ClusterWIS

A Decentralized Forest Information and Management System for the Cluster Forestry and Wood

Jürgen Roßmann, Michael Schluse, Martin Hoppen
Institute for Man-Machine Interaction
RWTH Aachen University
Aachen, Germany
email: {rossmann,schluse,hoppen}@mmi.rwth-aachen.de

Gregor Nägele, Tobias Marquardt
Department Robot Technology
RIF Institute for Research and Transfer e.V.
Dortmund, Germany
email: {gregor.naegele,tobias.marquardt}@rt.rif-ev.de

Christoph Averdung
CPA ReDev GmbH
Siegburg, Germany
email: averdung@supportgis.de

Werner Poschenrieder, Fabian Schwaiger
Chair of Forest Growth and Yield Science
Technical University of Munich
Freising, Germany
email:
{werner.poschenrieder,fabian.schwaiger}@lrz.tum.de

***Abstract*—The cluster forestry and wood's major challenges are its structural complexity and heterogeneity, its many stakeholders, and its decentralized processes. The aim of the ClusterWIS approach is to overcome these challenges. Its core idea is the development of a novel forest information system based on a decentralized infrastructure integrating new planning and consulting methods and interconnecting existing decentralized work processes. It provides end-to-end encrypted communication to run the various processes and to supply them with data while using international standards throughout the system and keeping participation requirements low.**

Keywords-forest information system; sustainable feedstock management; wood and biomass mobilization; decentralized data management.

I. INTRODUCTION

The cluster forestry and wood is the economic sector comprising all stakeholders from forest owners to forestal service providers and the woodworking industry. Its major challenges are its structural complexity and heterogeneity, a huge number of stakeholders with often contrary objectives, and decentralized processes. In the federal state of North Rhine-Westphalia (Germany) alone, 150,000 private forest owners own two-thirds of the forest (90% of which own less than 5 ha), and many small service providers (for planning, tending, logging, etc.) exist [1]. Furthermore, the "production plant" forest provides not only wood as its main product (used for building, paper or as a fuel) but also serves as a long-term CO2 reservoir or as a recreation area. Altogether, this renders process optimization far more complex than in classical manufacturing industry.

Thus, for a sustainable feedstock management and an efficient wood and biomass mobilization throughout the cluster, the increasing demand for wood from sustainably cultivated forests need to be aligned with the requirements of climate change and resilience, environmental protection and society in general. This is the aim of the research project ClusterWIS (WIS for German "Waldinformationssystem" – Forest Information System). For that purpose, new planning and consulting methods need to be introduced and existing decentralized work processes need to be refined and interconnected.

Often, centralized approaches are used to resolve this structural weakness of the cluster. However, this contradicts its highly decentralized organization. Furthermore, many conservative forest owners do not accept an obligatory centralized data management for reasons of data privacy (especially in Germany). For this reason, the foundation of the ClusterWIS approach is a novel, decentralized infrastructure based on standards for data modeling and data exchange. It provides end-to-end encrypted communication to run the various processes and to supply them with highly topical inventory and process data. To provide for the cluster's heterogeneity, it keeps the participation requirements for third party systems low. Furthermore, international standards are used throughout the system like Open Geospatial Consortium (OGC) Web service standards, Geography Markup Language (GML) for data exchange in general, ForestGML [2] for *n*D temporal inventory data, ELDAT [3] for timber logistics data, StanForD [4] for forest machine data, or papiNet [5] for communication with the paper industry. However, the approach is open to other formats and standards.

A ClusterWIS network (Figure 1) comprises applications and services as its nodes, connected by means of the secure communication infrastructure. In the context of the research project, stakeholders will use specialized desktop and mobile applications (e.g., for forest information, forest inventory, production planning, etc.) or Web applications (e.g., for forest owners, service providers, etc.) to access this network. Specialized services, e.g., for processing remote sensing data or forest growth simulations, perform computationally expensive and data intensive tasks for a broad user group even on thin clients like mobile devices. Finally, services for administrative tasks like communication, cloud storage or registration build the network's backbone.

