



# WhatsApp Encryption Overview

Technical white paper

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# Messaging Security

## Introduction

This white paper provides a technical explanation of WhatsApp's end-to-end encryption system. Please visit WhatsApp's website at [www.whatsapp.com/security](http://www.whatsapp.com/security) for more information.

WhatsApp Messenger allows people to exchange messages (including chats, group chats, images, videos, voice messages and files), share status posts, and make WhatsApp calls around the world. WhatsApp messages, voice, and video calls between a sender and receiver that use WhatsApp client software use the Signal protocol outlined below. See "Defining End-to-End Encryption" for information about which communications are end-to-end encrypted.

The Signal Protocol, designed by Open Whisper Systems, is the basis for WhatsApp's end-to-end encryption. This end-to-end encryption protocol is designed to prevent third parties and WhatsApp from having plaintext access to messages or calls. Due to the ephemeral nature of the cryptographic keys, even in a situation where the current encryption keys from a user's device are physically compromised, they cannot be used to decrypt previously transmitted messages.

A user can have multiple devices, each with its own set of encryption keys. If the encryption keys of one device are compromised, an attacker cannot use them to decrypt the messages sent to other devices, even devices registered to the same user. WhatsApp also uses end-to-end encryption to encrypt the message history transferred between devices when a user registers a new device.

This document gives an overview of the Signal Protocol and its use in WhatsApp.

## Terms

### Device Types

- Primary device - A device that is used to register a WhatsApp account with a phone number. Each WhatsApp account is associated with a single primary device. This primary device can be used to link additional companion devices to the account. Supported primary device platforms include Android and iPhone.
- Companion device - A device that is linked to an existing WhatsApp account by the account's primary device. Primary device platforms, such as iPhone and Android, do not support being linked as a Companion device.

## Public Key Types

- Identity Key Pair – A long-term Curve25519 key pair, generated at install time.
- Signed Pre Key – A medium-term Curve25519 key pair, generated at install time, signed by the Identity Key, and rotated on a periodic timed basis.
- One-Time Pre Keys – A queue of Curve25519 key pairs for one time use, generated at install time, and replenished as needed.

## Session Key Types

- Root Key – A 32-byte value that is used to create Chain Keys.
- Chain Key – A 32-byte value that is used to create Message Keys.
- Message Key – An 80-byte value that is used to encrypt message contents. 32 bytes are used for an AES-256 key, 32 bytes for a HMAC-SHA256 key, and 16 bytes for an IV.

## Other Key Types

- Linking Secret Key - A 32-byte value that is generated on a companion device and must be passed by a secure channel to the primary device, used to verify an HMAC of the linking payload received from a primary device. The transmission of this key from companion devices to the primary device is done by scanning a QR code.

## Companion Linking

- Linking Metadata - An encoded blob of metadata assigned to a companion device during linking, used in conjunction with the companion device's Identity Key to identify a linked companion on WhatsApp clients.
- Signed Device List Data - An encoded list identifying the currently linked companion devices at the time of signing. Signed by the primary device's Identity Key using the 0x0602 prefix.
- Account Signature - A Curve25519 signature computed over the 0x0600 prefix, Linking Metadata, and companion device's public Identity Key using a primary device's Identity Key.
- Device Signature - A Curve25519 signature computed over the 0x0601 prefix, Linking Metadata, companion device's public Identity Key, and primary's devices public Identity Key using a companion device's Identity Key.

# Client Registration

## Primary Device Registration

At registration time, a WhatsApp client transmits its public Identity Key, public Signed Pre Key (with its signature), and a batch of public One-Time Pre Keys to the server. The WhatsApp server stores these public keys associated with the user's identifier.

## Companion Device Registration

To link a companion device to a WhatsApp account, the user's primary device must first create an Account Signature by signing the new device's public Identity Key and the companion device must create a Device Signature by signing the primary's public Identity Key. Once both signatures are produced, end-to-end encrypted sessions can be established with the companion device.

To link a companion device:

1. The companion client displays its public Identity Key ( $I_{companion}$ ) and a generated ephemeral Linking Secret Key ( $L_{companion}$ ) in a linking QR code.  $L_{companion}$  is never sent to WhatsApp server.
2. The primary client scans the linking QR code and saves  $I_{companion}$  to disk.
3. The primary loads its own Identity Key as  $I_{primary}$ .
4. The primary generates Linking Metadata as  $L_{metadata}$  and updated Device List Data containing the new companion as  $ListData$ .
5. The primary generates an Account Signature for the companion,  $A_{signature} = \text{CURVE25519\_SIGN}(I_{primary}, 0x0600 || L_{metadata} || I_{companion})$ .
6. The primary generates a Device List Signature for the updated Device List Data,  $ListSignature = \text{CURVE25519\_SIGN}(I_{primary}, 0x0602 || ListData)$ .
7. The primary serializes the Linking Data ( $L_{data}$ ) containing  $L_{metadata}$ ,  $I_{primary}$  and  $A_{signature}$ .
8. The primary generates a Linking HMAC,  $\text{PHMAC} = \text{HMAC-SHA256}(L_{companion}, L_{data})$ .
9. The primary sends  $ListData$ ,  $ListSignature$ ,  $L_{data}$  and  $\text{PHMAC}$  to WhatsApp server. See "Transport Security" for information about the secure connection between WhatsApp clients and servers.
10. The server stores  $ListData$  and  $ListSignature$ , and forwards  $L_{data}$  and  $\text{PHMAC}$  to the companion.

11. The companion verifies PHMAC, decodes  $L_{metadata}$  into  $L_{metadata}$ ,  $I_{primary}$  and  $A_{signature}$ , and verifies  $A_{signature}$ .
12. The companion saves  $L_{metadata}$  and  $I_{primary}$  to disk.
13. The companion generates a Device Signature for itself,  $D_{signature} = \text{CURVE25519\_SIGN}(I_{companion}, 0x0601 || L_{metadata} || I_{companion} || I_{primary})$ .
14. The companion uploads  $L_{metadata}$ ,  $A_{signature}$ ,  $D_{signature}$ ,  $I_{companion}$ , the companion's public Signed Pre Key (with its signature), and a batch of public One-Time Pre Keys to WhatsApp server.
15. The server stores the uploaded data associated with the user's identifier combined with a device specific identifier.

