

ICMP Router Discovery Messages

Status of this Memo

This RFC specifies an IAB standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "IAB Official Protocol Standards" for the standardization state and status of this protocol. This document is a product of the IETF Router Discovery Working Group. Distribution of this memo is unlimited.

Abstract

This document specifies an extension of the Internet Control Message Protocol (ICMP) to enable hosts attached to multicast or broadcast networks to discover the IP addresses of their neighboring routers.

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1. Terminology

The following terms have a precise meaning when used in this document:

system	a device that implements the Internet Protocol, IP [9].
router	a system that forwards IP datagrams, as specified

in [2]. This does not include systems that, though capable of IP forwarding, have that capability turned off. Nor does it include systems that do IP forwarding only insofar as required to obey IP Source Route options.

- host any system that is not a router.
- multicast unless otherwise qualified, means the use of either IP multicast [4] or IP broadcast [6] service.
- link a communication facility or medium over which systems can communicate at the link layer, i.e., the protocol layer immediately below IP. The term "physical network" has sometimes been used (imprecisely) for this. Examples of links are LANs (possibly bridged to other LANs), wide-area store-and-forward networks, satellite channels, and point-to-point links.
- multicast link a link over which IP multicast or IP broadcast service is supported. This includes broadcast media such as LANs and satellite channels, single point-to-point links, and some store-and-forward networks such as SMDS networks [8].
- interface a system's attachment point to a link. It is possible (though unusual) for a system to have more than one interface to the same link. Interfaces are uniquely identified by IP unicast addresses; a single interface may have more than one such address.
- multicast interface an interface to a multicast link, that is, an interface to a link over which IP multicast or IP broadcast service is supported.
- subnet either a single subnet of a subnetted IP network [7] or a single non-subnetted IP network, i.e., the entity identified by an IP address logically ANDed with its assigned subnet mask. More than one subnet may exist on the same link.
- neighboring having an IP address belonging to the same subnet.

2. Protocol Overview

Before a host can send IP datagrams beyond its directly-attached subnet, it must discover the address of at least one operational router on that subnet. Typically, this is accomplished by reading a list of one or more router addresses from a (possibly remote) configuration file at startup time. On multicast links, some hosts also discover router addresses by listening to routing protocol traffic. Both of these methods have serious drawbacks: configuration files must be maintained manually -- a significant administrative burden -- and are unable to track dynamic changes in router availability; eavesdropping on routing traffic requires that hosts recognize the particular routing protocols in use, which vary from subnet to subnet and which are subject to change at any time. This document specifies an alternative router discovery method using a pair of ICMP [10] messages, for use on multicast links. It eliminates the need for manual configuration of router addresses and is independent of any specific routing protocol.

The ICMP router discovery messages are called "Router Advertisements" and "Router Solicitations". Each router periodically multicasts a Router Advertisement from each of its multicast interfaces, announcing the IP address(es) of that interface. Hosts discover the addresses of their neighboring routers simply by listening for advertisements. When a host attached to a multicast link starts up, it may multicast a Router Solicitation to ask for immediate advertisements, rather than waiting for the next periodic ones to arrive; if (and only if) no advertisements are forthcoming, the host may retransmit the solicitation a small number of times, but then must desist from sending any more solicitations. Any routers that subsequently start up, or that were not discovered because of packet loss or temporary link partitioning, are eventually discovered by reception of their periodic (unsolicited) advertisements. (Links that suffer high packet loss rates or frequent partitioning are accommodated by increasing the rate of advertisements, rather than increasing the number of solicitations that hosts are permitted to send.)

The router discovery messages do not constitute a routing protocol: they enable hosts to discover the existence of neighboring routers, but not which router is best to reach a particular destination. If a host chooses a poor first-hop router for a particular destination, it should receive an ICMP Redirect from that router, identifying a better one.

A Router Advertisement includes a "preference level" for each advertised router address. When a host must choose a default router address (i.e., when, for a particular destination, the host has not

been redirected or configured to use a specific router address), it is expected to choose from those router addresses that have the highest preference level (see Section 3.3.1 in the Host Requirements -- Communication Layers RFC [1]). A network administrator can configure router address preference levels to encourage or discourage the use of particular routers as default routers.

