Development of distributed hydro-information system for the Drina river basin

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Abstract — **Hydro information systems in Serbia are in constant development from the early 80's. Considerable advancements have been made in application of modern methodologies and technologies, with practical use in hydro power and water resources management. In order to provide support to management of complex hydropower systems and their digital simulations it is necessary to establish communication between measurement systems and computational models, although they were not primarily designed on the concepts of mutual integration and possible reusability. This paper presents a solution for distributed hydro-meteorological and hydropower data acquisition, simulation and design support that is based on service-oriented architecture (SOA) principles. The complex and heterogeneous information flow used by these systems is portioned into separate data and computational functions that use common open protocols for mutual communication. Based on these techniques, the paper presents the design of SOA hydro-information system and its application in case of Drina river basin management.**

I. INTRODUCTION

The contemporary approach to water resources management requires the formation of high-speed computational systems that could provide support to short- and long-term planning of water resources exploitation; they would be based on measured data reflecting the state of a system (meteorological and hydrological values, water consumption etc.) and the existing mathematical models (flow in river channels, transformation of rainfall into runoff, etc.). The comprehensive discussion on this subject is presented in the paper Divac et al.[1].

The support to management and simulation of complex hydropower systems demands connectivity and interaction of measurement systems and computational hydrological models, both of which are not designed primarily with the goal of integration and reusability in mind.

For the time being, automatic measurement systems and remote objects management within hydropower systems are mostly carried out in the form of the SCADA (Supervisory Control And Data Acquisition) systems that were previously built on a monolithic concept, i.e., each of the systems was independent from the other ones and there was no communication between them. Along with the development of SCADA systems, the distributed systems have been created that operate on multiple workstations that are grouped together into a local network – the LAN network. Along with automatic measurements covered by the SCADA systems, and those are mostly related to hydropower and hydraulic values that change rapidly, there are also the ancillary measurement systems applied for the slow-changing values, like certain meteorological or hydrological values, etc. It is a common practice to realize these measurement systems simultaneously, but in separate information systems, what makes the use of the obtained measurement data as inputs into simulation models much more complicated.

Like it was already demonstrated in the paper Divac et al. [2], collected data are often used as input data for simulation models; each of the models has its own data definition methods and requires data from diverse measurement systems (including forecasted values). Simulation models are used for planning, operational management and optimization and it is of highest importance that the data is available and accurate.

The concept of a hydro-information system has been recently developed and it connects measurement systems and simulation models for the purpose of water resources planning and management. Although hydro-information systems are not necessarily designed on the service-oriented principles, every day practice demonstrates that it is highly desirable for the software solution of such a system to be defined as an open service-oriented architecture, due to the diversity of measurement systems and simulation models. Such an approach would simplify the complexity of a solution and improve the re-usability of the software, along with the possibility of a dynamic integration of different components and simplification of their maintenance and development.

This paper presents a solution to the distributed acquisition of hydro-meteorological and hydropower data, based on the principles of the service-oriented architecture (SOA), which is at the same time open to different simulation models and future components. This solution is used in various hydro-information systems, and here will be presented on case of Drina hydro-information system as most complex river basin, belonging to Serbia, Montenegro and Bosnia and Herzegovina.

II. HYDRO-INFORMATION SYSTEMS

It can be stated that the strategic goal of implementation and application of distributed hydro-information systems (HIS for short) is the creation of conditions that can help the optimum management of water resources, as well as the solving of the existing and potential conflicts within the particular catchment or in the particular region in relation to the conflict of interests or development projects existing in different countries, local communities, firms and other legal or physical bodies.

Because of the complexity of water resources exploitation, both of natural and artificial origins, hydro-information systems have been designed as platforms with broad extension possibilities, whose structure is frequently modified as a result of changes in the mode of exploitation. Regardless of a HIS system or the goals of its development, the most important part of such a system is its hydrologic component, because the natural water flow is the most important factor in water resources management. For this reason, the two terms mentioned above are usually used as synonyms, but it has to be stated that a hydrologic information system is only a component that is common to the most of HIS-systems and generally has a monolithic structure; while, on the other hand, hydro-information systems represent potentially broader systems that include electricity generation, irrigation, water supply and other artificial activities within a system, as well. The use of complex hydrological models is common in hydro-information systems, as is in the case of HIS for Drina river basin.

