A security analysis comparison between Signal, WhatsApp and Telegram

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Abstract

This paper aims to provide a security analysis comparison between three popular instant messaging apps: Signal, WhatsApp and Telegram. The analysis will focus on the encryption protocols used by each app and the security features they offer. The paper will evaluate the strengths and weaknesses of each app, and provide a summary of their overall security posture. Additionally, this paper will discuss other considerations such as user base, data collection and usage policies, and other features which may impact the security of the apps. The results of this analysis will provide insights for individuals and organizations looking to choose a secure instant messaging app for their communication needs. In this paper we reviewed the main encryption standards and we compared the features, traffic analysis, protocols, performance and recent security breaches for WhatsApp, Signal and Telegram. The paper includes packet sniffing using Wireshark and Fiddler.

Keywords: security analysis comparison, encryption protocols, packet sniffing.

1 Introduction

End-to-end encryption based instant messaging apps have captured the attention of many users due to increased security, ease of use and and privacy concerns. End-to-end encryption is used when data security is necessary, including in the communications, healthcare and e-commerce industries. Companies use the encryption to comply with data privacy and security laws. This paper starts by presenting end-to-end encryption, what it is and what other standards exist. Some differences between the features of Telegram , WhatsApp and Signal have been written. It is talked in detail from physical forensic analysis and results from other authors. The experiments are about traffic analysis and packet analysis. The paper contains information about all the protocols used by each application and the most recent vulnerabilities and security breaches.
Signal, WhatsApp, and Telegram are all popular instant messaging apps that offer end-to-end encryption to secure conversations. However, there are some key differences in their security features and implementation.

Signal is widely considered to have the strongest encryption and security features among the three. It uses the Signal Protocol, which is considered to be one of the most secure encryption protocols available. It also has a number of security-enhancing features such as the ability to verify the identity of contacts and the option to enable disappearing messages.

WhatsApp also uses end-to-end encryption, but it uses the less-proven WhatsApp Protocol for encryption. WhatsApp also has a larger user base and therefore a bigger attack surface.

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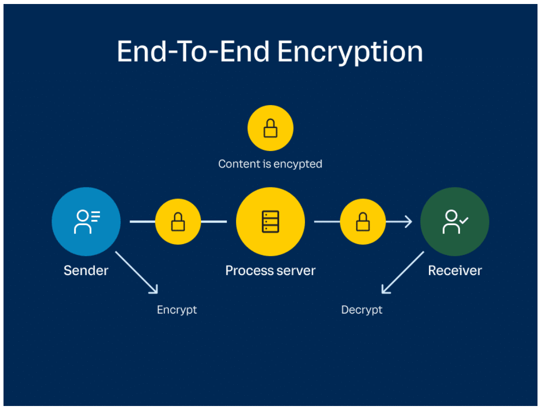
However, it is owned by Facebook, which is known for its data collection and usage practices, this could raise some concerns about privacy

Telegram also uses end-to-end encryption, but it has some limitations compared to Signal and WhatsApp. Telegram's encryption is optional and is only available in its "Secret Chats" feature, which means that the majority of users may not be using end-to-end encryption. Telegram also stores the encryption keys on its servers, which can be considered as a security vulnerability.

1.1 What is End-to-End Encryption

The major security feature of secure instant messaging is end-to-end encryption, that is used for protecting the protocol security when considering malicious server-based attacks.
In an end-to-end encrypted system, the only entities that can access the data are the sender and the intended recipients – no one else. Neither hackers nor unwanted third parties can access the encrypted data on the server. In true end-to-end, encryption occurs at the device level. Messages and files are encrypted before they leave the phone or computer and are not decrypted until they reach their destination.
Communications encryption in which data is encrypted when being passed through a network, but routing information remains visible.[nis21]



End-to-end encryption schema.[Rin21]

1.2 Other encryption standards

Before the wide use of end-to-end encryption apps, most protocols used encryption at rest or encryption in transit. Both methods are inferior in terms of protection against eavesdropping or message modification attacks.

Data at rest is the data housed on computer data storage in any digital form, whether it's in cloud storage, file hosting services, or databases.Encryption at rest is designed to prevent the attacker from accessing the unencrypted data by ensuring the data is encrypted when on disk. Encryption in transit protects data in motion by encrypting and decrypting the data over every hop in a network. This means that encryption in transit has the decrypted data on the server and on the endpoint devices.

1.3 Feature Comparison

Instant messaging tools are frequently used, as part of social media. Table 1 shows side-by-side the feature comparisons for WhatsApp, Telegram and Signal to give some perspective on where they stand. All three are free, use end-to-end encryption, have the possibility of sending images, videos or different files. For video calls or voice calls Telegram is not recommended due to the fact that it doesn't have this features. Now, the instant messengers focus on security issues, with completely safe, private and self-destructing messages, so it is natural to wonder which of the three one is safer.

