Energy Informatics: Overview (II)

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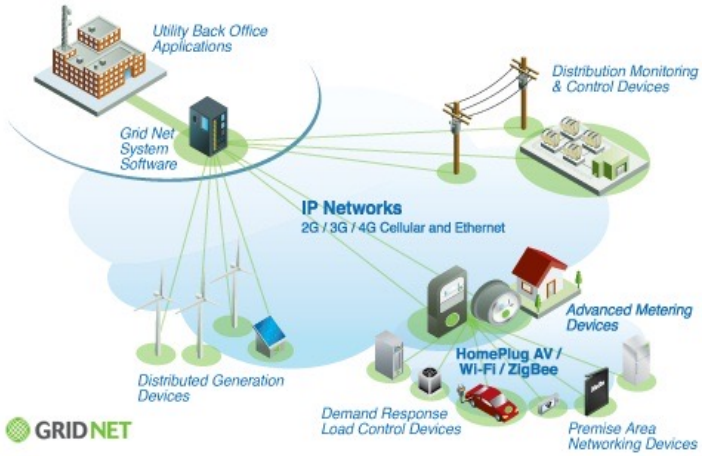
Learning Objectives

From this lecture, it is aimed that the students will be able to learn about

- **Learn the basic concepts in smart grid**
- **Learn about the communications and networking technologies for smart grid**
- **Understand the challenges, advantages and disadvantages of applying different ICT (Information and Communications Technology) technologies for smart grid**

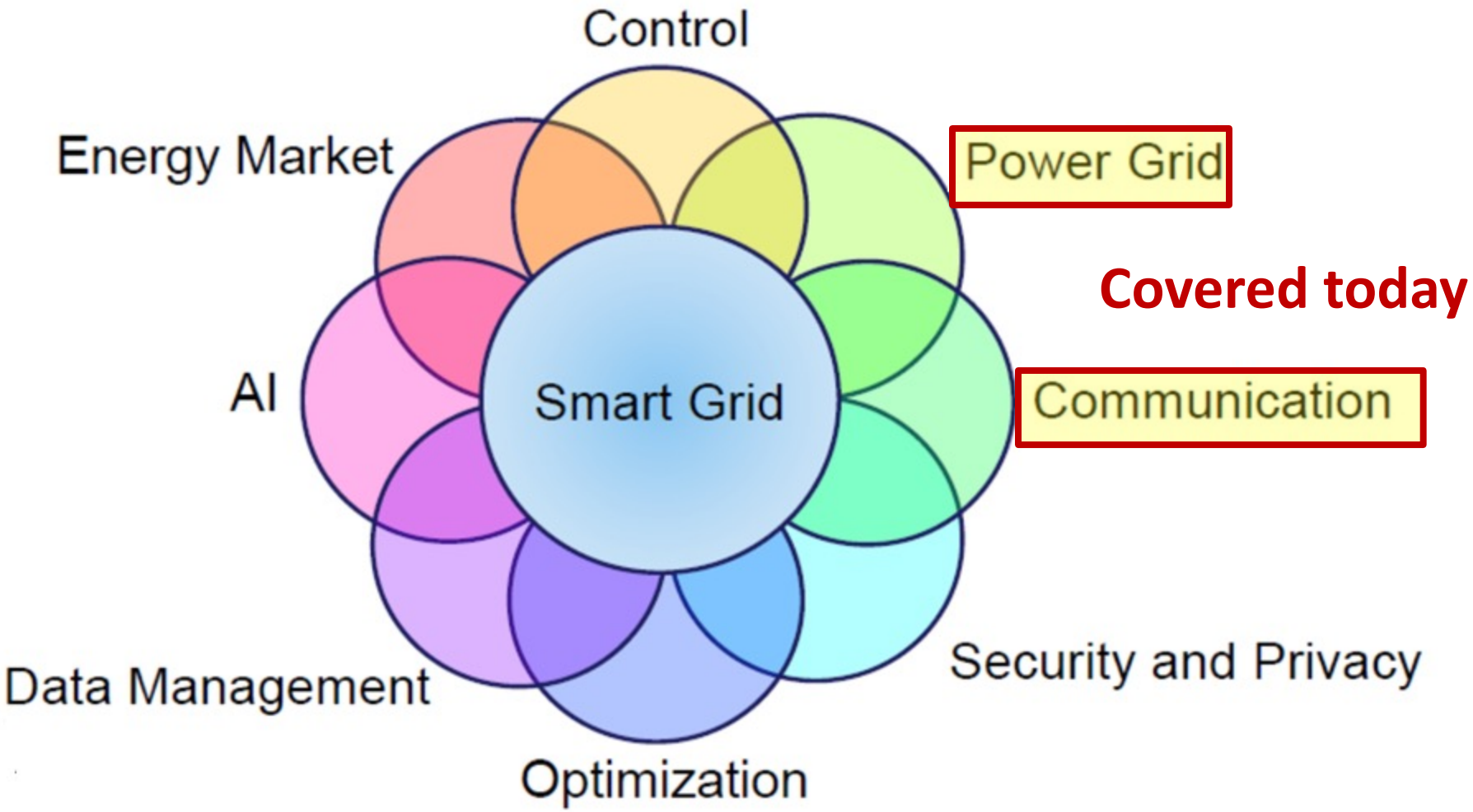
Outline

Smart Grid



ICT for Smart Grid

Smart grid: an interdisciplinary field



Power systems

Power generation (hydropower, solar, wind power, nuclear etc)

High-voltage power transmission

Medium voltage distribution lines

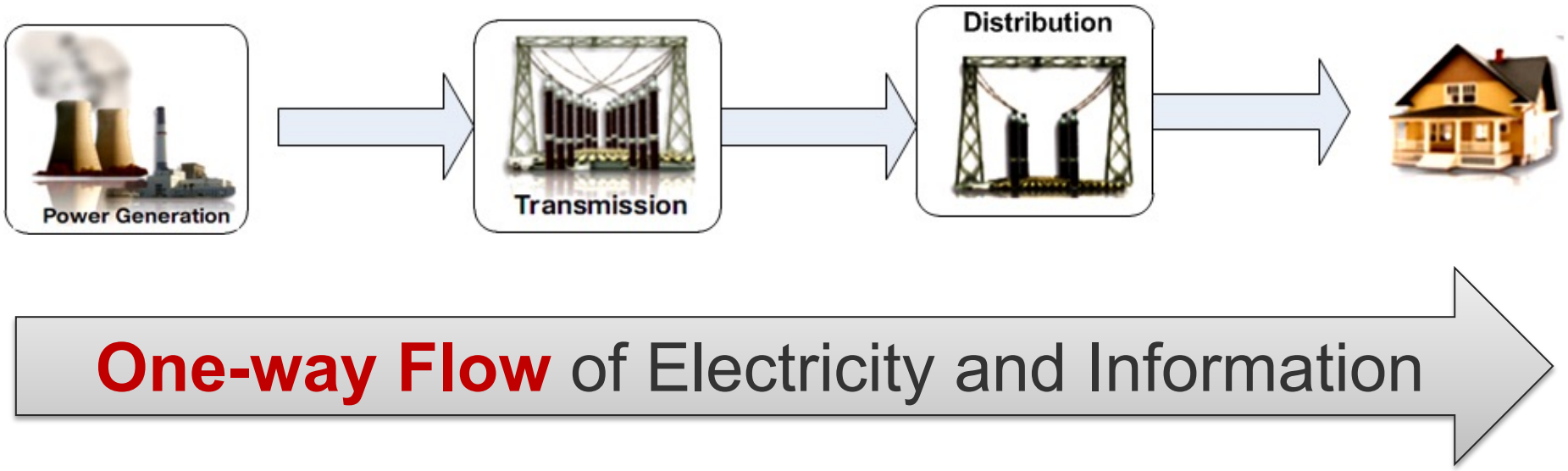
Commercial, industrial and residential users

Traditional Power Grid

Power is generated in a plant

Power is distributed through the long-distance high-voltage transmission networks to the local community

