.1. Need for VPN in Wireless Networks

The WLAN did not focus on security as a primary requirement. Generally the main focuses were on connectivity, throughput and other architectural and functional issues. As compared to wired networking the wireless networking is inherently more prone to attacks and less secure. Physical boundary for a wireless network cannot be confined. Although WEP is an existing security mechanism for WLAN, researchers have found many vulnerabilities in it. The WEP is also subjected to numerous attacks. These security issues of WLAN, lead the researchers, vendors and analysts to look for a solution to prevent these attacks. The tunneling of data using VPN technology is a widely agreed robust protection against many threats and attacks.

5. OPENVPN

The OpenVPN is free and open source user space VPN solution which tunnels the traffic through transport layer using TCP or UDP protocol for encapsulation and transfer of data. It uses virtual network interface (VNI) for capturing incoming traffic before encryption and sending outgoing traffic after decryption. Security in OpenVPN is handled by the OpenSSL [12] cryptographic library which provides strong security over Secure Socket Layer (SSL) using standard algorithms such as Advanced Encryption Standard (AES), Blowfish, or Triple DES (3DES). The OpenVPN uses a mode called Cipher Block Chaining (CBC) which makes the cipher text of the current block dependent on the cipher text of the previous block. This prevents an attacker from seeing patterns between blocks with identical plaintext messages and manipulating one or more of these blocks. The VNI appears as actual network interface to all applications and users. Packets of incoming traffic sent via a VNI are delivered to a user-space program attached to the VNI. A user-space program may also pass packets into a VNI. In this case the VNI injects these packets to the operating system network stack to sends it to the location mentioned in destination address field of the packets. The TUN and TAP are open source VNI. The TAP simulates an Ethernet device and it operates with layer 2 packets such as Ethernet frames. The TUN simulates a network layer device and it operates with layer 3 packets such as IP packets [29, 30] In Figure 1, the working of OpenVPN is explained and in Figure 2, the data flow in OpenVPN environment is shown.

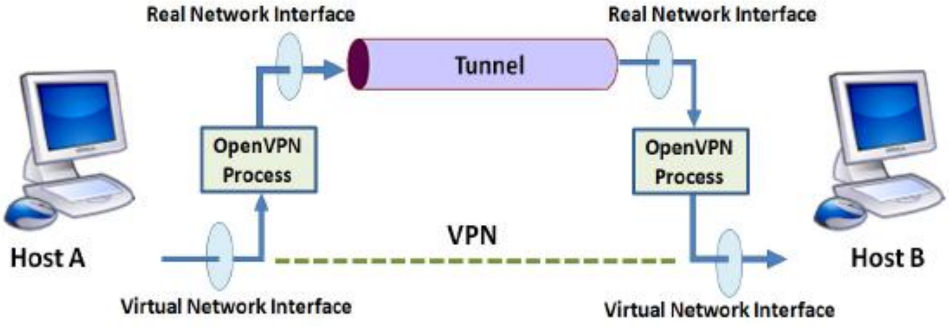


Figure 1. OpenVPN Tunnel between two end points.

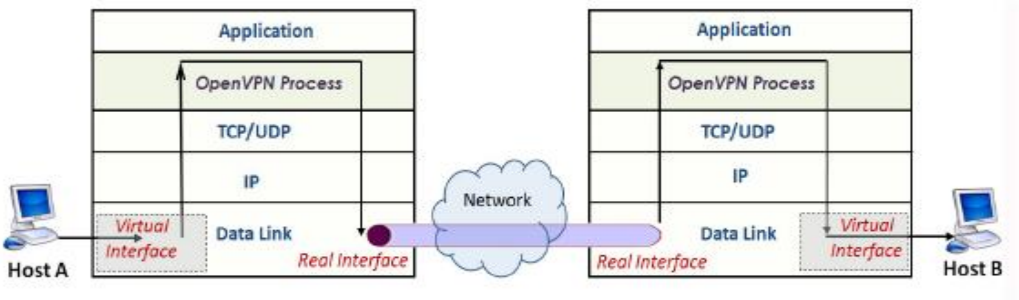


Figure 2. OpenVPN – Data Flow

The OpenVPN performs the following to secure the communications:

- Receives the packets of outgoing plain traffic from user space program by using the VNI.
- After receiving the packets, it compresses the received packets using Lempel-Ziv-Oberhumer (LZO) compression.
- After compression, it encrypts the packets using OpenSSL cryptographic library. For our experimentation we are using AES-128.
- OpenVPN also applies sliding window method to provide replay protection.

