A New Twist In SSDP Attacks

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NETSCOUT.

Executive Summary

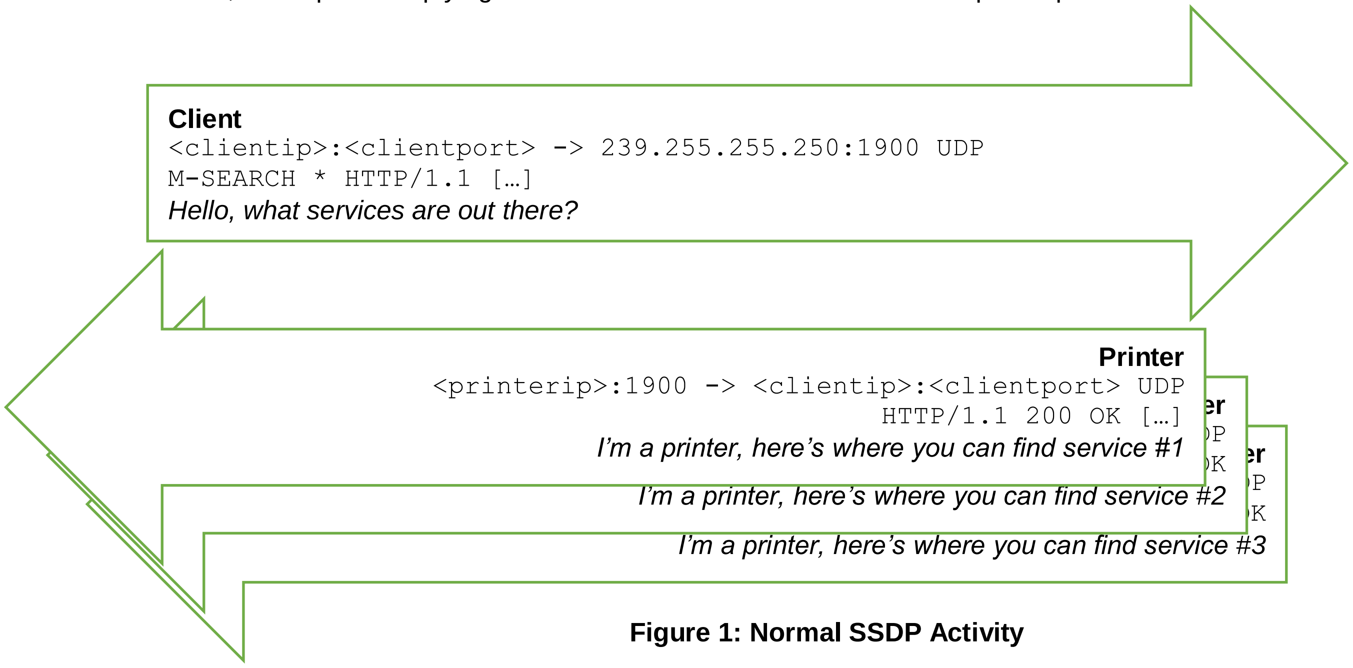
Arbor ASERT has uncovered a new class of SSDP abuse where naïve devices will respond to SSDP reflection/amplification attacks with a non-standard port. The resulting flood of UDP packets have ephemeral source and destination ports, making mitigation more difficult - a SSDP diffraction attack. This behavior appears to stem from broad re-use in CPE devices of the open source library libupnp. Evidence from prior DDoS events suggest that attackers are aware of this behavior and may choose a pool of these misbehaving victims based on the efficacy of their attack. Using Arbor products to mitigate these attacks require inspecting packet content to filter the flood of SSDP replies and non-initial fragments.

Key Findings

- SSDP has been abused for reflection/amplification attacks for many years. In 2015, Arbor identified attacks utilizing SSDP traffic from ephemeral source ports.
- SSDP diffraction attacks that use ephemeral ports can defeat naïve port filtering mitigations.
- Surprisingly, the majority of the roughly 5 million SSDP servers reachable via the public Internet will respond from an ephemeral source port.
- The behavior stems from use of the open source library libupnp, which appears to be used in a variety of CPE devices.
- Defending against SSDP diffraction attacks requires inspecting packet content.

