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LoWPAN Backbone Router
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Abstract

ISA100.11a is a Working Group at the ISA SP100 standard committee that covers Wireless Systems for Industrial Automation and Process Control. The WG is mandated to design a scalable, industrial grade LoWPAN for devices such as sensors, valves, and actuators. The upcoming standard uses the 6LoWPAN format for the network header. It also introduces the concept of a Backbone Router to merge small LoWPANs via a high speed transit and scale the ISA100.11a network. This paper proposes an IPv6 version of the Backbone Router concept.

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1. Introduction

ISA100.11a is a Working Group at the ISA SP100 standard committee that covers Wireless Systems for Industrial Automation and Process Control. The ISA100.11a is mandated to design a scalable, industrial grade wireless network and application layer suite of protocols for low power devices such as sensors and actuators, with a response time on the order of 100ms.

In order to meet industrial requirements for non-critical monitoring, alerting, supervisory control, open loop control and some closed loop control applications, the Working Group is leveraging advanced technology at every layer, including a mix of DSSS and FHSS at the MAC/PHY layer, path diversity at Data Link Layer, and endorsed the 6LoWPAN format for the network header, making it possible to utilize IP based protocols such as BACnet IP, Profibus IP and Modbus TCP without significant changes to those protocols.

The ISA100.11a WG has also introduced the concept of a Backbone Router that would interconnect small LoWPANs over a high speed transit network and scale a single ISA100.11a network up to the thousands of nodes.

This paper specifies IP layer functionalities that are required to implement a such Backbone Router with IPv6, in particular the application of the "IP Version 6 Addressing Architecture" [[RFC4291](#)], "Neighbor Discovery for IP version 6" [[RFC4861](#)] and "IPv6 Stateless Address Autoconfiguration" [[RFC4862](#)]. The use of EUI-64 based link local addresses, Neighbor Discovery Proxying and Optimistic Duplicate Address Detection are discussed. Also, the concept of Transit Link is introduced to implement the transit network that is envisioned by ISA100.11a.

This draft solves the problem of finding the other Backbone Router or gateway on the transit link from a 64 bits address that is used as interface ID for building a link local address. The Backbone Router

acts as proxy for all nodes attached to it through a process of registration. The Backbone Router also acts as a server for all Neighbor Discovery flows from and to its nodes, avoiding the burden of multicast over the LoWPAN.

The way the PAN IDs and 16-bit short addresses are allocated and distributed in the case of an 802.15.4 network is not covered by this specification. This specification is compatible with a deployment where each Backbone Router is connected to a different PAN-ID that is managed locally, as well as a deployment where the whole transit link and all nodes attached are a single PAN-ID. Similarly, the aspects of joining and securing the network are out of scope.

[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](#)].

Readers are expected to be familiar with all the terms and concepts that are discussed in "Neighbor Discovery for IP version 6" [[RFC4861](#)], "IPv6 Stateless Address Autoconfiguration" [[RFC4862](#)], "IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals" [[RFC4919](#)] and "Transmission of IPv6 Packets over IEEE 802.15.4 Networks" [[RFC4944](#)].

Readers would benefit from reading "Mobility Support in IPv6" [[RFC3775](#)], "Neighbor Discovery Proxies (ND Proxy)" [[RFC4389](#)] and "Optimistic Duplicate Address Detection" [[RFC4429](#)] prior to this specification for a clear understanding of the art in ND-proxying and binding. This document defines additional terms:

Transit Link

This is an IPv6 link that interconnects 2 or more backbone routers. It is expected to be deployed as a high speed backbone in order to federate a potentially large set of LoWPANs. Also referred to as a LoWPAN backbone or transit network.

Backbone Router

An IPv6 router that interconnects the LoWPAN with a Transit Link.

Extended LoWPAN

This is the aggregation of multiple LoWPANs as defined in [\[RFC4919\]](#) interconnected by a Transit Link via Backbone Routers and forming a single IPv6 link.

Binding

The association of the LoWPAN node IPv6 address and Interface ID with associated proxying states including the remaining lifetime of that association.

Registration

The process during which a LoWPAN node sends a Binding ND message to a Backbone Router causing a binding for the LoWPAN node to be registered.

