

Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: September 8, 2017

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March 7, 2017

Device Pairing Using Short Authentication Strings
draft-ietf-dnssd-pairing-01.txt

Abstract

This document proposes a device pairing mechanism that establishes a relationship between two devices by agreeing on a secret and manually verifying the secret's authenticity using an SAS (short authentication string). Pairing has to be performed only once per pair of devices, as for a re-discovery at any later point in time, the exchanged secret can be used for mutual authentication.

The proposed pairing method is suited for each application area where human operated devices need to establish a relation that allows configurationless and privacy preserving re-discovery at any later point in time. Since privacy preserving applications are the main suitors, we especially care about privacy.

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1. Introduction

To engage in secure and privacy preserving communication, hosts need to differentiate between authorized peers, which must both know about the host's presence and be able to decrypt messages sent by the host, and other peers, which must not be able to decrypt the host's messages and ideally should not be aware of the host's presence. The necessary relationship between host and peer can be established by a centralized service, e.g. a certificate authority, by a web of trust, e.g. PGP, or -- without using global identities -- by device pairing.

This document proposes a device pairing mechanism that provides human operated devices with pairwise authenticated secrets, allowing mutual automatic re-discovery at any later point in time along with mutual private authentication. We especially care about privacy and user-friendliness.

The proposed pairing mechanism consists of three steps needed to establish a relationship between a host and a peer:

1. Discovering the peer device. The host needs a means to discover network parameters necessary to establish a connection to the peer. During this discovery process, neither the host nor the peer must disclose its presence.
2. Agreeing on pairing data. The devices have to agree on pairing data, which can be used by both parties at any later point in time to generate identifiers for re-discovery and to prove the authenticity of the pairing. The pairing data can e.g. be a shared secret agreed upon via a Diffie-Hellman key exchange.
3. Authenticating pairing data. Since in most cases the messages necessary to agree upon pairing data are send over an insecure channel, means that guarantee the authenticity of these messages are necessary; otherwise the pairing data is in turn not suited as a means for a later proof of authenticity. For the proposed pairing mechanism we use manual interaction involving an SAS (short authentication string) to proof the authenticity of the pairing data.

1.1. Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

1.2. Document Organization

NOTE TO RFC EDITOR: remove or rewrite this section before publication.

This document is organized in two parts. The first part, composed of Section 1, Section 2, and Section 3 presents the pairing need, the list of requirements that shall be met, and the general design of the solution. This first part is informational in nature. The second part, composed of Section 4 and Section 5, is the actual specification of the protocol.

In his early review, Steve Kent observed that the style of the first part seems inappropriate for a standards track document, and suggested that the two parts should be split into two documents, the first part becoming an informational document, and the second focusing on standard track specification of the protocol, making reference to the informational document as appropriate. We, the authors, will seek working group approval before performing this split.

2. Problem Statement and Requirements

The general pairing requirement is easy to state: establish a trust relation between two entities in a secure manner. But details matter, and in this section we explore the detailed requirements that guide our design.

2.1. Secure Pairing Over Internet Connections

Many pairing protocols have already been developed, in particular for the pairing of devices over specific wireless networks. For example, the current Bluetooth specifications include a pairing protocol that has evolved over several revisions towards better security and usability [BTLEPairing]. The Wi-Fi Alliance defined the Wi-Fi Protected Setup process to ease the setup of security-enabled Wi-Fi networks in home and small office environments [WPS]. Other wireless standards have defined or are defining similar protocols, tailored to specific technologies.

This specification defines a pairing protocol that is independent of the underlying technology. We simply make the hypothesis that the two parties engaged in the pairing can discover each other and then establish connections over IP in order to agree on a shared secret.

[[TODO: Should we support certificates besides a shared secret?]]

2.2. Identity Assurance

The parties in the pairing must be able to identify each other. To put it simply, if Alice believes that she is establishing a pairing with Bob, she must somehow ensure that the pairing is actually established with Bob, and not with some interloper like Eve or Nessie. Providing this assurance requires designing both the protocol and the user interface (UI) with care.

Consider for example an attack in which Eve tricks Alice into engaging in a pairing process while pretending to be Bob. Alice must be able to discover that something is wrong, and refuse to establish the pairing. The parties engaged in the pairing must at least be able to verify their identities, respectively.

