Increased Use of Renewable Energy Sources in Wireless Communication Networks

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Overview

- **Motivation**
- **Technological Challenges**
- **Proposed Solution**

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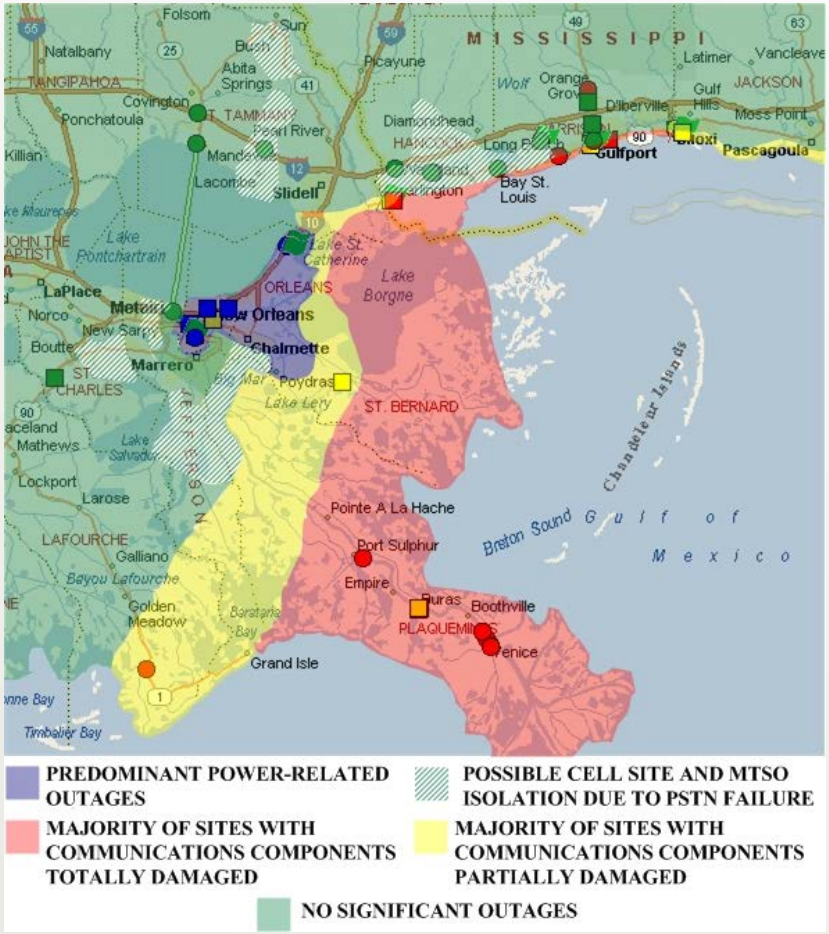
Motivation

- **Lessons from past natural disasters**

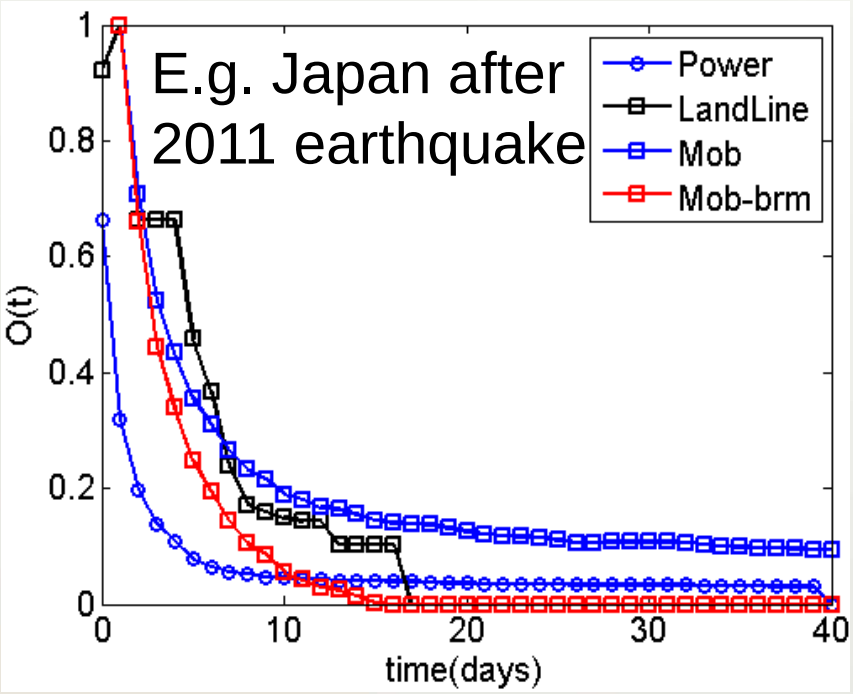
- Power issues is one of the main causes of communication outages after natural disasters.
- E.g. Hurricane Katrina