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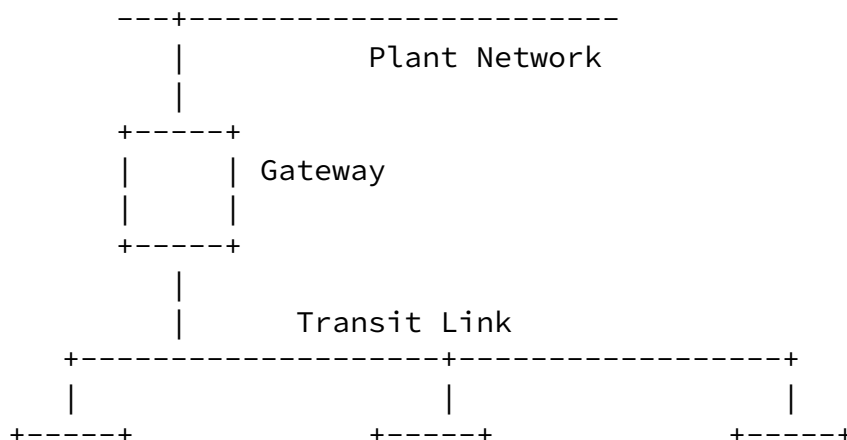
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[3.](#) Overview

A Transit Link federates multiple LoWPANs as a single IP link, the extended LoWPAN. Each LoWPAN is anchored at a Backbone Router. The Backbone Routers interconnect the LoWPANs over the Transit Link. A node can move freely from a LoWPAN anchored at a Backbone Router to a LoWPAN anchored at another Backbone Router on the same Transit Link and conserve its link local and any other IPv6 address it has formed.



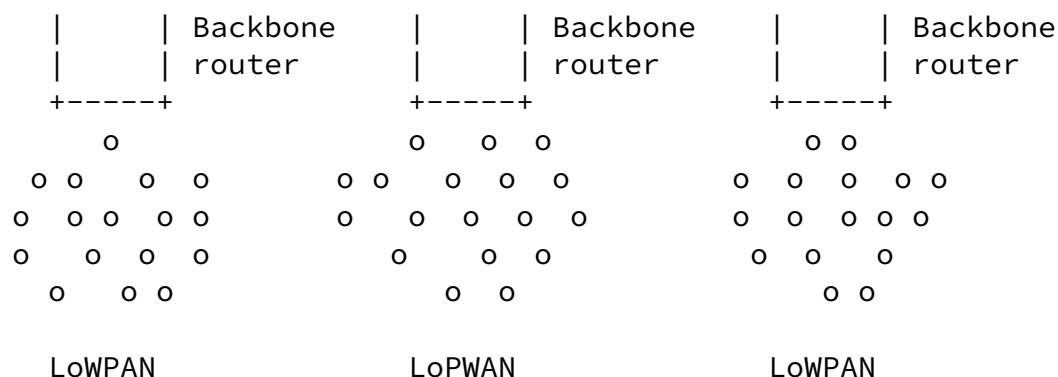


Figure 1: Transit Link and Backbone Routers

In order to achieve this, the Transit link is used as reference for Neighbor Discovery operations, by extending the concept of a Home Link as defined in [[RFC3775](#)] for Mobile IPv6. In particular, Backbone Routers perform ND proxying for the LoWPAN nodes in the LoWPANs they own.

The backbone router operation is compatible with that of a Home Agent. This enables mobility support for sensor devices that would move outside of the network delimited by the transit link. This also enables collocation of Home Agent functionality within Backbone Router functionality on the same interface of the router.

The Backbone Router is centric for ND operation inside the LoWPAN. Part of the reason is the cost of the support for multicasting over the LoWPAN that this specification avoids for the Neighbor Solicitation flows. As a result, a LoWPAN node performs unicast exchanges to its Backbone Router to claim and lookup addresses, and the Backbone Router proxies the ND requests over the Transit Link when necessary.

This specification documents the extensions to IPv6 Neighbor Discovery that enables a LoWPAN Node to claim and lookup addresses using a Backbone Router as an intermediate proxy. The draft also documents the use of EUI-64 based link-local addresses and the way they are claimed by the Backbone Routers over the transit link.

For the purpose of Neighbor Discovery proxying, this specification

documents the LoWPAN binding cache, a conceptual data structure that is similar to the MIP6 binding cache.

Another function of the Backbone Router is to perform 6LowPAN compression and uncompression between the LoWPAN and the Transit Link and ensure MTU compatibility. Packets flow uncompressed over the Transit Link and are routed normally towards a Gateway or an Application sitting on the transit link or on a different link that is reachable via IP.

4. New Neighbor Discovery options

4.1. Binding Update Option

The binding Update Option echoes the BU in [\[RFC3775\]](#) for Mobile IPv6. At this stage of the specification, there is no control bit or suboption. The BU option is used in Neighbor Solicitation messages sent by the LoWPAN node to its Backbone Router for registration.