Features			
Feature Name	WhatsApp	Telegram	Signal
Backups	✓	✓	local backup
Block user	✓	✓	✓
Broadcast	✓	–	✓
Group chat	✓	✓	✓
Online status	✓	✓	–
Price	Free	Free	Free
Secure conversation	E2E encryption	E2E encryption (Not Default)	E2E encryption
Send images	✓	✓	✓
Send videos	✓	✓	✓
Send files	✓	✓	✓
Share contact	✓	✓	✓
Share location	✓	✓	✓
Video calls	✓	–	✓
Voice calls	✓	–	✓

Table 1: WhatsApp, Telegram and Signal specs comparison.

2 Security

2.1 Forensics Analysis

Computer forensics is the application tehniques and investigation methods to obtain and protect evidence from a particular computing device in a way that is suitable for presentation in a court of law. The goal of computer forensics is to perform a structured investigation and maintain a documented chain of evidence to find out exactly what happened on a computing device and who was responsible for it. In this following subsection, we will talk about Signal, WhatsApp and Telegram and how well the apps hid user data.

2.1.1 WhatsApp

A very useful feature for clients, the offline backups WhatsApp does are the key to obtaining encrypted data with sensitive information. For the forensic analysis of WhatsApp, the authors in paper [Tha13] used a UFED physical analyzer to obtain the file system extraction, database files with details of chat sessions. Xtract 2.0 was also used to organize the database files in a HTML. A vulnerability of the AES cypher implementation on android made it possible to obtain the key. All messages, phone numbers and statuses can be seen.

2.1.2 Telegram

In [ACG17] there was forensic analysis of artifacts generated by Telegram on Android smartphones. Telegram is the only instant messaging app in this paper that doesn't automatically use end-to-end encryption. Each user is identified by a Telegram ID and a Telegram username and a profile photo. Telegram also stores various data in the internal memory of the device like all the contacts of a user, the chronology of voice calls, photos, videos and messages in chats. Even telegram groups can be gathered from this analysis.

2.1.3 Signal

For signal data forensics was attempted using UFED 4PC (Universal Forensic Extraction Device) and UFED Physical Analyzer version 6.3.11.36 with an internal build version 4.7.1.477 in [Jud18].

The parent company of Signal, Whisper Systems has released the complete source code of the application so developers can report any problems back to the creators if a component is not functioning as it should. This enables developers to make their own copies of Signal using the same encryption code. Whisper Systems will provide support for their own applications ans server but not for user made ones. Because Signal stores messages, keys, and passphrases on the user device a physical attack would be the best course of action.

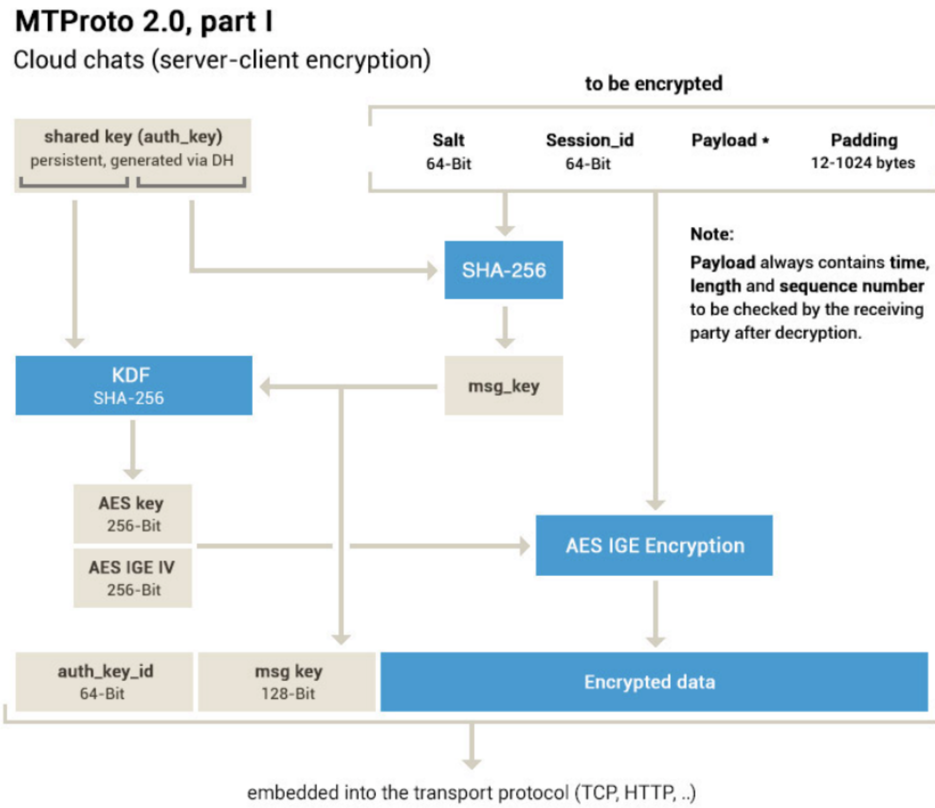
The extraction is physical and it gathers all the bits of information from the hard disk. Due to the increase security of phones, a big factor in the success of data forensics for signal is the model and operating system of the mobile device.