Motivation

- **Lessons from past natural disasters**

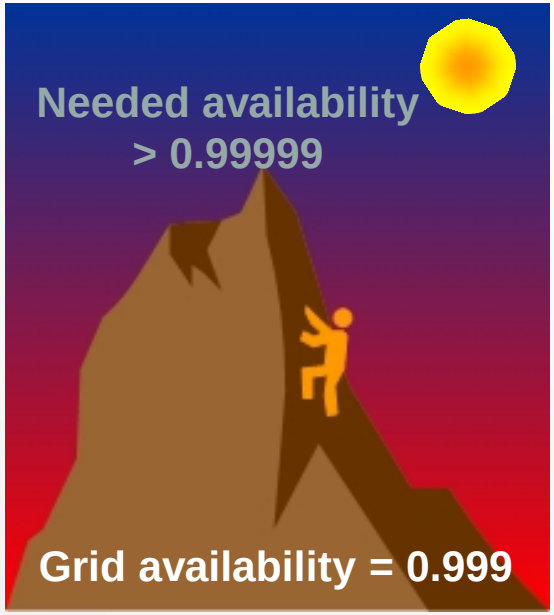
- Correlation between power outages and communication outages is stronger in cases where there are insufficient number of onsite or deployable gensets.
- Due to energy storage at communication sites, communication outages lags power outages.

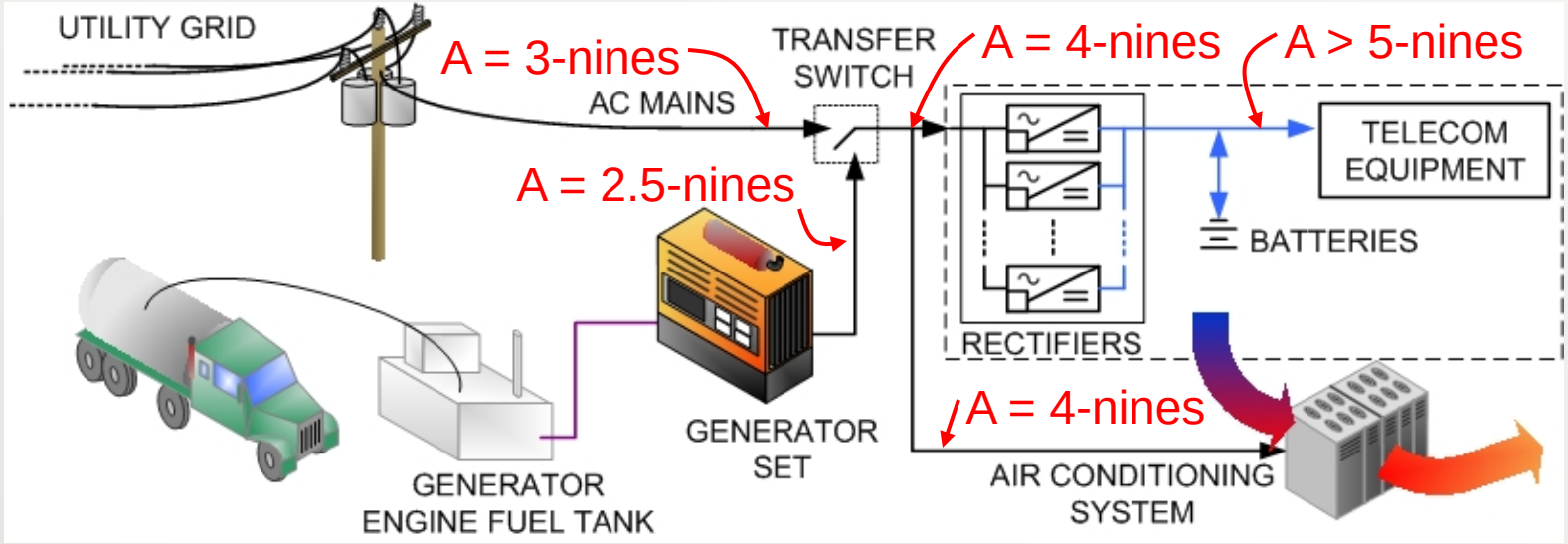


Miyako, Japan, 4/2011

Motivation

- **Network operators-based solution: conventional standby power plants**
- Inefficient use of installed capital
- Battery energy storage is essential in order to reach telecom-grade availability levels
- Power availability for air conditioners is below the minimum required in telecom applications