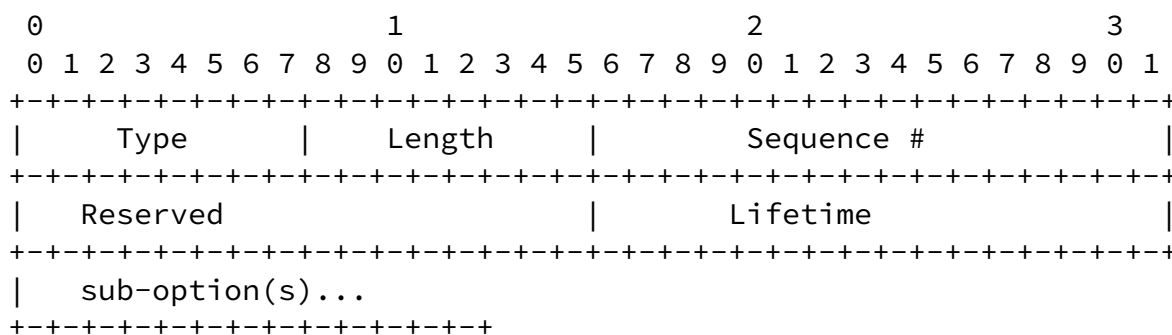


Figure 2: NS BU option

Type: 8-bit unsigned integer. Value is "to be assigned by IANA".

Length: 8-bit unsigned integer set to 1 when there is no suboption. The length of the option (including the type and length fields and the suboptions) in units of 8 octets.

Sequence #: A 16-bit unsigned integer used by the receiving node to sequence Binding Updates and by the sending node to match a

returned Binding Acknowledgement option with this Binding Update option.

Lifetime: 16-bit unsigned integer. The number of time units remaining before the binding MUST be considered expired. A value of zero indicates that the Binding Cache entry for the mobile node MUST be deleted. (In this case the specified care-of address MUST also be set equal to the home address.) One time unit is 4 seconds.

4.2. Binding Acknowledgement Option

The Binding Ack Option echoes the Binding Ack in [RFC3775] for Mobile IPv6. At this stage of the specification, there is no control bit or suboption. The Binding Ack option is used in Neighbor Advertisement messages sent by the Backbone Router to a LoWPAN node to acknowledge its registration. A status indicates the completion.

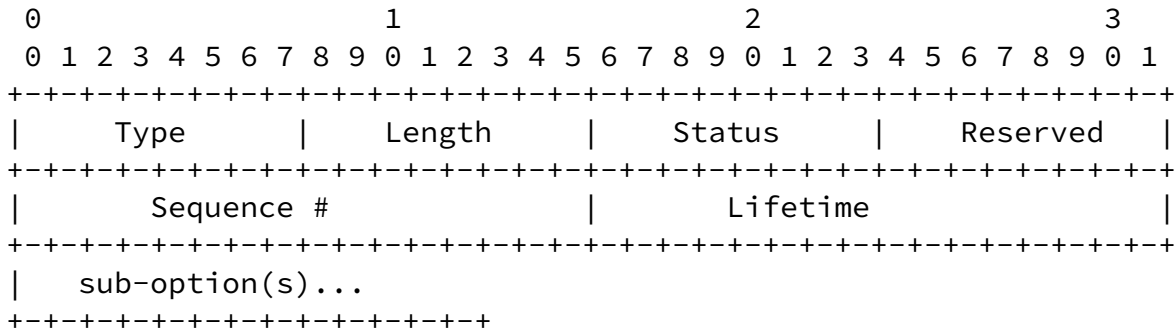


Figure 3: NA Binding Ack option

Type: 8-bit unsigned integer. Value is "to be assigned by IANA".

Length: 8-bit unsigned integer set to 1 when there is no suboption. The length of the option (including the type and length fields and the suboptions) in units of 8 octets.

Status: 8-bit unsigned integer indicating the disposition of the Binding Update. Values of the Status field less than 128 indicate that the Binding Update Option was accepted by the Backbone Router. Values greater than or equal to 128 indicate that the

Binding Update was rejected by the Backbone Router. The following

Status values are currently defined:

- 0 Binding Update accepted (primary)
- 2 Binding Update accepted (secondary)
- 128 Reason unspecified
- 129 Administratively prohibited
- 130 Insufficient resources
- 134 Duplicate Address Detection failed
- 135 Duplicate Address Detection failed

Sequence #: 16-bit unsigned integer. The Sequence Number in the Binding Acknowledgement is copied from the Sequence Number field in the Binding Update. It is used by the LoWPAN node in matching this Binding Acknowledgement with an outstanding Binding Update.