The role of the hydrological model in hydro-information systems is to provide a reliable assessment of the planning and development of water management and energy and agricultural sectors. Based on these objectives, hydrological tools have been developed that transform the meteorological variables into the runoff from the catchment. Forecasted runoff is then used to manage the catchment, through water facilities, such as accumulation, gates, etc. By using various optimization algorithms with hydrological model, it is also possible to provide decision support to management.

Usually, hydrological models are designed as empirical, but with advances in numerical procedures and computer hardware, there are more and more efficient deterministic models in use. The advantage in the use of deterministic hydrological models is that, due to the number of input parameters, these models are more accurate than empirical model, provided that the parameters are determined based on the actual characteristics of the basin. In addition, the advantage is reflected in higher temporal and spatial discretizations, that are limited only by hardware. Today, the hydro-information systems use distributed hydrological models such as WaterWare [3], MIKE SHE [4], and Ribasim [5]. Hydrological model WEAP21 [6] combines the requirements of users in the basin and the hydrological modelling process, where there is a possibility of adding a system of reservoirs and canals. There is also an example of complex water management information systems that use hydrological model [7].

In HIS for Drina river basin, a deterministic model with disaggregated parameters is used, where the parameters are estimated on the basis of soil and hydro geological composition, as well as vegetative cover.

III. SERVICE-ORIENTED ARCHITECTURE

In software-related terminology, service-oriented architecture (SOA for short), denotes a method of software development that can fulfil user requests by supplying services in form of standardized services. Within the SOA architecture, each party offers its resources by means of services that can be accessed in a standardized way[8]. Most often this architecture relies upon the implementation of Web services (using SOAP or REST), although the implementation is also possible by means of any other standard[9].

Unlike the traditional architectures, SOA consists of weakly integrated components that, however, display a high degree of interoperability in supplying services. This interoperability is based on the formal definition of a service, which is platform- or program language-independent. The service-oriented architecture is also independent from any development platform (such as .NET or Java). This enables software components to become extremely autonomous, because the service-providing logic is completely detached from its development environment.

The SOA architecture usually indicates the use of web services, within the Internet, as well as within an Intranet environment. The standards that form the base of web services are XML, HTTP (or HTTPS), SOAP, WSDL and UDDI. It is necessary to stress it again that SOA can be based on any other accepted standard.

Finally, SOA is by no means visible to its consumers, and, furthermore, it does not even exist if there are no consumers who make use of services. The greatest advantages of the SOA architecture are its flexibility and extensibility, as well as the possibility of the operation of different programmers' profiles on the development of actual solutions; in addition, there is also the usability of the existing heterogeneous resources instead of the continuous investment into the redesigning of the system. SOA can be rather labelled as an evolution in the architecture than as a revolution, because it represents the implementation of the best experiences from different technologies that have been used so far.

The basic structural components of a service-oriented HIS are shown in Fig. 1. The solutions that are based on SOA are in fact scalable, secure, easy to monitor, interoperable and independent from any particular operating system. Such an approach to development conceals from the programmer and the user the complexity of the process of overcoming the incompatibility between the components used; at the same time, it detaches a certain processing logic from a certain client application. In other words, different users in the form of browsers, desktop applications, like Matlab, Excel, or ArcGis, or other user components, can access the single data source in the same way.

According to their purpose, the presented services can be grouped in the following way:

- Basic services – controlling and monitoring of a server that represents an interface to the already existing systems, databases, applications etc. that are being connected to a HIS. To this group belong also the updating services, replication services etc.
- Services for access to external resources – they make possible the access to different external sources that dispose over hydrologic data. They are used for browsing and data acquiring, as well as for the periodic regeneration of metadata storages.
- Services for access to measurement devices – represent a way of communication between separate devices, i.e., sensors that can be directly integrated into a HIS.
- Data filtration services – represent the necessary component of the processing of raw measurement data from the sensors, because such data is usually afflicted by errors, inaccuracies and periodic communication and working process breakdowns[10].
- Services for access to resources – perform collecting, browsing, updating and acquiring of data that is already on HIS servers.

