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Title: PNNI Routing Support for Ad Hoc Mobile Networking: The Multilevel Case

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Abstract: This contribution extends the Outside Nodal Hierarchy List (ONHL) procedures described in ATM Forum Contributions 97-0766 and 97-0933. These extensions allow multiple mobile networks to form either an ad hoc network or an extension of a fixed PNNI infrastructure. A previous contribution (97-1073) covered the simplest case where the top-most Logical Group Nodes (LGNs), in those mobile networks, all resided at the same level in a PNNI hierarchy. This contribution covers the more general case wherein those top-most LGNs may reside at different PNNI hierarchy levels. Both of the SNL contributions consider "flat" ad hoc network architectures – in the sense that each mobile network always participates in the PNNI hierarchy at the pre-configured level of its top-most LGN.

1.0 INTRODUCTION:

Two previous ATM Forum contributions [1,2] covered the most important mobile network case – namely one mobile network joining, and leaving, a fixed PNNI infrastructure. Those contributions defined a mobile network as a group of ATM switches that are mobile, yet fixed with respect to each other. One practical example is an ATM LAN on a plane or ship.

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This informational contribution extends the Outside Nodal Hierarchy List (ONHL) procedures described in [1,2]. These extensions allow multiple mobile networks to form either an ad hoc network or an extension of a fixed PNNI infrastructure. A previous contribution [3] covered the simplest case where the top-most Logical Group Nodes (LGNs), in those mobile networks, all reside at the same level in a PNNI hierarchy. This informational contribution covers the more general case wherein those top-most LGNs reside at different hierarchy levels. This contribution discusses very general ad hoc network topologies. However, realistic ad hoc networks will probably not have more than a few (e.g., two) PNNI levels.

This contribution considers a "flat" ad hoc network architecture – in the sense that each mobile network always participates in the PNNI hierarchy at the pre-configured level of its top-most LGN. While this simple, flat architecture seems applicable to small ad hoc networks with low mobility rates, it may not meet all of the routing requirements of more general ad hoc network topologies [4,5]. As such, future contributions should also consider more complex hierarchical architectures in which the level of a mobile network's top-most LGN can change. Those hierarchical architectures may provide better link-state aggregation in large ad hoc networks.

2.0 PROTOCOL EXTENSIONS for AD HOC NETWORKING:

This section starts with the simplest case -- namely two mobile networks without an adjoining fixed infrastructure. It then generalizes that procedure to N mobile networks, again without an adjoining fixed infrastructure. Finally, it describes how a merged mobile network can join, and subsequently leave, a fixed PNNI infrastructure.

2.1 Two Mobile Networks Without an Adjoining Fixed Network

Consider the simplest case of two mobile networks, A and B. Assume that the top-most LGN in network A resides at a lower PNNI hierarchy level than the top-most LGN in network B (i.e., level(B) > level(A)). Assume that they have no adjoining fixed networks.

Those two mobile networks can learn each other's hierarchies via the ONHL process given in 97-0766 [1]. After their top-most LGNs realize that they reside at two different hierarchy levels there are two options. The simplest one is given below. It has obvious problems. After it is enumerated and discarded, a better solution is presented.

The simple option's protocol outline is as follows.

i) Have A and B exchange Nodal Hierarchy Lists (NHLs).
ii) A and B realize that their top-most LGNs reside at different levels.
iii) B does nothing.
iv) A instantiates LGNs at the necessary hierarchy levels so that its top-most LGN's level matches B's top-most level.
v) A re-floods its new NHL downwards in its network.
vi) B learns A's new NHL (via the ONHL process of [1,2]).
vii) A and B use the previously-proposed procedures in [3], for mobile-to-mobile networks, to agree on a common top-most PGID for their combined mobile network.