A Router Advertisement also includes a "lifetime" field, specifying the maximum length of time that the advertised addresses are to be considered as valid router addresses by hosts, in the absence of further advertisements. This is used to ensure that hosts eventually forget about routers that fail, become unreachable, or stop acting as routers.

The default advertising rate is once every 7 to 10 minutes, and the default lifetime is 30 minutes. This means that, using the default values, the advertisements are not sufficient as a mechanism for "black hole" detection, i.e., detection of failure of the first hop of an active path -- ideally, black holes should be detected quickly enough to switch to another router before any transport connections or higher-layer sessions time out. It is assumed that hosts already have mechanisms for black hole detection, as required by [1]. Hosts cannot depend on Router Advertisements for this purpose, since they may be unavailable or administratively disabled on any particular link or from any particular router. Therefore, the default advertising rate and lifetime values were chosen simply to make the load imposed on links and hosts by the periodic multicast advertisements negligible, even when there are many routers present. However, a network administrator who wishes to employ advertisements as a supplemental black hole detection mechanism is free to configure smaller values.

3. Message Formats

ICMP Router Advertisement Message

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
Type										Code										Checksum											
Num Addrs										Addr Entry Size										Lifetime											
Router Address[1]																															
Preference Level[1]																															
Router Address[2]																															
Preference Level[2]																															
.																															
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IP Fields:

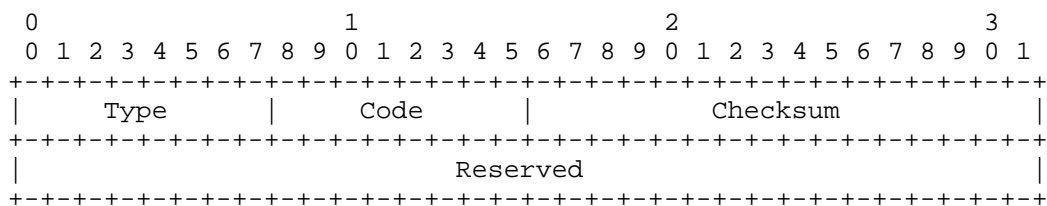
Source Address	An IP address belonging to the interface from which this message is sent.
Destination Address	The configured AdvertisementAddress or the IP address of a neighboring host.
Time-to-Live	1 if the Destination Address is an IP multicast address; at least 1 otherwise.

ICMP Fields:

Type	9
Code	0
Checksum	The 16-bit one's complement of the one's complement sum of the ICMP message, starting with the ICMP Type. For computing the checksum, the Checksum field is set to 0.

Num Addrs	The number of router addresses advertised in this message.
Addr Entry Size	The number of 32-bit words of information per each router address (2, in the version of the protocol described here).
Lifetime	The maximum number of seconds that the router addresses may be considered valid.
Router Address[i], i = 1..Num Addrs	The sending router's IP address(es) on the interface from which this message is sent.
Preference Level[i], i = 1..Num Addrs	The preferability of each Router Address[i] as a default router address, relative to other router addresses on the same subnet. A signed, twos-complement value; higher values mean more preferable.

ICMP Router Solicitation Message



IP Fields:

Source Address	An IP address belonging to the interface from which this message is sent, or 0.
Destination Address	The configured SolicitationAddress.
Time-to-Live	1 if the Destination Address is an IP multicast address; at least 1 otherwise.

ICMP Fields:

Type	10
Code	0

Checksum	The 16-bit one's complement of the one's complement sum of the ICMP message, starting with the ICMP Type. For computing the checksum, the Checksum field is set to 0.
Reserved	Sent as 0; ignored on reception.

4. Router Specification

4.1. Router Configuration Variables

A router that implements the ICMP router discovery messages must allow for the following variables to be configured by system management; default values are specified so as to make it unnecessary to configure any of these variables in many cases.

For each multicast interface:

AdvertisementAddress

The IP destination address to be used for multicast Router Advertisements sent from the interface. The only permissible values are the all-systems multicast address, 224.0.0.1, or the limited-broadcast address, 255.255.255.255. (The all-systems address is preferred wherever possible, i.e., on any link where all listening hosts support IP multicast.)

