CYBERNETICA

X-Road – A Complete Solution for Inter-organizational Information Exchange

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1 Introduction

By the end of 1990s, public administration in Estonia had reached the level where most of the state registers were computerized. However, interoperability of different registers was still very weak because of several reasons. First, there were many legal entities responsible for different registers and this caused several organizational issues. Besides legal aspects, there were also major technical problems to be solved – most of the registers had been developed independently, using different database backends and having non-standardized interfaces. Thus there was a definite need for an infrastructure that would serve as a bridge between different agencies and registers, enabling the data to be stored and maintained in one place and to request it over the Internet by other agencies only when needed. Of course, many state registers contain private data and access to such information must be restricted accordingly. Thus, high security requirements had to be enforced during the whole project.

The infrastructure addressing the issues above was developed in 2001–2002 by the Estonian government and called X-Road (Crossroad). Later, several improvements and extra features were added. The current document describes the state X-Road project has reached by the end of 2006, but this is by no means the end of the road. There are several aspects yet to be considered, most notably interoperability of different X-Road infrastructures. These issues will be shortly addressed in the end of the document.

2 Description of the X-Road System

2.1 Background and Requirements

In Estonia, there are roughly 500–1000 different state registers (depending a bit on the definition of a register), all very different by their architecture, managed and developed by different organizations and financed separately.

The variety of potential users is even larger – in principle, every person, every company, every government and non-government organization has right to access certain kinds of information stored in state registers. Most of these companies and organizations are rather small, they have only limited budget and limited knowledge of security; all of this being even more true for private individuals.

The security requirements, at the same time, are rather high. Registries contain mostly personal data that is in some cases used to make high value decisions and in some cases needed in real time.

The initial analysis showed that the priorities of the security requirements for the X-Road infrastructure were the following.

1. All applications required **authenticity** and **integrity** of the data. Additionally, the data received over X-Road was required to have **evidentiary value**, i.e. the receiver had to be able to prove the origin of the data.

2. It was envisioned that X-Road would be used by time-critical applications, like verifying identities on the border or performing police operations. Thus X-Road had to provide high **availability**.

3. And finally, **confidentiality** was required in most, but not all cases.

While satisfying these security requirements, the main goal of X-Road still had to be achieved – exchanging information between different agencies had to be as smooth as possible. Even more, X-Road system architecture had to take into account the fact that information systems of the organizations participating in X-Road were very different. It was unrealistic to assume that many of the systems would have been substantially reorganized.

The following sections cover different solutions introduced to satisfy all the above requirements in X-Road inftasrtucture. Section 2.2 deals with security mechanisms whereas Sections 2.3, 2.4 and 2.5 describe the general technical and organizational aspects of X-Road.

2.2 Security Mechanisms

2.2.1 Evidentiary Value and Integrity

To ensure evidentiary value and integrity of the data, all messages going out from the registers are signed. In order to be able to sign anything, certified signature keys are needed and those are provided by a special third party – X-Road Central Agency – that acts as a certification authority.

In order to preserve evidentiary value of the messages over longer time periods, just plain signing is not enough, because signature keys can become revoked or compromised. To overcome such problems, X-Road infrastructure includes logging and time-stamping facilities. All messages received over X-Road are logged and the logs are linked together using cryptographic hash function. The intermediate hash values are periodically time-stamped by the X-Road central agency. This allows detecting the message log tampering attempts. Later in case of disputes, message receiver can use the logs and central time stamps to prove the origin and time of received messages.

2.2.2 Availability

In order to achieve high availability of the infrastructure, X-Road is built as a distributed system with minimal number of central services. Besides that, measures must be taken against temporary unavailability of some services and possible Denial-of-Service (DoS) attacks.

There are three kinds of security-related central services needed by X-Road infrastructure and these are provided by the X-Road Central Agency:

- **Certification** is an off-line process and hence not really vulnerable to availability thearts.

