Cyber-Physical Systems for SmartGrid

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The growth of urbanization has resulted in the surge of the energy demand required. Meanwhile the traditional utility grid lacks infrastructure to cope with the energy inefficiency. In fact, "More than 90 percent of the energy coming out of the ground is wasted and doesn't end as useful" [1]. As a result, the goal of "SmartGrid" is to enhance utility grids to efficiently deliver sustainable, economic and secure supplies based on the interactions between all users connected to them. This is in contrast with traditional utility grids, in which electricity consumers are not active participants. The underlying technology of SmartGrids is Internet of Things (IoS), which is defined as [2] "a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network."

While IoS provides a low-level network infrastructure that enables SmartGrids, we believe that an overarching approach is to seamlessly integrate the cyber world and the physical world. The Cyber-Physical Systems (CPS) allow both digital information as well as traditional energy (e.g. electricity) to flow through a two-way smart infrastructure connecting everything surrounding us. The National Science Foundation (NSF) CPS Summit [3] defines CPS as "physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core". Researchers from multiple disciplines such as embedded systems and sensor networks have been actively involved in this emerging area.

Our vision [7], [8], [9] of CPS is as follows: networked information systems that are tightly coupled with the physical process and environment through a massive number of geographically distributed devices. As networked information systems, CPS involves computation, human activities, and automated decision making enabled by information and communication technology. More importantly, these computation, human activities and intelligent decisions are aimed at monitoring, controlling and integrating physical processes and environment to support operations and management in the physical world. The scale of such information systems range from micro-level, embedded systems to ultra-large systems of systems. CPS thus break the boundary between the cyber and the physical by providing a unified infrastructure that permits integrated models addressing issues from both worlds simultaneously. In this paper, we propose a Web-of-Things (WoT) framework that augments the Internet-of-Things in order to deal with issues such as information-centric protocol, deterministic QoS, context-awareness, etc. We argue that substantial extra work such as our proposed WoT framework is required before IoT can be utilized to address technical challenges in SmartGrid.

The building block of WoT is Representational State Transfer (REST), which is a specific architectural style [4]. It is, in effect, a refinement and constrained version of the architecture of the Web and the HTTP 1.1 protocol [5], which has become the most successful large-scale distributed application that the world has known to date. Proponents of REST style argue that existing RPC (Remote Procedure Call)-based Web services architecture is indeed not Web-oriented. Rather, it is merely the Web version of RPC, which is more suited to a closed local network, and has serious potential weakness when deployed across the Internet, particularly with regards to scalability, performance, flexibility, and implementability [6]. Structured on the original layered client-server style [4], REST specifically introduces numerous architectural constraints to the existing Web services architecture elements in order to: a) simplify interactions and compositions between service requesters and providers; b) leverage the existing WWW architecture wherever possible.

The WoT framework for CPS is shown in Fig. 1, which consists of five layers – WoT Device, WoT Kernel, WoT Overlay, WoT Context and WoT API. Underneath the WoT framework is the cyber-physical interface (e.g. sensors, actuators, cameras) that interacts with the surrounding physical environment. The cyber-physical interface is an integral part of the CPS that produces a large amount of data. The proposed WoT framework allows the cyber world to observe, analyze, understand, and control the physical world using these data to perform mission / time-critical tasks.

Based on the WoT framework in Fig. 1, the CPS reference architecture is shown in Fig. 2, which aims to capture both domain requirements and infrastructure requirements at a high level of abstraction. It is expected that CPS applications can be built atop the CPS reference architecture.

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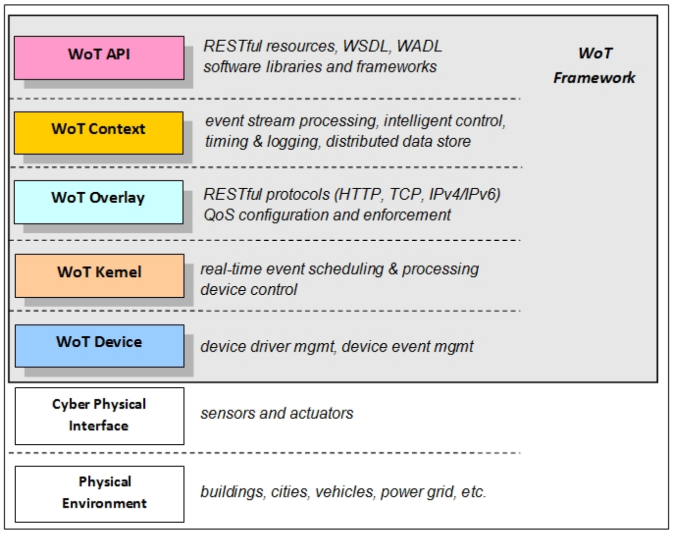