Default: 224.0.0.1 if the router supports IP multicast on the interface, else 255.255.255.255

MaxAdvertisementInterval

The maximum time allowed between sending multicast Router Advertisements from the interface, in seconds. Must be no less than 4 seconds and no greater than 1800 seconds.

Default: 600 seconds

MinAdvertisementInterval

The minimum time allowed between sending unsolicited multicast Router Advertisements from the interface, in seconds. Must be no less than 3 seconds and no greater than MaxAdvertisementInterval.

Default: $0.75 * \text{MaxAdvertisementInterval}$

AdvertisementLifetime

The value to be placed in the Lifetime field of Router Advertisements sent from the interface, in seconds. Must be no less than MaxAdvertisementInterval and no greater than 9000 seconds.

Default: $3 * \text{MaxAdvertisementInterval}$

For each of the router's IP addresses on its multicast interfaces:

Advertise

A flag indicating whether or not the address is to be advertised.

Default: TRUE

PreferenceLevel

The preferability of the address as a default router address, relative to other router addresses on the same subnet. A 32-bit, signed, twos-complement integer, with higher values meaning more preferable. The minimum value (hex 80000000) is used to indicate that the address, even though it may be advertised, is not to be used by neighboring hosts as a default router address.

Default: 0

The case in which it is useful to configure an address with a preference level of hex 80000000 (rather than simply setting its Advertise flag to FALSE) is when advertisements are being used for "black hole" detection, as mentioned in Section 2. In particular, a router that is to be used to reach only specific IP destinations could advertise its address with a preference level of hex 80000000 (so that neighboring hosts will not use it as a default router for reaching arbitrary IP destinations) and a non-zero lifetime (so that neighboring hosts that have been redirected or configured to use it can detect its failure by timing out the reception of its advertisements).

It has been suggested that, when the preference level of an address has not been explicitly configured, a router could set it according to the metric of the router's "default route" (if it has one), rather than defaulting it to zero as suggested above. Thus, a router with a better metric for its default route would advertise a higher preference level for its address. (Note that routing metrics that are encoded such that "lower is better" would have to be inverted

before being used as preference levels in Router Advertisement messages.) Such a strategy might reduce the amount of ICMP Redirect traffic on some links by making it more likely that a host's first choice router for reaching an arbitrary destination is also the best choice. On the other hand, Redirect traffic is rarely a significant load on a link, and there are some cases where such a strategy would result in more Redirect traffic, not less (for example, on links from which the most frequently chosen destinations are best reached via routers other than the one with the best default route). This document makes no recommendation concerning this issue, and implementors are free to try such a strategy, as long as they also support static configuration of preference levels as specified above.

4.2. Message Validation by Routers

A router must silently discard any received Router Solicitation messages that do not satisfy the following validity checks:

- IP Source Address is either 0 or the address of a neighbor (i.e., an address that matches one of the router's own addresses on the arrival interface, under the subnet mask associated with that address.)
- ICMP Checksum is valid.
- ICMP Code is 0.
- ICMP length (derived from the IP length) is 8 or more octets.

The contents of the ICMP Reserved field, and of any octets beyond the first 8, are ignored. Future, backward-compatible changes to the protocol may specify the contents of the Reserved field or of additional octets at the end of the message; backward-incompatible changes may use different Code values.

A solicitation that passes the validity checks is called a "valid solicitation".

A router may silently discard any received Router Advertisement messages. Any other action on reception of such messages by a router (for example, as part of a "peer discovery" process) is beyond the scope of this document.

4.3. Router Behavior

The router joins the all-routers IP multicast group (224.0.0.2) on all interfaces on which the router supports IP multicast.

The term "advertising interface" refers to any functioning and enabled multicast interface that has at least one IP address whose configured Advertise flag is TRUE. From each advertising interface, the router transmits periodic, multicast Router Advertisements, containing the following values:

- In the destination address field of the IP header: the interface's configured AdvertisementAddress.
- In the Lifetime field: the interface's configured AdvertisementLifetime.
- In the Router Address[i] and Preference Level[i] fields: all of the interface's addresses whose Advertise flags are TRUE, along with their corresponding PreferenceLevel values. (In the unlikely event that not all addresses fit in a single advertisement, as constrained by the MTU of the link, multiple advertisements are sent, with each except the last containing as many addresses as can fit.)