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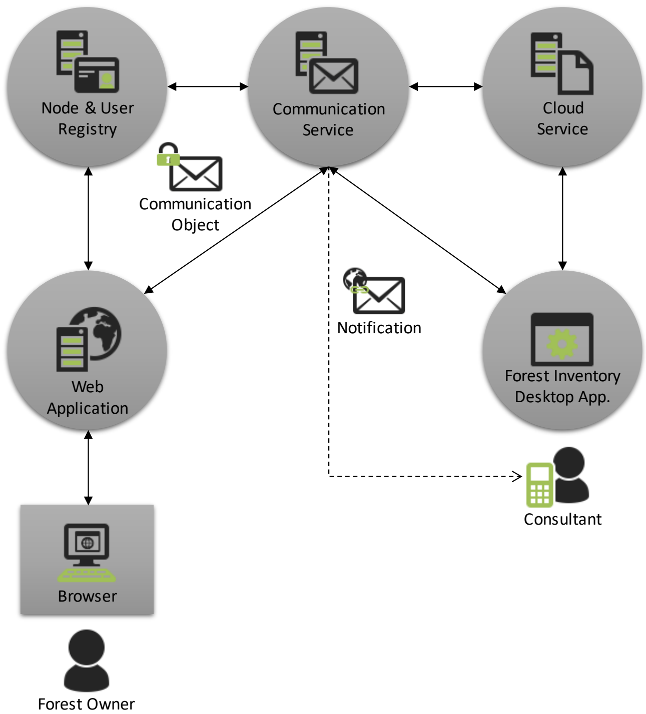

Figure 1. A ClusterWIS network consists of service and application nodes.

For the first time, this decentralized network allows for process optimization across the cluster. In the research project, eight interdependent reference processes (like forest information, planning, consulting, timber trade and production) are analyzed in detail.

The rest of this paper is structured as follows: Section II presents work related to our own and motivates the development of the ClusterWIS approach. Sections III and IV give more details on the ClusterWIS infrastructure and its communication approach. Sections V and VI introduce the ClusterWIS applications (desktop, mobile, Web) and specialized services while Section VII gives an overview of the reference processes analyzed in the research project. Finally, Section VIII concludes this paper.

II. RELATED WORK

ClusterWIS is built on its project partners' preliminary work. Important results come from the research project series Virtual Forest in general, its commercial spin-offs, the underlying SupportGIS technology, and the forest growth simulator SILVA [26]. ClusterWIS aims at making these results available to the whole cluster. Besides summarizing this work, this section introduces similar approaches developed by others.

A. *The Virtual Forest*

The ClusterWIS approach is built on the methods of the "*n*D Forest Management System Virtual Forest" [6], developed in the research project series "Virtual Forest". It provides the necessary technological framework as well as the basis for data modeling, management and distribution.

The idea of the Virtual Forest is a central database that manages all forestal data. It provides various applications for remote sensing data processing (tree species classification [7], stand attributes evaluation [8], or single tree delineation and attribution [9]), forest inventory, planning in biological and technical production, forest machine simulation for training, and support of the logging process.

The technological basis of the central database is the SupportGIS technology [10]. It is widely used for GIS related applications, is based on the standards of OGC and ISO, and powered by object-relational databases. It efficiently manages large amounts of data and supports exchange by standard OGC Web services. Furthermore, data can be managed in *n* spatiotemporal dimensions [2], allowing to track and analyze forestal data over time.

The Virtual Forest uses ForestGML [2], a GML-based modeling language, to model forestal data on a consistent, OGC compliant basis. This facilitates its widespread usage and allows for the usage of OGC Web services.

Central parts of the system are currently implemented in two German state enterprises. While the Virtual Forest focuses on the usage in such large, homogenous enterprises, ClusterWIS aims at making these results available to the whole cluster by decentralizing the approach.

