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Software-defined networking in cyber-physical systems: A survey☆

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ABSTRACT

Cyber-Physical Systems (CPSs) rely on networks that interconnect sensors and actuators to perform measurement, supervision and protection functions in different domains, such as transportation and industrial automation control systems. These networks must be able to support mobile wireless CPSs that are demanding new requirements related to flexibility and heterogeneity without compromising the Quality of Service (QoS). However, it is hard to determine, for example, the optimal resource allocation or the most reliable paths without global network information. In this way, the Software-Defined Networking paradigm is being considered as key to overcome such emerging needs. In particular, an SDN controller is able to establish paths between sensors and actuators according to bandwidth, latency, redundancy, and safety considerations. Thus, the goal of this paper is to review the state of the art of SDN approaches applied to mission-critical applications by identifying trends, challenges and opportunities for the potential development of software-defined cyber-physical networks.

1. Introduction

Recently-coined terms, such as for example, Industry 4.0, the Fourth Industrial Revolution or Industrial Internet, revolve around the use of Cyber-Physical System (CPSs); that is to say, complex architectures where physical entities or processes are remotely controlled by cyber-components. These components are in charge of performing the configuration of communication capabilities and the data-processing functions, as sketched in Fig. 1. The purpose of this figure is to illustrate the communication between the physical domain, formed by networked nodes, and the cyber domain, where the control plane should ensure satisfactory performance in meeting different requirements related to system manageability, security, reliability, and so on. Fig. 1 also shows a wide range of mission-critical applications, such as transportation, industrial automation systems or electrical power grids, and some illustrative scenarios that have received considerable attention in recent years.

CPSs have emerged on the basis of Industrial Control System, where data acquisition and processing elements of a Networked Control System (NCS) are traditionally arranged in hierarchical levels and applications (ANSI/ISA-95 model). Until now, the design of industrial automation networks has been based on an isolation model, where the control of the Operational Technology (OT) is separate from the Information Technology (IT) perspective. However, despite the previously mentioned levels representing a hierarchical architecture, a CPS tends to be designed as a network connecting all physical

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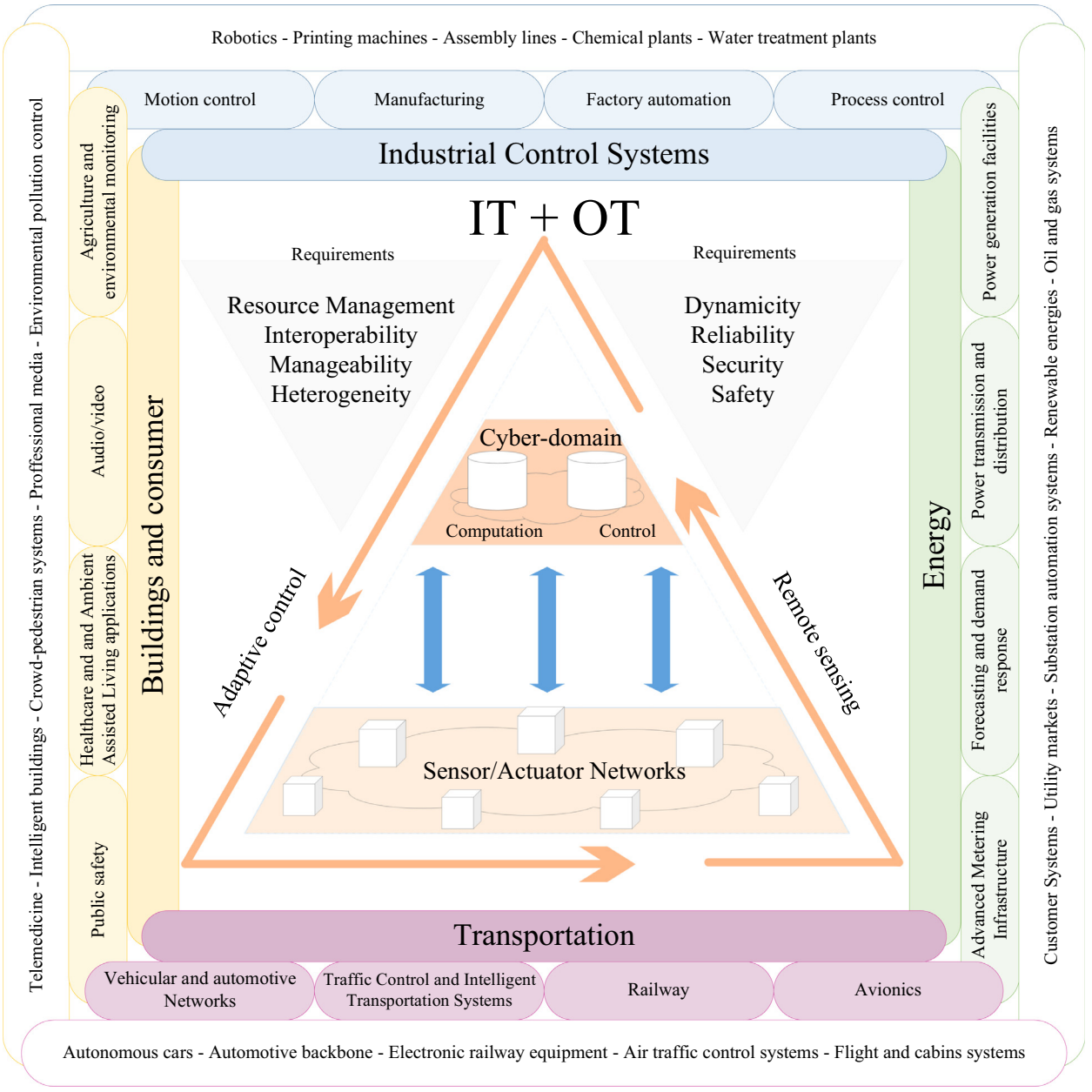

Fig. 1. CPS feedback operation, applications and requirements.

and computational elements in a production infrastructure. Thus, the significance of the CPSs lies on a fully integration between production processes and communications. This paper presents a thorough analysis of the requirements of emerging CPSs, which pose new challenges to the current network architectures. Particularly, it is necessary to design communication systems that enable dynamic performance, where changes in physical device settings involve responses from the network configuration. The cooperative interaction between network protocols and advanced control systems will provide a new ecosystem for future CPS applications. This gives the Software-Defined Networking (SDN) paradigm the opportunity to play a leading-edge role in building CPSs.

Software-defined networks are those in which control and data plane are decoupled. Standardized protocols, such as OpenFlow, Forwarding and Control Element Separation (ForCES, RFC 5810) or the combination of the Path Computation Element Protocol (PCEP, RFC 5440) and BGP Link State Distribution (BGP-LS, RFC 7752) schemes allow external entities to have a global view of the network. Although the SDN technologies are now well-known in data center and telecom environments, the provided programmability is becoming attractive for smart industrial applications. In this way, there are new approaches to extend existing SDN architectures to enable enabling industrial-grade QoS capabilities within CPS domains.

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