The Semantics of Price and of Price-Responsive Nodes

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Abstract

Demand optimization will be crucial as we move forward. In particular, we need to increase generation capacity utilization without having to build peaking plants and other reserve generation to meet forecasted demand and facilitate the penetration of renewable and other intermittent sources of energy. To this end, we need to enable suitable pricing, price-responsive end nodes, together with pricing mechanisms and market structures to enable robust demand optimization.

We address the factoring and independent evolution of prices to enable Virtual End Node (VEN) response. VENs may be individual devices, building energy service interfaces (ESIs[2]) [1], and/or facility Energy Management Systems. (In a separate paper [2], we present models of price-responsive devices).

Using results [Sastry, Cox, Considine, Grid-Interop 2011] we show that prices rather than abstractions of price (e.g. simple levels) are critical to VEN portability across the world.

We show how to divide the problem into independently realizable segments:

(a) The source of price information, including transactable and non-transactable prices, which we call *price streams*

(b) The delivery of price information applying existing standards and implementations, including requirements and possible extensions though standard interoperation

(c) The acceptance of price information by the *responsive* end node

We cannot describe price-responsiveness without a discussion of the semantics of price—from prices at which one can buy and sell, to non-transactable prices, to prices that are disconnected from actual economics—followed by implication for selection and use of price streams, and the relative stability of node algorithms.

These evolving price semantics are gradations in the "price-taker" role for end nodes today on the way to fully Transactive Energy.

Forward prices are highly beneficial to effective and efficient actions by nodes, not only to avoid congestion and shortage, but also to make better use of predictable and recurring surpluses from intermittent local generation and at certain times.

We show how the inclusion of all markets and price setting in the chain of price delivery can be accomplished in a way that aligns with present and future business models.

We include a specific high-level plan for deployment of robust price-responsive and price-transactive nodes.

1. GOALS

We want to enable independent development and deployment of price-responsive devices and facilities. We've previously demonstrated that actual prices are both important and simplify device implementation.

We distinguish from abstractions or simple levels (nominal prices disconnected from real economics), which require actual prices in addition to the abstractions. [3].

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[1] Organization for the Advancement of Structured Information Standards, a Standards-Developing Organization http://www.oasis-open.org

[2] An Energy Service Interface (ESI) is a bi-directional, logical, abstract interface that supports the secure communication of information between internal devices (i.e., electrical loads, storage and generation) of a facility and external parties.

2. FOUNDATIONS

We presume a standards-based foundation, including common schedules, price and product definition, and a standard means to communicate the relevant information.

2.1. Cross-Cutting Standards

The NIST Smart Grid Framework and Roadmap [NIST Framework] called for two crosscutting standards needed for effective smart grid interoperability, and an interoperable demand response and distributed energy resource interaction standard

We use the standards and terminology resulting from that program, and three standards described in the following sections.

2.1.1. Common Schedule

First is common schedule. The iCalendar specification is the basis of virtually all business and personal scheduling today. OASIS produced the WS-Calendar [WS-Calendar 2011] extensions to express energy schedules to which we can attach prices, quantities, and more.

2.1.2. Price and Product Definition

The key information about energy product definition includes what the product is (energy, demand, and more including so-called source certificates), when it is delivered, and details for market information exchange. OASIS Energy Market Information Exchange (EMIX) [EMIX 2012] is the standard produced in collaboration with the NIST Smart Grid project.

A product is defined in and with a specific *market context*. Prices and other information such as quantities are attached to a WS-Calendar schedule in a standardized and interoperable manner. EMIX addresses essentially all market products in today's retail and wholesale markets.

2.2. Energy Interoperation

OASIS Energy Interoperation [ENERGY INTEROPERATION 2012], NIST Priority Action Plan 9, includes services to exchange Demand Response (DR) &Distributed Energy Resource (DER) information, and transactive market interactions including price distribution. (NIST Priority Action Plan 9) Energy Interoperation is a scalable set of service-oriented interactions using state-of-the-art software engineering approaches.

OpenADR 2 [OpenADR Alliance] is based on a profile of Energy Interoperation, and concentrates on the DR/DER related interactions.

