

A group of principals {A, B, C, ...} wish to exchange messages with assurance that when A sends a message, B promptly receives it unmodified and knows it came from A. The sender can pick any subset of the group, and that recipient list is part of the message. Anyone outside the group has no technical means to forge messages or see the content of messages, only lengths.

The principals know each other and have pairwise exchanged keys face-to-face in advance. Any existing member may add new ones, but the group is intended to stay small and fully connected. As soon as A adds D, messages from A can include D but B and C will not be able to reply to D or receive acknowledgments until they also have face-to-face meetings with D. There is no need or mechanism for revoking keys; just leave a principal off the conversation.

When A sends to B and C, A and B each expect to receive automatic acknowledgments directly from C but this may take a long time since C may be offline or C may even refuse to send acks. It is left to social pressure to police such behavior, though a simple timeout mechanism corrects for some loss of acks due to network failures.

The principals are willing to communicate, but do not totally trust each other. A good analogy would be diplomatic couriers carrying letters in sealed envelopes between possibly hostile countries. For example, A might lie to B when claiming that the message was sent to C, A might secretly send the message to D, B might publish the message, A might send different messages to B and C but pretend they are the same, and so on. If too much of this chaos were to happen in practice, a new design would be needed. The implementation tries to diagnose anomalies, to help principals distinguish technical failures from deliberate betrayals, but takes no extreme measures. This messaging might superficially resemble more advanced group communication protocols, but there is no Byzantine fault tolerance and no dependence on central servers or network properties; we only rely on the pairwise authenticated encrypted delivery and acknowledgement described above.

If an adversary corrupts one of the principals C, only old and new messages sent to C should leak. The adversary is assumed to have active control of the network and hence can prevent all message delivery by deletion or jamming, but without somehow stealing keys should not be able to selectively block individual messages. The adversary can replay messages and thereby create a bandwidth Denial of Service attack but not cause confusion at the endpoints, which discard duplicate messages automatically. Given our hypothesized untrustworthy principals, it would also be possible for A to flood B with messages that pass verification but are only designed to consume storage and screen resources; it would be prudent for the endpoint software to enforce limits against this attack. The adversary is assumed to have a moderate size quantum computer. For the sake of argument in this document, we also assume the adversary does not have physical access to endpoint devices or the supply chain and is unable to defeat emission security of the devices. This last might be the most unrealistic assumption; we make it not because we

think the threat is unimportant but only to separate a part of the work that we believe does not affect the cryptographic design.

We do not strongly conceal that A and B are communicating. In some deployments, A and B may wish to obscure how much they are communicating and the lengths of individual messages, but in this first version we do not supply background traffic generators or padding schemes or health check messages to detect jamming; senders can do that themselves. We also postpone obscuration of MAC address or OS fingerprints or other identifiers of endpoint devices.

Message bodies are either 1) UTF8 text (not necessarily English) without markup or 2) a simple JPEG. Perhaps the list of recognized formats will grow over time, but we guarantee safe delivery and display even of arbitrarily malicious messages. Messages must contain no executable content, require no complicated parsing or external inclusions, and avoid any misleading bitmap display. At the October workshop, we discussed the relative merits of text and audio/video. Obviously, interactivity and body language can help communication. But people felt that was mostly true within a single culture and that in the international situation, carefully composed and translated text is better, at least often enough to be worth this choice if it helps security. Also, the audio/video system designers said that they can have difficulties initializing or debugging, so they like the idea of a backup using pure text. Existing systems demonstrate that it would be wise to define some pre-agreed standard messages, such as the international maritime code of signals or the NATO-Russia INCSEA coded messages, which would seek to provide core pre-translated meanings to which crisis-specific additional text could be added.

Principals may be available only intermittently, so they own and operate always-on, well-connected relay devices at the network edges. Little is assumed about the network except ability to deliver ciphertext from one relay to another; there are no sessions or management systems or central servers. The relays need only provide occasional delivery of ciphertext to endpoint devices, possibly by physical delivery of storage media so that all cryptography could remain offline. To improve reliability, identical ciphertext is likely to be sent multiple times in distinct ways between relays. If A sends to B and to C, messages are separately encrypted and transmitted from A to B and from A to C, in arbitrary order. Keeping to the theme of simplicity and robustness, we do not try to optimize away this cost.