The Signal app has some glaring problems when there is access to the physical device. Deleted messages, timestamps, who sent the message and even its own status can be read on some phones models. Using the UFED analyser even Signal contact phone numbers and photos were possible to obtain.

2.2 Protocol Models

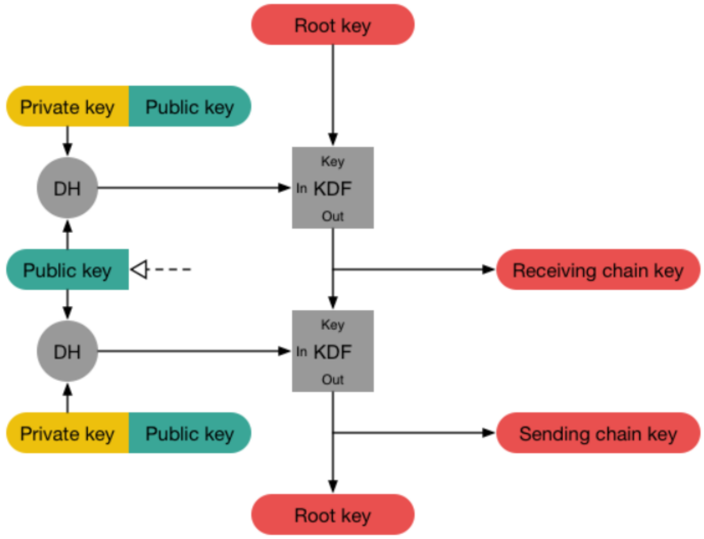
2.2.1 Telegram

Telegram uses the MTProto 2.0 protocol for both server client encryption and end-to-end encryption. Before a message (or a multipart message) is transmitted over a network using a transport protocol, it is encrypted in a certain way, and an external header is added at the top of the message that consists of a 64-bit key identifier auth_key_id (that uniquely identifies an authorization key for the server as well as the user) and a 128-bit message key msg_key. The indepth client, server, client interaction can be best understood from the figure below: [mtp]



2.2.2 Signal

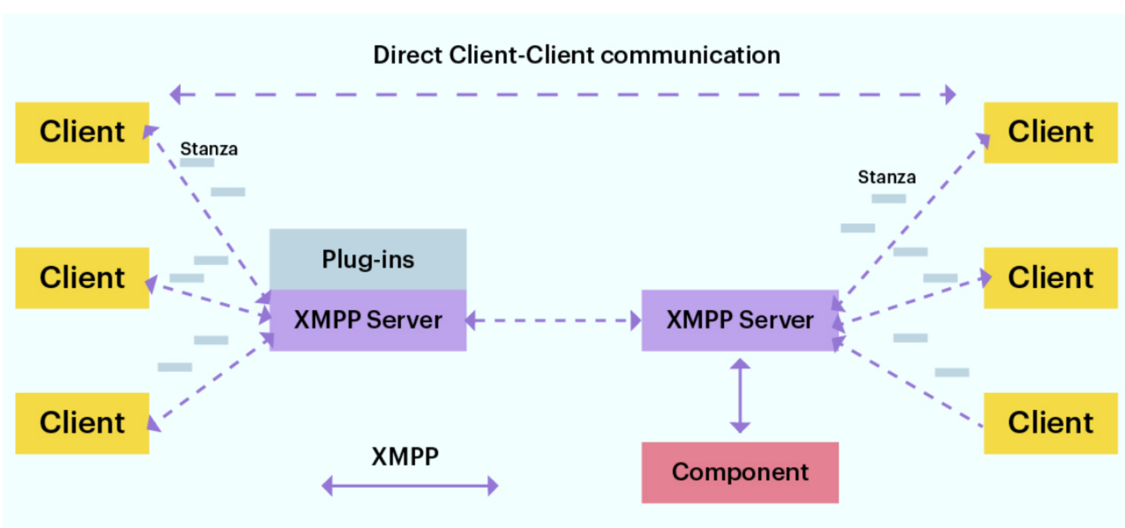
Signal uses the Double Ratchet algorithm, which is used by two parties to exchange encrypted messages based on a shared secret key. The parties derive new keys for every Double Ratchet message so that earlier keys cannot be calculated from later ones. The parties also send Diffie-Hellman public values attached to their messages. The results of Diffie-Hellman calculations are mixed into the derived keys so that later keys cannot be calculated from earlier ones. These properties give some protection to earlier or later encrypted messages in case of a compromise of a party's keys.[sig16]



KDF is defined as a cryptographic function that takes a secret and random KDF key and some input data and returns output data. The output data is indistinguishable from random provided the key isn't known (i.e. a KDF satisfies the requirements of a cryptographic "PRF"). If the key is not secret and random, the KDF should still provide a secure cryptographic hash of its key and input data. The HMAC and HKDF constructions, when instantiated with a secure hash algorithm, meet the KDF definition.

