A Non-anchored Unified Naming System for Ad Hoc Computing Environments

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Abstract

A ubiquitous computing environment consists of many resources that need to be identified by users and applications. Users and developers require some way to identify resources by human readable names. In addition, ubiquitous computing environments impose additional requirements such as the ability to work well with ad hoc situations and the provision of names that depend on context.

The Non-anchored Unified Naming (NUN) system was designed to satisfy these requirements. It is based on relative naming among resources and provides the ability to name arbitrary types of resources. By having resources themselves take part in naming, resources are able to contribute their specialized knowledge into the name resolution process, making context-dependent mapping of names to resources possible. The ease of which new resource types can be added makes it simple to incorporate new types of contextual information within names.

In this paper, we describe the naming system and evaluate its use.

1 Introduction

Computer systems are composed of a multitude of resources that must be identified. Such resources can be identified among computer systems using memory addresses, process identifiers, IP addresses, universally unique identifiers, etc. However, these are extremely unwieldy for humans. For this reason, computer systems usually provide a variety of ways to identify resources by human readable names. A naming system resolves such human readable names into a machine readable form.

This need is no less for ubiquitous computing environments. A ubiquitous computing environment is composed of a large number of mobile and immobile computing elements that should work seamlessly with each other. In addition, the many computing elements may be used in a wide variety of situations that cannot be anticipated during development and deployment of the computing environment, which requires that the environment support ad hoc situations and ad hoc deployment of computing elements.
A naming system which provides human readable names for such environments should work well even with unpredictable situations, and yet it should allow for context dependent naming of resources in order to support seamless operation among computing elements. It should also be easy to add new communication methods and information sources as the need arises. However, previous naming systems have difficulties supporting these requirements.

One of the more common problems in previous naming systems is the use of a single global namespace [1, 3]. Namespace conflicts arise when independently deploying multiple instances of such a naming system. The same thing may be named differently in different deployments of the naming system, and even worse, different things may be named the same way. A global deployment of the naming system avoids these problems, but global deployment is very difficult. DNS [10] is practically the only case where a naming system was successfully deployed globally.

However, even global deployment does not solve all problems with using a global namespace. Designing a global namespace such that every object in the world can be named, expressive enough to provide context dependent naming, and yet simple enough so that people can easily understand it may not be feasible. There are also problems in how to name things in ad hoc situations and how to handle disconnected operation from the global naming infrastructure.

Another problem with some of the existing naming systems is that they are limited in the types of resources that can be named [1, 3, 11, 7]. Such limitations can force the use of multiple naming systems that all work differently for each resource type. This will also result in a great amount of redundancy, especially if each naming system needs to be able to handle comparable degrees of expressiveness.

An additional problem is that an individual component often needs to be able to handle all kinds of information sources in order to assign names to resources. For example, the intentional naming system [1] requires that a network service must be able to find out all relevant context that is reflected in the intentional name in order to register itself with the naming system. Relevant context may include location, user, activity, etc. Not only would it be difficult for an individual component to handle all relevant context, but it is even more difficult if additional context needs to be reflected in names.

Our approach is to have resources directly name each other using local names. A name is a chain of these local names, and only makes sense with respect to a specific resource. By using a flexible resource description scheme and a recursive resolution process, each resource only needs to know how to handle a limited number of resource types. New resource types can be added relatively easily by updating only a limited number of existing resources. Certain resource types could resolve local names in a context-dependent manner.

This approach works naturally in ubiquitous computing environments. By using only relative naming, all of the problems associated with using a global namespace can be avoided. Having resources name other resources, making the addition of new resource types easy, and the ability to use arbitrary resource types makes it possible to express arbitrary context within a name. And the
general way in which resources can be described allows the use of a single consistent naming system for naming all sorts of resources. This is in contrast to other naming systems that have aimed to support ubiquitous computing environments such as INS [11], Solar [3], CFS [7], UIA [6], etc., which do not handle all of the above requirements.