This option works, but it has two problems. First, A and B were intentionally placed at different hierarchy levels. It seems inelegant, and arbitrary, to force A to operate at a higher level. There are also address-space concerns, since the network operator may have a limited supply of address prefixes at B's level. The second problem is that this option has poor recursion properties. If another mobile network, C, appears with a top-most level higher than B's top-most level then A and B would both have to instantiate top-most LGNs at C's level. If C leaves then do A and B revert to B's configured top-most level? Or do they continue to operate at C's top-most level?

A better solution allows A to join B at A's configured top-most level. The protocol outline is as follows.

i) Have A and B exchange NHLs
ii) A and B realize that their top-most LGNs reside at different levels.
iii) B does nothing.
iv) A runs the ONHL procedures of [1,2] -- treating one of the lower level PGs in network B as a "fixed network".

This second protocol should be faster than the first one proposed above. First, network A doesn't have to instantiate any new LGNs. Second, networks A and B do not have to run the previously-proposed Mobile Peer Group ID Selection process (MPGIDS) [3]. (That process is a distributed election that takes place in the top-most LGNs in A and B if their levels are the same. The MPGIDS state machine is patterned on the existing PNNI Peer Group Leader Election (PGLE) state machine.) Instead, all the decision making is self-contained in A's topmost LGN.

The next subsection covers the N-network case. It shows that recursion is possible; however, the routing paths may become suboptimal.

2.2 Three Mobile Networks Without an Adjoining Fixed Network

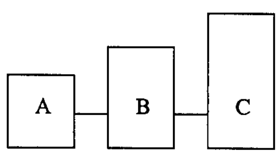
Consider the case of three mobile networks, A, B and C. Let the ordering of their top-most LGN's levels be level(C) > level(B) > level(A). Assume that they have no adjoining fixed networks. There are then four sub-cases.

2.2.1 All three networks have connectivity to each other.

All three networks exchange NHLs. After that occurs, network A can join either network B or network C. If A joins B then it joins below the level of B's top-most LGN. Hence, if B joins C after A has joined B then A's top-most PGID does not change. The procedures of [1,2] ensure that network B's choice for its top-most PGID does not change the PGIDs in any of B's lower-level PGs. Hence, B's decision, for its top-most PGID, does not affect A's choice for its top-most PGID. Similarly, B's choice of topmost PGID has no effect on the lower-level PGIDs in network C. So, if network A joins network C then B's decision for its top-most PGID does not affect network A. (Note: this all holds true even if A is in the process of joining B, while B is in the process of joining C. Even during that transient condition, networks A and B can still make independent decisions -- if they reside at different levels in the PNNI hierarchy.)

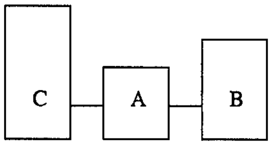
Finally, if level(B) equals level(A) then A and B should make independent decisions as to which network C peer group(s) to join. That process should be conceptually identical to networks A and B independently joining a fixed-network infrastructure. The relevant protocols are given in [1,2,3].

2.2.2 A can talk to B. B can talk to C. A and C can't talk.



Conceptually, this is the same as section 2.2.1. A joins B and B joins C. Networks A and B can still make independent decisions. Network C still does nothing -- other than examine ONHLs within its own network.

2.2.3 A can talk to C and B, but B and C can't talk.



The pertinent question is, "How does B achieve a common hierarchy with network C, when they can't directly exchange NHLs with each other?". One simple solution generalizes the ONHL up-propagation procedure proposed in [1,2]. Those contributions stopped the OHNL up-propagation at the top-most LGN within each mobile network. This contribution proposes that each mobile-network's top-most LGN also flood its ONHL list within its topmost PG. (For bandwidth efficiency in wireless networks, it might do so only if either another LGN in that PG also advertises that it's part of a mobile network or if that PG's PGL advertises that it's part of a mobile network.) This flooding provides that PGL with the ONHLs from both its network's nodes and the ONHLs from any attached lower-level mobile networks. So, if that PGL is part of a lower-level PG in another mobile-network then its decision process, for which ONHL that it will up-propagate, is now based on a complete set of ONHLs. That may eventually help its mobile network's top-most LGN select a better primary access point. An example may help.

