Title: PNNI Routing Support for Ad Hoc Mobile Networking: A Flat Architecture

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Abstract: This contribution extends the Outside Nodal Hierarchy List (ONHL) procedures described in ATM Form Contribution 97-0766. These extensions allow multiple mobile networks to form either an ad hoc network or an extension of a fixed PNNI infrastructure. This contribution covers 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. Future contributions will cover the general case where those top-most LGNs reside at different hierarchy 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.

## 1.0 INTRODUCTION:

A previous ATM Forum contribution [1] covered the most important mobile network case – namely one mobile network joining, and leaving, a fixed PNNI infrastructure. This informational contribution extends the Outside Nodal Hierarchy List (ONHL) procedures described in [1]. These extensions allow multiple mobile networks to form either an ad hoc network or an extension of a fixed PNNI infrastructure. This contribution covers the simplest case where the top-most Logical Group Nodes (LGNs), in those mobile networks, all reside at

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the same level in a PNNI hierarchy. Future contributions will cover the general case where those top-most LGNs reside at different hierarchy 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 [2,3]. 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. Since this is an informational contribution, it presents several high-level design options for each case. The best options will then depend on the anticipated service scenarios.

### 2.1 Two Mobile Networks without an Adjoining Fixed Network

Consider the simplest case of two mobile networks, A and B. Let their top-most LGNs reside at the same level in the PNNI hierarchy. Assume that they have no adjoining fixed networks. Those networks can then learn each other's hierarchies via the ONHL process given in [1]. At that point, there are two main issues.

- How do A and B determine whether their neighbor is fixed or mobile?
- After that, how do A and B pick the PGID for their merged top-level PG?

The first question seems to require a new TLV (Type-Length-Value) entity in some Information Group (IG). So, one solution adds a new "Mobility State Information Group" (MS-IG) to the existing PNNI Hello Protocol [4]. The default value for the new Mobility State TLV, in that MS-IG, is zero -- which implies "fixed network". (Note: this allows backward compatibility with fixed networks. However it could cause problems, since it assumes that the *absence* of a received value implies a "fixed network".) Some other value then denotes a "mobile network". Finally, this IG's content must be up-propagated to the top-most PGL in each mobile network, along with the chosen OHNL.

A second solution would "tag" each level in the existing Nodal Hierarchy List (NHL) IG as either fixed or mobile. For backward compatibility, those tags might occur in a separate, optional Mobility State TLV entity within the existing NHL IG. The previously proposed OHNL process [1] could then also up-propagate that new TLV. (For backwards compatibility, the mobile networks' access points might have to add the Mobility State TLV to the incoming NHLs from fixed networks that are running PNNIv1. Again, this may cause problems since the *absence* of a value implies a "fixed" network.) The relative merit of these two approaches is probably determined by the Mobile Peer Group ID Selection process discussed below.

After networks A and B learn that each other is "mobile", and also each other's hierarchies, they must then run some "Mobile Peer Group ID Selection" (MPGIDS) process that decides which top-most LGN's PGID will be used by the merged top-most mobile PG. (For convenience, the selected LGN will be called the "Mobile Network Leader" (MNL). Suggestions for better terms than MPGIDS and MNL are encouraged!)

So, the next issue is what metric should the MPGIDS use? Three reasonable choices are:

i) Use the existing node IDs, or the LGNs' PGIDs.
ii) Use the existing Peer Group Leader Election (PGLE) Leadership Priorities.
iii) Use a new parameter, the "Mobile PGID Selection Priority".

For options (ii) and (iii), ties could be broken via either the nodes' IDs or the LGNs' PGIDs. After the MPGIDS process completes, the "winner" assumes the role of the fixed network in [1], and everything proceeds as stated in [1].

Option (i) is simple but inflexible. It requires no new parameters. Also, the previously proposed ONHL process [1] supplies all of the required decision information. However, a network designer can not assign preferred PGIDs to clusters of mobile networks. For small ad hoc networks this limitation may be acceptable though.

Option (ii) also works. It also requires no new parameters. However, the top-most LGN in all mobile networks should have a PGLE leadership priority of zero. This prevents mobile networks from affecting the PGLs in adjoining fixed networks. Finally, the PGLE leadership priority is not currently part of any IG in the PNNI Hello protocol across outside links. However, the proposed Mobile State IG could transport it, across outside links, in a new TLV.

Option (iii) seems the most flexible. It allows mobile networks to have a zero "fixed-network" leadership priority, while still allowing design flexibility in fully ad-hoc network clusters that have lost their fixed-network connectivity. This option does define a new parameter. However, the proposed Mobility State IG could transport it, across outside links, in a new TLV.