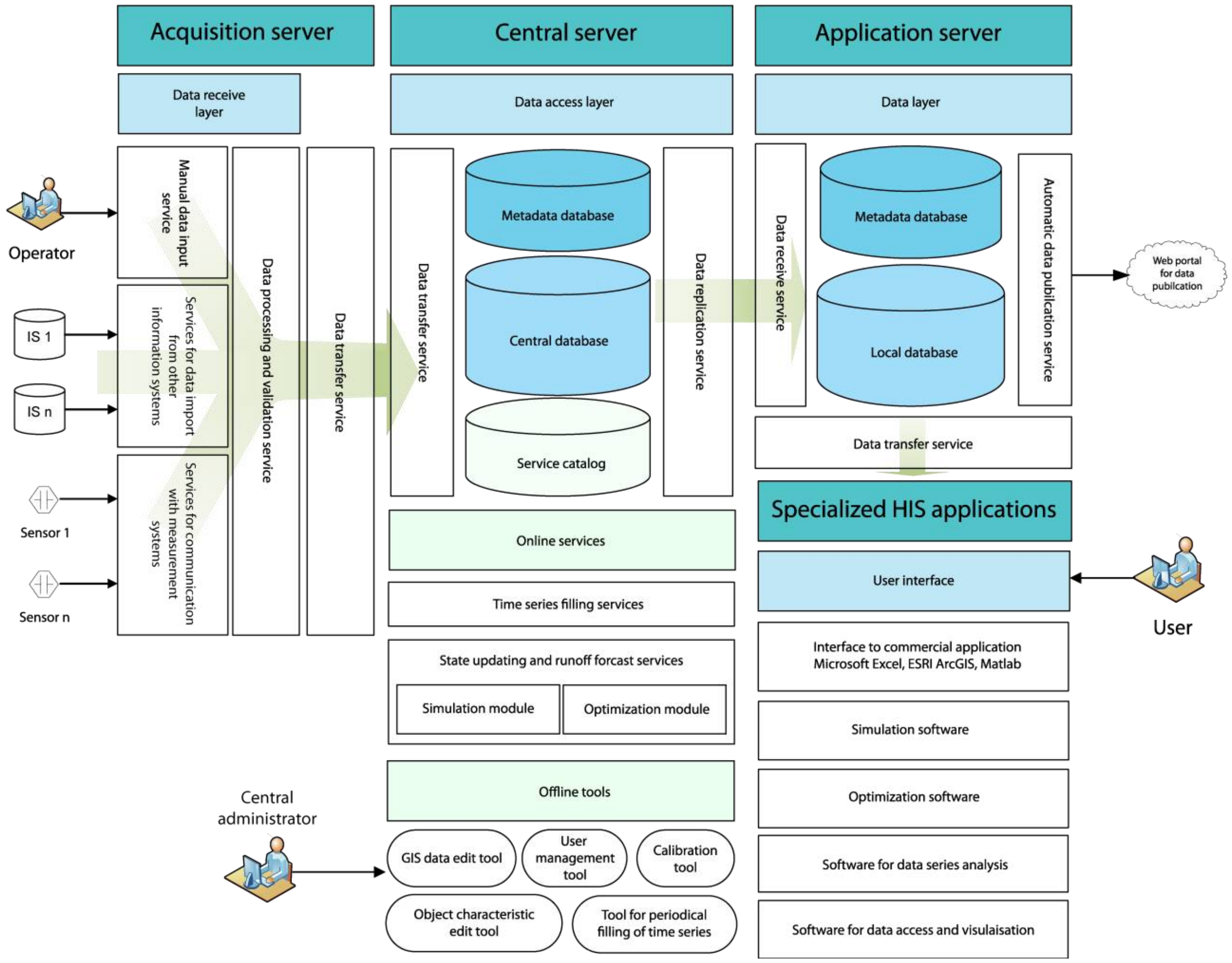

Figure 1 Structural components of a service-oriented HIS

- Application services – represent a large group of services that support the manipulation of objects of a higher rank, like a virtual catchment. These services include: compilation of lower-rank objects into the virtual catchment object, reliability analysis and filling-in of missing data in time series, data transformation and the synchronization of services' operation.
- Services for authentication and authorization – that are connected to the process of user application and assessment of data access privileges.