An Oversimplified Introduction To SSDP

SSDP (Simple Service Discovery Protocol) is a simple protocol designed to solve the problem of service discovery over a local network. The technology uses text-based HTTP messages over UDP (*aka* HTTPU) on the well-known port 1900. A client wishing to query for available services will issue a M-SEARCH command via HTTPU. **Figure 1** shows a client querying the network via multicast for available services, and a printer replying with details of three services in three response packets.



Client
<clientip>:<clientport> -> 239.255.255.250:1900 UDP
M-SEARCH * HTTP/1.1 […]
Hello, what services are out there?
Printer
<printerip>:1900 -> <clientip>:<clientport> UDP
HTTP/1.1 200 OK […]
I'm a printer, here's where you can find service #1
I'm a printer, here's where you can find service #2
I'm a printer, here's where you can find service #3

Figure 1: Normal SSDP Activity

On the wire, the M-SEARCH packet is almost always static, no matter the intent of the client. Refer to the UPNP specification for details about the meaning of these fields.

```
M-SEARCH * HTTP/1.1
HOST:239.255.255.250:1900
MAN: "ssdp:discover"
MX: 2
ST: ssdp:all
```

The SSDP server will respond with one or more HTTPU responses, one for each unique service that is available. UDP packets may contain multiple HTTPU responses separated by two carriage-return / newline characters.

```
HTTP/1.1 200 OK
CACHE-CONTROL: max-age=120
ST: urn:schemas-upnp-org:device:WANDevice:1
USN: uuid:fc4ec57e-b051-11db-88f8-
0060085db3f6::urn:schemas-upnp-org:device:WANDevice:1
EXT:
SERVER: Net-OS 5.xx UPnP/1.0
LOCATION: http://192.168.0.1:2048/etc/linuxigd/gatedesc.xml
```

An important field to understand for later discussion is the USN, or Unique Service Name. It is a UUID (Universally Unique Identifier) used to uniquely identify a device or service, although in practice UUIDs are re-used for entire device classes.

The LOCATION field is essential to the client - it points to a URL (TCP-based HTTP, not HTTPU) where the client can retrieve an XML-based description of the capabilities of the service. Some services will specify a SOAP (Simple Object Access Protocol) endpoint that clients can use to interact with the service, such as sending a job to a printer.

Other HTTPU verbs exist to manage discovery and graceful timeout of SSDP services but are not germane to this discussion.

Reflection/Amplification

The SSDP protocol is rife for Distributed Denial of Service (DDoS) abuse for one simple reason – many SSDP server implementations will answer requests sent to *unicast* addresses (e.g. 1.1.1.1), not just the well-known link-local multicast addresses for SSDP (239.255.255.250). Packets with multicast addresses as source or destination will not be routed via the Internet, but unicast addresses will. A roughly 100-byte request packet over UDP can yield as many as a dozen or more UDP responses (one for each service), all without the hurdle of having to setup a three-way TCP handshake. The resulting multiplicative effect of the responses will overwhelm the target. SSDP-based reflection/amplification attacks became fashionable in 2014, despite being well-understood long before then.

An attacker wishing to abuse SSDP for DDoS would take the following steps:

- Scan some portion of the Internet looking for IP addresses that respond to M-SEARCH queries with multiple (as many as possible!) packets.
- Using this list of abuse-able addresses, send a flood of M-SEARCH queries *with the source address spoofed to be the intended target*.
- Tweak the number of spoofed M-SEARCH packets until the target is overwhelmed.

Mitigating SSDP reflection/amplification attacks is straightforward since the attack packets *originate from source port 1900*, with an ephemeral destination port from the original spoofed request and contain an HTTPU response. Almost all uses of SSDP occur on the local network, and most large organizations don't rely on the protocol for mission-critical applications, so packets with a UDP/1900 source port can generally be filtered at network boundaries during a crisis.

Abnormal SSDP Attacks

Both the attack and defense of SSDP reflection/amplification attacks have been well understood for years. But, a handful of DDoS attacks ASERT observed in 2015 exhibited different characteristics than a vanilla SSDP attack. The attack traffic did consist of HTTPU responses solicited from spoofed requests, but *both the source and destination ports were ephemeral*. The attack was a flood of UDP packets with high-numbered ports as the source *and* destination, rendering traditional source port filtering ineffective.

What was interesting about the attacks are that they started as a flood of UDP/1900 source port HTTPU packets (a *normal attack*), but when port filtering was put in place, the attack shifted to HTTPU packets with ephemeral sources (a *diffraction attack*). Clearly either the attacker, or the author of the attack tool, was aware of the difference in efficacy of both the normal attack and the diffraction attack.

