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Abstract

The paper presents a new approach for treating security issues in various environments with special accent on Mobile databases, Semantic web and Grids. Target environments' specifications imply that a security model should have at least low space complexity, some level of autonomy and should be implementable in a distributed manner. To achieve all these requirements we propose a security model based on virtual organization that has ability to preserve and manage the trust between users. The model is build up on mathematical background based on hypergraphs that are the way how to reduce space complexity of the model and how to improve and simplify the implementation. To verify proposed model an experimental implementation SecGRID was programed and some results are presented.

1. Introduction

Rapid evolution in many computing areas brings up many useful aspects, but also many problems and issues to be addressed. In this paper we will concentrate on tree distributed environments namely:

- Mobile databases
- Semantic web
- Grid computing

Although all three have some different features, they also have a lot of in common. Before we proceed to these common features, let us briefly overview all three environments.

Mobile databases [1], [2], [3], offer the ability to access and exchange information anywhere, at any time. The possible network architectures can be summarized as:

- cellular networks
- multihop wireless networks - broadly known as ad hoc networks
- sensor networks

In the first case of *cellular networks*, some specialized nodes, called base stations, coordinate and control all transmissions within their coverage area - *a cell*. The base station grants access to the wireless channels in response to service requests received from the mobile nodes currently in its cell.

The primary characteristic of an *ad hoc network* architecture [4], [5], [6], [7] is the absence of any stationary structure. Ad hoc nodes can communicate directly with the nodes in their transmission range in a peer-to-peer fashion. Communication to distant nodes is achieved in multi-hop fashion. Therefore each ad hoc node acts also as a router, storing and forwarding packets on behalf of other nodes. The result is a generalized wireless network that can be rapidly deployed and dynamically reconfigured to provide on-demand networking solutions.
Besides the fact that mobile databases have a lot of advantages, they also have some challenges to cope with. Taking issues like power supply limits, limited bandwidth and unreliability of wireless lines, the security is one of the most important. Were an efficient and strong security solution not to be available, it would be very hard to achieve all advantages of ad hoc networks.

Sensor network can be characterized as networks build up from tiny sensing units having some communication and computation capabilities. The whole sensor network lifetime comprises three main phases. During the first, *deployment phase*, sensors are deployed in the sensor field. In the second phase, *post-deployment phase*, sensors have to build up a topology and then they have to cope with potential changes in it. This phase is in particular important as the topology changes continually for available energy, malfunctioning, etc. During the last phase, *redeployment phase*, some additional sensors may be deployed to replace malfunctioning nodes. Nodes in sensor network sense their vicinity for desirable phenomena and in a positive case sensors cooperate in multi-hop communication fashion to deliver data to a unit responsible for its further processing. As sensor networks are a bit specific, we do not addressed them in the paper anymore.

The *Semantic Web* is often believed to be the successor of the current web. Its main idea is to describe resources in the form of machine processable meta-data allowing automation of the requested tasks connected with the retrieval and usage of these resources. Although the main focus of previous work was aimed at the creation of knowledge representation languages (RDF-S, DAML+OIL [8], OWL [9]), reasoning systems, and also at the tools helping to embed web pages with semantic markup, the emerging commercial applications such as e-commerce, banking or travel services face a lot of security issues. Without a secure solution, it would be very hard to exploit all promising features of semantic web vision. The first possible approach is to extend the current security mechanisms used in distributed systems (Kerberos [10], PGP [11], SPKI [12] etc.). These technologies, however, cannot be seamlessly transferred due to the fully decentralized nature of the web, extremely large number of resources, services, agents and users, and their heterogeneity. Moreover, the number of entities accessing resources and interacting with themselves can be very large and can rapidly change.

The *Grid computing* paradigm can be characterized by a large number of interconnected users and sites cooperating on a common task. Users in a Grid are usually organized in *Virtual Organizations* (VOs). A Virtual Organization is a temporary or permanent coalition of geographically dispersed individuals, groups, organizational units or entire organizations that pool resources, services and information to achieve common objectives. The Dynamic Virtual Organizations Membership and structure of such a VO may evolve over time to accommodate changes in requirements or to adapt to new opportunities in the business environment. Considering this, it is straightforward that grid computing strategies can be used in the web environment for security improvements.