Within the described architecture, the services are grouped together into the following sections according to the logical hardware implementation:

- Central server,
- Acquisition server,
- Application server and
- Specialized HIS applications.

A. *Central server*

The central server has a role to coordinate, distribute and synchronize data storage, as well as to control access to HIS data and services. The main function of the central hydro-information server is to put together all the relevant data and store them into the central database, as needed. Descriptions and references of all relevant data are to be found in the metadata database, on the central hydro-information server. The HIS services catalogue is also to be found on the central hydro-information server. The central server has more functional sections: data layer, online services and offline tools that are necessary for the proper functioning of the system.

The data layer of the central server represents a complex functional entity that has a role to control the archiving of data and to coordinate users' requests related to the acquiring of accessible data from any server within a HIS. In order to fulfil these tasks the data layer of the central server unites the following elements: the central database, the metadata database, the service catalogue, the data transfer service, and the data replication service.

B. *Acquisition server*

The role of the acquisition server within a hydro-information system is to collect and process data on the measurements within the physical system. An acquisition server consists of the following parts: data acquisition layer, data processing and validating service, data transfer service and a separate service for monitoring processes that take place on the server. The data that the server acquires can originate from automated measurement systems, other information systems or they can be manually entered through specific services. The processed and verified data is sent by the acquisition server to the central server, and a limited set of the data can be acquired by the acquisition server from the central server in order to perform the procedure of validation and data processing.

In order to secure the full functionality, the acquisition server has to include all the previously mentioned data sources, as well as the procedures for validation and communication with the central database. The acquisition server consists of the following elements:

- data acquisition layer (that includes the manual data entry service, the service for data acquisition from other information systems, and the service for the direct communication with measurement systems),
- data processing and validation service,
- data transfer service,
- data monitoring service and
- acquisition repository.

C. *Application server*

The application server is designed to control the access to data by different users, as well as to find and acquire the available data from the distributed HIS, which allows the particular user to have the universal access to all the available data of a certain HIS. The structure of the application server is very similar to the structure of the central hydro-information server. The main differences in comparison to the central server are in a lesser number of off-line tools that are adapted to the processing of local data, and omitting of on-line tools.

IV. IMPLEMENTATION OF HYDRO-INFORMATION SYSTEMS IN A DISTRIBUTED ENVIRONMENT

In the process of implementation of the presented software platform of the hydro-information system, the latest technologies were used for the design of the system as well as for the application creation process and the database implementation.

The system architecture design and the choice of adequate software technologies were performed with a goal of creating an open and scalable platform that can be equally productive both in a single-processor environment, as well as in a distributed environment. Since this is a complex system, with a tendency towards further extending and an increase in complexity, the scalability of the application is of great importance, with the intention right from the start to allow a large number of users to exploit the system simultaneously. This is the reason why an object-related approach was chosen for the development of the software and simulation models. The interoperability of a model and its methodologies and research results become the priority of the international co-operation, and this is one of the main reasons why it is necessary to apply an open architecture [11].

A. *Architecture of distributed systems*

In the process of the implementation of distributed systems, it is possible to apply numerous hardware and software solutions. On the basic implementation level, it is necessary to join a certain number of separate processors, through the connection on the same motherboard and the creation of multi-processor devices, or by creation of LAN networks of different complexity levels. On a higher implementation level, it is necessary to provide protocols for the communication between processes that are running on the separate microprocessors. Some of the standardized architectures are the following: client/server architecture, three-layer and multi-layer architecture, clusters, grid, peer-to-peer (P2P), mobile code architecture and the service-oriented architecture.

As the service-oriented architecture has already been described, now only an outline of the client-server architecture that was also applied for the creation of the user-related components shall be presented.

