Energy Informatics: overview (II)

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Learning Objectives

Throughout this lecture, it is aimed for the students to be able to

- **Learn the basic concepts in smart grid**
- **Learn 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**

Invited Talk by World-leading Scientist Today

- **Speaker**: Øystein Ulleberg, *Principal Scientist / Forskningsleder, Institute for Energy Technology (IFE); Associate Professor, University of Oslo*

- **Title**: Renewable Energy Basics

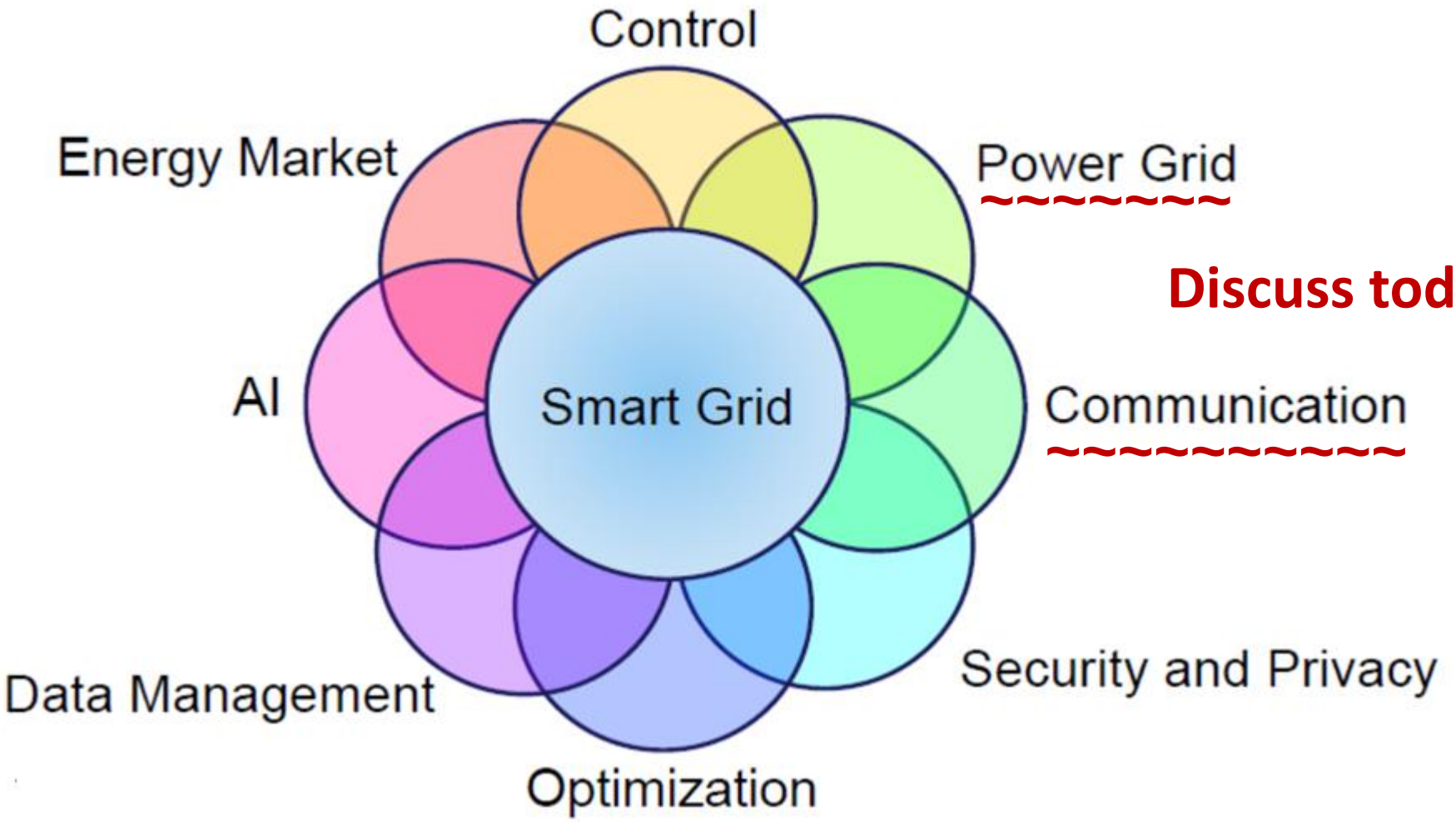
- **IFE (Institute of Energy)**: IFE was founded in 1948, and is an internationally leading research institute in Norway.