2.3. Adequate User Interface

Because the pairing protocol is executed without prior knowledge, it is typically vulnerable to "Man-in-the-middle" attacks. While Alice is trying to establish a pairing with Bob, Eve positions herself in the middle. Instead of getting a pairing between Alice and Bob, both Alice and Bob get paired with Eve. This requires specific features in the protocol to detect man-in-the-middle attacks, and if possible resist them. The reference [NR11] analyzes the various proposals to solve this problem, and in this document, we present a layman description of these issues in Section 2.4. The various protocols proposed in the literature impose diverse constraints on the UI interface, which we will review here.

2.3.1. Short PIN Proved Inadequate

The initial Bluetooth pairing protocol relied on a four digit PIN, displayed by one of the devices to be paired. The user would read that PIN and provide it to the other device. The PIN would then be used in a Password Authenticated Key Exchange. Wi-Fi Protected Setup [WPS] offered a similar option. There were various attacks against the actual protocol; some of the problems were caused by issues in the protocol, but most were tied to the usage of short PINs.

In the reference implementation, the PIN is picked at random by the paired device before the beginning of the exchange. But this requires that the paired device is capable of generating and displaying a four digit number. It turns out that many devices cannot do that. For example, an audio headset does not have any display capability. These limited devices ended up using static PINs, with fixed values like "0000" or "0001".

Even when the paired device could display a random PIN, that PIN will have to be copied by the user on the pairing device. It turns out that users do not like copying long series of numbers, and the usability thus dictated that the PINs be short -- four digits in practice. But there is only so much assurance as can be derived from a four digit key.

It is interesting to note that the latest revisions of the Bluetooth Pairing protocol [BTLEPairing] do not include the short PIN option anymore. The PIN entry methods have been superseded by the simple "just works" method for devices without displays, and by a procedure based on an SAS (short authentication string) when displays are available.

A further problem with these PIN based approaches is that -- in contrast to SASes -- the PIN is a secret instrumental in the security algorithm. To guarantee security, this PIN would have to be transmitted via a secure out of band channel.

2.3.2. Push Buttons Just Work, But Are Insecure

Some devices are unable to input or display any code. The industry more or less converged on a "push button" solution. When the button is pushed, devices enter a "pairing" mode, during which they will accept a pairing request from whatever other device connects to them.

The Bluetooth Pairing protocol [BTLEPairing] denotes that as the "just works" method. It does indeed work, and if the pairing succeeds the devices will later be able to use the pairing keys to authenticate connections. However, the procedure does not provide any protection against MITM attacks during the pairing process. The only protection is that pushing the button will only allow pairing for a limited time, thus limiting the opportunities of attacks.

As we set up to define a pairing protocol with a broad set of applications, we cannot limit ourselves to an insecure "push button" method. But we probably need to allow for a mode of operation that works for input-limited and display limited devices.

2.3.3. Short Range Communication

There have been several attempts to define pairing protocols that use "secure channels." Most of them are based on short range communication systems, where the short range limits the feasibility for attackers to access the channels. Example of such limited systems include for example:

- o QR codes, displayed on the screen of one device, and read by the camera of the other device.
- o Near Field Communication (NFC) systems, which provides wireless communication with a very short range.
- o Sound systems, in which one systems emits a sequence of sounds or ultrasounds that is picked by the microphone of the other system.

A common problem with these solutions is that they require special capabilities that may not be present in every device. Another problem is that they are often one-way channels. Yet another problem is that the side channel is not necessarily secret. QR codes could be read by third parties. Powerful radio antennas might be able to interfere with NFC. Sensitive microphones might pick the sounds. We will discuss the specific case of QR codes in Section 2.7.

2.3.4. Short Authentication Strings

The evolving pairing protocols seem to converge towards a "display and compare" method. This is in line with academic studies, such as [KFR09] or [USK11], and points to a very simple scenario:

1. Alice initiates pairing
2. Bob selects Alice's device from a list.
3. Alice and Bob compare displayed strings that represent a fingerprint of the key.
4. If the strings match, Alice and Bob accept the pairing.