The advertisements are not strictly periodic: the interval between subsequent transmissions is randomized to reduce the probability of synchronization with the advertisements from other routers on the same link. This is done by maintaining a separate transmission interval timer for each advertising interface. Each time a multicast advertisement is sent from an interface, that interface's timer is reset to a uniformly-distributed random value between the interface's configured MinAdvertisementInterval and MaxAdvertisementInterval; expiration of the timer causes the next advertisement to be sent from the interface, and a new random value to be chosen. (It is recommended that routers include some unique value, such as one of their IP or link-layer addresses, in the seed used to initialize their pseudo-random number generators. Although the randomization range is configured in units of seconds, the actual randomly-chosen values should not be in units of whole seconds, but rather in units of the highest available timer resolution.)

For the first few advertisements sent from an interface (up to MAX_INITIAL_ADVERTISEMENTS), if the randomly chosen interval is greater than MAX_INITIAL_ADVERT_INTERVAL, the timer should be set to MAX_INITIAL_ADVERT_INTERVAL instead. Using this smaller interval for the initial advertisements increases the likelihood of a router being discovered quickly when it first becomes available, in the presence of possible packet loss.

In addition to the periodic, unsolicited advertisements, a router sends advertisements in response to valid solicitations received on any of its advertising interfaces. A router may choose to unicast

the response directly to the soliciting host's address (if it is not zero), or multicast it to the interface's configured AdvertisementAddress; in the latter case, the interface's interval timer is reset to a new random value, as with unsolicited advertisements. A unicast response may be delayed, and a multicast response must be delayed, for a small random interval not greater than MAX_RESPONSE_DELAY, in order to prevent synchronization with other responding routers, and to allow multiple, closely-spaced solicitations to be answered with a single multicast advertisement.

If a router receives a solicitation sent to an IP broadcast address, on an interface whose configured AdvertisementAddress is an IP multicast address, the router may send its response to the IP broadcast address instead of the configured IP multicast address. Such an event indicates a configuration inconsistency, and should be logged for possible corrective action by the network administrator.

It should be noted that an interface may become an advertising interface at times other than system startup, as a result of recovery from an interface failure or through actions of system management such as:

- enabling the interface, if it had been administratively disabled and it has one or more addresses whose Advertise flag is TRUE, or
- enabling IP forwarding capability (i.e., changing the system from being a host to being a router), when the interface has one or more addresses whose Advertise flag is TRUE, or
- setting the Advertise flag of one or more of the interface's addresses to TRUE (or adding a new address with a TRUE Advertise flag), when previously the interface had no address whose Advertise flag was TRUE.

In such cases, the router must commence transmission of periodic advertisements on the new advertising interface, limiting the first few advertisements to intervals no greater than MAX_INITIAL_ADVERT_INTERVAL. In the case of a host becoming a router, the system must also join the all-routers IP multicast group on all interfaces on which the router supports IP multicast (whether or not they are advertising interfaces).

An interface may also cease to be an advertising interface, through actions of system management such as:

- administratively disabling the interface,

- shutting down the system, or disabling the IP forwarding capability (i.e., changing the system from being a router to being a host), or
- setting the Advertise flags of all of the interface's addresses to FALSE.

In such cases, it is recommended (but not required) that the router transmit a final multicast advertisement on the interface, identical to its previous transmission but with a Lifetime field of zero. In the case of a router becoming a host, the system must also depart from the all-routers IP multicast group on all interfaces on which the router supports IP multicast (whether or not they had been advertising interfaces).

When the Advertise flag of one or more of an interface's addresses are set to FALSE by system management, but there remain other addresses on that interface whose Advertise flags are TRUE, it is recommended that the router send a single multicast advertisement containing only those address whose Advertise flags were set to FALSE, with a Lifetime field of zero.

5. Host Specification

5.1. Host Configuration Variables

A host that implements the ICMP router discovery messages must allow for the following variables to be configured by system management; default values are specified so as to make it unnecessary to configure any of these variables in many cases.

For each multicast interface:

PerformRouterDiscovery

A flag indicating whether or not the host is to perform ICMP router discovery on the interface.

Default: TRUE

SolicitationAddress

The IP destination address to be used for sending Router Solicitations from the interface. The only permissible values are the all-routers multicast address, 224.0.0.2, or the limited-broadcast address, 255.255.255.255. (The all-routers address is preferred wherever possible, i.e., on any link where all advertising routers support IP multicast.)

