DOI: 10.2478/bhee-2014-0006

Professional paper/Stručni rad

LIGHTNING LOCALIZATION SYSTEM SCALAR

SISTEM ZA LOKALIZACIJU ATMOSFERSKIH PRAŽNJENJA SCALAR

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Abstract: The paper presents the lightning localization system (LLS) SCALAR with Bosnia and Herzegovina coverage. The system is based on the combined magnetic-direction-finding and time-of-arrival (MDF+TOA) and the time of arrival (TOA) sensors. The extension of SCALAR started in 2008 with the installation of three TOA sensors. From 2011 to 2013 four additional sensors were installed in Serbia, Bosnia and Herzegovina and Montenegro.

The lighting detecting sensors produce raw data which are transferred via various types of communication links to the processing centre in Vienna, where they are processed with the total lightning processor (TLP) software. TLP processes raw lightning data from sensors and sends the solutions in real-time to the providers of lightning data. Detection efficiency of LLS, reported by TLP software provider, is greater than 90% for Cloud-to-Ground (CG) and 30% for Cloud-to-Cloud lightning flashes. The accuracy of position determination lies within 200 - 300 m.

Key words: lightning, lightning localization system, real-time, location efficiency, location accuracy

Sažetak: U referatu je prikazan sistem za lociranje atmosferskih pražnjenja (LLS) SCALAR za region Bosne i Hercegovine. Sistem je baziran na kombinovanim senzorima s magnetnim određivanjem pravca i vremena pojave (MDF) i senzorima koji rade na principu vremena pojave (TOA). Proširenje sistema SCALAR-a počelo je 2008. godine kada su instalirana tri TOA senzora. Od 2011. do 2013. godine instalirana su četiri dodatna senzora u Srbiji, Bosni i Hercegovini i Crnoj Gori.

Senzori otkrivaju neobrađene podatke atmosferskih pražnjenja koji se šalju koristeće različite komunikacione veze prema procesnom centru u Beču, gdje se isti procesiraju koristeći software za analizu atmosferskih pražnjenja (TLP). Neobrađene podatke dobijene od senzora TLP procesira i dostavlja rješenja u realnom vremenu korisnicima podataka atmosferskih pražnjenja. Efikasnost lociranja LLS-a, na osnovu izvještaja korisnika softwarea TLP je veća od 90% kod oblak – zemlja (CG) i 30% kod oblak – oblak bljeska atmosferskog pražnjenja. Tačnost odredjivanja lokacije je unutar 200 - 300 m.

Ključne riječi: atmosferska pražnjenja, sistem lociranja atmosferskih pražnjenja, realno vrijeme, efikasnost lociranja, tačnost lociranja

INTRODUCTION

Lightning localization systems of today usually cover large geographical areas that often exceed national borders. This fact corresponds with the very nature of lightning as a meteorological phenomenon, the effects of which can be traced over substantial distances. The set-up of wide coverage systems that process collected data in a cooperative manner also provides many benefits for system owners and operators. Nationally based systems for countries with area below 100.000 km^2 are rarely built without the cooperation of neighboring countries. The main reason for this is that parties benefit if the data collected by sensors are exchanged on a sensor-per-sensor basis.

1. BRIEF HISTORY OF THE SYSTEM

In Slovenia, the activities in the field of lightning localization started in 1996 when 3 magnetic-direction-finding sensors were installed within a pilot project (Figure 1). The system was put in operation in 1997 and was immediately accepted by operators in the national control center [1].

Very soon it was established that the stand-alone network with no GPS time synchronization of the sensors does not provide grounds for the exchange of information with neighboring systems.

Nevertheless, valuable lessons were learned and the interest in the field of lightning localization reached the required level of interest. In addition to this, the results obtained from the pilot LLS proved that it was useful for the power system operation (Figure 2).

Two time-of-arrival sensors were purchased and installed (Figure 3) in 1998 and LLS SCALAR project has started.