We describe our approach in detail in section 2. Section 3 describes common components which resources may use when participating in naming. Section 4 describes some examples of resources and measures the overhead when using the naming system in lieu of querying the resources directly in order to identify a resource. We compare with related work in section 5 and conclude in section 6.

2 Overview

The unit of naming in the Non-anchored Unified Naming (NUN) system is a resource. A resource is something we wish to identify using human readable names. Similarly to how URIs and URNs are defined [2, 9], a resource is not something that will be concretely defined. This is because we do not want to restrict the types of resources which can be named. Examples of resources are documents, images, processes, computers, physical locations, schedules, people, etc. No infrastructure is required besides the resources themselves.

A resource is not only named, but it can also name other resources. Each resource is associated with a local namespace which is logically comprised of a set of local names, each of which are mapped to another resource. Ideally, the resource itself will resolve a local name directly into a machine readable description for another resource as in figure 1(a), since the resource itself would presumably best know which names make sense and how to resolve these names to other resources. When this is not possible, a separate resolver would have to resolve the local name for the resource as in figure 1(b). In the rest of the paper, we do not distinguish between the resource itself and a separate resolver.

A name in NUN is a chain of one or more local names. However, a name does not identify a resource by itself. Instead, a name identifies a resource only in the context of some other specific resource, which we will call the initial resource. When the initial resource is asked to resolve a name, the resource resolves the first local name in the chain to another resource, which is in turn asked to resolve the rest of the chain. Names and local names are explained in detail in section 2.1 while the resolution process is explained in section 2.3.

There is almost no constraint on how each resource maps a local name to another resource. This implies that the name graph, where each resource is a vertex and each binding of a local name to a resource is an edge, is a general directed graph. This is in contrast to many other naming systems where the name graph is structured, e.g. a tree or a forest of trees [10]. 1

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1The only constraint is that a resource must know how to resolve names from another resource it directly names by a local name. This constraint arises from how the resolution process works (see section 2.3).
the end point is the resource being identified. For example, resource E would resolve the name *(landlord bob files)* to resource B in figure 2.

Resources are not concretely defined. However, computer systems must still be able to actually use a resource and/or resolve names from a resource, so we require a way to describe resources in a machine readable form without restricting the type of resources that can be described. How this is done in NUN is explained in section 2.2.

### 2.1 Name structure

A name in NUN is actually a *compound name*, which is a chain of one or more *local names*. Given a *local name*, a resource can directly resolve it to another resource. A local name is composed of a primary name and an optional set of one or more attribute-value pairs. A primary name is a string which would typically be used to describe what the resource is. For example, *laptop* could
identify a laptop, and alice could identify a person whose name is Alice.

The optional set of attribute-value pairs maps an attribute label to a value. An attribute label is a string identifying the attribute, while a value may be a string, a nested name, or a resource description. A string value would be typically used when textually annotating the primary name in order to refine the resolution result, while a name value is typically used to identify a resource which may be relevant during name resolution. A name in an attribute-value pair is resolved with respect to the initial resource.

An example of an attribute-value pair with a string value could be resolution=1024x768 when we want a display with a resolution of 1024×768, while an example with a name value could be user=(printer owner) when we want a resource being used by the owner of a printer.

The value of an attribute-value pair may also be a resource description. A resource description is a machine readable description of a resource and is explained in section 2.2. Such a value is not meant to be read or written by humans. Instead, it is used to support the recursive name resolution process described in section 2.3.

The canonical syntax for names, which will be the default representation of names seen by users, is shown in figure 3. Some examples of names expressed in this syntax are:

- (printer) could denote the default printer for some user
- (printer administrator) could denote the administrator of the default printer for some user
- (documents research naming) could denote a file in some file server
- (author[n=3]) could denote the third author of some document
- (alice location display[user=(supervisor)]) could denote the display located where the person that some user names alice is, and to which the supervisor of this user is allowed access
2.2 Resource description

In order to name arbitrary resources, the machine readable description of a resource must not place restrictions on how resources can be described. And yet it must also include enough information such that resolving names from the described resource and actual use of the resource can be done automatically by computer.