Motivation

- Significant logistical challenges associated with operation of diesel gensets – lifeline dependence

Port Sulfur, Oct. 2010

- Electric service interruption

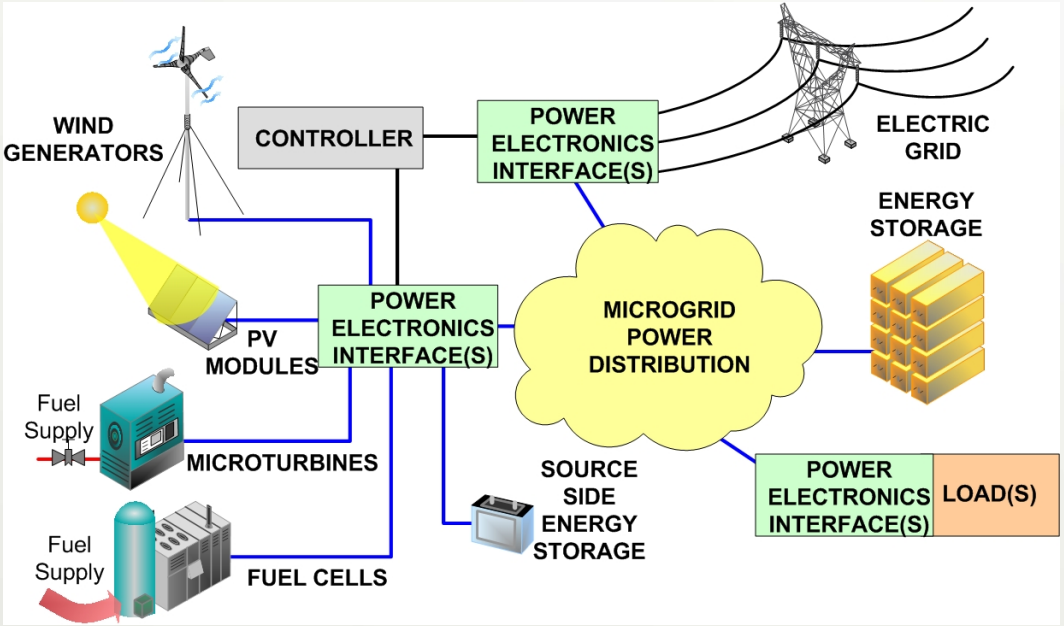
- After Isaac flooded roads made fuel delivery for permanent diesel gensets impossible

- Microgrids

• Microgrids are locally confined and independently controlled electric power grids in which a power distribution architecture integrates loads and distributed energy resources—i.e. local distributed generators and energy storage devices—which allow the microgrid to operate connected or isolated to a main grid.

• Two types of local sources:
  - Lifeline dependent
  - Renewable energy

• Microgrids and other systems with locally generated power have operated satisfactorily after Irene, Sandy and the 2011 earthquake in Japan



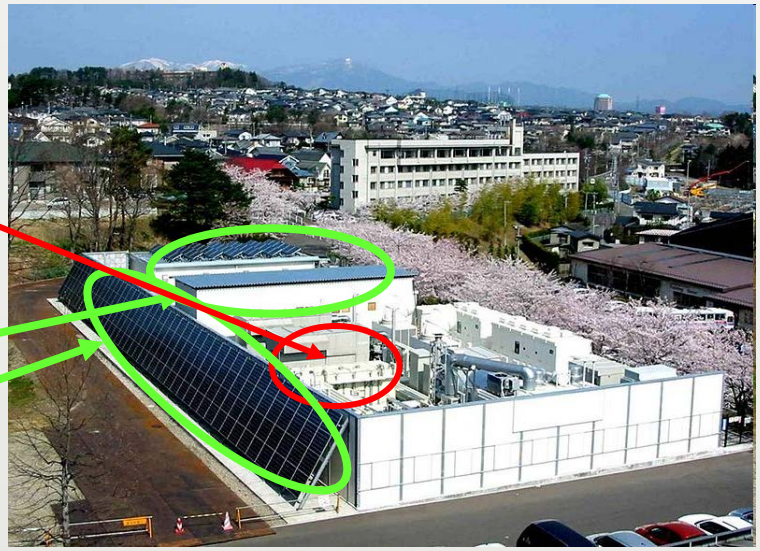
Microgrids

- **Renewable energy sources**

- Most renewable energy sources do not require lifelines, but…..
- Issues with PV systems:
  - Large footprints
  - Variable output (part stochastic, part deterministic)
- Issues with wind generators in cities
  - wind profiles and aesthetics