- **Time-stamping** is used only for log management in X-Road and is thus not time-critical either.
- **Directory service** is used to distribute addresses and certificate validity information, both being security and/or time critical in many scenarios. In X-Road, directory service is built on top of Secure DNS (DNS-SEC). This well-proven approach provides very robust, scalable directory service with built-in caching and redundancy. Security extensions of the DNS (signed zones) ensure that the data cannot be tampered with. All X-Road servers located at the participating organizations have their own local caching DNS server that ensures the availability of directory information even in case of (partial) network outage.

There are actually more organizational services provided by the Central Agency that will be discussed in Section 2.4.

X-Road protocol supports redundant servers and load sharing. When there is more than one server that offers some service, they will be used in random order by the clients. When one server does not answer the request, the client system will try another one. Negative answer is returned only in case all the servers are inaccessible.

X-Road servers also have some protection mechanisms against DoS attacks. Critical resources (i.e. CPU time and file handles) are shared between different clients in a fair manner. When one client (a possible attacker) sends a large number of messages, the resources allocated for this particular client are consumed quickly. The server keeps fulfilling the requests until there are no other clients. But as soon as some other client sends a message, it will get higher priority over the first client who sent many messages before.

2.2.3 Confidentiality

Most of the data that is exchanged via X-Road is not public or has some special access rules that must be followed. All major confidentiality threats can roughly be classified as external (e.g. network sniffing) or internal (e.g. gaining unauthorized access) attacks.

To combat external attackers, all data exchanged over X-Road is encrypted and standard SSL protocol is used for encryption.

In order to prevent internal attacks, two-level access control mechanism is used in X-Road, the two levels being inter-organisational and intra-organizational.

X-Road system core only deals with inter-organizational access control, where one organization grants access rights for some service to another organization as a whole. It is the responsibility of the other organization to ensure that only the right people can use this service, by using whatever technical and organizational means it finds appropriate. Obligation to enforce rightful usage of the service is stated in the service provisioning contract between the two organizations.

By isolating the details of the authentication and access control mechanisms used internally by the organizations greatly reduced impact to the existing systems. This was one of the key success factors of X-Road.

2.3 Technical Solution

If an agency wants to connect to the X-Road infrastructure (either as a service provider or a service consumer), it mostly needs to install a dedicated X-Road security server (called just X-Road server later on) in its premises. The only exception can be made for service consumers with limited requirements and capabilities, see Section 4.3 for a more detailed description. The X-Road server acts as a firewall between the agency's information system and the Internet. It routes messages to their recipients and secures messages both for transport (by encryption) and for long-term validation (by signing and logging).

On the service provider side, an additional adapter server is required. Adapter server transforms the requests obtained through the security server into the format understandable to the register and translates the responses the other way round. In terms of the client information system, the security infrastructure is completely transparent – the application level protocol used between the client information system and its security server matches exactly the protocol used between an adapter server and its security server.

Web services were chosen as a vendor and platform neutral message exchange protocol that is well supported and easy to use for application developers. Transparent usage of web services minimizes the impact to existing systems and makes integration of the X-Road services simple for developers.

Agencies exchange information using XML-based query-response protocols. In the first version of X-Road, XML-RPC was used. SOAP support with two-way transliteration to XML-RPC was added in the second version. The third version added support for SOAP attachments and asynchronous operation, where X-Road servers queue the messages targeted to other organizations. It is interesting to note that X-Road servers can process messages having potentially unlimited size.

