Mobile Ad Hoc Networking Working Group   Charles E. Perkins
INTERNET DRAFT   Nokia Research Center
8 July 2006   Thomas Clausen,
                                               Philippe Jacquet
                                       INRIA Rocquencourt, France

Multicast With Minimal Congestion Using Connected Dominating Sets
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Abstract
   Flooding is useful for many reasons in ad hoc networks, but
   causes congestion that can block traffic. Selecting multi-point
   relays (MPRs) reduces congestion due to flooding, but has several
   disadvantages. It is possible to select a subset of the MPRs to
   do the same job more effectively. In this document, signaling is
   specified for identifying a relatively small connected dominating set
   that can still manage the flooding operation.

1. Introduction

Flooding is useful for many reasons in ad hoc networks, but causes
congestion that can block traffic within such a network. The goal
of this document is to specify a flooding algorithm that greatly
reduces the number of packet retransmissions needed to flood the
whole network. Since there a many fewer retransmissions, the amount
of congestion due to flooding will be greatly reduced.

In order to reduce the total number of retransmissions, we can reduce
the number of nodes that perform the retransmissions, as long as
all nodes still receive at least one transmission of the flooded
packet. If a particular node can determine its one-hop and two-hop
neighborhoods, then it can identify a subset of its neighboring nodes
that still be able to reach every node of the two-hop neighborhood.
The nodes in such a subset are called "multi-point relays" (MPRs)
in the OLSR specification [7]. There are various ways to pick
enough MPRs so that, when each MPR retransmits a packet, the two-hop
neighborhood will be completely covered. These neighboring MPRs will
themselves have selected some of their other neighbors to be MPRs.
When the neighboring MPRs retransmit, then some of their neighbors
will again retransmit, until eventually the whole network is covered.

Selecting multi-point relays MPRs, as specified in OLSR [7] is
beneficial to reduce congestion due to flooding, but has several
disadvantages. Another related concept is that of a "connected
dominating set" (CDS). There are many distributed algorithms for
computing a CDS, with a variety of interesting properties. The set
of MPRs that retransmit a packet originated from a source node within
an ad hoc network is also a CDS. Otherwise, the set of MPRs would not
be able to cover the network by retransmission hop-by-hop.

In this document, signaling is specified for identifying a relatively
small connected dominating set that can still manage the flooding
operation.

The names of the multicast groups used for flooding are given as
"ALL_IPv4_MANET_NODES" and "ALL_IPv6_MANET_NODES" [5]. The backbone
nodes selected for flooding packets can, however, be used for

flooding to any designated multicast address as long as the members
of that multicast group form a connected subgraph of the ad hoc
network. Specifications for future multicast groups intended for
flooding or very dense dissemination should specifically indicate
that their members should communicate across the SMURF backbone.
Future documents may offer improved algorithms for the purpose of
identifying backbone nodes, while still utilizing the protocol in
this document for periodic updates to the necessary neighborhood
information.

    DISCUSSION: should there be a version field to handle
    unforeseen future incompatibilities?

2. SMURF 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 RFC 2119 [2].

   This section defines other terminology that is not already defined
   in [3].

      MPR

         A "multi-point relay" -- that is, a neighboring node that can
         relay flooded packets, thus assisting with the dissemination of
         those packets throughout the network

      broadcast

         Transmit to the IPv4 Limited Broadcast address,
         255.255.255.255, or else for IPv6 to the link-local
         AllNodesMulticast address.

      neighborhood, one-hop neighborhood

         The neighborhood (also called the one-hop neighborhood) of a
         node is the set of nodes which are directly reachable by that
         node.

two-hop neighborhood

>   The two-hop neighborhood of a node is the set of nodes which
>   are either directly reachable by that node, or directly
>   reachable by one of the neighbors of that node.

dominating set

>   A subset of a graph is a dominating set if every node in the
>   graph is eiher a member of the subset, or else a neighbor of at
>   least one node in the subset.

connected set

>   A set with more than one element is connected if every node in
>   the subset is a neighbor of some other node in the subset. A
>   set with fewer than two elements is connected.