2x350 kW natural gas generators

50 kW PV array

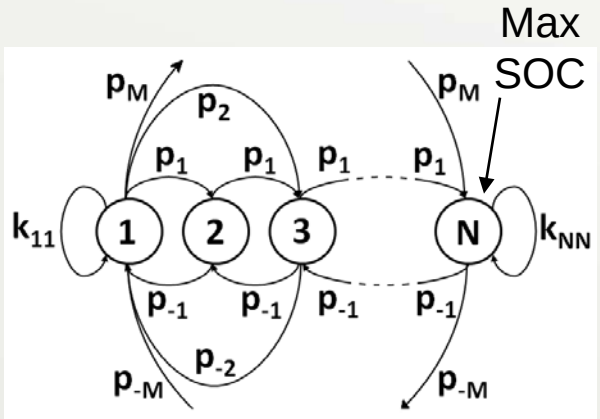


Microgrid in Sendai

Microgrids

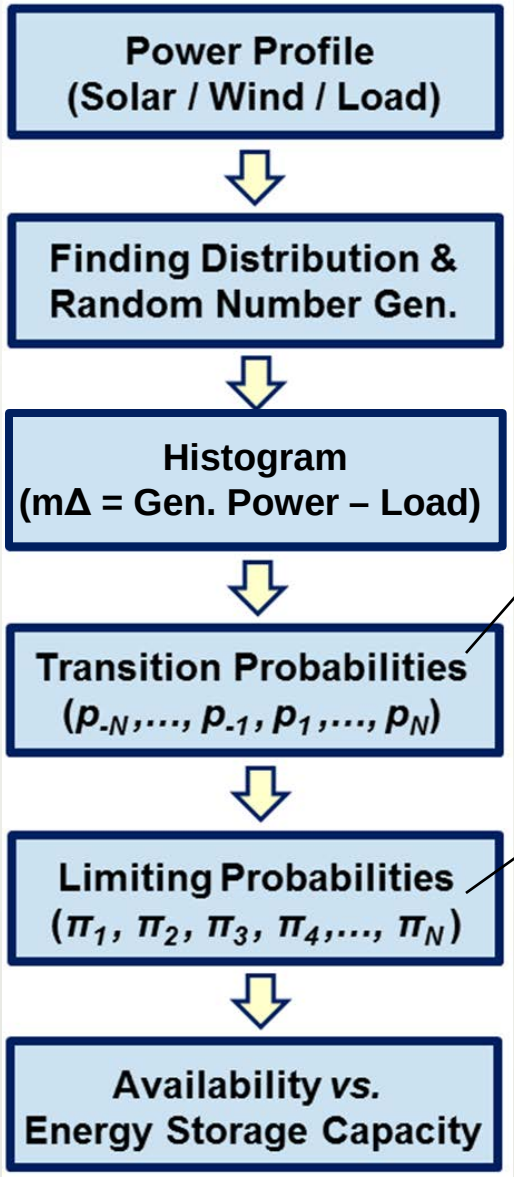
- **Availability of renewable energy sources with batteries**

- Markov-based model:



$$Capacity = (N-1)\underbrace{T\Delta}$$

Energy difference between two states



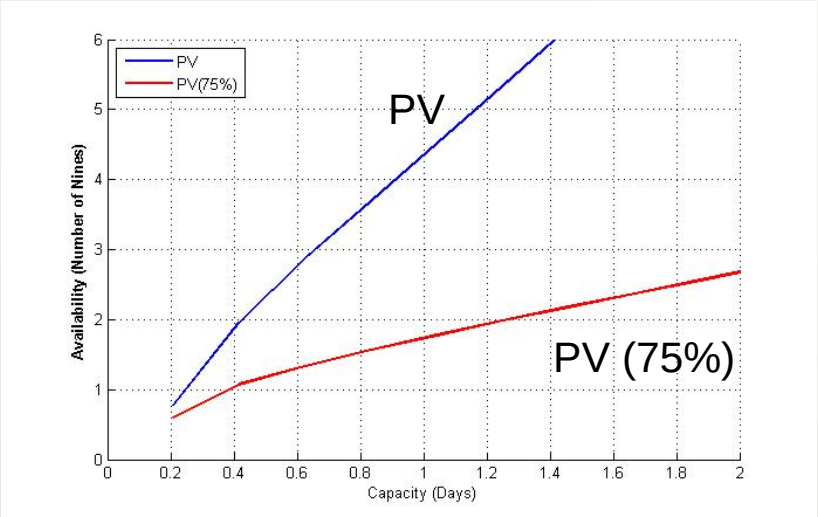
$$P = \begin{bmatrix} k_{11} & p_1 & p_2 & \cdots & & & \\ k_{11} & 0 & p_1 & \cdots & & & \\ \tilde{p}_{-2} & p_{-1} & 0 & \cdots & & & \\ \vdots & \vdots & \vdots & \ddots & & & \\ & & & & 0 & p_1 & \tilde{p}_2 \\ & & & & p_{-1} & 0 & k_{NN} \\ & & & & p_{-2} & p_{-1} & k_{NN} \end{bmatrix}_{N\times N}$$