Then it tunnels the packet using UDP or TCP protocol to the other end.

- On receiving the encrypted traffic at other end, the OpenVPN performs the reverse of cryptographic operations to verify integrity, authenticity etc.
- After successful completion of reverse cryptographic operations, it decompresses the packet.
- The decompressed packet is then passed via VNI to the user space program.

5.1. OpenVPN Cryptographic Operation

- OpenVPN uses a security model designed to protect against both passive and active attacks.
- OpenVPN security model is based on using SSL/TLS for session authentication and the IPSec ESP protocol for secure tunnel transport over UDP.
- OpenVPN uses the X509 PKI (public key infrastructure) for session authentication.
- OpenVPN uses TLS protocol for cryptographic key exchange.
- OpenVPN uses two factor authentication for authenticate the clients.
- OpenVPN uses OpenSSL cipher-independent EVP, an OpenSSL API that provides high-level interface to cryptographic functions, for encrypting tunnel data.
- OpenVPN uses HMAC-SHA1 algorithm for authenticating tunnel data.

5.2. Overcoming WEP vulnerabilities

In Table 3 shows how OpenVPN overcomes the WEP vulnerabilities by comparing it with WEP on various parameters.

Table 3. OpenVPN Comparison with WEP.

Parameter	WEP	OpenVPN	Remark
Initialization Vector (IV)	24 bit (Too small)	Cipher –dependent and equal to cipher block size.	OpenVPN solves the IV reuse problem of WEP.
Encryption Algorithm	RC4 stream cipher	All Block Cipher supported by OpenSSL. Ex. AES, Blowfish, DES etc.	Encryption is fast and more secure in penVPN.
CBC Mode	Not supported	Supported	OpenVP protects against know plain text attack.
Authentication	Open system and shared secret authentication	TLS based two factor Authentication	OpenVPN authentication is strong than WEP.

Data Authentication and Integrity check	By using Cyclic Redundancy Check (CRC)	All OpenSSL authentication mechanism like HMAC-SHA1, MD5 etc.	OpenVPN provides better data authentication and integrity check.
Key Management	No key management	PKI X509 and pre shared secret.	OpenVPN supports two Established key management.
Replay Protection	No	Yes	OpenVPN uses sliding window mechanism to provide replay protection
Attacks: Bit flipping, dictionary building, FMS etc.	Vulnerable to these attacks [5], [7], [8]	Secure against these attacks	OpenVPN provide security against well known WEP attacks.

6. EXPERIMENT SETUP FOR PERFORMANCE MEASUREMENT

For analyzing the impact of OpenVPN on performance of IEEE 802.11g WLAN we created two experiment scenarios. First was for measuring the throughput under normal conditions and the second was to analyze the variation of traffic throughputs over an IEEE 802.11g WLAN when OpenVPN is implemented in WLAN. The following parameters were used as metrics for performance measurement during our experiments:

- Throughput is the rate at which bulk of data transfers can be transmitted from one host to another over a sufficiently long period of time.
- Latency is the total time required for a packet to travel from one host to another, generally from a transmitter through a network to a receiver.
- Frame loss is measured as the frames transmitted but not received at the destination compared to the total number or frames transmitted.
- IP Packet delay variation is measured for packets belonging to the same packet stream and shows the difference in the one-way delay that packets experience in the network.