What's happening here? Let's dig in.

Scanning

To understand how the SSDP population behaves, in September 2017 ASERT scanned the entire Internet. Every public address on the Internet was sent a generic M-SEARCH packet, and the first response packets recorded. The M-SEARCH packet used a static UDP source port of 1901 as a proxy for an *ephemeral port*, so both **behaving** and **misbehaving** (see below) responses could be recorded. The average "hit-rate" where a query was answered was 0.14%, or just over 5 million responses. This comprehensive scan yielded more responses than our later scan, which had a more aggressive timeout.

Analysis

For the purposes of this discussion, we'll divide the population of responses into two categories. The **behaving** group is the set of addresses that, when sent an M-SEARCH query to UDP port 1900, responded with one or more UDP packets *with a source port of 1900*. Conversely, the **misbehaving** group is the set of addresses that when sent an M-SEARCH query to UDP port 1900 responded with one or more UDP packets *with a source port other than 1900*.

The first thing that immediately stands out, is that the population of **misbehaving** sources actually outnumbers those of **behaving**!

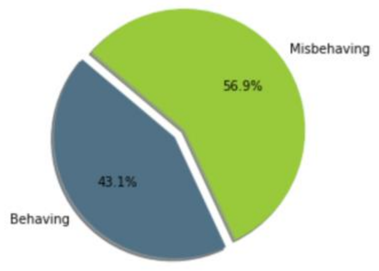


Figure 2: Misbehaving / Behaving Population

What can we learn about what makes the **misbehaving** group different than the **behaving**? The **behaving** group will all have source ports of 1900, but we can examine a histogram of the source ports from the **misbehaving** group.

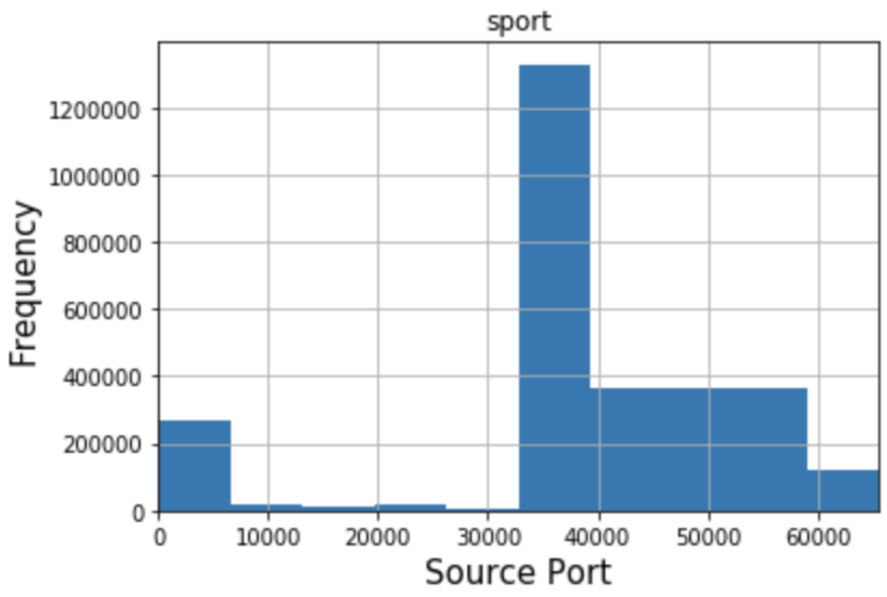


Figure 3: Histogram of Misbehaving Source Ports

Different operating systems choose ephemeral source ports from different ranges. Windows usually chooses lower port numbers (1,025-5,000), and we observe a handful that fit that description. Linux usually chooses from a larger pool (32,768-61,000), and there are many more here than the Windows group.

The following table provides geo-location information for both the behaving and misbehaving populations:

Behaving		Misbehaving	
Country	***Count***	***Country***	***Count***
China	628,121	China	585,104
Argentina	288,151	Russia	298,161
Russia	202,404	Vietnam	217,969
South Korea	139,623	South Korea	216,061
Taiwan	96,162	Venezuela	213,711
USA	89,452	Turkey	117,891
Italy	60,408	Algeria	108,088
India	56,592	Ukraine	101,320
Brazil	54,603	Japan	92,460
Tunisia	51,178	Greece	89,071

Figure 4: Top Ten Behaving/Misbehaving Countries

USN is a UUID that supposedly uniquely defines each specific device, although in practice entire device classes re-use this field. Unfortunately, there is no canonical registry mapping USNs to devices, but a naïve count does offer some clues.

