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Using Multicast DNS to protect privacy when exposing ICE candidates

Abstract

WebRTC applications collect ICE candidates as part of the process of creating peer-to-peer connections. To maximize the probability of a direct peer-to-peer connection, the endpoint's local IP addresses are included in this candidate collection. However, these addresses are typically private and, as such, their disclosure has privacy implications. This document describes a privacy-preserving way to share local IP addresses with other endpoints by concealing the addresses with dynamically generated Multicast DNS (mDNS) names.

Status of This Memo

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1. Introduction

As detailed in [IPHandling], exposing client local IP addresses by default to web applications maximizes the probability of successfully creating direct peer-to-peer connections between clients, but creates a significant surface for user fingerprinting.

[IPHandling] recognizes this issue, but also admits that there is no current solution to this problem; implementations that choose to use Mode 3 to address the privacy concerns often suffer from failing or suboptimal connections in WebRTC applications. This is particularly an issue on unmanaged networks, typically homes or small offices, where NAT loopback may not be supported.

This document proposes an overall solution to this problem by extending [ICESDP] to allow ICE implementations to register ephemeral mDNS [RFC6762] names for local IP addresses, and then provide those names, rather than the IP addresses, in their ICE candidates. While this technique is intended to benefit WebRTC implementations in web browsers, by preventing collection of private IP addresses by arbitrary web pages, it can also be used by any endpoint that wants to avoid disclosing information about its local network to remote peers on other networks.

WebRTC and WebRTC-compatible endpoints [Overview] that receive ICE candidates with mDNS names will resolve these names to IP addresses and perform ICE processing as usual. In the case where the endpoint is a web application, the WebRTC implementation will manage this resolution internally and will not disclose the actual IP addresses to the application.

While mDNS names are usually only valid within a local network, the same is true for private IP addresses, and therefore this does not limit the effectiveness of this technique.

2. Terminology

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].

3. Description

This section uses the concept of ICE agent as defined in [RFC8445]. In the remainder of the document, it is assumed that each browsing context (as defined in Section 7.1 of [HTMLSpec]) has its own ICE agent.

3.1. ICE Candidate Gathering

This section outlines how mDNS should be used by ICE agents to conceal local IP addresses.

3.1.1. Procedure

For each host candidate gathered by an ICE agent as part of the gathering process described in [RFC8445], Section 5.1.1, the candidate is handled as described below.

1. Check whether this IP address satisfies the ICE agent's policy regarding whether an address is safe to expose (typically, following the advice from Section 3.1.2.2 below). If so, expose the candidate and abort this process.

2. Check whether the ICE agent has previously generated, registered, and stored an mDNS hostname for this IP address as per steps 3 to 5. If it has, skip ahead to step 6.

3. Generate a unique mDNS hostname. The unique name MUST consist of a version 4 UUID as defined in [RFC4122], followed by ".local".

4. Register the candidate's mDNS hostname as defined in [RFC6762]. The ICE agent SHOULD send an mDNS announcement for the hostname, but as the hostname is expected to be unique, the ICE agent SHOULD skip probing of the hostname.

5. Store the mDNS hostname and its related IP address in the ICE agent for future reuse.

6. Replace the IP address of the ICE candidate with its mDNS hostname and provide the candidate to the web application.

ICE agents can implement this procedure in any way as long as it produces equivalent results. An implementation may for instance pre-register mDNS hostnames by executing steps 3 to 5 and prepopulate an ICE agent accordingly. By doing so, only step 6 of the above procedure will be executed at the time of gathering candidates.

In order to prevent web applications from using this mechanism to query for mDNS support in the local network, the ICE agent SHOULD still provide mDNS candidates in step 6 even if the local network does not support mDNS or mDNS registration fails in step 4.

This procedure ensures that an mDNS name is used to replace only one IP address. Specifically, an ICE agent using an interface with both IPv4 and IPv6 addresses MUST expose a different mDNS name for each address.

3.1.2. Implementation Guidance

3.1.2.1. Registration

Sending the mDNS announcement to the network can be delayed, for instance due to rate limits. An ICE agent SHOULD provide the candidate to the web application as soon as its mDNS name is generated, regardless of whether the announcement has been sent on the network.

3.1.2.2. Determining Address Privacy and Server-Reflexive Candidates

Naturally, an address that is already exposed to the Internet does not need to be protected by mDNS, as it can be trivially observed by the web server or remote endpoint. However, determining this ahead of time is not straightforward; while the fact that an IPv4 address is private can sometimes be inferred by its value, e.g., whether it is an [RFC1918] address, the reverse is not necessarily true. IPv6 addresses present their own complications, e.g., private IPv6 addresses as a result of NAT64 [RFC6146].

