# Peer-to-peer management in Ambient Networks

Csaba Simon[1], Róbert Szabó[1], Péter Kersch[1], Balázs Kovács[1], Alex Galis[2], Lawrence Cheng[2]

[1]Budapest University of Technology and Economics, Department of Telecommunications and Media Informatics, Magyar Tudosok krt. 2., 1117, Budapest, Hungary. {simon, szabo, kersch, kovacsb}@tmit.bme.hu
[2]University College London, Department of Electronic and Electrical Engineering, Torrington Place, London WC1E 7JE, United Kingdom. {a.galis, l.cheng}@ee.ucl.ac.uk

*Abstract*—**Nowadays the spread of wireless technologies and mobile devices shape networking visions of ambient and persistent mobile networks that mobile users are able to have resort to. Since ambient networks are heterogeneous, distributed and dynamically forming networks, new and sophisticated network management architecture is needed to cope with the special network preferences. In our paper we reveal a peer-to-peer management architecture, which creates management domains by dynamically organizing network components into a hierarchical management overlay networks We also present a prototype implementation of our proposal and the results of some performance measurements.**

*Index Terms*—**management, peer-to-peer, ubiqutos networking**

## I. Introduction

In the last decade we witnessed an exponentional growth in the installation base of wireless data communication devices. The wireless technology became a mature and cheap technology, being accessible for a wide user community. The growing proportion of wireless devices in the LANs will eventually lead to the disappearance of the frontiers between the wired and wireless networking paradigms. Although wireless technologies continously evolve improving their robustness and their efficiency, the characteristics of the wireless media and mobility issues still persist. The combined wired and wireless networks will have to meet the tougher challenges posted by their wireless parts. Additionally, the wireless interfaces will enable very dynamic connectivity scenarios, that should be supported by the wired half of the networks, as well. All these aspects will force network operators to reconsider the network management paradigms to allow more dynamic and simple assimilation or interaction of the existing managed network with new networks or individuals. Therefore we argue that the new networks, which will sorround us at our home, workplace or public spaces will natively support the management of wireless devices and will allow a seamless combination of various networks. The network management will act as a glue that enables the controlled share of resources.

Recently started EU project called “Wireless World Initiative – Ambient Networks” [1] aims at an innovative and industrially exploitable mobile network solution beyond 3G, which enables composition of networks across business and technology boundaries. To achieve desired goals, the project focuses on multi-radio access, network composition and connectivity, mobility and moving networks, smart multimedia routing and transport, context aware networks, security and network management. For a more detailed overview of the AN reader is referred to [2].

The key concept of Ambient Networks (AN) is network composition. Networks compose and gain connectivity through instant establishment of inter-network agreements. This will provide access to any network instantly. From the point of view of the end user, Ambient Networks will provide ubiquitous connectivity. Users are able to obtain connectivity instantly at any place at any time. Moreover, the user obtains ubiquity through network compositions that do not require manual interaction. Composition, in this document, refers to the instant negotiation (based on policies) between network resources under composition for the provisioning of an IP service.

Network composition brings new challenges to network management. First, the management systems of both networks should join into a consistent management system for the composed network. Management for such composed networks has to be simple and low cost (especially for personal networks), while scalable and robust, which will make these networks themselves scalable and robust.

In order to tackle the challenges posted by the complexity of composition and decomposition, we propose a peer-to-peer technology based approach. Peer-to-peer approach realizes interaction between individual management systems to establish a consistent management system for the entire composed network. Applying peer-to-peer principles to network management also promises a management system with higher scalability and robustness.

We consider the peer-to-peer Ambient NWs management as a possible solution to the management of future heterogenous networks. The next Section overviews the requirements and related work. Section III introduces our peer-to-peer-based solution to AN management. Section 4 presents a prototype implementation of the solution and some measurement-based performance evaluation. Finally we conclude our paper.

## II. Management issues of Ambient Netwroks

### A. Management requirements

We evaluated several scenarios to derive the requiremnts towards the AN management system (AMS), as detailed in [3] and [4]. If the AMS fulfills these requirements, an AN will optimize its resources to provide the services requested by its members, based on network conditions or administrative policies. Thus we concluded that the composition of different AMSs should answer the challenges below.

• A simple, flexible, efficient and scalable mechanism is needed to pool and share management information across heterogeneous networks.

• Composable AMSs should be service-oriented: they should be capable of supporting new services on demand through dynamic reconfiguration of network elements.

• Composed networks are autonomous, i.e. AMSs may leave or join arbitrarily. Also, unforseen events should not disable the AMS, it should be robust.