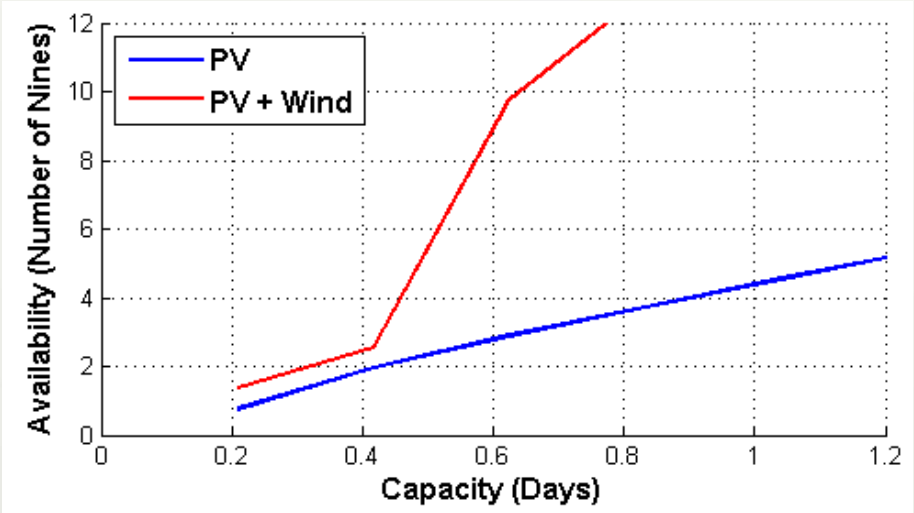
$$\pi_E = \sum_{i\in\{1,M\}} \left[p_{-i} \times \sum_{j\le i} \pi_j \right]$$

$$A = 1 - \pi_E$$

- **Renewable energy sources**

- Solutions to issues with renewable energy sources:
  - Combine them with local energy storage (e.g. batteries)
    - Very high availability requires significant stored energy
  - Diversify power sources (e.g. combine wind and PV)
    - Source diversification reduces energy storage capacity needs





Microgrid Planning

- **The paradox with energy storage (batteries)**

- Functions of energy storage in microgrids:
  - Complement renewable sources (minutes to hours)
  - Match different dynamic characteristics of sources and loads (seconds to minutes)
  - Failures ride-through/backup (seconds to hours)
  - Stability support (fraction of a second to seconds)
  - Reduced unavailability

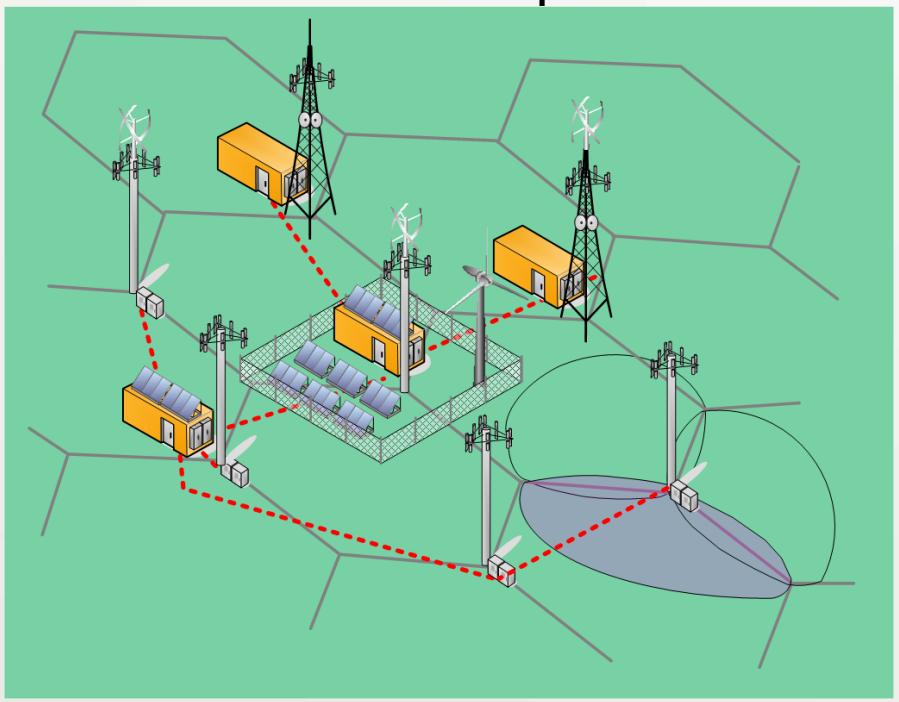
$$U_{mG} = U_{NB} e^{-T_{BAT} \sum_{\mu \epsilon M_{mcs}} \mu_{MCS,i}}$$