Instead, the determination of whether an address is public can be reliably made as part of the ICE gathering process. For each mDNS host candidate generated according the guidance above, the usual STUN [RFC5389] request is sent to a STUN server. This can be done for both IPv4 and IPv6 local addresses, provided that the application has configured both IPv4 and IPv6 STUN servers. If the STUN response returns the same value as the local IP address, this indicates the address is in fact public, although processing will continue as described below.

Regardless of whether the address turns out to be public or private, a server-reflexive candidate will be generated; the transport address of this candidate will be an IP address and therefore distinct from the hostname transport address of the associated mDNS candidate, and as such MUST NOT be considered redundant per the guidance in [RFC8445], Section 5.1.3. To avoid accidental IP address disclosure, this server-reflexive candidate MUST have its raddr field set to "0.0.0.0"/"::" and its rport field set to "9", as discussed in [ICESDP], Section 9.1.

Because a new candidate is always generated by the STUN query, the ICE agent SHOULD initially provide mDNS-wrapped candidates to the application and then follow with server-reflexive candidates once they are obtained, unless it has a priori knowledge that a given address is public and does not require mDNS wrapping.

To that end, once an address has been identified as public, the ICE agent MAY cache this information and skip mDNS protection for that address in future ICE gathering phases. Note that if the set of STUN

servers changes, any cached information SHOULD be discarded, as the new set may return different results.

3.1.2.3. Special Handling for IPv6 Addresses

As noted in [IPHandling], private IPv4 addresses are especially problematic because of their unbounded lifetime. However, the [RFC4941] IPv6 addresses recommended for WebRTC have inherent privacy protections, namely a short lifetime and the lack of any stateful information. Accordingly, implementations MAY choose to not conceal [RFC4941] addresses with mDNS names as a tradeoff for improved peer-to-peer connectivity.

3.1.2.4. mDNS Candidate Encoding

The mDNS name of an mDNS candidate MUST be used in the connection-address field of its candidate attribute. However, when an mDNS candidate would be the default candidate, typically because there are no other candidates, its mDNS name MUST NOT be used in the connection-address field of the SDP "c=" line, as experimental deployment has indicated that many remote endpoints will fail to handle such a SDP. In this situation, the IP address values "0.0.0.0"/"::" and port value "9" MUST instead be used in the c= and m= lines, similar to how the no-candidates case is handled in [ICESDP], Section 4.3.1.

Any candidates exposed to the application via local descriptions MUST be identical to those provided during candidate gathering (i.e., MUST NOT contain private host IP addresses).

3.2. ICE Candidate Processing

This section outlines how received ICE candidates with mDNS names are processed by ICE agents, and is relevant to all endpoints.

3.2.1. Procedure

For any remote ICE candidate received by the ICE agent, the following procedure is used:

1. If the connection-address field value of the ICE candidate does not end with ".local" or if the value contains more than one ".", then process the candidate as defined in [RFC8445].

2. If the ICE candidate policy is "relay", as defined in [JSEP], ignore the candidate.

3. Otherwise, resolve the candidate using mDNS. The ICE agent SHOULD set the unicast-response bit of the corresponding mDNS

query message; this minimizes multicast traffic, as the response is probably only useful to the querying node.

4. If it resolves to an IP address, replace the mDNS hostname of the ICE candidate with the resolved IP address and continue processing of the candidate as defined in [RFC8445].

5. Otherwise, ignore the candidate.

3.2.2. Implementation Guidance

An ICE agent may use a hostname resolver that transparently supports both Multicast and Unicast DNS. In this case the resolution of a ".local" name may happen through Unicast DNS as noted in [RFC6762], Section 3.

An ICE agent SHOULD ignore candidates where the hostname resolution returns more than one IP address.

An ICE agent MAY add additional restrictions regarding the ICE candidates it will resolve using mDNS, as this mechanism allows attackers to send ICE traffic to devices with well-known mDNS names. In particular, ICE agents SHOULD NOT resolve mDNS names if they are not in the format defined by Section 3.1.

3.3. Additional Privacy Considerations

The goal of this mechanism is to keep knowledge of private host IP addresses within the ICE agent while continuing to allow the application to transmit ICE candidates. Besides keeping private host IP addresses out of ICE candidates, implementations must take steps to prevent these IP addresses from being exposed to web applications through other means.

3.3.1. Statistics

Statistics related to ICE candidates that are accessible to the web application MUST NOT contain the IP address of a local or remote mDNS candidate; the mDNS name SHOULD be used instead.

