SMART BUILDINGS IN THE SMART GRID

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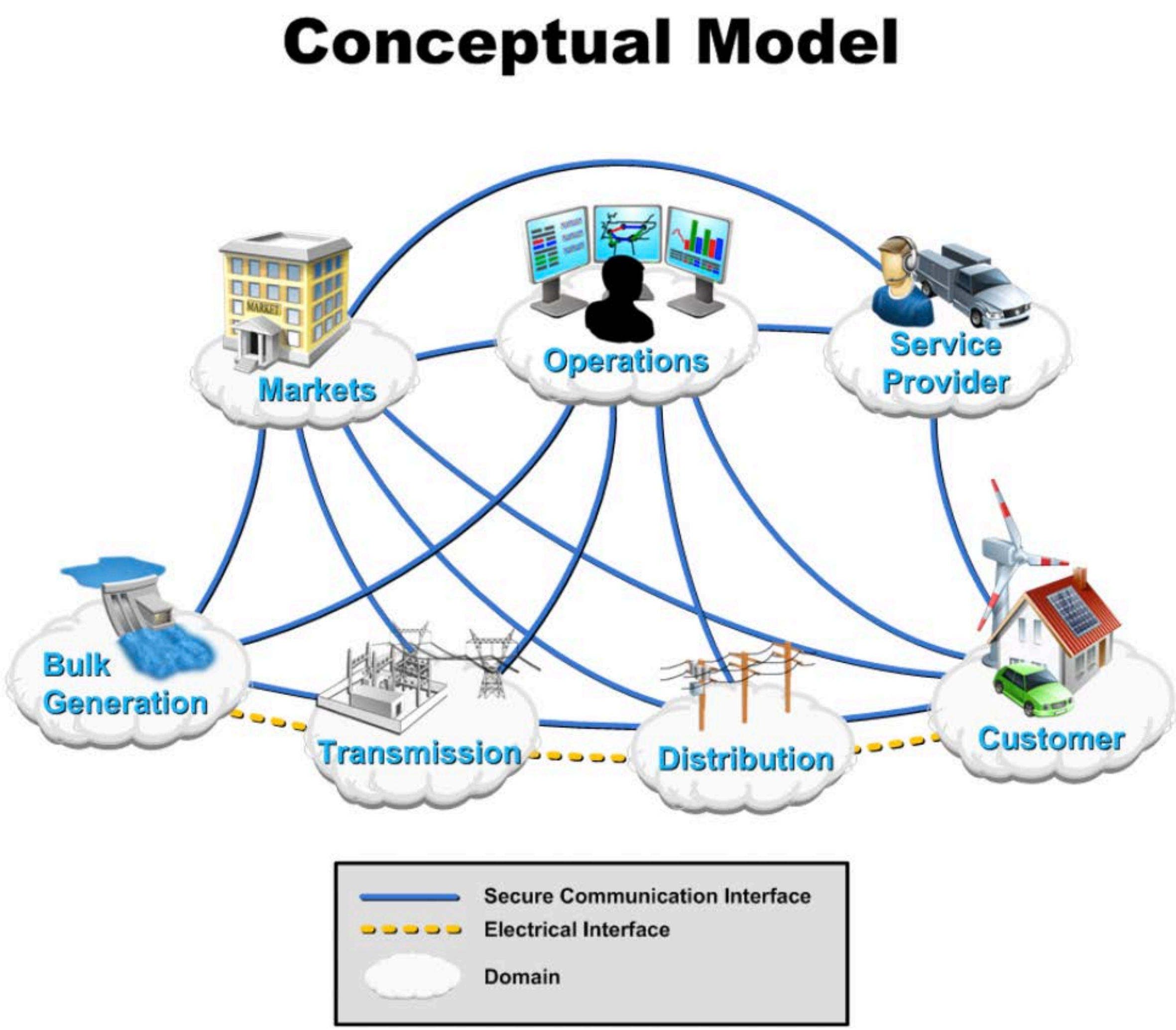
OUTLINE

- What are the smart grid and smart buildings?
- Within the Buildings
  - Structure and research topics
  - Cyber security concerns
- Interface to the Grid
  - Structure
  - Cyber security concerns