CDS (connected dominating set)

>   A subset of a graph is a CDS if it is a dominating set, and it
>   is connected.

flooding backbone

>   The flooding backbone of an ad hoc network is a CDS which is
>   used for flooding packets throughout the network, considering
>   every node in the ad hoc network as a node in a graph with
>   edges defined by the (one-hop) communication links that are
>   available between the nodes in the ad hoc network.

backbone

>   in this document, ``backbone'' always means the flooding
>   backbone

3. Overview

Each node listens for advertisements from its neighbors. From the
advertisements, the node updates its stored information about its

one-hop neighborhood and its two-hop neighborhood. The sender of
the advertisement is a member of the node's one-hop neighborhood,
and the sender's neighbors are either members of the node's one-hop
neighborhood or its two-hop neighborhood.

There are two kinds of periodic local topology advertisements,
which are used to enable each node to construct a representation
of its two-hop neighborhood and subsequently select MPRs. The
first is called the "full advertisement", which has complete lists
of all the necessary data. The second is called the "incremental
advertisement", which only has information that has changed since
the last full advertisement. It is expected that the incremental
advertisement will be much smaller than the full advertisement.

A node's neighborhood is considered to be composed of three mutually
exclusive subsets:

  - undistinguished first hop neighbors
  - MPRs
  - the node itself

Likewise, a node's two hop neighborhood is considered to be composed
of four mutually exclusive subsets:

  - second hop neighbors
  - undistinguished first hop neighbors

  - MPRs
  - the node itself

If a node is described as being in any one of these subsets, then
by convention and agreement it does not belong to any of the other
subsets. This eliminates overlap of information in the local
topology advertisements.

The following information is present in full advertisements:

  - advertisement sequence number
  - reluctance for offering service as a backbone node
  - first hop neighbors
  - MPRs
  - flags

The following information is present in incremental advertisements:

- advertisement sequence number of the last full advertisement
- reluctance for offering service as a backbone node
- addresses of new first hop neighbors
- addresses of new MPRs
- addresses of lost nodes
- flags

Any address in the lost node list has to be deleted from the neighbor list or the MPR list of the last full advertisement, and the nodes in these two lists reclassified if they were classified differently in the last full advertisement.

A neighboring node cannot be considered for selection as an MPR until the link to that node has been verified as bidirectional. For each neighbor, two conditions must be verified:

 1. an advertisement has been recently heard from the neighbor

 2. the node itself must appear as a member of the one-hop neighbors
    reported by that neighbor.

Once each node has constructed its two-hop neighborhood, it uses any reasonable algorithm to identify a subset of neighbors which are to be designated as MPRs. One algorithm that works well is the so-called "greedy algorithm":

 1. Initialize the set of uncovered two-hop neighbors to contain all
    known two-hop neighbors

 2. Pick the neighbor that is within range of the largest number of
    uncovered nodes in the two-hop neighborhood.

 3. Mark the two-hop neighbors reachable by that neighbor's local
    broadcasts as already covered.

 4. If there are no more uncovered two-hop neighbors, stop.

 5. Otherwise, iterate steps (2) -- (4).

Once the nodes have identified the MPRs in their neighborhoods, each
node must also determine whether to prune itself from the flooding
backbone (i.e., the connected dominating set of nodes which will take
responsibility for disseminating flooded data).

In order for a node to prune itself to the flooding backbone, it uses
the following algorithm [1]:

   1. It forms a "CDS identifier" by appending its IP address to its
      last advertised "reluctance" value.

   2. If it is the node with a CDS identifier lower than any of its
      neighbors, then it must continue to participate as a member of
      the flooding backbone.

   3. Otherwise, if it not a MPR of its neighbor with the lowest CDS
      identifier, then it may prune itself from the flooding backbone.

A node advertises the status of its decision to prune itself from the
CDS backbone in its advertisement messages.