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Rad dostavljen:17.07.2014; Rad prihvaćen: 14.10.2014.

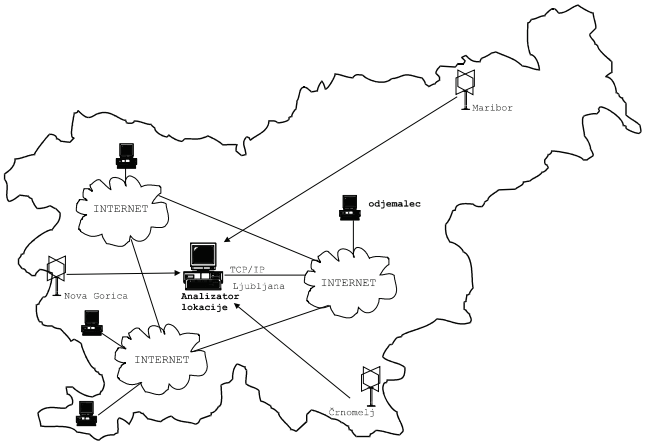


Figure 1: Sensor location in 1997

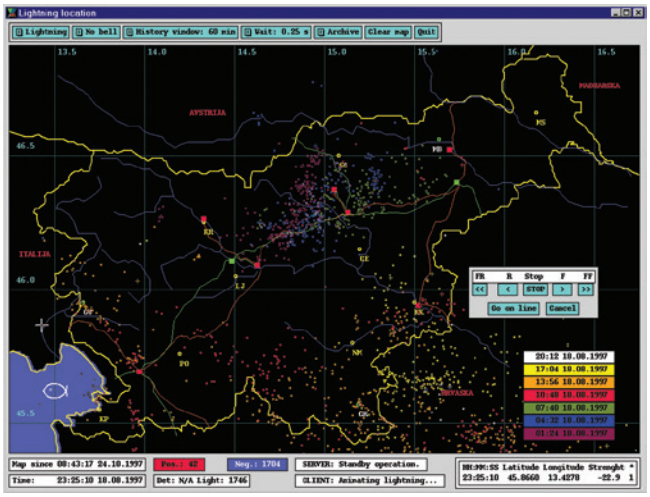


Figure 2: Sensor location and first results from pilot lightning localization project



Figure 3: The location of Slovenian and Austrian sensors in 1998

Own data processing for the country of 20,000 km^2 and the width of approximately 200 km could not be economically justified in 1998. For that reason it was decided to out-source raw data processing to the Austrian partner.

An important step was also taken in 1998 when Slovenia, Austria and Germany utilized public internet and private LAN for the exchange of sensors' raw data. First successful attempts on the lightning processing on the European scale were executed and the corner stone for

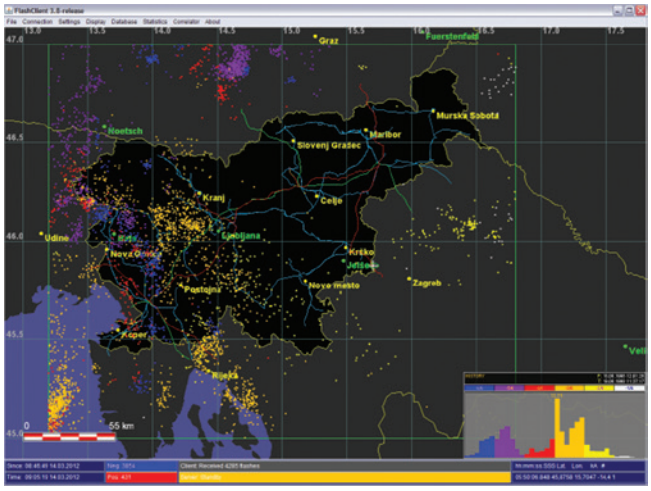


Figure 4: Located lightning flashes during thunderstorm on 18 August 1988

European Cooperation in Lightning Detection (EUCLID) was set. EUCLID assures that lightning data are processed with the known quality level, using the same processing algorithm and known sensor settings on the continental scale.