## Initiating Session Setup

In order for WhatsApp users to communicate with each other securely and privately, the sender client establishes a pairwise encrypted session with each of the recipient's devices. Additionally, the sender client establishes a pairwise encrypted session with all other devices associated with the sender account. Once these pairwise encrypted sessions have been established, clients do not need to rebuild new sessions with these devices unless the session state is lost, which can be caused by an event such as an app reinstall or device change.

WhatsApp uses this "client-fanout" approach for transmitting messages to multiple devices, where the WhatsApp client transmits a single message  $N$  number of times to  $N$  number of different devices. Each message is individually encrypted using the established pairwise encryption session with each device.

To establish a session:

1. The initiating client ("initiator") requests the public Identity Key, public Signed Pre Key, and a single public One-Time Pre Key for each device of the recipient and each additional device of the initiating user (excluding the initiator).
2. The server returns the requested public key values. A One-Time Pre Key is only used once, so it is removed from server storage after being requested. If the recipient's latest batch of One-Time Pre Keys has been consumed and the recipient has not replenished them, no One-Time Pre Key will be returned. Additionally, for each companion device (for both the initiator's account and the recipient's), the server also returns the Linking Metadata ( $L_{metadata}$ ), Account Signature ( $A_{signature}$ ) and Device signature ( $D_{signature}$ ) that was uploaded by the companion device when linked.
3. For every returned key set for a companion device, the initiator needs to verify  $A_{signature}$  by  $\text{CURVE25519\_VERIFY\_SIGNATURE}(I_{primary}, 0x0600 || L_{metadata} || I_{companion})$ , and  $D_{signature}$  by  $\text{CURVE25519\_VERIFY\_SIGNATURE}(I_{companion}, 0x0601 || L_{metadata} || I_{companion})$

$I_{primary} \parallel I_{primary})$ . If any of the verification fails for a companion device, the initiator terminates the encryption session building process immediately and will not send any messages to that device.

After getting the keys from server and verifying each device identity, the initiator starts to establish the encryption session with each individual device:

1. The initiator saves the recipient's Identity Key as  $I_{recipient}$ , the Signed Pre Key as  $S_{recipient}$ , and the One-Time Pre Key as  $O_{recipient}$ .
2. The initiator generates an ephemeral Curve25519 key pair,  $E_{initiator}$ .
3. The initiator loads its own Identity Key as  $I_{initiator}$ .
4. The initiator calculates a master secret as  $master\_secret = ECDH(I_{initiator}, S_{recipient}) \parallel ECDH(E_{initiator}, I_{recipient}) \parallel ECDH(E_{initiator}, S_{recipient}) \parallel ECDH(E_{initiator}, O_{recipient})$ . If there is no One Time Pre Key, the final ECDH is omitted.
5. The initiator uses HKDF to create a Root Key and Chain Keys from the  $master\_secret$ .

## Receiving Session Setup

After building a long-running encryption session, the initiator can immediately start sending messages to the recipient, even if the recipient is offline.

Until the recipient responds, the initiator includes the information (in the header of all messages sent) that the recipient requires to build a corresponding session. This includes the initiator's ( $E_{initiator}$  and  $I_{initiator}$ ). Additionally, if the initiator is a companion device, it also includes its  $I_{primary}$ ,  $L_{metadata}$ ,  $A_{signature}$  and  $D_{signature}$ .

When the recipient receives a message that includes session setup information:

1. If the sender is a companion device, the recipient needs to verify  $A_{signature}$  by  $CURVE25519\_VERIFY\_SIGNATURE(I_{primary}, 0x0600 \parallel L_{metadata} \parallel I_{companion})$ , and  $D_{signature}$  by  $CURVE25519\_VERIFY\_SIGNATURE(I_{companion}, 0x0601 \parallel L_{metadata} \parallel I_{companion} \parallel I_{primary})$ . If any of the verifications fail, the receiver stops building the encryption session and rejects the message from that sender device.
2. The recipient calculates the corresponding  $master\_secret$  using its own private keys and the public keys advertised in the header of the incoming message.
3. The recipient deletes the One-Time Pre Key used by the initiator.
4. The initiator uses HKDF to derive a corresponding Root Key and Chain Keys from the  $master\_secret$ .

## Exchanging Messages

Once a session has been established, clients exchange messages that are protected with a Message Key using AES256 in CBC mode for encryption and HMAC-SHA256 for authentication. The client uses client-fanout for all the exchanged messages, which means each message is encrypted for each device with the corresponding pairwise session.

The Message Key changes for each message transmitted, and is ephemeral, such that the Message Key used to encrypt a message cannot be reconstructed from the session state after a message has been transmitted or received.

The Message Key is derived from a sender's Chain Key that "ratchets" forward with every message sent. Additionally, a new ECDH agreement is performed with each message roundtrip to create a new Chain Key. This provides forward secrecy through the combination of both an immediate "hash ratchet" and a round trip "DH ratchet."

### Calculating a Message Key from a Chain Key

Each time a new Message Key is needed by a message sender, it is calculated as:

1. Message Key = HMAC-SHA256(Chain Key, 0x01).
2. The Chain Key is then updated as Chain Key = HMAC-SHA256(Chain Key, 0x02).

This causes the Chain Key to "ratchet" forward, and also means that a stored Message Key can't be used to derive current or past values of the Chain Key.

### Calculating a Chain Key from a Root Key

Each time a message is transmitted, an ephemeral Curve25519 public key is advertised along with it. Once a response is received, a new Chain Key and Root Key are calculated as:

1. ephemeral\_secret = ECDH(Ephemeral<sub>sender</sub>, Ephemeral<sub>recipient</sub>).
2. Chain Key, Root Key = HKDF(Root Key, ephemeral\_secret).

A chain is only ever used to send messages from one user, so message keys are not reused. Because of the way Message Keys and Chain Keys are calculated, messages can arrive delayed, out of order, or can be lost entirely without any problems.

