Towards an Architecture for Service-Oriented Process Monitoring and Control

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***Abstract*—The initiative AESOP (ArchitecturE for Service-Oriented Process-Monitoring and -Control) envisions a Service-oriented Architecture approach for monitoring and control of Process Control applications (batch and continuous process). Large process industry systems are a complex (potentially very large) set of (frequently) multi-disciplinary, connected, heterogeneous systems that function as a complex system of which the components are themselves systems. The future "Perfect Plant" will be able to seamlessly collaborate and enable monitoring and control information flow in a cross-layer way. As such the different systems will be part of an SCADA/DCS ecosystem, where components can be dynamically added or removed and dynamic discovery enables the on-demand information combination and collaboration. All current and future systems will be able to share information in a timely and open manner, enabling an enterprise-wide system of systems that will dynamically evolve based on business needs. The SOA-based approach proposed by AESOP can, on one hand, simplify the integration of monitoring and control systems on application layer. On the other hand, the networking technologies that are already known to control engineers could also simplify the inclusion of or migration from existing solutions and integration of the next generation SCADA and DCS systems at network layer.**

I. Motivation

Large process industry systems are a complex (potentially very large) set of (frequently) multi-disciplinary, connected, heterogeneous systems that function as a complex system whose overall properties are greater than the sum of its parts, i.e., very large scale integrated devices (not all time smart) and systems of which the components are themselves systems. Multidisciplinary in nature, they link many component systems of a wide variety of scales, from individual groups of sensors to e.g. whole control, monitoring, supervisory control systems, performing SCADA and DCS functions. The resulting combined systems are able to address problems which the individual components alone would be unable to do and to yield control and automation functionality that is only present as a result of the creation of new, emergent, information sources, and results of composition, aggregation of existing and emergent feature- and model-based monitoring indexes. The kind of very large scale distributed process automation systems that AESOP is addressing is required to meet a basic set of criteria known as Maier's criteria [16] i.e. (i) operational independence of the constituent systems, (ii) managerial independence of the constituent systems, (iii) geographical distribution of the constituent systems, (iv) evolutionary development and (v) emergent behavior.

Such systems should be based on process control algorithms, architectures and platforms that are scalable and modular (plug & play) and area applicable across several sectors, going far beyond what current Supervisory Data Acquisition and Control (SCADA), and Distributed Control Systems (DCS) and devices can deliver today. A first fast analysis of current implemented SCADA and DCS systems detects a set of major hinders for not completely fulfilling some of all those criteria: the big number of incompatibilities among the systems, hard code data, different view on how systems should be configured and used, co-existence of technologies from a very long period of time (more than 20 years), use of reactive process automation components and systems instead of having them working in a proactive manner. If we began hooking all these hinders, we would soon have an unmanageable mess of wiring, and custom software, and little or no optimal communication. To date, this has been the usual result, where "point solutions" have been implemented without an overall plan to integrate these devices into a meaningful "Information Architecture".

Looking at latest reported R&D solutions for Control and Automation of very large distributed systems, it is possible to identify today that there are already many known possibilities for covering some and if possible many or all the criteria addressed above. The AESOP concept is targeting optimization at architectural and functional levels of the logical and physical network architectures behind the process automation systems, mainly towards a potential optimal configuration and operation, e.g. of energy consumption in current complex and power hungry process industries, based on service-oriented process control algorithms, scalable and modular SOA-based SCADA and DCS platforms, going far beyond what current mainly centralized SCADA and DCS can deliver today.

To address integration of very large numbers of subsystems and devices, the AESOP project takes its roots in previous work carried out in several European collaborative projects such as SIRENA [2], SODA [8], SOCRADES[6], VINNOVA-Sweden etc., all of which demonstrated that embedding Web Services at the device level and integrating these devices with MES and ERP systems at upper levels of an enterprise architecture was feasible [6, 12, 13]. The first results shown in pilot applications running in the car manufacturing, electromechanical assembly and continuous process scenarios have been very successful [3], confirming that the use of Cross-layer Service Oriented Architectures in the Industrial automation domain is a very promising approach, able to be extended to the domain of control and monitoring of batch and continuous processes.