Statistics SHOULD NOT leak whether the mDNS resolution succeeds or fails. For that reason, RTCIceCandidateStats objects as defined in [WebRTCStats] SHOULD be generated for any remote mDNS candidate submitted to the ICE agent, even if the mDNS candidate is ignored as part of Section 3.2. An implementation strategy to obfuscate the address of an mDNS candidate in the statistics, regardless if it is resolved or not, is to replace the mDNS hostname of the ICE candidate with IP values "0.0.0.0" or "::".

In addition, a peer-reflexive remote candidate may be constructed from a remote host IP address as a result of an ICE connectivity check, as described in Section 7.3.1.3 of [RFC8445]. This check may arrive before the candidate due to signaling or mDNS resolution delays, as shown in the examples above.

To prevent disclosure of the host IP address to the application in this scenario, statistics related to ICE candidates MUST NOT contain the IP address of any peer-reflexive candidate, unless that IP has already been learned through signaling of a candidate with the same address and either the same or a different port; this includes cases where the signaled candidate is discarded as redundant according to Section 5.1.3 of [RFC8445].

3.3.2. Interactions With TURN Servers

When sending data to a TURN [RFC5766] server, the sending client tells the server the destination IP and port for the data. This means that if the client uses TURN to send to an IP that was obtained by mDNS resolution, the TURN server will learn the underlying host IP and port, and this information can then be relayed to the web application, defeating the value of the mDNS wrapping.

To prevent disclosure of the host IP address to a TURN server, the ICE agent MUST NOT form candidate pairs between its own relay candidates and remote mDNS candidates. This restriction applies to all remote mDNS candidate types, not just host candidates; mDNS candidates can be clearly identified from their connection-address fields. Note also that the converse is not an issue; the ICE agent MAY form candidate pairs between its own mDNS candidates and remote relay candidates, as in this situation host IPs will not be sent directly to the TURN server.

This restriction has no effect on connectivity; in the cases where host IP addresses are private and need to be wrapped with mDNS names, they will be unreachable from the TURN server, and as noted above, the reverse path will continue to work normally.

3.3.3. Generated Name Reuse

It is important that use of registered mDNS hostnames is limited in time and/or scope. Indefinitely reusing the same mDNS hostname candidate would provide applications an even more reliable tracking mechanism than the private IP addresses that this specification is designed to hide. In the case of a web application, the use of registered mDNS hostnames SHOULD be scoped by the web application origin, and SHOULD have the lifetime of the page executing the web application.

3.3.4. Specific Browsing Contexts

As noted in [IPHandling], privacy may be breached if a web application running in two browsing contexts can determine whether it is running on the same device. While the approach in this document prevents the application from directly comparing local private IP addresses, a successful local WebRTC connection can also present a threat to user privacy. Specifically, when the latency of a WebRTC connection latency is close to zero, the probability is high that the two peers are running on the same device.

To avoid this issue, browsers SHOULD NOT register mDNS names for WebRTC applications running in a third-party browsing context (i.e., a context that has a different origin than the top-level browsing context), or a private browsing context.

3.3.5. Network Interface Enumeration

Even when local IP addresses are not exposed, the number of mDNS hostname candidates can still provide a fingerprinting dimension. This is in particular the case for network interfaces with limited connectivity that will not generate server-reflexive or relay candidates.

The more mDNS names an endpoint exposes through mDNS hostname candidates, the higher the fingerprinting risk. One countermeasure is to limit this number to a small value.

Note that no additional fingerprinting risk is introduced when restricting mDNS hostname candidates to default route only.

3.3.6. Monitoring of Sessions

A malicious endpoint in the local network may also record other endpoints who are registering, unregistering, and resolving mDNS names. By doing so, they can create a session log that shows which endpoints are communicating, and for how long. If both endpoints in the session are on the same network, the fact they are communicating can be discovered.

Mitigation of this threat is beyond the scope of this proposal.

4. Update to RFC 8839

Section 5.1 of [ICESDP] states:

> An agent generating local candidates MUST NOT use FQDN addresses. An agent processing remote candidates MUST ignore candidate lines that include candidates with FQDN or IP address versions that are not supported or recognized.

This document extends [ICESDP] to specifically allow the generation and processing of ICE candidates with the ".local" FQDNs defined in {gathering}. The restrictions on other FQDNs are unaffected.

5. Potential Limitations

5.1. Reduced Connectivity

With typical ICE, endpoints on the same network will usually be able to establish a direct connection between their local IP addresses. When using the mDNS technique, a direct connection is still possible, but only if at least one side can properly resolve the provided mDNS candidates. This may not be possible in all scenarios.

First, some networks may entirely disable mDNS. Second, mDNS queries have limited scope. On large networks, this may mean that an mDNS name cannot be resolved if the remote endpoint is too many segments away.

When mDNS fails, ICE will attempt to fall back to either NAT hairpin, if supported, or TURN relay if not. This may result in reduced connectivity, reduced throughput and increased latency, as well as increased cost in case of TURN relay.