4. Full Advertisement

   The Full Advertisement has the following format:

```
 0                   1                   2                   3
 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      |    Length     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |         Sequence #         |Rel| #1-hop  |  #MPRs  | reserved|C|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 :          List of IP addresses of 1-hop neighbors            :
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 :           List of IP addresses of MPR neighbors             :
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

      Type

          Type == 1.

Length

   Length of the full advertisement data, in bytes, including all
   fields except for the Type and Length.

Sequence #

   Advertisement sequence number

Rel

   Reluctance (2 bits). A node selects a low value for its
   reluctance, if it is willing to be identified as an MPR, and
   thus potentially as a member of the connected dominating set.

#1-hop

   Number of one-hop neighbors

#MPRs

   Number of one-hop neighbors reclassified as MPRs

'C'

   The 'C' flag is set if the advertising node has selected itself
   as a member of the connecting dominating set for flooding

1-hop list

   List of IP addresses of 1-hop neighbors (#1-hop total
   addresses)

MPR list

   List of IP addresses of MPR neighbors (#MPRs total addresses)

The IP header TTL for the Full Advertisement packet MUST be 1.

   DISCUSSION: is 255 better?

   DISCUSSION: Is the Length field needed, or should we spend
   the bits on enlarging the other fields?

5. Incremental Advertisement

   The Incremental Advertisement has the following format:

```
 0                   1                   2                   3
 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      |     Length    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       Sequence #         |Rel| #1-hop|#MPRs| #lost |reservd|C|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:          List of IP addresses of 1-hop neighbors            :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:           List of IP addresses of MPR neighbors             :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:           List of IP addresses of lost neighbors            :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

   Type == 2.

Length

   Length of the incremental advertisement data, in bytes,
   including

Sequence #

   Advertisement sequence number

Rel

   Reluctance (2 bits). A node selects a low value for its
   reluctance, if it is willing to be identified as an MPR, and
   thus potentially as a member of the connected dominating set.

#1-hop

   Number of new one-hop neighbors

#MPRs

   Number of new nodes classified as MPRs

#lost

                Number of nodes no longer in the one-hop neighborhood
                (and, thus, not possibly MPRs) as shown in the last full
                advertisement

        'C'

                The 'C' flag is set if the advertising node has selected itself
                as a member of the connecting dominating set for flooding

        1-hop list

                List of IP addresses of new 1-hop neighbors (#1-hop total
                addresses)

        MPR list

                List of IP addresses of new MPR neighbors (#MPRs total
                addresses)

        lost list

                List of IP addresses of former neighbors that have not
                exhibited local connectivity recently (#lost total addresses)

    The IP header TTL for the Incremental Advertisement MUST be 1.

        DISCUSSION: is 255 better?

        DISCUSSION: Is the Length field needed, or should we spend
        the bits on enlarging the other fields?

6. Security Considerations

    This draft specifies a general mechanism for identifying a flooding
    backbone in an ad hoc network. It does not make any provision for
    securing the contents of the flooded data, either to protect against
    tampering or to protect against unauthorized inspection of the data.

It does not make any provision for ensuring that the nodes of the
flooding backbone are operating as expected. It does not make any
provision to guarantee the correctness of information presented
within the advertisement messages. The use of local broadcast for
the advertisement messages precludes the use of point-to-point
security associations such as might be used for constructing
Authentication Header digests.

In the future, if further security measures are to be undertaken,
one could attempt to utilize public keys for the purpose of
authenticating the flooded data, as long as the public keys were
known to be properly associated with the node in question (to avoid
man-in-the-middle attacks).

7. IANA considerations

   New multicast addresses have to be allocated. A new UDP port number
   has to be allocated for the neighborhood messages. ICMP is another
   possibility.

8. Acknowledgments

   Thomas Clausen and Emmanuel Baccelli were frequent contributors to
   the conversation which inspired the production of this document. The
   algorithm for identifying the flooding backbone was published as
   Research Report 4597 [1] by Cedric Adjih et al.

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Author's Addresses

   Questions about this memo can be directed to:

       Charles E. Perkins
       Networking Technology Laboratory / Nokia Research Center
       313 Fairchild Drive
       Mountain View, CA 94303
       +1 650 625 2986
       +1 650 625-2502 (fax)
       Charles.Perkins@nokia.com

       Thomas Heide Clausen
       INRIA Rocquencourt, BP 105,
       78153 Le Chesnay Cedex
       France
       +33 1 3963 5133
       Thomas.Clausen@inria.fr

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