The approach we use is to describe a resource using a resource type identifier and a resource specification, which is an arbitrary byte string that is interpreted according to the resource type specified. Using an arbitrary byte string allows us to describe any kind of resource, and the resource type identifier allows a computing element to recognize whether it can interpret the byte string appropriately.

A resource type identifier is a random bit string of fixed length.\(^2\) With a sufficiently large length, the probability of two resource type identifiers colliding is virtually zero. This allows developers to add new resource types without having to register the resource type identifier with a central authority. This is in contrast to other kinds of identifiers such as OIDs [17], where identifier assignment is ultimately derived from a central authority.

Given a resource type identifier in a resource description, a computing element is able to find out:

- whether it can resolve names from the described resource
- whether it can actually use the described resource

Currently a given resource description is assumed to describe the same resource in all circumstances. This may not always be possible (e.g. the resource specification may have to include a private IP address), so methods for circumventing this limitation without sacrificing the flexibility of the resource description scheme are currently under investigation.

Table 1 lists some examples of resource specifications that may be possible. Even with the limited number of examples, it is clear that there is a great variety of ways by which resources may be described and accessed.

2.3 Name resolution

A name identifies a resource only in the context of an initial resource. The initial resource must somehow be known to the consumer of the name. This can happen if the initial resource is a well-known one, e.g. it could be a directory provided by a large content provider. More typically, the consumer of the name will also be the initial resource, so there would obviously be no problem in locating the initial resource.

The consumer of the name must know how to resolve names from the initial resource. This can be done with the resource description for the initial resource.

\(^2\)NUN uses 256-bit identifiers. The selection of the bit length was primarily influenced by the potential use of SHA-256 for obtaining essentially random bit strings from other sources such as public keys.
Table 1: Examples of resource specifications.

| Resource type       | Specification                                      |
|---------------------|----------------------------------------------------|
| Number              | 100                                                |
| Static map of numbers | a=1,b=2,c=3                                        |
| HTML document       | `<html><head><title>Document for ...</title></head></html>` |
| IP network interface | 220.69.186.111                                      |
| IP multicast group  | 233.23.92.11                                       |
| DHT entry           | `bootstrap=69.32.121.23;id=0x788de9a2`             |
| INS location        | `[city=washington [building=whitehouse]]`          |
| GPS location        | N37 48.564 W122 28.636                              |

and if the consumer knows how to handle the specified resource type, but this is not essential. The consumer may have some other means of identifying and accessing the initial resource.

In practical terms, the initial resource acts as a black box which resolves a name into a resource description and the validity period during which it believes that the mapping is valid. Conceptually, the initial resource resolves the first local name in the name to some resource which we will call the intermediate resource. This resource is described in a machine readable form as in section 2.2.

Any name values in attribute-value pairs in the first local name are also resolved into a resource description during this step. The initial resource will also decide the validity period during which it believes that the mapping from the local name to the intermediate resource is valid.

If the name only included a single local name, then the initial resource will return the resource description to the consumer, which will use it to do whatever it needs to do with the described resource. Otherwise, the initial resource constructs a new name from the original name with the first local name omitted. Remaining name values in attribute-value pairs are also resolved into resource descriptions by the same process as described in this section.

The initial resource then uses the resource type identifier to figure out if it knows how to resolve names from the intermediate resource. If the resource type identifier is unknown, then the initial resource tells the consumer that it cannot resolve the given name. Otherwise, the initial resource requests that the intermediate resource resolve the new name constructed above to yet another resource. The intermediate resource basically follows the same procedure as the initial resource, with the initial resource playing the role of the consumer and the intermediate resource playing the role of the initial resource, and returns a resource description and validity period.