During experimental testing of the mDNS technique across a set of known mDNS-aware endpoints that had configured a STUN server but not a TURN server, the observed impact to ICE connection rate was 2% (relative) when mDNS was enabled on both sides, compared to when mDNS was only enabled on one side. In this testing, the percentage of connections that required STUN (i.e., went through a NAT) increased from 94% to 97%, indicating that mDNS succeeded about half the time, and fell back to NAT hairpin for the remainder. The most likely explanation for the overall connection rate drop is that hairpinning failed in some cases.

5.2. Connection Setup Latency

As noted in Section 3, ICE agents using the mDNS technique are responsible for registering and resolving mDNS names as part of the ICE process. These steps may delay establishment of a direct peer-to-peer connection, compared to when raw local IP addresses are used.

Given that these mDNS registrations and queries are typically occurring on a local network, any associated delays should be small. Also, as noted in Section 3.1, pre-registration can be employed to eliminate gathering delays entirely.

5.3. Backward Compatibility

For the most part, backward compatibility does not present a significant issue for the mDNS technique. When an endpoint that supports mDNS communicates with a legacy endpoint that does not, the legacy endpoint will still provide its local IP addresses, allowing the new endpoint to attempt direct connections to those addresses. Through the process of learning peer-reflexive candidates described in [RFC8445], the legacy endpoint will also learn the IP addresses of the mDNS-aware endpoint, allowing ICE to succeed even though the legacy endpoint cannot resolve the mDNS names. In the event the legacy endpoint attempts to resolve the mDNS names using Unicast DNS, this may cause ICE to take somewhat longer to fully complete, but should not have any effect on connectivity or connection setup time.

However, some legacy endpoints are not fully spec-compliant and can behave unpredictably in the presence of ICE candidates that contain a hostname, potentially leading to ICE failure. Specifically, the SDP parsers in these endpoints may raise a fatal error when receiving such candidates, rather than simply ignoring them.

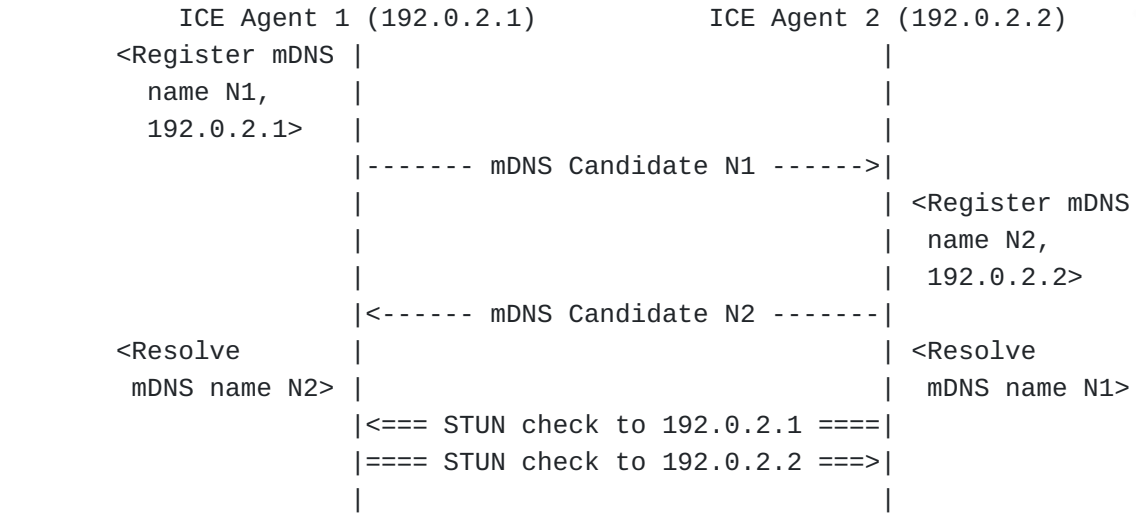
Some endpoints may also fail to handle a connectivity check from an address that they have not received in signaling (i.e., they do not support learning peer-reflexive candidates as described above), leading to ICE failure. During the aforementioned experimental testing, the connection rate when interacting with endpoints that provided raw IP addresses (and therefore should be unaffected) decreased by 3% (relative), presumably for these reasons.

6. Examples

The examples below show how the mDNS technique is used during ICE processing. The first example shows a simple case, the next two examples demonstrate how peer-reflexive candidates for local IP addresses can be created due to timing differences, and the final example shows a real-world case with IPv4, IPv6, and STUN.

6.1. Normal Handling

In this example, mDNS candidates are exchanged between peers and resolved normally to obtain the corresponding IP addresses.