SMART GRID



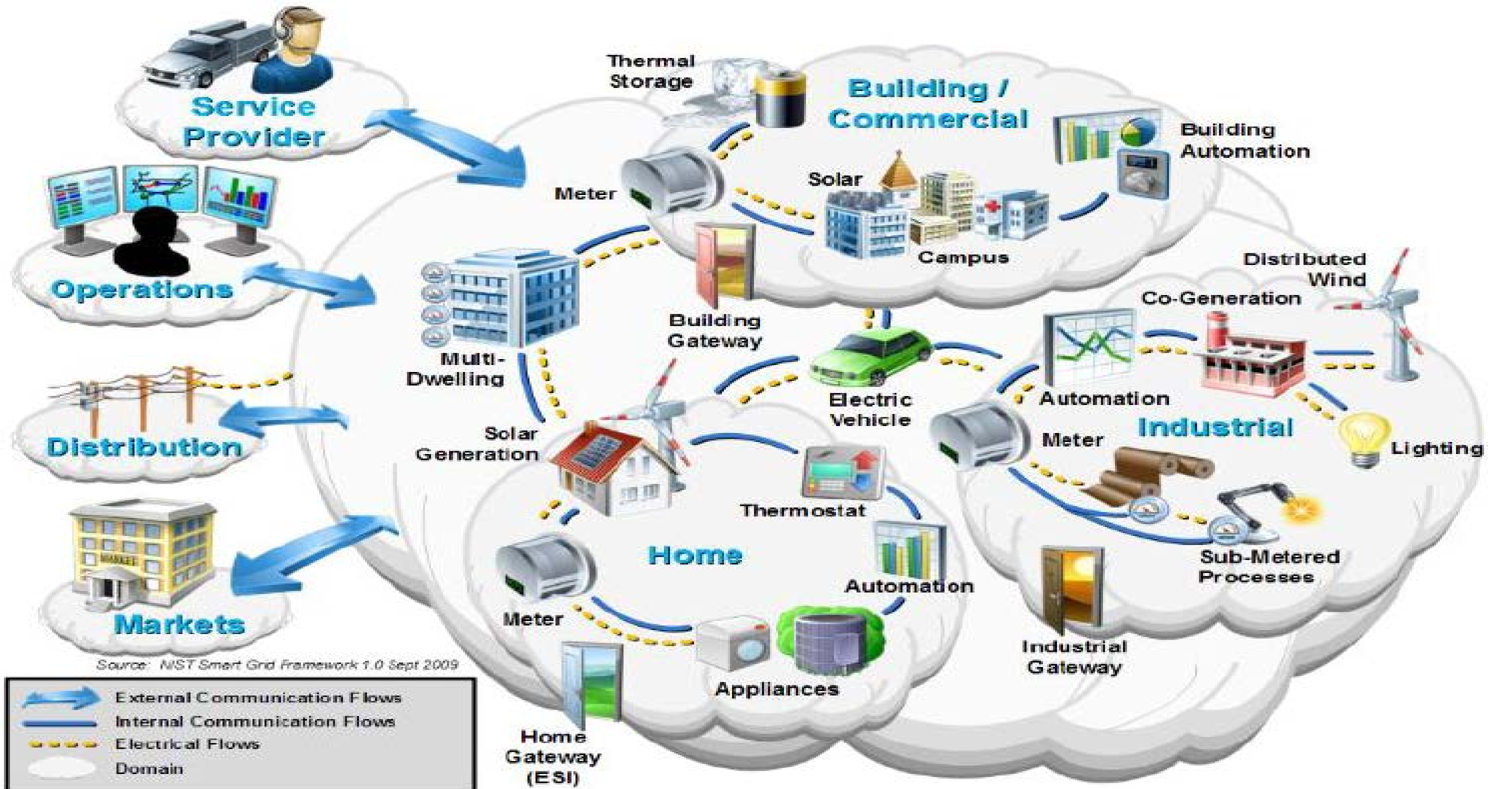
source: Smart Grid Roadmap by National Institute of Standards and Technology (NIST)

SMART GRID

- The term “Smart Grid” refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements
  - from the central and distributed generator through the high-voltage network and distribution system, *to industrial users and building automaton systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices*.
- The Smart Grid will be characterized by *a two-way flow of electricity and information* to create an automated, widely distributed energy delivery network.

source: Smart Grid Roadmap by National Institute of Standards and Technology (NIST)