Most existing pairing protocols display the fingerprint of the key as a 6 or 7 digit numbers. Usability studies show that this method gives good results, with little risk that users mistakenly accept two different numbers as matching. However, the authors of [USK11] found that people had more success comparing computer generated sentences than comparing numbers. This is in line with the argument in [XKCD936] to use sequences of randomly chosen common words as passwords. On the other hand, standardizing strings is more complicated than standardizing numbers. We would need to specify a list of common words, and the process to go from a binary fingerprint to a set of words. We would need to be concerned with internationalization issues, such as using different lists of words in German and in English. This could require the negotiation of word lists or languages inside the pairing protocols.

In contrast, numbers are easy to specify, as in "take a 20 bit number and display it as an integer using decimal notation".

2.4. Resist Cryptographic Attacks

It is tempting to believe that once two peers are connected, they could create a secret with a few simple steps, such as for example (1) exchange two nonces, (2) hash the concatenation of these nonces with the shared secret that is about to be established, (3) display a short authentication string composed of a short version of that hash on each device, and (4) verify that the two values match. This naive approach might yield the following sequence of messages:

Alice	Bob
g^xA -->	
	<-- g^xB
nA -->	
	<-- nB
Computes	Computes
$s = g^xAxB$	$s = g^xAxB$
$h = \text{hash}(s nA nB)$	$h = \text{hash}(s nA nB)$
Displays short	Displays short
version of h	version of h

If the two short hashes match, Alice and Bob are supposedly assured that they have computed the same secret, but there is a problem. The exchange may not deter a smart attacker in the middle. Let's redraw the same message flow, this time involving Eve:

Alice	Eve	Bob
g^xA -->		
	g^xA' -->	
		<-- g^xB
nA -->	<-- g^xB'	
	nA -->	
		<-- nB
	Picks nB' smartly <-- nB'	
Computes		Computes
$s' = g^xAxB'$		$s'' = g^xA'xB$
$h' = \text{hash}(s' nA nB')$		$h'' = \text{hash}(s'' nA nB)$
Displays short		Displays short
version of h'		version of h''

Let's now assume that, in order to pick the nonce nB' smartly, Eve runs the following algorithm:


```

s' = g^xAxB'
s" = g^xA'A'B
repeat
  pick a new version of nB'
  h' = hash(s|nA|nB')
  h" = hash(s"|nA|nB)
until the short version of h'
matches the short version of h"

```

Of course, running this algorithm will, in theory, require as many iterations as there are possible values of the short hash. But hash algorithms are fast, and it is possible to try millions of values in less than a second. If the short string is made up of fewer than 6 digits, Eve will find a matching nonce quickly, and Alice and Bob will hardly notice the delay. Even if the matching string is as long as 8 letters, Eve will probably find a value where the short versions of h' and h'' are close enough, e.g. start and end with the same two or three letters. Alice and Bob may well be fooled.

The classic solution to such problems is to "commit" a possible attacker to a nonce before sending it. This commitment can be realized by a hash. In the modified exchange, Alice sends a secure hash of her nonce before sending the actual value:

Alice	Bob
g^xA -->	<-- g^xB
Computes	Computes
$s = g^xAxB$	$s = g^xAxB$
$h_a = \text{hash}(s nA)$ -->	<-- nB
nA -->	verifies $h_a == \text{hash}(s nA)$
Computes	Computes
$h = \text{hash}(s nA nB)$	$h = \text{hash}(s nA nB)$
Displays short	Displays short
version of h	version of h

Alice will only disclose nA after having confirmation from Bob that $\text{hash}(nA)$ has been received. At that point, Eve has a problem. She can still forge the values of the nonces but she needs to pick the nonce nA' before the actual value of nA has been disclosed. Eve would still have a random chance of fooling Alice and Bob, but it will be a very small chance: one in a million if the short authentication string is made of 6 digits, even fewer if that string is longer.

Nguyen et al. [NR11] survey these protocols and compare them with respect to the amount of necessary user interaction and the computation time needed on the devices. The authors state that such a protocol is optimal with respect to user interaction if it suffices for users to verify a single b -bit SAS while having a one-shot attack success probability of 2^{-b} . Further, n consecutive attacks on the protocol must not have a better success probability than n one-shot attacks.