The exchange of ICE candidates relies on out-of-band signaling, for example, the SDP Offer/Answer procedure defined in [ICESDP]. In the above example, the candidate attributes in the SDP messages to exchange the mDNS candidates between ICE Agent 1 and 2 are as follows:

ICE Agent 1:

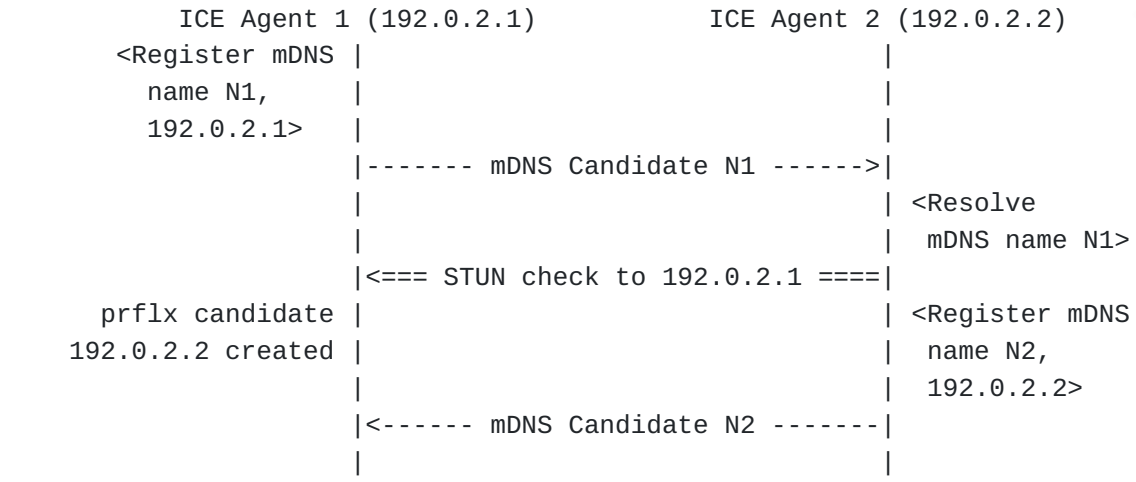
```
a=candidate:1 1 udp 2122262783 1f4712db-ea17-4bcf-a596-105139dfd8bf.loca
  54596 typ host
```

ICE Agent 2:

```
a=candidate:1 1 udp 2122262783 2579ef4b-50ae-4bfe-95af-70b3376ecb9c.loca
  61606 typ host
```

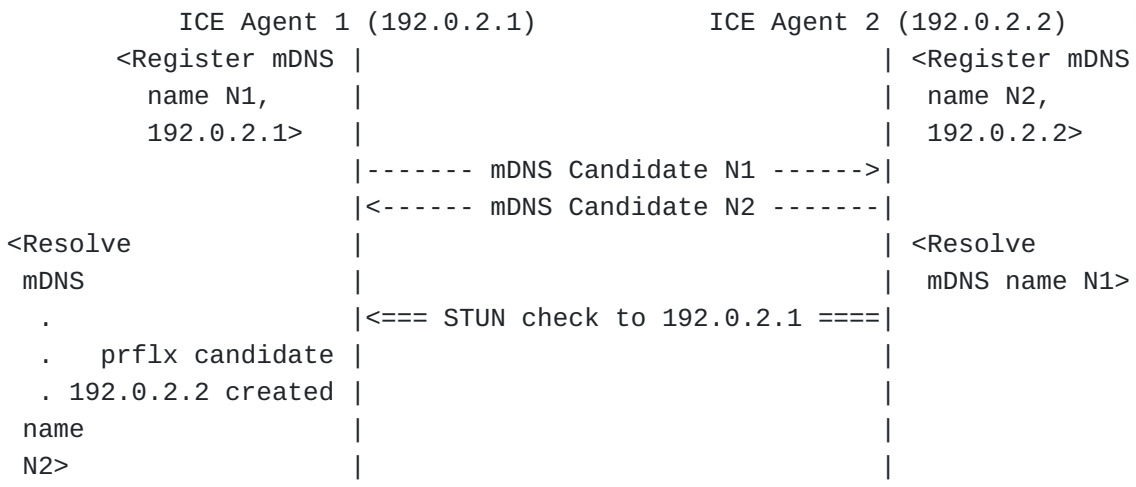
6.2. Peer-reflexive Candidate From Slow Signaling

In this example, a peer-reflexive candidate is generated because the mDNS candidate is signaled after the STUN checks begin.