USN	Count
`<none in initial response packet>`	466,247
`uuid:IGD{8c80f73f-4ba0-45fa-835d-042505d052be}000000000000`	410,071
`uuid:fc4ec57e-b051-11db-88f8-0060085db3f6::upnp:rootdevice`	147,621
`uuid:00000000-0000-0000-0000-000000000000::upnp:rootdevice`	50,410
`uuid:IGD{8c80f73f-4ba0-45fa-835d-042505d052be}000000000000::urn:schemas-upnp-org:device:InternetGatewayDevice:1`	29,400

Figure 5: Top Five Behaving USNs

The majority of **behaving** USNs are either `8c80f73f-4ba0-45fa-835d-042505d052be` (an Internet Gateway Device - mostly likely a CPE router), `fc4ec57e-b051-11db-88f8-0060085db3f6` (used by the MiniUPNP open source project), not specified, or zeroed out.

USN	Count
`uuid:75802409-bccb-40e7-8e6c-fa095ecce13e::upnp:rootdevice`	441,256
`uuid:160a0200-ac91-4b05-8adf-f5ccc5a5ebaa::upnp:rootdevice`	85,320
`uuid:uuid:160a0200-ac91-4b05-8adf-f5ccc5a5ebaa::upnp:rootdevice`	42,828
`uuid:75802409-bccb-40e7-8e6c-fa095ecce13e::urn:schemas-dummy-com:service:Dummy:1`	34,564
`uuid:75802409-bccb-40e7-8e6c-fa095ecce13e`	27,556

Figure 6: Top Five Misbehaving USNs

Of the **misbehaving** population, the `75802409-bccb-40e7-8e6c-fa095ecce13e` USN and its variants are by far the most popular. More on that in the next section.

Other optional fields can be used in an HTTPU response, including a `Server` header. Much like the HTTP counterpart, the `Server` header identifies the type of server responding to the request.

Behaving		Misbehaving	
Server	***Count***	***Server***	***Count***
`System/1.0 UPnP/1.0 IGD/1.0`	528,137	`Linux, UPnP/1.0, Portable SDK for UPnP devices/1.6.6`	521,424
`Custom/1.0 UPnP/1.0 Proc/Ver`	347,866	`Linux/2.6.36, UPnP/1.0, Portable SDK for UPnP devices/1.6.6`	277,539
`Linux UPnP/1.0 Huawei-ATP-IGD`	221,436	`Linux/2.6.30.9, UPnP/1.0, Portable SDK for UPnP devices/1.6.6`	225,443
`TBS/R2 UPnP/1.0 MiniUPnPd/1.2`	205,715	`Unspecified, UPnP/1.0, Unspecified`	187,252
`Linux/2.4.22-1.2115.nptl UPnP/1.0 miniupnpd/1.0`	181,986	`Linux/2.6.32.11, UPnP/1.0, Portable SDK for UPnP devices/1.6.19`	172,237
`Net-OS 5.xx UPnP/1.0`	156,938	`Linux/2.6.21, UPnP/1.0, Portable SDK for UPnP devices/1.3.1`	157,027
`miniupnpd/1.0 UPnP/1.0`	150,886	`Linux/3.0.8, UPnP/1.0, Portable SDK for UPnP devices/1.6.18`	153,981
`<none in initial response packet>`	70,039	`Linux/3.10.0, UPnP/1.0, Portable SDK for UPnP devices/1.6.18`	96,682

`LINUX-2.6 UPnP/1.0 MiniUPnPd/1.5`	50,087	`Linux/2.6.21.5, UPnP/1.0, Portable SDK for UPnP devices/1.6.6`	89,375
`uClinux/2.6.28.10 UPnP/1.0 MiniUPnPd/1.3`	29,728	`Linux/2.6.30, UPnP/1.0, Portable SDK for UPnP devices/1.6.6`	82,087

Figure 7: Top Ten Server Responses

The **behaving** `Server` responses are all over the map, but there is a clear pattern to the **misbehaving** side – `Linux/`*`[kernel version]`*`, UPnP/1.0 Portable SDK For UPnP devices/`*`[library version]`. Several different kernel and library versions are represented. The library is a major clue as to the identity of the misbehaving population.