Power is distributed to the customers



Problems with Current Power Grid

Not efficient

Transmission loss = 20%

Not reliable

- Failure can quickly spread

Not secure

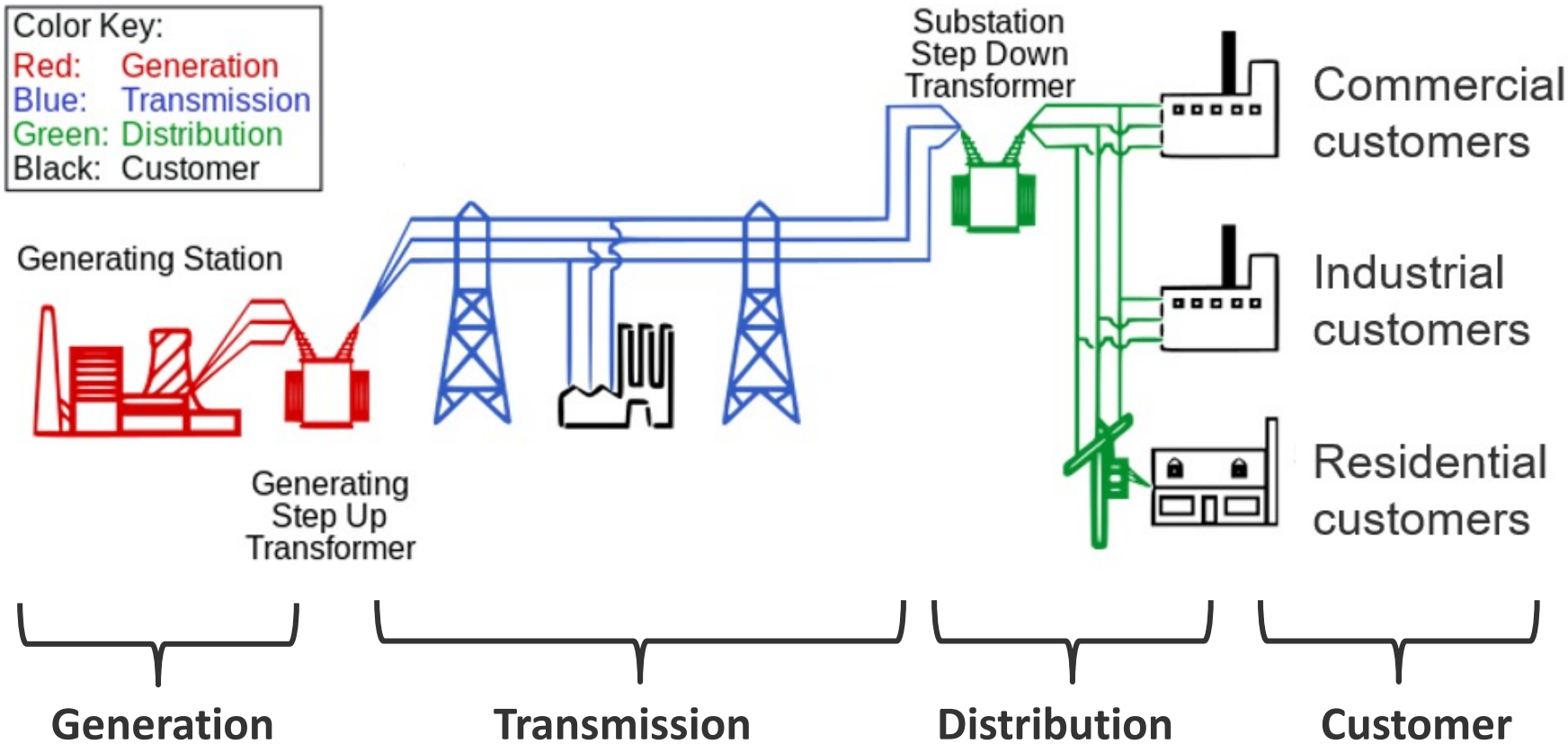
- Cyber attack

Not green

- Electricity accounts for 41% of energy related CO_2 emissions

The Grid Should be Smarter

Power systems – abstract model



Power generation sources

Power plants

Renewable energy sources

– Wind farm, Solar power

Hydropower

99% of all power production in Norway comes from hydropower

Q: which source produces most power in Norway?

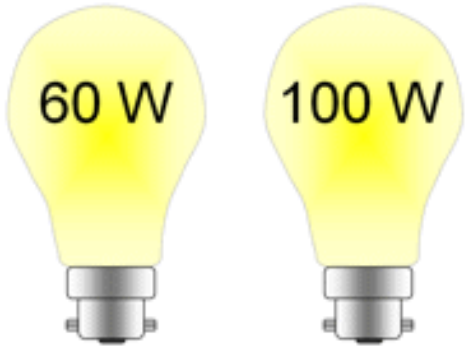
Concept: Power

Power: Instantaneous rate of energy consumption; How hard you work!

Power = Voltage x Current

Power Units:

- **Watts = amps times volts (W)**
- **kW = 1 x 10^3 Watt**
- **MW = 1 x 10^6 Watt**
- **GW = 1 x 10^9Watt**
- **TW = 1 x 10^{12}Watt**



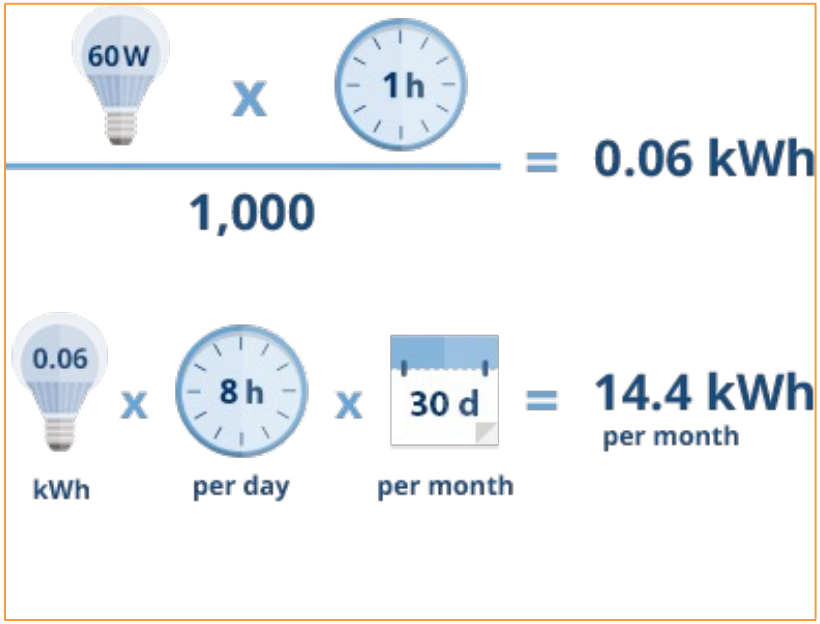
Concept: Energy

Energy Consumption = Power * Time:

- **Energy is what people really want from a power system,**
- **How much work you accomplish over time.**

Energy Units:

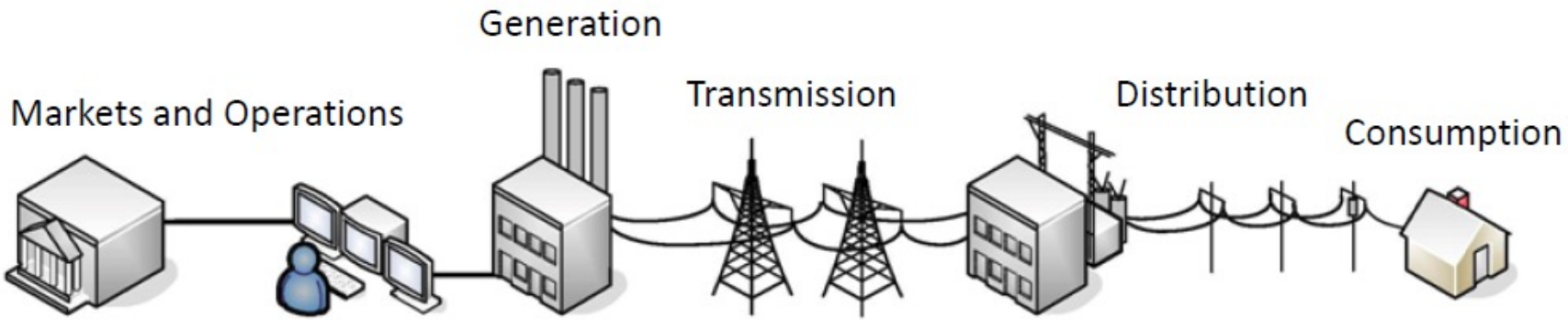
- **Joule= 1 watt-second (J)**
- **kWh=kilowatt-hour = 1000watt * 3600sec = 3.6 x 10^6 J**



Annual electric energy consumption in Norway in 2021 is about 223 TWh

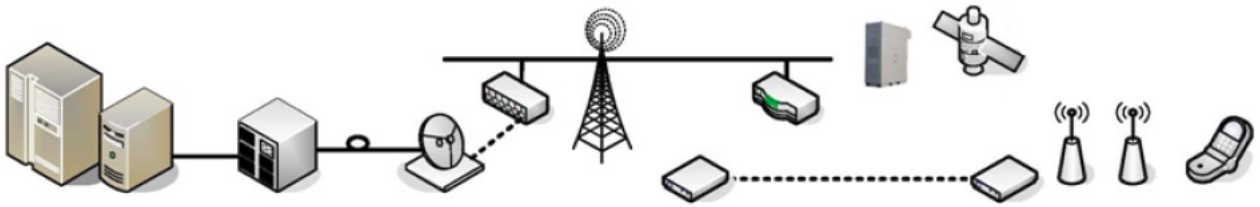
https://www.ssb.no/en/energi-og-industri/energi/statistikk/produksjon-og-forbruk-av-energi-energibalanse-og-energiregnskap

Smart Grid = Power Grid + ICT



Power infrastructure

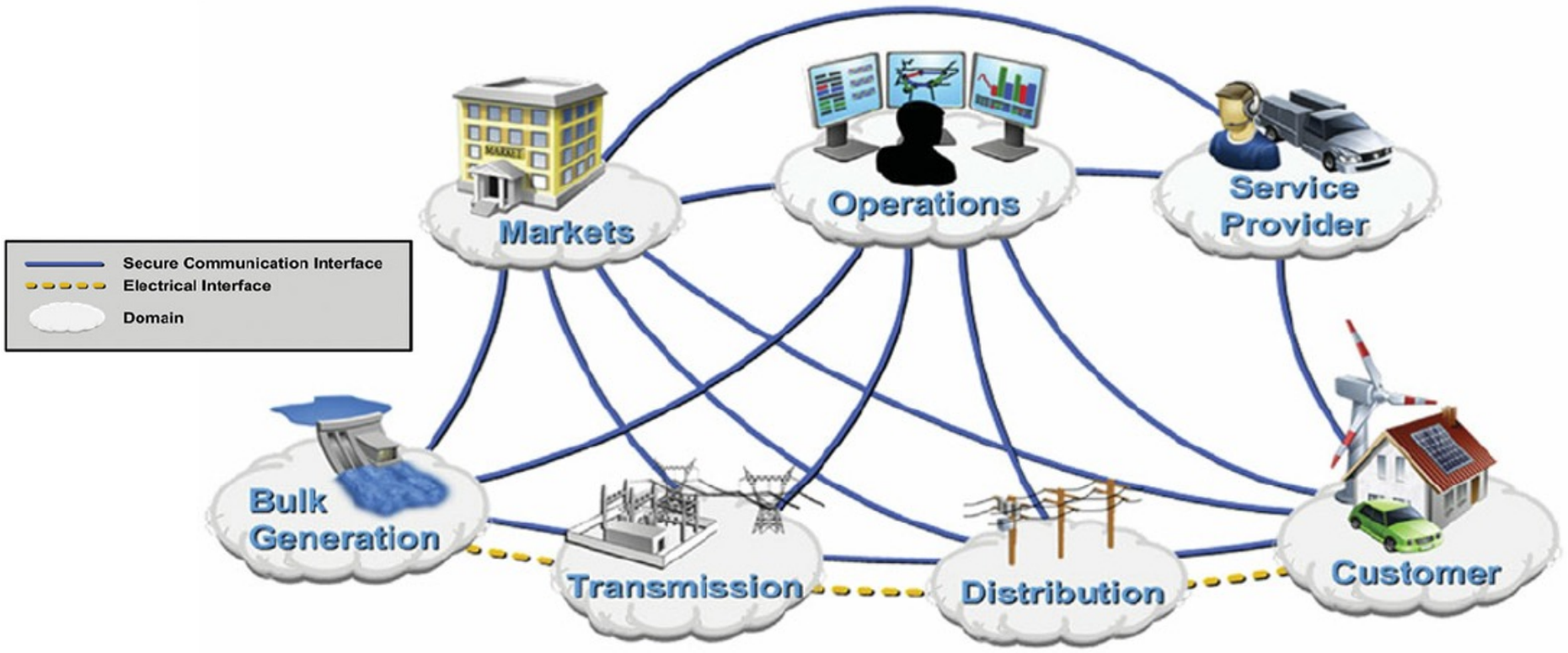
Two way flow of electricity and data



Communications infrastructure

*ICT: Information & Communications Technology

NIST (National Institute of Standard and Technology, USA**)**
Conceptual Model for Smart Grid



Interaction between 7 Smart Grid units through information flow and energy flow

NIST Conceptual Model for Smart Grid

Customers:

The end users of electricity

Typically, three types of customers: residential, commercial, and industrial

Customers may also generate, store, and manage the use of energy.