The initial resource then returns to the consumer the resource description and the intersection of the validity periods for the intermediate resource and the final resource that was resolved. Since the resource description is returned without modification, the initial resource need not know how to handle the described resource. Figure 4 outlines the resolution process.

The validity periods described above can be either fixed amounts of time
Figure 4: Name resolution process.

during which a mapping is presumably valid after name resolution, or they can be expiration times after which it is assumed that there is a significant probability of the mapping changing. For example, a mapping can be specified as being valid for 10 minutes after name resolution, or it can be specified as being valid until 09:00 on May 3, 2007.

3 Common components

Exactly how a resource resolves a name into another resource is entirely dependent on the resource itself. However, parts of the resolution process are basically the same among most resources, so a library which handles these common parts would be useful. The following are the components that would be included in such a library:

Name parser This parses a name expressed in the canonical syntax.

Recursive name resolver Given a resource description, one needs to be able to resolve names from the resource described. This component looks at the resource type identifier and invokes the appropriate code which can handle the specified resource type.
**Generic name resolver** Name resolution involves parsing the name, resolving the first local name to another resource, asking that other resource to resolve the rest of the name, and updating the validity period of the mapping. This sequence is basically the same for most resources, so a generic name resolver invokes the appropriate components in the correct order.

When the above components are provided by a library, a resource only needs to implement the interface which external computing elements use to resolve names, the mapping from local names to resources, and the code for resolving names from other resource types. The rest of the resolution process is handled by the generic name resolver.

We have implemented a library providing the above components in Java.

### 3.1 Optional components

Besides the components that have been previously mentioned, there are common components that only some resources would find useful. These components are not essential in the sense that name resolution would still work without them.

One such component is a name cache. A name cache embedded within a resource would cache mappings from names to resource descriptions. The cache would use the validity period of the mapping so that it can expire obsolete mappings. This would improve resolution speed when resolving names is slow for one or more resources, e.g. when a resource must be queried over a slow network or if a large amount of computation is required to resolve a local name.

To control access to local namespace of a resource, we can use authorization certificates to specify whether another resource may access the local namespace. Similarly, to ensure the authenticity of a mapping of a name to a resource, we can use a binding certificate which binds a name to a resource description during a limited time. We plan to use SPKI, a public key infrastructure, to implement this kind of access control and authenticity assurance. Similarly to NUN, SPKI does not rely on a global namespace for managing public keys.

We can also envision the use of a resource type repository which can map resource type identifiers to mobile code which is able to resolve names from a resource with the given resource type. A resource using such a repository would be able to name a much wider variety of resources easily. This would require some way to handle mobile code security and a lookup infrastructure such as a distributed hash table.

### 4 Evaluation

To illustrate the potential utility of NUN, we have created several simple resource types which cooperate with each other to provide human readable names to resources. The resource types are listed in Table 2. The resources are heterogeneous, where some resources are simple static pieces of data and others are
network services. Even the network services do not have to use the same communication methods. This is possible because we use the resource type identifier in a resource description to determine how to handle the described resource.

Given the resources listed in table 2, we can think of some plausible scenarios in which names are used:

- The calendar server needs to send a reminder to the moderator when there is a meeting during the day. It can find the moderator’s email address by querying itself the name (today meeting moderator email).
  The calendar server maps today to the appropriate time period and searches for the first event tagged with meeting. From the event description, it can extract the identifier of the moderator, which is then used to query the user database. The description for the moderator is obtained, from which the email address can be extracted.

- A user of a calendar may wish to know the status of the location for a scheduled meeting. He can use an application which asks the calendar server to resolve the name (today meeting location occupant) to find someone who is at the location.
  The application asks the calendar server to resolve the name by invoking an RMI method. The calendar server then internally resolves today and meeting as in the previous example. From the event description, it extracts the location identifier. It then asks the location manager to resolve the name occupant, which is resolved to the user identifier.
  Note that the application need only know how to query names from the calendar server and interpret the resource description for a user. It did not have to know about the internals of the calendar server or anything about the location manager.