- Issues with energy storage in microgrids
  - High cost
  - Weight and large volume issues
  - Demanding environmental conditions leads to lower availability and reduced battery life (hence, air conditioning may be needed).

Application

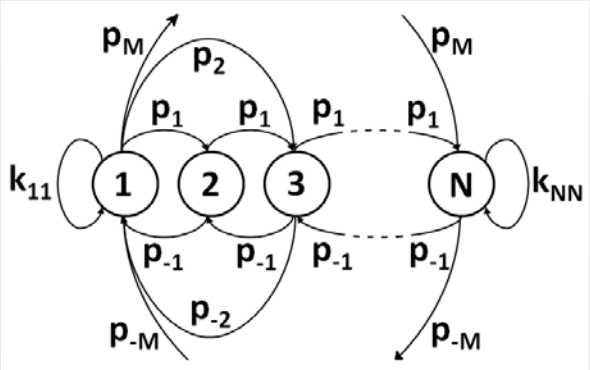
- **Sustainable wireless communication networks**

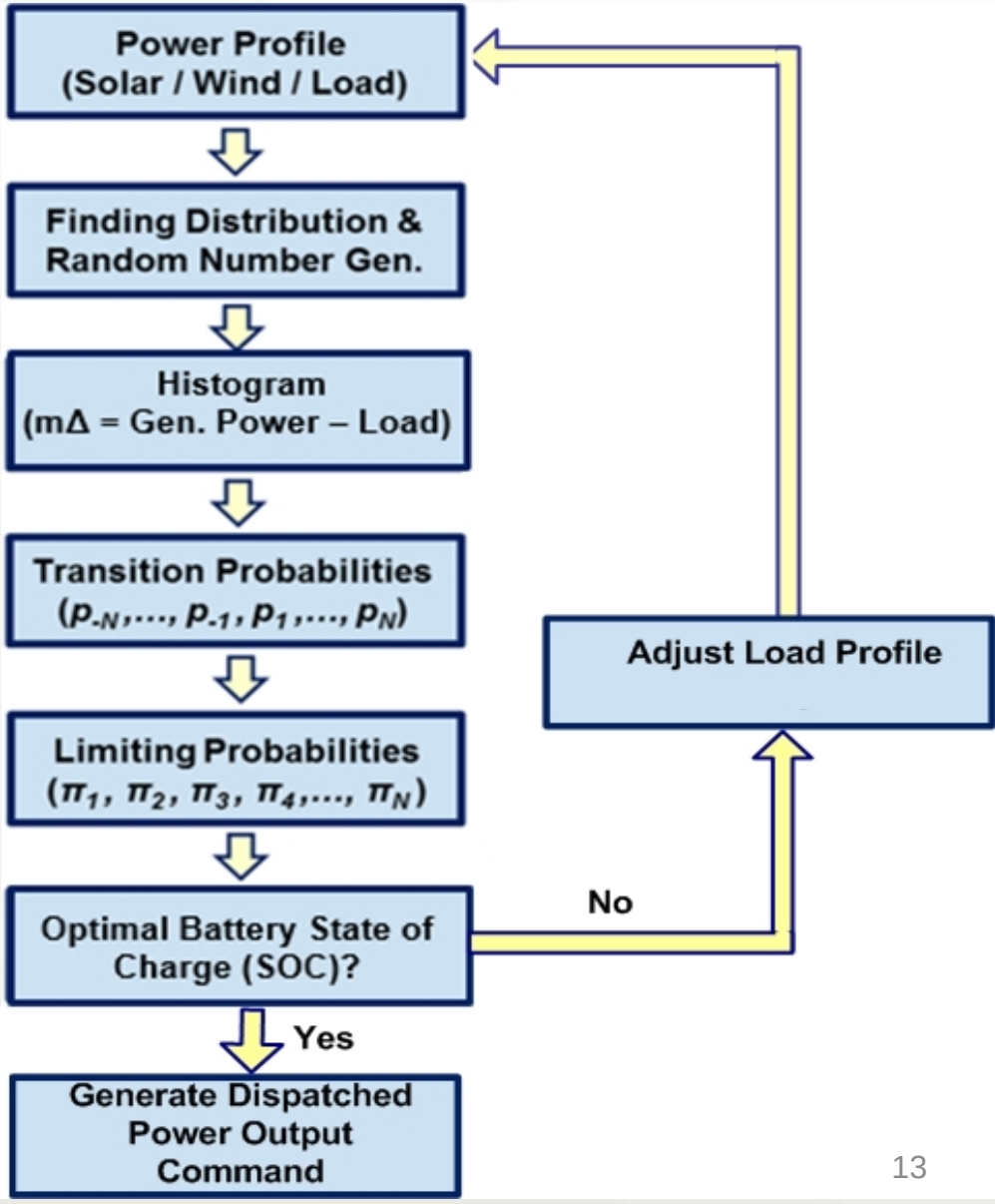
- Issues:
  - Low availability of distributed network elements (cell sites / base stations, a.k.a. “cell towers”) during extreme events due to power issues.
  - Renewable sources large footprint and variable output
- Solution:
  - Integrate traffic and electric energy management. I.e., traffic is regulated based on local energy resources and forecast
  - Create dc microgrids (called sustainable wireless area, SWA) by interconnecting a few (e.g. 7) base stations.