Outline

Smart Grid

ICT for Smart Grid

Smart grid: an interdisciplinary field



We have seen power systems everyday

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

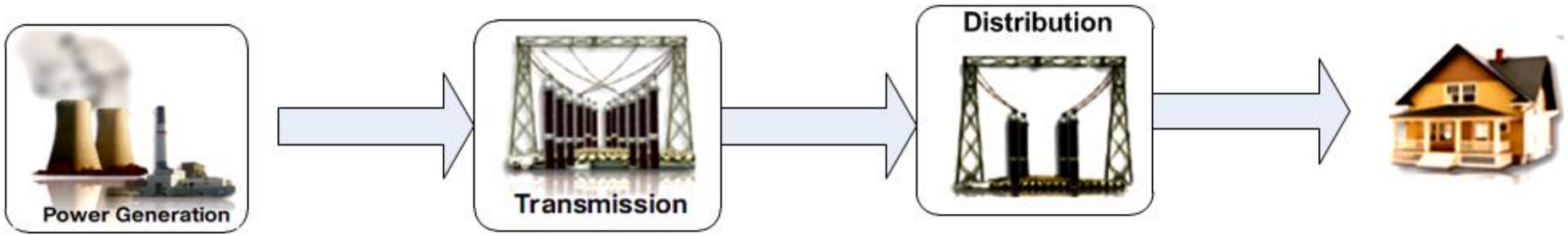
- High-voltage power transmission

- 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



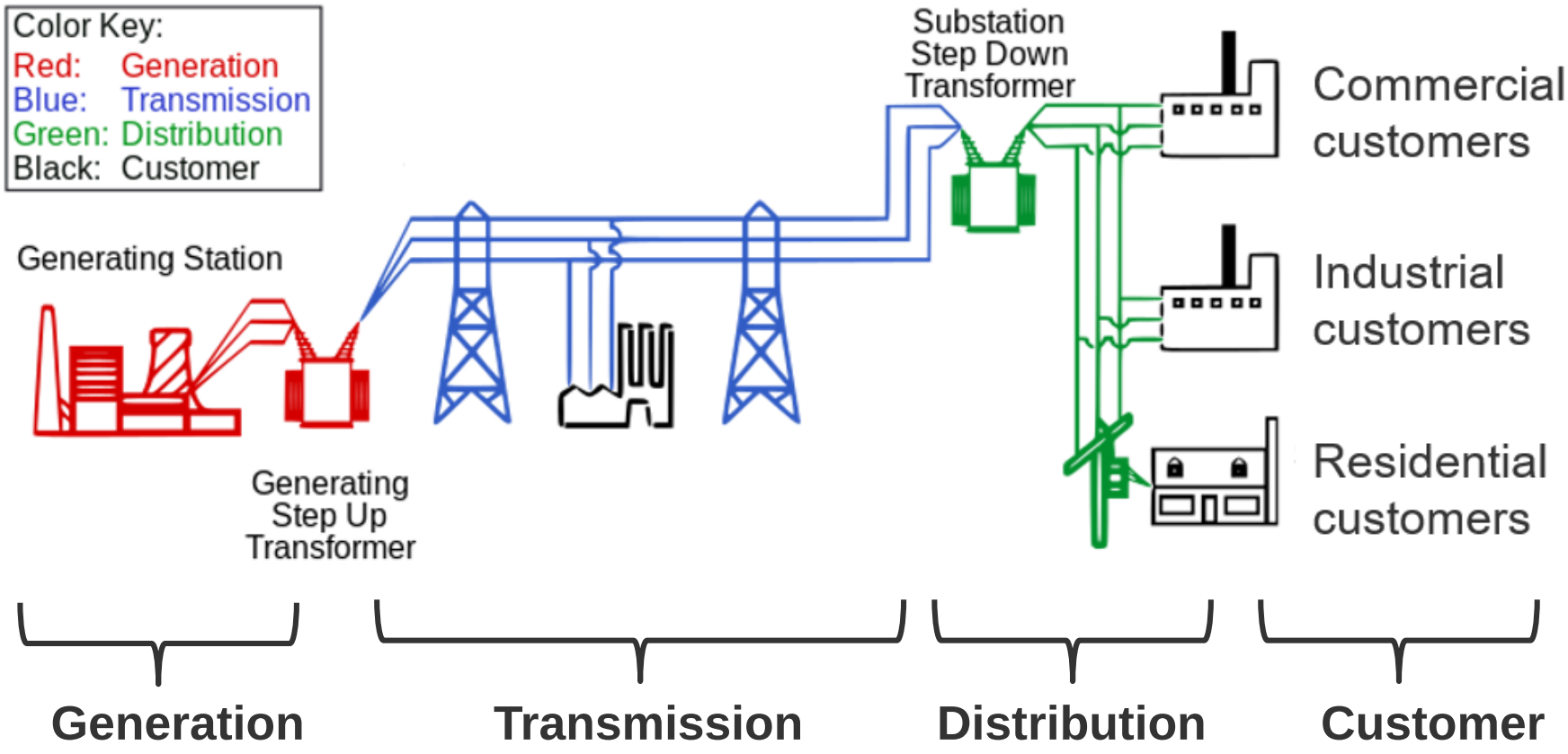
One-way Flow of Electricity and Information