There is still a theoretical problem, if Eve has somehow managed to "crack" the hash function. We build some "defense in depth" by some simple measures. In the design presented above, the hash " h_a " depends on the shared secret " s ", which acts as a "salt" and reduces the effectiveness of potential attacks based on pre-computed catalogs. For simplicity, the design used a simple concatenation mechanism, but we could instead use a keyed-hash message authentication code (HMAC [RFC2104], [RFC6151]), using the shared secret as a key, since the HMAC construct has proven very robust over time. Then, we can constrain the size of the random numbers to be exactly the same as the output of the hash function. Hash attacks often require padding the input string with arbitrary data; restraining the size limits the likelihood of such padding.

2.5. Privacy Requirements

Pairing exposes a relation between several devices and their owners. Adversaries may attempt to collect this information, for example in an attempt to track devices, their owners, or their "social graph". It is often argued that pairing could be performed in a safe place, from which adversaries are assumed absent, but experience shows that such assumptions are often misguided. It is much safer to acknowledge the privacy issues and design the pairing process accordingly.

In order to start the pairing process, devices must first discover each other. We do not have the option of using the private discovery protocol [I-D.ietf-dnssd-privacy] since the privacy of that protocol depends on a pre-existing pairing. In the simplest design, one of the devices will announce a "friendly name" using DNS-SD. Adversaries could monitor the discovery protocol, and record that name. An alternative would be for one device to announce a random name, and communicate it to the other device via some private channel. There is an obvious tradeoff here: friendly names are easier to use but less private than random names. We anticipate that different users will choose different tradeoffs, for example using friendly names if they assume that the environment is "safe," and using random names in public places.

During the pairing process, the two devices establish a connection and validate a pairing secret. As discussed in Section 2.3, we have to assume that adversaries can mount MITM attacks. The pairing protocol can detect such attacks and resist them, but the attackers will have access to all messages exchanged before validation is performed. It is important to not exchange any privacy sensitive information before that validation. This includes, for example, the identities of the parties or their public keys.

2.6. Using TLS

The pairing algorithms typically combine the establishment of a shared secret through an [EC]DH exchange with the verification of that secret through displaying and comparison of a "short authentication string" (SAS). As explained in Section 2.4, the secure comparison requires a "commit before disclose" mechanism.

We have three possible designs: (1) create a pairing algorithm from scratch, specifying our own crypto exchanges; (2) use an [EC]DH version of TLS to negotiate a shared secret, export the key to the application as specified in [RFC5705], and implement the "commit before disclose" and SAS verification as part of the pairing application; or, (3) use TLS, integrate the "commit before disclose" and SAS verification as TLS extensions, and export the verified key to the application as specified in [RFC5705].

When faced with the same choice, the designers of ZRTP [RFC6189] chose to design a new protocol integrated in the general framework of real time communications. We don't want to follow that path, and would rather not create yet another protocol. We would need to reinvent a lot of the negotiation capabilities that are part of TLS, not to mention algorithm agility, post quantum, and all that sort of things. It is thus pretty clear that we should use TLS.

It turns out that there was already an attempt to define SAS extensions for TLS ([I-D.miers-tls-sas]). It is a very close match to our third design option, full integration of SAS in TLS, but the draft has expired, and there does not seem to be any support for the SAS options in the common TLS packages.

In our design, we will choose the middle ground option -- use TLS for [EC]DH, and implement the SAS verification as part of the pairing application. This minimizes dependencies on TLS packages to the availability of a key export API following [RFC5705]. We will need to specify the hash algorithm used for the SAS computation and validation, which carries some of the issues associated with "designing our own crypto". One solution would be to use the same hash algorithm negotiated by the TLS connection, but common TLS

packages do not always make this algorithm identifier available through standard APIs. A fallback solution is to specify a state of the art keyed MAC algorithm.

2.7. QR codes

In Section 2.3.3, we reviewed a number of short range communication systems that can be used to facilitate pairing. Out of these, QR codes stand aside because most devices that can display a short string can also display the image of a QR code, and because many pairing scenarios involve cell phones equipped with cameras capable of reading a QR code.

QR codes are displayed as images. An adversary equipped with powerful cameras could read the QR code just as well as the pairing parties. If the pairing protocol design embedded passwords or pins in the QR code, adversaries could access these data and compromise the protocol. On the other hand, there are ways to use QR codes even without assuming secrecy.