- **Sustainable wireless communication networks**

- Availability can be improved without additional energy storage by modifying the transition probabilities.
- Transition probabilities can be modified by controlling the load (e.g. managing traffic) based on batteries state of charge or based on the present or expected future condition of the local power generators (including PV arrays).





Application

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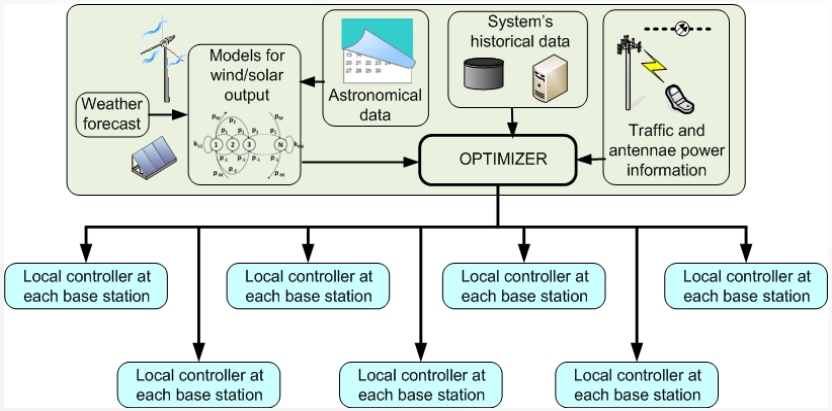
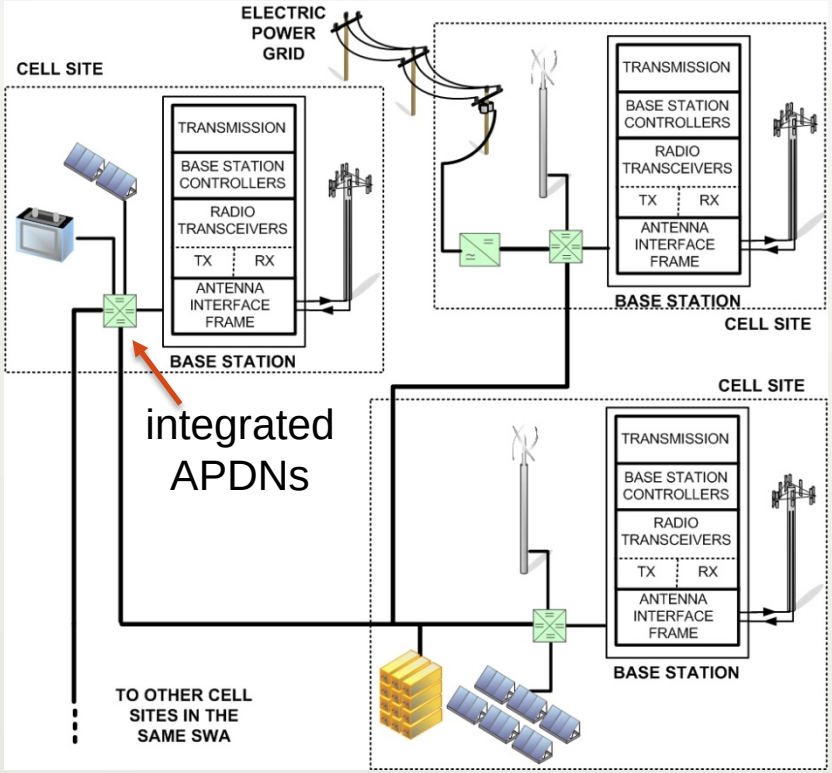