## In Chat Device Consistency

In end-to-end encrypted chats, for each outgoing message to a pairwise encryption session, including those sent during session setup, the sender includes information about the list of the sender and receiver's devices inside the encrypted payload. This information includes:

1. The timestamp of the sender's most recent Signed Device List
2. A flag indicating whether the sender has any companion devices currently linked
3. The timestamp of the recipient's most recent Signed Device List
4. A flag indicating whether the recipient has any known linked companion devices

When performing “client-fanout” to your own devices, 3 and 4 above continue to refer to the recipient of the original message.

## Transmitting Media and Other Attachments

Large attachments of any type (video, audio, images, or files) are also end-to-end encrypted:

1. The WhatsApp user's device sending a message (“sender”) generates an ephemeral 32 byte AES256 key, and an ephemeral 32 byte HMAC-SHA256 key.
2. The sender encrypts the attachment with the AES256 key in CBC mode with a random IV, then appends a MAC of the ciphertext using HMAC-SHA256.
3. The sender uploads the encrypted attachment to a blob store.
4. The sender transmits a normal encrypted message to the recipient that contains the encryption key, the HMAC key, a SHA256 hash of the encrypted blob, and a pointer to the blob in the blob store.
5. All receiving devices decrypt the message, retrieve the encrypted blob from the blob store, verify the SHA256 hash of it, verify the MAC, and decrypt the plaintext.

## Group Messages

End-to-end encryption of messages sent to WhatsApp groups utilize the established pairwise encrypted sessions, as previously described in the “Initiation Session Setup” section, to distribute the “Sender Key” component of the Signal Messaging Protocol.

When sending a message to a group for the first time, a “Sender Key” is generated and distributed to each member device of the group, using the pairwise encrypted sessions. The message content is encrypted using the “Sender Key”, achieving an efficient and secure fan-out for the messages that are sent to groups.

The first time a WhatsApp group member sends a message to a group:

1. The sender generates a random 32-byte Chain Key.
2. The sender generates a random Curve25519 Signature Key key pair.
3. The sender combines the 32-byte Chain Key and the public key from the Signature Key into a Sender Key message.
4. The sender individually encrypts the Sender Key to each member of the group, using the pairwise messaging protocol explained previously.

For all subsequent messages to the group:

1. The sender derives a Message Key from the Chain Key, and updates the Chain Key.
2. The sender encrypts the message using AES256 in CBC mode.
3. The sender signs the ciphertext using the Signature Key.
4. The sender transmits the single ciphertext message to the server, which does server-side fan-out to all group participants.

The “hash ratchet” of the message sender’s Chain Key provides forward secrecy. Whenever a group member leaves, all group participants clear their Sender Key and start over.

In Chat Device Consistency information is included when distributing a “Sender Key” and then excluded from the subsequent messages encrypted with the Sender Key.

# Message Add-ons in Community Announcement Groups

Group members cannot send regular messages in Community Announcement Groups but are able to interact with messages such as reacting to them by sending Message Add-ons. In order to improve the performance of Community Announcement Groups we will use Add-on Sender Keys instead of traditional Group Sender Keys to encrypt the Add-ons. When an admin sends a message into a Community Announcement Group it will be encrypted with a traditional "Group Sender Key" as described in "Group Messages", the end-to-end encrypted message payload will also contain a random key "Message Secret".

End-to-end encryption of add-ons sent to WhatsApp Community Announcement Groups utilize the established pairwise encrypted sessions, as previously described in the "Initiation Session Setup" section, to distribute a dedicated "Add-on Sender Key" component of the Signal Messaging Protocol. When sending an Add-on to a Community Announcement Group for the first time, an "Add-on Sender Key" is generated and distributed to each member device of the group, using the pairwise encrypted sessions. The Add-on content is encrypted using a key derived from the target message's "Message Secret" and then encrypted again using the "Add-on Sender Key", achieving an efficient and secure fan-out for the Add-ons that are sent to Community Announcement Groups.

The first time a WhatsApp group member sends an Add-on to a Community Announcement Group::

1. The sender generates a random 32-byte Chain Key.
2. The sender generates a random Curve25519 Signature Key key pair.
3. The sender combines the 32-byte Chain Key and the public key from the Signature Key into into an Add-on Sender Key message.
4. The sender individually encrypts the Add-on Sender Key to each member of the community announcement group, using the pairwise messaging protocol explained previously.

For all Add-ons sent to a community announcement group:

1. The sender derives an encryption key from the target message's Message Secret Add-on Target Key = HKDF(length=32, key=Target Message Secret, info=Target Message Identifier || Target sender Identifier || Add-on Sender Identifier || "Add-on type string").
2. The sender then encrypts the Add-on content with Add-on Target Key using AES-256-GCM to produce inner ciphertext.
3. The sender derives a Message Key from the Chain Key, and updates the Chain Key

4. The sender encrypts the inner ciphertext using AES256 in CBC mode to produce outer ciphertext.
5. The sender signs the outer ciphertext using the Signature Key.
6. The sender transmits the single outer ciphertext Add-on message to the server, which does server-side fan-out to all group participants.

The “hash ratchet” of the Add-on sender’s Chain Key in conjunction with the target message’s message secret provides forward secrecy. Whenever a group member leaves, all Admins clear their Group Sender Key and start over. Group members, including admins, will not clear their Add-on Sender Key when a group member leaves and instead will continue to use the existing key to encrypt for the remaining participants of the group. When promoted to admin group members will generate a new regular Group Sender Key but will not update their Add-on Sender Key.

## Sender Side Backfill

As described above, in WhatsApp, because each message is encrypted for each device with the corresponding pairwise session, the sender client must specify all the destination devices at the sending time. Any device which is not listed at the sending time will not be able to receive the encrypted message. Each client maintains a list of verified companion devices for WhatsApp accounts the user communicates with, as well as all other devices associated with its own account, and uses this list to specify the destination devices at the sending time.