B. *Forest Growth Simulator SILVA*

Silviculture today has to consider a wide range of ecosystem services (ES) that earlier were considered a by-product of traditional forestry. Moreover, on the background of climate change, forest management has to maintain climatic resilience and stability through provision of an adequate forest structure. Thus, forest consulting increasingly applies forest simulation models to estimate the effect of various silvicultural pathways on productivity, quality and further ES [11] [12]. Such ES are carbon sequestration, biodiversity, recreation, and groundwater recharge. As yet, they typically stand within the focus of state forestry. However, private forest stakeholders today also advocate to foster the adaptation of such services by private forestry based on financial incentives [13]. The forest ecosystem model [10] is a preferential tool to take into account ES synergies and tradeoffs and to optimize among various silvicultural objectives. It enables to compare scenarios that adhere to a sensible preselection of silvicultural pathways and to direct forest management towards the most effective subset of them. Such simulation models, as yet, are primarily available for state forestry, as state institutions maintain the necessary IT infrastructure.

The forest growth simulator SILVA provides such a simulation model and is already integrated into the aforementioned Virtual Forest system. SILVA implements the paradigm of a service oriented architecture (SOA). Its kernel is an independent application that does not expose any specific tasks but rather a wide collection of services that may be coupled and assembled to provide specific simulations or evaluations. Moreover, it provides its services through various types of interfaces, e.g., Simple Object Access Protocol (SOAP)-based. Thus, it integrates well into a distributed environment as well as a strictly local one.

Within the Virtual Forest project, several scenarios that integrate SILVA both locally and as a remote service into the larger environment were envisaged and tested.

C. Similar Approaches

Until now, others developed approaches similar to ClusterWIS. Some proprietary solutions are available, e.g., online platforms like “IHB Holzbörse” for timber trade [14] or the “Branchenbuch Wald und Forst” as a business directory for consultants [15]. The internet marketplace “CoSeDat" offers the possibility to exchange data and electronically signed PDF documents [16]. In Finland, UPM Paper offers “UPM Customer Online” [17], a digital service channel for customers. In summary, these approaches focus on specific aspects of the complex process chain, only. Hence, a permeability of shared data between the different processes is not given. Often, the idea was to develop centralized systems such as “virtual enterprises” [18] or the “FOCUS-Platform” [19]. As mentioned in the introduction, usually, this is not accepted by cluster actors.

Software solutions like “WaldPlaner” [20] already deliver functionality for planning and decision-making regarding sustainable forest management, but on their own they lack the necessary communication infrastructure and integration into larger processes. Approaches like the “Scottish Forest and Timber Technologies initiative”, supported by enterprises and industry, promote knowledge exchange and cooperation between enterprises in the sector [21]. They are successfully able to connect regional actors, but the know-how remains in small and medium sized enterprises of the region. The Web portals “Wald in Österreich” [22] in Austria and “WaldSchweiz” [23] in Switzerland serve the exchange of information in the sector.

Thus, existing approaches do not fulfill all the requirements of the complex and decentralized cluster forestry and wood. This motivates the development of the ClusterWIS approach as introduced in Section I.

III. Infrastructure

The cluster’s achievable efficiency is strongly related to the way its actors communicate. This requires a framework that does not unnecessarily restrict an actor’s professional view or its organization’s structure. The ClusterWIS infrastructure is based on secure networking of so-called ClusterWIS nodes. These nodes can either be applications (Section V), specialized Web services (Section VI) or services for administrative tasks.

To use its services and applications, any actor can register and participate in the ClusterWIS network. Well-established methods of IT security are employed to guarantee the safety of connections and exchanged data between actors, applications and Web services. Client-side Hypertext Transfer Protocol Secure (HTTPS) is used for authentication and secure connections. It is integrated into a public key infrastructure (PKI) that allows for end-to-end data encryption. Finally, authorization is based on GeoXACML (Geospatial eXtensible Access Control Markup Language) providing user rights on data and methods.

The administration of the ClusterWIS network is reduced to few central services:

- A node and user registry for all participating actors and nodes (applications and Web services) accessed via Lightweight Directory Access Protocol (LDAP).
- A communication service as a mediator between sender and receiver of so-called communication objects.
- A cloud service used to buffer communication objects, as a general data storage for the network, and as a platform to initialize and run OGC compliant Web services (Web Feature Service (WFS), Web Map Service (WMS) and Web Map Tile Service (WMTS)) on its stored data.