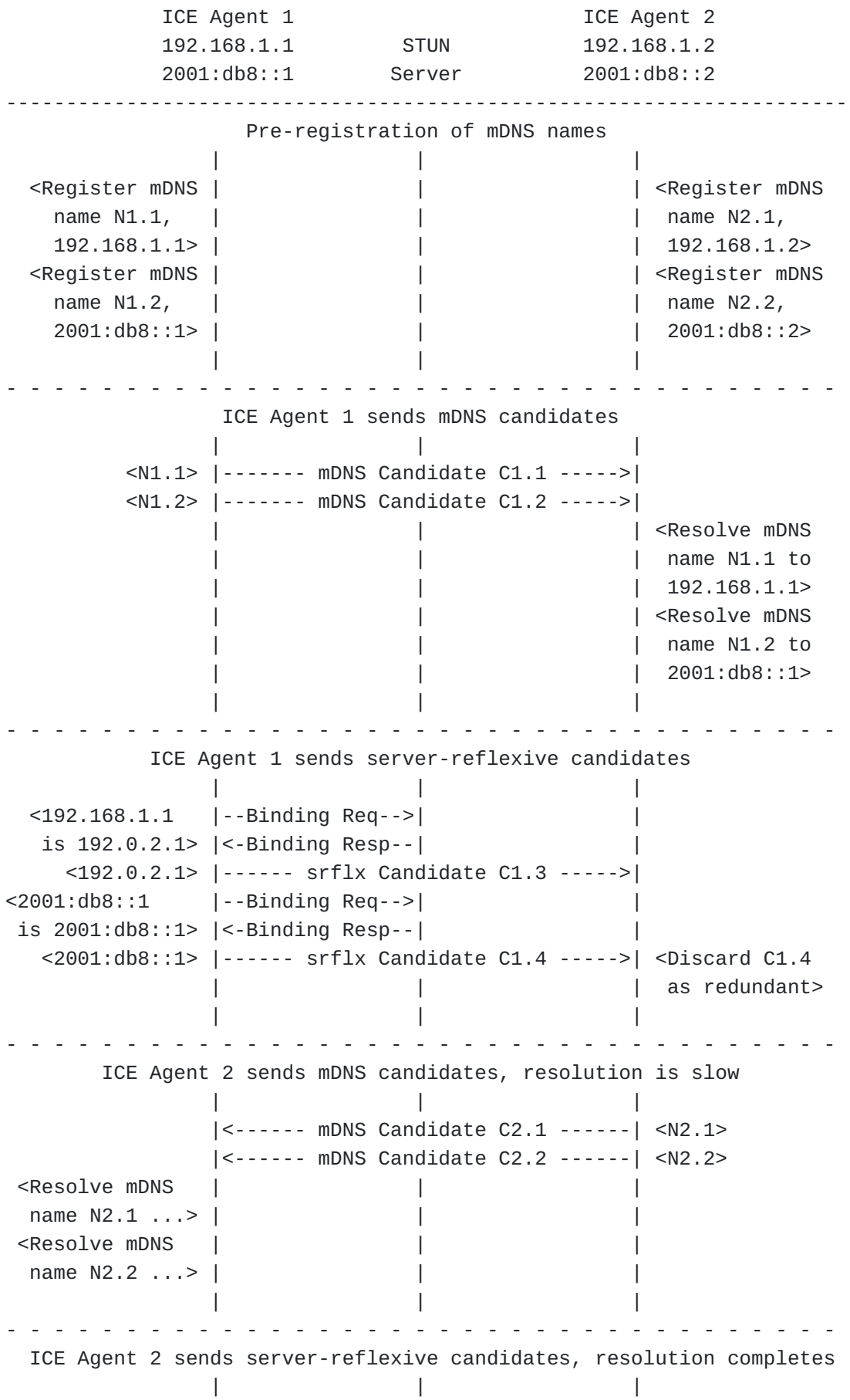
6.3. Peer-reflexive Candidate From Slow Resolution