6.1. Standard followed for performance measurement

We followed the IP Performance Metrics (IPPM) RFC 4148 [31], to measure the performance. The following is the list of metrics we have used along with the standard followed to measure these metrics.

- Maximum throughput achieved as per RFC 2544 [32],
- One-way Delay as per RFC 2679 [33],
- One-way Packet Loss as per RFC 2680 [34],
- IP Packet Delay Variation Metric as per RFC 3393 [35].

6.2. Requirements for Experimentation

The following is a list of the general Software and Hardware requirements for our experiments:

- Two laptops loaded with Red Hat Enterprise Linux 5,
- Ethernet Cables,
- TL-WA601G 108M TP-Link Wireless Access point,
- SPT-2000A Spirent test center.

6.3. Experiment Setup

In our experiment setup two laptops are connected using TP-Link Access point. The distance between the AP and the laptops is set to 4 meters to keep the signal strength high. Port-1 of Spirent test center is connected to laptop-1 and port-2 of Spirent is connected to laptop-2 using Ethernet cables of length 3 meters. These ports act as clients for laptops. These ports are used for traffic generation and analysis purpose. Port-1 of Spirent test center is used to generate the desired traffic for various data rates, frame sizes etc. Port-2 receives the traffic and analyses it. The analysis includes max throughput achieved, latency and packet delay variation with respect to various frame sizes. The 802.11g WLAN standard does not have inbuilt compression feature. OpenVPN supports both modes without compression and with compression, in our study we experimented both modes.

6.3.1. Performance without OpenVPN

The experiment setup for this is shown in Figure 3. We carried out this experiment for measuring the baseline performance of IEEE 802.11g WLAN.

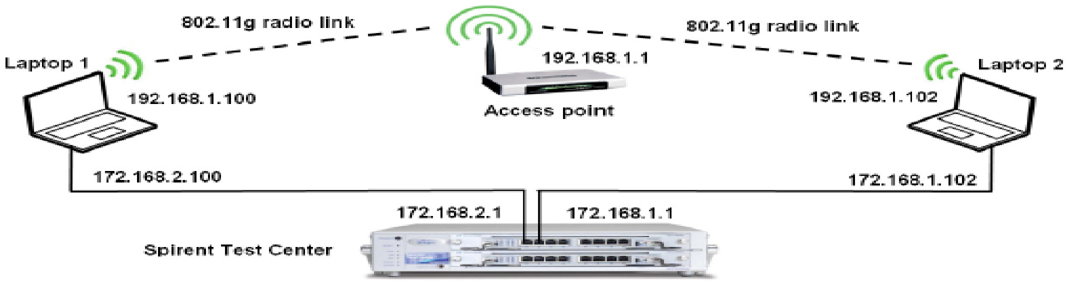


Figure 3. Experiment setup without OpenVPN

This experiment comprises of two steps. The first step measures the throughput with respect to UDP traffic, while the second step measures the throughput with respect to TCP traffic. In the first step, port-1 of Spirent test center sends UDP traffic of different frame sizes to laptop-1, which is connected to laptop-2 through wireless link using an Access Point (AP). Laptop-1 forwards this data to laptop-2 through AP and then laptop-2 send this data to port-2 of the Spirent test center. The second step of the experiment was conducted using the same environment variables described above, but this time TCP traffic was generated using port-1 to send traffic with different frame sizes from laptop1 to laptop2. We varied the size of the frame from 512 bytes to 1518 bytes.

6.3.2. Performance with OpenVPN

Now our next aim is to analyze the impact of applying OpenVPN security solution to 802.11g WLAN. In this scenario first we have to run our OpenVPN solution on both the laptops.

To analyze the impact of applying OpenVPN security to 802.11g WLAN on the throughput of UDP and TCP traffic in IEEE 802.11g WLAN, we performed the experiments in two steps. In first step we measured the impact on UDP traffic over IEEE 802.11g and in second step we measured the impact on TCP traffic over IEEE 802.11g. Experimentation was carried out in the same manner as for baseline performance measurement.

