Performance Analysis of Network Composition in Ambient Networks

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***Abstract**. Currently, resource sharing and service offering remains subject to troublesome, manual configuration and to extensive, previously established agreements. Ambient Networks have emerged to facilitate cooperation between heterogeneous networks, usually among different administrative domains and technologies. This cooperation can be achieved with the adoption of a new key networking concept which is called by composition. The performance of the composition is a key factor for determining the feasibility of Ambient Networks, since it is expected to be extensively used during a typical interaction between a user and the network, itself. This paper presents a network composition simulator and a performance evaluation that uses a voice service aimed for supporting the demands for composition. The obtained results show that, for the scenario which is under consideration, composition does no represent an obstacle when supported by a voice service.*

1. Introduction

The evolution and growth in the systems scale, computer networks, Internet, Web and resources and IT solutions (Information Technology) as all, associated to the high cost on provide IT services show up the necessity of sharing resources, provide services and network cooperation – done through agreements. Currently, these agreements need extensive manual configuration, as well as a previously knowledge about the network behavior it will act. However, the heterogeneity of devices, the diversity of available services, dynamism, mobility and asynchronous nature of devices and services make unviable the complex task of centralized management and prediction of state or operation context 0.

Ambient Networks (AN) 0 have been proposed to allow the competition and cooperation in the aforementioned context. It is a new networking concept, which aims at enable the cooperation of heterogeneous networks belonging to different operators or technology domains. This cooperation should be transparent, under demand and "plug-and-play", i.e., no previous configuration or negotiation should be required between network operators. The main innovative concept introduced by AN is Network Composition which allows fast adaptation of the network domain topology as required for mobile users and moving networks, providing access to any network, including personal mobile networks, through instantaneous and on demand agreements between the networks, called Composition Agreement.

It is important to evaluate the performance of the composition, since it represents a crucial factor in the viability of the Ambient Networks, due to the expected high demand for composition in an interaction of a typical user with the network. Moreover, a deep understanding of the main characteristics of composition and decomposition of Ambient Networks are also needed. Since these concepts are innovative, new management models must be developed and therefore performance analysis will provide significant subsidies for guiding this activity. Some relevant characteristics to be well understood are establishment, duration, cost, stability and frequency of a composition.

This work evaluates the viability of using dynamic network composition as a mechanism which is capable of providing instantaneous service access for the users. This mechanism should be sufficiently scalable to fulfill the high demands for ubiquous services from the mobile users. Complex compositions should be more stable and occur less frequently, introducing a lower impact not only in the user response time, but also in terms of the amount of resources needed to deploy them. On the order hand, frequent compositions should be performed in a fast and cheap way. Because it is unrealistic to test such concepts in a practical and real scenario (ANs are not available yet), a simulator was developed to allow a performance analysis study and to provide new insights, as weel as, to improve the general comprehension of the network composition mechanism.

The rest of the paper is structured as follows. Section 2 summarizes the main concepts of Ambient Networks including Network Composition. Section 3 presents PBMAN, a framework which aims at manage Ambient Networks. In section 4, the developed simulator, ANCSIm, is described. Section 5 shows the XPBMAN prototype and measurements performed using it. Section 6 presents the evaluation of Network Composition and the obtained results. Finally, section 7 draws some conclusion and topics for future work.

2. Ambient Networks

Nowadays it is common that a user owns different devices such as palmtops, cell phones or laptops. However, there is no network that interconnects these devices to share resources. An Ambient Network is a collection of networks, nodes and/or devices sharing a common control plane, called Ambient Control Space (ACS) 0. The ACS is comprised of a collection of functional entities (FEs), each one reflecting different control and management tasks, such as composition, mobility, security and QoS. These FEs work independently but cooperate with each other to guarantee total interaction between the networks. Each Ambient Network has a unique identifier and it is accessible for users or other Ambient Networks in a controlled way through well defined external interfaces.

Network Composition 0 is the key architectural concept and the main challenge of Ambient Networks that aims at enabling control-plane interworking and sharing of control functions among networks. Intuitively, composition can be thought as a mechanism for automatic negotiation of roaming and/or service level agreements (SLAs), which today are done manually. Composition goes beyond what the Internet and mobile networks can provide today and is not restricted to basic addressing and routing. Composition enables seamless mobility management, and improved network and service efficiency. It also hides interconnection details of cooperating networks to the outside.

A network composition may result in a new Ambient Network with a new identifier, or may extend an already existing Ambient Network with the identifier of that Ambient Network 0. When Ambient Networks compose, their ACSs interact with each other and the composed Ambient Network can appear to the outside as a single uniform Ambient Network. The ACSs are responsible for deciding which services and/or devices will be shared in the new network. This information will form the Composition Agreement (CA) 0 which defines the level of interworking between the networks. An individual Ambient Network may participate in multiple network compositions concurrently for different purposes.