- **Q: How?**

Market

The operators and participants in electricity markets

Participants in wholesale market: day ahead, hour ahead (We will discuss more in the lecture "Energy Market and Game Theory")

A market may involve prediction, bidding, auctions

NIST Conceptual Model for Smart Grid

Service Providers:

Organizations that provide service to both utilities and electricity consumers

Internet service providers, charging stations operators,…

Operation

The manager of the flow of electricity

Independent System Operators (ISOs) or Regional Transmission (System) Operations (RTOs). An ISO or RTO serves as a third-party independent operator of the transmission system.

Bulk Generation

Major power plants. The generators of electricity in bulk quantities. May also store energy for later distribution.

NIST Conceptual Model for Smart Grid

Transmission

- Carriers of bulk electricity over long distance
- A system operator is responsible for the security of power supply in its area
- In the Nordic countries, the system operators have the responsibility for both the security of supply and the high-voltage grid (the transmission grid).
- Statnett is Norway's transmission system operator

Distribution

- Distribution of electricity to and from customers
- May also store and generate electricity

Smart Grid Concept and Vision

- Cost-effective: cost-effective production and delivery of power
- Green: greater use of renewable resources; support for a large number of electric vehicles
- Customer-oriented: consumers can choose energy usage
- Secure: resilient to various cyber attacks
- Dynamic: dynamic pricing and load control
- Reliable: higher reliability of services
- Communication and control infrastructure to augment power grid operations

The transformation to a smart grid requires integrating computation, networking, communications and control

ICT FOR SMART GRID

Smart Grid needs communications and networking technologies

- Smart metering and Advanced Metering Infrastructure(AMI)
- Distributed generation and renewable energy integration
- Power outage detection
- Real-time monitoring, diagnostics and protection

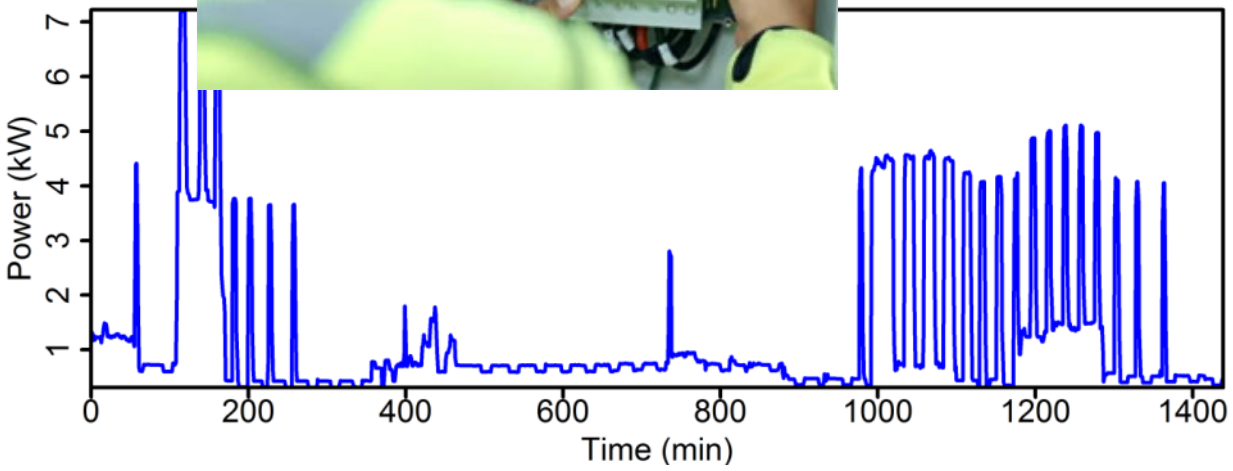
- Big data generated by massive number of sensors, meters, and telemetry
- Further analysis control, real time pricing
- Communications network support intelligent energy scheduling

Old electricity meters → Smart Meters

Analogue, Manual, annually or monthly

Digital, Bidirectional communication

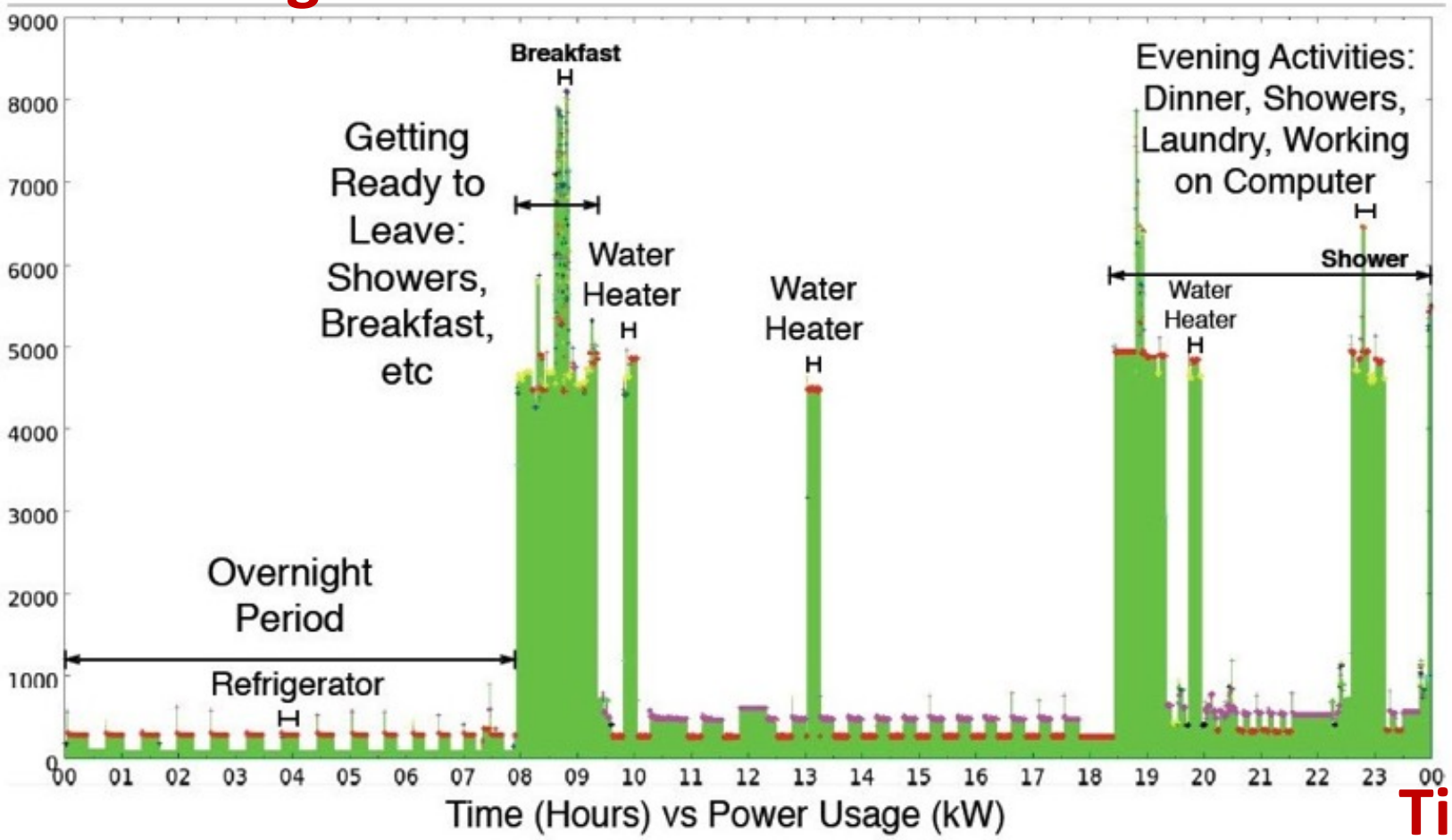
Hafslund Nett



Q: Any consequence of energy consumption data being available through smart meters?

Smart Meter Privacy Issues

Power Usage



Time

Molina-Markham A, Shenoy P, Fu K, Cecchet E, Irwin D. “Private memoirs of a smart meter”, BuildSys 2010.