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



Many different power generation sources

- Power plants

- Renewable energy sources
  - Wind farm
  - Solar

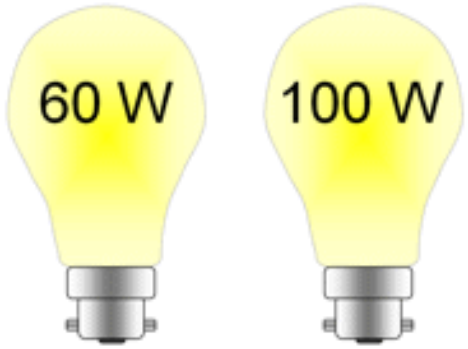
- Hydropower

99% of all power production in Norway comes from hydropower

- Q: which source produces most power in Norway?

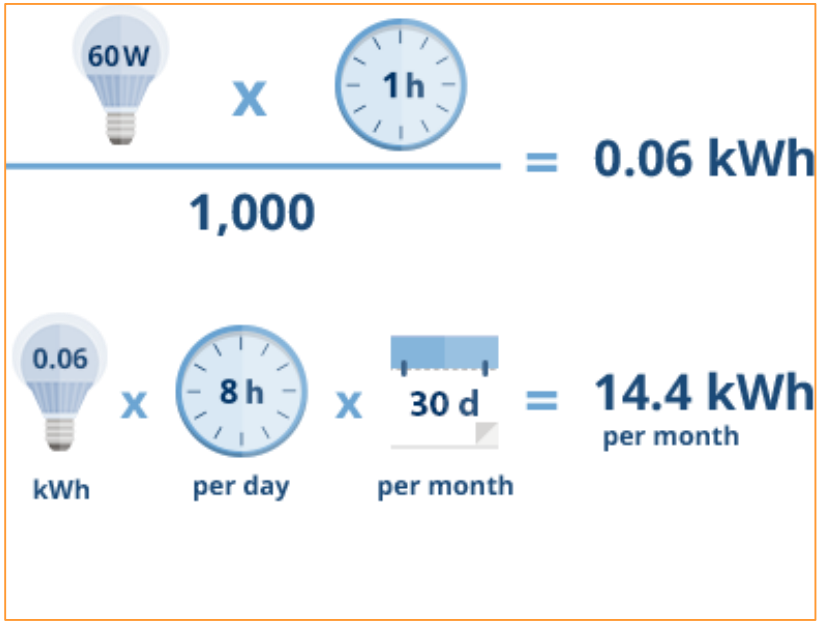
Concept: Power

- **Power: Instantaneous rate of consumption of energy, 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