II. Challenges and potential benefits

The application domain of large process systems composed of very large numbers of systems poses several challenges:

- Distributed monitoring and control of very large scale systems (tens of thousands of interconnected devices are encountered in a single plant) enabling plant efficiency control, product quality control and production quality control.
- A multitude of plant functions requesting information and functionality due to continuously changing and increasing business requirements.
- Integration of existing devices which generates the data and information necessary for the multitude of plant functionalities like plant operation, maintenance, engineering, business and technology, i.e. system of systems integration [11], operation and evolution.
- The very large spread in device and system performance requirements regarding e.g. response time, power consumption, communication bandwidth, security.
- Legacy compatibility (20 years old systems have to interoperate with modern systems).

When using Service-Oriented Architectures in Process Control applications, the following advantages are expected:

- Open batch and/or process automation monitoring and control systems that can be accessed by any other system of the enterprise architecture able to call for Services.
- Proactive batch and/or process automation monitoring and control systems: they are able to expose their functionalities as Services.
- Proactive batch and/or process automation monitoring and control systems: they are able to compose, aggregate and/or orchestrate services exposed by themselves and from other devices in order to generate new distributed SCADA and DCS functions (also exposed as "Services" at the shop floor).
- Proactive batch and/or process automation monitoring and control systems at the shop floor that are interoperable with SOA-based systems of the upper levels of the enterprise architecture (e.g. integrating ERP and MES with the SCADA and DCS).
- Open batch and/or process automation monitoring and control systems: a next generation of SOA-based process automation components offering plug-and-play capabilities, providing self-discovery of all devices and services [10] of the complete plant-wide system.
- Proactive batch and/or process automation monitoring and control systems: a next generation of SOA-based devices and system exposing SCADA and DCS self-adaptable (emergent) functionalities (as a consequence of e.g. automatic service composition or orchestration), taking care of real-time changes in the dynamic system.
- Open batch and/or process automation monitoring and control systems: Improved ease-of-use and simplified operation and maintenance of SOA-based SCADA and DCS systems embedded into devices due to the universal integration capabilities that the service is offering.
- Cost-effectiveness, thanks to optimized SCADA and DCS distribution at the device level on the shop floor and at upper IT system levels.
- Proactive batch and/or process automation monitoring and control systems: Generation of new Monitoring indexes and Control functions at different levels of the plant-wide system, as a result of using event propagation, aggregation and management properties of the SOA-based distributed SCADA and DCS as shown in Figure 3.
- Easier network management of large-scale networked systems. Based on these advantages a clear possibility is to generate system energy usage optimization. With the SOA-approach integration of subsystems having the appropriate information, it can be done both at the operator level and at the business level, where different approaches to energy optimization can be applied.

III. AESOP approach

Figure 1 shows all the levels, systems and components that can be found in a large-scale Process Industry monitoring and control scenario. In the plant, there are a set of process control stations (PS) that control different process sections in the plant. The PSs are connected to various devices, distributed I/O stations, PLCs etc. that are in there connected to the process equipment. For much larger and specific process equipment, the supplier also includes dedicated and unique devices, systems or complete control systems that are, from a system perspective, seen as black boxes (BB). In the overall plant monitoring and control, other systems and sections are also integrated like lubrication systems, transformers, switchgears, valves, ventilation, heating etc. For operators, engineers, maintenance personnel and management, there are one or several control and engineering rooms available but also hand-held devices for local monitoring and control. On the enterprise level, there are information access, control and analysis through various management and enterprise information and control systems.

AESOP envisions an infrastructure that goes well beyond existing approaches [11, 6], as depicted in Figure 2. It will