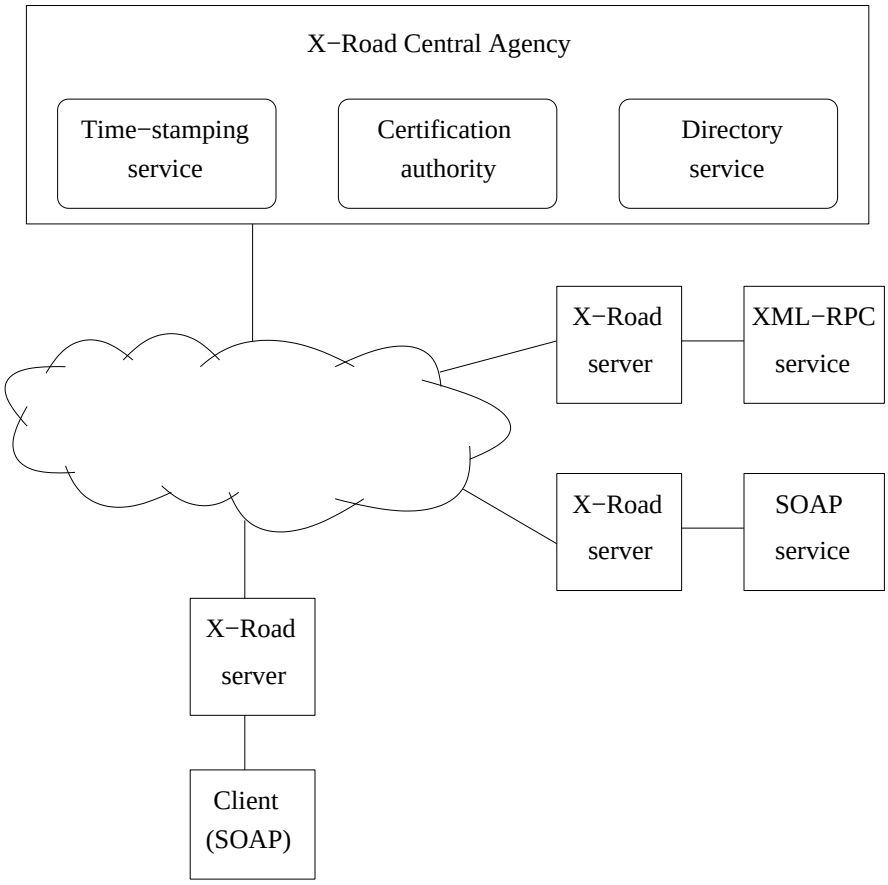
In addition to the real services provided by participating organizations, X-Road also provides some meta-services that can be used to find out the structure and properties of the system:

- It is possible to obtain the list of organizations providing and consuming different services.
- For each service provider, it is possible to find out the list of services provided for the consumers (only those services that are granted to the concrete consumer are shown).
- It is possible to obtain formal description of the service (in WSDL or proprietary XML format) for automatic generation of user interfaces.

For a client, X-Road server functions as a proxy to all services provided by other organizations, so all services are accessible through the same URL. The parameters of the requested service are specified in the SOAP header. They are also protected by digital signature and time-stamping mechanisms.

General overview of the X-Road infrastructure is depicted in Figure 1.

Figure 1: X-Road overview



2.4 Central Agency

As noted above, X-Road has a Central Agency that manages centralized tasks and is responsible for the X-Road infrastructure to stay operational. Since data received over X-Road can be used to take legal actions, one of the most important responsibilities of the Central Agency is to ensure legal status of the information exchanged via X-Road by enforcing the stated policies. Organizationally, Central Agency is also responsible for steering the further development of the X-Road and maintaining its consistency and integrity.

Besides security-related features described in Section 2.2.2, Central Agency also provides some technical services, like:

1. **Monitoring service**, that monitors all the servers in the system. Monitoring is used for resolving the operational problems in the system, for detecting security breaches by analyzing the message statistics and for collecting the statistics about system usage.

2. **Web-based portal** for accessing the X-Road services in a simple and centralized way. The portal is intended to be used for citizens and smaller organizations without sufficient IT capability.

2.5 X-Road Platform

X-Road servers are built on GNU/Debian Linux, one of the most stable, free and best maintained Linux distributions. All the additional software is packaged as Debian packages that can be installed and maintained using standard Debian tools. To simplify X-Road server installation by participating organizations, a self-contained installation CD is provided that installs and configures a GNU/Debian Linux system and X-Road software with minimal user intervention.

X-Road servers have a simple and clean graphical user-interface for maintenance and configuration tasks. There is also a built-in patching system that allows to distribute and update X-Road software in a secure way. All keys, including the top-level certification keys can be changed on the fly, without interruptions to the system operations and with minimal user intervention.