### B. Related work

Most of currently deployed network management systems – including the most widely used SNMP management framework [7] - are based on centralized client-server architecture. With the increasing size and complexity of managed networks, this management paradigm is no longer adequate. Client-server architecture doesn't scale well, is not fault tolerant and lacks flexibility. Several distributed network management protocols [9] have been proposed to overcome these problems and create management solutions that suits the needs of future heterogenous networks.

One of the first proposals towards a distributed approach was the "management by delegation" paradigm [10]. Delegation consists of downloading software code to a remote agent allowing local processing of some or all of management data. The mobile agent based management architecture [11][12] goes one step further, Instead of downloading management code for each agent, a single mobile agent can be launched from the managing entity, performing data processing and management actions. Agent intelligence is also a key concept in mobile agent based management. The intelligent agent paradigm [13] delegates to managed entities not only processing of management data but also management decision capabilities.

We propose a novel scheme based on the peer-to-peer paradigm that addresses the callanges introduced above. Its efficiency and simplicity are conferred by the peer-to-peer mechanisms. The scalability is assured by the overlay hierarchy, introduced in the following section. The management information databases are replicated among several peers to increase the robustness of the system. The decisions about possible combinations (or compositions) of networks are guided by policy-rules defined at peer-levels.

## III. P2P management

The management architecture application proposed here is based on the peer-to-peer and the policy driven management paradigms. It combines the distributed nature of the P2P architecture and the flexibility offered by policies. The key notions of the new management architecture are network composition and self-organization. Using their policy rules and P2P negotiation, peers self-organize themselves into a dynamic hierarchical overlay network structure. On one hand, the creation of this network structure is an important configuration management task, but even more important: the created hierarchical network structure also defines hierarchical management domains. By dynamically creating and maintaining these management domains, our architecture provides a scalable framework for all other management tasks.

### A. Peer-to-peer hierarchy

Hierarchical structures and clustering are commonly used methods to create scalable systems in a number of different networking areas like for example routing. The most important feature of our hierarchical management overlay network is that it is created dynamically and unlike in the above example for IP routing, it doesn't require any network administrator interaction.

The basic components of this management overlay network are *peers, super-peers* and *peer-groups*. A peer-group is a set of peers forming a common management domain. Thus a peer-group is roughly equivalent to the Ambient Network (AN) notion. The notion "peer-group" will be used mainly to describe overlay network structure.

Network management within a peer-group is distributed; there are no dedicated servers to manage relationships between peers of the group. To negotiate with other peer-groups, each peer-group elects a representative called super-peer. Logically, each peer group has one and only one super-peer. However for fault tolerance and fast recovery after super-peer crashes, super-peer management information is distributed within the group.

Super-peers may also form peer-groups at a higher hierarchy level hereby creating a hierarchical network structure. Figure 1 show the representations of an example hierarchical overlay network (thick lines mark super-peers). In this example network, both peers A, B, C and D, E, F form peer-groups.

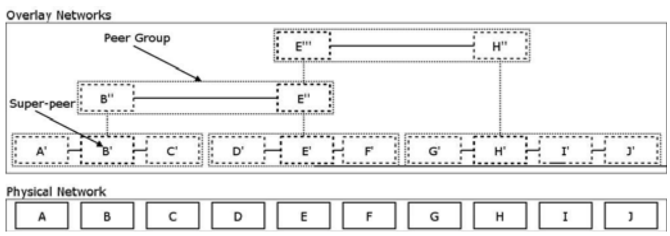


**Figure 1 – Hierarchical overlay network (tree representation)**

Also, super-peers of these two groups – B and E – form a higher level peer group. The number of hierarchy levels in the overlay network is not limited: one peer can be part of multiple peer-groups at different levels of the overlay hierarchy (e.g. peer E is part of three different peer-groups at different overlay levels).

Another characteristic of the p-AMO overlay network is that hierarchy levels are not absolute. This means that we can't assign an absolute hierarchy level index to a peer group (see again Figure 1, where the top level peer group comprises one peer at the 3th and an other at the 2nd hierarchy level).

However, a bottommost overlay is defined for all peers. This bottommost overlay is a dedicated layer, tightly related to the real physical network. Two peers can be neighbors at the bottommost level peer group only if they are physical neighbors. This restriction ensures that all members of a peer group can communicate with all other peers of the group (directly or through other peer group members). If the group was split into distinct parts that cannot communicate with each other then it could not be considered to be a common management domain. However physical neighborhood doesn't automatically imply neighborhood relationship at the bottommost overlay group. For example two peers with basically conflicting policies will not establish neighborhood relationship in the bottommost overlay network even if they are physical neighbors.

Maintaining the overlay structure in a highly dynamic distributed environment presents many challenges. Super-peers cannot be treated as fault tolerant highly available servers: they may fail or leave their group ungracefully at any time. Therefore network structure and topology information of a peer-group is stored in a redundant manner evenly distributed among group members. The detailed solution is presented in [5].