Ambient Networks may compose with others Ambient Networks in different types or degrees of composition, depending on how tightly the individual networks compose and how the control planes of the networks involved are self-reorganized. The type of composition may influence strongly the contents of the CA and the behavior of composed AN defining the level of cooperation between the composing ANs. Three types of composition were identified as the following: Network Integration, Control Sharing and Network Interworking 0. When individual network completely merge and create a unique new ACS, the composition is called Network Integration. When networks partially merge during a composition, it is called Control Sharing, where only a subset of the services/resources of the constituent individual networks will be part of the new composed network. Composition also encompasses legacy (current) forms of interactions between networks (i.e., connectivity), which are classified as Network Interworking.

3. PBMAN

PBMAN (Policy-Based Management for Ambient Networks) 0 is aimed at designing and implementing a management infrastructure for Ambient Networks. PBMAN adopts the Policy-based Management (PBM) technique and the main underlying enabling technology is Peer-to-Peer (P2P). A primary design principle adopted in PBMAN is to keep the architecture as general and simple as possible. As new experience is gained with designing and implementing the framework, new features and functionalities are added. PBMAN is focused on the role and implementation of the ACS functionality. There are two types of implementations for the ACS: PDN ACS and Agent ACS, the later comprised of User ACS and PEP ACS.

The Policy Decision Network (PDN) is responsible for implementing most of the PBMAN concepts and functionalities, mostly related to Policy-based Management and P2P interworking, such as storing and retrieving policies and taking decisions about received requests. In other words, the PDN is the P2P-based distributed implementation of the ACS for PBMAN. The PDN is comprised of two main entities, Decision Points and Repositories. A Decision Point, also called PDN Node or P-Node, is a policy server, which accepts some part of the whole PDN work. The PDN is able to interwork with other P-Nodes by a distributed P2P network, based on Distributed Hash Tables (DHT) 0, which is called PDN-ring. The PDN-ring provides PBMAN with the inherent features of P2P systems, such as load balancing, fault tolerance and scalability.

Agents are represented by hosts, equipments or devices utilized by users or by the network for providing services and enforcing policies. The interaction between agents and the PDN is based on the hierarchical P2P DHT-based adopted approach. There are two types of agents in PBMAN: PEPs and Users. PEPs are agents aimed at enforcing policies, such as routers, firewalls and remote access servers. PEP agents are also software and hardware for providing services, which must enforce policies for access control, security, accounting, etc. Users represent devices or networks of connected devices that a given real user is using for accessing AN services and resources. An Agent ACS runs on user endpoints and on PEPs.

By focusing on the efficiency and performance goals, PBMAN identifies some different types of network compositions, in order to be able to optimize each one as much as possible. Composition is currently classified in PBMAN according to the type of ACS involved (PDN and Agent). Three different types of composition are possible considering this criterion: PDN/PDN, PDN/Agent and Agent/Agent. The PDN/PDN composition requires the creation of a new PDN network. Some examples of this type are the composition of network providers (of any type), private (business) networks, home networks and moving networks (car, bus, train, plane). An important aspect about this type of composition is that they may take some considerable time to be performed, but they will typically happen only when the first user tries to access services of a remote network. PDN/Agent composition happens in order to provide communication between agents and the PDN. Typical usages are: the request of services and resources for users and the request of policies for PEPs, both from the PDN. Agent/Agent composition includes typical host to host and host to equipment interaction in the current Internet. Interaction of agents in an ad-hoc fashion is also considered.

4. ANCSim

Nowadays, the evaluation of network composition in a practical and real way is not possible yet, so a choice was made for making it through simulation. In order to achieve this goal, ANCSim (Ambient Network Composition Simulator) was specified and implemented. ANCSim is a specific purpose simulator for Composition of Ambient Networks, covering the main features described in sections 2 and 3. Current existing simulation tools, such as ns-2 0, present a level of granularity (evaluates through packages) and/or abstraction (no module for Ambient Networks) that does not fill the requirements demanded for analyzing the performance of network composition. Therefore, a specific simulator for evaluating it was developed.

ANCSim implements some important features of Ambient Networks in a high level of abstraction. It is assumed that networks are stable and failures such as packet loss and excessive delay do not occur. Actual network conditions are not taken into account in the simulations because the required detail level was considered to be neither suitable nor necessary to evaluate network composition.