Lifetime: 16-bit unsigned integer. The granted lifetime, in time units of 4 seconds, for which the Backbone Router SHOULD retain the entry for this LoWPAN node in its Binding Cache. The value of this field is undefined if the Status field indicates that the Binding Update was rejected.

5. LowPAN device operations

5.1. Forming addresses

All nodes are required to autoconfigure at least one address, a link-local address that is derived from the IEEE 64-bit extended media access control address that is globally unique to the device. Link-local address are described in [section 2.5.6 of \[RFC4291\]](#). [Appendix A](#) of that specification explains how the node builds an interface-ID based on the IEEE 64-bit extended MAC address by inverting the "u" (universal/local) bit.

As a result, knowledge of the 64-bit address of another node on the same extended LoWPAN is enough to derive its link-local address and reach it over IP. Another consequence is that the link local address is presumably unique on the Extended LoWPAN, which enables the use of Optimistic Duplicate Address Detection (oDAD) [\[RFC4429\]](#) over the Transit Link and the LoWPAN. The address is created as optimistic to enable its use in the binding process with the Backbone Router.

The node might also form Unique Local and Global Unicast addresses, for instance if it needs to be reachable from the outside of the Extended LoWPAN, or if it can manage its own mobility as prescribed by Mobile IPv6 [[RFC3775](#)]. In that case, the node needs to bind each individual address individually.

[5.2.](#) Binding process

The binding process is very similar to that of a MIP6 mobile node, though the messages used are Neighbor Discovery messages with new extensions to specify a binding relationship associated to the advertisements. A LoWPAN Address is tentative as long as the binding is not confirmed by the Backbone Router.

The LoWPAN node uses unicast Neighbor Solicitations to perform the binding. The destination Address is that of the Backbone Router. The source address the unspecified address as long as the address is still optimistic or tentative, and it is the link local address of the node after DAD is completed. The target address is the address being bound. A new binding-update option specifies parameters such as the binding lifetime.

The acknowledgment to an NS is a unicast Neighbor Advertisement with a new Binding Acknowledgement option that contains the status of the binding. The source of the packet is the link-local address of the Backbone Router. The destination address is the link-local address of the LoWPAN node, and the Target Address field contains the address being bound. That unicast NA is not to be confused with the response to a DAD and does not mean that the address is duplicated.

A bit in the Binding Acknowledgement option indicates whether the Backbone Router has completed DAD and now owns the bound address over the Transit Link. If the bit is set, the LoWPAN node set the address from optimistic to preferred.

This specification also introduces the concept of secondary binding. For redundancy, a node might place a secondary binding with one or more other Backbone Routers over a same or different LoWPANs. A flag in the binding option indicates whether the binding is secondary.

The Backbone Router might learn the PAN-ID and the 16-bit short address from the NS message if it was not already known by another means that is not within the scope of this specification.

[5.3.](#) Looking up neighbor addresses

A LoWPAN node does use multicast for its Neighbor Solicitation. Whether for DAD or lookup purposes, all NS messages are sent in

unicast to the Backbone Router, that answers in unicast as well.

The Target link-layer address in the response is either that of the destination if a short cut is possible over the LoWPAN, or that of the Backbone Router if the destination is reachable over the Transit Link, in which case the Backbone Router will terminate 6LoWPAN and relay the packet.

[5.4.](#) Answering address look up

A LoWPAN node does not need to join the solicited-node multicast address for its own addresses and should not have to answer a multicast Neighbor Solicitation. It may be programmed to answer a unicast NS but that is not required by this specification.

[6.](#) Backbone router operations

[6.1.](#) Exposing the Backbone Router

The Backbone Router forms a link-local address in exactly the same way as any other node on the LoWPAN. It uses the same link local address for the Transit Link and for all the associated LoWPAN(s) connected to that Backbone Router.

The Backbone Router announces itself using Router Advertisements (RA) messages that are broadcasted periodically over the LoWPAN. (note: can we merge RA with some other maintenance packet or distribute the info from the manager in some specific cases like ISA100.11a where such a thing exists?). (also, when the node moves to another LoWPAN, is there a way to let it know faster which is the Backbone Router so that it can stimulate a RA using RS?).

A new option in the RA indicates the Backbone Router capability. In this way a node can learn the PAN-ID and the 16-bit short address for the Backbone Router if it was not already acquired from another process that is not covered by this specification.

The Backbone Router MAY also announce any prefix that is configured

on the transit link, and serve as the default gateway for any node on the Transit Link or on the attached LoWPANs.

