A Management Model for Ad hoc Networks

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Abstract: The digital revolution we are experiencing today has brought an increased penetration of wireless devices in our life. Devices of all kinds spontaneously form ad hoc heterogeneous networks which need to be managed efficiently. This task is the motivation of our research efforts and we aim to provide solutions regarding the management of mobile ad hoc networks (MANET). We propose a novel two-tier policy-based distributed and hierarchical organisational model. We introduce three node modules which relate to the physical node capabilities rather than their organisational role. These modules are the managerial entity (ME), the cluster leader (CL) and the terminal node (TN). A distributed policy repository (DPR) is implemented using LDAP and its replication functionality is exploited to achieve on the fly replication. The defined policies guide the behaviour of the system by enforcing appropriate actions when the desired conditions are met.

1. Introduction

We experience today a digital revolution which has essentially changed our way of life. The penetration of technology is ubiquitous and innovative devices emerge allowing us to communicate and exchange information at anyplace and anytime. Wireless devices of all kinds spontaneously form ad hoc heterogeneous networks which need to be efficiently managed. This task is the motivation of our research efforts and we aim to provide solutions regarding the management of mobile ad hoc networks (MANET). The task of network management has never been easy and dates back to the beginning of computer networks. Today we witness a shift of the interest towards the management of ad hoc networks. After the maturity of ad hoc routing protocols, which dominated initial research interest, the need for managing ad hoc networks has emerged as an important issue and is currently receiving significant interest.

[1] discusses scalability issues in managing ad hoc networks and presents some variations of organisational models. The Ad hoc Network Management Protocol (ANMP) [2] has been one of the first efforts and introduced an SNMP-based solution for MANETs. Recently the “Guerilla” management architecture [3] used mobile agents and utility functions to implement an autonomic management environment. We have come across two policy-based proposals as well. The first proposal [4] is a policy-based management architecture that also uses mobile agents. The second proposal [5] is a policy-based system trying to provide quality of service (QoS).

Managing an ad hoc network is fundamentally different from managing a fixed one because of its diverse nature. Links in an ad hoc network are by default unreliable and intermittently connected. Link breakage is frequent and normal; therefore the repair of a link is not an issue as in fixed networks. Nodes can be arbitrarily up or down since mobility and resource management factors are involved. Once again this fact is unavoidable and inherent in ad hoc networks. Thus we understand that in order to manage an ad hoc network efficiently, we have to address several unresolved issues and provide solutions tailored for ad hoc networks. First of all a new organisational model needs to be designed. Departing from centralised approaches we propose an innovative distributed and hierarchical model. A Policy-Based Network Management (PBNM) paradigm is adopted since we believe it is quite promising and applicable in MANETs. Our PBNM approach re-uses the IETF standardisation efforts.

In Section 2 we elaborate on our design decisions and present how this approach is suited to the ad hoc environment providing solutions for managing MANETs. In Section 3 we analyse the proposed organisational model and describe how our policy design and language is applied and used. In Section 4 we describe our current deployment and implementation efforts. Section 5 presents the related work in the field of MANET management and Section 6 provides a conclusion of our work and the future directions of our research.

2. Managing Ad Hoc Networks and Policies

As we have already mentioned, the diverse nature of ad hoc networks calls for differentiation from traditional organisational models. The centralised model of manager-agent is dominant in the management of fixed networks for various reasons. However the adoption of this model for managing ad hoc networks is not efficient and other models should be considered. The organisational model we intend to adopt will be distributed and hierarchical. Focusing our interest in ad hoc networks we can easily understand why a centralised organisational model is not suitable. In an ad hoc network we can not rely on a single central entity to manage the network because nodes are intermittently connected. The major problem of a single point of failure introduces the need for a distributed organisational management model. Management intelligence should be spread among nodes making the network fault tolerant. In other words, ad hoc networks’ properties, like intermittent links, sparse bandwidth and limited resources, make the centralised model inapplicable. Having in mind the limitation implied by an ad hoc network we believe that the combination of distributed and hierarchical organisational model can give solution to the problems encountered by the centralised approach. The distributed and hierarchical approach relies on more than one entity to collectively and cooperatively manage the network by maintaining a loose hierarchy among nodes. In this way the task of management is fault tolerant and reliable. In the next section we present and analyse our proposal regarding this novel organisational model.