The so-called policy framework is responsible for the automated, rule-based, decision making in network composition situations. Each peer has its own policy that specifies its preferences and limitations on joining a given Ambient Network. The aggregate of the policies of the individual peers within a peer group is called the policy of an AN. For a detailed descripition of this framework the reader is asked to consult [6]

## *B. Composition Types*

The network composition process may finish in different ways. If the policy database of the two networks is close enough to each other (there is no contradiction in the preferences and the differences between policy rules can be accepted mutually), the networks can join in a way that is called *absorption or network integration*. Absorption is the full merging of the two networks. They will form a single management domain with one common super-peer.

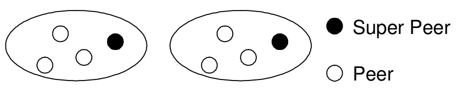


**Figure 2 – Example of two ANs before composition**

Take the case of two ANs in Figure 2. If they are composed through absorption, the result is a single, new AN, as presented in Figure 3.

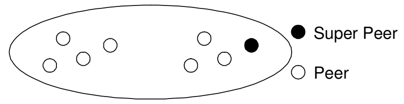


**Figure 3 – Composition through absorption**

In case the absorption of the networks is impossible according to the policy rules, there is a trade-off option between full absorption and full separation. This special partly joined way of operation is called: *gatewaying or control sharing*. In this case, one or more gatewaying nodes are selected in both networks, which will be responsible for the management and control-plane communication with the other network. No other way of network management communication is possible (i.e., the gatewaying node cannot be bypassed in inter-network control-communication). If we take again the two ANs from Figure 2, the composition through gatewaying would result in an overaly AN, as shown in Figure 4. Note, this is a logical overlay. We also marked the super-peer of the new overlay AN, which has been elected among the lower-level super peers.

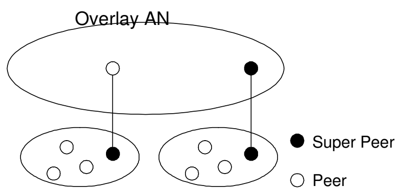


**Figure 4 – Composition through gatewaying**

It has to be emphasized that networks connected with gatewaying are not separated networks; they are composed networks but they do not share all information. This means that they will be seen as a single network from the outside so the networks have to be represented by one super-peer.

## *C. Dynamic Service Management*

We also prospose a management service overlay network (known as the Ambient Virtual Pipe). It is being developed based on a flexible and programmable infrastructure. This management service overlay network is created dynamically between AN management entities and to provide secure and QoS assured means of communication channels between management entities in composed ANs or across different ANs.

During the initial stage of AN composition, individual AN nodes with their own AN come together and request (if possible) to form a composed AN. For instance, AN1, AN2 and AN3 in Figure 5 are created through absorption respectively. Once a composed AN is created, a Super-Peer is elected among the participating AN nodes, being a representative of a community of peers within an AN domain. The AVP is now further developed as both a management service overlay network and as other services support overlay in order to be complementary from the Super-Peer concept for P2P management within AN. The AVP is management service overlay network that is used by the Super-Peers for enhancing, controlling, and deploying AN management services between

Super-peers in a more efficient way inside and across AN domain(s).

The AN4 overlay network from Figure 5 is *management service overlay network* across different underlying ANs. The need of this secure and QoS assured management service network overlay is essential. Traditionally, a network domain administrator is only concerned with administrative issues within its own domain. Customers within a particular domain whom are requesting for services can expect to be served with some level of service guarantee from its own network domain administrator.

Examples of service guarantees are QoS, security… etc. The inter-domain service management is complicated due to the heterogeneous environment of different domains. The idea of AN composition and the creation of a management service overlay network among Super-peers provides a mean to achieve inter-domain service management.

Note that the creation of this management service overlay network is achieved through the instantiation of AVPs across the participating Super-peers.

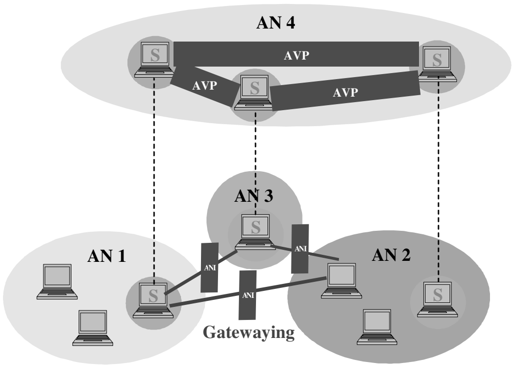


**Figure 5 – Example of Active Virual Peers**

AVPs provide the necessary QoS and resource assurance and security for protecting the management traffic within the management service overlay network in a dynamic fashion. The creation of AVPs between Super-peers is supported by a flexible and programmable infrastructure. All management traffic in the AVP is encrypted and the peer-to-Superpeer relation is confidential in the sense that a peer does not see any other Peer-to Superpeer relations. A programmable platform is therefore desirable to support the level of flexibility required by AVPs.