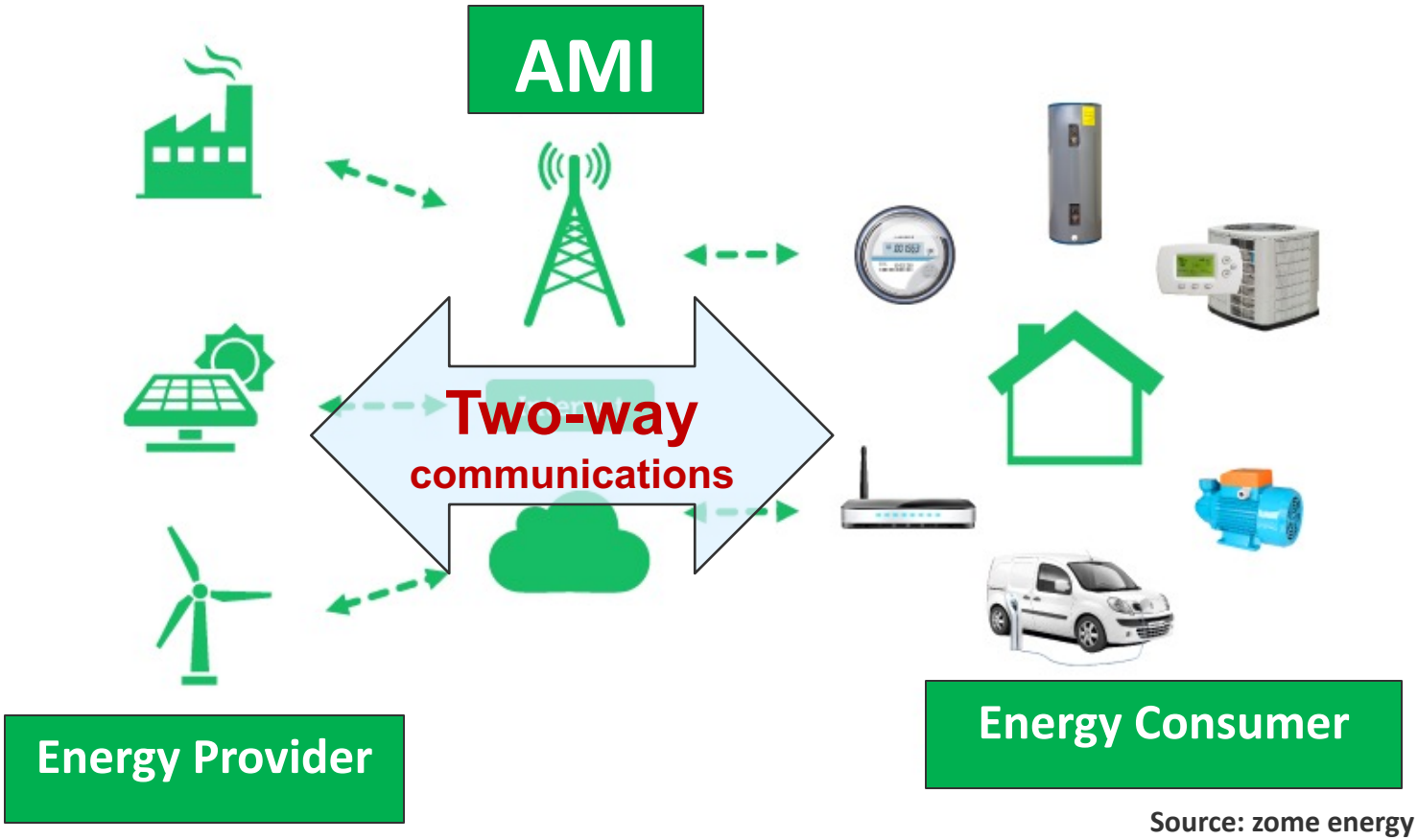
Smart Meter Functions

Smart meters perform the following functions

- **Energy consumption measurement**
- **Communications with other intelligent devices in the home and utility**
- **Time-based pricing**
- **Loss of power notification**
- **Remote turn on / turn off operations**
- **Power quality monitoring**

NVE- the Norwegian Water Resources and Energy Directorate, decided that all customers in Norway should receive new smart meters by 1 January 2019. About 2.5 million meters were replaced in Norway.

Advanced Metering Infrastructure (AMI)



Source: zome energy networks

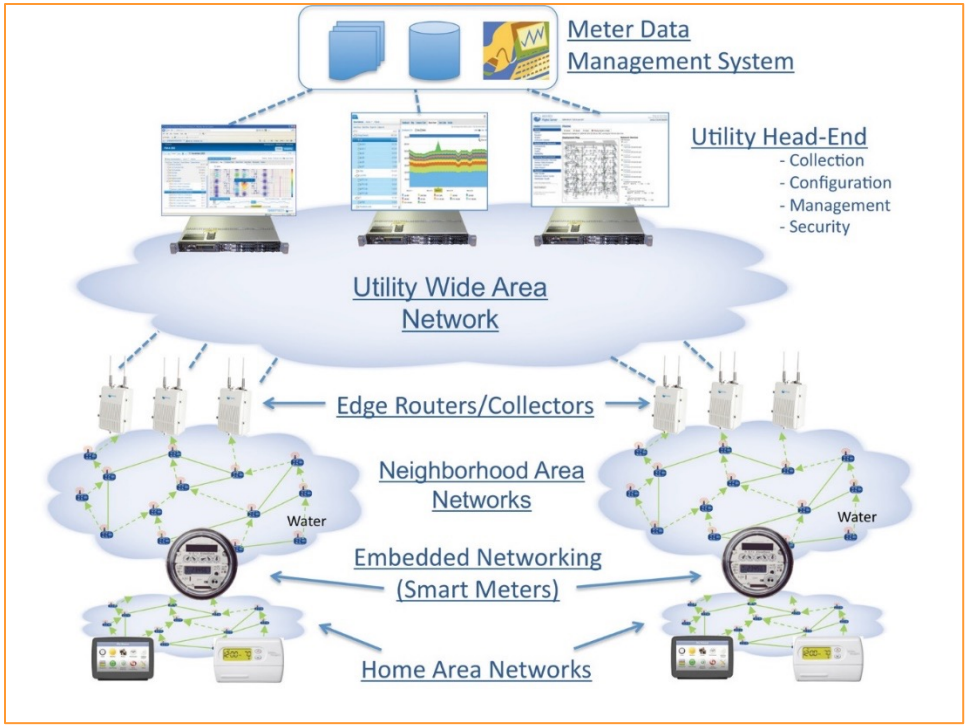
Smart meters are not working separately. They are organized as networks.

AMI is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between energy providers and energy customers.

Advanced Metering Infrastructure (AMI)

AMI integrates a number of technologies:

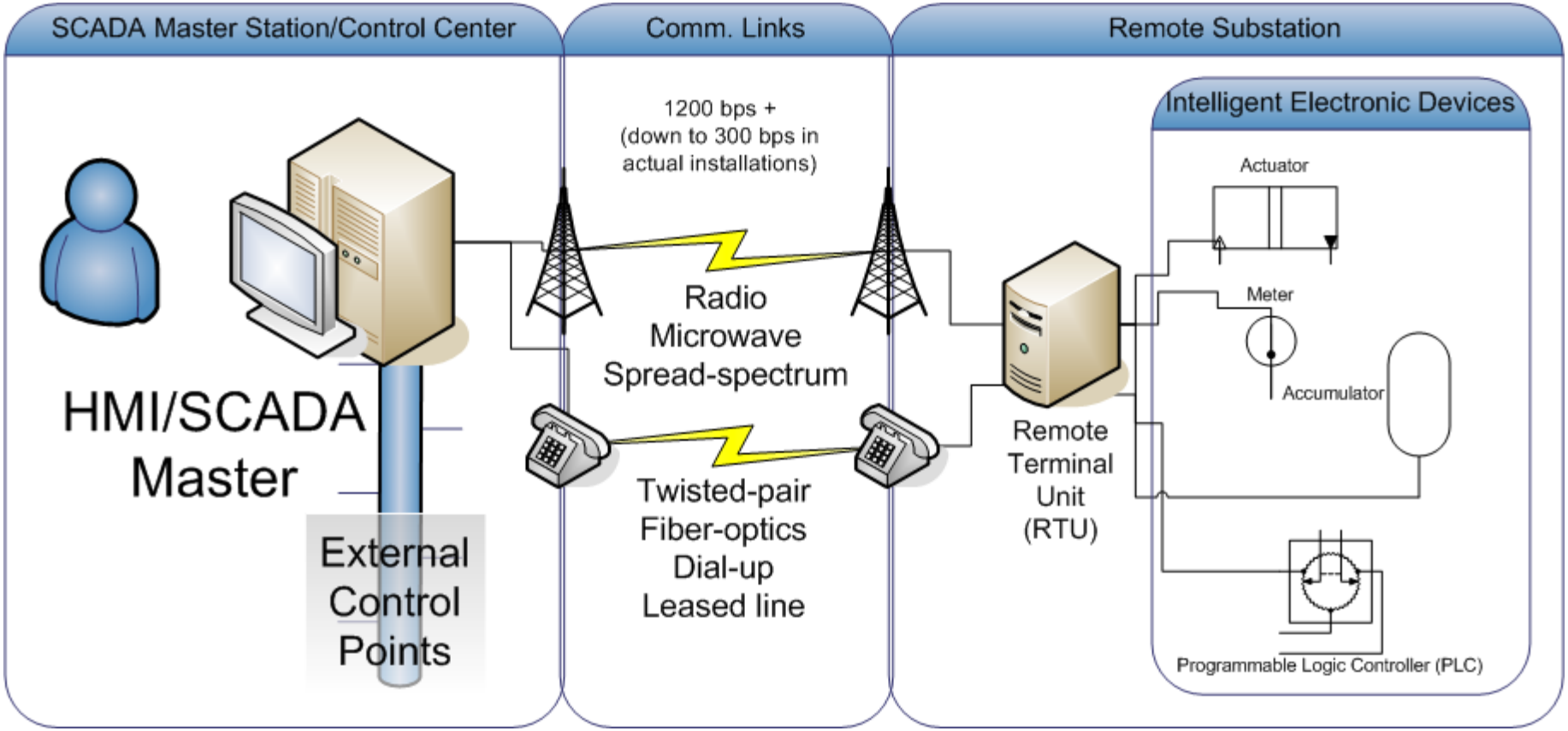
- **Smart meters at the consumer end**
- **Communication networks at different levels of the infrastructure hierarchy to connect the two ends**
- **Meter Data Management Systems (MDMS)**
- **Platform integrating the collected data into application at utility provider**



Source: National Energy Technology Laboratory for the U.S. Department of Energy

Supervisory control and data acquisition (SCADA)

SCADA is solution for data acquisition, monitoring and control over large geographical areas. The data is transferred to a master station to implement the necessary processing and control algorithms.