This lean infrastructure (combined with its communication approach presented in the next section) also keeps the participation requirements for third party systems low.

IV. Communication

Three basic rules apply to communication within a ClusterWIS network: Data and (service) requests are always transferred by secure connections and encrypted by the public key of the recipient. Furthermore, recipients account for conformant data usage inside their domain. Finally, it has to be assumed that many communication partners and systems are regularly offline (e.g., when being in the forest with bad reception).

A. Communication Object

The aforementioned communication objects are used to transfer data and corresponding requests (Figure 2). The structure comprises information on the type of data, the sender, the receiver and the tasks the data is intended for. Data comprises embedded files, links to files on cloud services, metadata describing files, or simple parameters for service calls. The complete communication object is realized as a ZIP archive containing the XML encoded data structure and additional embedded files. These files as well as the parts of the communication object in the dashed box are encrypted by the receiver’s public key. Thus, only its id, the sender and the receiver are visible.

B. Communication Service

The transfer of communication objects is operated by the communication service. The use of HTTPS and encryption of the data ensures that neither unauthorized third parties nor the cloud service or the communication service itself get access to the data.

A dispatch method for communication objects is specified for every receiving user (or node, as well) within the registry. This comprises:

- Notification by mail or smartphone push message that contains a download link to the communication object.
- Direct delivery using a SOAP interface of the recipient.
- Actively pulling the list of new communication objects from the communication service.

The communication service provides a SOAP interface to send a new communication object and to request a list of receivable communication objects.

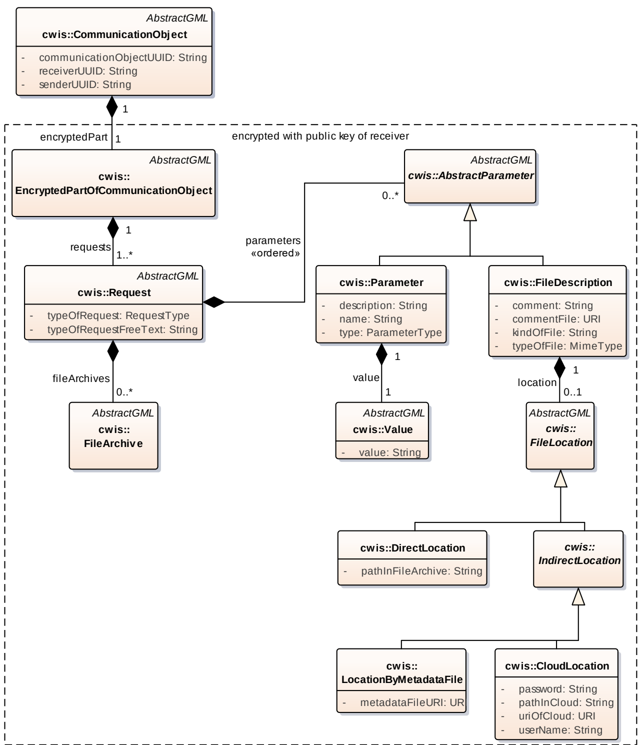

Figure 2. Structure of the ClusterWIS communication object.

A communication example is shown in Figure 1. A forest owner uses a browser to access the Web application (Section V.B) and create a communication object with a request for forest inventory. It is encrypted (public key of the consultant) and sent to the communication service, which buffers it into the cloud service and sends a notification to the recipient (consultant). The latter starts its Forest Inventory application (Section V.A.2), which asks the communication service for new communication objects that are subsequently downloaded from the cloud service. Finally, the consultant decrypts the communication object with his private key and processes the message. Note that all connections between nodes are additionally secured by client-side HTTPS, which is also used for authentication.