The dynamic creation of AVP is achieved by dynamically injecting active code to desired Super-peers in order to instantiate AVPs. QoS is assured through the injection of active code to dynamically prioritizing AVP traffic. DINA is used as a programmable platform in AN to support AVP provisioning [5]. Figure 5 also shows the actual deployment of AVP through a programmable network.

## IV. Prototype implementation

### A. *Peer-to-peer platform architecture*

Based on the management architecture presented above we implemented a peer-to-peer platform. The platform removes the burden of handling hierarchical network structures from management functions. The platform consists of two main parts, the core and several modules.

The core implements the most important and basic tasks (e.g. message delivery, overlay maintenance). Using the services of the core of the platform modules (applications) can be defined. These modules offer higher level services. In Figure 6 we represented the core with the vertical bar.

Modules implement several management functionalities. In order to add flexibility to our platform, some basic functionalities has been implemented as modules. The super-peer election funcion and the policy negotiation and maintenance functionalities all are implemented as modules. Thus if a new algorithm is requested by the operator or owner of a peer then this need can be satisified in a flexible manner. Additionaly, each management function is implemented in separate modules. E.g., we show the monitoring module in Figure 6.

Instant and automated network composition is one of the most important features of ambient networks. Every incoming composition requests is queued while composition negotiation is realized for earlier requests. Thus an overlay may run only one composition process at a time.

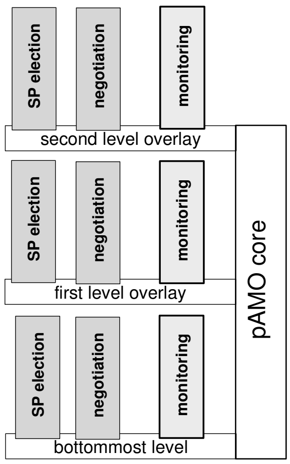


**Figure 6 – Peer-to-peer Ambient Management Overlay platform structure**

If a peer is responsible for inter-domain management of multiple ANs (that is, it has been elected as super-peer), the management platform will run a separate instance of this module per overlays. Figure 6 shows a peer with the bottommost layer and two additional overlays. Thus the modules are only responsible to manage their own overlay. Of course, this asks for a careful design of the message-flow among different overlays within the same peer, but we provide a variety of messaging APIs to ease this task.

### B. *Measurements*

We measured the delay from the detection of a new AN to the completion of the composition process. During this period three mechanisms are invoked, as follows. First, the enqueiung of the composition requests are performed. Then the decision on what type of composition to follow is taken. Finally, the new super-peers are elected and (in case of gatewaying) a new overlay is instanciated. We used two laptops with IEEE 802.11b network cards as two peers. At the start of the experiment, each laptop (peer) formed its own network, thus they acted as super peers, as well. Then they were allowed to detect each other, and then they initiated the composition process. The policy rules were set in such a way that the resulted composition was an absorption or gatewaying, depending on the experiment.

**Table 1. Performance of composition process**

| Composition type | Average delay [sec] | Stdandard deviation [%] |
|---|---|---|
| Absorption | 3.686 | 20.77 |
| Gatewaying | 4.140 | 18.67 |

We repeated each experiment ten times. We present the resulted average delays and the standard deviations (as percent of the average delay) in Table 1.

We analyzed the process in more detail and we detected that the enqueueing of composition intentions took 2.943 for gatewying and 2.803 for AB in average. These are quite large values (approximately 75% of overall delays), and in the later parts of the project we will try to reduce this overhead through a more efficient queueing and processing of these requests. Note that the 'pure' composition-related delay is less than 1 second for the absorption and 1.2 seconds for the gatewatying case. The difference between absorption and gatewaying is caused by the longer decision process and the initialization of the services in the new overlay. This latter takes 0.193sec in average.

## V. Conclusion

The aim of the "Wireless World Initiative – Ambient Networks" EU-IST project is to enable future wireless heterogenous networks to seamlessly compose across operators' boundraries. This paper introduced the system components of a novel peer-to-peer Ambient Management Overlay (p-AMO) framework that enabled the management of such highly dynamic networks.

We presented a peer-to-peer management framework based on multi-level super-peer hierarchies. The network composition can end in a full merger of the involved networks, called absorption. However, if the two networks do not want to share all their managed resources, they can go for a gatewayed composition. The decision on which alternative to take is negotiated among the representatives of the composing networks, called super-peers.

We presented the architecture of our protoype system that implements our conspets and we measured the performance of basic composition operations.

## VI. Acknowledgements

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