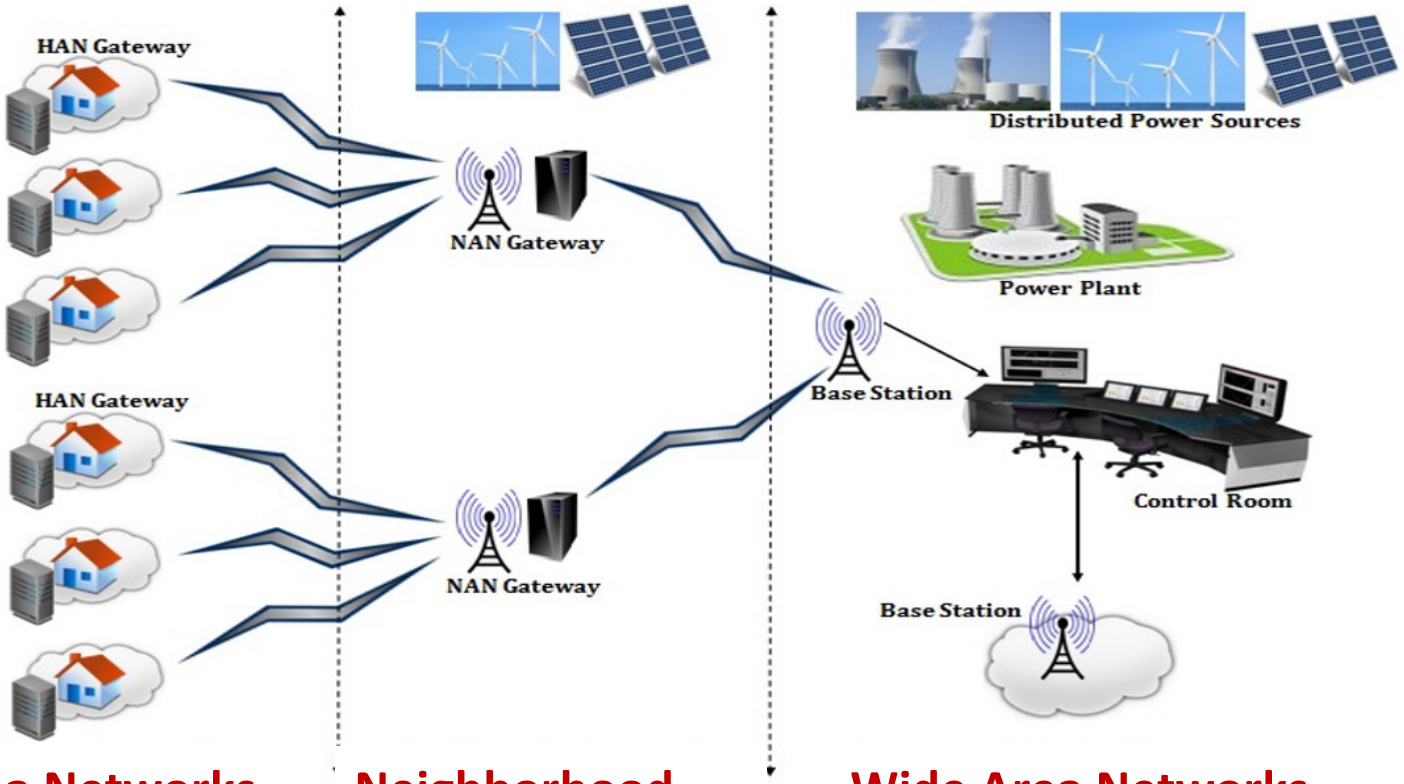
Picture: https://www.electricaltechnology.org/2015/09/scada-systems-for-electrical-distribution.html

Supervisory control and data acquisition (SCADA)

SCADA systems consist of:

- **RTU (Remote Terminal Unit): conveys signals from sensors to the control center.**
- **Communication networks: transfer data between field data interface devices and control units and the computers in the SCADA central host.**
- **MTU (Master Terminal Unit): a central computer server displays the entire system being monitored and controlled**

Communications Networks



Home Area Networks

HAN: interconnects appliances, energy management units, and home displays.

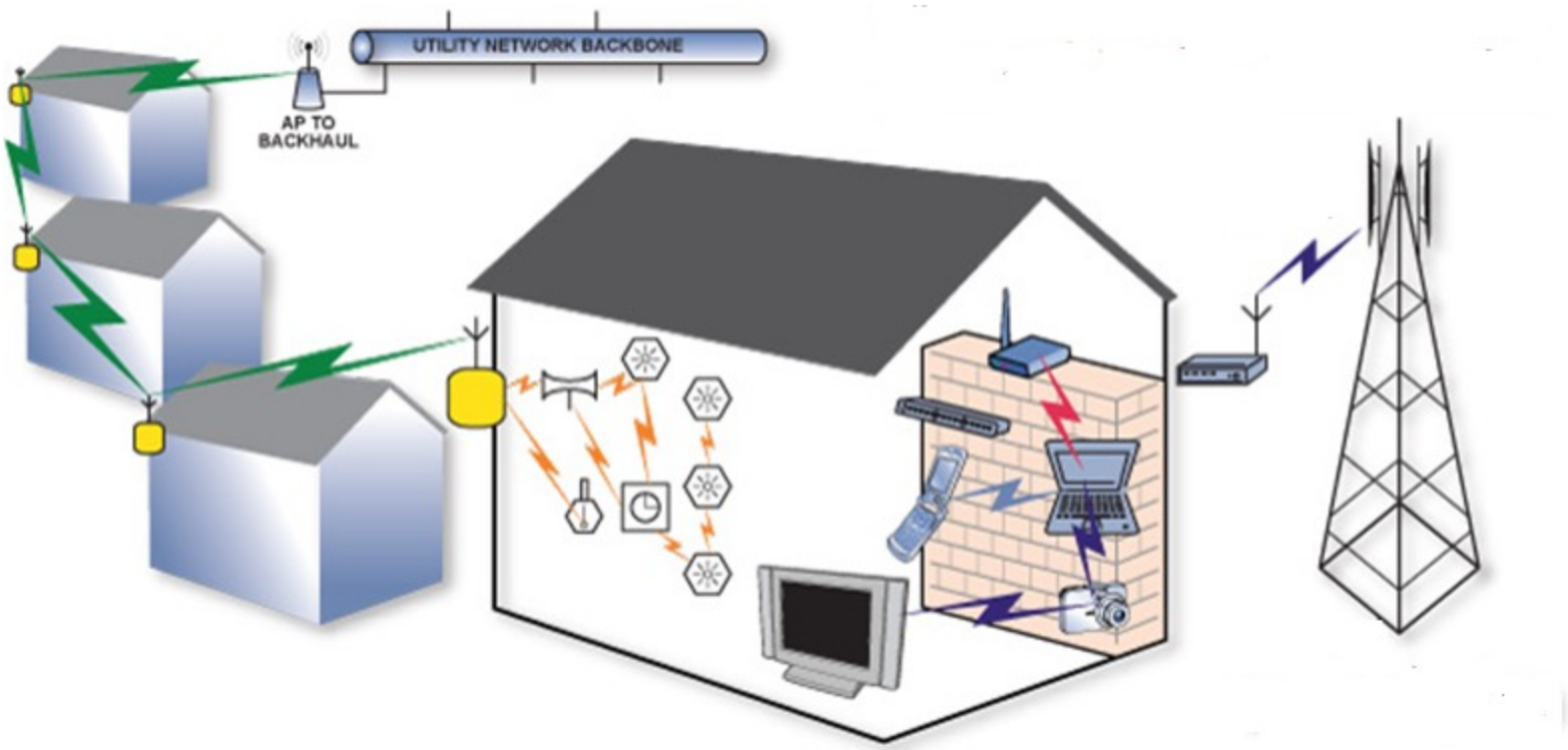
Neighborhood Area Networks

NAN: interfacing metering data and connect multiple HANs to local access points

Wide Area Networks

WAN: between the NANs and the utility systems to transfer information

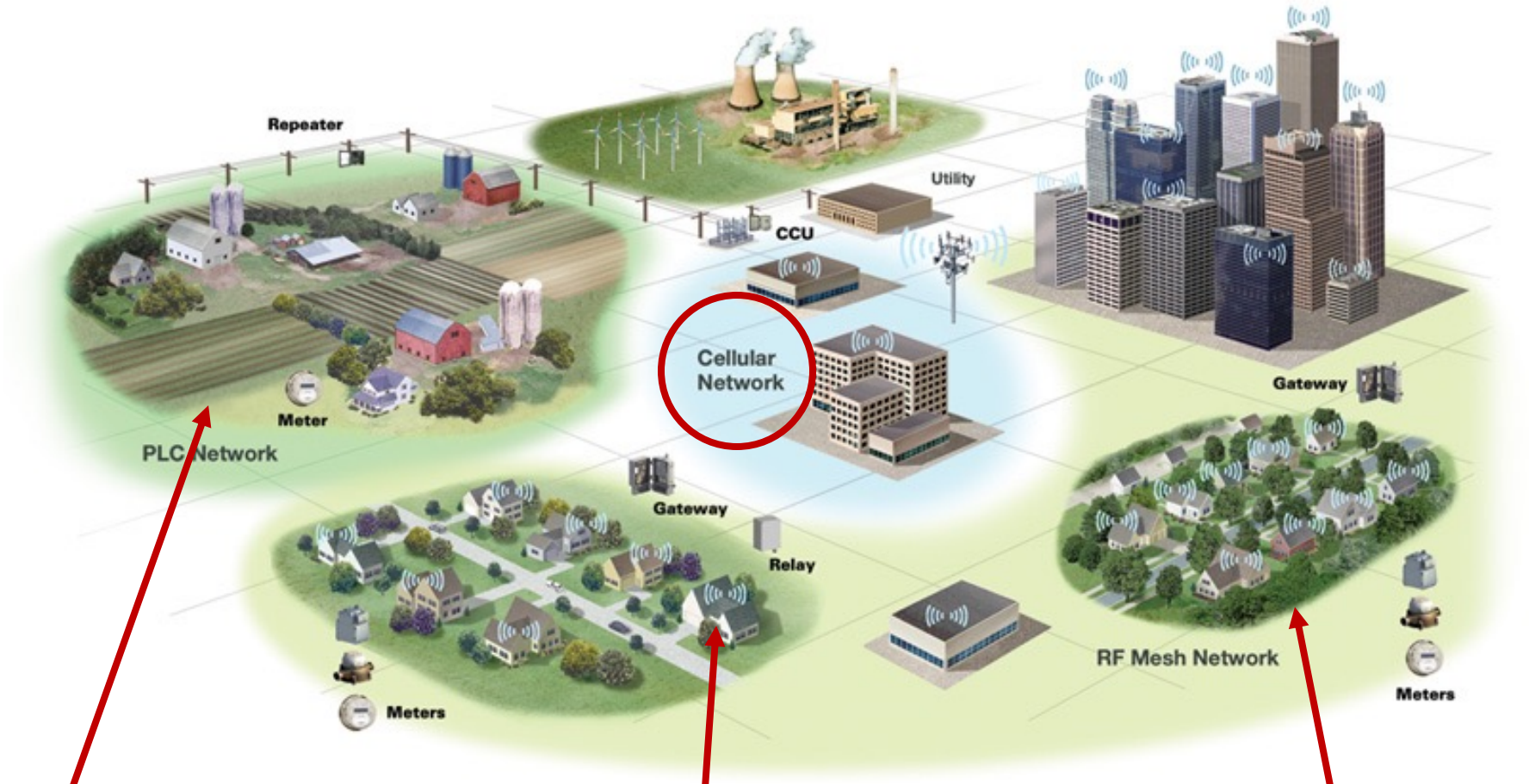
Home Area Networks (HAN)



HAN gathers sensor information from a variety of devices within a house, sends control information to these devices to better control energy consumption, and provides access to in-home appliances.