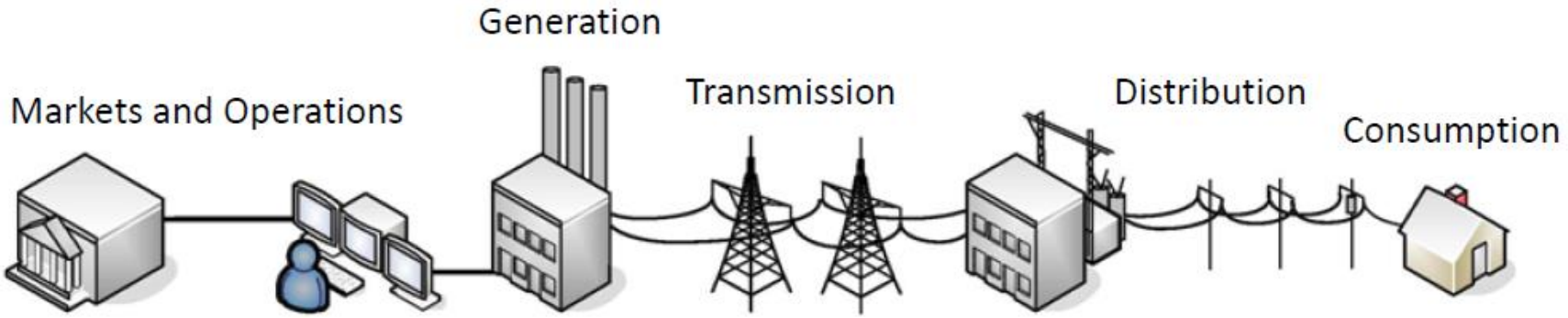
- Energy Consumption = Power * Time:
  - Energy is what people really want from a power system,
  - How much work you accomplish over time.
- Energy Units:
  - Joule= 1 watt-second (J)
  - kWh=kilowatt-hour = 1000watt * 3600sec = 3.6 x 10^6 J



- Annual electric energy consumption in Norway in 2015 is about 213TWh
- Q: 213 TWh=? Joule

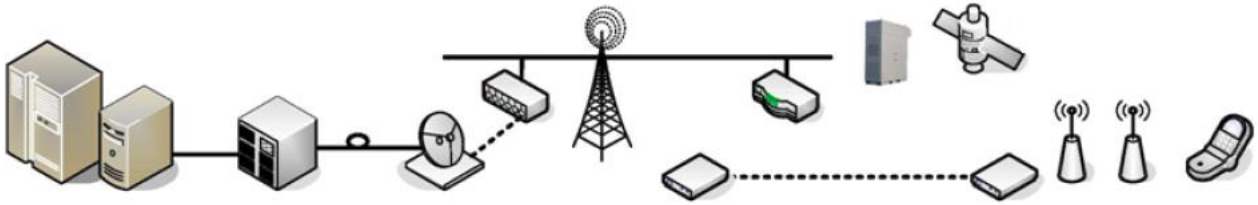
213 TWh = 213 x 10^9kWh
= 213 x 10^9 x 3.6 x 10^6J
= 7.668 x 10^{17}J

Smart Grid = Power Grid + ICT (Information & Communications Technology)



