Reducing Multicast in IPv6 Neighbor Discovery
draft-yourtchenko-colitti-nd-reduce-multicast-00

Abstract

   IPv6 Neighbor Discovery protocol makes wide use of multicast traffic,
   which makes it not energy efficient for the mobile WiFi hosts. This
   document describes two classes of possible ways to reduce the
   multicast traffic within IPv6 ND. First, within the boundaries of
   existing protocols. Second - with what the authors deem to be "minor
   changes" to the existing protocols.

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1. Introduction

Wireless networks based on the IEEE 802.11 standard (WiFi) are
ubiquitous in today's life. The multicast/broadcast behavior in
these networks has significantly lower performance than unicast in
the majority of the cases.

Also, in the current standard and implementations of the 802.11
protocols from the link-layer media standpoint the multicast is the
same as broadcast.

The Neighbor Discovery protocol makes substantial use of multicast
packets on the assumption that they provide the same or better
efficiency compared to unicast packets.

This misalignment results that the nodes on IPv6 networks with the
default configuration perform significantly poorer both from the
battery life standpoint and the bandwidth efficiency standpoint.

This document presents two groups of measures which reduce the shortcoming:

o The measures which are possible without any changes to the existing standards.

o The measures which require minimal changes to the standards.

Add some text here. You will need to use these references somewhere within the text: [RFC4862] [RFC4861] [RFC6620] [RFC3315]

2. Impact of Multicast Packets in 802.11 Networks

NOTE: much if not all of the subsequent text in this section might need to be transferred to vyncke-6man-mcast-not-efficient-01, which discusses why multicast is not an efficient media in the WiFi environments.

1. Multicast can impact power consumption on hosts if hosts receive multicast packets that are not addressed to them.

2. Excessive use of multicast can reduce the performance of wireless networks.

3. The extra packets are more expensive when they occur with the host not otherwise engaged in using the network.

4. Mobile nodes often have more than one processor and multiple power management states both for the central processing unit and for the WiFi portion (e.g. using only one antenna out of multiple). Often, the battery impact of rejecting a packet in the radio firmware is substantially lower than the impact of passing the packet to the main processor and rejecting it there.

In 802.11 networks, multicast frames towards clients have a greater battery impact than the unicast frames because they are transmitted to all hosts at once, with the AP setting the DTIM bit on the beacon packet to signal to the dozing hosts that the transmission is about to begin.

Thus, if the host were not to wake up right there and then, it would miss the multicast frame. Unicast packets are buffered on the AP and may have a more lenient delivery schedule, which would allow the devices to not have to wake up at every beacon interval (100ms).

The tradeoff between the energy savings and the latency of the multicast delivery may be manipulated by changing the parameter called DTIM interval, which determines how often (every Nth beacon)

the AP can send the indication about the multicast traffic to the
clients - with the default values being fairly low, usually in the
range of one to three.

Increasing these values increases the latency for the multicast
packets, therefore changing the DTIM interval beyond the defaults is
usually not recommended.

3. Quantifying the use of Multicast in Neighbor Discovery

Normal operation of Neighbor Discovery uses the following multicast
packets.

1. Duplicate Address Detection.
    Expected impact: One packet per IPv6 address (a host may be
    configured to do 2 or more) every time a host joins the network

2. Router Solicitations.
    Expected impact: One packet every time a host joins the network.

3. Router Advertisements.
    Expected impact:

    * One multicast RAs every [RA interval] seconds

    * One solicited RA per host joining the network (if solicited
       RAs are sent using multicast)

4. Neighbor solicitations. Expected impact: One every time a host
    talks to a new on-link destination talked to. The response is
    cached and typically does not expire unless the ND cache is under
    pressure and subject to garbage collection. Cache entries are
    refreshed (and possibly deleted) using unicast NUD packets, so
    cache refreshes do not cause multicast packets to be sent..

With the exception of periodic RAs (and possibly solicited RAs), none
of these packets are addressed to all nodes. RS packets are
addressed to all routers, and NS packets are addressed to solicited-
node multicast groups. Because solicited-node multicast groups
contain the last 24 bits of the IPv6 address, in most networks, each
solicited-node group will have at most one member.

4. Multicast-limiting measures with no changes in specifications

4.1. On-device robust multicast filtering

The hosts may implement on-device multicast filtering, such that if
devices receive multicast packets that are not addressed to them,
they will not send the packets to the main CPU but instead remain in
a lower sleep state.

