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F. Garneij
S. Chakrabarti
S. Krishnan
Ericsson
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Impact of IPv6 Neighbor Discovery on Cellular M2M Networks
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Abstract

The use of IPv6 in 3GPP cellular broadband networks for accessing the Internet and other data services like voice-over-LTE (VoLTE) has increased greatly as a result of EPS network deployments worldwide and new IPv6 capable smartphones and tablets. The upcoming rise of IoT/M2M is anticipated to bring billions of new devices into these networks and the majority of these devices will be using only IPv6. This document discusses the EPS network impact of IoT/M2M IPv6 connectivity specifically targeting the IPv6 Stateless Address Auto Configuration (SLAAC), as specified in [RFC4861] and [RFC4862], which currently is the only supported IPv6 address configuration mechanism in 3GPP standards.

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1. Introduction

Several of the IPv6 core protocols make widespread use of multicast messages as they wished to avoid broadcast messages. Unfortunately, in practice, the multicast operation at many link layers the degenerates into broadcast messages. 3GPP links are cellular links consuming expensive and limited radio spectrum. Thus such radio networks like to limit unnecessary signals in the network. IPv6 neighbor discovery is one of the core protocols required for the operation of IPv6, and this document shows how it can affect the cellular networks for M2M. M2M networks are usually low bandwidth radio networks.

In 3GPP networks, mobility and connectivity is generated by the arrangement of allocated radio resources and EPC node resources into a PDN connection. The following list gives the logical functions performed within the Evolved Packet System (EPS):

- o Network Access Control Functions.
- o Packet Routing and Transfer Functions
- o Mobility Management Functions.
- o Security Functions
- o Radio Resource management functions
- o Network Management Functions

For a User Equipment (UE) attached to a 3GPP network there are procedures defined related to device mobility, EPS Mobility Management (EMM) states and connectivity session, EPS Connectivity Management (ECM) states as described in [TS.23401] [Section 4.6](#). The purpose of this document is to analyze the EPS resources impacted by the procedures of the IPv6 Stateless Address Auto Configuration (SLAAC), as specified in [\[RFC4861\]](#) and [\[RFC4862\]](#), as it is utilized in 3GPP standards. Special attention is put on EPS control signaling load and the packets destined to UE generated by IPv6 periodic Router Advertisements (unsolicited multicast Router Advertisements). 3GPP also specifies its own values and behavior for Router Advertisement as described in 3GPP TS 29.061 [Section 11.2.1.3.4](#) IPv6 Router

Configuration Variables. This 3GPP adaptation defines how to send initial and periodic Router Advertisements in order to preserve radio resources and UE power consumption while still allowing for appropriate robustness and fast user-plane set-up time even in bad radio conditions to the radio.

Since in EPS, radio and network resources are not permanently assigned to a specific UE there is a cost associated with the allocation and release of resources and associated changes of states in EPS nodes. Thus, it is desirable to reduce or avoid any additional periodic packets that are not of any use to the application using the 3GPP derived UE connectivity. 2G and 3G radio

resource allocation have their own mechanisms with similar functionality but these are not described or considered in this document. The following M2M usecase scenario will clarify why periodic RA in 3GPP networks are harmful in especially for the M2M scenario.

Note that there are IETF informational guidelines for IPv6 usage in 3GPP EPS networks [[RFC6459](#)], but this draft requests an update in Standard IPv6 Neighbor Discovery specification to disallow periodic RAs.

[1.1](#). Definition Of Terms

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](#)].

3GPP Terminology

Second Generation Mobile Telecommunications, such as Global System for Mobile Communications (GSM) and GPRS technologies

Third Generation Mobile Telecommunications, such as UMTS technology

Fourth Generation Mobile Telecommunications, such as LTE technology.

3GPP

Third Generation Partnership Project. Throughout the document, the term "3GPP networks" refers to architectures standardized by 3GPP, in Second, Third, and Fourth Generation releases: 99, 4, and 5, as well as future releases.

eNodeB

The eNodeB is a base station entity that supports the Long-Term Evolution (LTE) radio interface.

EPS

Evolved packet System in LTE

GTP-U

GPRS Tunneling protocol for user plane

LTE

Long Term Evolution 3GPP Specification. It is a 4G mobile communication specification. The network speed in LTE is up to 10 times faster than the 3G network

Paging

A 3GPP defined mechanism for finding the radio base station at which a specific UE currently can be reached.

PDN Connection

The association between a UE represented by one IP address and/or one IPv6 prefix and a Packet Data network(PDN) associated to an Access Point Name(APN).

PGW or PDN GW

Packet Data Network Gateway (the default router for 3GPP IPv6 cellular hosts in EPS).

SGW or Serving GW

Serving Gateway: The user plane equivalent of a Serving GPRS Support Node (SGSN) in EPS and the default router for 3GPP IPv6 cellular hosts when using Proxy Mobile IPv6 (PMIPv6).

MME

Mobility Management Entity

UE

User Equipment or host terminal

M2M

Machine to Machine Communication networks and related standards. M2M includes industrial networks and communication. M2M uses IPv6 as dataplane.