The final HTTPU response field we'll examine is the `X-User-Agent`. Oddly enough, some responses will contain a `X-User-Agent` similar to a normal HTTP header's `User-Agent` field.

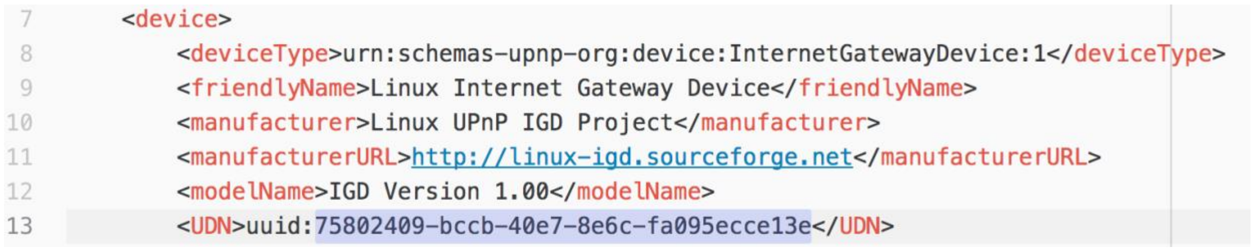
Behaving		Misbehaving	
X-User-Agent	***Count***	***X-User-Agent***	***Count***
`<none in initial response packet>`	2,158,308	`redsonic`	2,292,770
`redsonic`	8,009	`None`	544,430
`UPnP/1.0 DLNADOC/1.50`	2	`NRDP MDX`	184,99
`VisiMAX {8.03.00.00}`	1	`ZyXEL`	6,822
		`TrendChip-1.0 DMS`	987

Figure 8: Top Five X-User-Agents

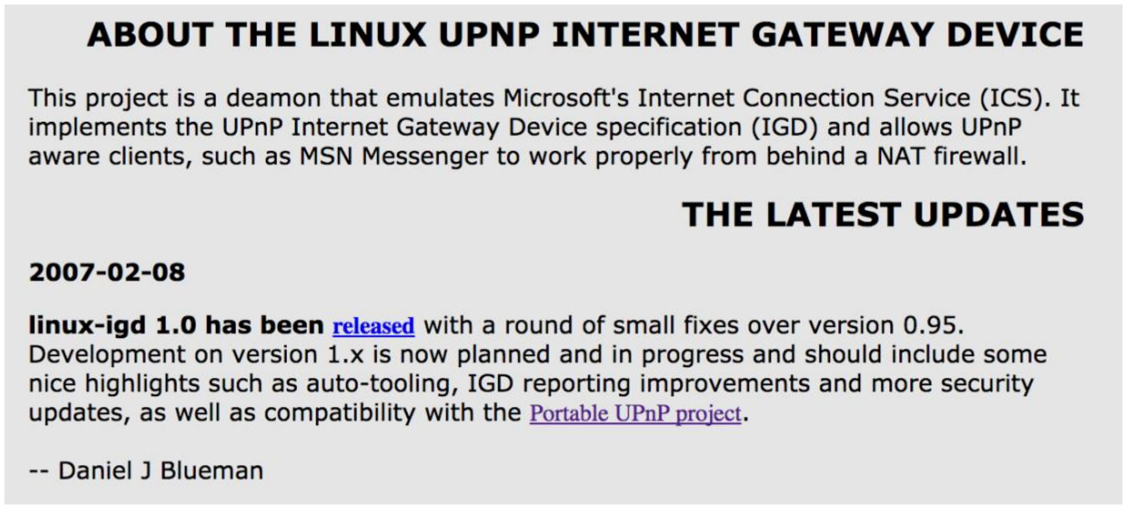
The obvious pattern here is that the **misbehaving** set overwhelmingly contains `redsonic`. While the **behaving** set has a small handful of the same, the vast majority don't include it.