Even thought the mentioned areas do have some specifications typical for them, such as huge amount of pages in the case of semantic web, mobility of users in mobile computing paradigm, or heterogeneity of connected sources in grids, they also have some common specifications. Further, while all of them offer ability to share resource, support communication and cooperation between users (but not only the human users), the security is the crucial issue being common for all mentioned areas. Therefore it is natural to expect solutions that try to solve the problem with the security for all of them.

The rest of the paper is organized as follows: section 2 briefly introduces the related security models. Our security model is then described more in details in the next section. Section 4 contains some experimental results. The paper is then concluded.

2. Security Models and Approaches

The security is one of the key concerns in many areas. The security level is usually one of the key factors influencing the usability of any proposal not only in computer science. Therefore, it is natural that security has been given attention by researches and many solutions and proposals for improving the security have been introduced. In general, two main levels of the security are:

- cryptography level
- trust level

It is important to note that these levels are not isolated one from another, but they are very often used complementary. A brief description of both levels follows.

2.1. Cryptography

On the first level strong cryptography algorithms are the basis, taking responsibility for shielding transmitted data against man-in-the-middle attack, threat of tap, etc. Cryptography plays also important role in certificates (Public Key Infrastructure - PKI [13]) enabling users to communicate, share resources and information, etc. Cryptography, however, is enough only when considering tasks like sending messages, sharing files, etc. with accent on secure transmission of sent data. This approach, nevertheless, suffers by lack of additional abilities required by human users, like when to share data, when to trust the sender, etc. Therefore the next level is responsible for the trust management.

2.2. Trust Models

The trust management approaches build an enhanced security level on underlying cryptography level. The main task is to build, preserve and manage relationships between users. The relationship are usually build up on the trust.

The trust of a party A to a party B for a service X is a measurable belief of A in that B behaves dependably for a specified period within a specified context (in relation to service X)

This approach is similar to the well known term of creating Virtual Organization in the grid environment. The necessary condition for practical evolution of VOs is to have a strong mechanism preserving their overall security.

2.3. Related Work

In the following a brief overview of the trust management approaches proposed for VO is given. Two main approaches are currently available for the *trust management*:

The policy-based approach has been proposed in the context of open and distributed services architectures [14], [15], [16], [17], [18] as well as in the context of Grids [19] as a solution to the problem of authorization and access control in open systems. Its focus is on trust management mechanisms employing different policy languages and engines for specifying and reasoning on rules for trust establishment. In addition, it is possible to formalize trust and risk within rule-based policy languages in terms of logical formulae that may occur in rule bodies. Currently, policy-based trust is typically involved in access control decisions. Declarative policies are very well suited for specifying access control conditions that are eventually meant to yield a boolean decision (the requested resource is either granted or denied). Systems enforcing policy based trust typically use languages with well-defined semantics and make decisions based on ”nonsubjective“ attributes (e.g., requester’s age or address) which might be certified by certification authorities (e.g., via digital credentials). In general, policy-based trust is intended for systems with strong protection requirements, for systems whose behavior is guided by complex rules and/or must be easily changeable, as well as for systems where the nature of the information used in the authorization process is exact.

The reputation-based approach has emerged in the context of electronic commerce systems, e.g. eBay. In distributed settings, reputation-based approaches have been proposed for managing trust in public key certificates, in P2P systems, mobile ad-hoc networks, and recently, in the Semantic Web, such as [20], [21], [22], [23], [24], [25]. Typically, the reputation-based trust is used in distributed networks where any involved entity has only a limited knowledge about the whole network. In this approach, the reputation is based on recommendations and experiences of other users/sites.

In the following we will put a strong emphasis on creating the underlying VO by “evolution”. In order to describe it we need a model which can efficiently capture VO changes. This model is described in the subsequent section.