2.2.3 WhatsApp

For data transmission, WhatsApp uses an open and free protocol called XMPP. It is based on XML and allows exchanging text messages, audio/video data, and files. WhatsApp uses the Extensible Messaging and Presence Protocol (XMPP) as the messaging protocol for its platform. XMPP is an open standard for real-time communication, which is used for instant messaging and online presence detection. WhatsApp uses a modified version of XMPP, which is optimized for mobile devices and low-bandwidth networks. The XMPP protocol is responsible for facilitating the exchange of messages between users and for handling other features such as group chat, voice and video calls, and file sharing.[com16]



The Extensible Messaging and Presence Protocol (XMPP) is based on the client-server model of communication, where a user's device (client) connects to a server in order to send and receive messages. When a user wants to send a message, the client establishes a connection to the server and sends the message in an XML format, which is then processed by the server. The server then delivers the message to the intended recipient's client, which receives and displays the message. XMPP also includes a presence feature which allows clients to detect and track the online status of other users, this is done by sending presence configurations from the client to the server and from the server to the other clients that are interested in the user's status. Additionally, XMPP supports many other features such as group chat, file sharing, voice and video calls and more by using different types of stanzas and extensions. It's important to note that XMPP is an open standard, which means that any developer can create their own server and clients that are compatible with the XMPP protocol, this also allows different servers to communicate with each other.

2.3 Security Breaches

2.3.1 WhatsApp

On November 25th 2022, a massive active user list was dropped because of API scrapping Meta refused to patch. The numbers of active users were sold for over 2000 dollars and will be use for vishing or phishing attacks. [cyb22]

Egypt	44,823,547	Kuwait	4,468,134	Philippines	879,699
Italy	35,677,323	Libya	4,204,514	Mauritius	848,558
USA	32,315,282	Bangladesh	3,816,339	Taiwan	734,807
Saudi Arabia	28,804,686	Canada	3,494,385	China	670,334
France	19,848,559	Palestine	3,367,576	Croatia	659,115
Turkey	19,638,821	Kazakhstan	3,214,990	Denmark	639,841
Morocco	18,939,198	Belgium	3,183,584	Greece	617,722
Colombia	17,957,908	Jordan	3,105,988	Afghanistan	558,393
Iraq	17,116,398	Singapore	3,073,009	Albania	506,602
Africa	14,323,766	Bolivia	2,959,209	Norway	475,809
Mexico	13,330,561	Hong Kong	2,937,841	Bulgaria	432,473
Malaysia	11,675,894	Poland	2,669,381	Japan	428,625
United Kingdom	11,522,328	Qatar	2,526,694	Macao	414,228
Algeria	11,505,898	Argentina	2,347,553	Namibia	409,356
Spain	10,894,206	Portugal	2,277,361	Jamaica	385,890
Russia	9,996,405	Cameroon	1,997,658	Hungary	377,045
Sudan	9,464,772	Lebanon	1,829,661	Ecuador	310,259
Nigeria	9,000,131	Guatemala	1,645,068	Iran	301,723
Peru	8,075,317	Tunisia	1,595,346	Slovenia	229,039
Brazil	8,064,916	Switzerland	1,592,039	Lithuania	220,160
Australia	7,320,478	Uruguay	1,509,317	Brunei	213,795
United Arab Emirates	6,978,927	Panama	1,502,310	Luxembourg	188,201
Syria	6,939,528	Costa Rica	1,464,002	Serbia	162,898
Chile	6,889,083	Bahrain	1,450,124	Cyprus	152,321
India	6,162,450	Finland	1,381,569	Puerto Rico	130,586
Germany	6,054,423	Czech Republic	1,375,988	Indonesia	130,331
Netherlands	5,430,388	Austria	1,249,388		
Oman	5,048,532	Sweden	1,092,140		
Yemen	4,617,359	Ghana	1,027,969		

cybernews

In Table 2 are presented the most significant vulnerabilities that appeared in the last 3 years on WhatsApp. [CVE22c]

Security vulnerabilities for WhatsApp			
CVE ID	Vulnerability type	Score	Short description
CVE-2021-24043	-	6.4	A missing bound check in RTCP flag parsing code could have allowed an out-of-bounds heap read if a user sent a malformed RTCP packet during an established call.
CVE-2021-24042	-	7.5	The calling logic for WhatsApp could have allowed an out-of-bounds write if a user makes a 1:1 call to a malicious actor.
CVE-2020-1909	Exec Code Mem. Corr.	7.5	A use-after-free in a logging library in WhatsApp could have resulted in memory corruption, crashes and potentially code execution.
CVE-2020-1907	Exec Code Overflow	7.5	A stack overflow could have allowed arbitrary code execution when parsing the contents of an RTP Extension header.
CVE-2020-1891	-	7.5	A user controlled parameter used in video call could have allowed an out-of-bounds write on 32-bit devices.