ANCSim is comprised of Ambient Networks and services. Each Ambient Network has a set of services that are used by its users or offered to others Ambient Networks. ANCSim supports the types of networks proposed in PBMAN: PDN and Agent. PDN networks are responsible for making a decision about the service requests and keeping management information such as services being used by composed networks and the number of active compositions in a particular moment. PDNs can be composed with each other. Agent Networks are attached to PDNs. In ANCSim, each Agent must be connected to exactly one PDN. This type of network represents users or user devices and is responsible for requesting services to others Agent Networks. Service requests are processed by the PDN where the Agent is connected to. The duration of each service is configured in the beginning of the simulation and each service has a limit in the number of users utilizing it. When this limit is reached, the service will be unavailable and a failure is reported to users. The service will be available again when one of the users using the service, stops to use it. This will free up the resource and other users will be able to use the service.

In ANCSim, the composition is triggered by a service request generated by an Agent network to another Agent network. The service request can generate or not a composition request according to the service availability in the networks involved. After check this condition, a path between source and target network must be selected. The path will be formed by all networks that interconnect these two networks and the requested service need to be available in all networks composing this path. After finding a path, the composition itself could be started. The composition takes place between the adjacent networks of the path found and are executed sequentially. Considering Figure 1, AG1 as source and AG7 as target. The path between these two networks is comprised of the following networks: AG1 – PDN1 – PDN2 – PDN5 – AG7. The composition will be realized between the networks AG1 and PDN1 (1 - Agent/PDN), PDN1 and PDN2 (2 - PDN/PDN), PDN2 and PDN5 (3 - PDN/PDN), PDN5 and AG7 (4 - Agent/PDN) respectivally.

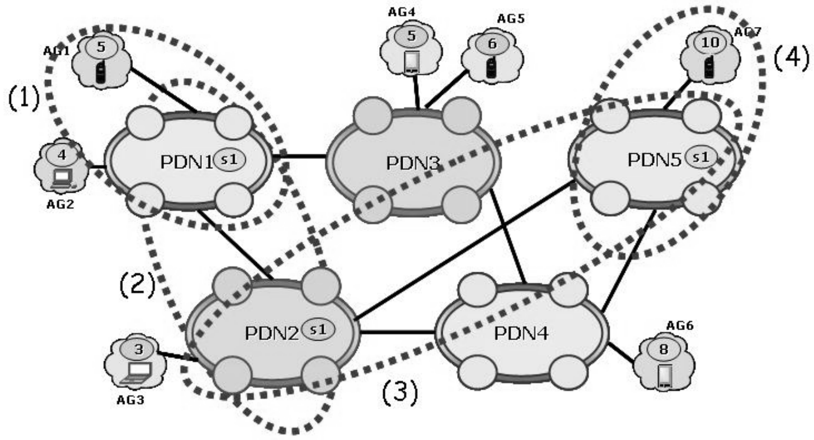


Figure 1. Composition Process

Decomposition will occur only if there is no active service session between the composed networks. Parameters defined in the beginning of simulation determine when decomposition should happen: immediately or after a specified time. In first case, as soon as the service is finalized, a verification is done to know if the networks need to remain composed or not. Decomposition will only occur between the networks that does not share any kind of services. In this case, the composition agreement is finalized and the services will not be shared anymore. In second case, this verification occurs after a specified time determined through factors defined in the beginning of the simulation. The goal with this approach is to avoid recomposing networks just a few time after decomposing them.

5. Measurements Results

In order to provide a higher level of reality to the results, the simulation model uses the composition duration times obtained from measurements in the X-PBMAN prototype. These data are closer to real results since thery are based on a real implementation, even though in a controlled environment. After the times had been collected, an empirical distribution was constructed in order to represent the collected data and it was used for generating the composition duration. Next sub-sections describe, respectively, X-PBMAN prototype and the measurements for Agent/PDN and PDN/PDN compositions.

5.1 X-PBMAN Prototype

A simplified proof-of-concept prototype implementation of PBMAN, called X-PBMAN, was developed to explore and understand the combined Policy-based Management and Peer-to-Peer approach adopted in PBMAN. X-PBMAN is implemented using the X-Peer 0 P2P middleware. X-Peer is a middleware designed and implemented for supporting P2P applications, based on a hierarchical architecture where super-peers (X-Peer nodes) communicate to each other through a DHT network. This feature allows X-Peer nodes to find any existing information in the network in at most *log(n)* hops, where *n* is the number of super-peers. The main advantage of this proposal is the assurance of information location in a distributed and hierarchical network. Also, X-Peer is aimed at supporting various different P2P applications in a single middleware platform, thus differing from current solutions that usually use a new network for each new application. Thess characteristic of the X-Peer architecture favours its use in the implementation of the PBMAN framework. Policy agents can be mapped to applications, whereas P-Nodes can be mapped to X-Peer nodes.