HAN can use ZigBee, WiFi, Power Line Communications (PLC)

Different communication technologies

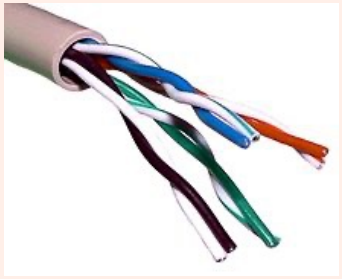


Powerline Communication (PLC)

Wireless Sensor Networks using Zigbee

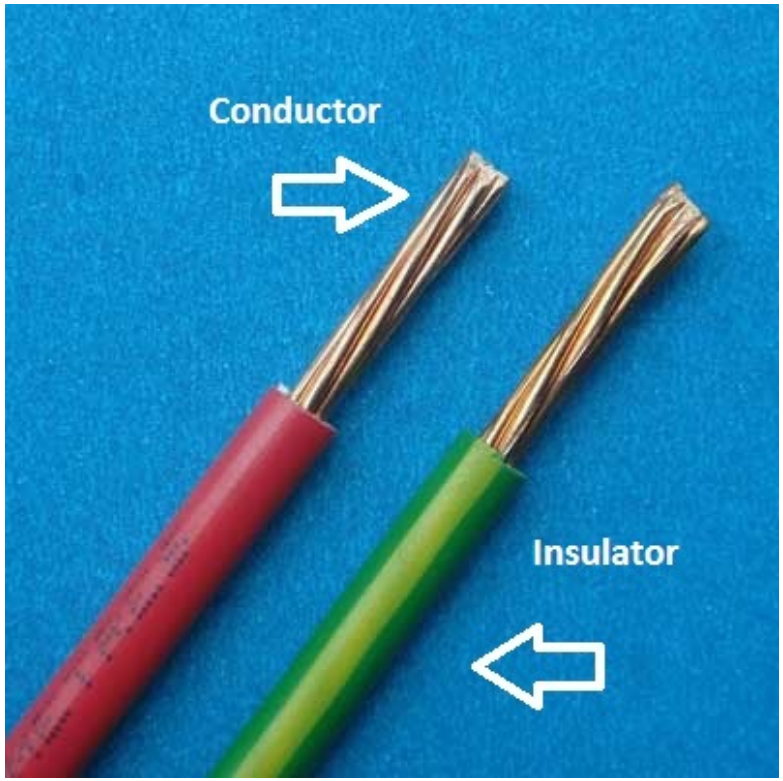
Mesh Networks

Communication Technologies for home area networks

Technology	Data Rates	Coverage	Medium	Band Licensed
PLC	1-200Mbps	1500m	Power cable	Free
Ethernet	100Mpbs	100m	UTP (unshielded twisted pair) cable 	Free
WiFi	5-100Mpbs	30-100m	Wireless	Free
Zigbee	0.02-0.2Mbps	10-75m	Wireless	free

Power Line Communications (PLC)

PLC is a communication technology that enables sending data over existing power cables.



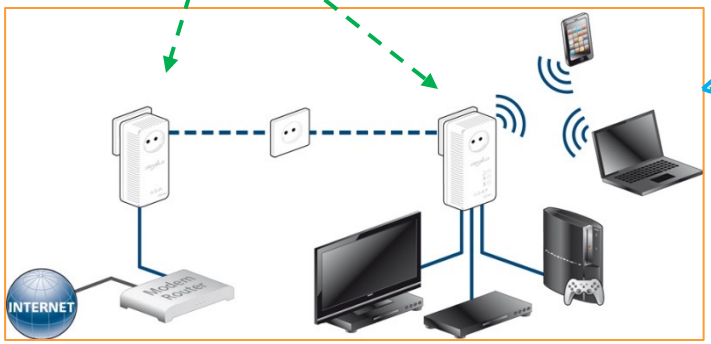
PLC carries data on a conductor that is also used simultaneously for electric power transmission or electric power distribution to consumers.

PLC is a wired communications technology, it can compete with wireless technologies with low cost since the infrastructure already exists

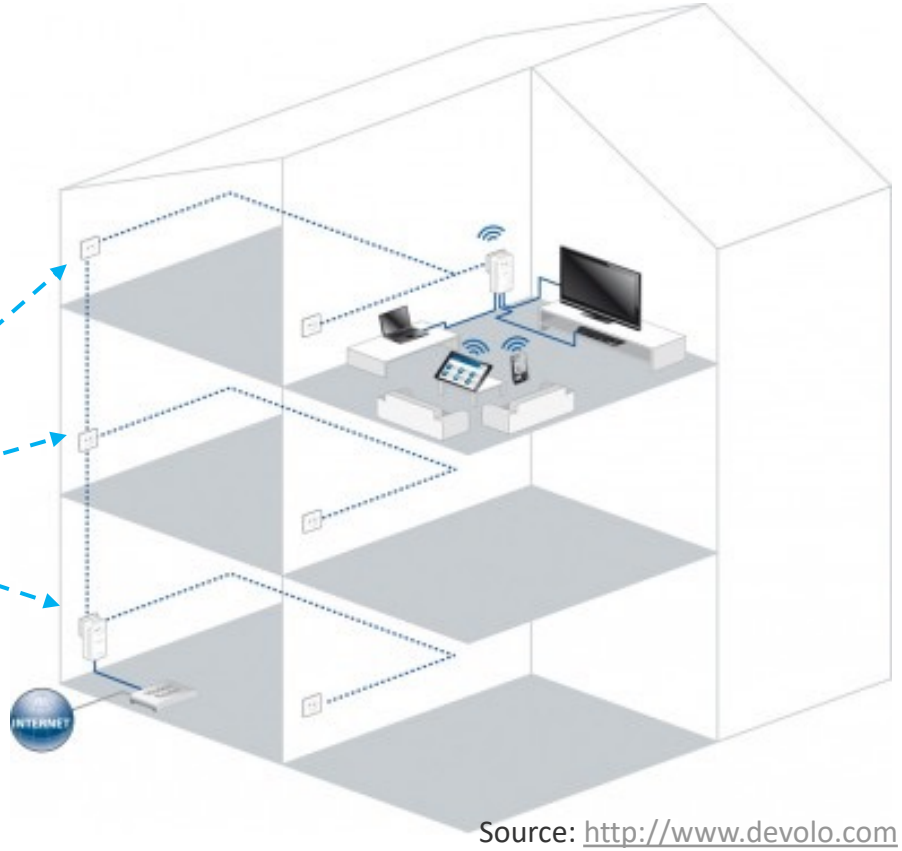
An example of PLC at home

PLC uses the household power grid to transfer data between computers equipped with suitable adapters. The data is modulated prior to transfer and sent as a signal via household power lines.

Adaptor



Network in each level



Source: http://www.devolo.com

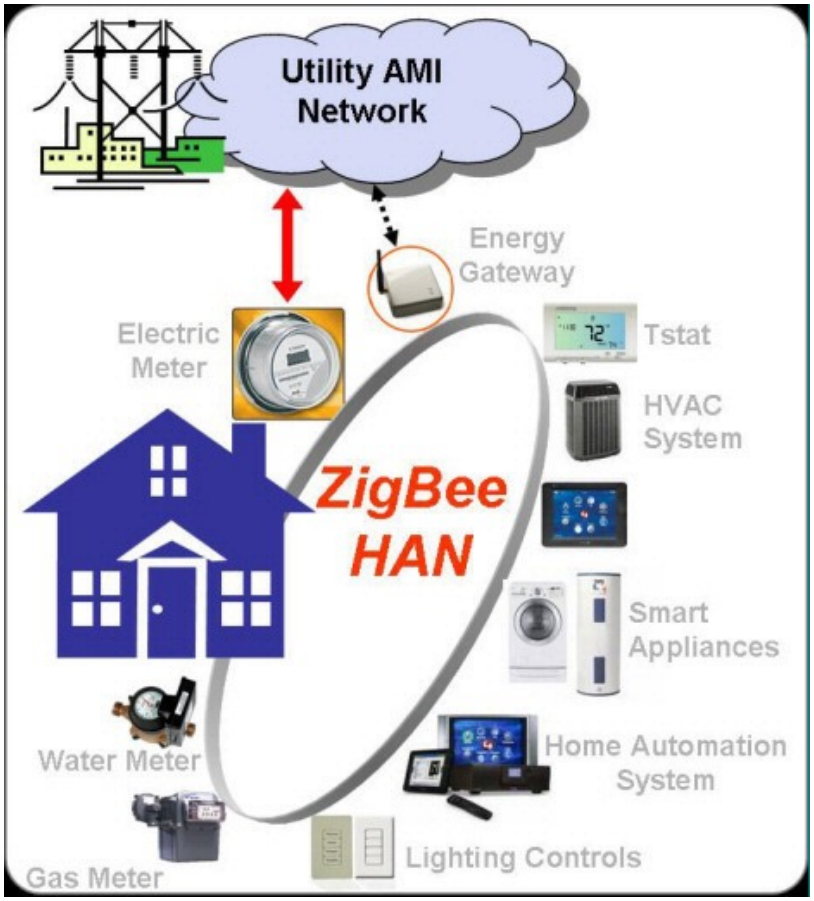
PLC for Home Area Networks

IEEE 802.15.4 - Zigbee for Smart Energy at Home

Zigbee is a short-range, low-data rate, energy-efficient wireless protocol for WSN

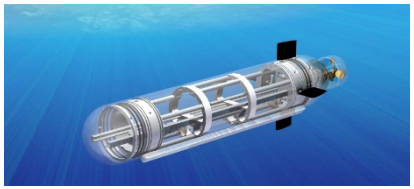
Zigbee defined two smart grid application profiles

- **Home automation**: lighting, window shades, monitoring, security
- **Smart energy**: Zigbee devices can control power supply switch of home appliance; Zigbee enabled smart meters efficiently manage **demand response**; actively respond to different prices and effectively balance the power consumption load in the power grid