TeMIX [4] (a profile of standards as specified by OASIS) is a standards-based information model & protocol for electricity transactions including forward & real-time transactions, wholesale and retail transactions, and transmission & distribution transactions. TeMix involves frequent communication between parties of small tenders (buy or sell offers) and transactions for products, and specifies four distinct categories of parties and associated services for interactions with markets.

2.2.1. Pairwise Interactions

Energy Interoperation defines market interactions through sets of pairs of interacting Parties. Demand response and related interactions define *Virtual Top Nodes* and *Virtual End Nodes* roles, which can be thought of as a hierarchical to map to highlight energy-related interactions.

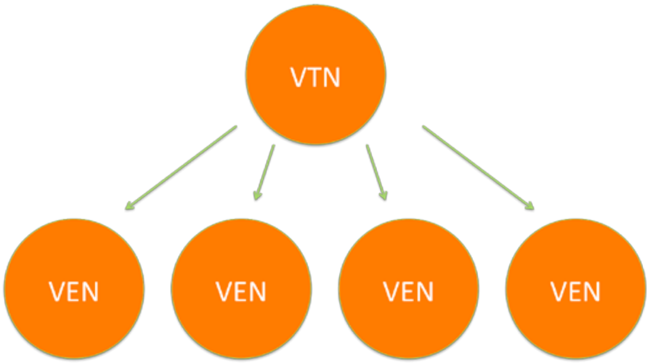

FIGURE 1 VIRTUAL TOP NODE AND VIRTUAL END NODES IN A GIVEN MARKET CONTEXT

Each VTN has one or more VENs with respect to a specific Market Context; each VEN is associated with exactly one VTN.

See [Energy Interoperation] for examples.

2.2.2. Actors and Interfaces

Actors support interfaces such as those for the VTN, VEN, and other Parties[3]. The actor does the work; the interaction is done by the actor through the interfaces and roles it supports.

2.3. Price Streams and Time Series

Streams are an extension to OASIS WS-Calendar [5] that factors out product definition, time intervals and references—the details of a set of contiguous intervals with prices attached. This defines a time series with the necessary information on product description.

We have applied analytic approaches to time series of price in other papers (e.g. [2] and [3]).

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[3] The actors that interact with markets, including those that are recipient of price information, are called Parties.

3. ARCHITECTURE FOR PRICE-RESPONSE

Our architecture must address the following issues:

- Support economic interactions, both one-way and two-way. We call the former *price distribution* and the latter *transactive operation*.
- Support independent evolution, which we accomplish by using the Energy Interoperation standard services. The service definitions are stable while the endpoints evolve independently.
- Support price streams. These are defined in Energy Interoperation and EMIX.
- Use standard interoperation as defined in Energy Interoperation.
- Build responsive end nodes with increasing levels of sophistication to derive maximum benefit from market mechanisms as they evolve

The NIST Framework and EMIX carefully address the difference between price and the pair (price, product definition). The essential difference is that price is merely a number; the product definition tells you what you buy or sell, and when it is scheduled for delivery, and the market context in which it is meaningful.

First we must discuss the semantics of price and its relationship to the economic behavior of an end node.

4. SEMANTICS OF PRICE

If a price stream is delivered, what is the relationship of that price and product definition to what the receiving node expects?

4.1. Goal: Use “Real Prices”

Ideally the prices will be *real* in that they are the prices paid by the party making the payment. Unfortunately, there are many uses of the word price in the literature with very different meanings. [See e.g., EPRI publications]

In fact much of the confusion comes from non-transactable prices decoupled economically and practically from their product definition.

For example, a device or node might behave differently based on regional Independent System Operator (*ISO*) prices. But those prices are disconnected from retail prices for the node because the prices are not transactable (the node didn’t participate in the market processes that defined them, and is not party to those economic transactions), they may be in the past, and the quantities purchased by the vast majority of nodes are not the wholesale prices quoted by ISO markets. Nevertheless, there is much interest in accepting ISO prices as actionable in that they may affect node behavior. (See e.g. [2] and below).

4.2. Algorithms and Actionable Information

Interestingly, a node may behave the same way with inputs that are not *real* in the sense of Section 4.1.

The node receiving the price stream must understand the semantics of the price stream and adjust its behavior to reflect the economic realities (see Section 5).

For better or worse, the response to a price can be programmed the same, regardless of the source, validity, or applicability of the price used.