Default: 224.0.0.2 if the host supports IP multicast on the interface, else 255.255.255.255

The Host Requirements -- Communication Layers RFC [1], Section 3.3.1.6, specifies that each host implementation must support a configurable list of default router addresses. The purpose of the ICMP router discovery messages is to eliminate the need to configure that list in hosts attached to multicast links. On non-multicast links, and on multicast links for which ICMP router discovery is not (yet) supported by the routers or is administratively disabled, it will continue to be necessary to configure the default router list in each host. Each entry in the list contains (at least) the following configurable variables:

RouterAddress

An IP address of a default router.

Default: (none)

PreferenceLevel

The preferability of the RouterAddress as a default router address, relative to other router addresses on the same subnet. The Host Requirements RFC does not specify how this value is to be encoded; to allow the preference level to be conveyed in a Router Advertisement or configured by system management, it is here specified that it be encoded as a 32-bit, signed, twos-complement integer, with higher values meaning more preferable. The minimum value (hex 80000000) is reserved to mean that the address is not to be used as a default router address, i.e., it is to be used only for specific IP destinations, of which the host has been informed by ICMP Redirect or configuration.

Default: 0

5.2. Message Validation by Hosts

A host must silently discard any received Router Advertisement messages that do not satisfy the following validity checks:

- ICMP Checksum is valid.
- ICMP Code is 0.
- ICMP Num Addrs is greater than or equal to 1.
- ICMP Addr Entry Size is greater than or equal to 2.

- ICMP length (derived from the IP length) is greater than or equal to $8 + (\text{Num Addrs} * \text{Addr Entry Size} * 4)$ octets.

The contents of any additional words of per-address information (i.e., other than the Router Address and Preference Level fields), and the contents of any octets beyond the first $8 + (\text{Num Addrs} * \text{Addr Entry Size} * 4)$ octets, are ignored. Future, backward-compatible changes to the protocol may specify additional per-address information words, or additional octets at the end of the message; backward-incompatible changes may use different Code values.

An advertisement that passes the validity checks is called a "valid advertisement".

A host must silently discard any received Router Solicitation messages.

5.3. Host Behavior

On any interface on which the host supports IP multicast, the host will be a member of the all-systems IP multicast group (224.0.0.1). This occurs automatically, as specified in [4]; no explicit action is required on the part of the router discovery protocol implementation.

A host never sends a Router Advertisement message.

A host silently discards any Router Advertisement message that arrives on an interface for which the host's configured PerformRouterDiscovery flag is FALSE, and it never sends a Router Solicitation on such an interface.

A host cannot process an advertisement until it has determined its own IP address(es) and subnet mask(s) for the interface on which the advertisement is received. (On some links, a host may be able to use some combination of BOOTP [3], RARP [5], or ICMP Address Mask messages [7] to discover its own address and mask.) While waiting to learn the address and mask of an interface, a host may save any valid advertisements received on that interface for later processing; this allows router discovery and address/mask discovery to proceed in parallel.

To process an advertisement, a host scans the list of router addresses contained in it. It ignores any non-neighbor addresses, i.e., addresses that do not match one of the host's own addresses on the arrival interface, under the subnet mask associated with that address. For each neighboring address, the host does the following:

- If the address is not already present in the host's default

router list, a new entry is added to the list, containing the address along with its accompanying preference level and a timer initialized to the Lifetime value from the advertisement.

- If the address is already present in the host's default router list as a result of a previously-received advertisement, its preference level is updated and its timer is reset to the values in the newly-received advertisement.
- If the address is already present in the host's default router list as a result of system configuration, no change is made to its preference level; there is no timer associated with a configured address. (Note that any router addresses acquired from the "Gateway" subfield of the vendor extensions field of a BOOTP packet [11] are considered to be configured addresses; they are assigned the default preference level of zero, and they do not have an associated timer. Note further that any address found in the "giaddr" field of a BOOTP packet [3] identifies a BOOTP forwarder which is not necessarily an IP router; such an address should not be installed in the host's default router list.)

Whenever the timer expires in any entry that was created as a result of a received advertisement, that entry is discarded.