Linux UPNP

The UUID that appears in **misbehaving** sources, but is almost completely absent from normal sources is `75802409-bccb-40e7-8e6c-fa095ecce13e`. When searching for information about these long opaque UUIDs, you'll normally only find information about DDoS attacks. But this UUID clearly belongs to the Linux UPNP Internet Gateway Device. From the source code `linuxigd-1.0/etc/gatedesc.xml`:



```
    <device>
        <deviceType>urn:schemas-upnp-org:device:InternetGatewayDevice:1</deviceType>
        <friendlyName>Linux Internet Gateway Device</friendlyName>
        <manufacturer>Linux UPnP IGD Project</manufacturer>
        <manufacturerURL>http://linux-igd.sourceforge.net</manufacturerURL>
        <modelName>IGD Version 1.00</modelName>
        <UDN>uuid:75802409-bccb-40e7-8e6c-fa095ecce13e</UDN>
```



ABOUT THE LINUX UPNP INTERNET GATEWAY DEVICE

This project is a deamon that emulates Microsoft's Internet Connection Service (ICS). It implements the UPnP Internet Gateway Device specification (IGD) and allows UPnP aware clients, such as MSN Messenger to work properly from behind a NAT firewall.

THE LATEST UPDATES

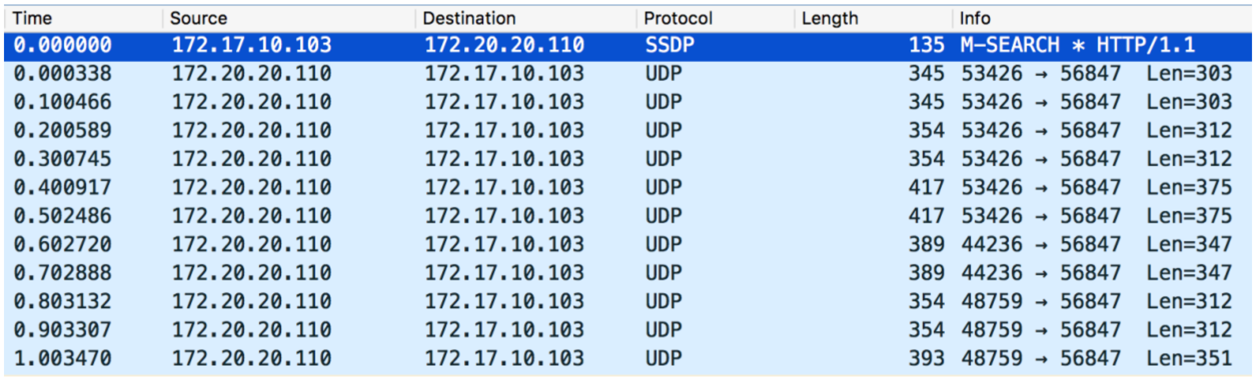
2007-02-08

linux-igd 1.0 has been released with a round of small fixes over version 0.95. Development on version 1.x is now planned and in progress and should include some nice highlights such as auto-tooling, IGD reporting improvements and more security updates, as well as compatibility with the Portable UPnP project.

-- Daniel J Blueman

The Linux UPNP Internet Gateway Device is an implementation of Microsoft's Internet Connection Service (ICS), a SSDP-aware protocol that solves the double-NAT problem. When two Internet users behind NAT devices wish to directly connect, for example to share a file without going through a third party, they can negotiate temporarily opening ports on both sides with the ICS protocol.

The Linux UPNP Internet Gateway Device only implements the ICS protocol, it relies on the Portable SDK for UPnP Devices (libupnp) for handling the lower-level UPNP. We installed the entire suite in our test lab to try and elicit the abnormal behavior. Here is a packet capture from our first normal M-SEARCH command:



Time	Source	Destination	Protocol	Length	Info
0.000000	172.17.10.103	172.20.20.110	SSDP	135	M-SEARCH * HTTP/1.1
0.000338	172.20.20.110	172.17.10.103	UDP	345	53426 → 56847 Len=303
0.100466	172.20.20.110	172.17.10.103	UDP	345	53426 → 56847 Len=303
0.200589	172.20.20.110	172.17.10.103	UDP	354	53426 → 56847 Len=312
0.300745	172.20.20.110	172.17.10.103	UDP	354	53426 → 56847 Len=312
0.400917	172.20.20.110	172.17.10.103	UDP	417	53426 → 56847 Len=375
0.502486	172.20.20.110	172.17.10.103	UDP	417	53426 → 56847 Len=375
0.602720	172.20.20.110	172.17.10.103	UDP	389	44236 → 56847 Len=347
0.702888	172.20.20.110	172.17.10.103	UDP	389	44236 → 56847 Len=347
0.803132	172.20.20.110	172.17.10.103	UDP	354	48759 → 56847 Len=312
0.903307	172.20.20.110	172.17.10.103	UDP	354	48759 → 56847 Len=312
1.003470	172.20.20.110	172.17.10.103	UDP	393	48759 → 56847 Len=351

It exhibits the ephemeral port behavior *by default*! This dump was captured on the device running the Linux UPNP Internet Gateway, so no external network tampering like NAT is in effect.