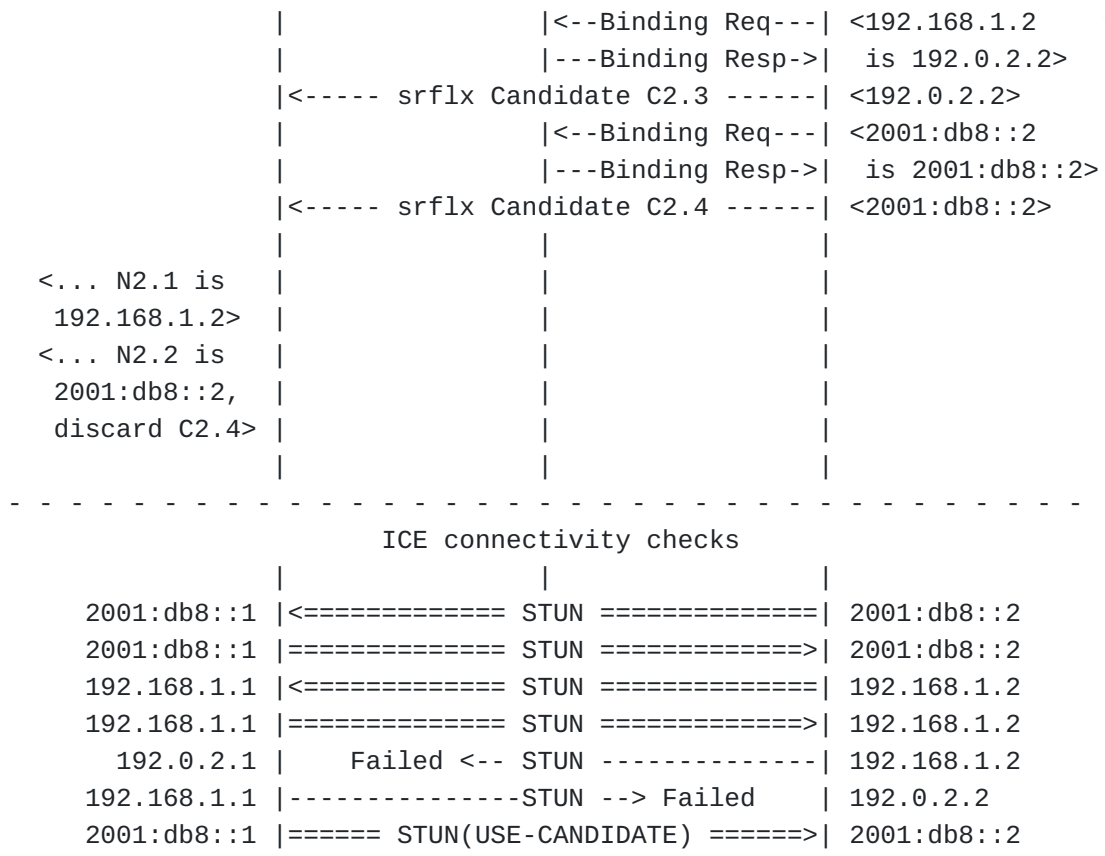
In this example, a peer-reflexive candidate is generated because the mDNS resolution for name N2 does not complete until after the STUN checks are received.



6.4. IPv4, IPv6, and STUN handling

This last example demonstrates the overall ICE gathering process for two endpoints, each with a private IPv4 address and a public IPv6 address. They preregister their mDNS names to speed up ICE gathering.


ICE Agent 1
192.168.1.1
2001:db8::1
STUN
Server
ICE Agent 2
192.168.1.2
2001:db8::2
Pre-registration of mDNS names
<Register mDNS name N1.1, 192.168.1.1>
<Register mDNS name N1.2, 2001:db8::1>
<Register mDNS name N2.1, 192.168.1.2>
<Register mDNS name N2.2, 2001:db8::2>
ICE Agent 1 sends mDNS candidates
<N1.1>
<N1.2>
------- mDNS Candidate C1.1 ----->
------- mDNS Candidate C1.2 ----->
<Resolve mDNS name N1.1 to 192.168.1.1>
<Resolve mDNS name N1.2 to 2001:db8::1>
ICE Agent 1 sends server-reflexive candidates
<192.168.1.1 is 192.0.2.1>
--Binding Req-->
<-Binding Resp--
<192.0.2.1>
------ srflx Candidate C1.3 ----->
<2001:db8::1 is 2001:db8::1>
--Binding Req-->
<-Binding Resp--
<2001:db8::1>
------ srflx Candidate C1.4 ----->
<Discard C1.4 as redundant>
ICE Agent 2 sends mDNS candidates, resolution is slow
<------ mDNS Candidate C2.1 ------
<------ mDNS Candidate C2.2 ------
<N2.1>
<N2.2>
<Resolve mDNS name N2.1 ...>
<Resolve mDNS name N2.2 ...>
ICE Agent 2 sends server-reflexive candidates, resolution completes