However, when sending a message, it is possible for a client to miss valid companion devices if its maintained device list is out-of-date. The mechanism “Sender Side Backfill” is designed so that these missed devices may recover from permanently missing the entire message. When WhatsApp receives the encrypted message from the sender, it compares the hash of all the destination devices listed by the sender, to the hash of server-side device records of these accounts. If there is a mismatch between two hash values, the server will notify the sender to update the devices list for itself and all the recipient accounts. The sender client will verify all fetched new companion devices, establish the pairwise sessions with those devices using the same method described in the “Initiating Session Setup” section, encrypt and resend the original message to these new devices.

To ensure the confidentiality of the message, this backfill mechanism is only allowed within a short duration after the initial message sending. Additionally, the backfill message will never be sent to any companion device which failed the device verification. Moreover, during the backfill process, if a recipient registers on a new phone, all its companion devices will be excluded from the resending list. Therefore, the resend message will never be sent to any companion device of a recipient with a changed identity key.

## Message History Syncing

Immediately after linking a companion device, the primary device end-to-end encrypts a copy of messages from recent chats. The primary device will also include a copy of the user's stored public identity key when copying messages for one-to-one chats. This process, called Messaging History Syncing, generates bundles of the end-to-end encrypted messages and other data for the chat using the same mechanism of encryption as described in the "Transmitting Media and Other Attachments" section. Steps 1 through 5 explain the specifics regarding key, IV, mac generation, as well as the encryption, transmission, and decryption of these end-to-end encrypted bundles. Once a companion device has successfully decrypted, unpacked, and stored all the messages of a given bundle, all the associated data (including the downloaded encrypted bundle blob, the pointer to the encrypted blob storage, and all the keys) are deleted from the companion device.

## Call Setup

WhatsApp voice and video calls are end-to-end encrypted. When a WhatsApp user initiates a voice or video call:

1. The initiating client ("initiator") establishes encrypted sessions with each of the devices of the recipient (as outlined in the Initiating Session Setup Section), if these haven't been set up yet.
2. The initiator generates a set of random 32-byte SRTP master secrets for each of the recipient's devices.
3. The initiator sends an incoming call message to each of the devices of the recipient. Each recipient's device receives this message, which contains the end-to-end encrypted SRTP master secret.
4. If the responder answers the call from one of the devices, a SRTP encrypted call is started, protected by the SRTP master secret generated for that device.

The SRTP master secret is persisted in memory on the client device and used only during the call. WhatsApp servers do not have access to the SRTP master secrets.

## Group Calling

WhatsApp group calls are end-to-end encrypted. Unlike one-to-one calls that setup keys only once, in group calls, keys are reset whenever a participant joins the call or leaves the call.

Key reset in group calls is achieved by the following steps:

1. When a participant joins or leaves the call, the WhatsApp server arbitrarily selects one of the active participants as the key distributor.
2. The key distributor generates a random 32-byte SRTP master secret.
3. The key distributor establishes an encrypted session with the active device of each connected participant in the current group call (as outlined in the Initiating Session Setup Section), if these haven't been setup yet.
4. The key distributor initiates one message with end-to-end encrypted SRTP master secret for each participant. When these messages are delivered, a SRTP encrypted group call ensues.

Note that in a group call, a participant becomes active when they initiate a group call or accepts the group call invitation from any of their devices. Therefore each active participant has exactly one active device.

The SRTP master secret is persisted in-memory, and is overwritten when a new SRTP master secret is generated and delivered. To continue decrypting data encrypted with the old key while all participants transition to the new key, the old 'SRTP' crypto session is kept alive for upto 5 seconds after group update.

WhatsApp servers do not have access to them, and cannot access the actual audio and video media.

To ensure call quality and to avoid race conditions from conflicting user actions, the WhatsApp server stores the state of the current group call (for example: participant list, call initiator) and media metadata (e.g. resolution, media type). With this information, the WhatsApp server is able to broadcast participant membership changes and select one as key distributor to initiate key reset. membership changes and select one as key distributor to initiate key reset.

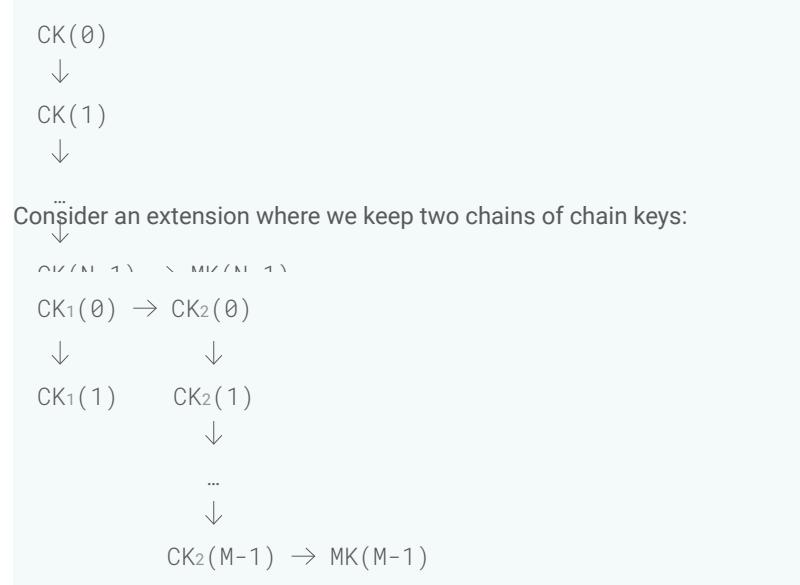
## Statuses

WhatsApp statuses are encrypted in much the same way as group messages. The first status sent to a given set of devices follows the same sequence of steps as the first time a WhatsApp group member sends a message to a group. Similarly, subsequent statuses sent to the same set of devices follow the same sequence of steps as all subsequent messages to a group. When a status sender removes a receiver either through changing status privacy settings or removing a number from their address book, the status sender clears their Sender Key and starts over.

## Live Location

Live location messages and updates are encrypted in much the same way as group messages. Currently, sending and receiving live locations is only supported on primary devices. The first live location message or update sent follows the same sequence of steps as the first time a WhatsApp group member sends a message to a group. But, live location demands a high volume of location broadcasts and updates with lossy delivery where receivers can expect to see large jumps in the number of ratchets, or iteration counts. The Signal Protocol uses a linear-time algorithm for ratcheting that is too slow for this application. This document offers a fast ratcheting algorithm to solve this problem.