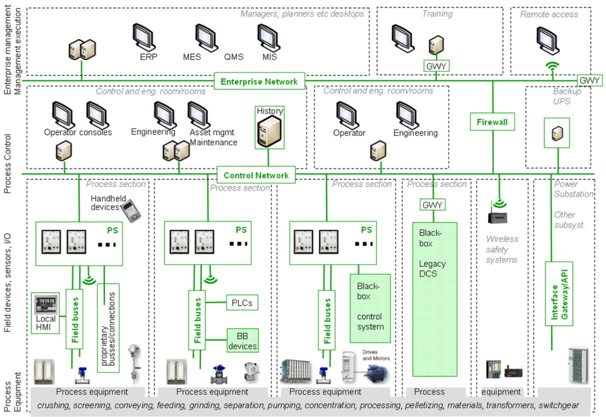

Fig. 1. General architecture of a process control system

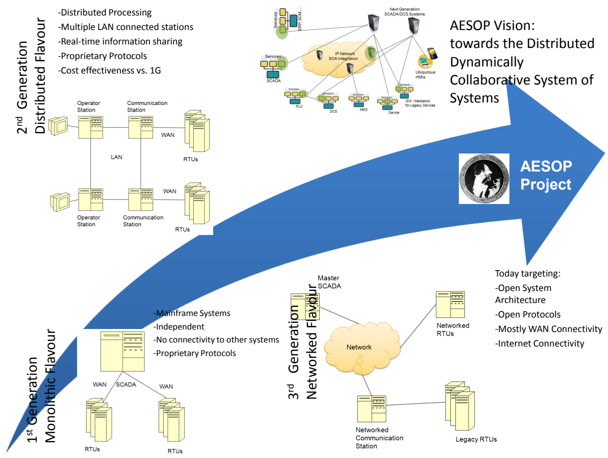

Fig. 2. AESOP impact on evolution of supervisory systems

enable cross-layer service-oriented collaboration not only at horizontal level, e.g. among cooperating devices and systems, but also at vertical level between systems located at different levels of a Plant-Wide System (PWS) enterprise architecture [6, 5]. Focusing on collaboration and taking advantage of the capabilities of cooperating objects [17], poses a challenging but also very promising change on the way future plants will operate, as well as to the way we design software and model their interactions. The future "Perfect Plant-Wide System" [7, 6, 14, 1] will be able to seamlessly collaborate and enable monitoring and control information flow in a cross-layer way. As such the different systems will be part of a SCADA/DCS ecosystem, where components can be dynamically added or removed and dynamic discovery enables the on-demand information combination and collaboration. All current and future systems will be able to share information in a timely and open manner, enabling an enterprise-wide system of systems [11] that will dynamically evolve based on business needs. With this approach we also want to target future compliance and follow concepts and approaches that will enable us to design today the perfect "legacy" system of tomorrow, which will be able to be easily integrated in long-running infrastructures (e.g. the pharmaceutical one with lifetime of 15-20 years).

To achieve the vision, we focus on collaborative large-scale dynamic systems. To enable the optimal operation we will use process control algorithms, architectures and platforms that are scalable and modular (plug & play) and are applicable across several sectors; we will demonstrate this in the pharmaceutical and mining sectors. The vision goes clearly far beyond from what current Supervisory Data Acquisition and Control (SCADA) and Distributed Control Systems (DCS) can deliver today. Collaborations will be able to be created dynamically, serve specific purposes and will spawn multiple domains.

The application of Ethernet-based networking technologies evolves having the examples of Fieldbus HSE, EtherNet/IP, Modbus/TCP, PROFInet, etc. technologies used for DCS and SCADA solutions. The SOA-based approach proposed by AESOP can, on one hand, simplify the integration of monitoring and control systems on application layer. On the other hand, the networking technologies that are already known to control engineers could also simplify the inclusion of or migration from existing solutions and integration of the next generation SCADA and DCS systems at network layer.

The main Science and Technology objectives of AESOP are:

- Propose a system-of-systems approach for monitoring and control based on Service-Oriented Architecture (SOA) for very large scale distributed systems in Process Control applications (up to tens of thousands of devices).
- Investigate how large is the percentage of all devices that reliably can be incorporated in the SOA architecture, i.e. how "deep" we can go with SOA? Are we able to get SOA at the device level inside process control loops?
- Build a foundation for predictive performance of such SOA architecture based on a formal approach to event based systems.
- Propose a transition path from legacy systems (e.g. a 20-year old machine) to a SOA compliant system.
- Propose a transition path from the new SOA-based SCADA and DCS to be an adequate legacy system in the next 5-10 years.

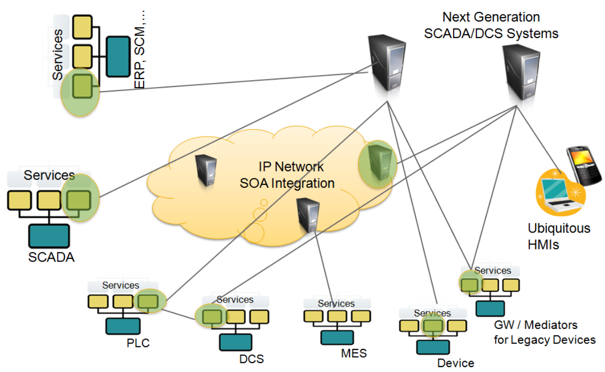

Fig. 3. AESOP concept: Far beyond current Process Control systems towards the "Distributed Dynamically Collaborative" system of systems

IV. Beyond the State of the Art

Several projects exist that complement what AESOP targets. We discuss here on some of them and define the Δ with AESOP.