Policies are seen as a way to guide the behaviour of a system through high level declarative directives. Beyond this definition, we view policies as means of extending the functionality of a management system dynamically, in conjunction with pre-existing hard-wired management logic [6].We consider a policy-based management paradigm suitable for ad hoc networks. In contrast with mobile code techniques, policy-based management is safer and less prone to malicious intruders because it provides limited and predefined programmability to its nodes, while at the same time is dynamic and adaptive to network behaviour.

An important issue is the representation of policies in a system and the policy language which is used. Both depend on the selection of an appropriate information model which will provide the common ground for identifying managed objects and defining policies. Standardisation efforts driven by the combined work between IETF (Internet Engineering Task Force) and DMTF (Distributed Management Task Force) has produced a series of RFCs defining the Policy Core Information Model (PCIM) [7,8] and extensions for QoS as well as mapping guidelines for the LDAP model representation [9,10]. The suggested architecture from IETF is depicted in Figure 1 and consists of four basic components: (i) Policy Management Tool (PMT), (ii) Policy Repository (PR), (iii) Policy Decision Point (PDP), (iv) Policy Enforcement Point (PEP). We choose to comply with IETF's directives by adopting this policy architecture and PCIM as the information model to represent policies. Based on this decision the definition of a policy language is implied and at this stage we use the simple but effective clause for *policy rules: if <condition> then <action>*.

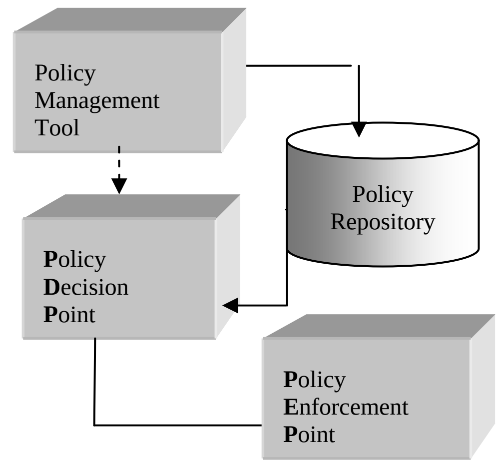

Figure 1 IETF's PBNM System Architecture

Beyond the selection of a language to define policies, the next issue to address is what policies are to be defined for the purpose of managing an ad hoc network. The issue of policies definition is mostly independent from the policy language and representation. It is more related to what are the management goals and objectives rather than what is to be managed. In our example implementation presented in Sections 3 and 4, we describe the definition and enforcement of policy rules which relate to the placement of the Policy Repository component. The placement of the Policy Repository and generally policy storage is a significant issue which needs to be resolved. The prevailing solution for policy storage is the Lightweight Directory Access Protocol (LDAP). The reasons for the dominance of LDAP as a policy repository are some of the useful features it has to offer. The object oriented design and implementation of a Directory using LDAP, the inherent capabilities to distribute and/or replicate the directory among network nodes make it attractive to ad hoc network management. Replication will increase policy availability, making the network more survivable and manageable.

3. Model design and architecture

As we have already mentioned, the diverse nature of ad hoc networks call for differentiation from traditional organisational models. Our approach is a two tier distributed and hierarchical model of a policy-based management system. The common terminology used in literature for node roles is adopted, i.e. manager node (mn), cluster head (ch) and cluster node (cn). In Figure 2 we can see the deployment of our organisational model with the "node modules" depicted. We introduce three modules that relate to the physical node capabilities rather than their organisational role. These modules are the manager entity (ME), the cluster leader (CL) and the terminal node (TN). From an organisational point of view, in this figure we have two manager nodes (top two MEs) and three cluster heads (two CLs and a ME in the middle) forming a "Hyper-cluster". The rest of the nodes act as cluster nodes. The key point in this model is that in spite of being highly distributed, it offers a logically centralised management capability.

a. <u>A distributed and replicated policy repository (D-PR)</u>: Replicas of the repository are distributed among Hyper-Cluster's nodes, thus ensuring on one hand maximum repository availability and on the other hand a single logical view of the stored policies. Effective management of clusters can be achieved even when temporarily disconnected from the network manager. The policy repository is a critical component and, as mentioned, we can not rely on a single node to store it in an ad hoc network. For this reason the repository should be replicated. We introduce the Distributed Policy Repository component, which is a logical entity physically distributed among hyper-cluster's nodes. The idea is that a replicated repository would be stored in selected nodes thus distributing traffic load and processing overhead. In addition to the MEs serving as managers, each cluster head which accommodates a replica of the repository will serve as an access point for repository requests within its cluster.

b. Three different software modules (ME, CL, TN): This feature allows us to cover a wide area of device capabilities and resources. Exploiting the full power of devices like laptops is possible, while at the same time lightweight devices like mobile phones and legacy devices can participate in the ad hoc network.