Chain keys are currently one-dimensional. To ratchet  $N$  steps takes  $N$  computations. Chain keys are denoted as  $CK(\text{iteration count})$  and message keys as  $MK(\text{iteration count})$ .

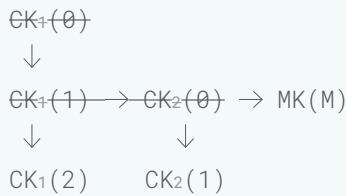


In this example, message keys are always derived from  $CK_2$ . A receiver who needs to ratchet by a large amount can skip  $M$  iterations at a time (where  $M$  is an agreed-upon constant positive integer) by ratcheting  $CK_1$  and generating a new  $CK_2$ :



A value of  $CK_2$  may be ratcheted up to  $M$  times. To ratchet  $N$  steps takes up to  $[N/M] + M$  computations.

After a sender creates a message key and encrypts a message with it, all chain keys on the path that led to its creation must be destroyed to preserve forward secrecy.



Generalizing to  $D$  dimensions, a sender can produce  $D$  initial chain keys. Each chain key but the first is derived from the preceding chain key using a distinct one-way function: these are the right-pointing arrows in the diagram above. Senders distribute all  $D$  chain keys to receivers who need them, except as noted below.

```
RNG → CK1(0) → CK2(0) → ... → CKD(0)
```

Legal values for  $D$  are positive powers of two less than or equal to the number of bits in the iteration counter: 1, 2, 4, 8, 16, and 32. Implementors select a value of  $D$  as an explicit CPU-memory (or CPU-network bandwidth) tradeoff.

If a chain key  $CK_j$  (for  $j$  in  $[1, D]$ ) has an iteration count of  $M$ , it cannot be used. This algorithm restores the chain keys to a usable state:

1. If  $j = 1$ , fail because the iteration count has reached its limit.
2. Derive  $CK_j$  from  $CK_{j-1}$ .
3. Ratchet  $CK_{j-1}$  once, recursing if necessary.

Moving from one iteration count to another never ratchets a single chain key more than  $M$  times. Therefore, no ratcheting operation takes more than  $D \times M$  steps.

Signal uses different functions for ratcheting versus message key computation, since both come from the same chain key. In this notation  $\{x\}$  refers to an array of bytes containing a single byte  $x$ .

```

    MK      = HmacSHA256(CKj(i), {1})
    CKj(i+1) = HmacSHA256(CKj(i), {2})
  
```

Each dimension must use a different function. Keys are initialized as:

```

    j = 1 : CK1(0) = RNG(32)
    j > 1 : CKj(0) = HmacSHA256(CKj-1(0), {j+1})
  
```

And ratcheted as:

```
CKj(i) = HmacSHA256(CKj(i-1), {j+1})
```

# App State Syncing Security

## Introduction

App State Syncing enables a consistent experience across devices, and is end-to-end encrypted. Prior to supporting companion devices, the WhatsApp client was the sole owner and the source of truth for all client settings and other data, referred to as App State. With the introduction of companion devices, App State is synchronized between all of the user's devices securely, using end-to-end encryption.

Example App State Syncing client settings and other data include the following:

- Chat properties, such as Muted, Pinned, Deleted
- Message properties, such as Deleted for Me, Starred
- Contact-related properties, such as contact names, broadcast list names
- Most recently used GIFs, stickers, emojis

App State does not include user messages' content, nor keys that could be used to decrypt messages, nor settings that might impact the secrecy of messages.

The synchronization of App State between a user's devices requires storage of end-to-end encrypted data on the WhatsApp server to facilitate the transmission between the different devices for the user's account. WhatsApp servers do not have access to the keys that could be used to decrypt the App State data that is stored.

A **Collection** is a representation of several use-cases that are grouped together. For example, various Chat Properties (see above) can be modelled as a single Collection. Collections are implemented as a dictionary (a set of Index-Value pairs) and are fixed to specific client versions.

Initially, Collections are empty. To modify a Collection, a client device submits a **Mutation** which either sets a new Value for a given Index (SET Mutation), or removes the pair from the Collection (REMOVE Mutation).

A group of Mutations submitted together constitute a **Patch**, which atomically changes the Collection from version N to version N + 1. The server maintains

an ordered queue of Patches (**Patch Queue**), which consists of all Patches submitted in the last X days.

A server-side process, called a **Base Roller**, periodically builds a **Snapshot** which represents the state of the Collection after applying all Patches up until and including the Patch with version N. The first Snapshot is built from the entire Patch Queue, while subsequent Snapshots are built by applying new Patches to the previous Snapshot. A Snapshot can be used to initialize a newly registered device or to optimize the data traffic by sending a Snapshot instead of the list of Patches.

App State Syncing is designed to guarantee the secrecy and integrity of the data being synchronized. The pairwise encrypted sessions (as outlined in the Initiating Session Setup Section) are used for transferring secret keys between different devices of the same account.

## Terms

- Base Key - Input key material used to generate the keys used to encrypt the data or provide its integrity.
- Index MAC Key - Key derived from the Base Key via HKDF and used to compute the HMAC of the index.
- Value Encryption Key - Key derived from the Base Key via HKDF and used to encrypt the combined Mutation index and value. The encryption is done via AES-256 in CBC mode.
- Value MAC Key - Key derived from the Base Key via HKDF and used to compute the HMAC of the combined Mutation index and value. Used on the MAC stage of Encrypt-then-MAC approach to provide authenticated encryption.
- Snapshot MAC Key - Key derived from the Base Key via HKDF and used to provide anti-tampering for Snapshots generated by Base Roller.
- Patch MAC Key - Key derived from the Base Key via HKDF and used to provide anti-tampering for Patches.
- KeyID - Unique identifier for the Base Key. Base Keys are rotated periodically and when a device is removed from the account to provide eventual future secrecy. An attacker in possession of a removed device and access to the server can no longer decrypt the content of SET Mutations submitted after the removal.
- Operation - Byte value which identifies a Mutation as SET or REMOVE.