The P-Node architecture is depicted in Figure 2. It was designed and implemented for the X-PBMAN prototype, which performs some of the functionalities of the PDN ACS. Some external entities a P-Node has to interact with are also shown in the picture. The current version of the architecture is comprised of six modules, representing the Functional Entities (FE) of the ACS. A specific software module of X-PBMAN implements each FE.

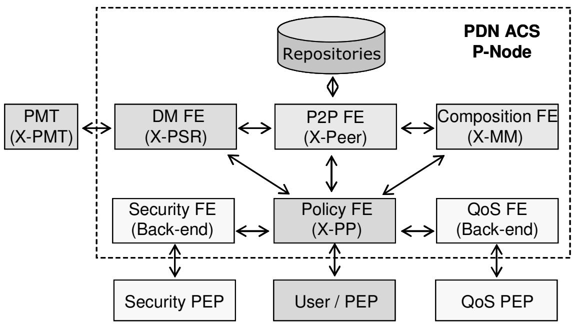


Figure 2. P-Node Architecture

The P2P FE is the core function of the P-Node, implemented directly by the X-Peer node, taking care of DHT-based policy location, routing, search and retrieval. The Composition FE is in charge of managing PDN/PDN composition in PBMAN. This module is called X-Peer Multi-ring Manager (X-MM), because a composition implies in creating a new PDN ring (DHT network) and managing two or more rings simultaneously. The Policy FE is the entry point for service requests and is responsible for processing policies to be enforced by PEPs. It is called X-Peer Policy Processing Module (X-PP). The DM FE implements a layer that extends the data storage capabilities of the DHT-network, in order to make it able to deal with more complex data structures, such as lists and tables. The QoS FE and Security FE are part of the policy system back-end, whereas the QoS and security PEPs are specific modules usually running on network devices in charge of configuring support services. The Repositories are implemented by the basic X-Peer storage method. The PMT (Policy Management Tool) provides functionalities for editing policies, management information and its relationships.

5.2 Measurements

In X-PBMAN prototype, an Agent/PDN composition is understood as an authentication in X-Peer middleware. This authentication is triggered by a service request. The Agent/PDN measurements were realized considering the topology presented in Figure 3.

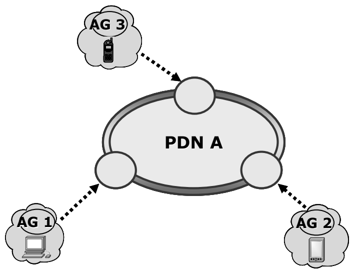


Figure 3. Agent/PDN Composition Topology

The topology is comprised of one PDN and three Agents requesting a login in X-Peer. The PDN is also receiving requests in background from other X-Peer applications resulting in different loads depending on the service request generated. The goal is representing different types of PDNs which treats different number of requests according to the number of Agents linked to each one. The measurement experiments were repeated 1000 times, i.e., 1000 Agent/PDN composition times were obtained. Also, three different levels of load were considered, low, medium and high, which represent the use of 10%, 50% and 90% of the CPU processing time. Figure 4 shows the histogram representing low level of load.

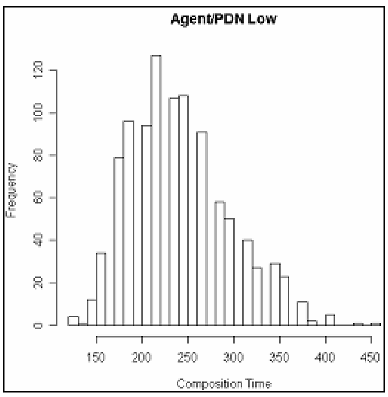


Figure 4. Agent/PDN Composition for Low Load

The histogram shows that the values of Agent/PDN compositions time vary among 150 and 400 ms. Table 1 shows the values of mean and standard deviation for the collected data representing Agent/PDN composition duration according to the load.

Table 1. Agent/PDN Composition Mean and Standard Deviation

Parameter	Mean (ms)	Standard Deviation (ms)
Low	240.927	55.6841
Medium	251.305	60.72391
High	289.847	73.80477

After the composition time had been collected, the data was tested using the Kolmogorov-Smirnov goodness-of-fit test in order to know if it follows any known distributions (for example, Normal, Lognormal, Exponential, Weibull, etc). Although, all these hipotesis were rejected. Assuming this, a choice was made in order to construct an empirical distribution. The empirical distribution was constructed considering the quantiles from 1 to 100 and it is used to determine the composition time of Agent/PDN compositions during simulations.