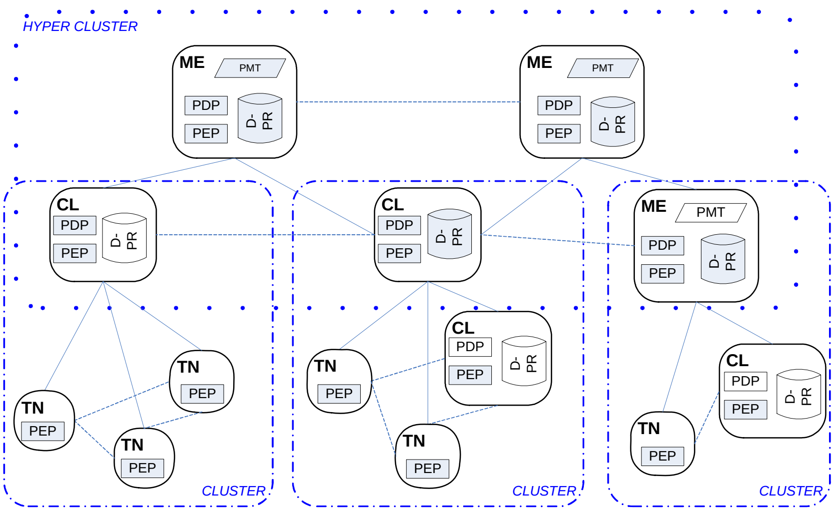

Figure 2 Deployment model

The Managerial Entity (ME) module is executed on privileged nodes which have the responsibility of managing the network. In other words, the nodes which have preinstalled this software are candidate network managers. These relatively powerful nodes, like laptops, accommodate the full functionality of the policy-based architecture. All four components of a PBNM system are present. When assigned to the manager node (mn) role, this module offers the capability of managing the network by introducing policies with the PMT. In this case it has the responsibility of verifying the new policies but most of all analysing them. Finding and resolving any policy conflicts should be also supported. The module also supports the cluster head (ch) and the cluster node (cn) role and is able to switch between the three roles depending on network status.

The Cluster Leader (CL) module is similar to the Managerial Entity (ME) module, but it lacks network management capabilities. The absence of a PMT component restricts it from introducing policies and consequently it can not be assigned to the manager node (mn) role. This module is hosted by relatively powerful to medium range devices and its main functionality is to manage a cluster when assigned to the cluster head (ch) role. It serves as a Policy Decision Point for its cluster and depending on network status it may hold a replica of the repository.

The Terminal Node (TN) module is the simplest module in the system and its main responsibility is to enforce policies locally. It is hosted by low-end devices, like mobile phones, with restricted capabilities. It only includes a PEP which has the functionality to enforce policy decisions received from its cluster head's PDP over its managed objects.

c. A multi-manager paradigm: We allow more than one physical nodes to act as a manager since ad hoc networks can be collectively managed by different managing entities. The idea behind the multi-manager paradigm lies in the nature of ad hoc networks and the purpose of their formation. As mentioned earlier, ad hoc networks can form spontaneously from users or groups with no previous affiliation. So from an administrative point of view, having more than one managers give us the flexibility to form networks between distinct administrative authorities. This is done without any of them being forced to give up its management privileges.

d. The formation of a Hyper-Cluster: The overall manager nodes and cluster heads form a Hyper-cluster where management operations are performed. Management intelligence and the policy repository are distributed among these nodes. Peer-to-peer communication between cluster heads is allowed for exchanging management information.

Beyond the design of the organisational model, we started the modelling of the policies which will guide the behaviour of the system. Our efforts focus on the definition of the necessary policies rather than the formal definition of a policy language. For this reason we choose to follow the generic definitions of IETF which allows us to specify and customise any policy by subclassing the existing objects defined in PCIM [7,8]. At first step, we choose to model the policies which will drive the placement and replication degree of the Distributed Policy Repository (DPR). The DPR component is a physically distributed component, which consists of the master Policy Repositories (PR), placed on manager nodes (mn) and their replicas, placed on selected cluster heads (ch). One or more replicas may exist depending on network status and node mobility. A manager node has the ability to dynamically define the behaviour and the replication degree of the DPR by inserting related policies on the fly