In the case of a HIS, clients are the tools that users employ to access the system's data and parameters, and the content that they work on is supplied by a server in the system or is being transferred to the database by the means of a service on the server.

B. *Object-oriented development of a simulation environment*

The object-oriented development of a simulation environment involves the use of the object-oriented design and object-oriented program tools. The result of such a development is evidently an environment that functions on the basis of an object-oriented simulation [12]. The features of an object-oriented language involve fundamentally different modelling process as compared with the process of the conventional modelling and simulation. The application of object-oriented concepts for simulations is nowadays considered to be the key factor that provides the efficiency of modelling and software development in implementation of simulation models that should be modular and flexible.

The computational methods are based on the mathematical system theory, object-oriented theory and a large number of mathematical principles. It is interesting, that there is a natural connection between the development environment defined in this manner and the system theory [13]. The entities of the environment are defined in accordance with the system theory and their relations are formulated in order to achieve the morphism over system descriptions. On the other hand, the abstraction that characterizes the system theory requires an actual implementation in order to be applicable to real systems.

V. HYDRO-INFORMATION SYSTEM "DRINA"

The basin of the River Drina represents the most important unused hydropower potential in the Balkans. The area or the River Drina basin is circa 19570 km2 (30.5% of this area belongs to Serbia, 31.5% to Montenegro and 37% to Bosnia and Herzegovina). So far 9 hydropower plants within the River Drina basin have been built that have the total installed power of 1932 MW and the average annual generation of 6350 GWh. Within Drina river basin it is possible to build substantial hydropower capacities, which would allow for the additional annual electricity generation of more than 7000 GWh.

The "Drina" hydro-information system (HIS Drina for short) is a distributed hydro-information system designed according to previously presented service-oriented architecture, created for the decision-making support for management of the waters in the river Drina basin. It consists of various data management services, databases and numerical modules.

The system is built on commercial technologies, with use of SQL Server database and .NET Framework. Services in the system are published as Web Services.

Figure 2 HIS Drina web portal

A. *Data management*

The full use of HIS Drina relies on availability of data gathered from monitoring networks. The data required as simulation input are mostly meteorological measurements, while data necessary for state updating procedures [14] also include hydrological measurements and power plants' productions and other information important for interpretation of current state of river basin.

Acquisition of this data is mostly automated, which is done by importing from other informations systems and SCADA systems through specially designed services. Some data are manually measured and acquired through manual entry application by staff. Considerable amount of data is transferred from old archives and databases, which readily provides data for long-term analysis.

In total, over 200 measurement stations are included in acquisition and represented with real-time and historic data. This data is readily available for use in user applications and numerical modules. Selected data can be monitored through HIS Drina web portal, which provides data for all interested parties within river basin.

B. *Simulation model*

The simulation model is the principal part of the complex software and it represents the core of the distributed system for the support to the integral management of waters in the river Drina basin. The model is related to water flow and exploitation in a broad and complex area that covers the whole river Drina basin. Water enters the system in the form of precipitation and there is a system of user demands (demands regarding electricity generation as a function of time or demands related to the capturing of certain quantities of water as a function of time). The model includes the formation of the runoff from the rainfall[15], taking into account the influence of snow[16], relief and soil, as well as all other linear flow forms[17], i.e., flows through natural water courses in accordance with morphological performances, flows through artificial objects (dam spillways and outlets, hydropower plants, tunnels, channels, pipelines etc.). A large number of parameters of the model of the formation of runoff on complex catchment areas requires the implementation of the state-of-art estimation methods [18], in order to achieve the best possible matching between calculated and measured values of discharge on a certain hydro-profile, where a representative hydrologic station with reliable discharge measuring exists. It is also very important to model the changes of flow conditions as a function of time, due to management decisions.

The realization of an integral algorithm (which includes natural and artificial watercourses, as well as users' requests, supply priorities etc.) has provoked the use of system models in which discrete changes of state within the system or its environment occur discontinuously in time. For this reason, a library of models has been developed, as well as the corresponding simulation platform based on the application of the Discrete Event System Specification – DEVS, as it is presented in the paper [19]. On the basis of the developed library, it is possible to define a large number of scenarios and to perform manipulation upon a dynamic and flexible model that allows for all sorts of modifications, in relation to its parameters and in relation to structure of the model itself.