SMART BUILDING



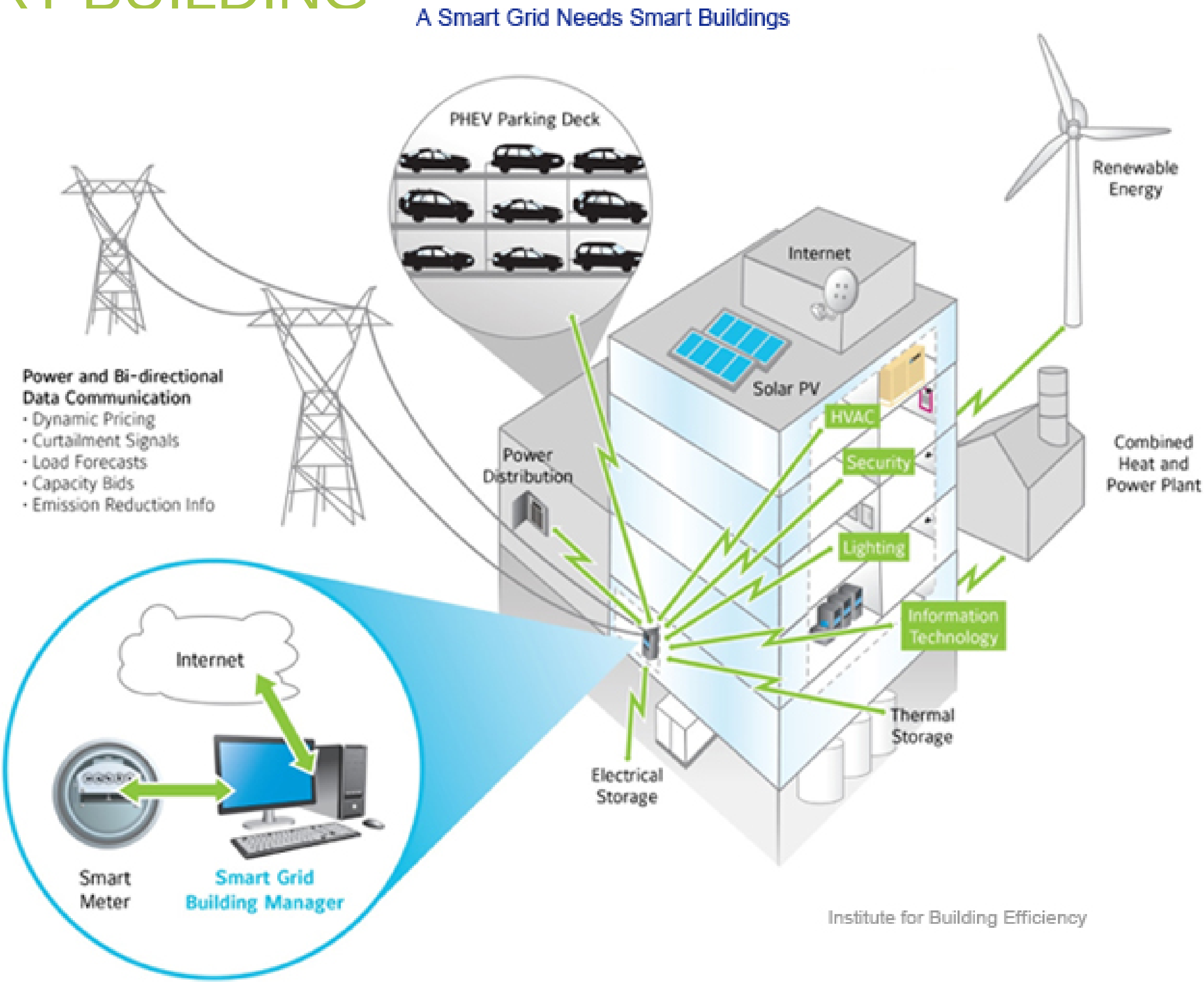
Smart buildings:

- Self-configuring, self-commissioning, and self-learning
- Optimize operation and maximize energy savings
- Participate in transactions *within/between buildings*, and *with*

Energy savings from

- Commercial/Residential building automation (small/medium size)
- Advanced controllers in new refrigeration systems
- Demand control ventilation
- Predictive thermostats in homes

SMART BUILDING



Google ← $3.2B / Jan. 2014 — nest ← $555M / Jun. 2014 — dropcam

Mission: Reinvent important products for energy-efficient homes

Sensor-driven/Wi-Fi-enabled /learning thermostat

Smoke/carbon monoxide detector

Impact: Saved Southern CA customers an average of 11.3% of AC-related energy usage

Pictures source: https://nest.com/

WITHIN THE BUILDING

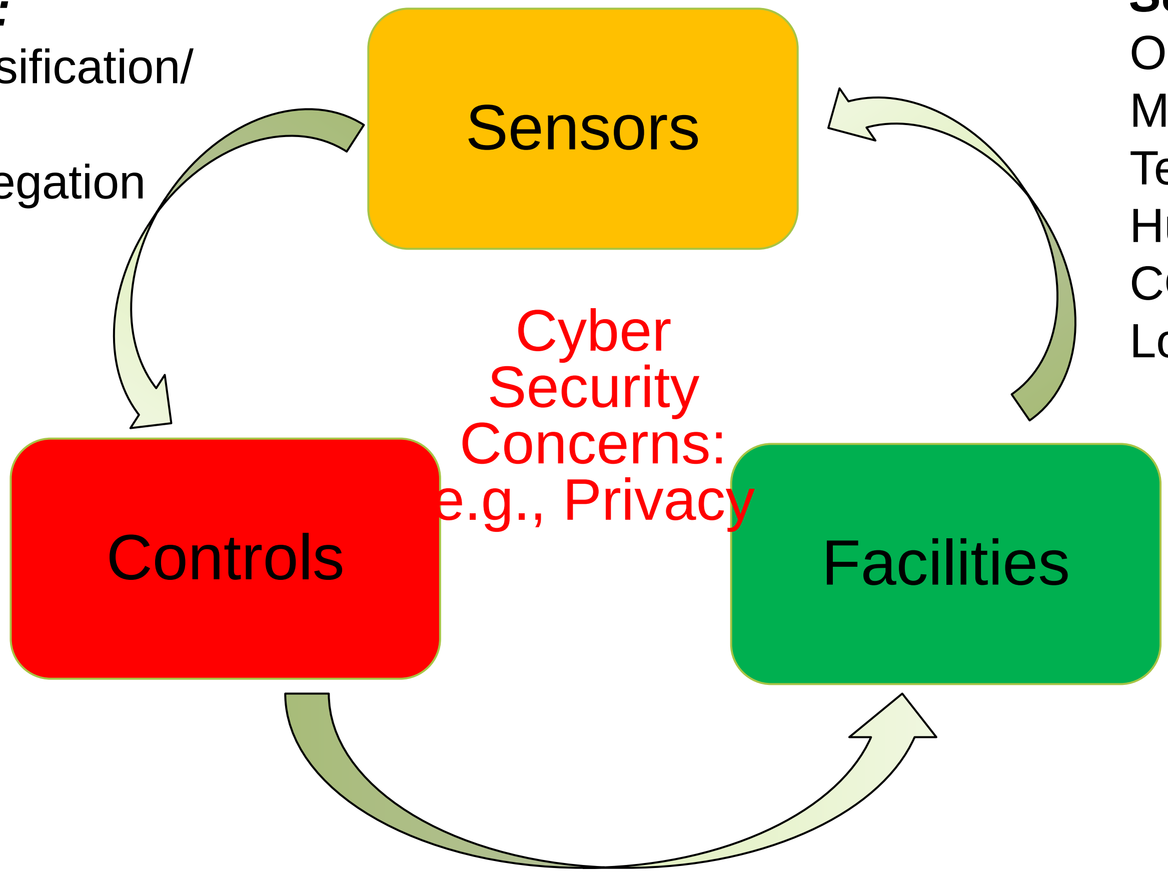
- Sensors and Controls
- Building Management System (BMS) (lighting, temperature control)
- Elevator Controls
- Security Feeds
- Smart Meters