Digging Into The Source

The libupnp project that actually implements the SSDP protocol is clearly of interest, so let's go even deeper and examine the source code, beginning with the latest version as of this writing 1.6.22 (released May 2017). Beginning with `libupnp-1.6.22/upnp/src/ssdp/ssdp_server.c`. The function `readFromSSDPSocket()` handles requests sent to UDP/1900:

```
	byteReceived = recvfrom(socket, requestBuf, BUFSIZE - (size_t)1, 0,
				(struct sockaddr *)&__ss, &socklen);
```

It does some basic validation of the M-SEARCH request, eventually spawning another thread to handle the response ending up in the function `NewRequestHandler()` in `libupnp-1.6.22/upnp/src/ssdp/ssdp_device.c`:

```
static int NewRequestHandler(
    /*! [in] Ip address, to send the reply. */
    struct sockaddr *DestAddr,
    /*! [in] Number of packet to be sent. */
    int NumPacket,
    /*! [in] . */
    char **RqPacket)
{
```

The parameter `DestAddr` contains the presumably spoofed source address and the ephemeral port which sent the request. This crucial issue here is that the response creates a new socket, *resulting in a new ephemeral source port that is not 1900*:

```
    ReplySock = socket((int)DestAddr->sa_family, SOCK_DGRAM, 0);
```

The code continues to incorrectly assume it will respond to a unicast M-SEARCH request by setting the socket to multicast and TTL (time-to-live) to 4, without any error checking.

```
    int ttl = 4;
```

```
        setsockopt(ReplySock, IPPROTO_IP, IP_MULTICAST_IF,
                (char *)&replyAddr, sizeof(replyAddr));
        setsockopt(ReplySock, IPPROTO_IP, IP_MULTICAST_TTL,
                (char *)&ttl, sizeof(int));
```

It finally packages up all the responses and sends them to the destination:

```
        rc = sendto(ReplySock, *(RqPacket + Index),
                strlen(*(RqPacket + Index)), 0, DestAddr, socklen);
```

So why did the potentially mitigating TTL value of 4 fail to protect us? For that answer, we have to dive into the Linux kernel.

The call to `setsockopt()` did succeed, but the Linux kernel regards that only as a suggestion. In `linux/net/ipv4/ip_output.c` (link), the function `__ip_make_skb()` is responsible for delivering IP datagrams.

```
    if (cork->ttl != 0)
        ttl = cork->ttl;
    else if (rt->rt_type == RTN_MULTICAST)
        ttl = inet->mc_ttl;
    else
        ttl = ip_select_ttl(inet, &rt->dst);
```

First it will check `cork`, which ensures that IP fragments use the same TTL, and is not applicable here. Next the value `inet->mc_ttl` is taken from our earlier call to `setsockopt()`, but notice that it will only use this if the routing table entry for this particular destination is `RTN_MULTICAST` (aka, a multicast address). The response to the M-SEARCH request is being sent to a unicast address, so this check fails and falls through to use the default TTL!