- Control architecture:
  - Central controller:
    - Optimization
  - Local controller at each base station:
    - Droop autonomous controller:
      - Operates the base station if central controller or communication link fails
      - Address constant-power loads stability issues

- Electrical architecture:
  - Includes power electronic circuits in distribution nodes (APDNs)



Application

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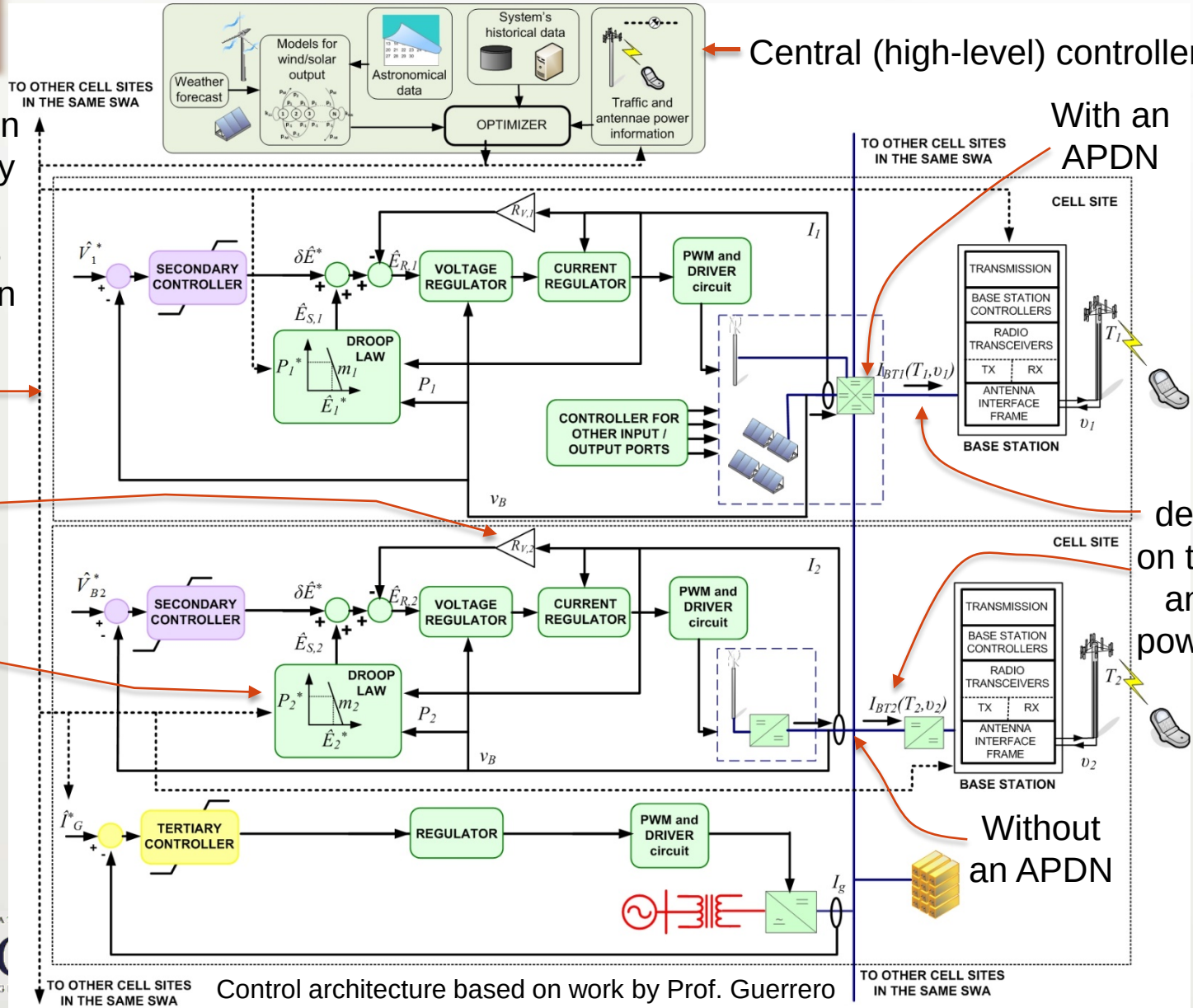

Control architecture based on work by Prof. Guerrero

Thank you very much

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