- … Security where? Protecting how?

SENSING AND CONTROLS

Data analytics:
regression/classification/
clustering
energy disaggregation

Sensing:
Occupancy
Motion
Temperature
Humidity
CO2
Load



Control & optimization:
Adaptive control (MPC)
Robust/Stochastic Opt.

BUILDING MANAGEMENT SYSTEMS

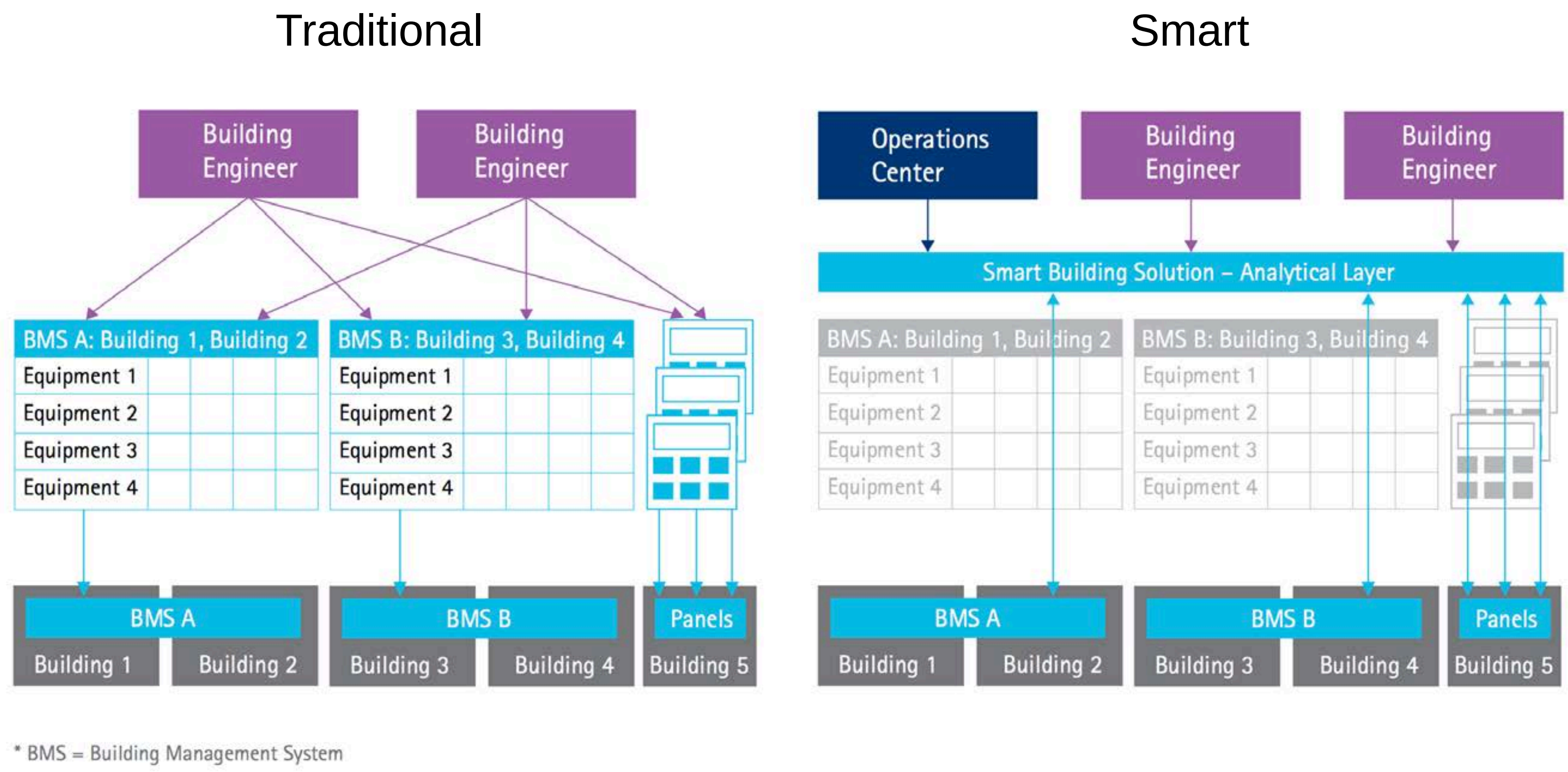
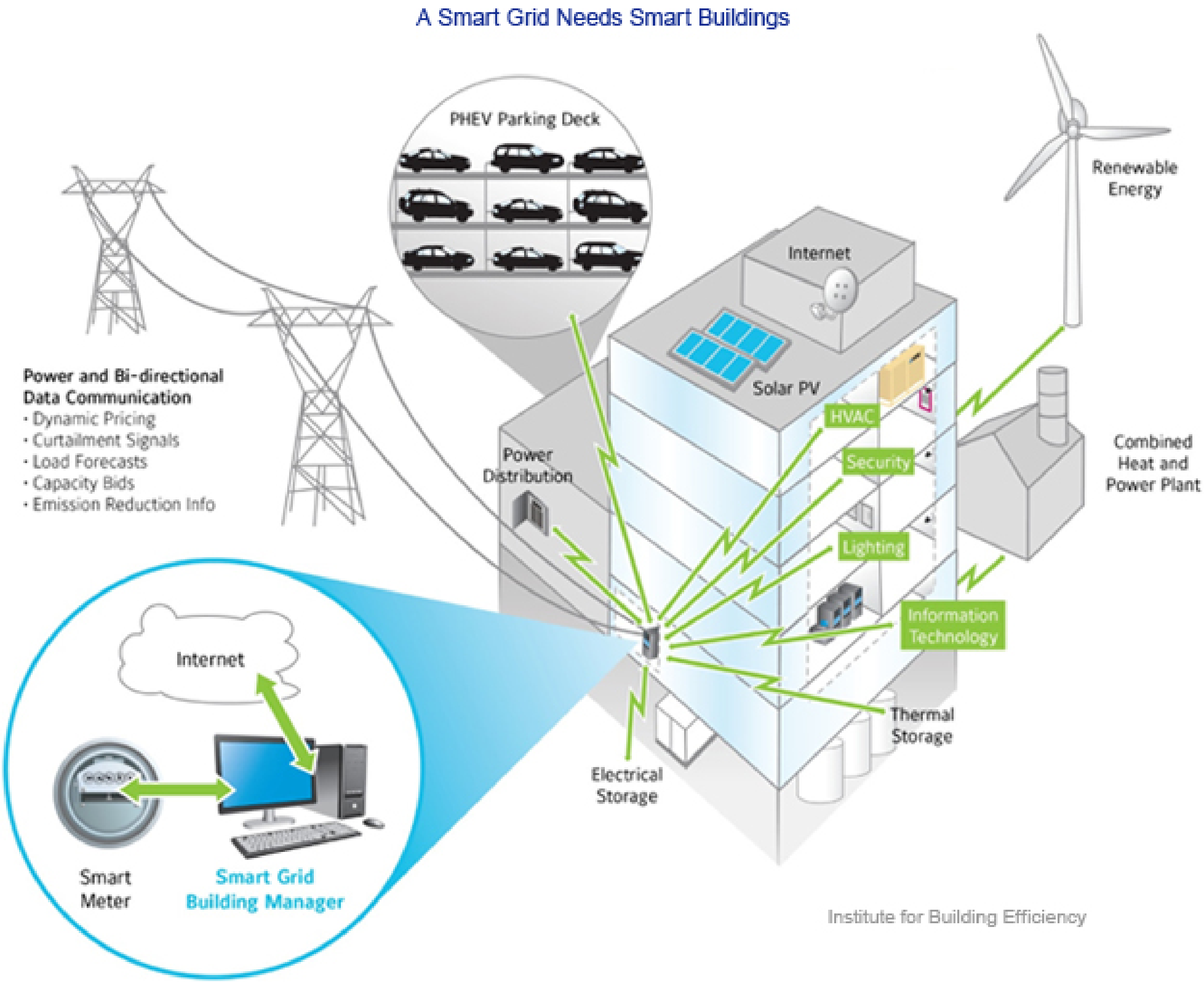


Image: Accenture energy smart buildings report

REVISITING


A Smart Grid Needs Smart Buildings
PHEV Parking Deck
Renewable Energy
Internet
Solar PV
HVAC
Security
Lighting
Information Technology
Combined Heat and Power Plant
Power Distribution
Power and Bi-directional Data Communication
· Dynamic Pricing
· Curtailment Signals
· Load Forecasts
· Capacity Bids
· Emission Reduction Info
Thermal Storage
Electrical Storage
Internet
Smart Meter
Smart Grid Building Manager
Institute for Building Efficiency

Source: Honeywell HBS Enterprise Integration

INTERFACE TO THE SMART GRID

- Internet of Things (IoT) Big Picture
  - Industry experts predict: the number of connected devices for the IoT will surpass 15 billion nodes by 2015 and reach over 50 billion by 2020.
  - Smart electricity grids that adjust rates for peak energy usage: savings of $200 billion to $500 billion per year by 2025 (McKinsey report).
- Improve the grid reliability
  - Buildings can be viewed as a distributed energy resources (as a battery).
  - Participate in the market to mitigate the uncertainty from the renewables.