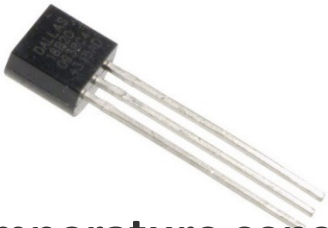


Sensors

Sound sensor



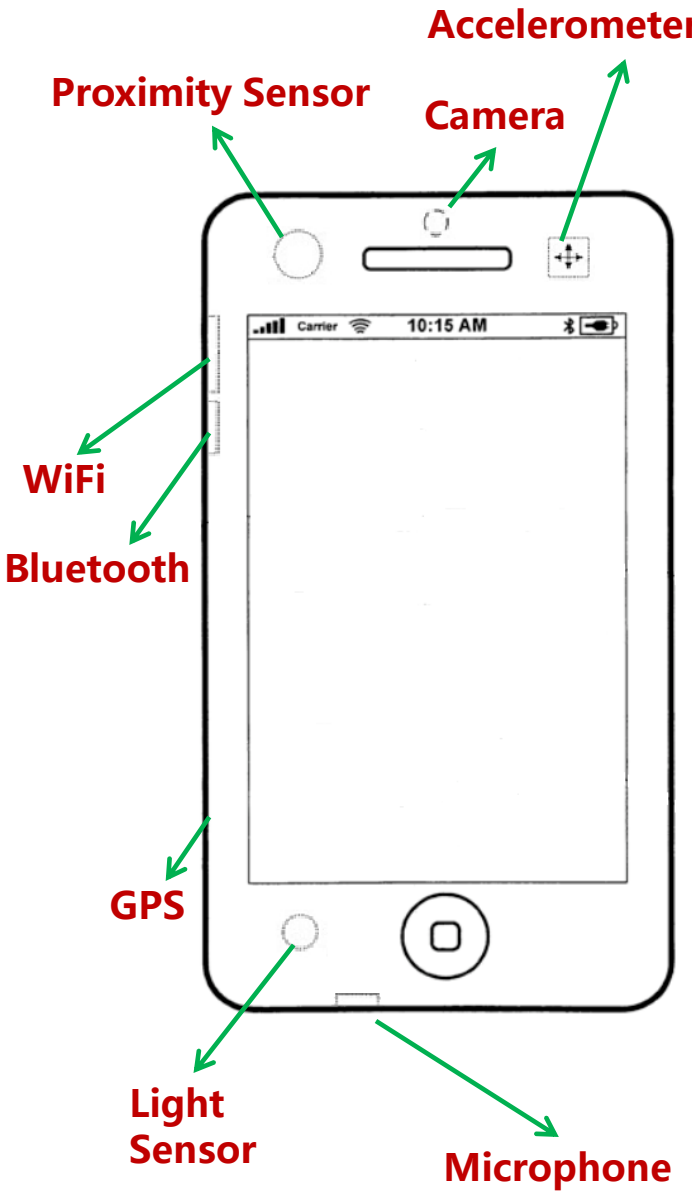
Underwater sensor



Temperature sensor

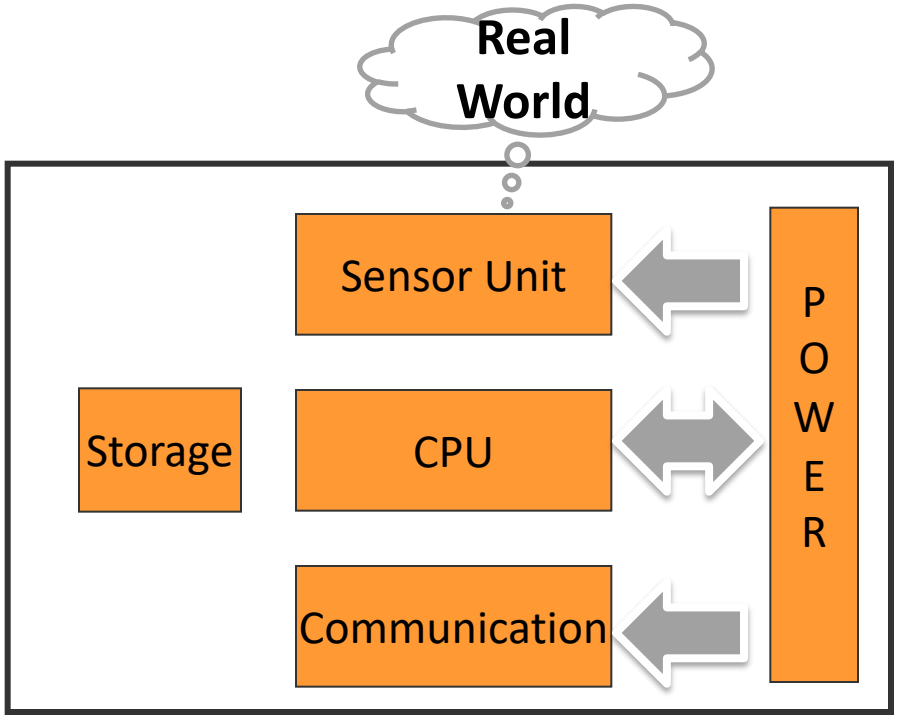
Pressure sensor

Sensor with solar panel



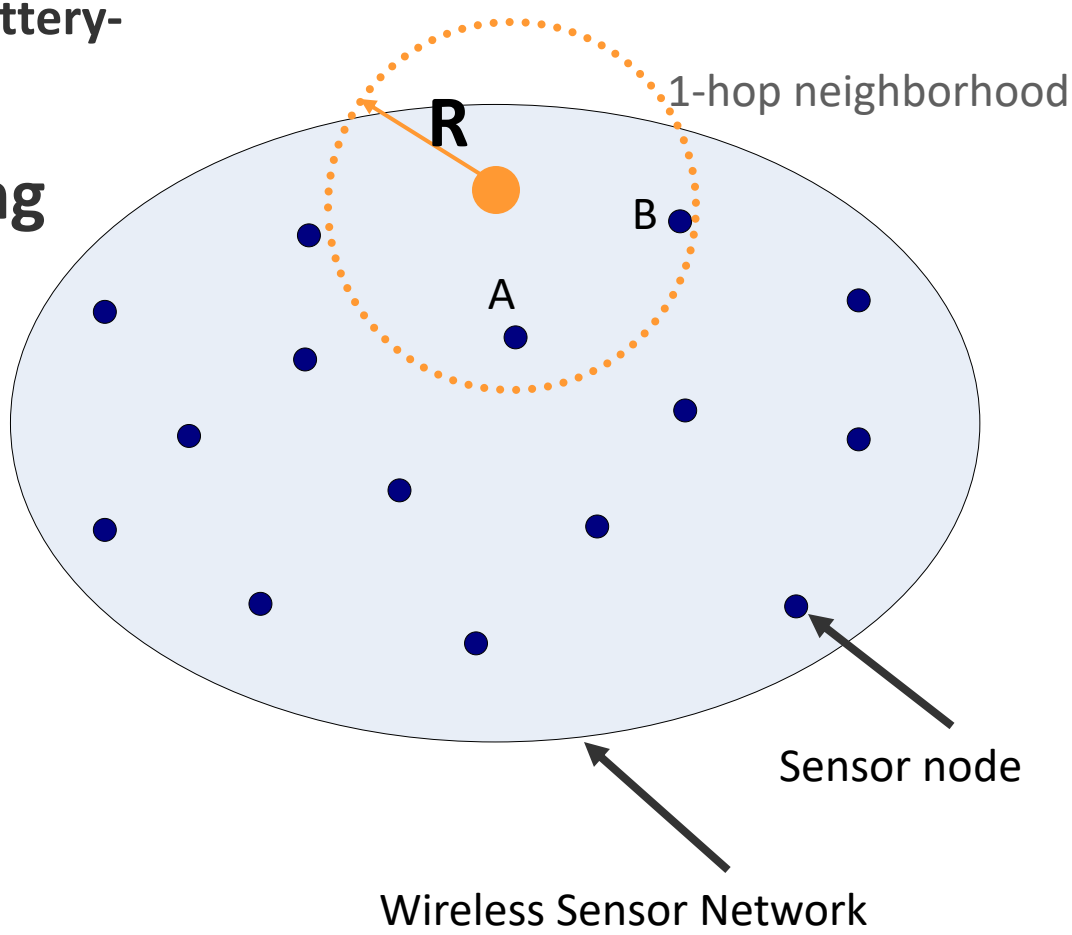
Sensor Nodes Model

- Communication: low-power; low data rate and limited range.
- Low-power processor: Limited processing.
- Memory: limited storage
- Limited power: powered by battery with long-time operation in unattended areas
- Sensors
  - temperature, light, etc.
  - Cameras, microphones.



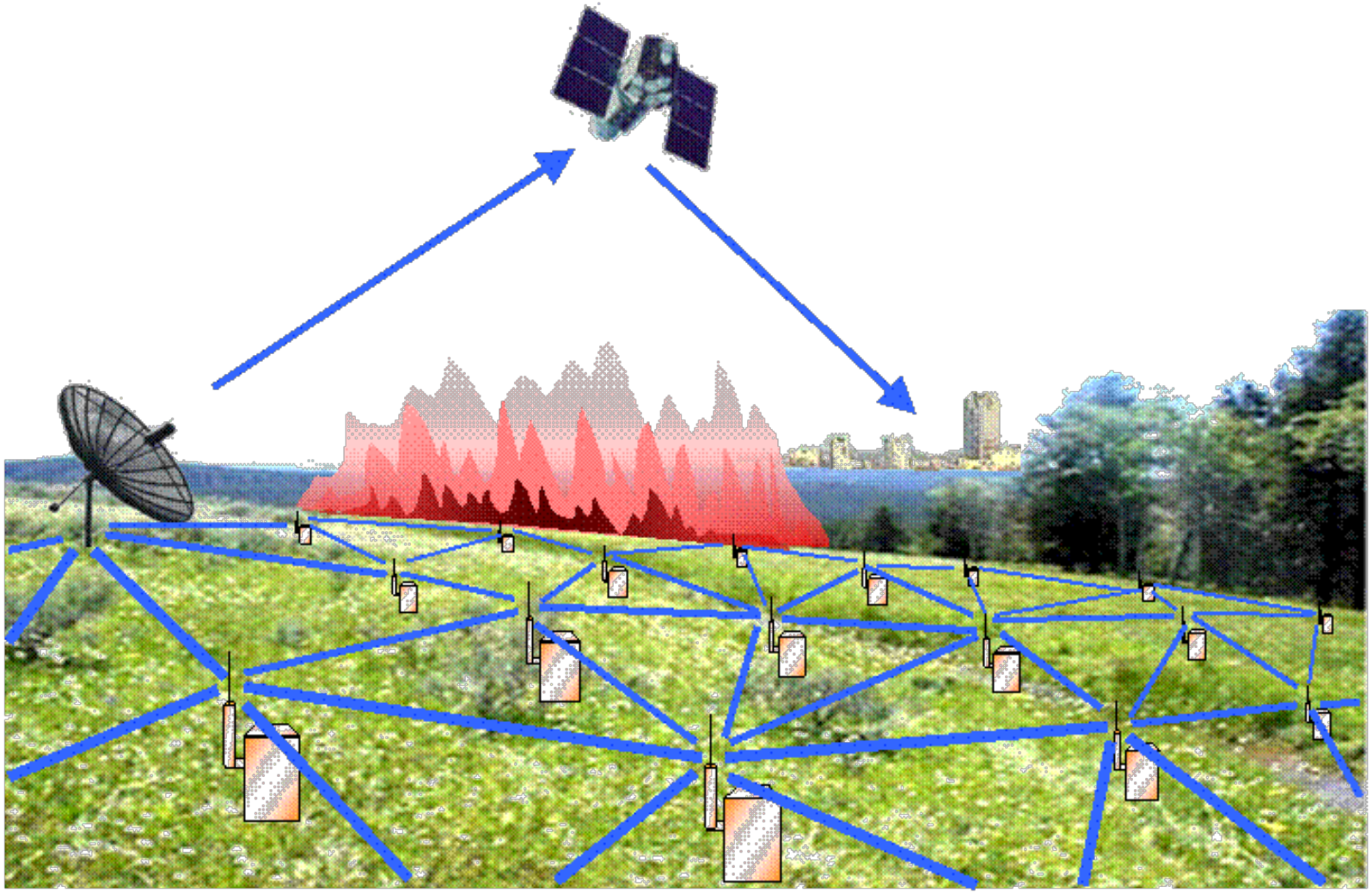
Wireless Sensor Networks

- **Networks of typically small, battery-powered, wireless devices.**
  - **On-board processing**
  - **Communication**
  - **Sensing**