As discussed in [3] a price is always easier to use than simple abstractions that confuse the economic effects.[4]

4.3. Decoupled Incentives

What are the incentives for the node to take a particular action in response to price changes?

If the price stream considered is not coupled to the costs of the node, we are led to secondary or tertiary considerations. For example, a rebate for an appliance purchase that can respond to “prices” is economic, but is decoupled from actual energy prices.

And if the node responds to nominal prices, that amounts to remote control, in effect applying Mechanism Design Theory[5] [6] to control node behavior without direct economic cost or (more importantly) direct economic benefit.

4.4. Transactable or Not

The first characteristic of price semantics is whether the product (implied or not) at that price, time, and location is *transactable*—can there be a buy or sell at that price?

As we’ve seen, appliances do not see transactable prices looking at wholesale price streams.

Forward, or future prices may be transactable or may be non-transactable. Is there a market where one can buy or sell at a specific price at a specific location and specific time in the future?

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[4] If the actual cost for level 2 is approximately the same is that for level 3, and level 4 is ten times higher, then the economic effect of choosing level 2 versus 3 differs from that of choosing level 3 versus level 4. As we argue in the reference, since real actionable prices must be available, those real prices must be used.

[5] The creators of Mechanism Design Theory won the Nobel Memorial Prize in Economic Sciences in 2007.

Certain retail tariffs, e.g. Time of Use [REF] are clearly transactable, as the price is known in advance.

4.5. Predictability

How predictable is a price? Am I getting a stream of indicative or relative prices? How likely is it that I can transact or act on those prices as received?

4.5.1. Forward, Ex Ante, and Ex Post

Forward prices are for a particular time in the future. All of the product definition issues apply; the usual contrast is with either historical prices or real-time prices.

Prices may be determined *ex ante* or *ex post* ("in advance" or "after the fact"). An ex post price may not be transactable unless the node participated in the determination (market or other means).

4.5.2. Inaccurate or Uncertain

Non-transactable forward prices may be inaccurate; they are in effect predictions. Another term used is *indicative* prices.

The degree of certainty must be addressed by the node, and whether the predicted prices may indeed obtain at that future time. Historical information may be monitored to determine how well the non-transactable forward prices match the actual prices that will obtain (either transactable forward or transactable real-time).

4.6. Relationship to Reality

How do the elements of the price stream relate to reality? Some aspects of uncertainty or inaccuracy may also be considered. But we know that if prices are transactable by someone, they may not relate to the prices the node pays—the wholesale price rarely applies to retail purchases.

4.6.1. Fiat Prices

One reason for disconnection from reality is that someone is, in effect, determining prices and providing a price stream with those *fiat prices*. This is typically related to applications of Mechanism Theory (See Section 4.3).

4.6.2. Market Prices

Market prices and price streams come from some market clearing process. We look at the abstraction of prices, not how those prices are determined. But one semantic aspect is important: is the price *ex ante* or *ex post*? (See Section 4.5.1). If the node cannot participate in the market, market prices may still be closely related to prices paid by the node.

4.6.3. Abstracted Prices

Some approaches to abstractions of price give a set of names or numeric levels (see discussion in [3]; we use that terminology here). While these may be treated as prices the economic effect is deliberately disconnected; on a scale from 1 to 11, an 11 is intended to represent a high price. But the cut point dividing level 10 and 11 intentionally changes over time, as the general prices change over time.

4.7. Actor Role

The node may take one of two roles with respect to a price stream:

- A *price-taker* or
- A *market participant*

In the latter case, the node participates in the market through interactions not shown here (but defined in Energy Interoperation). In the former case, the node accepts the prices and may act on them. The prices may be decoupled from reality in the ways we've described, but the node takes action nonetheless.

In either case, the coupling between the nominal price received and the economics of energy use and purchase may differ in all of the semantic dimensions we've discussed.

4.8. Conclusions—Semantics of Price

We have established several semantic dimensions that may be applied to the concept of price. We summarize these dimensions in Table 1.

Dimension
Transactable? (Can I buy or sell?)
Actual prices? (What does the node pay?)
Fiat prices? (Is there an economic basis with respect to the node?)
Actionable? (Is action appropriate using the price?)
Forward? (Is the price for the future, the past, or right now?)
Indicative? (Is the abstracted information on direction only?)
Certain or uncertain?
Abstracted or real?