QR codes could be used at two of the three stages of pairing: Discovering the peer device, and authenticating the shared secret. Using QR codes provide advantages in both phases:

- o Typical network based discovery involves interaction with two devices. The device to be discovered is placed in "server" mode, and waits for requests from the network. The device performing the discovery retrieves a list of candidates from the network. When there is more than one such candidate, the device user is expected to select the desired target from a list. In QR code mode, the discovered device will display a QR code, which the user will scan using the second device. The QR code will embed the device's name, its IP address, and the port number of the pairing service. The connection will be automatic, without relying on the network discovery. This is arguably less error-prone and safer than selecting from a network provided list.
- o SAS based agreement involves displaying a short string on each device's display, and asking the user to verify that both devices display the same string. In QR code mode, one device could display a QR code containing this short string. The other device could scan it and compare it to the locally computed version. Because the procedure is automated, there is no dependency on the user diligence at comparing the short strings.

Offering QR codes as an alternative to discovery and agreement is straightforward. If QR codes are used, the pairing program on the server side might display something like:

Please connect to "Bob's phone 359"
or scan the following QR code:

```

mmmmmmmm m m mmmmmmmmm
# mmm # ## "m # mmm #
# ### # m" # " # ### #
#mmmmmm# # m m #mmmmmm#
mm m mm"## m mmm mm
" ##"mm m"# ##### "m" #
#"mmm mm# m"# " "m" "m
mmmmmmmm #mmm###mm# m
# mmm # m "mm " " "
# ### # " m # "## "#
#mmmmmm# ### m"m m m

```

If Alice's device is capable of reading the QR code, it will just scan it, establishes a connection, and run the pairing protocol. After the protocol messages have been exchanged, Bob's device will display a new QR code, encoding the hash code that should be matched. The UI might look like this:

Please scan the following QR code,
or verify that your device displays
the number: 388125

```

mmmmmmmm mmm mmmmmmmmm
# mmm # " "#m# # mmm #
# ### # "# # # ### #
#mmmmmm# # m"m #mmmmmm#
mmmmmm mmm" m m m m m
#"m mmm#"#"#"#m m#m
" "mmmmmm"m#"#"#"m # m
mmmmmmmm # "m"m "m#"#m
# mmm # mmm m "# #"
# ### # #mm#"#m "
#mmmmmm# #mm#"#"m "m"

```

Did the number match (Yes/No)?

With the use of QR code, the pairing is established with little reliance on user judgment, which is arguably safer.

2.8. Intra User Pairing and Transitive Pairing

There are two usage modes for pairing: inter-users, and intra-user. Users have multiple devices. The simplest design is to not distinguish between pairing devices belonging to two users, e.g.,

Alice's phone and Bob's phone, and devices belonging to the same user, e.g., Alice's phone and her laptop. This will most certainly work, but it raises the problem of transitivity. If Bob needs to interact with Alice, should he install just one pairing for "Alice and Bob", or should he install four pairings between Alice phone and laptop and Bob phone and laptop? Also, what happens if Alice gets a new phone?

One tempting response is to devise a synchronization mechanism that will let devices belonging to the same user share their pairings with other users. But it is fairly obvious that such service will have to be designed cautiously. The pairing system relies on shared secrets. It is much easier to understand how to manage secrets shared between exactly two parties than secrets shared with an unspecified set of devices.

Transitive pairing raises similar issues. Suppose that a group of users wants to collaborate. Will they need to set up a fully connected graph of pairings using the simple peer-to-peer mechanism, or could they use some transitive set, so that if Alice is connected with Bob and Bob with Carol, Alice automatically gets connected with Carol? Such transitive mechanisms could be designed, e.g. using a variation of Needham-Scroeder symmetric key protocol [NS1978], but it will require some extensive work. Groups can of course use simpler solution, e.g., build some star topology.

Given the time required, intra-user pairing synchronization mechanisms and transitive pairing mechanisms are left for further study.

3. Design of the Pairing Mechanism

In this section we discuss the design of pairing protocols that use manually verified short authentication strings (SAS), considering both security and user experience.

We divide pairing in three parts: discovery, agreement, and authentication, detailed in the following subsections.