Table 2: Vulnerabilities found on WhatsApp.

2.3.2 Telegram

In Table 3 are presented the most significant vulnerabilities that appeared in the last 2 years on Telegram. [CVE22b]

Security vulnerabilities for Telegram			
CVE ID	Vulnerability type	Score	Short description
CVE-2021-40532	-	7.5	Telegram Web K Alpha before 0.7.2 mishandles the characters in a document extension.
CVE-2021-37596	XSS	4.3	Telegram Web K Alpha 0.6.1 allows XSS via a document name.
CVE-2021-36769	-	5.0	An attacker can cause the server to receive messages in a different order than they were sent a client.
CVE-2021-31321	Overflow	5.8	A remote attacker might be able to overwrite Telegram's stack memory out-of-bounds on a victim device via a malicious animated sticker.
CVE-2021-31321	Overflow	5.8	A remote attacker might be able to overwrite heap memory out-of-bounds on a victim device via a malicious animated sticker.

Table 3: Vulnerabilities found on Telegram.

2.3.3 Signal

In Table 4 are presented the most significant vulnerabilities that appeared in the last 5 years on Signal. [CVE22a]

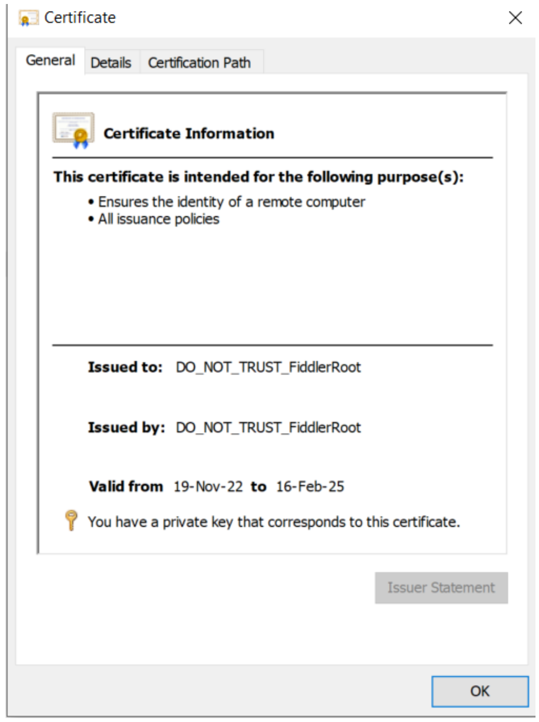
Security vulnerabilities for Signal			
CVE ID	Vulnerability type	Score	Short description
CVE-2022-28345	-	5.0	An attacker can spoof, for example, example.com, and masquerade any URL with a malicious destination.
CVE-2020-5753	-	5.0	Signal Private Messenger allows a remote non-contact to ring a victim's Signal phone and disclose currently used DNS server.
CVE-2019-17192	DoS	7.5	A remote attacker could easy cause a denial of service.
CVE-2019-17191	-	5.0	The Signal Private Messenger allows a caller to force a call to be answered and the audio channel may be open before the callee can block eavesdropping.
CVE-2018-16132	-	7.8	A large image sent to a user to exhaust all available memory when the image is displayed, resulting in a forced restart of the device.

Table 4: Vulnerabilities found on Signal.

3 Experimental Results

3.1 Package Sniffing

In this section all HTTPS traffic was decrypted using a tool from Fiddler that created an obviously fake certificate that we allowed on our testing machine.



Continuing this we will have to get a hold of the secret keys, but access to the physical device is needed.