TABLE 1 SEMANTICS OF PRICE SUMMARY DIMENSIONS

5. ECONOMIC INTERACTION AND RESPONSE

5.1. Strategy

We separate the functions and interfaces; see Figure 2.

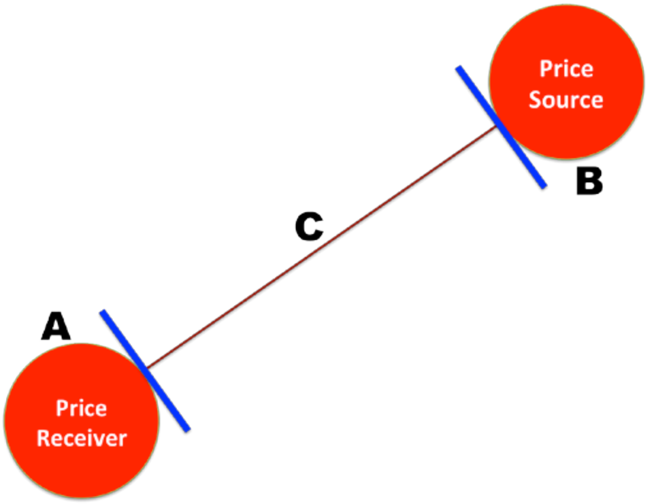

FIGURE 2 PRICE SOURCE AND RECEIVER FOR A PRICE STREAM, SHOWING THE STANDARD COMMUNICATION AND INTERFACES

From the pairwise interactions we can build complex structures where each actor has the same software interfaces; as we will see in Section 5.4 there will be other operations on price as reflected forward in the graph to each VTN's VENs.

In the following sections we look at A (the price receiver, or node), B (the price source producing a price stream), and C (the standard interoperation) separately.

5.1.1. Price Source

See B in Figure 2.

Each price source generates a price stream; the semantics of the price streams vary across sources.

Over time and across price sources, we may have streams that reflect the varying semantics we discussed in Section 4 including non-transactable (say from wholesale markets where prices reflect supply and demand over a region) to transactable (micromarkets as in [7]), to fully transactive operation.

Note that transactive operation is a characteristic of the behavior of the markets involved, the source, and the recipient node.

5.1.2. Price Receiver

See A in Figure 2.

A node that supports transactive operation participates in a market or markets. A price-taker node may accept transactive control operations, or receive prices that are relevant and transactable.

5.1.3. Standard Interoperation

See C in Figure 2.

We use the standard Energy Interoperation [8] services to deliver price streams. This standard encompasses the OpenADR 2 profiles, and also directly supports price streams.

So not only do we have a standard base that is widely used, we don't have to reinvent the capabilities.

5.2. Divide and Conquer

We apply a typical *divide and conquer* [9] approach.

We can evolve the price sources independent of the interoperation and price receiver. As highlighted at the beginning of Section 3, this allows the independent evolution, such as selecting new or improved price sources.

Similarly the Interoperation can remain constant over longer periods of time. Energy Interoperation supports all of the services needed for price distribution and for transactive operation. The rate of change is much slower than price receivers and price sources, and the standard is structured to allow incremental evolution as with other service-oriented approaches.

The price receivers can also evolve independent of the price sources and interoperation technology.

From the perspective of the price supplier and price receiver, the service interface bars in Figure 2 is constant; innovation and evolution of the actors is independent so long as the interface can be supported. This is a key benefit of applying Service-Oriented Architectures [10].

5.3. Benefits of This Approach

This approach satisfies the goals and requirements for the architecture stated in Section 3. In particular we support

- Economic interactions (one-way and two-way)
- Independent evolution (see Section 5.2)
- Price streams are a native structure in Energy Interoperation
- We are using standard interoperation
- We can build responsive end nodes (see e.g. [2])

Other benefits are addressed in the following subsections.

5.3.1. Implement in Parallel

The price sources (streams) can evolve in parallel with the price recipients (nodes), so they can clearly be implemented in parallel.

5.3.2. Transactive Operation

Our approach supports Transactive operation, not merely Mechanism Theory-based control. [4]

5.3.3. Mix and Match

A price receiver can use the same code and service interactions to communicate with any price source. This is a major advantage, as deployed price receivers can communicate with any price stream that follows the standards and the architecture.