DATA

- Sensors
  - All sorts of data, how do you use it?
  - Protect it?
  - Who owns the data?
- Green Button Initiative
  - Consumer data access

GREEN BUTTON

- http://www.greenbuttondata.org

RESEARCH

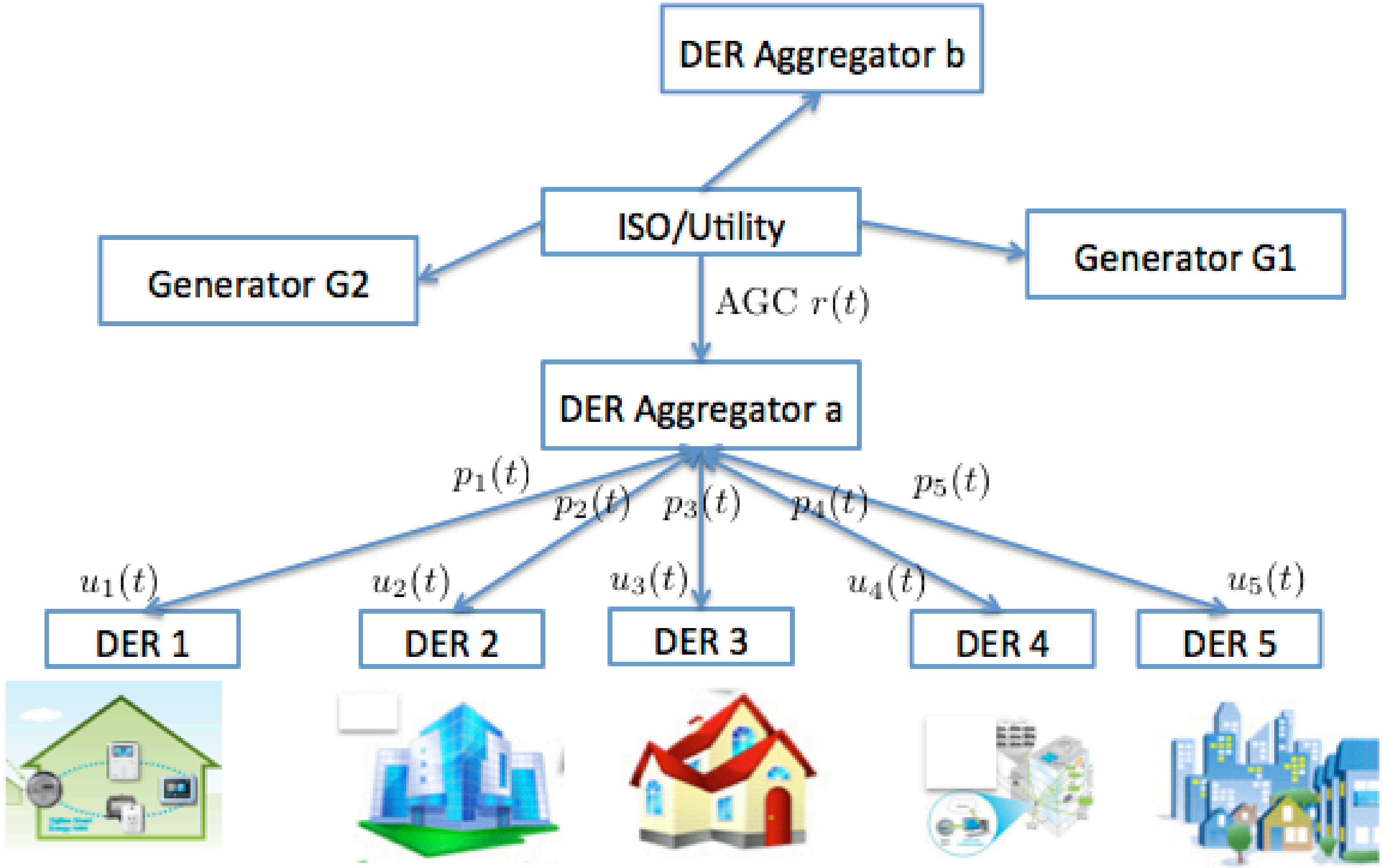
VOLTRON

- An intelligent agent platform for the smart grid
  - Opensource
  - Gaining a lot of traction in smart buildings
  - Provides a framework for decentralized cooperative decision making
- More info here
  - http://gridoptics.pnnl.gov/VOLTTRON/

MY RESEARCH: IMPACT OF CYBER EVENTS

- Smart Buildings can serve as Distributed Energy Resources (DERs)
- Problem: There have not been reliability studies: the impact of uncertainties on the performance:
  - Uncertainties introduced from (i) communication network and (ii) random failures in DERs
- Goal: Quantify the impact of close coupling of cyber and physical components on
  - load DERs
  - system-wide performance