3. Security Model Based on Virtual Organization

As was mentioned previously, VO can be useful model for treating the trust between users in all related environments (mobile databases, semantic web, grids). On the other hand, VO model can be limited by some specific features of the environment:

- *mobile database* environment in addition to mobility of users also poses severe limitations to storage and computation capabilities of devices
- *semantic web* environment with almost unlimited number of users poses requirements on storage complexity
- *grids* with heterogeneity and geographic diversity of resources

this list of additional limitations showns that a model having the following specification is required:

1. The model should be able to store large amount of users in low storage complexity. VOs are very often modeled and depicted as (oriented) weighted graphs. But the complexity of storing information about all members in VO might be very high. The given complexity is $O(n^2)$, where n is the amount of vertexes. This is, however, unacceptable in case of mobile database environment and also semantic web might very quickly exceed storage capacity of particular node.
2. The model should have some level of autonomy in building relationships and the trust among users. The autonomous feature of the model is crucial when considering environments where users’ relationships became complicated or agent technologies are used. Such feature is highly useful when users would like to create strongly connected groups *on-the-fly*. Nowadays approaches usually assume that such groups are created by somebody and usually manually. We consider such creation as a bottleneck of these models.
3. The model should be implementable in a distributed (heterogeneous) environment. A distributed implementation is the key factor influencing model capabilities and usefulness.

Our approach is therefore build up on the previous list of requirements. The next section describes the very base of our proposal.

3.1. The Security Model

We believe that the security model that fulfill all listed requirements from the previous section should have an appropriate mathematical background. The reason is, that the background can simplify the implementation and also improve efficiency by offering a set of well known techniques for storing, organizing and optimizing implementations. As a consequence, let us shortly describe the used mathematical model of hypergraphs.

Hypergraph is quadruple (V, E, W_v, W_e), where V is a set of vertexes, E is set of edges ($E \in 2^V$), W_v is a set of vertexes' weights and finally W_e is a set of edges' weights. The main difference between graphs and hypergrahs is that an hyperedge can be incident to more then two vertexes. A hypergraph is in Figure 1. It is example of hyperpraph containing 5 hyperedges and 8 vertexes.

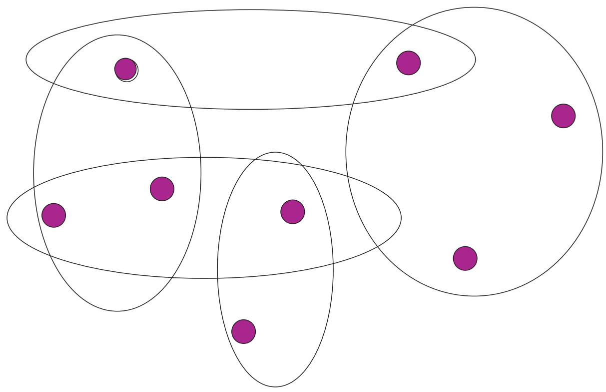

Figure 1: An example of hypergraph.

In Figure 2 the same situation is sketched, but now using graphs instead of hypergraphs. The edges in Figure 2 are shown in different colors and styles according to hyperedges from Figure 1.

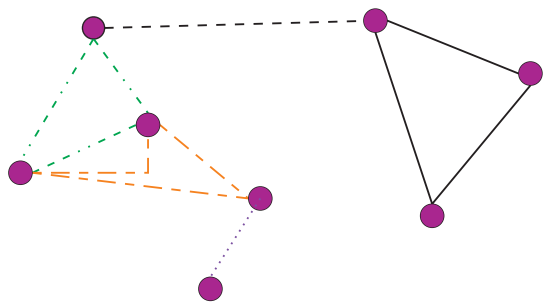

Figure 2: An example of graph showing groups of vertexes.

It is clear that hypergraphs are generalization of graphs. It is also clear that hypergraphs are richer structures than graphs. On the other hand, the richness of hypergraph brings some implementations issues (but these issues are out of scope of the paper).

Let now return to the list of three additional limitations from the previous section.

- The first item on the list was the low space complexity. In the case of graphs the space complexity is $O(n^2)$, which is unacceptable. On the other hand, in Figure 1 one can see how VO can be stored as hypergraph. In such a case VO is not stored as sets of vertexes, edges and their incidences, but simply by a membership of hyperedges. Therefore hypergraphs can be very useful for modeling VO reducing the space complexity.
- The second requirement is a kind of autonomy. One of possible solutions is to have set of rules that take care of all edges and also vertexes in the VO. Hence, we proposed a set of rules for reevaluating edges' and vertexes' weights (see [26].
- Third item on the list requires implementation in distributed environment. When trying to build up a list of all possible distributed implementation, one should start with implementations based on *Remote Procedure Call* (RPC), like CORBA[27] or JavaRMI [28]. Another technology worth mentioning are *services*. As an example let us mention web services based on WSDL[29] and SOAP[30]. One of the last possibility is to use *message passing*. The main advantage of message passing is simple and environmentally independent implementation. With respect to our needs and also to target environments the best choice is message passing with its simple, straightforward and efficient implementation.