3.1.1 WhatsApp

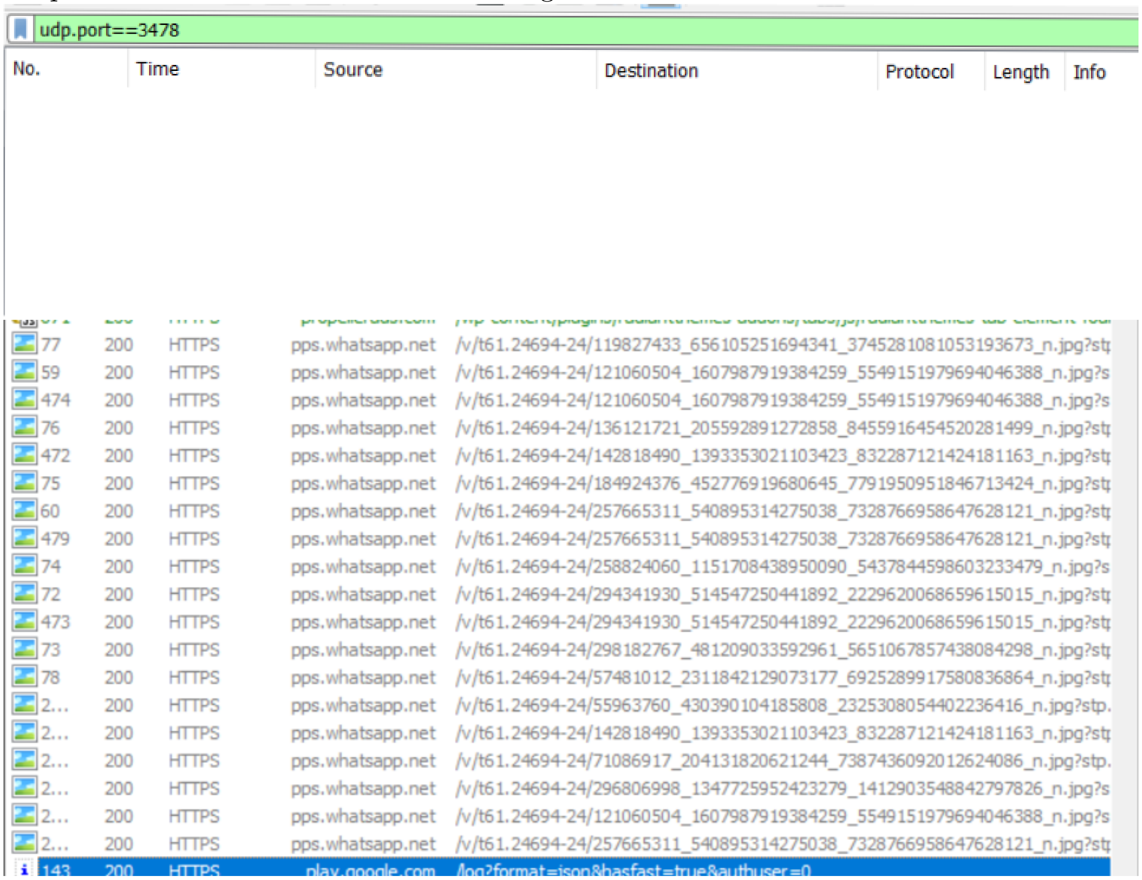
Popular IM applications like Telegram, WhatsApp, and Signal deploy encryption (either end-to-end or end-to-middle). WhatsApp calls are using only UDP and TCP, an analysis about the collected traffic can be collected and categorized. [SSA19]

We used WhatsApp online app and windows version and we tracked the both on Wireshark and Fiddler. The paper has identified TCP ports 443, 4244, 5222, 5223, 5228, 5242 and UDP ports 3478. We have used Fiddler Classic packet sniffer to obtain the SSL handshake for WhatsApp at TCP port 443. We have obtain the same results on Wireshark. UDP packets always contact STUN servers which are:

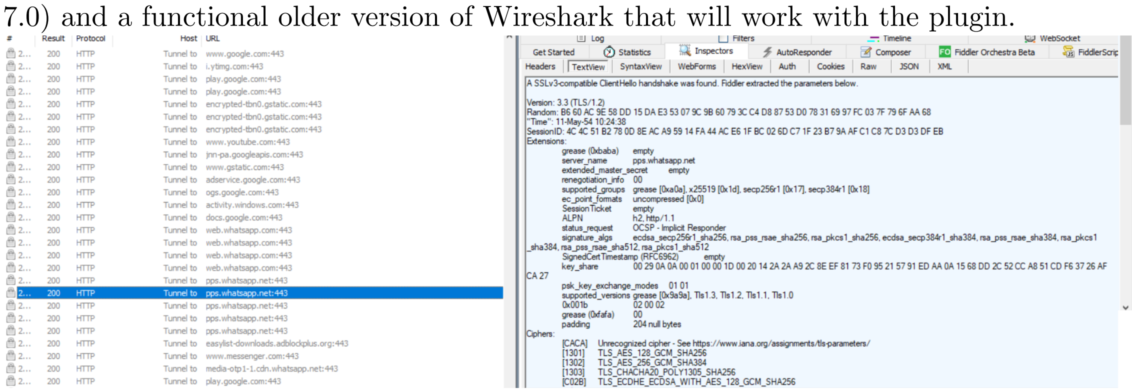
- 31.13.78.51
- 31.13.79.52
- 157.240.7.51
- 157.240.13.51
- 157.240.16.51
- 157.240.23.52

3.1.2 Surfshark Results

No packets were found for UDP after using Wireshark.



We have listen to port 443 on TCP using Fiddler and found the handshake for a WhatsApp conversation. It used to be possible to track a conversation and decrypt messages if one of the recipients used their secret in a Wireshark plugin located at this address: https://github.com/davidgfnet/wireshark-whatsapp We need a lower android version (under 7.0) and a functional older version of Wireshark that will work with the plugin.