|<--Binding Req---| <192.168.1.2
|---Binding Resp->| is 192.0.2.2>
|<----- srflx Candidate C2.3 ------| <192.0.2.2>
|<--Binding Req---| <2001:db8::2
|---Binding Resp->| is 2001:db8::2>
|<----- srflx Candidate C2.4 ------| <2001:db8::2>
<... N2.1 is 192.168.1.2>
<... N2.2 is 2001:db8::2, discard C2.4>
ICE connectivity checks
2001:db8::1 |<========== STUN ==========| 2001:db8::2
2001:db8::1 |========== STUN ==========>| 2001:db8::2
192.168.1.1 |<========== STUN ==========| 192.168.1.2
192.168.1.1 |========== STUN ==========>| 192.168.1.2
192.0.2.1 | Failed <-- STUN ----------| 192.168.1.2
192.168.1.1 |----------STUN --> Failed | 192.0.2.2
2001:db8::1 |====== STUN(USE-CANDIDATE) ======>| 2001:db8::2

```
 Ice Agent 1 candidates:

C1.1: candidate:1 1 udp 2122262783 9b36eaac-bb2e-49bb-bb78-
                21c41c499900.local 10004 typ host
C1.2: candidate:2 1 udp 2122262527 76c82649-02d6-4030-8aef-
                a2ba3a9019d5.local 10006 typ host
C1.3: candidate:1 1 udp 1686055167 192.0.2.1
                30004 typ srflx raddr 0.0.0.0 rport 0
C1.4: candidate:2 1 udp 1686054911 2001:db8::1
                10006 typ srflx raddr 0.0.0.0 rport 0

 Ice Agent 2 candidates:

C2.1: candidate:1 1 udp 2122262783 b977f597-260c-4f70-9ac4-
                26e69b55f966.local 20004 typ host
C2.2: candidate:2 1 udp 2122262527 ac4595a7-7e42-4e85-85e6-
                c292abe0e681.local 20006 typ host
C2.3: candidate:1 1 udp 1686055167 192.0.2.2
                40004 typ srflx raddr 0.0.0.0 rport 0
C2.4: candidate:2 1 udp 1686054911 2001:db8::2
                20006 typ srflx raddr 0.0.0.0 rport 0
```

7. Security Considerations

7.1. mDNS Message Flooding

The implementation of this proposal requires the mDNS querying capability of the browser for registering mDNS names or adding remote ICE host candidates with such names. It also requires the mDNS responding capability of either the browser or the operating platform of the browser for registering, removing or resolving mDNS names. In particular,

- the registration of name requires optional probing queries and mandatory announcing responses ([RFC6762], Section 8), and this is performed at the beginning of ICE gathering;

- the addition of remote ICE host candidates with mDNS names generates mDNS queries for names of each candidate;

- the removal of names could happen when the browsing context of the ICE agent is destroyed in an implementation, and goodbye responses should be sent to invalidate records generated by the ICE agent in the local network ([RFC6762], Section 10.1).

A malicious Web application could flood the local network with mDNS messages by:

- creating browsing contexts that create ICE agents and start gathering of local ICE host candidates;

*destroying these local candidates soon after the name registration is done;

*adding fictitious remote ICE host candidates with mDNS names.

[RFC6762] defines a general per-question and per-record multicast rate limiting rule, in which a given question or record on a given interface cannot be sent less than one second since its last transmission. This rate limiting rule however does not mitigate the above attacks, in which new names, hence new questions or records, are constantly created and sent. Therefore, a browser-wide mDNS message rate limit MUST be provided for all mDNS queries and responses that are dispatched during the ICE candidate gathering and processing described in Section 3. A browser MAY implement more specific rate limits, e.g., to ensure a single origin does not prevent other origins from registering, unregistering, or resolving mDNS names.

7.2. Malicious Responses to Deny Name Registration

If the optional probing queries are implemented for the name registration, a malicious endpoint in the local network, which is capable of responding mDNS queries, could send responses to block the use of the generated names. This would lead to the discarding of this ICE host candidate as in Step 5 in Section 3.1.

The above attack can be mitigated by skipping the probing when registering a name, which also conforms to Section 8 in [RFC6762], given that the name is randomly generated for the probabilistic uniqueness (e.g. a version 4 UUID) in Step 3 in Section 3.1. However, a similar attack can be performed by exploiting the negative responses (defined in [RFC6762], Section 8.1), in which NSEC resource records are sent to claim the nonexistence of records related to the gathered ICE host candidates.

The existence of malicious endpoints in the local network poses a generic threat, and requires dedicated protocol suites to mitigate, which is beyond the scope of this proposal.

7.3. Unsolicited ICE Communications

As noted in Section 4.2 of [RTCWebSecurity], an attacker may use ICE as a way to send unsolicited network traffic to specific endpoints. While this is not specific to mDNS hostname candidates, this technique makes it easier to target devices with well-known mDNS names.

Also, the same technique can be used as an oracle to determine whether some local services are reachable in the local network. This

knowledge can be used for fingerprinting purposes or as a basis for attacking local networks.

As noted in Section 3.2, ICE agents are discouraged to resolve mDNS names that are not in the format defined by Section 3.1 and may further constrain the mDNS names they will actually try to resolve.

8. IANA Considerations

This document requires no actions from IANA.

9. References

9.1. Normative References

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