3 Current State

X-Road is currently used by the Government of Estonia and private companies. X-Road is the preferred way for connecting governmental agencies and is also used by private companies to exchange data with government and with the other organizations.

In August 2006, there were 69 service providers and 366 service consumers connected to the X-Road. The number services from all the X-road service providers was about 700.

Some statistics concerning the usage of X-Road in Estonia:

- During the year 2003, the total number of X-road queries was 590 000.
- Number of queries made via the X-road in 2004 was over 7.75 million.
- Daily record of queries in 2004 was 118 000 queries per day.
- Number of queries made via the X-road in 2005 was over 13.45 million.

In order to get a better idea what kinds of services are provided over X-Road in Estonia, let's look at the following examples.

- **Parent benefit in Internet** In order to process parent benefit applications, information from five different registers and information systems is needed: Citizens' Portal, Register of Social Insurance Board, Population Register, IS of Health Insurance Fund and IS of Tax and Customs Office. Before implementing the X-Road infrastructure, citizens were forced to obtain several paper documents from these registers and to deliver the applications physically. Now the citizen can use Citizens' Portal to apply for parent benefit by inputting only the basic application data. All the additional information that can be obtained from registers is fetched automatically. The tasks of civil servants processing the applications is also simplified a lot. There used to be 7 different paper forms that needed revising. Now there are only digital documents left and most of the processing is done in an automated fashion.
- **Document repository** Document management systems of public sector have an interface with the central document exchange point. They periodically send and receive documents for and from other systems. There is no more need for traditional post or scanned documents, all documents with metadata in XML format are exchanged over X-Road.

4 Nationwide X-Road Implementation

If X-Road infrastructure is to be implemented on a national (or even international) level, several legal and technical problems must be solved first. This section gives a short overview of the respective prerequisites.

4.1 X-Road Central Agency

If X-Road implementation is planned in a new jurisdiction, first and foremost, an organization is needed that acts as X-Road Central Agency. Due to its tasks and great responsibilities, this organization must have both legal and IT capability. After a suitable body has been chosen or established, the following steps are necessary.

1. A set of policies and rules for operating the X-Road infrastructure is needed. It would be a good idea to align the security measures within

the existing security frameworks (e.g. BSI in Germany) and define the required security levels via existing terms. X-Road Central Agency is responsible for ensuring that only the organizations meeting the stated security requirements can connect to X-Road.

2. Next, X-Road Central Agency must develop its own security policy and operation procedures to ensure proper handling of security critical data and achieving the required legal status of the information exchanged over X-Road.

3. Finally, X-Road central services must be installed and configured. Due to their importance, the servers must be located in secured premises. Hence, some extra effort might be needed for securing the server room. It would be good idea to have several, physically separated locations for central services.

4.2 Service Provider

If some organization wants to start acting as a service provider in X-Road infrastructure, it has to take the following steps.

1. Service provider must ensure that it has sufficient security measures in place, in order to join X-Road. Security policies and operational procedures may be revised and updated according to the legal requirements and/or policies enforced by the X-Road Central Agency.

2. X-Road server(s) must be installed and configured in the premises of the organization.

3. Existing or new SOAP or XML-RPC services must be developed according to X-Road specifications. It is very easy to create the web services for the X-Road and only minimal changes to the existing systems are required.

4. After making contracts with service consumers, access rights to use the service are granted to the client organizations.

4.3 Service Consumer

If some organization wants to start using services provided by other parties of X-Road, it must first ensure that it has sufficient security measures in place in order to join X-Road. Security policies and operational procedures may be revised and updated according to the legal requirements and/or policies enforced by the X-Road Central Agency. One of the most important steps is to ensure that sufficient user authentication and access control mechanisms are in place.

Service Consumer has two options for using the X-Road services:

1. X-Road services are integrated into its information system.

2. X-Road portal is used.

4.3.1 Integration of the Services

This is the preferred way to use X-Road services and is accomplished by taking the following steps.