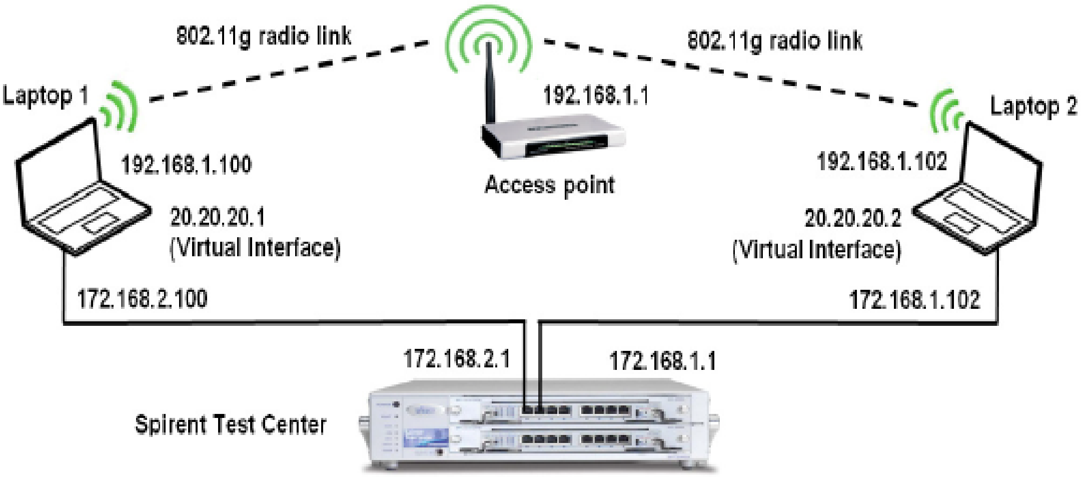


Figure 4. Experiment setup with OpenVPN

7. EXPERIMENT RESULT AND ANALYSIS

The results for all test scenarios of our experiment were collected from the test bed illustrated in the experiment setup section. Each experiment was repeated for twenty iterations to find the average performance values.

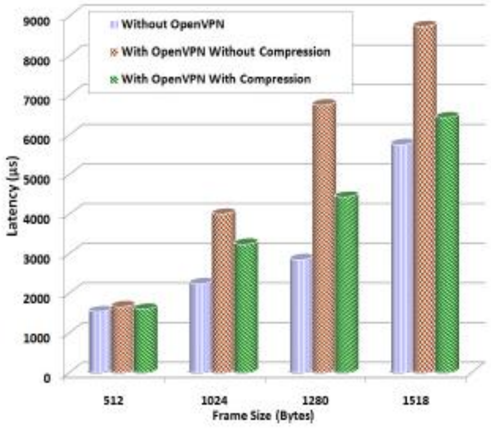
7.1. Throughput

The UDP and TCP throughput are measured as per RFC 2544 standards for different frame sizes. The results of these experiments for UDP are presented in Table 5 and in Figure 5. The results of these experiments for TCP are presented in Figure 5 and Figure 6 indicates that the throughput increases for both UDP and TCP traffic with increased frame size. Throughput increases because when the data transmitted using large frames the total overhead for transmitting the data due to frame headers will be less as compare to when the data is transmitted using small frames. The throughput is decreased slightly when OpenVPN is applied because of the increased overhead which is due to encapsulation and cryptographic operations used by OpenVPN. When compression is used with OpenVPN throughput increases since compression reduces the packet size in physical interface. Throughput in this case is better than the throughput in normal case i.e. without OpenVPN because IEEE 802.11g does not has inbuilt compression and after compression packet size reduces considerably if data is not randomly distributed which is true most of the time.

As mentioned above, throughput of WLAN decreases slightly for both UDP and TCP traffic after applying OpenVPN security. Table 7 lists the decrease in throughput corresponding to each frame size and for UDP and TCP traffic. From the table it is clear that maximum decrease in throughput is 15.84% (0.86 Mbps) in case of UDP traffic. In case of TCP traffic the maximum decrease in throughput is 16.91% (0.53Mbps).

