Why an Application Agnostic Internet Model May Not Work for Communication in Cyber-Physical Energy Systems

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Introduction

The integration of communication and computing technologies in electric power systems is seen as an enabling factor for the future smart grid[1]. However, this integration, on its own, will not provide any benefit if intelligent communication-based control schemes are not developed. While the potential benefit of the use of communication and distributed control in smart grid is enormous, so is the challenge of designing a system that can work in a stable and robust manner under communication constraints and uncertainties [1][2]. In general, the introduction of distributed communication-based control is a departure from traditional methods of controlling power systems. While there has been a great deal of attention to communication technologies and protocols for power systems (e.g., [3][4][5]), there has been a lack of models and methods for power-system-aware communication strategies. By strategies we mean models and structures that describe how native communication technologies and connectivity services should be configured and used in a power system.

We argue that in cyber-physical energy systems (CPES) the traditional application-agnostic integration of communication technologies, following the model of the Internet, will not suffice. Although Internet is one of the main success stories of our time, its architecture is focused on non-critical information services and is not meant for critical CPES applications. CPES are characterized by tight coupling of the power system and cyber aspects, which is in contrast with the internet assumption of minimal dependence between different layers of the system. We believe that the existing communication technologies can only be adequate for enabling CPES if they are employed in intelligent information networking structures rather than as simple connectivity services.

Communication in CPES and What Current Technologies Provide

According to a report by the National Energy Technology Lab for the US Dept. of Energy in 2007 [1], Integrated Communications is one of the five key and challenging technology areas that need to be addressed to realize the vision of future smart grid. Such integration has so far been focused on defining power system specific protocols (such as IEC61850[5], DNP3[3], etc.) for providing application level data services on top of existing wired or wireless communication technologies. The approach is to employ the data transfer services of the lower layer communication technologies in much the same way that Internet operates, that is, the communication network and the application can be agnostic to each other. Quality guarantees are then either non-existent or provided by over-designing the underlying network. We argue that this approach will not meet the very wide spectrum of communication requirements that have been identified for smart grid or CPES [6]. In contrast to this approach, the traditional method of building communication-based control schemes for power systems has been to use dedicated links and preplanned networks; this approach obviously lacks the flexibility and cost effectiveness that comes with the Internet based approach.

A solution to these issues may be the use of Quality of Service (QoS) enabled Internet protocols. A wide range of QoS enabling protocols and technologies have already been developed in the past decade; however, they are almost non-existent in actual deployments due to the lack of business cases and the fact that performance degradation for most internet applications can still be tolerated. Even the most demanding internet applications (e.g., video conferencing) are considered non critical in comparison to cyber-physical systems.

Nevertheless, QoS enabled Internet protocols are worth investing in, given the stringent requirements of some CPES applications. While we recognize this possible step in integrating communication technologies into power systems, we still argue that the specific needs of CPES systems are not met by only improving the

[1] NIST's 2012 report on Framework and Roadmap for Smart Grid Interoperability Standards

underlying networking and communication technology. This is due to the fact that the dynamics and behavior of power system applications are very different from those of the demanding internet applications for which QoS mechanisms were developed (e.g., video conferencing). For example, most demanding internet applications have large bandwidth requirements and can trade bandwidth and delay (usually tolerating delay), while timeliness of the messages in a power system cannot be compromised (e.g., in protection and fault isolation applications). For this reason, we believe that designing robust energy systems that will function under communication constraints and uncertainties requires rethinking how communication services are integrated from a system-control perspective (rather than creating control-agnostic or application-agnostic networks).

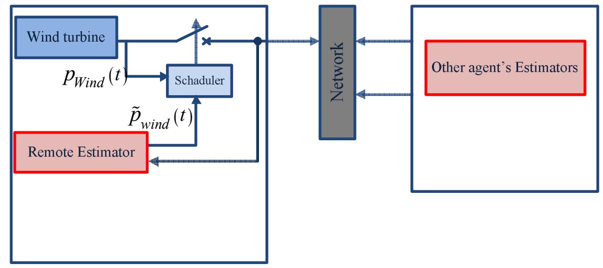

Figure 1 sender/receiver design for on-demand (error-dependent) communication strategy

Communication Strategies for CPES

Our recent work on on-demand communication strategies for distributed energy systems [7][8] is an example of application-aware strategies that would work with protocols such as DNP3 or IEC61850. Though we recognize that this work is not a comprehensive solution for all possible CPES scenarios, we believe it provides a good example for communication strategies that tie CPES application needs with available communication technologies.

The idea is that communicating entities in a CPES are essentially devices that monitor or control dynamical systems; therefore, communication can be viewed as a means to enable remote tracking of these dynamical systems, for the purpose of control. On-demand communication strategies will base data exchange between CPES intelligent electronic devices (IEDs) on estimator performance; meaning that the tracking and control objectives drive the communication load, as opposed to simple measurement and communication of raw data in application agnostic architecture. Figure 2 shows the architecture of a sender-receiver pair and the resulting communication instances. It is observed that the generated load is orders of magnitude less than what the traditional strategy of sampling (measuring) and communicating a signal produces, while the performance of the system is still maintained at the same level.