4. Experimental Application SecGRID

An experimental implementation SecGRID was programed in ANSI/C and its aim was to verify that proposed algorithms for edge reevaluation preserve consistency of the VO. By the consistency of the VO we mean that the structure will:

- *not degenerate to one huge VO containing all nodes*
- *not degenerate to huge amount of very small VOs*
- *preserve relationships (expressed by an edge weight) between users*

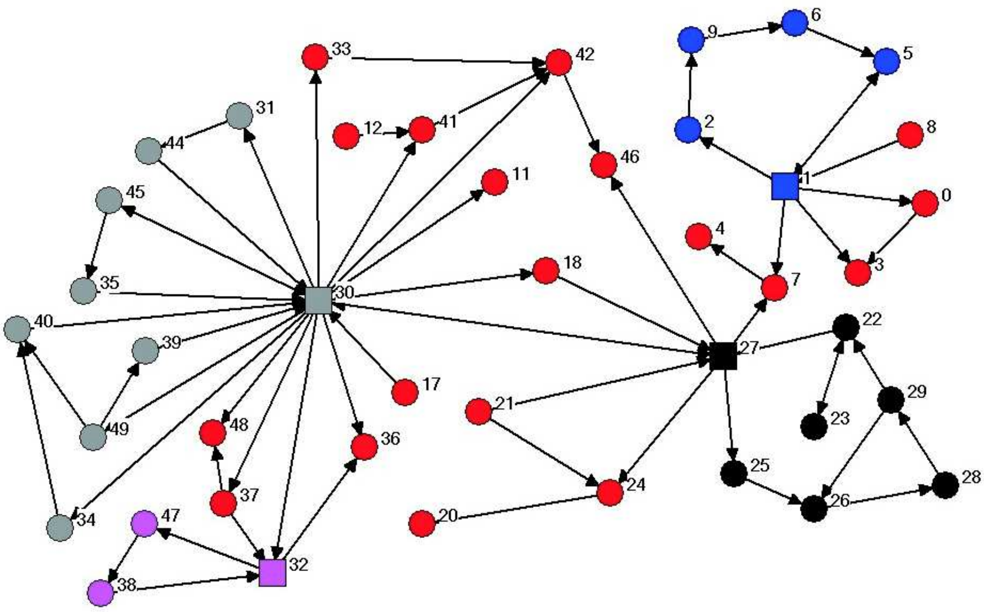

Figure 3: Experimental implementation output.

To verify the model the simulation comprised two phases:

1. random generation of edges
2. intentional edge generation with special accent on problematic situation in the VO evolution

One of the resulted graphical representation, which was obtained using NetDRAW [31], is shown in Figure 3. The Figure shows a situation after few steps of adding edges into the structure have been done. Users are depicted as circles in the color according to group membership, apart from the reds that are members of nongroup. Every group has also a leading member that has additional responsibilities, e.g. outer group communication support. The leaders are shown as squares in the color corresponding to group membership. For the sake of lucidity, the edges weights are not shown.

¿From the figure it can be seen that the consistency is preserved and the vertexes are uniformly distributed into groups. Note that group corresponds to a hyperedge in our hypergraph model and that the implementation uses hypergraphs with hyperedge incidence 2.

5. Conclusions

The aim of the paper was to propose a new security model for mobile databases, semantic web and grids. The paper gave a brief overview on two separate levels of the security (cryptography and the trust) followed by a list of features specific to the target environments. Having summarized all requirements we described our proposal based on Virtual Organization model for the trust security level. Our model uses hypergraph theory as its mathematical basis, as the hypergraphs have abilities to reduce the space complexity of the model. The results obtained through the experimental implementation are given to verify the "evolution" phase of the proposed model demonstrated that it does not degenerate to any of the limiting cases. Although the model is based on hypergraphs with full cardinality of hyperedges, the experimental application is based on hypergraph with hyperedges' cardinalities reduced to 2.

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