ADAMS (Action for the dissemination and adoption of the MARTE and related standards for component based middleware) is relevant to AESOP, as we extensively utilize middleware components to connect and manage embedded devices and applications. Adoption of a consistent standard to describe that environment is going to bring remarkable advantages in terms of flexibility and scalability of the solution. AESOP will provide a real test site and industrial environment where MARTE approach and methodology could be tested.

CHAT (Control of heterogeneous automation systems: technologies for scalability, reconfigurability and security) is about developing core components (algorithms, protocols and procedures) of the next generation of distributed control systems, able to tackle the supervision and control of larger and more complex plants while drastically reducing infrastructure, maintenance and reconfiguration costs. CHAT deals with lower level control modeling, i.e. no SOA level integration. AESOP targets a wider integration of devices, subsystems and functionalities based in a service approach. AESOP can provide data and information from CHAT technology (algorithms, protocols and procedures) as services, thus enabling their usage in a global integration of devices, subsystems and functionalities.

DISC (Distributed supervisory control of large plants) is about the design of supervisors and fault detectors exploiting the concurrency and the modularity of the plant model. It is to use several techniques like modularity in the modeling and control design phases; decentralized control with communicating controllers; modular state estimation, distributed diagnosis and modular fault detection based on the design of partially decentralized observers; fluidization of some discrete-event dynamics to reduce state-space cardinality. The expected outcome of this project are: new methodologies for modular control design and diagnosis of complex distributed plants and new tools for the modeling, simulation and supervisory control design that will be part of an integrated software platform. AESOP can extend DISC especially towards enterprise integration based on SOA.

FEEDNETBACK (Feedback design for wireless networked systems) aims to close the control loop over wireless networks by deriving and applying a co-design framework that allows the integration of communication, control, computation and energy management aspects. It addresses issues on complexity, temporal and spatial uncertainties, such as delays and bandwidth in communications and node availability. Whereas FEEDNETBACK focuses on efficient, robust and affordable networked control that scales and adapts to changing application demands, AESOP is focusing on fundamental/general control and monitoring paradigm investigating event-based operation.

FLEXWARE (Flexible wireless automation in real-time environments) focuses on WiFi radio control for the use in real-time process monitoring and control. The middleware of providing services and service integration at device, subsystem and system level addressed by AESOP can directly make use of FLEXWARE device technology. For instance, by running an SOA stack on such devices we can realize device integration in the AESOP architecture.

GINSENG (Performance control in wireless sensor networks) deals with QoS at the communication level. Current results indicate that devices can be given the ability to determine communication QoS. This can then be offered as a service to a global device, subsystem and functionality integration as addressed by AESOP.

HD-MPC (Hierarchical and distributed model predictive control of large-scale systems) deals with the complexity of the control task. The project proposes to use a hierarchical control set-up in which the control tasks are distributed over time and space. In such a set-up, systems of supervisory and strategic functionality reside at higher levels, while at lower levels the single units, or local agents, must guarantee specific operational objectives. AESOP is targeting a more fundamental change in control and supervision paradigm, targeting flat event-based networks.

NESTER (Networked embedded and control systems technologies for Europe and Russia) will base its analysis on industrial vertical sectors needs such as manufacturing and process plants, which are the application fields of AESOP. The AESOP project could take advantage in the dissemination and exploitation phase of a huge number of potential opportunities in the Russian market; on the other hand the outcomes from AESOP could be useful in many sectors (e.g. natural gas and other process industries) for members of the knowledge network.

PRoSE (Promoting standardization for embedded systems) is a supporting standardization action in the field of Embedded Systems (ES) in which standards are of strategic importance for the creation of markets. ProSE will provide a vision and recommendations on the way that Embedded Systems standards can create cross-business domains synergies. It will be of strong interest for AESOP to cooperate with ProSE, thus enabling a broader standardization as a result of AESOP.

WIDE (Decentralized and wireless control of large-scale systems) (i) envisions a generic modeling and control design method for large-scale distributed systems such as manufacturing and process plants and large scale infrastructures; (ii) proposes a new engineering approach to the design of scalable distributed model predictive controllers that optimize operational efficiency under resource and safety constraints while ensuring robustness to component and communication failures; (iii) enables the use of wide-area wireless sensor networks for closing the control loop. AESOP will cooperate with WIDE and extend it towards SOA-based enterprise integration.