7.2. Average latency

We measured the average latency as per RFC 2679 standards for both UDP and TCP traffic with various frame size. Figure 5 and Figure 6 shows the experimental result for average latency. The figures clearly indicate that the latency increases for both UDP and TCP traffic as we increase the frame size. This is due to the fact that round trip time is proportional to the size of frame. From these figures it is also clear that latency is less for normal case as compare to the two cases of OpenVPN mode because in OpenVPN mode additional processing is required for performing cryptographic operation, compression and encapsulation. From the experiment results we also analyzed that the latency in case of OpenVPN without compression is more than in case of OpenVPN with compression. Even though compression takes some processing time it reduces the frame size which results in decreased transmission time as compare to the transmission time when frame is not compressed.



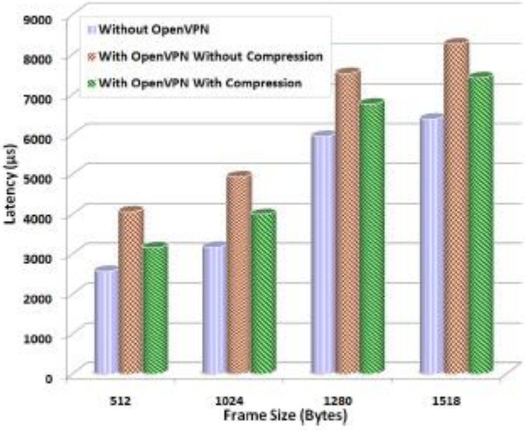


Figure 5. UDP Average Latency according to frame size.

Figure 6. TCP Average Latency according to frame size.

7.3. Frame Loss Percentage

Frame Loss Percentage is measured as per RFC 2680 standards for UDP and TCP traffic with different loads. The results of these experiments are presented in Figure 7 and Figure 8. These figures indicate that as we increase the load the Frame Loss Percentage increases for both UDP and TCP traffic. The frame loss percentage increases exponentially as the load crosses the throughput value corresponding to particular frame size.

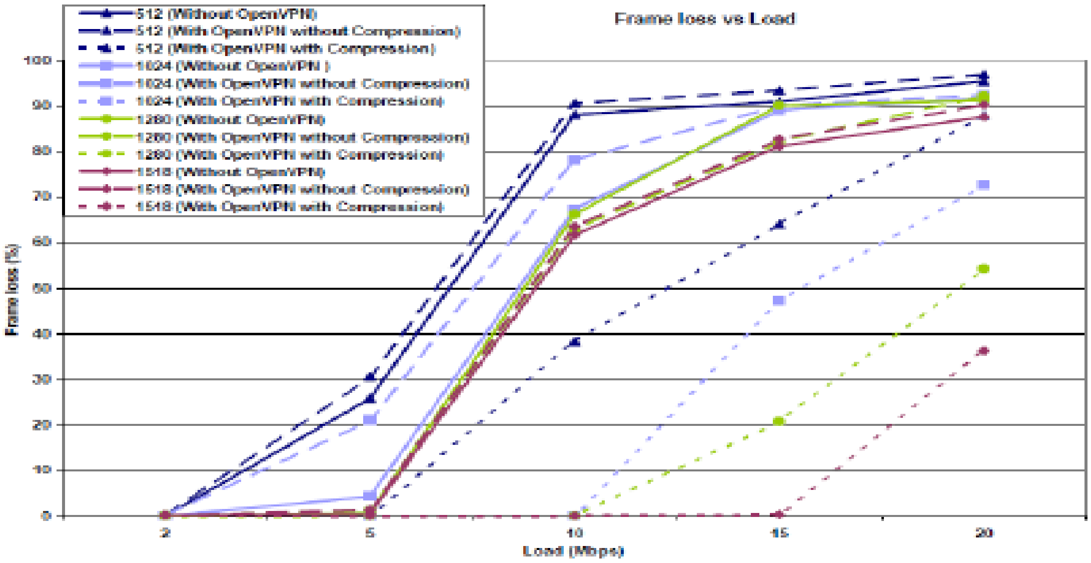


Figure 7. UDP Frame Loss Percentage according to frame size.