3.1. Discovery

The goal of the discovery phase is establishing a connection, which is later used to exchange the pairing data, between the two devices that are about to be paired in an IP network without any prior knowledge and without publishing any private information. In accordance with TLS, we refer to the device initiating the cryptographic protocol as client, and to the other device as server; the server has to be discoverable by the client.

Granting privacy during the discovery phase without relying on prior knowledge demands another user interaction (besides the SAS verification during the authentication phase). There are two possible ways of realizing this user interaction depending on whether QR codes are supported or not. If QR codes are supported, the discovery process can be independent of DNS-SD, because QR codes allow the transmission of a sufficient amount of data. Leveraging QR codes, the discovery proceeds as follows.

1. The server displays a QR code containing the instance name, the IPv4 or IPv6 address, and the port number of the service/
2. The client scans the QR code retrieving the necessary information for establishing a connection to the server.

If QR codes are not supported, the discovery proceeds as follows.

1. The server displays its chosen instance name on its screen.
2. The client performs a discovery of all the "pairing" servers available on the local network. This may result in the discovery of several servers.
3. Among these available "pairing servers" the client's user selects the name that matches the name displayed by the server.
4. Per DNS-SD, the client then retrieves the SRV records of the selected instance, select one of the document servers, retrieves its A or AAAA records, and establishes the connection.

3.2. Agreement

Once the server has been selected, the client connects to it without further user intervention. Client and server use this connection for exchanging data that allows them to agree on a shared secret by using a cryptographic protocol that yields an SAS. We discussed design aspects of such protocols in Section 2.4.

3.3. Authentication

In the authentication phase, the users are asked to validate the pairing by comparing the SASes -- typically represented by a number encoded over up to 7 decimal digits. If the SASes match, each user enters an agreement, for example by pressing a button labeled "OK", which results in the pairing being remembered. If they do not match, each user should cancel the pairing, for example by pressing a button labeled "CANCEL".

Depending on whether QR codes are supported, the SAS may also be represented as QR code. Despite the fact that using QR codes to represent the authentication string renders using longer authentication strings feasible, we suggest to always generate an SAS during the agreement phase, because this makes realizations of the agreement phase and the authentication phase independent. Devices may display the "real" name of the other device alongside the SAS.

3.4. Public Authentication Keys

[[TODO: Should we discuss public authentication keys whose fingerprints are verified during pairing?]]

4. Solution

In the proposed pairing protocol, one of the devices acts as a "server", and the other acts as a "client". The server will publish a "pairing service". The client will discover the service instance during the discovery phase, as explained in Section 4.1. The pairing service itself is specified in Section 4.2.

4.1. Discovery

The discovery uses DNS-SD [RFC6763] over mDNS [RFC6762]. The pairing service is identified in DNS SD as "_pairing._tcp". When the pairing service starts, the server starts publishing the chosen instance name. The client will discover that name and the corresponding connection parameters.

If QR code scanning is available as OOB channel, the discovery data is directly transmitted via QR codes instead of DNS-SD over mDNS. The QR data contains connection data otherwise found in the SRV and A or AAAA records: IPv4 or IPv6 address, port number, and optionally host name.

[[TODO: We should precisely specify the data layout of this QR code. It could either be the wire format of the corresponding resource records (which would be easier for us), or a more efficient representation. If we chose the wire format, we could use a fix name as instance name.]]

4.2. Agreement and Authentication

The pairing protocol is built using TLS. The following description uses the presentation language defined in section 4 of [RFC5246]. The protocol uses five message types, defined in the following enum:


```
enum {
    ClientHash(1),
    ServerRandom(2),
    ClientRandom(3),
    ServerSuccess(4),
    ClientSuccess(5)
} PairingMessageType;
```

Devices implementing the service MUST support TLS 1.2 [RFC5246], and MAY negotiate TLS 1.3 when it becomes available. When using TLS, the client and server MUST negotiate a ciphersuite providing forward secrecy (PFS), and strong encryption (256 bits symmetric key). All implementations using TLS 1.2 MUST be able to negotiate the cipher suite TLS_DH_anon_WITH_AES_256_CBC_SHA256.

Once the TLS connection has been established, each party extracts the pairing secret S_p from the connection context per [RFC5705], using the following parameters:

Disambiguating label string: "PAIRING SECRET"

Context value: empty.