C. *OPC UA*

The decentralized ClusterWIS approach is similar to those approaches subsumed as “Industry 4.0” in the manufacturing industry. Furthermore, ClusterWIS communication not only takes place between actors but also from and to forest machinery. This motivates the integration of standard Industry 4.0 protocols into the network. As a well-established standard, Open Platform Communications – Unified Architecture (OPC UA) [25] is advisable for this purpose. Especially, as it provides a decentralized client server architecture without the need for central servers, it integrates well into the ClusterWIS PKI, it is an open and vendor-independent standard, it is robust, and it supports participants being temporarily offline.

Thus, to complement the aforementioned SOAP-based approach, ClusterWIS nodes may also be equipped with an OPC UA client and server component allowing the exchange of communication objects.

V. APPLICATIONS

An important part of the ClusterWIS approach are the user and scenario specific portals the actors can use to access the network. These comprise desktop, mobile and Web applications.

A. *Desktop and Mobile Applications*

Desktop and mobile end-user applications provide online as well as offline access to ClusterWIS features. They can be used by actors like forest owners, service providers, or contractors to view, gather, modify, and exchange forestal data. In the context of the research project, applications are based on the Virtual Forest prototypes. They use the VEROSIM framework [24] that combines an integrated runtime database with subject-specific modules to create adapted applications for diverse scenarios.

Four different applications are being developed and refined to meet the requirements of the project’s reference processes as described in Section VII:

1) *Forest Information*

The Forest Information application acts as an information portal to the data managed by ClusterWIS. Its primary functions are visualization, combination and analysis of geographic and business data, e.g., orthophotos, satellite imagery, Lidar, cadaster, inventory, or regulatory data. This data may be available locally via files and databases or provided by OGC-compliant Web services (WMS, WMTS, WFS) within the ClusterWIS network.

2) *Forest Inventory*

This application supports the forest inventory process. It allows a service provider to work with data made available by the commissioning forest owner and provides tools to record relevant stand attributes and single tree information. As this data is typically gathered on-site, the software also offers assistance for spatial localization during the process.

3) *Forest Planning*

The Forest Planning application provides a user-friendly and efficient interface to forest growth simulation. This comprises input parameterization as well as result analysis and visualization. The computationally intensive simulation itself is sourced out to a service (see Section VI.B).

4) *Technical Production*

This application supports the technical production process in its different phases, namely preparation of work assignments, assistance of forest workers and machine operators with instructions, and practical guidance as well as documentation of the harvesting operations and its results.

B. *Web Applications*

Web applications are ideally suited to provide a low-threshold access to the ClusterWIS network. They do not need client-side installation and can be used on both desktop and mobile devices alike. Capacity and performance scaling is easy and new features can be provided to users with no effort. Finally, Web applications easily support operation in secure networks.

The browser-based GIS SGJ GeoHornet is one example of such a Web application that is used in ClusterWIS. It has already successfully been employed in the Virtual Forest project as well as its commercial spin-offs. Various data sources like ForestGML databases or Web services can be accessed and embedded. This way, e.g., a registered forest owner can get an overview of his or her entire property. GeoHornet also provides methods to plot maps and enhance these plots with own graphical and textual annotations. It can create, send and receive communication objects, e.g., to send a request to another actor in the ClusterWIS network. GeoHornet can be customized for the user's demands.

VI. Specialized Services

As mentioned in Section I, besides backbone services (Sections III-IV), the ClusterWIS network comprises specialized services, e.g., to process remote sensing data or simulate forest growth.

A. *Remote Sensing Data Processing*

Often, the data necessary for a sustainable feedstock management can only be made available using remote sensing methods like tree species classification [7], stand attributes evaluation [8], or single tree delineation and attribution [9]. However, such methods usually need to access, process and store vast amounts of raw geo data, unfeasible, e.g., for mobile apps. Furthermore, existing methods need to be enhanced to easily incorporate stakeholders to refine the data with their expert knowledge (e.g., provide tree samples to optimize local tree species classification results). Thus, a goal of the ClusterWIS project is to make these methods available as services to allow the usage of suitable hardware on server side and to provide service interfaces for user provided calibration data.