It is worth noting that this may require a less deep sleep state than
the one required to monitor the TIM in the beacon frames. Also,
filtering the packets on the device does not address the inefficiency
in spectrum utilisation caused by excessive multicast frames.

4.2. Unicast Solicited Router Advertisements

[RFC4861] in section 6.2.6 already allows to do so via a MAY verb (if
the solicitation's source address is not the unspecified address).
This is further weakened by the subsequent qualifier being "but the
usual case is to multicast the response to the all-nodes group." As
a result of this, a lot of implementations do multicast the solicited
RAs, significantly impacting the devices.

To help address this, all router implementations SHOULD have a way to
send solicited RAs unicast in the environments which wish to do so.

4.3. Infrastructure-based multicast filtering

Ensure that solicited-node multicasts only go to the specific nodes.
This can be implemented either using multicast snooping or by
converting multicast packets to unicast packets that are addressed to
a subset of the hosts..

The latter can be done in two ways:

o on the 802.11 level alone, preserving the destination within the
   inner Ethernet frame as multicast

o on the 802.11 and 802.3 levels, as clarified by the [RFC6085]

Some networks track individual device IP addresses for security and
tracking reasons, typically by snooping DAD packets or device traffic
as described in [RFC6620]

In these networks, the infrastructure is already aware of which IP
addresses are mapped to which MAC addresses, and can use this
information to selectively unicast neighbor solicitations to the
nodes that will be interested in them.

Most wireless networks are infrastructure-based. The 802.11 standard
defines that all communications in such networks will happen via the
access points. Therefore, the infrastructure has a chance to
intelligently filter any multicast packets that are coming from both
local (served by the same access point) and remote (located behind
the wired infrastructure) hosts or routers, before forwarding them
onto the air to their ultimate destination.

4.4. Proxy the Neighbor Discovery protocol on the access point

802.11 standard defines also that all of packets sent from the client
to the Access Point (either for the local over-the-air delivery or
for forwarding on to the wired side) are acknowledged (even the
multicast ones).

With this in mind, in the scenarios like DAD, a proxy ND
implementation has inherently a much better chance of working than
the "regular" forwarding of the multicast DAD NS (and the return
forwarding of the multicast DAD NA in case of DAD collision that was
detected).

Therefore, the environments which want to increase the robustness of
the DAD, may wish to proxy the ND on behalf of the clients, therefore
reducing the overall client-directed multicast traffic (which is
unacknowledged) and increasing the robustness against the poor radio
conditions.

4.5. Maximized Interval for Periodic RAs

Assuming the solicited RAs are sent unicast, increasing the interval
of the periodic RAs is a natural way of further reducing the amount
of multicast packets in the air.

The bounding factor is AdvDefaultLifetime, which is limited by the
[RFC4861], section 6.1 on the sending side to 9000 seconds.

Thus, to find the "right" value one will have to balance the
robustness in the face of higher packet loss on the segment with the
energy consumption by the endpoints. Some real-world mid-scale
networks (on the order of 10000 hosts within a single /64)
successfully used a value of one RA in 1800 seconds.

However, it is impossible to specify the "best" value - everything
will depend on the quality of the local WiFi installation and the
radio conditions, with the constraint of 9000 seconds currently
specified by the standard.

4.6. **Increasing the advertised Reachable value**

   The NUD with the default settings and active traffic will enter the
   PROBE state as frequently as every ~30 seconds. [RFC4861] section
   7.3.3 defines: "If no response is received after waiting RetransTimer
   milliseconds after sending the MAX_UNICAST_SOLICIT solicitations,
   retransmissions cease and the entry SHOULD be deleted. Subsequent
   traffic to that neighbor will recreate the entry and perform address
   resolution again."

   Short-term connectivity issues at link layer may cause a trigger for
   the symptoms described in the [RFC7048], therefore triggering the
   nodes to send multicast neighbor solicitations. However, most of the
   hosts do not implement at this time the changes suggested there.
   With the default short timeouts and a wireless environment which
   forwards multicasts without the filtering, these retransmissions may
   contribute to further possible failures of NUD in other hosts. In
   the extreme high density and mobility environments (conferences,
   stadiums) this may result in avalanche effect and significantly
   increase the portion of multicast traffic.

   Furthermore, an 802.11 segment usually has a single gateway (possibly
   in a FHRP redundant configuration), therefore making NUD not very
   useful at all: if that gateway does not function, there is no
   alternative.

   For these kinds of environments it may be useful to significantly
   increase the REACHABLE_TIME from 30000 milliseconds to 600000 seconds
   and higher. One possible concern here, however, may be the overflow
   of the ND table on the gateway, so, again, there is no "best" value
   suitable for all the networks.

