EAGER—Empowering Smart Energy Communities: *Connecting* Buildings, People, and Power Grids

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MOTIVATION

- By 2050, 70% of the world's population is bound to live and work in cities
- Two-thirds of global energy consumption can be attributed to cities, leading to 71% of global direct greenhouse gas emissions
- Solution? **Smart Cities** with innovative building and smart grid designs
- Buildings' energy consumption contribute to more than 70% of electricity usages
- Futuristic cities designs should global energy consumption while maintaining stable electric-grid operations

RESEARCH GAPS

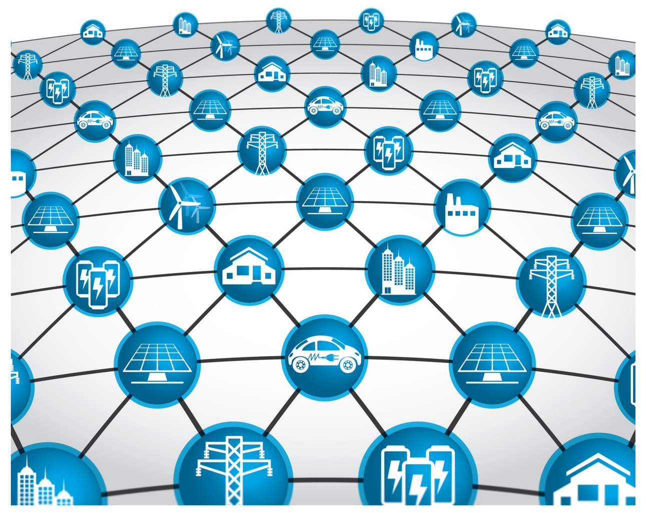
- At a *community level*, there is no holistic **framework** that buildings and power grids can simultaneously utilize to optimize their performance. The challenges are:

a) **lack of a multi-time scale mathematical framework that couples the real-time decisions of buildings, grid stakeholders**

b) **lack of a computationally-tractable, implementable solution methodology on a large number of power grid-nodes, buildings**

RESEARCH OBJECTIVES

- Investigate a novel framework that fills the aforementioned knowledge gaps
- Test the following hypothesis: *Connected buildings, people, and grids will achieve significant energy savings and stable operation within a smart and connected community*
- Furnish individual buildings and power grid devices with custom, decentralized demand response signals



INTELLECTUAL MERITS

1. An innovative method to model a cluster of buildings and their controls, integrated with grid operations and people
2. A novel optimization framework to solve complex control problems for large-scale coupled systems; and
3. A methodology to assess the impacts of connected buildings in terms of (a) grid's operational stability and (b) buildings' optimized energy consumption.

TASK 1 — BUILDING & OCCUPANCY MODELING AT COMMUNITY LEVELS

- Model occupancy behavior in a building cluster by layered spatial-temporal statistical models based on multivariate logistic regression:

$$\boldsymbol{\eta} = \boldsymbol{C}^\top \log(L\boldsymbol{\pi}) = \boldsymbol{X}\boldsymbol{\beta}$$

- Large-scale data sets available from living-lab testbeds and IEA Annex 66 database
- Mathematical model depicting the evolution of intrinsic states for clusters of buildings:

$$\dot{\boldsymbol{x}}_b = \boldsymbol{A}_b\boldsymbol{x}_b + \boldsymbol{A}_{bg}\boldsymbol{x}_g + \boldsymbol{B}_{u_b}\boldsymbol{u}_b + \boldsymbol{B}_{w_b}\boldsymbol{w}_b + \boldsymbol{\phi}_b$$

TASK 2 — INTEGRATING OCCUPANCY MODELS, BUILDINGS, GRID DYNAMICS

- Dynamics of building-impacted power network:

$$\boldsymbol{E}_g\dot{\boldsymbol{x}}_g = \boldsymbol{A}_g\boldsymbol{x}_g + \boldsymbol{A}_{gb}\boldsymbol{x}_b + \boldsymbol{B}_g\boldsymbol{u}_g + \boldsymbol{B}_{w_g}\boldsymbol{w}_g + \boldsymbol{\phi}_g$$

