Describe application:

Industrial machines/robots have been widely deployed to achieve cost saving solutions and mass production in the field of manufacturing. Traditionally, these solutions have been designed for repetitive and high-volume tasks. Nowaday, machine builders no longer design single-purpose machines − they create flexible, multipurpose machines that address today's manufacturing needs such as smaller lot sizes, customer-specific variations of products, and the trend toward highly integrated products that combine different functionalities in one device. Modern machines can operate more autonomously than ever before, but often require multiple software components to interact with one another, some of which − requiring High-Performance Computing (HPC) resources − are best executed at servers in the Edge/Fog/Cloud. Although current Cloud services already offer dynamic resource and network allocation for a variety of applications, they might not satisfy the stringent Quality of Service (QoS) that industrial robotic applications might demand. For example, these applications may need high amount of bandwidth (Gigabytes per second) and small delay and jitter in order to maintain high-quality and real-time communication while sending Kinect's frames from multiple sensors to servers in the Cloud.

Describe today's solutions (if any):

The baseline technology. The red and blue boxes in Figure 1 show a typical structure of a data-centric solution for Industrial Internet of Things (IIoT). A middleware protocol and API standard integrate components of a system together, providing low-latency data connectivity, reliability and a scalable architecture that business and mission-critical IIoT applications need. Middleware examples include the open source Robotic Operating System (ROS) Industrial (ROS-I) and the Data Distributed Service (DDS) from the Object Management Group (OMG). Applications communicate by publishing and subscribing to topics identified by their topic names. Subscriptions can specify time and content filters to get only a subset of the data being published on the topic. Different ROS-I Nodes or DDS Domains are completely independent from each other. There is no data-sharing across the ROS-I nodes and DDS domains. A number of platforms are leveraged by the middleware, including operating systems (OS), transport and network layer protocols. The latter are responsible for the data transfer between nodes/domains. In a typical advanced manufacturing application, machines incorporate motion/vision (as part of the control system), vibration and power monitoring for assuring machine health, low energy usage and optimal machine operation. These same machines also require synchronization between the control functions, machine vision, and measurements, using in some cases 1 (µs) time synchronization, with a deterministic data communication that can support 1 (kHz) or better closed-loop control. Efforts to achieve said desirable performance goals include:

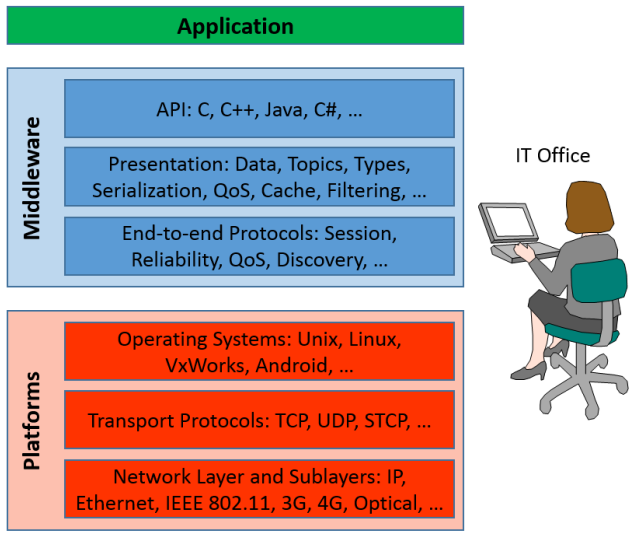

Figure 1: Structure of data-centric solution for IIoT.

- Time Sensitive Networking (TSN), which is an update to the IEEE Ethernet standard intended to address the needs of control systems with standard Ethernet technology.
- NI, Intel, Cisco, and others are collaborating in organizations such as IEEE, the Avnu Alliance, and the Industrial Internet Consortium (IIC) to define, standardize, and drive adoption of this new technology.

These solutions are mainly based on copper cables.

Define the fundamental research problems that must be addressed:

Time sensitive networks (TSNs) are designed to provide deterministic services, i.e., guaranteed packet transport with bounded low latency. For example, the TSN Task Group is part of the IEEE 802.1 Working Group, and aims to add functionalities to the Ethernet standard in order to achieve such quasi-deterministic services. TSNs are well-suited to support time sensitive applications. For example, a number of applications in advanced manufacturing requires good synchronization between the control functions, machine vision, and measurements, e.g., using 1 (μs) time synchronization, with a deterministic data communication that supports 1 (kHz) or better closed-loop control.

Precise synchronization is required across Ethernet switches in order to reserve network resources end-to-end, and ensure low-latency packet transfer between hosts. Background (non-time sensitive) traffic must be carefully scheduled in order to avoid performance degradation in the TSN traffic at the switch. Free space optical (FSO) technologies offer flexibility and ease of deployment, when compared to wired solutions. These technologies are also immune from electromagnetic interference (EMI), a feature that makes FSO particularly attractive on the manufacturing production floor.

The following open problems should be addressed. While FSO communication is immune from EMI, it may be affected by other noise sources. For example, in the presence of welding procedures, FSO communication may be compromised and unable to deliver the real-time data exchange and synchronization that are required by demanding manufacturing robotics applications. Another problem that remains to be addressed is the ability to achieve accurate synchronization across distributed nodes. Any network jitter is a potential impairment to achieving this goal. While TSN Ethernet based solutions are being designed to improve network wide synchronization, other switching technologies should be investigated in conjunction with FSO links.

Identify benefits if the problem gets solved:

FSO technologies are only moderately applied in today's manufacturing. However, this technology has the potential to offer much more, when compared to conventional copper-based and radio solutions, which are more commonly applied. If some of the key drawbacks of FSO could be overcome, this technology would provide an ideal medium of communication on the production floor, in that, it would be easy and cost effective to deploy, it would provide high transmission rates, and it would be immune to EMI noise that originates from various machineries.