Length value: 32 bytes (256 bits).

Once S_p has been obtained, the client picks a random number R_c , exactly 32 bytes long. The client then selects a hash algorithm, which SHOULD be the same algorithm as negotiated for building the PRF in the TLS connection. If there is no suitable API to retrieve that algorithm, the client MAY use SHA256 instead. The client then computes the hash value H_c as:

$$H_c = \text{HMAC_hash}(S_p, R_c)$$

Where "HMAC_hash" is the HMAC function constructed with the selected algorithm.

The client transmits the selected hash function and the computed value of H_c in the Client Hash message, over the TLS connection:

```
struct {
    PairingMessageType messageType;
    hashAlgorithm hash;
    uint8 hashLength;
    opaque H_c[hashLength];
} ClientHashMessage;
```

messageType Set to "ClientHash".

hash The code of the selected hash algorithm, per definition of HashAlgorithm in section 7.4.1.1.1 of [RFC5246].

hashLength The length of the hash H_c, which MUST be consistent with the selected algorithm "hash".

H_c The value of the client hash.

Upon reception of this message, the server stores its value. The server picks a random number R_s, exactly 32 bytes long, and transmits it to the client in the server random message, over the TLS connection:

```
struct {  
    PairingMessageType messageType;  
    opaque R_s[32];  
} ServerRandomMessage;
```

messageType Set to "ServerRandom".

R_s The value of the random number chosen by the server.

Upon reception of this message, the client discloses its own random number by transmitting the client random message:

```
struct {  
    PairingMessageType messageType;  
    opaque R_c[32];  
} ClientRandomMessage;
```

messageType Set to "ClientRandom".

R_c The value of the random number chosen by the client.

Upon reception of this message, the server verifies that the number R_c hashes to the previously received value H_c. If the number does not match, the server MUST abandon the pairing attempt and abort the TLS connection.

At this stage, both client and server can compute the short hash SAS as:

SAS = first 20 bits of HMAC_hash(S_p, R_c + R_s)

Where "HMAC_hash" is the HMAC function constructed with the hash algorithm selected by the client in the ClientHashMessage.

Both client and server display the SAS as a decimal integer, and ask the user to compare the values. If the server supports QR codes, the server displays a QR code encoding the decimal string representation of the SAS. If the client is capable of scanning QR codes, it may scan the value and compare it to the locally computed value.

If the values do not match, the user cancels the pairing. Otherwise, the protocol continues with the exchange of names, both server and client announcing their own preferred name in a Success message

```
struct {  
    PairingMessageType messageType;  
    uint8 nameLength;  
    opaque name[nameLength];  
} ClientSuccessMessage;
```

messageType Set to "ClientSuccess" if transmitted by the client, "ServerSuccess" if by the server.

nameLength The length of the string encoding the selected name.

name The selected name of the client or the server, encoded as a string of UTF8 characters.

After receiving these messages, client and servers can orderly close the TLS connection, terminating the pairing exchange.

5. Security Considerations

We need to consider two types of attacks against a pairing system: attacks that occur during the establishment of the pairing relation, and attacks that occur after that establishment.

During the establishment of the pairing system, we are concerned with privacy attacks and with MITM attacks. Privacy attacks reveal the existence of a pairing between two devices, which can be used to track graphs of relations. MITM attacks result in compromised pairing keys. The discovery procedures specified in Section 4.1 and the authentication procedures specified in Section 4.2 are specifically designed to mitigate such attacks, assuming that the client and user are in close, physical proximity and thus a human user can visually acquire and verify the pairing information.

The establishment of the pairing results in the creation of a shared secret. After the establishment of the pairing relation, attackers who compromise one of the devices could access the shared secret. This will enable them to either track or spoof the devices. To mitigate such attacks, nodes MUST store the secret safely, and MUST

be able to quickly revoke a compromised pairing. This is however not sufficient, as the compromise of the pairing key could remain undetected for a long time. For further safety, nodes SHOULD assign a time limit to the validity of pairings, discard the corresponding keys when the time has passed, and establish new pairings.

6. IANA Considerations

This draft does not require any IANA action.

7. Acknowledgments

We would like to thank Steve Kent for a detailed early review of this document.

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