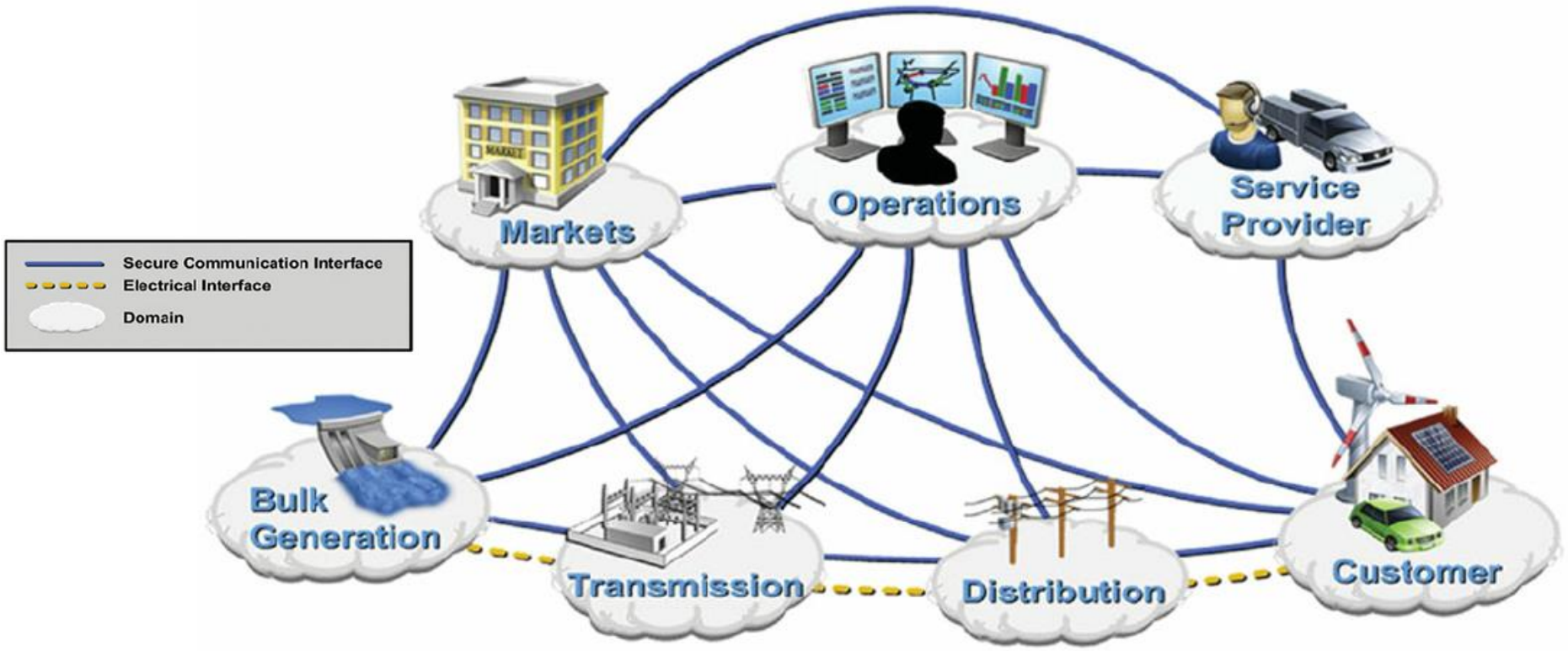
Power infrastructure

Two way flow of electricity and data



Communications infrastructure

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



- **Interaction in 7 Smart Grid domains through information flows and energy flows.**
- **Each domain involves its own actors and applications**

NIST Conceptual Model for Smart Grid

Customers:

- The end users of electricity
- Normally, we have three types of customer, each with its own domain: 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 providing service to both utilities and electrical consumers
- Internet service providers, charging stations operators,…

Operation

- The manager of the movement of electricity
- Independent System Operators (ISOs) or Regional Transmission Organization (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 attack
- Dynamic: dynamic pricing and load control
- Reliable: higher reliability of services
- Communication and control infrastructure network to augment power grid operations

Smart Grid needs Computation, Networking, Communications, and Control

ICT FOR SMART GRID

Smart Grid needs communications and networking technologies

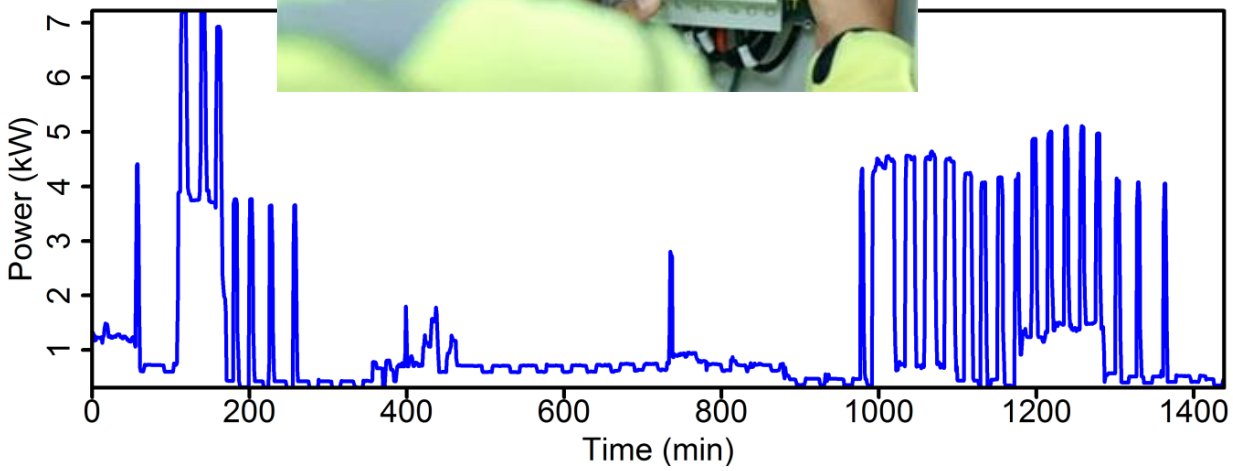
- Smart metering and Advanced Metering Infrastructure(AMI)
- Distributed generation and renewable energy integration
- Power outage detection
- Real-time monitoring, diagnostics and protection
- Big data generated by massive number of sensors, meters, and telemetry
- Further analysis control, real time pricing
- Communications network support intelligent energy scheduling