To limit the storage needed for the default router list, a host may choose not to store all of the router addresses discovered via advertisements. If so, the host should discard those addresses with lower preference levels in favor of those with higher levels. It is desirable to retain more than one default router address in the list so that, if the current choice of default router is discovered to be down, the host may immediately choose another default router, without having to wait for the next advertisement to arrive.

Any router address advertised with a preference level of hex 80000000 is not to be used by the host as default router address; such an address may be omitted from the default router list, unless its timer is being used as a "black-hole" detection mechanism, as discussed in Section 4.1.

It should be understood that preference levels learned from advertisements do not affect any of the host's cached route entries. For example, if the host has been redirected to use a particular router address to reach a specific IP destination, it continues to use that router address for that destination, even if it discovers

another router address with a higher preference level. Preference levels influence the choice of router only for an IP destination for which there is no cached or configured route, or whose cached route points to a router that is subsequently discovered to be dead or unreachable.

A host is permitted (but not required) to transmit up to MAX_SOLICITATIONS Router Solicitation messages from any of its multicast interfaces after any of the following events:

- The interface is initialized at system startup time.
- The interface is reinitialized after a temporary interface failure or after being temporarily disabled by system management.
- The system changes from being a router to being a host, by having its IP forwarding capability turned off by system management.
- The PerformRouterDiscovery flag for the interface is changed from FALSE to TRUE by system management.

The IP destination address of the solicitations is the configured SolicitationAddress for the interface. The IP source address may contain zero if the host has not yet determined an address for the interface; otherwise it contains one of the interface's addresses.

If a host does choose to send a solicitation after one of the above events, it should delay that transmission for a random amount of time between 0 and MAX_SOLICITATION_DELAY. This serves to alleviate congestion when many hosts start up on a link at the same time, such as might happen after recovery from a power failure. (It is recommended that hosts include some unique value, such as one of their IP or link-layer addresses, in the seed used to initialize their pseudo-random number generators. Although the randomization range is specified in units of seconds, the actual randomly-chosen value should not be in units of whole seconds, but rather in units of the highest available timer resolution.)

A host may also choose to further postpone its solicitations, subsequent to one of the above events, until the first time it needs to use a default router.

Upon receiving a valid advertisement containing at least one neighboring address whose preference level is other than hex 80000000, subsequent to one of the above events, the host must desist from sending any solicitations on that interface (even if none have

been sent yet), until the next time one of the above events occurs. The small number of retransmissions of a solicitation, which are permitted if no such advertisement is received, should be sent at intervals of SOLICITATION_INTERVAL seconds, without randomization.

6. Protocol Constants

Router constants:

MAX_INITIAL_ADVERT_INTERVAL	16 seconds
MAX_INITIAL_ADVERTISEMENTS	3 transmissions
MAX_RESPONSE_DELAY	2 seconds

Host constants:

MAX_SOLICITATION_DELAY	1 second
SOLICITATION_INTERVAL	3 seconds
MAX_SOLICITATIONS	3 transmissions

Additional protocol constants are defined with the message formats in Section 3, and with the router and host configuration variables in Sections 4.1 and 5.1.

All protocol constants are subject to change in future revisions of the protocol.

7. Security Considerations

This extension of ICMP makes it possible for any system attached to a link to masquerade as a default router for hosts attached to that link. Any traffic sent to such an imposter is vulnerable to eavesdropping, to denial of forwarding service, and to modification by insertion, deletion, or alteration of packets. It should be noted that, on most multicast or broadcast links on which this protocol is expected to operate, eavesdropping is already possible by any system attached to the link, and the Address Resolution Protocol (ARP) used on those links offers a similar opportunity for service denial and message stream modification. For environments where those threats are deemed unacceptable, there are configuration variables to disable dynamic router discovery by hosts.

The Router Advertisement message format is defined so as to allow additional information to be added to the message in a backward-compatible manner. One possible use of that capability is to add

digital signatures or some other form of authentication information to the advertisements, to enable hosts to verify their authenticity. This is FOR FURTHER STUDY.

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Author's Address

Stephen E. Deering
Xerox Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

Phone: (415) 494-4839

EMail: deering@xerox.com

Or send comments to gw-discovery@gregorio.stanford.edu.