- In order to begin a presentation, a computer may need a file named naming.ppt owned by a user within a certain location. It can query the name (occupant files naming.ppt) from the location manager using the location identifier. Here we see that an occupant is not only a named resource but can also names other resources.
  The location manager will find the user identifier, obtain the user description from the user database, extract the URL prefix of his file collection, and get the URL for the desired file. As in the previous example, the original computer does not need to know anything about users.

The resource types in table 2 were implemented in Java. Each were assigned a random identifier and their resource specifications were defined. Name resolution code and resource types which have builtin support for NUN use the library described in section 3, with the exceptions of the string and file resource types, which do not map any local names.
| Resource type | Description |
|---------------|-------------|
| String        | Simple character strings. Email addresses and common names are of this type. A string does not map any local name to other resource. |
| File          | A file specified by a URL. While it would be ideal if each file mapped names to other resources according to its semantic content, the namespace of a file is empty in our implementation. |
| File collection | A collection of files. This is specified as a URL prefix. A local name is mapped to a file by prepending the prefix to the local name. |
| Location      | A physical location maintained by a location manager. Each location is specified by a unique random identifier. A location maps the local name occupant to the user who is in the location. The location manager is a TCP/IP based server. It can return the list of users in a specified location. It has builtin support for NUN, so it can directly resolve names for a physical location when a specially crafted message is received. |
| Calendar      | This is an RMI-based calendar server. It supports the query of events within a specified time period that are tagged with specific strings. It also supports NUN natively, so that it can directly resolve names when a certain RMI method is invoked. It maps names such as today to time periods. |
| Time period   | This is a time period in a specific calendar. It maps a local name to the first event within the time period which includes the local name as a tag. The calendar server resolves names for this resource. |
| Event         | A scheduled event in a calendar. An event may be tagged by several strings such as meeting or playtime. Each event is associated with a moderator, a location, and a set of related files. Events are described in a static text format. Name resolution is done by interpreting the static data into the appropriate resource description. |
| User          | Represents a physical user. Each user is specified by a unique random identifier, which is used for indexing a user in a user database server. The user database server is based on TCP/IP, which returns a description of the user based on the identifier. The server does not include support for naming, so separate name resolution code is required to map local names by interpreting the description. The resolution code maps local names to email addresses and the collections of users’ files. |

Table 2: Sample resource types.
Table 3: Resource discovery times over Gigabit Ethernet in milliseconds.

| Name                                      | With NUN   | Manually  |
|-------------------------------------------|------------|-----------|
| (today meeting moderator email)           | 3.33 ± 3.51| 3.28 ± 3.84|
| (today meeting location occupant)         | 2.22 ± 0.77| 2.37 ± 5.79|
| (occupant files naming.ptt)               | 1.78 ± 2.21| 1.38 ± 0.76|

Table 4: Resource discovery times over wireless network in milliseconds.

| Name                                      | With NUN   | Manually  |
|-------------------------------------------|------------|-----------|
| (today meeting moderator email)           | 347 ± 2047 | 390 ± 1019|
| (today meeting location occupant)         | 350 ± 1419 | 391 ± 973 |
| (occupant files naming.ptt)               | 393 ± 983  | 390 ± 981 |

The user database resided in a 3GHz Pentium D machine with 3GB of RAM, while the location manager and calendar server resided in 1GHz PowerPC machines with 1GB of RAM each. In one configuration the systems were connected over Gigabit Ethernet, while in another configuration they were connected to each other by a 802.11g wireless network.