The scenario used to realize the PDN/PDN measurements is depicted in Figure 5. The scenario is represented by two PDNs, each one comprised of one P-Node. The experiment consist of compose these two PDNs and collect the time spent with this composition operation. The measurement experiments were repeated 1000 times, i.e., 1000 PDN/PDN composition times were obtained. Two PDNs, comprised each one of 1 P-Node, were used. Also, six different levels of load were considered, which represents different types of service being provided in each PDN (1, 10, 20, 30, 40 and 50 services).

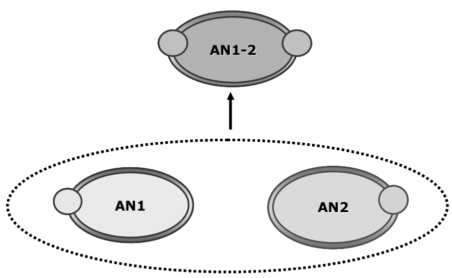


Figure 5. PDN/PDN Composition Topology

Table 2 shows the values of the mean and standard deviation for the collected data considering the load.

Table 2 - PDN/PDN Composition Mean and Standard Deviation

Load	Mean (ms)	Standard Deviation (ms)
1 service	8731.03	181.673
10 services	9387.34	322.2046
20 services	11818.92	1301.812
30 services	17297.37	2228.206
40 services	21552.05	3765.524
50 services	29740.15	4653.615

Figure 6 shows the histogram represent 30 services where the values vary between 15 and 20 s. In addition to the obtained with the other loads, this result confirms that a PDN/PDN composition is a expensive operation and takes considerable time to be performed.

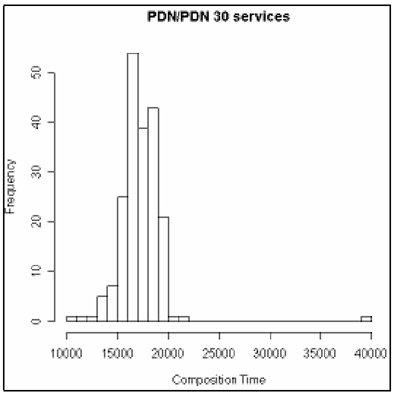


Figure 6. PDN/PDN Composition for 30 services

After the composition time had been collected, the data was tested using the Kolmogorov-Smirnov goodness-of-fit test in order to know if it follows any known distributions. Although, like Agent/PDN, all these hipotesis were rejected. Assuming this, a choice was made in order to construct an empirical distribution.

According to the number of users in each PDN and the collected data, the empirical distribution was constructed as shown in Table 3. The number total of users is related to the number of users of the composed network (comprised of the two PDNs involved in composition).

Table 3. PDN/PDN Composition Distributions

Total Number of Users	Distribution
< 200	Dist1
200 - 2000	Dist2
2000 - 4000	Dist3
4000 - 6000	Dist4
6000 - 8000	Dist5
> 8000	Dist6

The empirical distributions were constructed considering the quantiles from 1 to 100 of each specific collected data and it is used to determine the composition time of PDN/PDN compositions.

6. Simulation Results

This section explains the performance evaluation itself. Next subsections describe, respectively, the configuration used to run the experiments and the results.

6.1 Experiment Configuration

The topology used in the experiments is depicted in Figure 7. It represents part of RNP Network 0. This topology was chosen considering that both PDNs and Agent networks are structured and stable. The assumption is that this type of network is more likely to happen in early deployments of Ambient Networks where mobile users try to access services provided by stable networks.

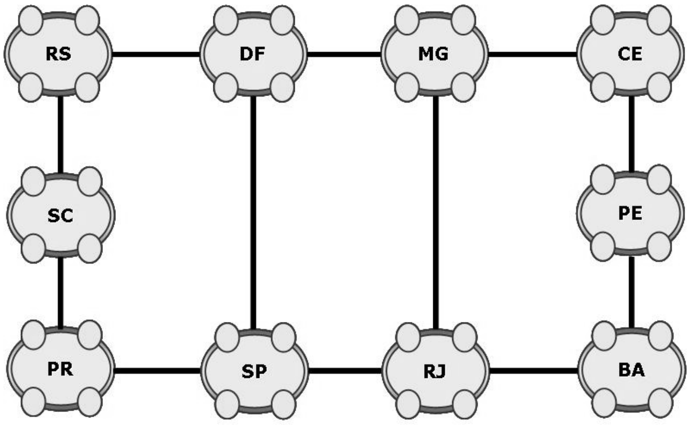


Figure 7 - RNP Network

Table 4 presents the parameters used in simulation. The values were chosen through preliminary simulations.