In some deployments, the principal has an attaché who carries and operates the endpoint cryptographic display device. An acknowledgment is understood to mean that the attaché has decrypted and personally read the message, but not necessarily shown it to the principal yet. The principal is encouraged to follow up promptly with an explicit reply as well, quoting a translation or paraphrase to avoid misunderstanding, even if internal thought and discussion are ongoing so that a full response is not immediately ready.

Highest priority is put on security, next is reliability, and lowest is efficiency. Messages are assumed small enough that there is no need to economize on bandwidth or processing time. We seek security through simplicity and open design. The principals are assumed to be in hostile

countries with stringent security reviews that the hotline system must pass. Context for this hotline proposal is communication between world leaders trying to avoid war. Some believe it could be part of a desperate-last-resort backup plan in NC3, but we do not even know the classified requirements for such a system, so better to leave that aside. For a purely civilian scenario, imagine a multinational enterprise incident response team in the early hours when they fear all of their existing infrastructure and credentials have been compromised. In short, the system should resist attack by very talented and well resourced adversaries.

To clarify what we mean above and to sketch how it can be implemented, we descend now into more concrete detail.

When A meets B, she sends him:

- *principal* = four byte tag, identifying A in message recipient lists
- K_{AB} = random key for encrypting messages from A to B
- *keyID* = four byte tag indicating K_{AB} is in use
- *cipher* = index into a list of approved ciphersuites and protocol versions for K_{AB}
- routing, such as IP address of a relay or HF radio broadcast plan or courier

Also, A records that K_{AB} is for sending (only) to B, and maintains a counter N_{AB} of how many plaintext bytes have been encrypted under the key, across all messages. B records his own preferred nickname for entering and displaying *principal* on his device and then sends A his own K_{BA} and other values. The *principal* tag needs to be unique among the set of (at most a few hundred) principals and never changed because it is used in stored messages. The *keyID* would not strictly need to be unique, but simplest for B if it is, so B will ask A to pick another random *keyID* in case of collision. Although none of these values is published to the world, they may be known to untrusted principals so only K_{AB} is considered an essential secret.

The default cipher is [AES-256-GCM](#). To be even more specific: we use a twelve byte nonce included as the initial part of the ciphertext and comprised of a four byte random value, the four byte *keyID*, and the four byte counter N_{AB} . The counter should be independently known by sender and recipient but if it does not match expectations in this version of the protocol we merely issue a warning. A future stricter version might declare synchronization lost and shut down all further communication. Re-keying is mandated before the counter overflows, for cryptographic reasons. Recognizing that advances in cryptography or hardware or national pride may dictate alternatives, we allow for other ciphers than AES but do not support version negotiation. The sender gets to choose, at initial key exchange, ciphers and key lengths; the recipient may refuse.

The plaintext begins with a four byte protocol identifier, a random number used to sanity check that compatible versions of the protocol are in use. Then comes a four byte message type code, such as UTF8 or JPEG or special codes to designate ack messages, discussed later. Following the type code is an eight byte "unix time" date in units of seconds, a four byte *principal* indicating the sender, a two byte count n of recipients, and n four byte fields indicating recipients. Binary integers are unsigned and in network byte order. All remaining bytes in the plaintext are message body.

The date represents time of composition rather than sending, so that the same timestamp goes to all recipients. Senders are not expected to maintain perfect clocks, but we do expect date uniqueness among a sender's messages and monotonicity consistent with the key byte counter. Implausible dates, either violating monotonicity properties or from a clock evidently off by hours or days should be flagged to recipients, for example by displaying with ??? suffix. No specific action needs to be taken by the recipient in this case, just extra skepticism.