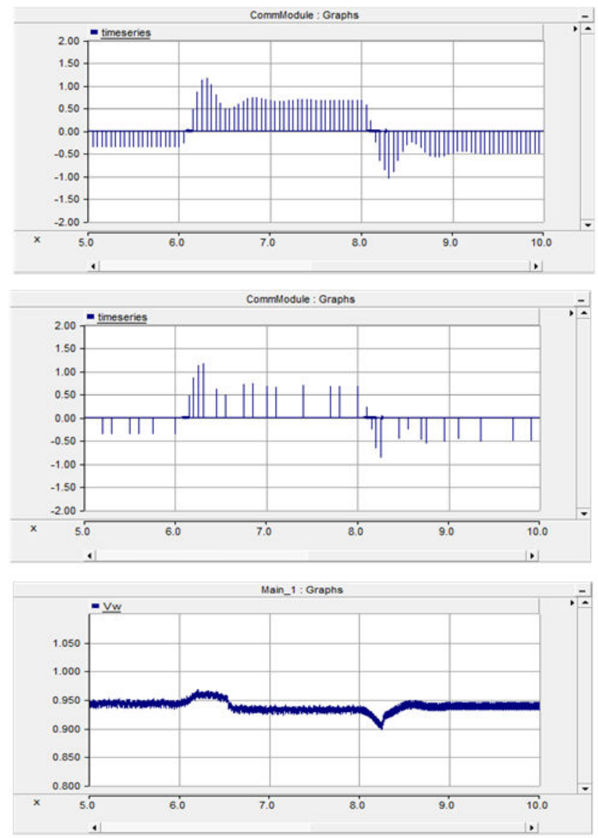

Figure 2: An example of communication events for the system in figure 3, (top) communication events when using traditional application agnostic communication (middle) using on-demand method (bottom) resulting voltage measurement for both cases showing stabilized voltage.

Co-Simulation of Power and Communication Networks

In order to study the communication strategies impact on CPES, we also need to develop co-simulation capabilities [7] that allow integrated simulation of power systems at transient level as well as communication links and networks. Figure 3 shows our current work on this subject which has produced an embedded network simulator inside PSCAD power simulation tool [7]. This tool has been used to evaluate the effectiveness of the on-demand communication strategies of [7].

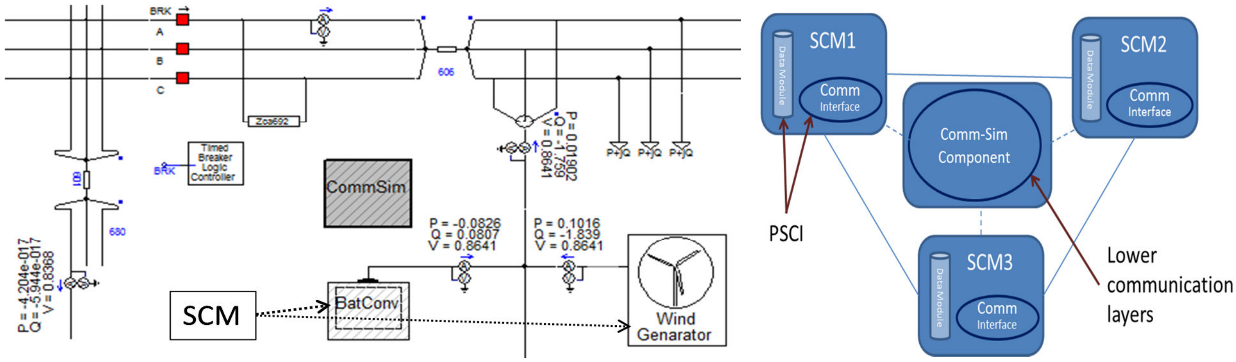

Figure 3: Our PSCAD test-bench based on IEEE 13-node test feeder and including communication simulator modules (left). Our embedded network simulator modules (right)

Finally, we note that although it might be possible to demonstrate prototypes of CPES using existing internet based communication technology, robust and large scale deployments of CPES will require communication strategies that are not application agnostic. The on-demand method presented in our recent work provides an example of such strategies. Nevertheless a comprehensive power application aware communication model for CPES remains to be developed.

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Yaser P. Fallah is an Assistant Professor in the Lane Dept. of Computer Science and Electrical Engineering, West Virginia University. Prior to joining WVU in 2011, he was a Research Scientist at the University of California at Berkeley, College of Engineering (2008-2011). His current research activities, supported by industry, USDoT and USDoE grants, are in the areas of networked cyber physical systems, intelligent transportation systems, and smart energy systems. Dr. Fallah has chaired the technical program committees of IEEE WiVEC 2011 and IEEE PIMRC 2011 (Intelligent Transportation Network track) conferences.

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Steve Bossart is the Lead Energy Analyst at Project Management Center, National Energy Technology Laboratory (U.S. Department of Energy), Morgantown, WV. His current research focus is on metrics and benefits analysis of Smart Grid Investment Grants and Demonstration Projects. He is the author of over 70 publications covering a wide range of technical areas including coal gasification, waste management, environmental controls for coal-based processes, nuclear decommissioning, and Smart Grid.