STRUCTURE


DER Aggregator b
ISO/Utility
Generator G2
Generator G1
AGC $r(t)$
DER Aggregator a
$p_1(t)$
$p_2(t)$
$p_3(t)$
$p_4(t)$
$p_5(t)$
$u_1(t)$
$u_2(t)$
$u_3(t)$
$u_4(t)$
$u_5(t)$
DER 1
DER 2
DER 3
DER 4
DER 5

FORMULATION

- The dynamics of DERs including local controllers can be captured by generalized battery models.
  - Commercial buildings HVAC system [1]
  - Thermostatically controlled loads (TCL): although one TCL can be only operated in ON/OFF mode; a set of TCLs can respond to continous command signal (i.e., have a continuous thermal model). [2]
- Generalized battery model (atomic model)

$$\dot{x}_i(t) = -a_i x_i(t) - u_i(t) + w_i(t);$$
$$-C_i \leq x_i(t) \leq C_i, -\underline{n}_i \leq u_i(t) \leq \overline{n}_i,$$

for $i = 1, 2, \cdots, n$, where $w_i(t)$ represents the external disturbance.
$u_i(t)$ is the command signal from the aggregator to DER i.
$x_i(t)$ is the DER dynamic state, also called state of charge (SoC) of the battery, related to temperature for TCL.

AGGREGATOR CONTROL

- We adopt the same control mechanism as AGC. We denote $u(t)$ as a control state, and its evolution is governed by

$$\dot{u}(t) = c(r(t) - \sum_{i=1}^{n} p_i(t));$$

c is a tuning parameter, we choose it to be $\frac{1}{\Delta t}$ (Δt is the time interval of aggregate control) so that the mismatch is quickly compensated in the following control cycle.

- Because of the fast response of DERs. We assume no dynamics on the power supported by DERs, i.e., $p_i(t) = u_i(t)$ under normal condition.

$$\dot{u}(t) = c(r(t) - \sum_{i=1}^{n} \eta_i u_i(t));$$

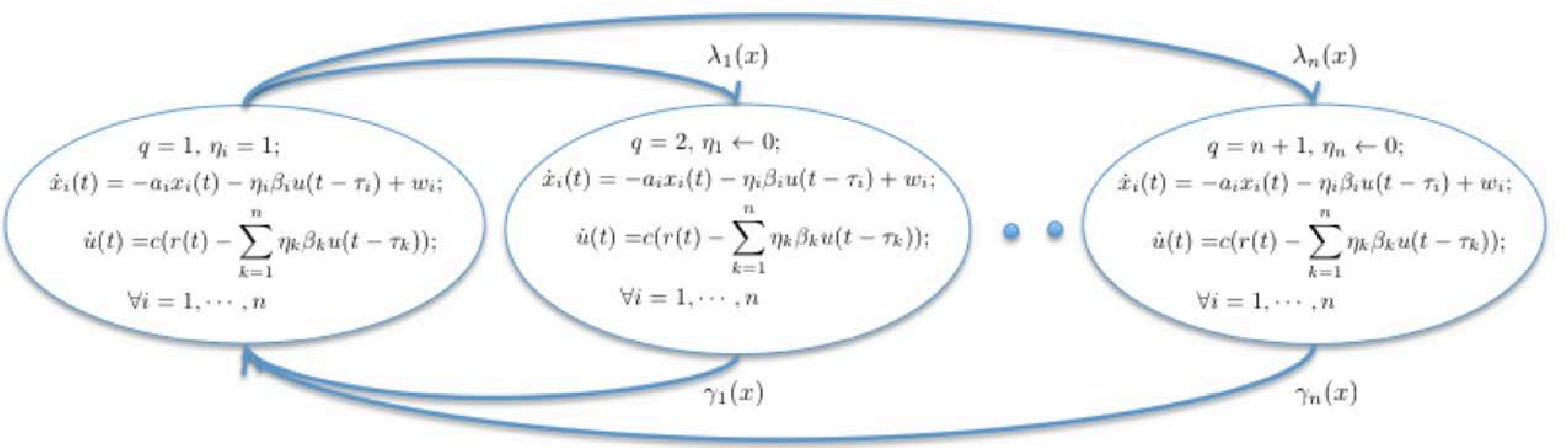
- Then, the command signal to each DER:

$$u_i(t) = \beta_i u(t).$$

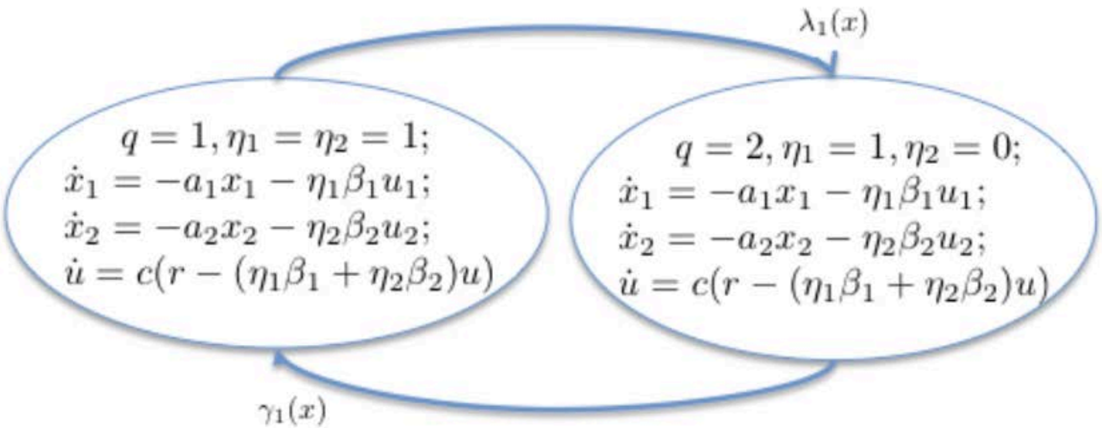
In terms of uncertain sources

- communication network
  - communication delays
  - failures (e.g., packet drops, permanent component failure)
- DER
  - random failures in DER local controllers and other hardware
  - random DER external disturbance (e.g., building occupancy, solar radiation)
- random failures in the aggregator computing platform

In terms of modeling: stochastic hybrid model



TWO-UNIT TWO MODE CASE

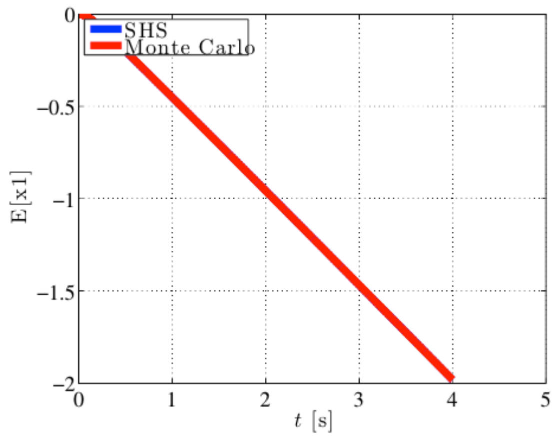


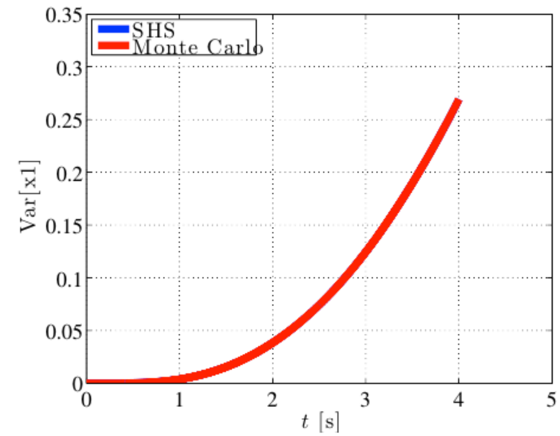
Parameters are adopted from [1, 2].

a_1[s^{-1}]	C_1 [kW·s]	a_2[s^{-1}]	C_2 [kW·s]	β_1	β_2
1.003×10^{-4}	8356	6.944×10^{-5}	14400	0.5	0.5
λ_1[s^{-1}]	γ_1[s^{-1}]	$r(t)[kW]$			
0.01	0.1	1			

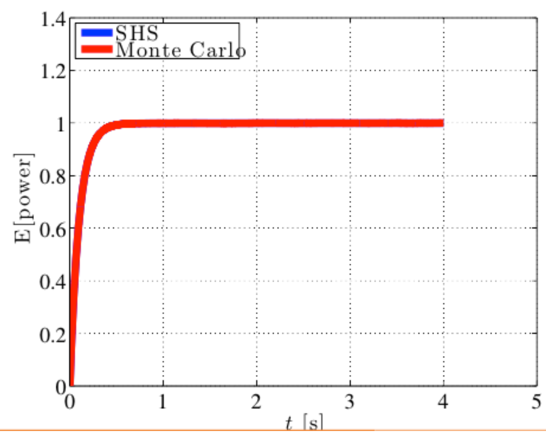
TWO-UNIT TWO MODE CASE

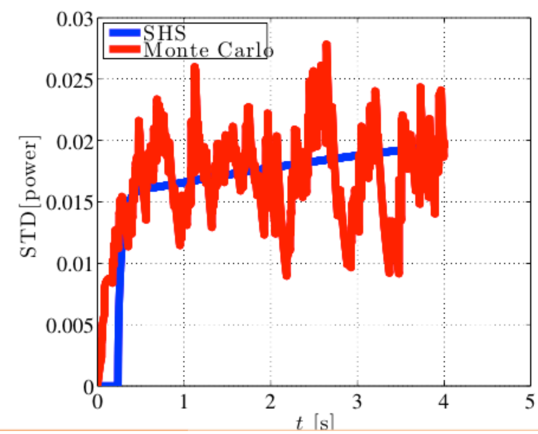
Mean and variance of DER 1's SoC





Mean and standard deviation of total power support





THANK YOU!

- Thank You!