We measured the time it took to resolve names into resources for the examples we discussed. We also measured the time it took when we queried the resources directly to obtain the necessary contextual information and to discover the desired resource based on this information. The actual work done between the two approaches is basically the same, but using the former approach is much simpler since we only need to query the appropriate resource with a name that is easy to construct. The latter approach requires that code be written for each situation to query the necessary information sources, which is substantially more complex and is often not possible.

Table 3 compares the amount of time each approach takes when the systems are connected over Gigabit Ethernet. Each name resolution was repeated 1000 times. The measurements show that using NUN incurs negligible impact on performance. In fact, the overhead from NUN pales in comparison to the variability due to the network. This is even more pronounced with a wireless network, as can be seen in table 4.

5 Related Work

Several systems have been developed to provide naming for ubiquitous computing environments. Most of them are designed to identify only one kind of resource using a global namespace.

INS [1] identifies network services using intentional names, which specify the kind of network service desired instead of the network address. It supports the lazy binding of names to resources by combining naming and transport. Network services must have access to all relevant contextual information when registering an intentional name. INS uses a network of intentional name resolvers as its
The naming service in Solar identifies event publishers using queries based on a small attribute-based specification languages. It was designed to support thin client devices by offloading the resolution of names and tracking of context changes to an infrastructure composed of Planets, which reside on fixed hosts and provide Solar services. The naming system supports context-dependent naming and notifies applications when the mapping from a name to a publisher changes. Publishers must be aware of all possible context when registering a name with the naming system.

CFS is a file system which provides context-dependent file names. It uses a dynamic directory structure instead of a static directory structure, where each level in the directory hierarchy restricts the accessible files according to the desired context. Each file must be tagged with metadata describing all contexts to which it may be relevant, and the file server must know how to discover all relevant contextual information.

UIA identifies mobile devices using relative names. It focuses on the secure dissemination of statically assigned names and is unable to map names dynamically in a context-dependent manner.

There have been naming systems not targeted for ubiquitous computing environments that also use relative naming. Tilde and Prospero are file systems based on relative naming. Prospero is also able to support a limited form of location-aware computing by creating symbolic links according to the login terminal of a user.

NUN is similar to federated naming systems such as UNS and JNDI in that it basically federates the local namespaces of multiple resources. A large conceptual difference is that NUN makes no distinction between objects that are named and naming contexts which name objects. A large practical difference is that unlike the aforementioned systems, NUN does not require that a single computing element contain all code required to resolve names.

Like INS, Active Names combines naming and transport. Its purpose is to provide an extensible network infrastructure based on names. The routing mechanism is similar to the name resolution process in NUN in that a name can be divided into multiple components, and each component in the name determines the next program used in routing a data packet. The work done by each program is arbitrary, so a great deal of flexibility is possible when routing packets.

6 Conclusions

In this paper, we have described the Non-anchored Unified Naming system. Instead of having a naming service which exists independently from resources, its approach is to have resources themselves name other resources by local names. The rationale is that a resource is best suited to apply its own specialized knowledge and capabilities when resolving names which incorporate them.

A name is a chain of local names which is resolved by an initial resource,
which is determined according to the needs of users and applications. Eschewing the use of absolute naming and using only relative naming makes it simple to handle unpredictable situations that may arise within a ubiquitous computing environment.

NUN is capable of naming arbitrary resources by resolving names into a resource described by a flexible resource description scheme. This allows the use of a consistent naming scheme for identifying arbitrary types of resources. It also makes it simple to incorporate new kinds of contextual information within the name simply by adding new resources which provide the desired information.

The name resolution process does not require that a single computing element know how to handle all resource types. This simplifies the implementation of resources and reduces the amount of memory required to support naming. This allows limited devices such as PDAs or other electronic appliances to participate in the naming process, where they may contribute their specialized knowledge to the naming process.

The ease by which new contextual information sources may be added, the ability to handle ad hoc situations, and the ability to provide a consistent naming scheme for arbitrary resources makes NUN suitable for identifying resources in a ubiquitous computing environment.

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