Fig. 1. WoT Framework for CPS.

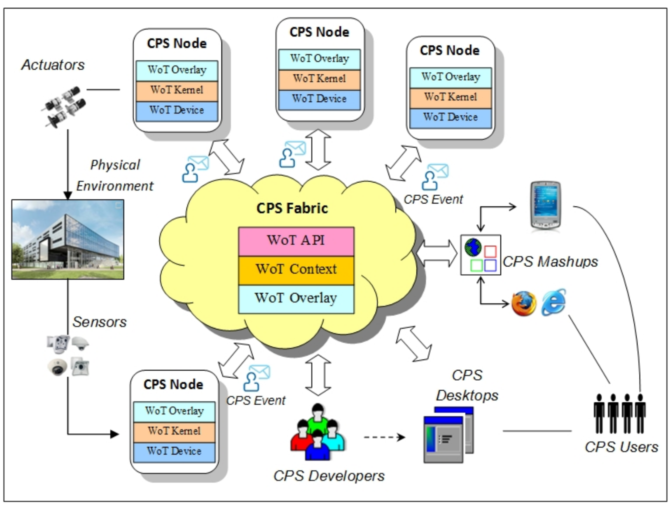

Fig. 2. CPS Reference Architecture.

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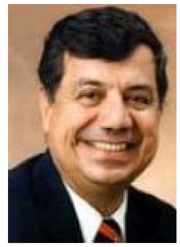

Tharam S. Dillon (M'83–SM'87–F'98) is internationally recognised for his research on Semantic Web, Web services, knowledge discovery, data mining, neural networks, intelligent systems, object-oriented systems, communications, real time systems, fault tolerant systems, and distributed protocol engineering. He is Chair of the IFIP International Task Force WG2.12/124 on Semantic Web and Web Semantics, and was the chair of the IEEE/IES Technical Committee on Industrial Informatics. He has been appointed to be Chair of IFIP TC12 on Artifical Intelligence from September 2009.

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Professor Dillon is an expert in Web Service Architecture, Web Semantic, Ontologies, XML Modeling, Modeling the Reliability of Computer Systems, Object based Conceptual Modeling and Design, Knowledge Discovery and Trust in Service Oriented Environments, Web of Things, Cloud Computing, Data Mining of Structured and Semi-Structured Information, as well as Validation of complex state based systems including protocols using high level Petri nets. He has also been active in the field of XML based systems for over the last 9 years. He has recently given keynote speeches at major IEEE and IFIP conferences on (1) Reference Architecture for Web Services and (2) Semantic Grid Services (3) Biomedical Ontologies (4) Ontologies for Software Engineering (5) Mining Substructures in Proteins. Professor Dillon has a strong track record of working on ontologies and web semantics. His previous work in Real Time Systems, Semantics and the Web includes Sub Ontologies, Integrated Multiagent Ontology Development Methodology, Real Time XML Profile, Ontology Description Language, Object Oriented Conceptual Modelling, Modelling the Dynamics using Coloured Petri nets, SE methodology for Developing Composite Web Services and SOA architectures . He has also developed important algorithms for data mining of complex structures including tree structured data and sequence data. He has also proposed the use of Web 2.0 and social networking in conjunction with ontologies, web services and agents. Sensor network applications he is involved in include vehicular traffic management, intelligent airport, power system monitoring, smart grid, remote oil platform monitoring and control and intelligent and adaptive manufacturing.

Professor Dillons research has made significant contributions to a number of application areas including bioinformatics, logistics, banking and finance, electrical power systems including the smart grid, telecommunication, sustainability and management.