3.1.3 Signal

Traffic analysis of the Signal app can be tried by incorporating the firewall approach for the investigation. The firewall helps to understand the pattern of connectivity and communication activities, forcing the Signal client to connect to its server in a controlled environment to reveal the obscured design of Signal app. [AHS+21]

3.1.4 Surfshark Results

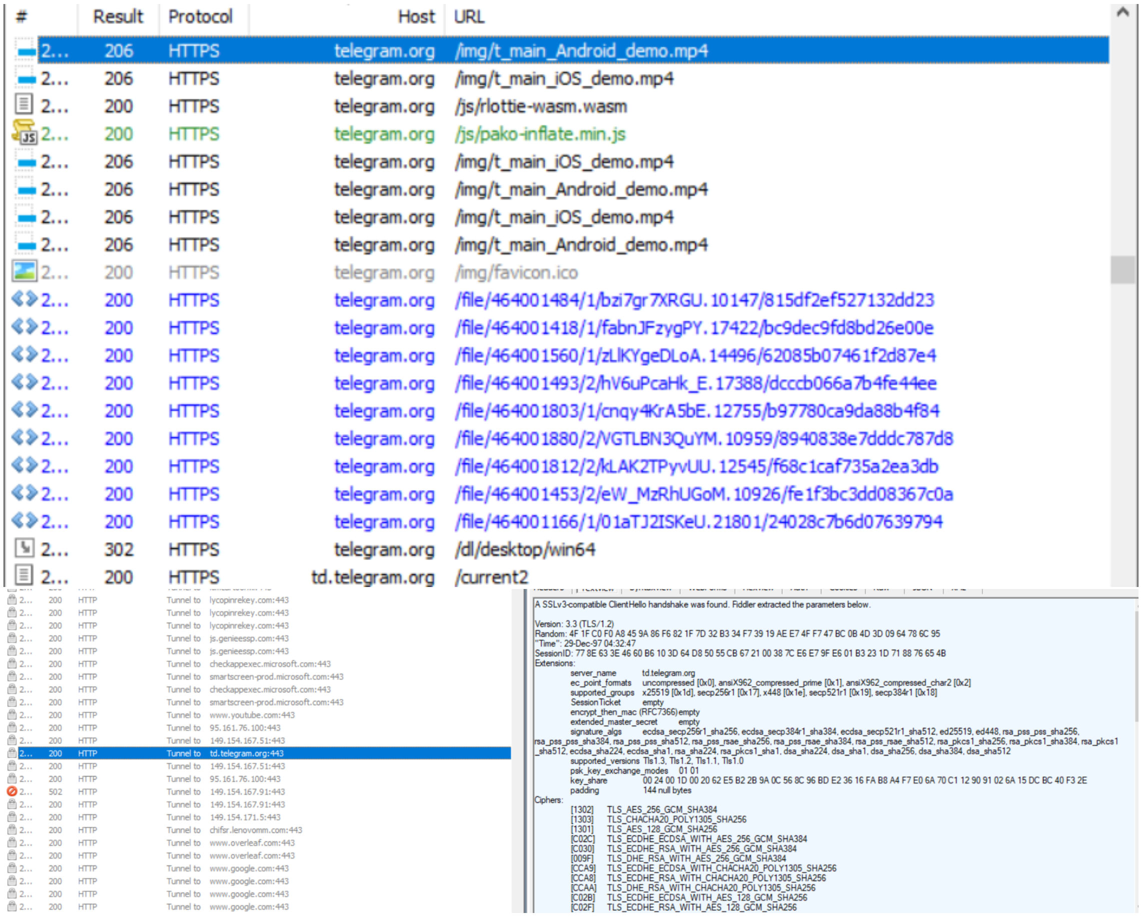
No.	Time	Source	Destination	Protocol	Length	Info
18681	347.703456	44.[redacted].247	192.1[redacted]116	TLSv1.2	105	Change Cipher Spec, Encrypted Handshake Message
18682	347.706349	192[redacted]116	44.21[redacted].247	TLSv1.2	699	Application Data
18683	347.706393	192[redacted]116	44.21[redacted].247	TLSv1.2	953	Application Data
18685	347.835925	44.[redacted].247	192.1[redacted]116	TLSv1.2	264	Application Data
18703	349.244253	192[redacted]116	13.24[redacted].111	TLSv1.2	115	Application Data
18708	349.408549	13.[redacted].111	192.1[redacted]116	TLSv1.2	116	Application Data
18841	358.989003	192[redacted]116	34.21[redacted].155	TLSv1.2	96	Application Data
18844	359.186801	34.[redacted].155	192.1[redacted]116	TLSv1.2	92	Application Data
18848	359.380713	192[redacted]116	20.19[redacted].182	TLSv1.2	157	Application Data
18850	359.453181	20.[redacted].182	192.1[redacted]116	TLSv1.2	227	Application Data
18861	359.845896	34.[redacted]64	192.1[redacted]116	TLSv1.2	81	Application Data
18862	359.846428	192[redacted]116	34.12[redacted]64	TLSv1.2	85	Application Data
18992	365.734037	192[redacted]116	13.24[redacted].111	TLSv1.2	115	Application Data
18999	365.862097	13.[redacted].111	192.1[redacted]116	TLSv1.2	207	Application Data
19065	370.969575	192[redacted]116	162.2[redacted]7.54	TLSv1.2	110	Application Data
19099	373.541956	192[redacted]116	52.2[redacted].136	TLSv1.2	317	Application Data
19413	395.862665	192[redacted].116	13.2[redacted].111	TLSv1.2	115	Application Data
19414	395.989493	13.[redacted]2.111	192.[redacted]16	TLSv1.2	207	Application Data
19415	395.991055	192[redacted].116	104.[redacted]3	TCP	55	[TCP Keep-Alive] 61932 → 443 [ACK] Seq=556 Ack=5663 Win=64257 Len=1
19416	396.003565	104[redacted]43	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61932 [ACK] Seq=5663 Ack=557 Win=63986 Len=0 SLE=556 SRE=557
19417	396.030071	192[redacted].116	13.2[redacted].111	TCP	54	61922 → 443 [ACK] Seq=2633 Ack=6298 Win=64188 Len=0
19418	396.186313	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61929 → 443 [ACK] Seq=14805 Ack=4188849 Win=64800 Len=1
19419	396.189200	192[redacted].116	142.[redacted]0.211	TCP	55	[TCP Keep-Alive] 61931 → 443 [ACK] Seq=1231 Ack=4317 Win=64952 Len=1
19420	396.194076	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61928 → 443 [ACK] Seq=18105 Ack=4300876 Win=63670 Len=1
19421	396.204940	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61929 [ACK] Seq=4188849 Ack=14806 Win=65535 Len=0 SLE=14805 SRE=14806
19422	396.205085	142[redacted]80.211	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61931 [ACK] Seq=4317 Ack=1232 Win=65535 Len=0 SLE=1231 SRE=1232