We allocate a message type code "ack" for acknowledgments, where the message body consists of the four byte sender ID and the eight byte timestamp in the sent message. Such ack messages are individually sent to the sender and other group recipients of the original message. Note that, unlike in a previous version of this doc, there is no message content checksum, so that a suspicious sender could enable message watermarking per recipient. We accept the n^2 cost because our groups are assumed small and we seek simplicity and robustness.

Another message type code "query-ack" asks for a message acknowledgment for a specific message, as a way to deal with lost acks. Thus if A sends to B and C and only receives an ack from B, after a suitable delay A may send a query-ack to C, who will re-send an acknowledgment message to A and B or else a "negative-ack" message to A. We envision that as acks arrive, the display of messages will show check marks ✓ next to the recipient nicknames. No particular guidance is provided on the timeout for sending query-ack; ten minutes would be a plausible value, perhaps with exponential backoff. A lot of these query-ack messages may accumulate for a principal that is away for an extended period, so automated processing is essential.

We close with miscellaneous answers to frequently asked questions not covered above.

In some diplomatic situations, it matters immensely who sends the first message or places the call. Reflecting existing practice, our protocol does not attempt to fudge this but rather assumes it is handled by lower officials or by "Track 2" intermediaries. Thus it is expected that there will be several parallel hotlines or groups of principals, each group treated independently. There are conceivable technical solutions involving distributed asynchronous "ready-to-receive" protocols, but after discussion it was decided that those introduce undesirable diplomatic uncertainty and complexity. Maybe it suffices if A and B, or their bots, keep a light conversation going so the first serious message is not such a dramatic event?

There is no key renegotiation. If the byte-limit is reached or if a compromise is signalled somehow, principals have to re-establish keys from scratch in a new face-to-face meeting. That is harsh, but years of experience hardening an important identity system landing.google.com/advancedprotection taught me account recovery is the weak link. My expectation is that the aide operating the hotline endpoint for the principal, "carrying the football" in NC3 parlance, is highly professional and does not carelessly lose keys. The byte-limit is so large and messages so small that regular updates should never be needed. Just re-key every

couple years when you meet up at the UN or G7 or whatever. Frankly, my advice would be to set up more than one secure endpoint, each with its own keys, and keep the backup in a safe; only get it out for testing and in extremis. Or instead of having just one guy carrying the football, have two guys carrying independent footballs. If one is on vacation, the other will do. If one is compromised, tell all correspondents and only use the backup. Your correspondents may find it a hassle that you have more than one key, although mostly they will just be replying to a message and so I hope it is manageable. Since an Alice-Bob pairing may have more than one key, Alice may use nicknames Bob-p1 and Bob-p2. Anyway, let's not complicate the story or initial deployment with this wrinkle. Nothing in our design prevents a prudent principal from adopting the practice in later years when desired.

Sender and receiver see the same message content as a consequence of authenticated encryption, but cannot prove this to anyone else. This ability to repudiate past messages is deliberate and could be useful but is not a primary functional requirement.

As an optional protective measure, A and B may exchange revocation passphrases. If either hears such a distress passphrase anytime in the future, whether in an ordinary phone call or in a press announcement or whatever, then they know that the partner's system has been compromised; key material and messages should be erased to the extent feasible. Even the existence of these passphrases may be known only by the principals or only by the attachés. This proposal is highly tentative, as it could well lead to more harm than good through untimely catastrophic failure of the system or risk to personnel. Anyone with practical experience is especially requested to give us advice.

From our understanding of how hotlines are used, message plaintext is assumed to be retained rather than ephemeral and may be exported from the cryptographic device. Therefore the authenticated encryption should protect against known and chosen plaintext / ciphertext but does not need to provide forward secrecy. It would be possible for A and B to hash K_{AB} after each message, or use a symmetric-key ratchet, but we did not see a need. Double ratchet would not be feasible because we assume no interaction, only one-way messages with time delay.