In the diagram above, assume that network A has joined a PG in network B. In that case, network A would advertise the combined NHL for A and B over its outside link to network C. (That advertisement conforms to normal PNNI operation.) Similarly, network A would receive network C's NHL over that same outside link. That ONHL information would up-propagate to Network A's top-most LGN via the procedures of [1,2]. Network A's top-most LGN would then flood that ONHL throughout the lower-level PG in network B that it joined. The procedures proposed by [1,2] allow that PG's PGL, in network B, to select one and only one ONHL for up-propagation within Network B. So, there are two options.

i) Lower-level PGLs can still only up-propagate one, and only one, ONHL. However, the selection process is now constrained. They should preferentially select based on the level of the top-most LGN in the OHNL. (Note: contribution 97-1073 [3] has already suggested preferential selection based on mobility state such "fixed", "mobile" and "mobile, but attached".)

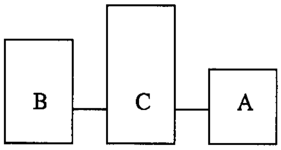
ii) Lower-level PGLs up-propagate one, and only one, ONHL for each attached network (but still not one for each access point). Those lower-level PGLs could still indicate their preferred NHL. (This requires some additional flags in the ONHL proposed in [1,2].)

Option (i) is simpler. It also minimizes protocol overhead. It provides Network B with the NHL of the highest-level adjoining mobile network (This is network C in our example. In the general case, network B would preferentially obtain the NHL of the highest-level fixed-network. Its next preference would be the highest-level "mobile, but attached" network.) This allows B to join a lower-level PG in network C.

Option (ii) may provide flexibility during network optimization though since it provides the top-most LGNs with better connectivity information. In either case, network B's choice of top-most PGID still has no effect on the PGIDs in network A. However, after B joins network C then A's advertised NHL must include network C's hierarchy also. (Again, this seems to conform to normal PNNI operation.)

If network A has joined network C then the protocol is simpler. Network A's NHL, that it advertises over its outside links, includes the combined NHL of both network A and network C. (That behavior seems consistent with normal PNNIv1 operation.) In that case, network B joins the appropriate PG in network C, based on the combined ONHL of networks A and C.

2.2.4 C can talk to A and B, but A and B can't talk.



This is a trivial subcase of section 2.2.1. Networks A and B both treat network C like a fixed infrastructure in [1,2]. Networks A and B can still make independent decisions. Network C still does nothing -- other than examine ONHLs within its own network.

So, the proposed protocols work for general, hierarchical ad-hoc network topologies. However, they do divorce the physical and logical topologies. Hence, the routing paths may be suboptimal and address summarization is still a problem.

2.3 A Merged Mobile Network Meets a Fixed Network Infrastructure

Consider the merged mobile networks A, B and C with the interesting connectivity given in Section 2.2.2 above. (Again, let the ordering of their top-most LGN's levels be level(C) > level(B) > level(A).) Let's then consider four interesting sub-cases.

2.3.1 All three mobile-networks have fixed-network connectivity.

In this case, all three mobile networks have received at least one NHL from the fixed-network through at least one access point in each of those mobile networks. (Note: Contribution 97-1073 discussed adding additional tags to the NHL/ONHLs [3]. Those tags differentiate between "fixed", "mobile" and "mobile, but attached" networks. A "mobile, but attached" network is a mobile network that is currently using a fixed-network PGID for its top-most PGID.) The proposed, modified ONHL up-propagation process [3] gives preference to fixed-network ONHLs. Hence, each mobile network's top-most LGN would eventually receive a fixed-network ONHL. So, each mobile network could make an independent decision to join some fixed-network PG via the procedures of [1,2].