2. The M2M Scenario and IPv6 Neighbor Discovery Impact

The analysis considers an IoT/M2M UE deployment scenario with infrequent packet communications occurrences than would normally be seen in an interactive device such as a smartphone. Given such an infrequent communication pattern, the UE is highly likely to be in IDLE ECM state when a downlink packet is sent from the PGW or the SGW. Sending a packet to the UE while in ECM IDLE state triggers a paging process followed by a UE Service Request and radio resource allocation. These procedures are considered as among the heavier procedures in EPS with regards to control signaling load and node state changes. They cause increased utilization of the radio interface as well as increased processing loads in the nodes involved in the procedures. It is also likely that other devices with different communications usage patterns like smartphones may compete over network resources causing the procedure to be repeated in order to complete. Thus, unnecessary control signals such as periodic RA causes paging and waste of radio resources in cellular networks.

The M2M use case below considers the following network dimensioning for a single PGW node based on information derived from real world network deployment best practices:

- o There are 10,000,000 simultaneous IPv6 connections to IoT/M2M devices from PGW. There are no dedicated bearers available. Communication direction for IoT/M2M service is from network to UE infrequent (e.g. twice a day or less). GTP-U is used between PGW and SGW as described in TS.23401 of 3GPP specification. The following list shows the condition of the network, number of resources and UE behavior in a typical 10M IPv6 connection-based M2M network.
- o If EPS Connectivity Management (ECM) state is ECM_IDLE, paging will be triggered when a packet is received by the UE
- o Each Tracking Area (TA) contains 100 base stations (eNodeB)
- o MME UE Tracking Area Identifier (TAI) list containing 10 TA which gives $10 * 100$ eNodeB = 1000 eNodeB for a UE TAI list
- o The MaxRtrAdvInterval configuration of [RFC4861](#) has been set to its maximum allowed value to minimize unsolicited multicast RAs

Based on the above data, the following analysis has been done. The analysis focuses on the connectivity state changes and resource allocation related to 1) Packet Routing and Transfer Functions 2) Mobility Management Functions 3) Radio Resource Management Functions

3. Analysis of Results

The unsolicited multicast RAs are sent at randomized intervals based on a timer that is set to uniformly distributed random values between the interface's configured MinRtrAdvInterval and MaxRtrAdvInterval as described in [Section 6.2.4. of RFC4861](#). We assume maximum possible values for MinRtrAdvInterval and MaxRtrAdvInterval in order to discover the *best-case* scenario.

$$\begin{aligned}\text{MaxRtrAdvInterval} &= 1800 \text{ seconds} \\ \text{MinRtrAdvInterval} &= 0.75 \times 1800 = 1350 \text{ seconds} \\ \text{Average RA interval} &= (1800 + 1350) / 2 = 1575 \text{ seconds} \\ \text{RAs/second} &= \text{number of nodes/average RA interval} \\ &= 10^7 / 1575 = 6349\end{aligned}$$

If the periodic router advertisements are allowed in the network, the measurement result shows that approximately 6300 Router advertisement packets can be sent to the eNodeB(base station) from the Edge Router/Gateway device(PGW). And there is ~100 to ~1000 state changes per second for MME, eNodeB, UE in the network.

If we assume there are 1000 base stations (eNodeBs) in the network there will be approximately 6.3 million paging messages per second as each unsolicited RA will initiate paging on each eNodeB. Each of these RAs will also trigger state changes in the MME, the SGW, the eNodeB and the UE radio bearer. There will be approximately 50000

(12600*4) state changes per second in the network. This causes significant increases in processing power as well as network traffic. This will cause serious issues to network operators. This illustrates the point is that even when unsolicited multicast RAs are fairly infrequent, there is a huge effect on the M2M/IOT 3GPP networks.

It has been shown that a single unsolicited downlink packet can

consume energy and bandwidth and ties up resources in the EPS network and UE. It is desirable to free up the 3GPP networks from such periodic signaling traffic (in this case IPv6 ND) so that energy and bandwidth can be saved and the saved energy and bandwidth can be used for actual data traffic destined to users. Given the result above the unsolicited RA traffic generated by the PGW is roughly equal to the effort needed to poll all 53 million UK gas and electricity meters once a day. If it amuses the reader, the number of unsolicited RA sent by the PGWs connecting the IPv6-only UK smart meters during a day can easily be derived using the data in this document.

Since all the UE are known to the PGW which acts as their default router and packets to one UE to another go via PGW in many deployments, the Address Registration Method(ARO) described in [\[efficient-nd\]](#) is quite useful for reducing/avoiding periodic RA and having the PGW or SGW keeping track of the UE registration status for selectively exchanging the IPv6 Neighbor Discovery messages. In addition the Address Registration Method(ARO) allows the PGW to learn the IPv6 address that is used by the UE which is not possible using currently defined 3GPP usage of SLAAC.

[4.](#) Acknowledgements

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Appendix A.

Authors' Addresses

Fredrik Garneij
Ericsson
Sweden

Email: fredrik.garneij@ericsson.com

Samita Chakrabarti
Ericsson
USA

Email: samita.chakrabarti@ericsson.com

Suresh Krishnan
Ericsson
8400 Decarie Blvd.
Town of Mount Royal, QC
Canada

Phone: +1 514 345 7900 x42871
Email: suresh.krishnan@ericsson.com