Between 1998 and 2002, the major attention was devoted to the development of the software for advanced services [2, 3, 4]. Advanced services are those services that besides the information on lightning location (Figure 4) provide also value added information needed by the end-users in different industries; power system generation, transmission and distribution (Figure 5 and Figure 6), meteorological services, telecom, railways, air traffic control, insurance companies and others.

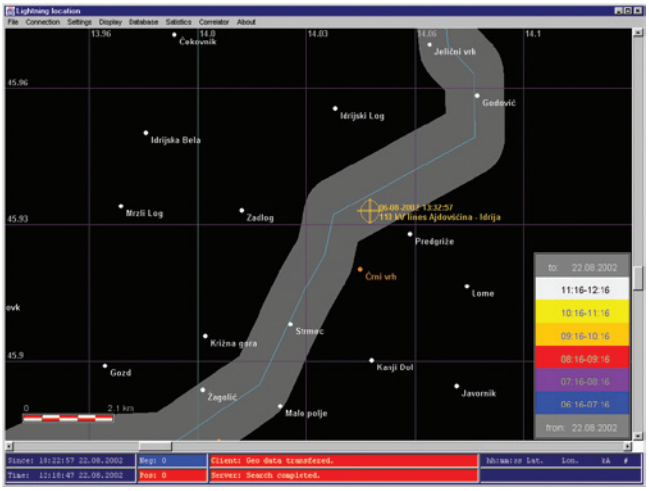


Figure 5: Real-time transmission line and distribution feeder fault correlation (110 kV Ajdovščina – Idrija on 6 August 2002

Between 2003 and 2008, the main effort was put into the network upgrading with new sensors and in building the reference lightning detection network (RLDN) with 20 sensors (Figure 7). RLDN provides reference data for comparison of lightning detected by SCALAR and RLDN and calibration. Based on location and time differences

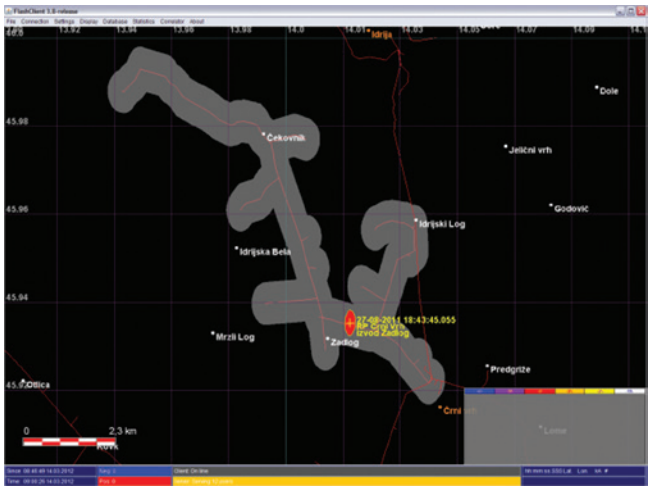


Figure 6: Real-time distribution feeder fault correlation (feeder Zadlog RP Črni vrh 27 August 2011)

of both systems, the improvements of localization algorithm are performed. The result of the improved localization algorithm is better efficiency and accuracy of the lightning localization [5].

It could be said that in 2008 Slovenian LLS SCALAR reached the state-of-the-art level in the lightning localization domain based on the chosen technology.