2.3.2 Only mobile-network A has fixed-network connectivity.

Assume that only mobile-network A has received a fixed-network NHL from one of its access points. That fixed-network NHL is preferentially up-propagated to A's top-most LGN. At that point, A changes PGIDs from network B to some fixed-network PGID. Network A also sets its Mobility State from "mobile" to "mobile, but attached" (see [3]). Finally, network A's NHL now contains upper-level PGIDs from the fixed-network. At this point, A has a hierarchy mismatch with mobile network B. Hence, network A loses connectivity to both networks B and C. However, networks B and C can still continue as a single merged mobile network. Eventually, network B's top-most LGN will receive the combined ONHL for network A and the fixed-network. After that, network B's top-most LGN will join a PG in the fixed network. Network B will then change its Mobility State to "mobile, but attached". In addition, network B's NHL will now include the upper-level fixed-network PGIDs for the fixed-network PG that network B joined. Hence, network B's NHL must be a subset of the fixed-network PGIDs that were advertised in network A's NHL. Similarly, network C will also join the fixed-network in a PG that is an ancestor of both A and B's choice for fixed-network PG. Hence, this case illustrates a realistic topology wherein a lower-level mobile-network's choice for its fixed network PG subsequently constrains the choices available to the other higher-level mobile-networks.

2.3.3 Only mobile-network C has fixed-network connectivity.

Assume that only mobile-network C has received a fixed-network NHL from one of its access points. That fixed-network NHL is preferentially up-propagated to C's top-most LGN. At that point, C changes its top-most PGID to some fixed-network PGID. Network C also sets its Mobility State to "mobile, but attached". Finally, network C's NHL now contains upper-level PGIDs from the fixed-network. However, network C's choice for its top-most PGID has no effect on the PGIDs of its lower-level PGs. Hence, network C's choice for its top-most PGID has no effect on any PGID in either network A or B. Hence, networks A and B obtain fixed-network connectivity without the transient disruptions of Sections 2.3.1 and 2.3.2.

2.3.4 Only mobile-network B has fixed-network connectivity.

For network A, this case is similar to Section 2.3.3. Network B joins a fixed network PG. However, network B's choice for its top-most PGID has no effect on the PGIDs of its lower-level PGs. Hence, network B's choice for its top-most PGID has no effect on any PGID in network A. In contrast, Network C will see some transient disruption, after it learns the fixed network hierarchy via Network B's new NHL. After receiving its new ONHL from Network B, Network C can join a fixed network PG via the protocols of [1,2]. Again, Network C's choice for its fixed network PG is constrained by Network B's previous choice.

3.0 CONCLUSIONS

Section 2 showed that a merged mobile-network can recursively obtain fixed-network connectivity. However, it again points out a fundamental design tradeoff. There may be less network disruption if only the top-most LGN in the merged network joins the fixed-network. In that case, only one PGID changes. However, that simplification violates the design principle that each mobile network should make independent decisions. (That principle can not be iron-clad though. Sections 2.3.2 and 2.3.4 illustrated realistic topologies where a lower-level mobile-network's choice for its fixed network PG subsequently constrained the choices available to the other higher-level mobile-networks.)

REFERENCES:

[1] D. Dykeman, I. Iliadis, P. Scotton, L. Frelechoux, and S. Ray, "PNNI routing support for mobile networks", ATM Forum Contribution 97-0766, September, 1997.

[2] D. Dykeman, I. Iliadis, P. Scotton, L. Frelechoux, and S. Ray, "Routing support for mobility (baseline text)", ATM Forum Contribution 97-0933, December, 1997.

[3] L. Martinez, P. Sholander and L. Tolendino, "PNNI Routing Support for Ad Hoc Mobile Networking: A Flat Architecture", ATM Forum Contribution 97-1073, December 1997.

[4] S. Corson and J. Macker, "Mobile Ad Hoc Networking: Routing Protocol Performance Issues and Evaluation Considerations", Internet Draft (ftp://ftp.ietf.org/internet-drafts/draft-ietf-manet-issues-00.txt), September, 1997.

[5] C. Perkins, "Mobile Ad Hoc Networking Terminology", Internet Draft (ftp://ftp.ietf.org/internet-drafts/draft-ietf-manet-term-00.txt), September, 1997.

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