C. *User applications*

Previously presented system components need user interface to communicate properly with users of HIS Drina. Several user applications were designed to enable full use of HIS data and simulation models: software for data access and visualisation, software for data series analysis, optimization and simulation software.

Thanks to user-friendly interface and coupling of rainfall/runoff model, DEVS simulation, and optimization algorithms, it is made possible for operators of hydro power plants and reservoirs to apply information from HIS Drina in reservoir operation in near real-time. At the same time, HIS Drina provides local and state authorities with additional information on state of Drina river basin, like: estimated snow coverage with water equivalents, what-if analysis (e.g. flood risks) and other valuable data for basin management and planning.

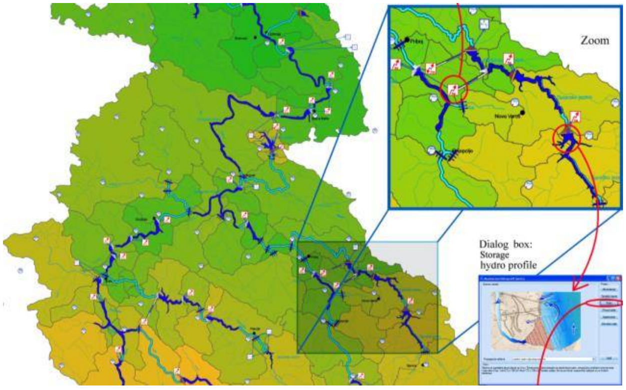

Figure 3 User interface of DEVS simulation model

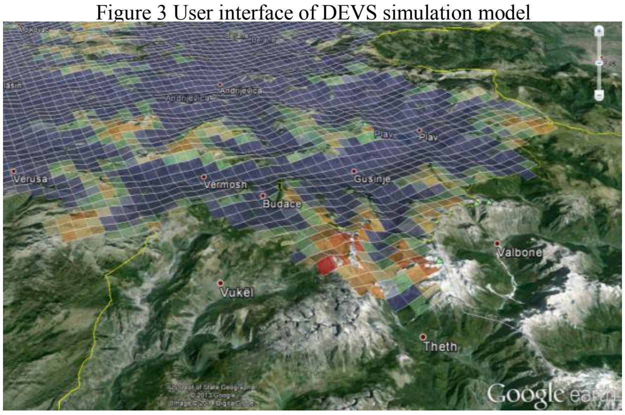

Figure 4 Estimated snow coverage with water equivalents

VI. CONCLUSIONS

The presented service-oriented architecture of a HIS itself represents a platform for a future development of components and functionality for each particular case. This does not indicate that the platform functioning is influenced by its actual application, but that the openness of the presented solution allows the specific components to be included effortlessly into a system, in a much easier way than before. This fact also allows the broader application of a HIS in support for the management of water resources.

A HIS should provide for the necessary components, protocols and objects that would, by the means of the hierarchical integration of data and entities within water management systems, allow an integral system analysis and support water resources management. The application of interdisciplinary procedures, algorithms and techniques on the observed data can allow the expansion of a HIS beyond its use in exploitation of water management and hydropower facilities towards the use in the field of ecology, economy and social issues.

One of the main goals of the implementation and use of a HIS is the creation of a virtual hydro-meteorological and hydropower observatory [20, 21]. This term implies an overall survey of the information that describes the natural environment of a catchment area, hydro-meteorological and hydropower measurements, simulation models of processes and phenomena and a conceptual frame for formulation of new hydrologic perceptions. The virtual hydro-meteorological and hydropower observatory can be achieved by the implementation of a service-oriented HIS within the limits defined by the catchment area.

The presented architecture applied on Drina river basin in form of HIS Drina offers a sound basis for further development of relevant algorithms and models that could allow for the creation of a virtual hydro-meteorological and hydropower observatory that is an important part of the contemporary system for the integrated management of water resources. This is one of the most important goals set for the further development of HIS Drina and other HIS systems in Serbia and region.

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