The transit link Maximum Transmission Unit serves as base for Path MTU discovery and Transport layer Maximum Segment Size negotiation (see [section 8.3 of \[RFC2460\]](#)) for all nodes in the LoWPANs. To achieve this, the Backbone Router announces the MTU of the transit link over the LoWPAN using the MTU option in the RA message as prescribed in section "4.6.4. MTU" of IPv6 Neighbor Discovery

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[\[RFC4861\]](#).

LoWPAN nodes SHOULD form IPv6 packets that are smaller than that MTU. As a result, those packets should not require any fragmentation over the transit link though they might be intranet-fragmented over the LoWPAN itself as prescribed by [\[RFC4944\]](#).

More information on the MTU issue with regard to ND-proxying can be found in Neighbor Discovery Proxies [\[RFC4389\]](#) and [\[I-D.van-beijnum-multi-mtu\]](#).

[6.2.](#) Binding process

Upon a new binding for a link-local address based on a IEEE 64-bit extended MAC address, the Backbone Router uses Optimistic DAD on the Transit Link. Any other Backbone Router that would happen to have a binding for that same address SHOULD yield and deprecate its binding to secondary if it was primary. A positive acknowledgement can be sent to the LoWPAN node right away if oDAD is used on the Transit Link.

The Backbone Router operation on the transit link is similar to that of a Home Agent as specified in Mobility Support for IPv6 [\[RFC3775\]](#). In particular, the Neighbor Advertisement message is used as specified in section "10.4.1. Intercepting Packets for a Mobile Node" with one exception that the override (O) bit is not set, indicating that this Backbone Router acts as a proxy for the LoWPAN and will yield should another Backbone Router claim that address on the Transit Link. This enables the LoWPAN node to join a different Backbone Router at any time without the complexities of terminating a current binding.

This specification also introduces the concept of secondary binding. Upon a secondary binding, the Backbone Router will not announce or defend the address on the transit link, but will be able to forward packets to the node over its LoWPAN interface. For other addresses, the rules in [[RFC3775](#)] apply for compatibility.

[6.3.](#) Looking up neighbor addresses

A Backbone Router knows and proxies for all the IPv6 addresses that are registered to it. When resolving a target address, the Backbone Router first considers its binding cache. If this address is in the cache, then the target is reachable over the LoWPAN as indicated in the cache. Else, the Backbone Router locates the target over the transit link using standard "Neighbor Discovery" [[RFC4861](#)] over that link.

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If the target is located over a LoWPAN owned by another Backbone Router, then that other Backbone Router is in charge of answering the Neighbor Solicitation on behalf of the target node.

[6.4.](#) Answering address look up

To enable proxying over the Transit Link, a Backbone Router must join the solicited-node multicast address on that link for all the registered addresses of the nodes in its LoWPANs. The Backbone Router answers the Neighbor Solicitation with a Neighbor Advertisement that indicates its own link-layer address in the Target link-layer address option.

A Backbone Router expects and answers unicast Neighbor Solicitations for all nodes in its LoWPANs. It answers as a proxy for the real target. The target link-layer address in the response is either that of the destination if a short cut is possible over the LoWPAN, or that of the Backbone Router if the destination is reachable over the Transit Link, in which case the Backbone Router will terminate 6LoWPAN and relay the packet.

[6.5.](#) Forwarding packets

Upon receiving packets on one of its LoWPAN interfaces, the Backbone Router checks whether it has a binding for the source address. If it

does, then the Backbone Router can forward the packet to another LoWPAN node or over the Transit link. Otherwise, the Backbone Router MUST discard the packet. If the packet is to be transmitted over the Transit link, then the 6LoWPAN sublayer is terminated and the full IPv6 packet is uncompressed and reassembled.

When forwarding a packet from the Transit Link towards a LoWPAN interface, the Backbone Router performs the 6LoWPAN sublayer operations of compression and fragmentation and passes the packet to the lower layer for transmission.

7. Security Considerations

This specification expects that the link layer is sufficiently protected, either by means of physical or IP security for the Transit Link or MAC sublayer cryptography. In particular, it is expected that the LoWPAN MAC provides secure unicast to/from the Backbone Router and secure broadcast from the Backbone Router in a way that prevents tempering with or replaying the RA messages.

The use of EUI-64 for forming the Interface ID in the link local address prevents the usage of Secure ND ([\[RFC3971\]](#) and [\[RFC3972\]](#)) and

address privacy techniques. Considering the envisioned deployments and the MAC layer security applied, this is not considered an issue at this time.

8. IANA Considerations

Need new NS/NA option numbers for the binding flow.

9. Acknowledgments

The author wishes to thank Geoff Mulligan for his help and in-depth review.

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