5.3.4. Configuration not Code

Not only can any price receiver accept any price stream (remember that the semantics are not part of the receiving), but the change is merely a configuration as to what price stream(s) to which the receiver will listen.

Some simple nodes may only accept a single price stream, as they do not have the logic or program capacity to deal with more than one stream. Those nodes also have a single configuration step (essentially pointing to the correct source stream) and that information may be dynamically determined.

Our approach does not directly address the semantics of the information. The difference between transactable and non-transactable information is part of the service definitions.[6]

5.4. Value and Cost Chains

We close this section with a broader issue, delivering useful dynamic price streams to end nodes. See Figure 3.

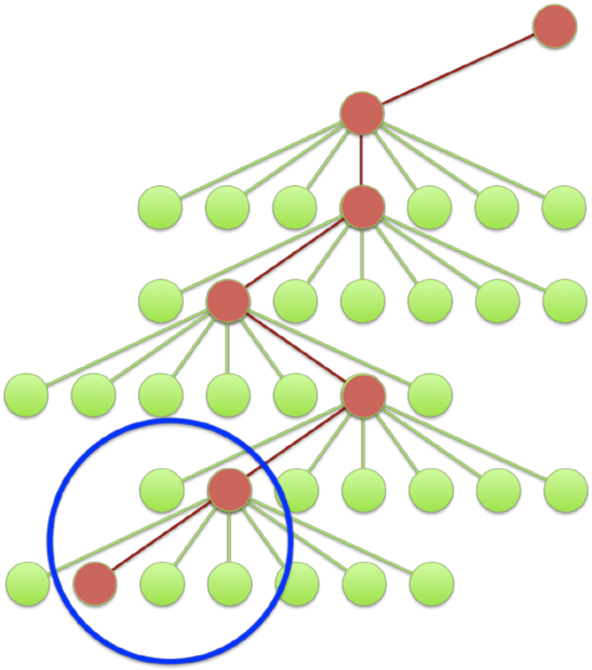

FIGURE 3 A COST OR VALUE CHAIN--THE BIG PICTURE

This shows paths through a graph of price sources and price receivers, alternatively of VTNs and VENs.

For example, it is useful to think of the top node in Figure 3 as representing a regional market; say an ISO or RTO in North America. The wholesale price stream is neither transactable nor similar to the prices that the end node (in the bottom row) would expect to pay.

Consider the changes to a price stream produced by the wholesale market as the prices go toward end nodes. We might imagine a business structure in which each layer adds its respective markup to the price received from the layer above, and delivers that new price stream to the layer below.

As we move from the top to the bottom of Figure 3 we may consider the additions to be either cost of value at each step.

We call the chain in red within the graph either the *cost chain* or the *value chain* according to what transformation takes place at each intermediate node, and the focus we intend to take.

Different levels of non-wholesale distributors, which add their respective markup, can in this manner finally create a retail price stream to the end node.

We must keep in mind that the transformations are in the business domain, and may reflect regulatory actions as well as market conditions and desired margins.

6. SUMMARY AND CONCLUSIONS

We have defined *price* streams.

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[6] The *EiQuote* and *EiTender* services differ in the transactability (EiTender) or not (EiQuote) of the payload.

We have shown the interoperation architecture for price-responsive nodes; other papers [2] [3] address the details of price-responsive node architecture.

We have shown how to decouple the evolution of actors and implementations related to price streams by using a service-oriented architecture.

We have shown how decoupling allows a configuration-based rather than application (actor) coding-based changes to accommodate different price streams.

This allows independent and rapid development and deployment of price streams, price sources, and price recipients (price-responsive nodes).

7. FUTURE WORK

The understanding of the semantics of price is crucial to understanding economic and other motivations from both a business and a technical perspective.

Connecting this understanding to possible ranges of “prices” and the relevant products is needed to understand potential response, and to trade off the expense of alternate “price” mechanisms.

We anticipate combining this work with detailed end node (including device) models as described in another paper in this conference to separate the sources and qualities of sources for price streams, and help build a new generation of price-responsive end nodes and devices.