The keyID is included in the nonce to enable endpoints to select messages intended for them from a relay that may hold messages for other endpoints as well. In principle, an endpoint could download everything and try all keys. The keyID is only meaningful to A and B and anyone doing enough traffic analysis to deduce who A and B are. The intent is that only one keyID is valid at a time for A and B. If they want to have multiple keys for redundancy, it is wiser to do that at the level of fully independent endpoint devices and independent principal tags as well. It would be possible to change the app to do more complicated key management without changing the protocol, but that invites operator error. At initial and subsequent key exchange, new key material overwrites old; obsolete keyID could appear and be ignored if old messages get replayed.

Ack messages do not themselves get ack'd. If A sends a message to B and C but never hears back from C, then A will send a query-ack. If A does get the ack from C but B does not, there is

no correction mechanism. This seemed good enough, but ought to be part of the prototype trial with real principals in made-up scenarios so we find out how much they care. The protocol does not include an automatic negative-ack mechanism, though the byte counter does make it technically possible for the endpoints to highlight some failures and let the operators clarify manually. In this, we may be showing an American bias toward two-party conversations. We need to include Europeans in our prototype trial, since they may have more nuanced views about multi-party play.

When all is working normally, at the time B first views a message sent to many principals, some recipients will have checkmarks and some not. If B views the message again tomorrow, normally almost all will have checkmarks, but perhaps not if some are off on vacation; that is taken as a mild signal that not everyone is actively in the conversation. Only if there seems to be a persistent problem would B raise the matter with A or with C or with technical advisors. It frequently seems to happen in the real world of email that months later C claims to A or B that he never saw the message. Acks help with this. Or maybe not; deniability does have its advantages.

Message acknowledgment is well known to be effectively unsolvable in the network model we have adopted. The acks here are hoped to be good enough to be useful to principals without introducing excessive complexity. Only testing will reveal if this hope is justified.

One could fairly criticize that we have documented above the easiest parts of the hotline. An associated document "hotline systems architecture" is in preparation that expands upon the plan for a very secure endpoint device (the "puck") and the plan for the relay device (the "rock") and redundant networking. As an extremely tentative hint: imagine the puck has a licensed simple RISC-V processor, maybe OpenTitan, built at an older-tech US fab. No WiFi or USB or cameras or microphones, just keyboard connector and HDMI and the ethernet that comes with that. Key exchange and communication with the rock is over CAT5. The puck will boot over eSPI from Oreboot firmware and run something like seL4 with small components on top (as in Ken Thompson's "I had a file system, all I needed to add was an editor, a compiler, and a kernel.") plus a minimal network stack, all written in Go. I think of it a bit like Qubes, only using capabilities instead of virtual machines for the isolation of network stack. There is no multi-user sharing of the puck, so side-channel protection is not a prime concern. Controlled sharing off-puck of message text is important to keep the operator from working around security; I'm going to try it with Upspin. The puck should be so small and cheap that you update it by grinding it up and getting a new one. The rock can be a more ordinary computer but uses a mix of multi-homed IP and spread spectrum digital mode terrestrial radio to get the desired network resilience. There will also need to be a design for the practical operation, testing, training, and deployment.

With existing certified-secure technology, it sometimes happens that government officials want to securely communicate with partners that they can't totally trust and their best option is to use obsolete crypto devices from years ago, still secure enough for the purpose, a bit clunky, but not a catastrophic loss if one gets into enemy hands. Because of the open source and comparatively

low cost we target, one can imagine a variant of our hotline system being able to meet that need, though wise to revisit key exchange and the lack of forward secrecy.

Comments are welcome! Please email Eric Grosse, grosse@gmail.com. This formulation of the problem and design arose primarily out of discussions with (in chronological order) Phil Reiner, Peter Hayes, John Gower, Donna Dodson, Marty Hellman, Dan Boneh, Fred Schneider, and an MIT LL team led by David A. Wilson but they do not endorse this draft and all errors are mine. In particular, the choice of GCM is controversial because of extreme care needed in implementation, and I was leaning toward ASCON-80pq but persuaded to stick with the better studied AES. I also wish to thank Deborah Gordon, Ron Minnich, Doug Randall, Devabhaktuni Srikrishna, Adam Wick and anonymous participants in the Tech4GS / Nautilus / Stanley / CISAC workshop, October 21-22 2019.