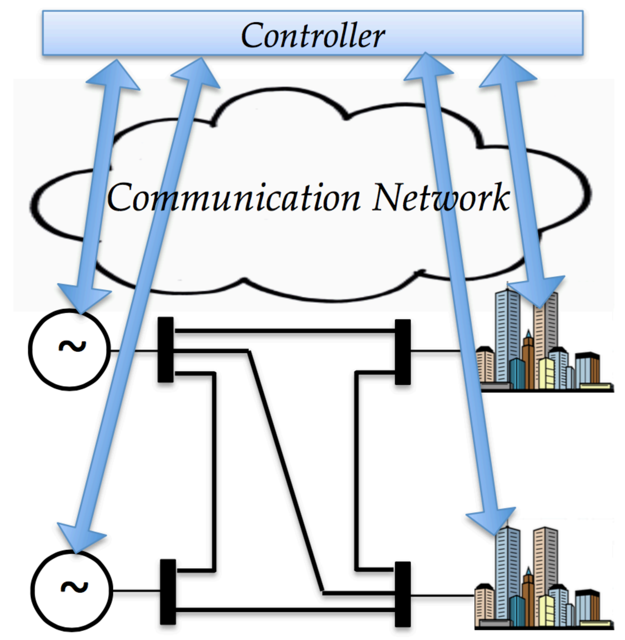
- Global optimization problem to minimize the cost on both buildings and grid:

$$\begin{aligned} \min_{\boldsymbol{u}} \quad & \int_{t_0}^{t_f} \boldsymbol{H}(\boldsymbol{x},\boldsymbol{u},\boldsymbol{w})\, dt \\ \text{subj. to} \quad & \boldsymbol{E}_x\dot{\boldsymbol{x}} = \boldsymbol{A}_x\boldsymbol{x} + \boldsymbol{B}_u\boldsymbol{u} + \boldsymbol{B}_w\boldsymbol{w} + \boldsymbol{\phi}(x,u) \\ & \boldsymbol{u}^{\min} \leq \boldsymbol{u} \leq \boldsymbol{u}^{\max}, \boldsymbol{x}^{\min} \leq \boldsymbol{x} \leq \boldsymbol{x}^{\max} \\ & \boldsymbol{u}_b \in \mathcal{U}, \boldsymbol{x}_b \in \mathcal{X}. \end{aligned} \qquad \text{(OPT)}$$

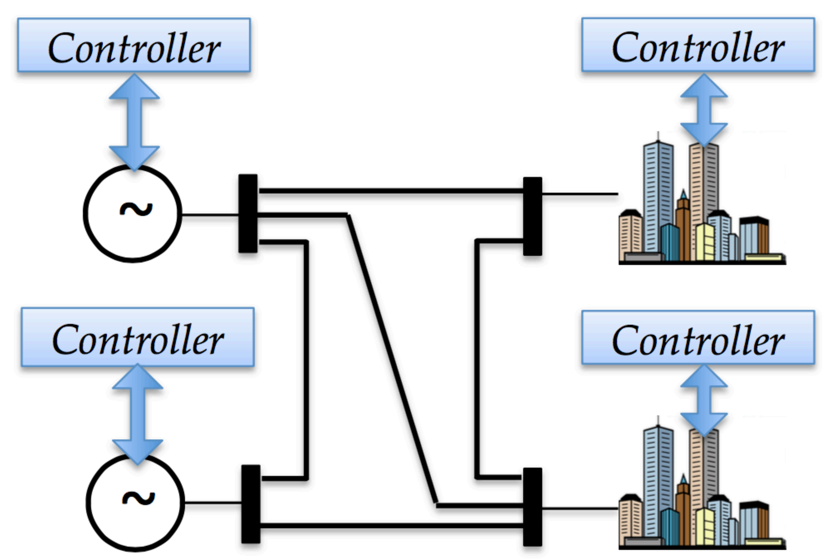
TASK 3 — LARGE-SCALE CONTROL: EMPC-BASED APPROACH