and without shutting down the system or the DPR component. The system can be in one of three possible states: (i) Single repository: At this state the ad hoc network is considered as relatively static, i.e. node mobility is low and the link quality is fairly good. Therefore all hypercluster's nodes can efficiently retrieve policies from a single PR master copy. (ii) Selective replication: At this state the ad hoc network volatility is increased, i.e. node mobility causes frequent link breakage and the link quality is fair. Some additional PR replicas are instantiated in critical points within the hypercluster to reduce bandwidth utilisation and efficient policy retrieval. (iii) Full replication: At this state the ad hoc network is considered as extremely volatile, i.e. node mobility is high and the link quality is very poor. Therefore all hypercluster's nodes need to keep a local PR replica in order to efficiently retrieve policies and provision their cluster with them. A graphical representation of these states is shown is Figure 3.
We must note that the scope of these policies applies only within the Hyper-cluster nodes, thus it is obvious that a hierarchy of policies is designed.

4. Deployment and Implementation Issues

Based on the design and modelling we have described earlier, our initial implementation efforts focus on one hand on the modular and extensible implementation of the node modules (ME,CL,TN) and on the other hand on the extension of the PCIM to accommodate the modelled policies. Our approach is to develop the four components of a PBNM system (PMT, PDP, PEP and PR) separately and use the appropriate components in each module. We have partially implemented the Managerial Entity (ME) and Cluster Leader (CL) using Java 2 SE (1.4.2) and tested them in a small scale emulated network.

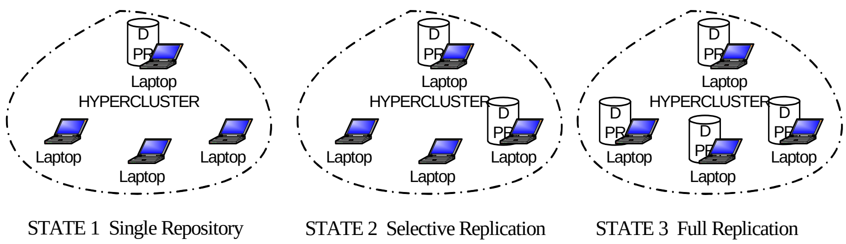

Figure 3 Replication states for the DPR component

We have modelled the policies which guide the DPR replication state in PCIM. Using PCLS and PCELS RFCs [9,10] we have mapped PCIM policies to appropriate LDAP classes and based on these we have implemented our LDAP schema extensions for the new classes we have defined. We also define a new metric: the Fluidity Meter (FM), which characterises how fluid and volatile is the ad hoc network. It ranges from 0 to 9, with bigger values representing higher fluidity. This metric will be extracted from collected network and context information. In our current implementations FM is emulated and we assume that it is available at the application layer. Policies will define in which state the network should be by defining the limiting values (LowLim and HighLim) for each state. PDPs will enforce the defined actions by checking the conditions and monitoring the Fluidity Meter (FM) of the network. The three policies we have defined are the following:

if (FM = {0 .. LowLim}) then (Repl_Deg := State1)
if (FM = {LowLim .. HighLim}) then (Repl_Deg := State2)
if (FM = { HighLim to 9 }) then (Repl_Deg := State3)

The change of the replication state is guided by the above policies. These are entered in the system by the GUI of PMT which relies inside a ME module. The actual implementation of this state change is succeeded using the syncrepl functionality of openLDAP. We have used the openLDAP LDAP server with the schemas mentioned before for the implementation of the Distributed Policy Repository. Using the syncrepl functionality of openLDAP we have implemented the replication of the master PR to slave copies of PR on the fly and without the need to disrupt the operation of the master. The policy-driven state change between State 1 to State 2 and the replication procedure is fully implemented.

5. Conclusions and future work

In our first attempt to tackle the problem of managing ad hoc networks we have identified several crucial issues to be resolved. We have focused on the design of a suitable organisational model which will cater for the diverse needs of MANETs. We chose a Policy-based management paradigm which will enable a controlled yet dynamic programmability of the network. Our proposed organisational model differentiates node roles from node modules (ME, CL, TN). We introduce the notion of the Distributed Policy Repository which will increase policy availability to PDPs and reduce the traffic and performance overhead at the manager node. Policies guide the behaviour of the DPR and define its replication state according to network status and node mobility. In our future work we intent to define new policies to provide the means to effectively control the whole network. We will examine the use of a more sophisticated policy language and will address critical issues such as policy analysis and policy conflict detection and resolution.

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