V. Case Studies

AESOP is user-driven and several use cases expressing the wishes of end-users will be realized. These lead to technological improvements in control as well as in monitoring in process control. The use cases listed hereafter are spanning an evolutionary process starting from a process controlled in a classical way with migration to an event-driven approach to a complete system controlled and monitored based on the new approaches targeted by AESOP. The wide range of applications illustrates the needs to build new concepts applicable across several sectors. Example use cases under investigation include:

- Plant lubrication system: The objective of this use case will be to demonstrate an improved plant performance enabled by higher-quality data coming from sensors. As part of the validation, a general migration scenario from the classical control system to the new environment will be demonstrated too.
- Oil lubrication: This use case will demonstrate improved data acquisition capabilities of the new SCADA concept, which will be validated via deployment of new intelligent measurement devices. The collected information will help to better assess status of the lubrication system and make decisions on the required maintenance work.
- Plant energy optimization: The application focus of this scenario will be on plant energy efficiency, however from the technology point of view. It will aim to demonstrate new event-driven processing capabilities that will support dynamic reconfiguration of selected monitoring and control applications. Validation scenarios will address consistency of models used at different levels of the control hierarchy, cross-layer integration, and on-demand optimization capabilities.

All prototype applications will be validated under real conditions on the given end-user site, or partially in a simulated environment. Already defined performance metrics will be used to measure operational improvements enabled by the new technologies. All lessons learned, feedback from the field, identified gaps, and other aspects will be used as feedback to asses the architecture concepts of AESOP.

VI. Innovation Perspectives

Innovation coming from the visionary architectural approach AESOP will follow can be described in three dimensions i.e. (i) end-user perspective, (ii) supplier perspective and (iii) tools and basic technology perspective. Each of these dimensions as depicted in 4 shows the state of the art and an identified future both from end-user benefit perspective and the technology that will support these benefits.

A. End-user dimension

The industrial state of the art of large process control systems can be exemplified by more than 23000 I/Os running in classical hierarchical control architecture. Parallel to the control system, other systems, e.g. for maintenance exist. End-users run a number of such large process control systems, continuous or batch. They already have identified areas where cooperation between systems like those discussed above can generate large benefits regarding e.g. production efficiency,

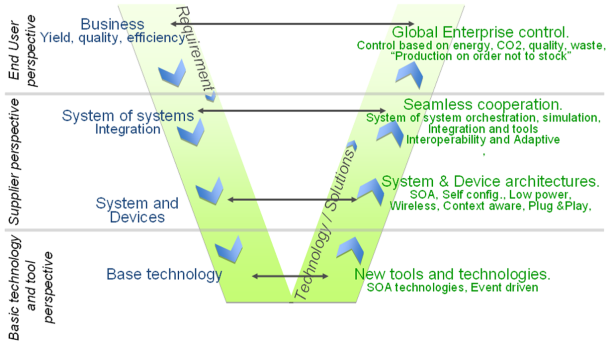

Fig. 4. State-of-the-art perspectives

product quality control, energy usage optimization, CO_2 minimization. Research projects like Mine of the future (National Swedish project) are currently providing results targeting the needs for increased integration of ProcessIT systems. Here the capability of seamless and timely integration of data and information between systems and functionalities is identified as critical. These capabilities have to be flexible to handle continuously changing business and technologies.

Based on the SOA approach supported by standard-based and formal-based software design methods, the AESOP project will define architectures, technologies and migration strategies and tools suitable for addressing seamless and timely integration of data and information from subsystems and devices. Altogether, this will open for large improvements in the flexibility of monitoring and control of very large systems. Thus making it economically and man power-wisely possible to address knowledge improvement possibilities regarding product and production quality as well as e.g. energy usage optimization.

B. Supplier perspective

The SOCRADES project evaluated several SOA solutions, applicable at the device level, including Devices Profile for Web Services (DPWS [19]) and OPC Unified Architecture (OPC-UA [15]), in the context of manufacturing automation. The DPWS solution was provided as a complete open-source software component, which was embedded in several devices and tools, and was completely demonstrated in electronic assembly demonstrators, continuous process control and in interoperability trials. A potential merger between DPWS and OPC-UA was also identified, but was not implemented for non-technical reasons. Potential solutions were identified to reduce the costs of embedding DPWS in very simple devices. Some generic web services were identified and specified. The SODA project looked at the eco-system required to build, deploy and maintain an SOA application in several application domains (industrial, but also home, automotive, telecommunication etc.) [8]. An preliminary business evaluation [4] of the SOCRADES results revealed a promising future for SOA solutions in the factory, and also revealed several challenges that still need to be tackled.