Old electricity meters → Smart Meters

Analogue, Manual, annually or monthly

Digital,Bidirectional communication

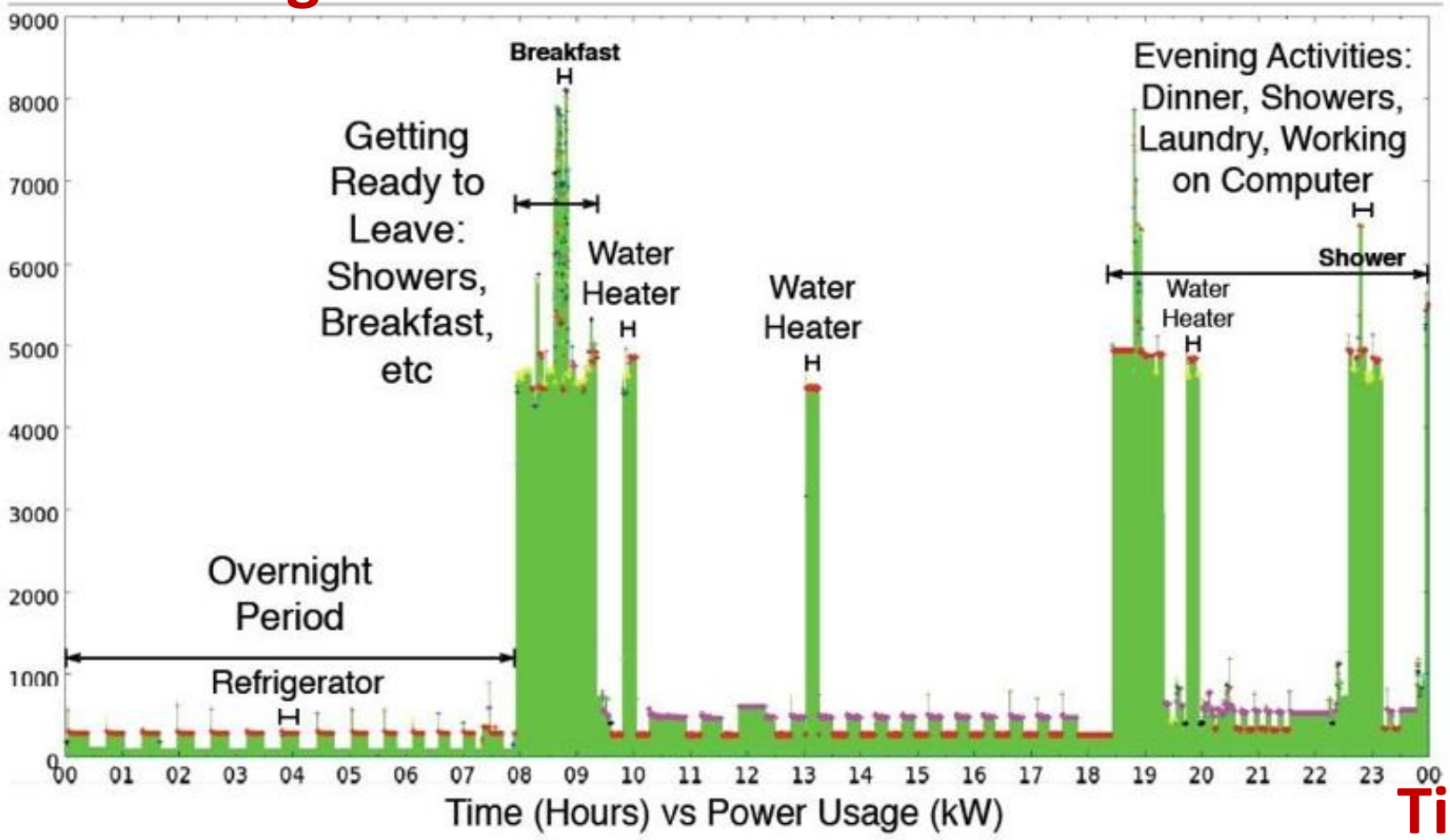
Hafslund Nett



- **Q:** any consequence if smart meters know all energy consumption data?