The final issue is the state machine for the MPGIDS. It could be modeled on the current PGLE state machine [4]. In that case, the enhanced PNNI Hello protocol must carry the MPGIDS information across outside links. That information includes the LGN's selection priority, the "My PGID Was Selected" bit and the node ID associated with the its preferred PGID. Finally, the MPGIDS information must also be up-propagated to each mobile network's top-most PGL. The proposed MS-IG could do this. So, the MPGIDS process may drive the design choice between a new TLV in the existing NHL versus one in a new MS-IG. It may be easier to put all of the mobility-related information (Mobility State tags (mobile or fixed), the MPGIDS information,...) into one new MS-IG, rather than appending it to the existing NHL IG.

There are some important differences between the proposed MPGIDS and the existing PGLE though. The current PGLE occurs across horizontal links within a single PG. Hence, the PGLE participants can exchange information via their direct Routing Control Channels (RCCs). However, the MPGIDS must operate across outside links. Hence, the MPGIDS information is initially propagated by the Hello protocol and other flooding mechanisms. Those mechanisms may be much slower than direct RCCs within one PG. After mobile networks A and B select a common top-most PGID, they can then exchange the MPGIDS information via a faster RCC.

### 2.2 A Mobile Network Joins an Existing Merged Mobile Top-Most PG

Let a third mobile network, C, arrive and have connectivity to either network A or B, or both. Also assume that there is no adjoining fixed network. Finally, assume that C's top-most LGN resides at the same PNNI hierarchy level as A's and B's. In that case Network C can learn the NHL of A or B, or both, via the OHNL process [1]. After that process completes, there are two options.

i) Network C uses the top-most PGID chosen by networks A and B.
ii) All three top-most LGNs re-run the MPGIDS process described in Section 2.1.

Option (i) might provide better stability. However, option (ii) conforms to the existing PGLE procedures. So, it seems the preferred model for the MPGIDS process. (The current PGLE process improves stability by increasing the PGL's advertised leadership priority by GroupLeaderIncrement after its election. Similarly, the MPGIDS process could implement a SelectionIncrement.) In either case, the top-most mobile LGNs can select a new PGID for their merged mobile network. One mobile network then assumes the role of the fixed network in [1], and that contribution's procedures then apply to the other mobile LGNs.

The procedures of Sections 2.1 and 2.2 allow an arbitrary number of mobile networks to form a topmost PG. After that occurs, they can route into each other's networks. There are several open issues though. First, address summarization and routing topology may be suboptimal. Second, there is a scaling problem since the number of LGNs participating in the MPGIDS is the same as the number of mobile networks. However, these two drawbacks also occur in a fixed network with the same number of $(n-1)^{th}$ level PGs. The routing problem could be solved if the switches could self-organize into "optimal" PGs. However, that problem is still a research issue. (The self-organization technique and the definition of "optimal" are both research topics.) In any event, the address summarization problem would still remain.

A third problem is that a newly-arrived mobile network will force a change in the merged mobile network's PGID if its selection priority is higher than that of the existing Mobile Network Leader. This same problem exists in fixed networks. However, in this case the PGID change temporarily affects routing (of connection setups) within the top-most mobile PG. In fixed networks, a PGL change does not affect routing within its peer group. This problem could be fixed by choosing option (i) in this Section. However, as previously mentioned, option (ii) conforms to the current PGLE procedures. So, it seems preferred.

A fourth problem is that reference [1] only up-propagates one OHNL to the top-most LGN in each mobile network. The proposed MPGIDS process requires that each mobile network's MS-IG be up-propagated. (There need not be duplicate MS-IGs associated with each pair of communicating mobile networks. Each mobile network could only send its MS-IG over a designated "primary access point" to each other connected mobile network. Alternatively, the lower-level LGNs could filter out duplicate MS-IGs from the same mobile network.) A fifth problem then occurs as follows. Assume that networks A and B have connectivity; as do networks B and C. However, networks A and C only have connectivity via network B. In that case, how do networks A and C obtain each other's MPGIDS information? One answer requires that each top-most LGN flood the MPGIDS information from its received MS-IGs across its primary access points to other mobile networks. (Again, flooding techniques seem required because the top-most LGNs are not yet in a common PG.)

The final problem is whether A, B and C should continue to use flooding techniques, for the MPGIDS, after they have a common top-most PGID. At that point, they can open direct RCCs between each other. The RCC mechanism would both reduce network signaling traffic -- which is important in wireless/mobile networks – and speed the MPGIDS process. However it also might complicate the MPGIDS process. The reason is that a newly-arrived mobile network would still use the flooding process, while the other mobile networks might use pair-wise RCCs.

### 2.3 Merged Mobile Networks Encounter a Fixed Network

The following procedures allow the merged A-B-C mobile network to recursively join a fixed network infrastructure. Assume, for example, that mobile networks A and B now have border nodes with a fixed PNNI infrastructure. Assume that mobile network C has connectivity to both networks A and B.