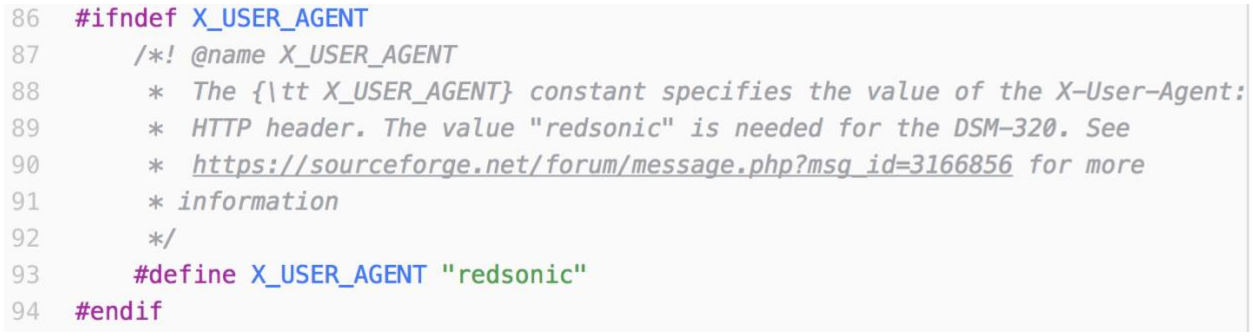
The `Server: Linux/[kernel version], UPnP/1.0 Portable SDK For UPnP devices/[library version]` HTTPU header was found almost entirely in the **misbehaving** set. Sure enough, libupnp sets this by default, and even accounts for the `Unspecified, UPnP/1.0, Unspecified` header as the fourth largest in the **misbehaving** set seen in **figure 7**:

```
#ifdef UPNP_ENABLE_UNSPECIFIED_SERVER
    snprintf(info, infoSize, "Unspecified, UPnP/1.0, Unspecified\r\n");
#else /* UPNP_ENABLE_UNSPECIFIED_SERVER */
#ifdef WIN32
    OSVERSIONINFO versioninfo;
    versioninfo.dwOSVersionInfoSize = sizeof(OSVERSIONINFO);

    if (GetVersionEx(&versioninfo) != 0)
        snprintf(info, infoSize,
            "%d.%d.%d %d/%s, UPnP/1.0, Portable SDK for UPnP devices/"
            PACKAGE_VERSION "\r\n", versioninfo.dwMajorVersion,
            versioninfo.dwMinorVersion, versioninfo.dwBuildNumber,
            versioninfo.dwPlatformId, versioninfo.szCSDVersion);
    else
        *info = '\0';
#else
    int ret_code;
    struct utsname sys_info;

    ret_code = uname(&sys_info);
    if (ret_code == -1)
        *info = '\0';
    snprintf(info, infoSize,
        "%s/%s, UPnP/1.0, Portable SDK for UPnP devices/"
        PACKAGE_VERSION "\r\n", sys_info.sysname, sys_info.release);
#endif
#endif /* UPNP_ENABLE_UNSPECIFIED_SERVER */
```

Finally, remember the `X-User-Agent: redsonic` HTTPU header enormously prevalent in the misbehaving set? It also comes from libupnp. In `libupnp-1.6.22/upnp/src/ inc/ssdplib.h`:



```
#ifndef X_USER_AGENT
    /*! @name X_USER_AGENT
     *  The {\tt X_USER_AGENT} constant specifies the value of the X-User-Agent:
     *  HTTP header. The value "redsonic" is needed for the DSM-320. See
     *  https://sourceforge.net/forum/message.php?msg_id=3166856 for more
     * information
     */
    #define X_USER_AGENT "redsonic"
#endif
```

libupnp includes this X-User-Agent by default, although it can be changed at compile-time by users of the library.

We believe devices that use libupnp are responsible for the aberrant DDoS behavior we have observed for the following reasons:

- The UUID `75802409-bccb-40e7-8e6c-fa095ecce13e` over represented in the **misbehaving** set is the Linux UPNP Internet Gateway Device, which uses libupnp.
- libupnp creates a new socket for responses, resulting in a new ephemeral port.
- The unique `Server` HTTPU header, hugely skewed towards the misbehaving set is the default value in libupnp.
- The `X-User-Agent: redsonic` HTTPU header, also vastly over represented in the **misbehaving** set is used by default in libupnp.

Mitigation

There is a strong argument for making SSDP servers only respond to multicast requests, but this is not how it works today. Making such a major change could subtly break misbehaving clients that depend on the behavior. Possibly the easiest fix, for **behaving** and **misbehaving** SSDP servers is to correctly set a small TTL on all reply packets. Reflection/amplification traffic would still make it out a few hops, but would not be effective enough to use in a real-world DDoS attack.

Conclusion

Attacks will always incrementally evolve just enough evade defenses. In this case we identified an effective new twist on an old, well-understood attack type. This revelation reminds us that defenders must constantly be aware of evolving attack methods and be as adaptable as the attackers. This specific attack highlights two trends we see time again: old code containing bugs being re-used in new consumer products, and subsequent exposure of those vulnerable populations.