## Encryption of Mutations

In order for Base Roller to coalesce sequences of actions to the same index, it needs the index submitted to the server to be deterministic. HMAC of the index

is used as an identifier of the index-value record the Mutations refers to. This also makes sure that the indexes that the server sees have the same length and prevent the server from guessing the record for which the Mutation is applied.

Values (together with indexes, as mentioned above) are encrypted using standard authenticated encryption (described below) with random IVs.

Combined index and value plaintext are supplemented with arbitrary length padding in order to enable some model of differential privacy on the type of the records.

1. Generate the Index MAC Key, Value Encryption Key, Value MAC Key, Snapshot MAC Key, and Patch MAC Key from Base Key by means of HKDF.
2. Compute HMAC-SHA2-256 of the index.
3. Construct the plaintext by combining Index and Value with random padding (used to obfuscate the size of the Mutation from the server).
4. Construct the associated data by concatenating Operation with KeyID.
5. Apply Encrypt-then-MAC approach with AES-256-CBC keyed by Value Encryption Key and HMAC-SHA2-512 keyed by Value MAC Key.
6. MAC computed on Step 2, ciphertext computed on Step 5, together with Operation and KeyID form an encrypted Mutation.

## Anti-Tampering

The anti-tampering mechanisms described below are designed to prevent:

- Drop, reorder, or replay Mutation within a Patch
- Drop, reorder, or replay (including a construction of new Patches) Patches within a Collection or even between the Collection
- Drop or replay Mutations within a Snapshot constructed by a Base Roller

## Snapshot Integrity

The server periodically runs a Base Roller which compacts the Patch Queue into a single Snapshot. Clients cannot predict when the Snapshot is going to be built (at the extreme the Snapshots could be built on every Patch). Thus, clients include an additional unforgeable checksum for each Patch in order to be able to verify all possible Snapshots built by the server.

Our approach relies on a homomorphic hashing algorithm called LtHash. It has the following two important properties:

- Set homomorphism: for any two disjoint sets  $S$  and  $T$ ,  $\text{LtHash}(S) + \text{LtHash}(T) = \text{LtHash}(S \cup T)$ .

- Collision resistance: it is difficult (computationally infeasible) to find two distinct sets  $S$  and  $T$  for which  $\text{LtHash}(S) = \text{LtHash}(T)$ .

A 1024-bit variant called LtHash16 and HKDF as an extensible output function (XOF) is used. For each Collection clients must maintain a 1024-bit value of LtHash16 computed over the current Snapshot of the Collection. The MAC computed over the content of plaintext index and value together with authenticated data is used as input to the LtHash.

Upon receiving or constructing a new Patch, the set homomorphism property of LtHash is used to compute the new 1024-bit value corresponding to the new state (after applying the Patch in question):

- Assume that the current value of digest is CurrentLtHash, and Patch P is being processed.
- Build a set R of MACs of previous states of all records that are affected (deleted with REMOVE or overwritten with a SET operation).
- Build a set A of MACs of all SET records (in encrypted form) in the Patch P.
- Construct NewLtHash = LtHash16Add(LtHash16Subtract(CurrentLtHash, R), A). See below on how these operations are defined.

LtHash16Add operation mentioned above is defined as follows:

```

LtHash16Add(H, A):
    R = H
    for Item in A:
        R = LtHash16AddSingle(R, Item)
    return R

LtHash16AddSingle(H, I):
    X = HKDF(1024, "WhatsApp Patch Integrity", I)
    return PointwiseAdd16(H, X)

```

where PointwiseAdd16 performs pointwise overflowing addition of two 1024-bit byte arrays interpreting them as arrays of 16-bit unsigned integers. Operation LtHash16Subtract is defined similarly to LtHash16Add replacing pointwise addition with pointwise subtraction.

Further, a MAC over the computed value of LtHash16 concatenated with 8 byte Patch version and the name of the Collection is computed:

```

SnapshotMAC = HMAC_SHA_256(
    SnapshotMACKey,
    LtHash ||
    TO_64_BIT_NETWORK_ORDER(PatchVersion) ||
    TO_UTF8(CollectionName)
)

```

## Patch Queue Integrity

To prevent tampering with content of a Patch, clients must compute the HMAC over the 32-byte MACs of each individual Mutation that is part of the Patch together with the Patch version number and Collection Name:

```

PatchMAC = HMAC_SHA_256(
    PatchMACKey,
    SnapshotMAC ||
    MutationMAC_0 ||
    MutationMAC_1 ||
    ..
    MutationMAC_N ||
    TO_64_BIT_NETWORK_ORDER(PatchVersion) ||
    TO_UTF8(CollectionName)
)

```

where MutationMAC<sub>i</sub> is the last 32 bytes of value ciphertext of Mutation #i in the Patch, and PatchVersion is the version of the Patch about to be submitted (i.e. latest known version of the Collection plus one). Note that upon receiving a Patch, the client must verify it, including the expected version of the Patch (which must match the server-assigned version).

Both values PatchMAC and SnapshotMAC are included in the Patch and submitted to the server.

## Verification

After downloading a Patch, clients must first verify its correctness by recomputing the PatchMAC and comparing it with the value included with the Patch. After that, clients verify that SnapshotMAC is correct as well by repeating the steps outlined above.

The Base Roller process on the server must preserve SnapshotMAC (and the KeyID used to generate it) of the latest Patch that was used to construct the Base Rolled Snapshot. This value is used by a client that received a Snapshot to independently verify its integrity by applying LtHash16 over all of its records and further compute the MAC as described above.

## Key Rotation

A Key Rotation involves a client randomly generating a new key tuple and broadcasting it to all other devices. In the event of Key Rotation, all future Mutations must not use any previous key version. To preserve the ability of the server to coalesce the Mutations applied to a record when updating across a key boundary, a client must submit a REMOVE Mutation with the old key and a SET Mutation (if needed) with the new key.

It is notable that a simultaneous REMOVE and SET occurring as the key version increases will be relatively easy for the server to correlate as equating to an update of the record. In collusion with anyone with access to the old key, WhatsApp would therefore be able to determine with high confidence the value of the new index; and might be able to assume that this means it has been updated.