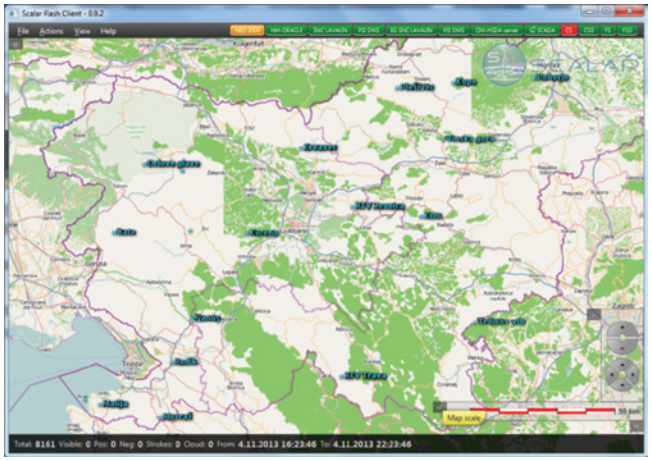


Figure 7: Location of RLDN sensors

2. GENERAL ARCHITECTURE OF LIGHTNING LOCALIZATION SYSTEMS

Each LLS has to comprise of the following functional segments (Figure 8):

1. *Measurements:* This segment is realized with sensors that measure an electromagnetic wave produced by the lightning discharge. The measured quantities differ between the technologies, but basically we categorize them in time-of-arrival (TOA) sensors or combined magnetic-direction-finding and time-of-arrival (MDF+TOA).
2. *Communications:* This segment allows data exchange between segments. It provides a real-time data delivery from the remote sensors to the processing segment, from processing segment to the basic and value added services segment, and finally to the end-users. The most common communication media is a direct connection to the internet or in case where a wired connection is not possible, GPRS, UMTS or a similar protocol via a mobile network is used.
3. *Processing:* Within this segment raw data collected by the sensors are processed. It provides numerical results that comprise of GPS stamped time, lightning location (longitude and latitude), peak current with polarity, multiplicity and some quality description information.
4. *Services:* This segment by means of information technology offers various services for different end-users. This layer is especially important since addressing the end-users with the right solution requires in-depth domain knowledge of processes that are affected by lightning. Only with this approach the end-user may get most out of LLS and its value added services. It should be emphasized that the geographical information on customer's infrastructure, public infrastructure and basic geographical entities (villages, towns, cities, rivers, lakes, highways etc.) plays an important role.
5. *Users:* Users from different domains and industries access basic and value added services provided by the service segment. Different users utilize different services, e.g. a power system transmission operator uses the real-time access and real-time power line outage correlation, while insurance companies always require only past-time data.

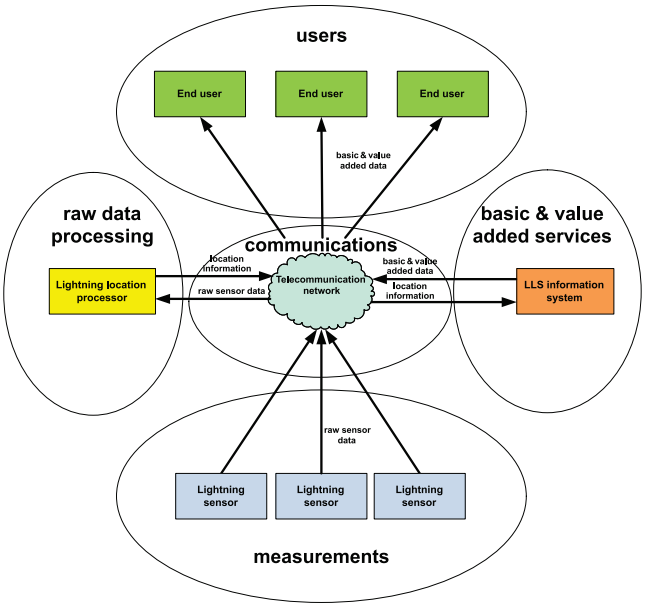


Figure 8: General architecture of modern lightning location systems

It should be noted that *Processing* and *Basic & Value Added Services* depicted in Figure 8 may be set at the same physical location.