Table 4 - Simulation Parameters

Parameter	Description	Value
Simulation Time	Total Simulation Time in hours	1h
Replication Number	Number of replications of a series of experiments	30 replications
Services	Services provided by the networks that comprises the topology	VoIP and QoS
Duration	Mean duration of service in each Agent Network	2 minutes

Table 5 presents the factors and levels used in the simulation. Factors are variables that affect the outcome of the experiments. Each factor has a set of alternative values (levels). Levels are the values each factor can assume, that is, each level is an alternative for the correspondent factor.

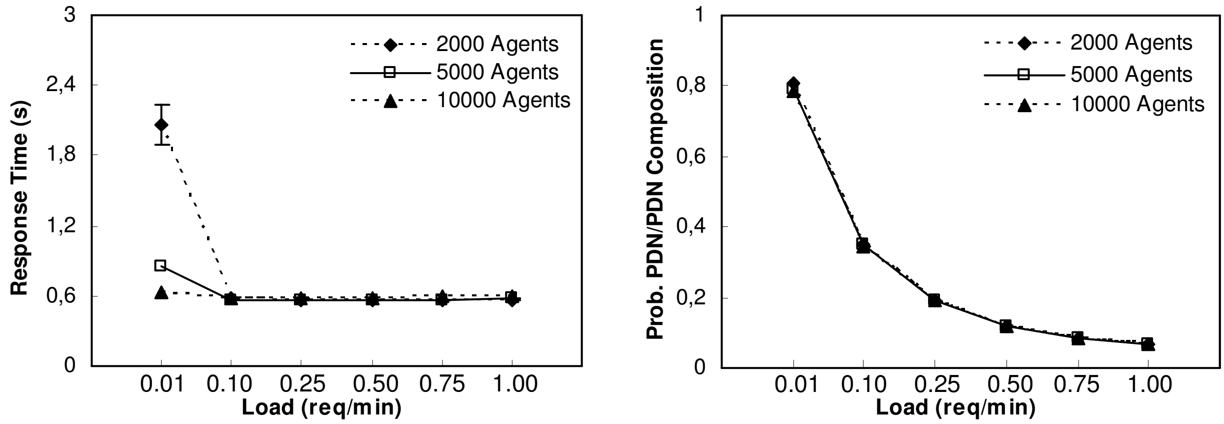
Table 5 - Simulation Factors and Levels

Factor	Description	Levels
Composition Overtime	Time that the networks wait to establish the decomposition	0, 10, 50 and 100%
Agent/PDN compositions per PDN	Percentage of Agent/PDN composition that each PDN can accept (Admission Control)	10, 50 and 100%
Number of Agent Networks	Total number of Agent networks in the topology	2000, 5000 and 10000 Agents
Load	Frequency with each service is requested	0.01, 0.1, 0.25, 0.5, 0.75 and 1 calls per minute.

6.2 Results

This section presents the performance evaluation of composition and decomposition in Ambient Networks. The goal is to determine how the composition process influences the service perceived by the users, adopting the response time as the most important metric. The mean values of the metrics are presented in graphs with confidence interval of 99%. However, it was omitted from almost all graphs because it was not significant and to facilitate visualization.

The response time is the first aspect considered. It consists of the amount of the time that a user waits for the requested service to be available. The goal of this evaluation is to analyze the influence of composition in response time and to determine whether the composition can degrade or not the user experience. By varying the load over the network and its size (number of agents attached to it), two graphs were derived and are presented in Figure 8.1