The following two mechanisms are used to combat this:

1. Post-Rotation Update Obfuscation - When submitting a Mutation to the server, clients will use this opportunity to rotate some other number of records, ensuring that WhatsApp cannot determine which of the old indexes was being updated, and cannot directly map any of the old records to which new record represents them.
2. Asynchronous Key Catch-Up - Ensures that after a Key Rotation, there will be at some point in the future when no current records are encrypted with the preceding key(s). This means that on some cadence, clients will issue a series of SET and REMOVE to re-encrypt old records under a new key version, without updating the actual plaintext values. Catch-Up updates are indistinguishable from a logical UPDATE operation, so that the server in collusion with a removed device can never determine when an old record is being updated.

The key must be rotated whenever a device is being unregistered. Additionally, clients rotate the key periodically (for example once a month).

Each device maintains a list of the encryption keys together with additional data:

1. KeyData - Actual base key bytes
2. KeyID - ID of the key
3. Fingerprint - Data structure which identifies a list of devices existing at the moment when the key was generated (and thus was shared with)
4. Timestamp - Time when the key was created

The KeyID is composite and consists of 4 byte Epoch and 2 byte DeviceID. Epoch is selected randomly between 1 and 65536 by the primary devices during the registration of the first companion device, and after that increases by 1 every time a device rotates a key. The DeviceID component of the KeyID is used to resolve races between several devices rotating the key at the same time, so that all keys will receive unique IDs. To settle on a single key after such an event, clients prefer the key with the smallest DeviceID component when Epoch components are equal. Otherwise, always prefer the KeyID with the largest Epoch. Additionally, one (or in rare cases several) encryption keys can be active at any given time.

Key Rotation must happen under the following conditions:

- If a client detects that a previously known device was removed, it must locally mark all active encryption keys as expired.

- Upon receiving an AppStateSyncKeyShare message mark all keys with smaller Epoch as expired.
- Upon receiving a Mutation in any Collection mark all keys with a smaller Epoch as expired.
- When a client wants to submit a new Patch to the server it first must check the list of known keys. If there is one that is still active it uses it. Otherwise, it performs the Key Rotation. To rotate the key:
  1. Generate a new KeyID by concatenating DeviceID with an incremented Epoch (maximum value among all known encryption keys).
  2. Generate new key material from CSPRNG.
  3. Generate a new Fingerprint from the current registration data.
  4. Persist the key information and send it to all other devices using the corresponding pairwise encrypted sessions.
  5. Use the key to encrypt the Mutations and submit them to the server.
- In some cases, clients cannot determine whether a key is still valid based on event ordering alone. To compute whether the last known active key is valid or not, clients compare the key's Fingerprint with the current device registration data.

If a device receives a Mutation from the server and the KeyID is not known, a device can request to resend the encryption keys from other devices.

To guarantee that encryption keys are not shared with untrusted devices, all client applications only send them via authenticated pairwise encrypted sessions:

1. While performing Key Rotation, a device must send the new key to all other devices which are known to be authorized by the primary.
2. When a device receives a new key from a device which is not authorized by the primary this key is ignored.

To make sure that other devices will not inadvertently use an encryption key that should be expired on device removal, the device that performs the removal (the companion device itself or primary device) submits a Patch into all Collections marking all the current keys as expired. This Patch informs other devices that encryption keys with epoch less or equal to the provided epoch should not be used going forward.

## Verifying Keys

WhatsApp users additionally have the option to verify the keys of their devices and the devices of the users with which they are communicating in end-to-end encrypted chats, so that they are able to confirm that an unauthorized third party (or WhatsApp) has not initiated a man-in-the-middle attack. Verification can be done by scanning the QR code or by comparing the 60-digit number between two primary devices. WhatsApp users can also verify individual companion devices manually by using a primary device to check the same QR code or 60-digit number.

The QR code contains:

1. A version.
2. The user identifier for both parties.
3. The full 32-byte public Identity Key for all devices of both parties.

When either device scans the other's QR code, the keys are compared to ensure that what is in the QR code matches the Identity Key as retrieved from the server.

The 60-digit number is computed by concatenating the two 30-digit numeric fingerprints for each user's device Identity Keys. To calculate a 30-digit numeric fingerprint:

1. Lexicographically sort public Identity Keys for all of the user's devices and concatenate them.
2. Iteratively SHA-512 hash the sorted Identity Keys and user identifier 5200 times.
3. Take the first 30 bytes of the final hash output.
4. Split the 30-byte result into six 5-byte chunks.
5. Convert each 5-byte chunk into 5 digits by interpreting each 5-byte chunk as a big-endian unsigned integer and reducing it modulo 100000.
6. Concatenate the six groups of five digits into thirty digits.

## Companion Device Removal

Companion devices can log themselves out from a WhatsApp account, may be logged out by the user's primary device, or may be logged out by the WhatsApp server. When a primary device logs out or detects the log out of one or more of its companion devices, while one or more companions remain linked, it generates and uploads new Signed Device List Data removing the previously authorized device.

To update the signed device list:

7. The primary detects a device removal and loads its own Identity Key as  $I_{primary}$ .
8. The primary generates updated Device List Data containing the currently linked devices, as  $ListData$ .
9. The primary generates a Device List Signature for the updated Device List Data,  $ListSignature = CURVE25519\_SIGN(I_{primary}, 0x0602 || ListData)$ .
10. The primary sends  $ListData$  and  $ListSignature$  to WhatsApp server. See “Transport Security” for information about the secure connection between WhatsApp clients and servers.

Even if no device removal has been detected, while one or more companions remain linked, primary devices will periodically upload updated Signed Device List Data following the above steps to produce a signature with an updated timestamp.

## Signed Device List Expiry

In end-to-end encrypted chats, Signed Device Lists are expired with a Time to Live of 35 days or less. Clients will only send and receive messages and calls with the primary device of an account with an expired Signed Device List. Once an updated Signed Device List is received with a more recent timestamp, senders will once again communicate with a user’s linked companion devices.

On receipt of In Chat Device Consistency Data with an updated timestamp for the sender’s device list, receiving devices reduce the TTL of the sender’s current device list to 48 hours or less from receipt of the message. In order to maintain message reliability the reduced TTL will not be enforced until the receiving client comes online after the 48 hour window.