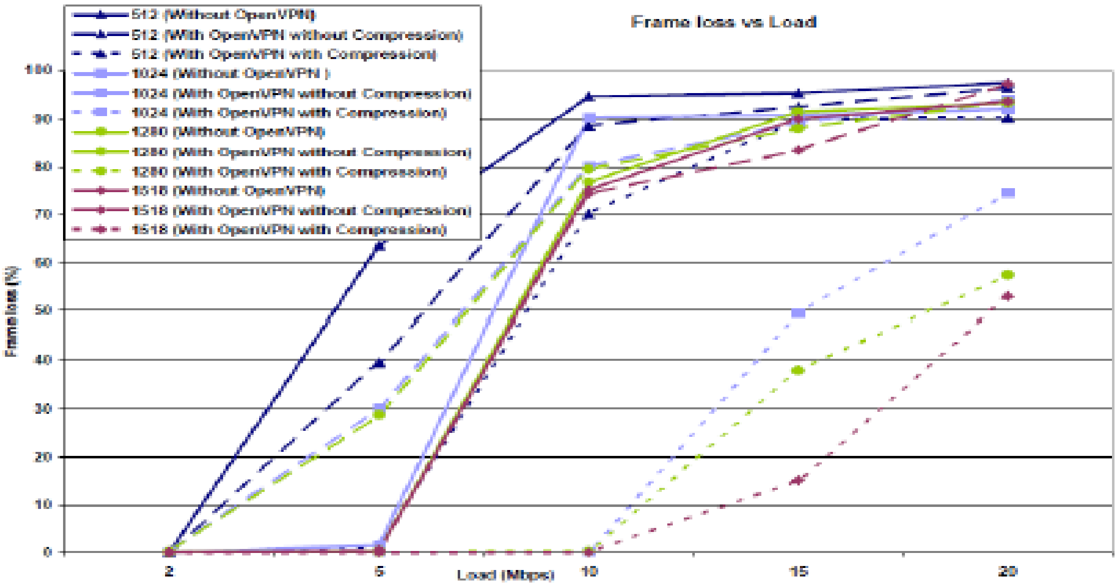


Figure 8. TCP Frame Loss Percentage according to frame size.

7.4. IP Packet Delay Variation

The IP Packet delay variation is measured as per RFC 3393 standards for UDP traffic for different frame size with different transmission rates. The result of this experiment is presented above. This figure indicates that as we increase the load the IP Packet delay variation increases. From the above figures we observe that with the use of compression with OpenVPN, the IP Packet delay variation decreased as compared to normal case because compression reduces the payload size of packet.

8. CONCLUSIONS

The benefit of wireless networks is driving the explosive growth of the WLAN market, where security has been the single largest concern for wireless network deployment. Through this paper we discuss why security is a major concern for WLAN. We have investigated and listed security vulnerabilities and attacks on the standard security mechanism for WLAN called WEP. We also explained how VPN can be used as a security solution for WLAN. In this work a transport layer tunneling based VPN solution named OpenVPN was adopted and implemented for 802.11g WLAN. To show how OpenVPN overcomes the weaknesses of WEP, we have compared OpenVPN with WEP based on various security parameters. The performance analysis was carried out with respect to throughput, latency, frame loss and IP packet delay variation. To measure these performance matrices we have followed RFC4148, RFC 2544, RFC 2679, RFC 2680 and RFC 3393. Experimentation was carried out for both UDP and TCP traffic with respect to various data rates and frame sizes using Spirent test center to analyses the impact of OpenVPN on performance of 802.11g WLAN. From the experimental results we can conclude that there is slight decrease in performance of 802.11g WLAN with the implementation of OpenVPN. But there is an increase in the performance of 802.11g WLAN with the use of compression in OpenVPN.

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