B. *Forest Growth Simulation*

Forest growth simulators - beyond scenarios of stand development - provide further services that are closely connected to a simulator's core function. Such services are virtual tree generation based on stand structure attributes and computation of assortments using individual tree data. Hence, one relevant task within ClusterWIS is to extend existing data formats, such as ForestGML, to comply with the time-related data content that is specific to simulation models.

SILVA provides stand development as a result of rule-based management plans. That way, the simulator may provide scenarios that put emphasis on a specific subset of ecosystem services or that promote the development of specific stand structures and species mixtures. The seamless and manifold integration of SILVA [26] into the ClusterWIS infrastructure enables to couple to any other service that might receive data from the simulator or provide essential basic data to it. That objective is particularly important on the background of eocsystem service provision. Ecosystem services are typically linked by mutual synergies and tradeoffs. Therefore, one relevant coupling scenario is the linkage between SILVA and vegetation distribution models. Such specialized land surface models [12] represent processes of vegetation growth, seed dissemination and disturbance. Thus, they may provide valuable results about the establishment of regeneration trees and individual young trees to forest growth simulators. Moreover, as vegetation models often use a simplified representation of main stand development, they might straightforwardly integrate individual tree data provided by the growth simulator.

VII. Reference Processes

ClusterWIS not only provides an infrastructure, protocols and applications. It also specifies processes for a sustainable feedstock management realized on this foundation, which will be tested and demonstrated in actual forest stands. An important aspect of ClusterWIS is that these processes do no longer take place in a parallel and unrelated manner but start to interact with each other. A selection of practically relevant reference processes is considered within the project and briefly introduced below:

A. *Forestal data provision*

Sustainable natural resource management requires information and planning. For that purpose, up-to-date, highly qualitative, and detailed (geo) data is needed. Data is usually compiled of various data sources (ForestGML-structured data, third party spatial base data and business specific data). Currently, the comprehensive provision of such data to the cluster is an unresolved problem. Thus, this process describes the provision within the ClusterWIS network.

B. *Forest information*

This process describes an actor's access to the provisioned forestal data of a specific area in the right time at the right place, comprising visualization, analysis, and editing.

C. *Forest inventory*

Forest inventory is the acquisition and management of environmental data in forestry. Thus, the purpose of this process is to provide the cluster with always up-to-date, detailed and high-quality data. An important aspect in this context is to automatically and logically connect different data sources and, if applicable, different timestamps (for trend analysis) within the *n*D forest information system.

D. *Planning and consulting*

The comprehensive data provided by the ClusterWIS network enables consultants to give forest owners efficient and goal-orientated advice on how to manage their forests. In particular, they can use simulation tools to demonstrate how different management alternatives result in different future outcomes.

E. Timber trade

The ClusterWIS network opens new ways for getting in contact. By providing all relevant information to all actors involved in the process, a more efficient communication between sellers and buyers can be established. Thus, ClusterWIS provides the framework for a more efficient timber trade and contributes to a more efficient wood and biomass mobilization.

F. Sustainable Harvesting

Integrated into the aforementioned processes within the ClusterWIS network, the technical production process can access a vast number of relevant data. This allows for the planning of more sustainable harvesting measures. It comprises the (simulated) determination and visualization of wood assortments, harvesting costs, accessibility and harvesting routes, average skidding distances, as well as aspects of nature conservation. Besides planning, this process also comprises the execution of planned measures and their documentation, where the latter can again be used in downstream processes.

VIII. CONCLUSION

The cluster forestry and wood is an important economic sector. Yet, its major challenges (structural complexity and heterogeneity, huge number of stakeholders, and decentralized processes) are insufficiently addressed in current IT solutions. The ClusterWIS approach can resolve these problems by providing a decentralized, secure, and lean infrastructure for communication and data management. Based on this infrastructure, services and applications are orchestrated to realize novel, interconnected, and sustainable processes for feedstock management among the cluster's actors.

In the current phase of the ClusterWIS research project, the infrastructure and all reference processes are analyzed and specified in detail. The next step is the realization and implementation of the infrastructure (services, applications, etc.) and the execution of a first communication demo scenario.

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