3. ARCHITECTURE OF THE LIGHTNING LOCALIZATION SYSTEM SCALAR

3.1. Sensors

In 2008, three TOA sensors were installed in Croatia that significantly improved coverage of EUCLID network in the south-eastern part of Europe. In 2011, the first TOA sensor was installed in Niš (SRB) which became the most remote south-east sensor improving coverage of central and west Serbia. In 2012, two MDF+TOA sensors were installed in Rogatica and Bihać (BIH). In 2013, the sensor in Podgorica (MNE) was installed while the Pula sensor was upgraded to MD+TOA. SCALAR system has 9 sensors in total as depicted in Figure 9.

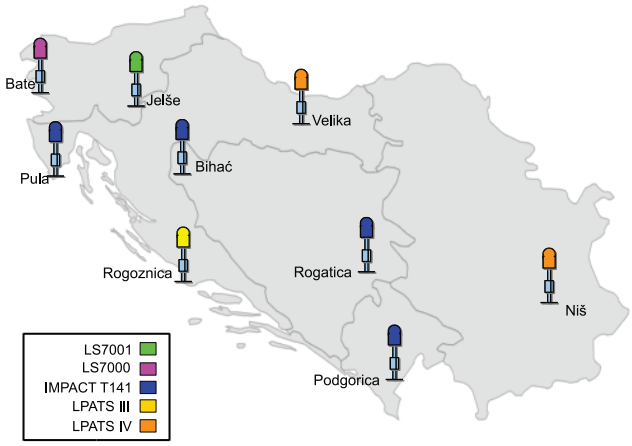


Figure 9: Sensor locations in Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Serbia

Figure 10 shows sensors within EUCLID cooperation covering majority of the Europe continent.

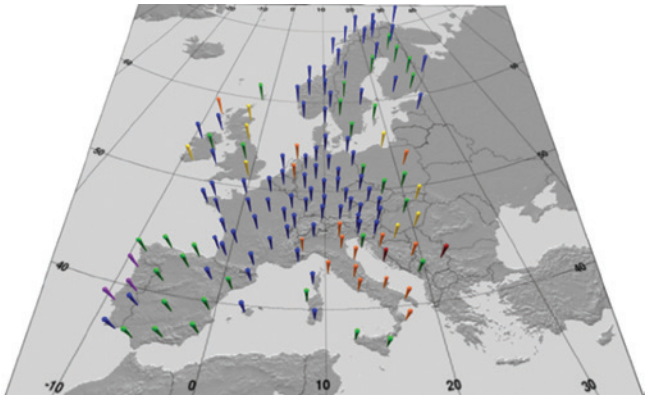


Figure 10: Sensor within the EUCLID network

Sensors in BIH and MNE greatly improved efficiency as well the accuracy of the system, primarily in Bosnia and Herzegovina.

The detection efficiency is calculated by a proprietary model of LLS manufacturer and is used to design LL systems. The model-based estimation, with some EUCLID sensors from the Italian network SIRF, shows a 90% better efficiency for cloud-to-ground lightning (Figure 11).

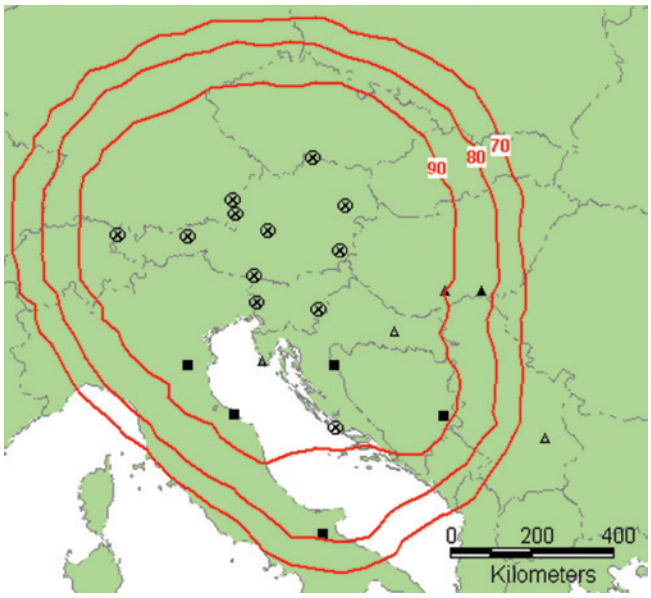


Figure 11: Location efficiency (%) of the SCALAR LLS

The accuracy estimation based on the same model is within 200 - 300 m (Figure 12).