- (OPT) cannot be solved analytically—it is a nonconvex optimal control problem
- Task's objective: develop tractable optimal control laws
- We address the time-scale discrepancy by designing a two-level Explicit MPC (EMPC)
- We plan to solve the EMPC version of (OPT) by developing three different approaches:

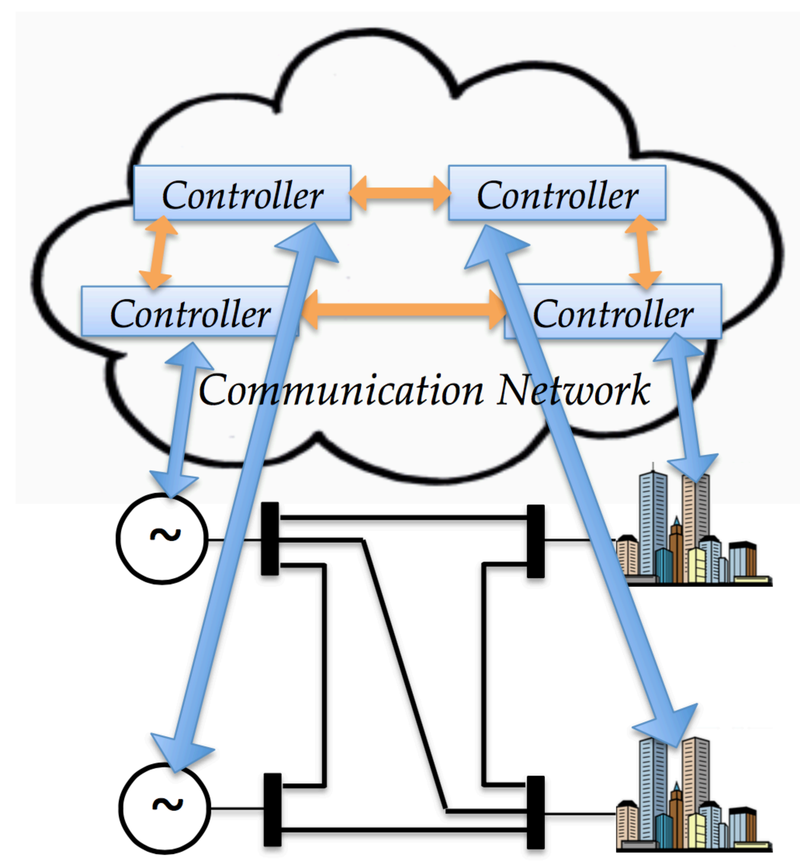
a) Centralized architecture



b) Decentralized architecture



c) Distributed architecture



TASK 4 — EVALUATION

- Project evaluation will be conducted through a *living lab* approach
- We will work closely with Southern California Edison (SCE) to validate our proposed algorithms
- We will simulate its primary distribution feeder with 1000+ buildings as the test case
- Smart meter data and building information are available from SCE's smart meter data warehouse
- Performance of our approach to connect buildings, grid and people will be evaluated at three levels (buildings, power grid, and the people/community)

BROADER IMPACTS

- Our research studies the impacts of a smart, connected community on energy supply, demand and stability of power networks
- Development of creative modeling framework to connect buildings, people, grid
- Investigation of new computational tools to address the time-scale discrepancies
- Project will benefit minorities at UTSA & UCR—**Hispanic Serving Institutions**
- Research will be integrated with education:

a) Creation of course modules offered by PIs

b) Contributions to a new master online program focused on sustainable energy at UCR

PROJECT SCHEDULE

Table 1: Division of responsibilities and timetable of tasks

Research Tasks	Year1 (1 2 3 4)	Year 2 (1 2 3 4)	% Responsibility: UTSA	% Responsibility: UCR
Task 1	Building and Occupancy Modeling			
Subtask 1.1			40	60
Subtask 1.2			80	20
Task 2	Integrating Occupancy Models with Grid and Building Dynamics			
			80	20
Task 3	Large Scale Control Framework			
			80	20
Task 4	Evaluation			
			60	40