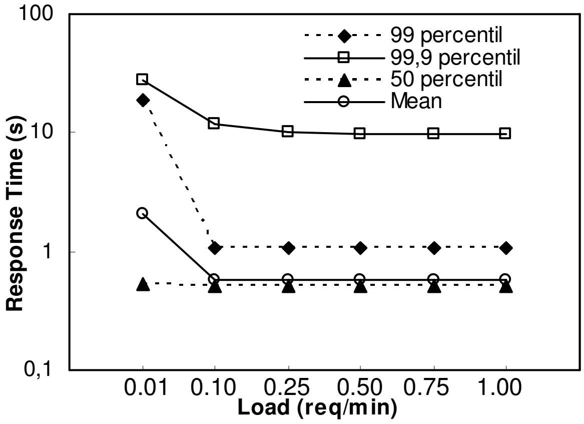
(a) 100% Agent/PDN and Overtime 0

(b) 100% Agent/PDN and Overtime 0

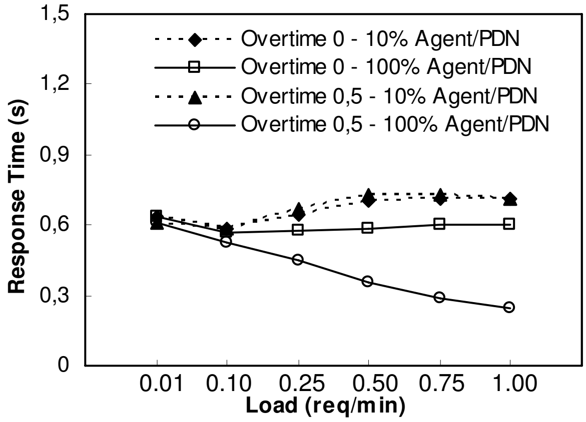
Figure 8. Response time for different loads and network sizes (a) and the probability composition given a service request (b).

The first graph, Figure 8(a), shows the average response time under different load conditions for networks of three sizes. The results show that as the load increases, the influence of the networks size on the response time becomes less significant. Also, the response time tends to decrease and stabilize with higher loads. This occurs because, when the load is lower, fewer service requests are done and there will be fewer users using the compositions. A composition is finalized when its users stop needing it, when a new user request needs the same composition, it needs to be redone and the response time for this user will increase. This will not occur when the load is higher because there will be users needing the composition most of the time, what prevents premature decompositions. In this situation, a new service request will probably not need new compositions to be done, what can be seen in the graph of Figure 8(b), which shows the probability of composition given a service request. As the probability decreases, fewer compositions will be needed by a request and lower will be the response time.

The results obtained show that most of the users' requests, under typical conditions, will receive low response times, as depicted by the graph of Figure 9 (a). This graph shows that the response time of 99% of the requests is limited in 1s given loads higher than 0.1 request per minute. These results are for a network with 2000 agents, which was the worst scenario evaluated. Even for high loads, some requests will still have response times of about 10s, but these requests represents less than one percent of the total number of requests.



(b) 2000 Agents, 100% Agent/PDN and Overtime 0

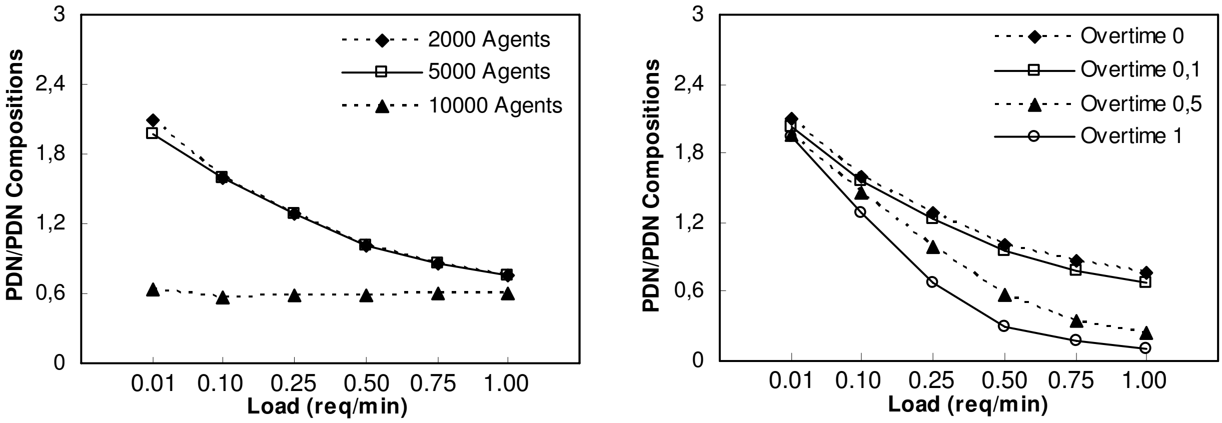


(b) 2000 Agents and 100% Agent/PDN

Figure 9. Response time percentiles (a) and the influence of overtime and admission controle (b).

A way to prevent premature decompositions is to extend artificially the lifetime of a composition so that fewer recompositions will be needed. The time a composition is kept alive with no requests depending on it was called *overtime*, which is calculated over the time the composition should be torn down due to inactivity (0.5 of overtime means that the networks will stays composed by more 50%, at least). The graph in Figure 9(b) shows the influence of overtime in scenarios with and without admission control (i.e. limiting the number of agent networks that can be composed simultaneously with a PDN). With a very restrictive configuration (10% Agent/PDN compositions allowed), the overtime has little influence over the response time. Such configuration causes very high request blocking and limits the effective load on the network, what explains the higher response times. When 100% Agent/PDN compositions are permitted, a 0.5 overtime can decrease the response time as the load increases, while the no-overtime configuration keeps the response time constant. Therefore, a well-configured overtime can contribute with the general network performance.