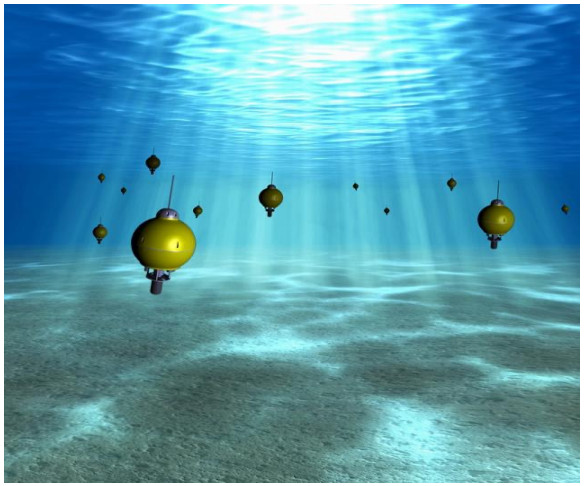


- **R: transmission range**
- ***V*: the set of sensor nodes**

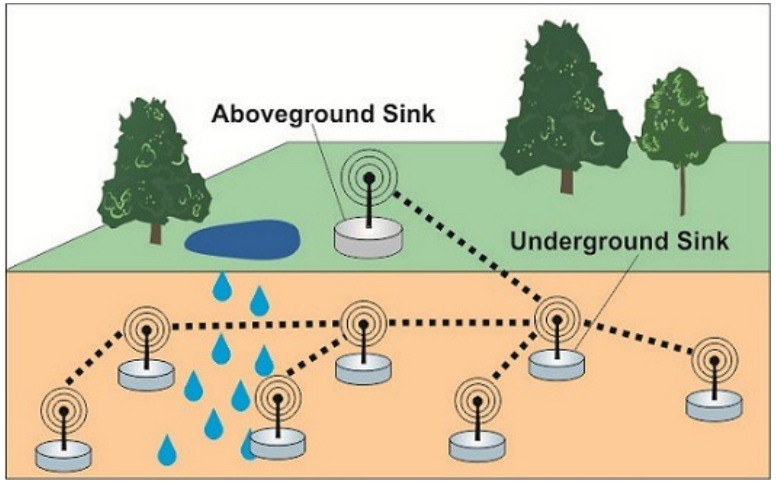
Typical application and system architecture: forest fire detection



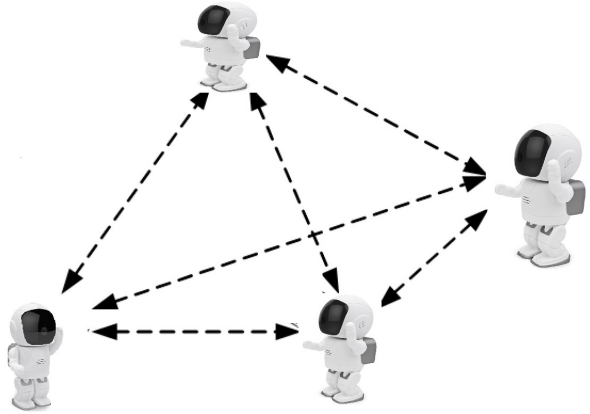
Different Types of Sensor Networks



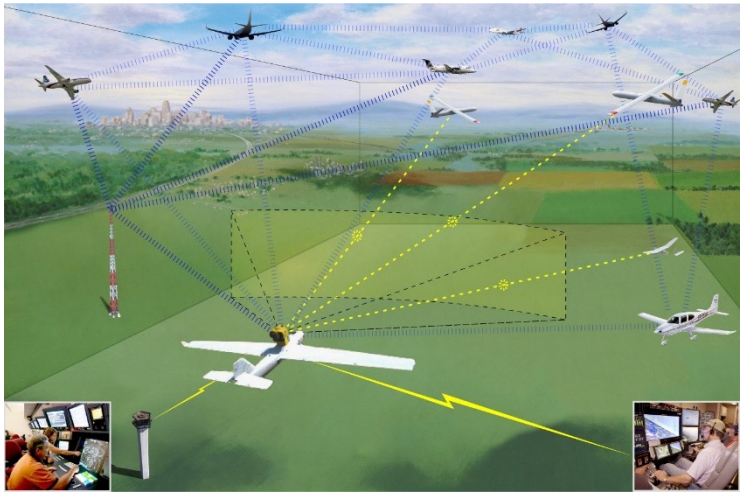
Underwater Sensor Networks



Underground Sensor Networks



Mobile Robot Networks



UAV (Unmanned Aerial Vehicles)/Drones

WSNs for Smart Grid: power generation side

WSNs enable communications and control capabilities at low cost. Both utilities and customers can transfer, monitor, predict, and manage energy usage effectively.

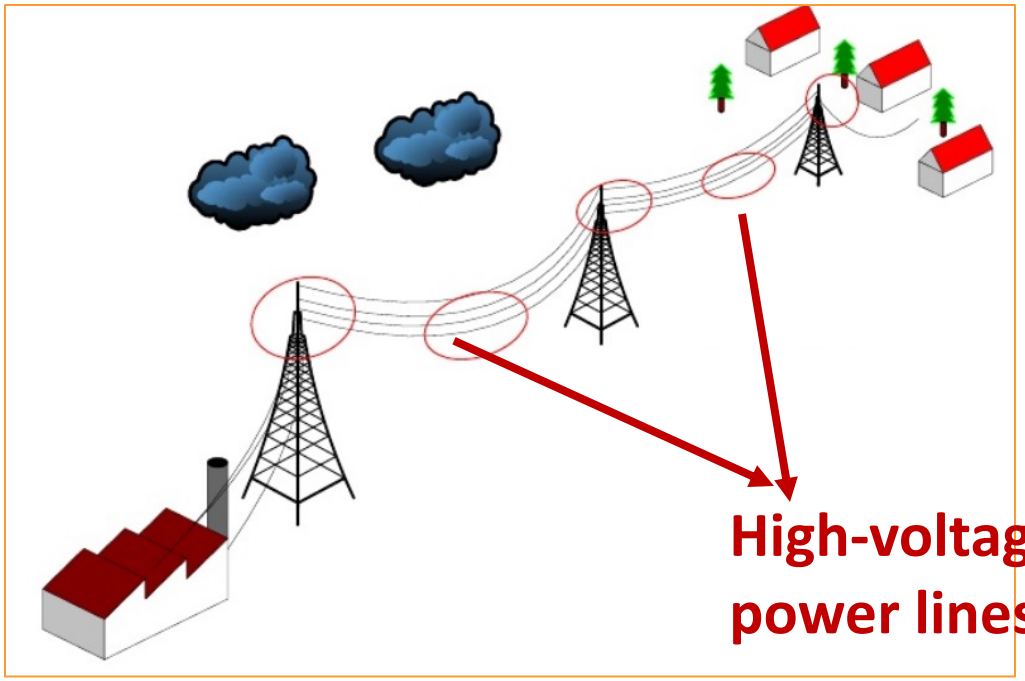
In the traditional power grid, energy generation facilities are generally monitored with wired sensors

- **limited in numbers**
- **located only at a few critical places**

In practice, the renewable energy generation facilities in the smart grid can be in remote areas, and operate in harsh environments

WSNs offer an ideal technology for continuous monitoring and control of the generation facilities in the smart grid

WSNs for Smart Grid - Transmission side



- Real-time monitoring and securing of the transmission lines
- Close monitoring in case of lightning, icing, hurricanes, landslides, overheating
- Detecting and locating failure in power lines; and relaying information to control stations

WSNs for Smart Grid - Distribution side

- Real-time monitoring of the distribution segment: substations, power outage
- Substations transform voltage from high to low, or the reverse. Substation failure consequences can be very severe
- Xcel Energy is the first power company to use UAV/drones to inspect substations in 2015

Xcel Energy: https://www.xcelenergy.com/

MORE CONSIDERATIONS…

Microgrid

"A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode."

- US. Department of Energy definition

Plain Language: in many respects, microgrids are smaller versions of the traditional power grid.

Q: Why do we need microgrid?

- **Easy integration of local renewable energy into the grid**
- **Increased local control, reliability and security of power**

Microgrids can help neighborhoods keep the lights on in an extreme weather situation like Hurricane Sandy.

Super storm Sandy Black Out in Lower Manhattan

Electric Vehicles (EV)

Charging Station

In Electric Vehicles system, information exchange is required between EVs, charging stations and billing and management systems.

Q: what communication technology can be used for this requirement?

Power line communication can be a solution, utilizing installed power lines, providing strong security and enabling large scalability

References

- Department of Energy, “The Smart Grid: An Introduction”, at https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages.pdf

- V.Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, and G. Hancke, "A Survey on Smart Grid Potential Applications and Communication Requirements", IEEE Transactions on Industrial Informatics, vol. 9, no.1, pp.28-42, Feb. 2013.

- Y. Yan, Y. Qian, H. Sharif, and D. Tipper, "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges" IEEE Communications Surveys & Tutorials, vol.15, no.1, 2013