4.7. **Clearing the on-link bit in the advertized prefixes**

   The mobile nodes have generally fairly limited memory, so in the
   environments where there are thousands of nodes on a single /64, it
   might be burdensome for them to manage a large neghbor table. Having
   a lot of hosts with large neighbor tables may mean also a lot of NUD
   maintenance activity, with the potential for the catastrophic failure
   of the NUD therefore increasing in the high-density environments.

   Clearing the on-link bit in the advertised prefixes causes the hosts
   to send all the traffic to each other via the default gateway - thus
   dramatically reducing the size of the neighbor table and the burden
   of its maintenance on the hosts.

   The remaining impact of the link-local addresses still present in the
   cache can then be mitigated by blocking the direct communications

between the hosts at L2, which is a standard feature in the wireless LAN equipment. This operation effectively turns a wireless LAN segment into a collection of point-to-point links between the hosts and the access point, not dissimilar to the operation of private VLANs in the wired LAN case - making the subnet effectively NBMA.

4.8. Explicit creation of state with DHCPv6 address assignment

Turning the WLAN subnet into an NBMA has a consequence that the DAD may no longer work - which may create a problem with the global addresses. Therefore, it may be necessary to transfer the control over the address assignment to a centralized entity.

Also, the 802.11 protocols operate in the unlicensed bands, which means that the radio conditions may vary greatly. The 802.11 LLC protocol itself does have a fairly robust L2 retransmission mechanism for the acknowledged packets (up to 64 retransmissions). However, there still may be times when the radio conditions are so poor that this robustness is not enough. If the network were to use the snooping to maintain the strict policies (e.g. restrict the source addresses of the traffic), merely snooping the ND may not work, and the data-driven recovery mechanisms might be unacceptable.

In these cases one may consider using DHCPv6 as an address assignment mechanism, which would provide the explicit management of state by the client, and the retransmissions required to create the necessary state on the network side without requiring the node to send the data.

4.9. Client link shutdown within the router lifetime expiry

Some nodes after a longer period of time may decide to completely shut down the radio. This will of course result in the best battery usage, but will incur a tradeoff that waking up the client from the network side will be impossible. However, this mode of operation is the only one not using DHCPv6 which may allow complete avoidance of multicast RA packets: if the client never stays awake for longer than the router lifetime, it will not require the multicast RA processing. This optimization is here for completeness of the discussion - since it changes the connectivity of the client.

5. Multicast-limiting measures with small changes in specifications

5.1. Remove the send-side limit on AdvDefaultLifetime of 9000 Seconds

[RFC4861], section 6.1 limits the AdvDefaultLifetime on the sending side to 9000 seconds, while explicitly requiring the receiving side

to process all the values up to 65535 (maximum allowed by 16-bit
unsigned integer that the AdvDefaultLifetime is).

This artificial limit means a hard limit on the maximum router
lifetime that can be specified in the configuration. (The authors
tried two router implementations: Cisco IOS and radvd. More
information welcome).

This artificial restriction prevents from using very long router
advertisement intervals that would otherwise be possible - with the
difference being more than 7x!

Additionally, allowing the router lifetime of 65535 seconds, coupled
with sufficiently long lifetimes for the prefix, would cover the vast
majority of the lifetimes of the devices on the WiFi networks. 65535
seconds is 18.2 hours, and the typical mobile devices might not even
stay on the same network for such a long period of time. This would
allow to increase the robustness of the network in the face of bad
radio conditions causing the high loss of the multicast RAs.

5.2. Explicitly Client-Driven Router Advertisements

We can logically extend the "client link shutdown" in the direction
of smaller connectivity loss, and imagine that the client, instead of
completely shutting the radio down, would flap its radio link
somewhere close to router lifetime expiry, therefore, while acting
fully within the standards it will be able to maintain the
connectivity during all but very short period of time, without any
use of periodic RAs.

It may be interesting to explore a modification of the client
behavior such that the "flap time" converges to zero, and eventually
allowing the client to initiate a unicast Router Solicitation some
time shortly before the router lifetime expires. This will have the
result of the client being able to maintain the connectivity without
the need of processing any periodic RAs. The advantage of doing so
is that the RS-RA exchange will happen at the time convenient for the
client sleep schedule - thus allowing to maximize the battery life.

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7. IANA Considerations

   None.

8. Security Considerations

   Not discussed in -00.

9. Normative References

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