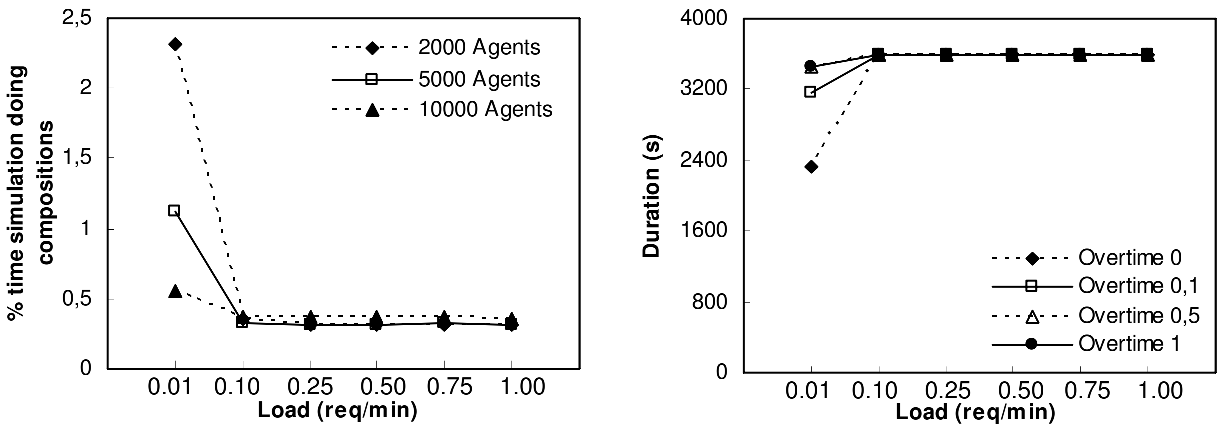
With respect to scalability, the graph in Figure 10(a) shows that the number of PDN/PDN compositions, which are far more expensive than Agent/PDN compositions, tend to decrease as the load increases for small and medium networks; for the network with ten thousand agents the number of compositions stay stable but always below the others. The reason is because more agents keep the compositions busy for more time, preventing unnecessary decomposition, as explained before. Improved results can be obtained using the overtime feature, as shown in Figure 10(b). Here the number of PDN/PDN compositions per service request is presented. The common behavior is to decrease the number of composition as the load increases. This behavior is enhanced by giving extra time to compositions. With no overtime, at least one composition will be needed by service request in average. For overtime 1, the number of compositions is reduced to less then 0.2 under higher loads. Based on these results, it is possible to say that to give extra time to compositions is a good strategy to reduce the number of compositions and the costs associated with them.



(a) 100% Agent/PDN and Overtime 0 **(b) 2000 Agents and 100% Agent/PDN**

Figure 10. Compositions per service request by network size (a) and overtime (b).

One way to see the cost of compositions is to determine the time spent by the networks processing compositions with other networks. The graph in Figure 11(a) show the cost of the compositions for the three network size evaluated. It is possible to see that the networks spend, in average, less than 0.5% of time doing compositions under higher loads; for low loads the ratio is limited in 2.5%. The next graph, Figure 10(b), explains this fact. This graph shows the composition durations, which are kept close to the simulation time, meaning that the compositions are made during the network startup and stay alive during almost all the network operation time.



(a) 100% Agent/PDN and Overtime 0 **(b) PDN/PDN - 10000 Agents and 100% Agent/PDN**

Figure 11. PDN/PDN Composition cost by network size (a) and duration (b).

7. Conclusions

This paper presents a performance evaluation of Network Composition which is the main important concept of Ambient Networks. Also, measurements are presented with the use of PBMAN, a Policy-Based Management framework for Ambient Networks, based on the P2P technology.

The research and proposal of network composition are recent and a performance analysis study could not be made in a practical and realistic way. So a choice was made for making it by means of simulations. In order to achieve this goal, a specific purpose simulator for Composition of Ambient Networks, called ANCSim, was designed and implemented. The results obtained show, in general, that the composition does not represent an obstacle to the deployment of Ambient Networks since PDN/PDN compositions, which take considerable time to be performed, will typically happen only when the first user tries to access services of a remote network.

As a future work, an evaluation using more complex scenarios that permit analysis of behavior from different perspectives, while focusing the situation from the network operator's point of view, will be a welcomed initiative. Futhermore, it will also be welcomed the implementation and evaluation of mobility and connectivity aspects that may permit the test of these important concepts in Ambient Networks.

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