19423	396.208594	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61928 [ACK] Seq=4300876 Ack=18106 Win=65535 Len=0 SLE=18105 SRE=18106
19424	396.338632	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61926 → 443 [ACK] Seq=25701 Ack=5971068 Win=64800 Len=1
19425	396.353285	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61926 [ACK] Seq=5971068 Ack=25702 Win=65535 Len=0 SLE=25701 SRE=25702
19426	396.771954	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61930 → 443 [ACK] Seq=817 Ack=1555 Win=64800 Len=1
19427	396.784166	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61930 [ACK] Seq=1555 Ack=818 Win=65535 Len=0 SLE=817 SRE=818
19428	397.004392	192[redacted].116	104.[redacted]3	TCP	55	[TCP Keep-Alive] 61932 → 443 [ACK] Seq=556 Ack=5663 Win=64257 Len=1
19429	397.016834	104[redacted]43	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61932 [ACK] Seq=5663 Ack=557 Win=63986 Len=0 SLE=556 SRE=557
19430	397.206344	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61929 → 443 [ACK] Seq=14805 Ack=4188849 Win=64800 Len=1
19431	397.206344	192[redacted].116	142.[redacted]0.211	TCP	55	[TCP Keep-Alive] 61931 → 443 [ACK] Seq=1231 Ack=4317 Win=64952 Len=1
19432	397.209191	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61928 → 443 [ACK] Seq=18105 Ack=4300876 Win=63670 Len=1
19433	397.219914	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61929 [ACK] Seq=4188849 Ack=14806 Win=65535 Len=0 SLE=14805 SRE=14806
19434	397.226971	142[redacted]80.211	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61931 [ACK] Seq=4317 Ack=1232 Win=65535 Len=0 SLE=1231 SRE=1232
19435	397.228393	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61928 [ACK] Seq=4300876 Ack=18106 Win=65535 Len=0 SLE=18105 SRE=18106
19436	397.353703	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61926 → 443 [ACK] Seq=25701 Ack=5971068 Win=64800 Len=1
19437	397.365694	54.[redacted]5.13	192.[redacted]116	TCP	66	[TCP Keep-Alive ACK] 443 → 61926 [ACK] Seq=5971068 Ack=25702 Win=65535 Len=0 SLE=25701 SRE=25702
19438	397.785581	192[redacted].116	54.1[redacted].13	TCP	55	[TCP Keep-Alive] 61930 → 443 [ACK] Seq=817 Ack=1555 Win=64800 Len=1

3.1.5 Telegram

Specifically, we will talk about surveillance parties that are capable of identifying members of target instant messaging communications (e.g., politically sensitive IM channels) with very high accuracies, and by only using low-cost traffic analysis techniques. [BSH+20]

3.1.6 Surfshark Results

We succeeded in capturing the SSL handshake and public images from telegram. It uses the same port as Whatsapp on TCP:443.



4 Conclusion

In summary, Signal is generally considered to have the strongest security features and encryption among the three, followed by WhatsApp, and Telegram. However, it's important to consider other factors such as user base, data collection and usage policies, and other feature when making a decision on which app to use.

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