However, none of these projects was addressing the specific challenging requirements coming with large-scale distributed systems for batch and continuous process applications, e.g. how deep into the system can we go with SOA solutions (including addressing costs, real-time and security issues)? How can services with real-time aspects be modeled, analyzed and implemented? How can we manage a system with thousands of dynamic SOA-compliant devices (in the overall system, which may be composed on many different control loops, each one with several devices)?

The AESOP project will define SOA architecture for monitoring and control of very large systems. With support from formal-based and standard technology tools the technology limits for SOA on subsystems and devices will be investigated regarding real-time, event aggregation and filtering, event-driven mechanisms etc. It will be possible to demonstrate and, subsequently, provide business concepts which costs will effectively address end-users desires.

C. Tools and basic technology dimension

Currently, the tools and basic technologies supporting SOA architectures for seamless and timely integration of data and information from subsystems and devices and related communication systems are based on standard programming languages like C and Java and operating systems like Linux, Windows and a variety of RT OSs. Automated debugging and verification will require formal based tools and architectures. Such technologies for instance are Hume [18] and Timber (www.timber-lang.org). These approaches are a starting point for enabling automatic code generation and functionality verification.

In order to reach beyond state of the art, AESOP will start with business requirements for the future, analyze them and find which type of requirements applies on systems of systems, and after that on systems and devices to finally end on base technology requirements that derive from business requirements. When having the base technology requirements, AESOP will define the type of new tools and technologies that will meet those requirements. After that, defining system and device architectures using seamless cooperation technologies will finally provide a solution for global enterprise control that meets future business requirements. The AESOP project will investigate and introduce formal-based technologies, thus open for automated verification of code functionality and guaranteed real-time performance, making code generation, debugging and verification more economical.

VII. Impact

Major strategic drivers for large process industry customers are the complex, multi-disciplinary, connected, heterogeneous characteristics of their systems. The AESOP project will be addressing these drivers by looking at several aspects such as how to address the complexity of large-scale distributed systems; tools and methodologies to be used all along the application life-cycle by very different users in order to ease the development, deployment, use and maintenance of the application; implementations of distributed networked SCADA/DCS systems in automation devices and systems, by applying the SOA paradigm, over solutions like IPv6/6LoWPAN; migration paths between existing legacy systems (up to 20-year old) and new SOA-based SCADA/DCS systems.

Monitoring and control (M&C) heavily depends on the integration of embedded systems, and is expected to grow from € 188 Bn in 2007, by € 300 Bn, reaching € 500 Bn in 2020 [9]. This will have a significant impact in several domains and more specifically in process industry. We consider though that the architectural and technological concepts developed within AESOP to be applied also to other domains; under this light the impact that AESOP would achieve might be significant and cross-domain. This could enable Europe as a technology leader in Service-Oriented Process Monitoring and Control.

VIII. Conclusion

AESOP envisions, design, implement and demonstrate a Service-oriented Architecture approach for monitoring and control of Process Control applications (batch and continuous process). AESOP aims at dealing with several key challenges that arise such as real-time web services, wireless, interoperability, plug and play, self-adaptation, reliability, cost-effectiveness, energy-awareness, high-level cross-layer integration and cooperation, event propagation, aggregation and management.

Using SOA we will go beyond existing distributed monitoring and control systems, towards complex infrastructures linked in a cross-layer way from devices to enterprise systems [6]. Transition from legacy systems will be studied for existing ones, and we will make sure that the envisioned approach will make an excellent open legacy system in 20 years from now. The SOA-based approach proposed by AESOP can, on one hand, simplify the integration of monitoring and control systems on application layer. On the other hand, the networking technologies that are already known to control engineers could also simplify the inclusion of or migration from existing solutions and integration of the next generation SCADA and DCS systems at network layer. AESOP will not only design, implement a visionary architecture for Service-Oriented Process Monitoring and Control, but will also demonstrate the application feasibility in pilots. The use cases provided from several end-users will be implemented by technology developers and demonstrated in pilot applications.

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