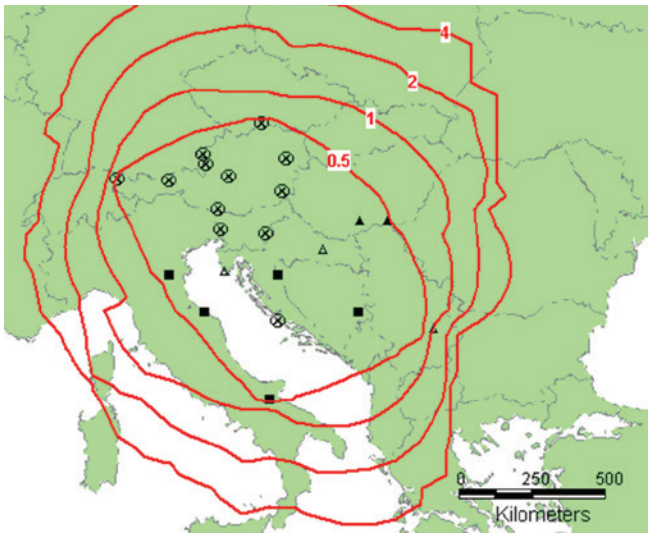


Figure 12: Location accuracy (km) of the SCALAR LLS

3.2. Communications

All raw data need to be processed in near real-time, which mean that only some seconds delay is acceptable. Data communication varies from location to location but in general the TCP/IP protocol over the local area network, public internet or mobile network is used. It is essential that communication links ensure high reliability and bandwidth as the missing or late raw data jeopardize the performance of the LLS system.

3.3. Processing

Raw sensor data processing is performed by Austrian partner OVE who operates the Austrian lightning information system – ALDIS. Besides raw data processing, the storage of raw and calculated data is also provided, which serves an off-site data storage facility.

Special attention is paid to raw sensor's data quality which enables operators to solve potential sensor or communication malfunctioning.

3.4. Information system for basic and advanced services

The lightning information system offers basic and value added services for end-users in the power system and other domains. In 2012 and 2013, a complete rebuild of lightning information system took place. A new lightning information system employs the service-oriented architecture (SOA), implements new technologies (JavaFX) and new available internet services (OpenStreet Maps, MapQuest or other geography service providers).

The SCALAR's architecture shown in Figure 13 allows for organizing SCALAR in different domains. A single SCALAR *FlashClient* can be simultaneously connected to different domains, where each domain offers one or more specific services e.g. correlation service [6], raster images, radar images, statistical data etc.

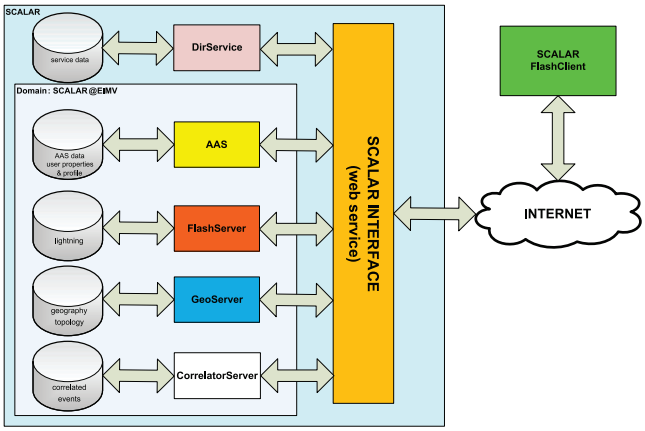


Figure 13: Architecture of lightning information system of SCALAR

Services that allow for access of real-time and archived lightning data are realized through a multithreaded and multiuser server named *FlashServer*. Lightning information are displayed with a SCALAR *FlashClient* software package, which has rich geography offered from internet services like OpenStreetMap or other providers (Figure 14).