## Companion Device Compromise

The Time to Live of Device List Signatures, and In Chat Device Consistency revoke the associated signed device lists after 35 days and 48 hours respectively. If a companion device’s private keys become compromised the compromised device should no longer be used, and removed from the account. Devices are revoked automatically after their removal to limit the potential for a third party who compromised the device colluding with WhatsApp to continue to send and receive messages from the previously linked account. The primary device’s identity key pair can be re-generated by deleting and reinstalling WhatsApp on your primary device to revoke all devices immediately.

## Transport Security

Communication between WhatsApp clients and WhatsApp chat servers is layered within a separate encrypted channel using Noise Pipes with Curve25519, AES-GCM, and SHA256 from the Noise Protocol Framework for long running interactive connections.

This provides clients with a few nice properties:

1. Extremely fast lightweight connection setup and resume.
2. Encrypts metadata to hide it from unauthorized network observers. No information about the connecting user's identity is revealed.
3. No client authentication secrets are stored on the server. Clients authenticate themselves using a Curve25519 key pair, so the server only stores a client's public authentication key. If the server's user database is ever compromised, no private authentication credentials will be revealed.

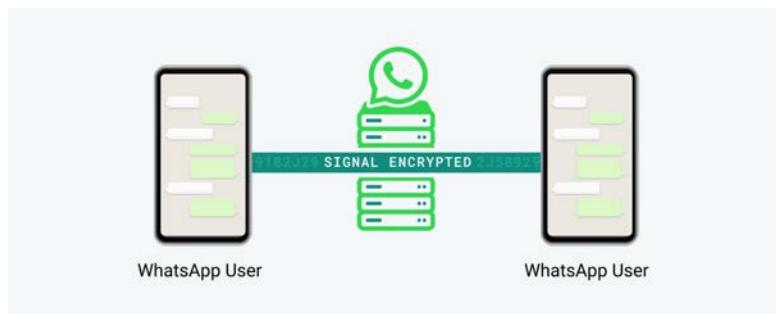
Note: In cases where a business user delegates operation of their Business API client to a vendor, that vendor will have access to their private keys - including if that vendor is Facebook. However, these private keys will still not be stored on the WhatsApp chat server. See below for details.

## Defining End-to-End Encryption

WhatsApp defines end-to-end encryption as communications that remain encrypted from a device controlled by the sender to one controlled by the recipient, where no third parties, not even WhatsApp or our parent company Facebook, can access the content in between. A third party in this context means any organization that is not the sender or recipient user directly participating in the conversation.

# Implementation on WhatsApp Services

This is straightforward when it comes to two people communicating on their phones or computers using WhatsApp Messenger or the WhatsApp Business App: each person's WhatsApp endpoint is running on a device they control.

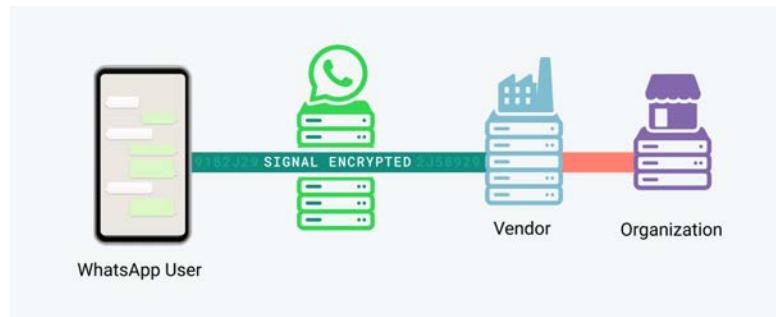


Some organizations may use the WhatsApp Business API, an application that can be deployed as a WhatsApp endpoint on a server. The Business API allows those organizations to programmatically send and receive messages.

WhatsApp considers communications with Business API users who manage the API endpoint on servers they control to be end-to-end encrypted since there is no third-party access to content between endpoints.



Some organizations may choose to delegate management of their WhatsApp Business API endpoint to a vendor. In these instances, communication still uses the same Signal protocol encryption and clients on or after version v2.31 are configured to generate private keys within the vendor-controlled API endpoint. However, because the WhatsApp Business API user has chosen a third party to manage their endpoint, WhatsApp does not consider these messages end-to-end encrypted.



In 2021, organizations who use the Business API will be able to designate WhatsApp's parent company, Facebook, as the vendor that operates the Business API endpoint on their behalf. Since such messages are not delivered directly to an endpoint controlled by the organization, WhatsApp does not consider chats with organizations who choose to use Facebook to operate their API endpoint to be end-to-end encrypted.

## Encryption Has No Off Switch

All chats use the same Signal protocol outlined in this whitepaper, regardless of their end-to-end encryption status. The WhatsApp server has no access to the client's private keys, though if a business user delegates operation of their Business API client to a vendor, that vendor will have access to their private keys - including if that vendor is Facebook.

When chatting with an organization that uses the Business API, WhatsApp determines the end-to-end encryption status based only on the organization's choice of who operates its endpoint.

The encryption status of an end-to-end encrypted chat cannot change without the change being visible to the user.

## Displaying End-to-End Encryption Status

Across all our services, WhatsApp makes the end-to-end encryption status of a chat clear. If the user's phone sees that it's communicating with an API endpoint that delegates operation of its API to a vendor, the phone will display this to the user. The user can also double check the encryption status within the chat or in the business info section of their app.

These changes will take effect in all WhatsApp versions after January 2021.

## Conclusion

All WhatsApp messages are sent with the same Signal protocol outlined above. WhatsApp considers all messages, voice calls, and video calls sent between all devices controlled by a sender user and all devices controlled by a recipient user to be end-to-end encrypted. WhatsApp message history syncing and app state syncing are also protected by end-to-end encryption. Communications with a recipient who elects to use a vendor to manage their API endpoint are not considered end-to-end encrypted. If this occurs, WhatsApp makes it clear to users within the chat.

The Signal Protocol library used by WhatsApp is based on the Open Source library, available here:

<http://github.com/whispersystems/libsignal-protocol-java/>