> i) First, let PGIDs from fixed-network PGs have precedence in the ONHL selection process. (Note: the proposed Mobility State TLV can convey this

precedence.) Mobile networks A and B leave the merged mobile top-most PG after they detect a fixed-network neighbor. At that point, networks A and B stop participating in the MPGIDS process. Next, they join some fixed-network PG(s) via the procedures of [1]. (Note: A and B may join different fixed-network PGs, since they autonomously acquire their top-most PGIDs from the fixed network.)

ii) After mobile networks A and B obtain fixed-network PGIDs, they no longer have a common top-most PGID with mobile network C. So, C must re-learn the new NHL of its "mobile, but-attached" neighbors. This also occurs via the ONHL process [1].

iii) The MS-IG for networks A and B must now convey another mobility state -- namely "mobile but attached". This indicates that this mobile network's top-most PGID is that of a fixed-network PG. So, during the ONHL up-propagation there are three priority levels -- fixed, "mobile but attached" and mobile. Hence, mobile networks will preferentially attach to fixed network PGs. However, their next preference is for "mobile, but attached" networks that are using a PGID from the fixed network. (Section 2.4 clarifies the need for the "mobile, but attached" state. That section discusses how the mobile network cluster leaves the fixed infrastructure.) Finally, if all of mobile network's neighbors are mobile, then it still runs the distributed MPGIDS process described in Sections 2.1 and 2.2.

iv) The mobile networks that now adjoin a "mobile, but attached" network must re-run the procedures of [1] with some "mobile, but attached" network as master.

v) Re-run steps (ii) through (iv) until each mobile-network learns the PGID of a fixed-network PGID. (Obviously, this may take a while.) Again, each mobile-network that uses a fixed-network PGID sends "mobile, but attached" in its MS-IG.

A second approach would have the mobile networks continue to run the MPGIDS process, after they have fixed-network connectivity. In that case, the selected MNL would acquire the PGID of a single fixed-network PG. After that, the MNL would flood that fixed-network PGID to the rest of the mobile-network cluster. This approach may entail less disruption -- since the entire mobile-network cluster would learn its new PGID faster in some circumstances. However, this second approach does not allow each mobile network to make independent decisions as to which fixed-network to join. Hence, it may be less scaleable than the first approach given in this section. Another problem is propagating the ONHLs that contain fixed-network PGIDs from the mobile network that has fixed-network connectivity to the MNL's network. That propagation requires a minor modification to [1], wherein PGLs only up-propagate ONHLs. Instead, each individual mobile network's top-most LGN would also flood OHNLs within the merged mobile-network's top-most PG – once it formed.

### 2.4 The Mobile-Network Cluster Loses Fixed-Network Connectivity

Wireless links may undergo transient problems. Hence initial operation should be as a partitioned PG with the fixed-network PGID. However, at some point, the fixed-network PGID should timeout. (Note: the default PNNI timer interval is 75 seconds. That may be unacceptable for mobile-network applications.) After that timeout, the mobile-network cluster should revert back to fully-mobile operation. The single network case is covered in 97-0766. The multi-network case is similar.

Once all of the mobile networks lose contact with the fixed-network LGN, their top-most LGNs can realize that all of the remaining LGNs are advertising "mobile, but attached". However, no LGN is advertising "fixed". (Again, there may be a problem since the absence of a mobility-state value implies a fixed-network. That implication seems dictated by backward compatibility concerns though.) That makes no sense. Hence, the network must have lost all of its links to the fixed infrastructure. At this point, there are two options.

> i) The mobile networks can revert to their own mobile PGIDs. After that, they can form a new combined mobile-network via the procedures of Sections 2a and 2b. (This may take a while.)
>
> ii) The mobile networks' top-most LGNs can retain their fixed-network PGID while they run the MPGIDS process. The combined mobile network then uses the newly selected top-most PGID.

In either case, a race condition may occur. For example, if network C takes too long to time-out its RCC to the fixed-network LGN then networks A and B may think that network C still has fixed-network connectivity. In that case, A and B might begin the procedure of Section 2.2, with Network C as the "mobile, but attached" network. However, after C finally times-out its fixed-network connectivity, then everything should work.

**3.0 CONCLUSIONS:**

This contribution's protocol extensions allow multiple mobile networks to form either an ad hoc network or an extension of a fixed PNNI infrastructure. It covered the simplest case where the top-most LGNs, in those mobile networks, all reside at the same level in a PNNI hierarchy. Future contributions will cover the general case where those top-most LGNs reside at different PNNI hierarchy levels.

The proposed Mobile PGID Selection (MPGIDS) process allows 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. The MPGIDS is a distributed, multiparty process that propagates it decision information via flooding. Hence, it may not meet all of the routing requirements of more general ad hoc network topologies [2]. However, it may be applicable to small ad hoc networks with low mobility rates. It may also apply to slow-moving gateway nodes that translate between PNNI and some ATM-centric version of MANET.

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