End-users usually request that in addition to the general geography (political borders, cities, towns and villages, rivers, sea coast, etc.) also the infrastructure geographic information like transmission network and substations are displayed within the display system (Figure 15).

For that reason *GeoServer* was developed serving as a GIS sever of all general and specific geographic data that are of interest of end-users and which are supplied by the end-users.

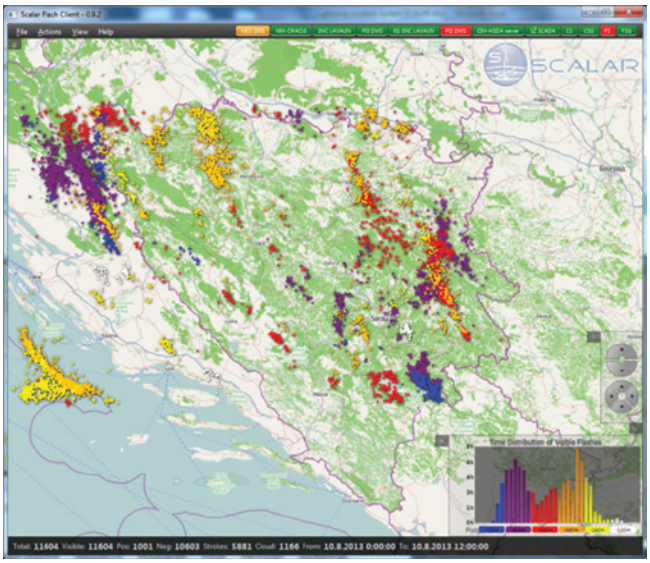


Figure 14: SCALAR *FlashClient* graphical display showing located lightning events on 10 August 2013

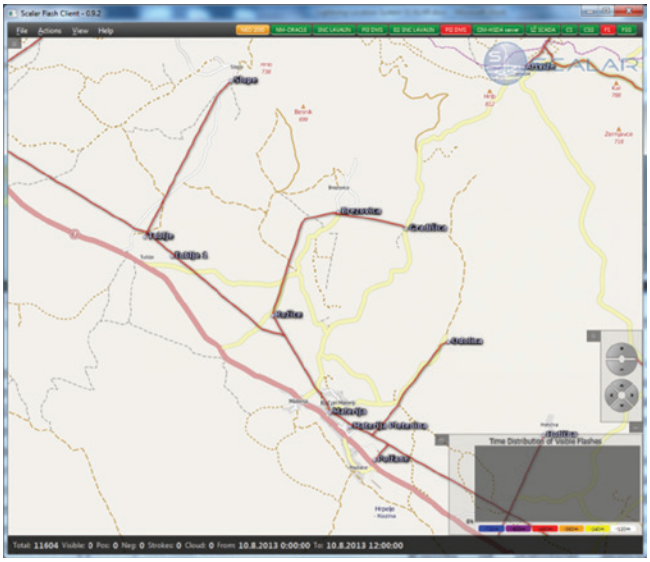


Figure 15: SCALAR *FlashClient* graphical display showing part of distribution network

Among the value added services a correlation service that offers real-time transmission and distribution power line correlation of line faults should be emphasized.

This service, which is performed through *CorrelatorServer*, significantly improves quick fault localization. The correlator correlates circuit-breaker maneuvers provided by the SCADA system with a lightning stroke in temporal and spatial domain (Figure 16).

Special attention is paid to the statistical analysis of collected data. High resolution flash density maps and statistical analysis of lightning amplitudes became a routine input data for the insulation coordination of new and upgraded power lines (Figure 17).