We caution that fiat prices and prices disconnected from economic reality (including so-called “simple levels”) risk diluting motivations and decreasing responsiveness to price; the extent to which price streams are uncertain, non-actionable, and non-transactable will affect the economic utility of these methods, and provide less response to surplus and shortage than might be anticipated.

Further application of our semantic model to evaluate possible price streams shows promise as a means to create more useful and valuable information exchanges between price setters, markets, and price users, whether the users interact in markets or not.

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BIOGRAPHY

Chellury Ram Sastry

Dr. Chellury Ram Sastry is currently a Senior Manager at Samsung Telecommunications America LLC, focusing on various advanced R&D thrust areas including machine-to-machine communication, smart/connected home, and smart energy technologies including interoperability and standards.

Prior to joining Samsung, Ram was a Smart Grid Program Director with the Energy, Environment, and Material Sciences division at Battelle Memorial Institute, Columbus, OH. He was also with the Electricity Infrastructure Group in the Energy and Environment Directorate at Pacific Northwest National Laboratory (PNNL), Richland, WA managed and operated by Battelle. He was responsible for providing R&D, business development, and technical marketing leadership in various thrust areas including advanced smart grid enabled demand management to provide value-add services to residential and small commercial building customers, transmission/distribution modeling & simulation, and smart grid data analytics.

Prior to joining Battelle/PNNL, Ram was a Project Manager and Senior Research Scientist with Siemens Corporate Research (SCR), Princeton, NJ. One of the highlights of his tenure at SCR was an R&D program he was responsible for to enhance the product portfolio of various Siemens businesses (smart homes, remote health care, industrial automation etc) based on radio frequency identification (RFID), wireless sensor networks, and embedded machine-to-machine technologies.

He has published several papers in refereed journal and conference proceedings, and has been a plenary speaker at well-known conferences including Connectivity Week, Grid-Interop etc. He also has several patents against his name, and a number of provisional patent and patent applications under consideration.

Ram has a B.S. degree in electrical engineering from Indian Institute of Technology, Chennai, India M.S. /Ph.D. degrees in electrical engineering and an M.A. degree in Mathematics from University of Pittsburgh.

William Cox

William Cox is a leader in commercial and open source software definition, specification, design, and development.

He is active in the NIST Smart Grid Interoperability Panel and related activities. He contributed to the NIST conceptual model, architectural guidelines, and the NIST Framework 1.0.

Bill is co-chair of the OASIS Energy Interoperation and Energy Market Information Exchange Technical Committees, past Chair of the OASIS Technical Advisory Board, a member of the Smart Grid Architecture Committee, and of the WS-Calendar Technical Committee.

Bill has developed enterprise product architectures for Bell Labs, Unix System Labs, Novell, and BEA, and has done related standards work in OASIS, ebXML, the Java Community Process, Object Management Group, and the IEEE, typically working the boundaries between technology and business requirements.

He earned a Ph.D. and M.S. in Computer Sciences from the University of Wisconsin-Madison.

Toby Considine

Toby Considine is a recognized thought leader in applying IT to energy, physical security, and emergency response. He is a frequent conference speaker and provides advice to companies and consortia on new business models and integration strategies.

Toby has been integrating building systems and business processes for longer than he cares to confess. He has supported and managed interfaces to and between buildings, cogeneration plants, substations, chilled water plants, and steam and electrical distribution. This work led to Toby’s focus on standards-based enterprise interaction with the engineered systems in buildings, and to his work in the Organization for the Advancement of Structured Information Standards (OASIS).

Toby is chair of the OASIS oBIX Technical Committee, a web services standard for interface between building systems and e-business, and of the OASIS WS-Calendar Technical Committee. He is editor of the OASIS Energy Interoperation and Energy Market Information Exchange (EMIX) Technical Committees and a former co-Chair of the OASIS Technical Advisory Board.

Toby has been leading national smart grid activities since delivering the plenary report on business and policy at the DOE GridWise Constitutional Convention in 2005. He is a member of the SGIP Smart Grid Architecture Committee, and is active in several of the NIST Smart Grid Domain Expert Workgroups.

Before coming to UNC, Mr. Considine developed enterprise systems for technology companies, apparel companies, manufacturing plants, architectural firms, and media companies old and new. Before that, Toby worked in pharmaceutical research following undergraduate work in developmental neuropharmacology at UNC.