1. Separated X-Road server is installed in the organization's premises and configured.
2. The information system of the organization is modified to use X-Road services proxied by the X-Road server.
3. Finally, after making the contract with service provider, the user access rights are set up according to the contract.

4.3.2 Portal

X-Road Central Agency may choose to run X-Road portal. In this case the client organization does not need to have X-Road security server or information system. This is very convenient for private individuals or smaller organizations without remarkable IT capability.

The client organization must still satisfy some security requirements.

1. There must be organizational and physical security measures in place that ensure that the information obtained via X-Road is handled in a safe manner.
2. Organization must appoint the User Manager who is responsible for setting up the user access rights in the X-Road portal.
3. Finally, after making the contract with service provider, the user access rights are set up by the User Manager according to the contract.

In Estonia, there is a special Citizen Portal run by X-Road Central Agency. Citizen Portal acts as an agency information system that can be used by all citizens to access information about themselves. All queries that are accessible to Citizen Portal take citizen's personal identification code as an argument (usually it is the only argument) and return information stored in the registry concerning this particular citizen. Although almost all Citizen Portal queries are informational, some queries are developed which allow citizens to send documents to state agencies. Citizen Portal can use two methods for authenticating persons: using the authentication certificate stored on the Estonian national ID card or authentication mechanisms provided by Internet banks.

5 International X-Road Implementation

Future developments of the infrastructure and policy standards are needed when X-Road is to be implemented internationally. Both legal and technical systems need amendments.

If there are two (or more) countries/jurisdictions whose organizations wish to start sharing information over X-Road, there are in principle three possible approaches to extend the infrastructure.

1. A new higher level is defined having all the present X-Road infrastructures as its descendants. This higher level would get a new root key that would be used to sign all the descendants' root keys, thus creating a trust path to verify for the agencies participating in separate infrastructures.

2. There exist both national and international X-Road infrastructures that are basically independent. An agency is allowed to belong to several infrastructures at the same time. This approach would allow not to change any existing infrastructures, and joining the international X-Road could even be done invisibly to the agencies (by issuing new certificates for the existing public keys).

3. All nations have their own X-Road infrastructures and no additional ones are defined. In order to allow international information exchange, bilateral agreements are made between the existing Central Agencies and the respective governmental bodies acknowledging legitimacy of the data received from the other infrastructure. Such bilateral agreements can later develop in a natural way into multilateral ones. On the technical level, the root key of one X-Road infrastructure is used to certify the root key of another infrastructure and vice versa (so-called *cross-certification*).

The first and the second approach both suffer from similar shortcomings. Establishing a new international infrastructure with a new Central Agency would need major political agreements between different countries, e.g. the question in whose premises this new Central Agency would reside still needs an answer. It is not clear how countries with contradicting interests would reach such agreements.

In a way, both of these solutions also act against the spirit of X-Road. The major motivation for different organizations to join the infrastructure is to simplify and unify its communications with other parties. When a new higher/parallel infrastructure is introduced, the participating organizations potentially need to undertake another process of joining, together with the implied bureaucracy and general management issues. This may decrease the organizations' motivation to join the international X-Road considerably.

It is currently the belief of the authors of this report that the third approach (cross-certification) hits the best balance between the obtained benefit and new problems caused. This approach avoids the politically sensitive problem of international Central Agency and lets each country to stay on top of its own infrastructure instead. The main technical problem to be solved is integrating different DNS-SEC directory services. On one hand, directory service is the most security critical component of X-Road, and on the other hand information contained in the directory of one participating infrastructure (keys, addresses) must be available for other infrastructures, too. Other services (log

time-stamping, monitoring, web portal) do not require such level of integration – e.g. each Central Agency will still be providing time-stamping service for its own infrastructure.

From the legal point of view, some changes may be needed to the legislation of participating countries to give the Central Agencies enough power to make the required agreements. Among other things, it should be decided how potential disputes are solved.

However, the software used in X-Road servers does not currently support any of the approaches described above, since the services are meant to run in a single flat infrastructure only. This implies the need for extra development efforts, but those can be made only after the corresponding political decisions have been taken.