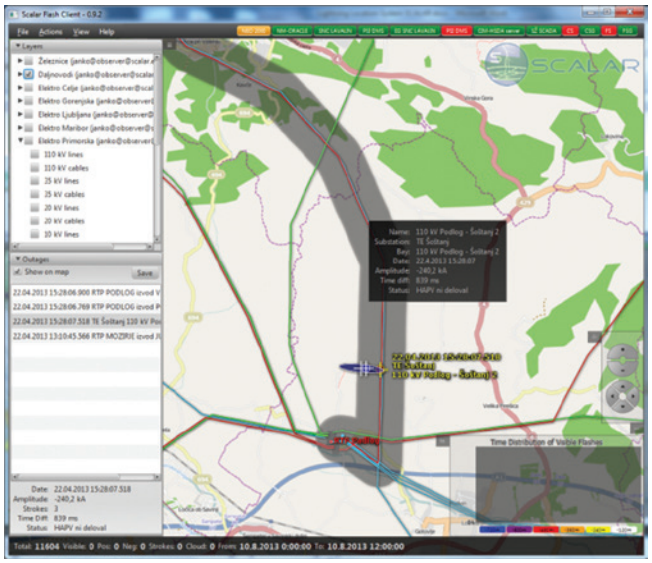


Figure 16: SCALAR *FlashClient* displays correlated outage on a 110 kV line Podlog – Šoštanj 2 on 22 April 2013

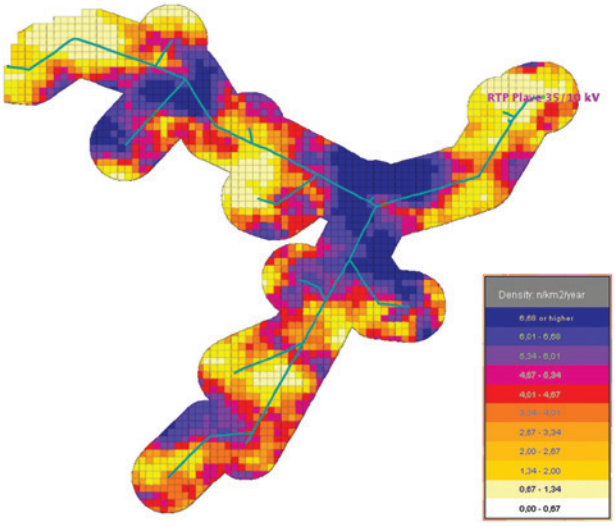


Figure 17: High resolution flash density map for the Dobrovo feeder – Plave substation

The results of statistical analysis also indicated the optimization of number and location of line surge arresters for the improvement of lightning performance on medium voltage.

4. CONCLUSION

By installing 7 additional sensors in Croatia, Serbia, Bosnia and Herzegovina and Montenegro, the lightning localization system SCALAR, which is capable of efficiently and accurately locating cloud-to-ground and cloud-to-cloud lightning, was established in the southeast Europe. SCALARLLS is a part of European Cooperation in Lightning Detection (EUCLID) which assures that lightning data are processed with the known quality level, using the same processing algorithm and known sensor settings on continental scale.

In addition to basic services the system also offers value added services like correlation of transmission and distribution power lines outages in real-time.

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BIOGRAPHY

Janko Kosmač *studied at the Faculty of Electrical Engineering at the University of Ljubljana where he received his BSc (1990), MSc (1993) and PhD (1996) degrees. From 1990 to 1996 he was a junior researcher at the Faculty of Electrical and Computer Engineering at the University of Ljubljana, where he was involved in transient overvoltage studies and harmonics propagation. From 1996 to 2014 he has been employed at the Elektroinštitut Milan Vidmar (ElMV), Ljubljana, where he led the development of SCALAR lightning localization system. Currently he is employed at ELES, the Slovenian TSO, as power system operation expert.*