Smart Meter Privacy Issues

Power Usage



Time

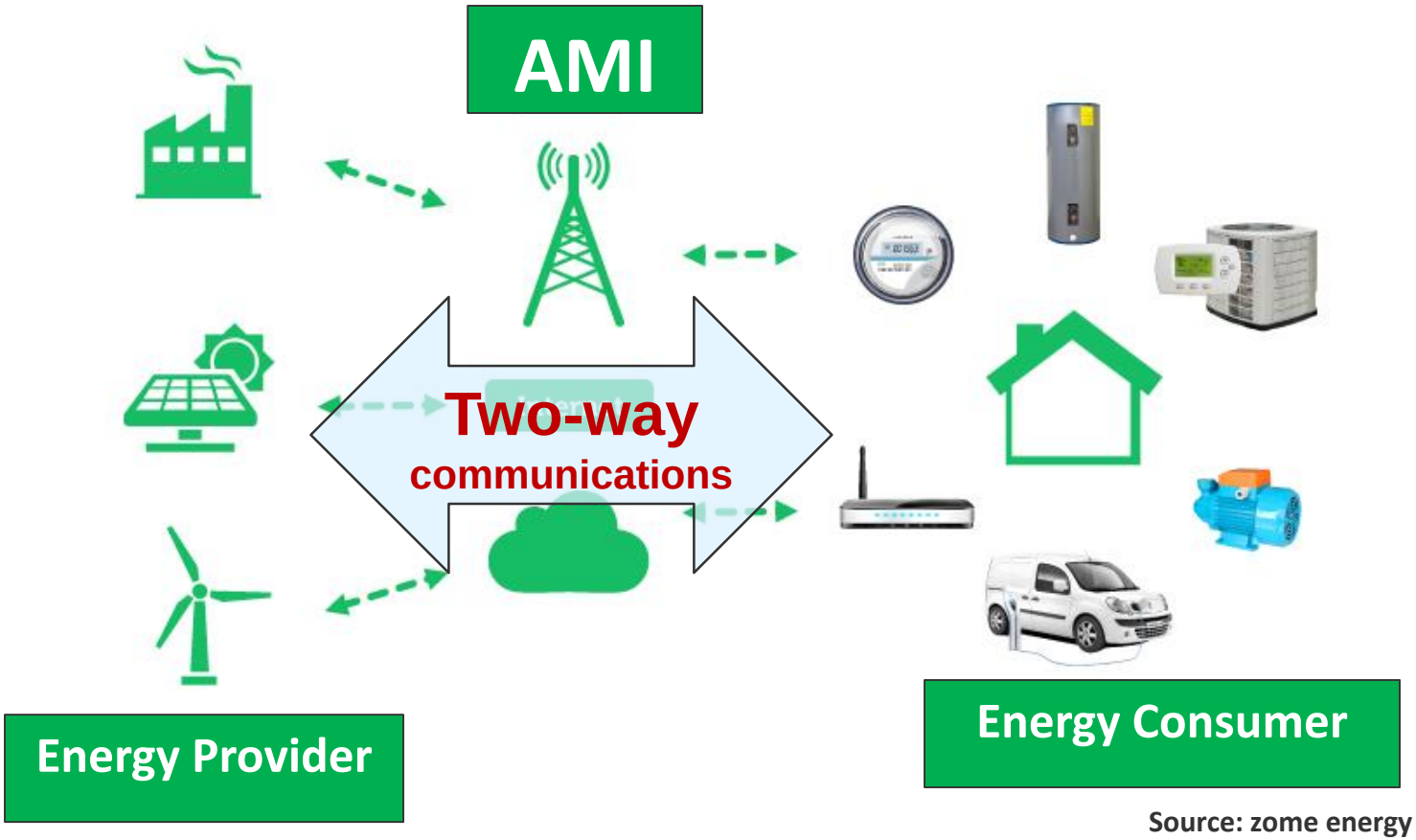
Molina-Markham A, Shenoy P, Fu K, Cecchet E, Irwin D. “Private memoirs of a smart meter”, BuildSys 2010.

Smart Meter Functions

- Smart meters perform 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): is Norwegian energy market regulator; and has decided that all customers in Norway will receive new smart meters by 1 January 2019. About 2.5 million meters will be replaced in Norway.

https://www.nve.no/energy-market-and-regulation/retail-market/smart-metering-ams/

Advanced Metering Infrastructure (AMI)



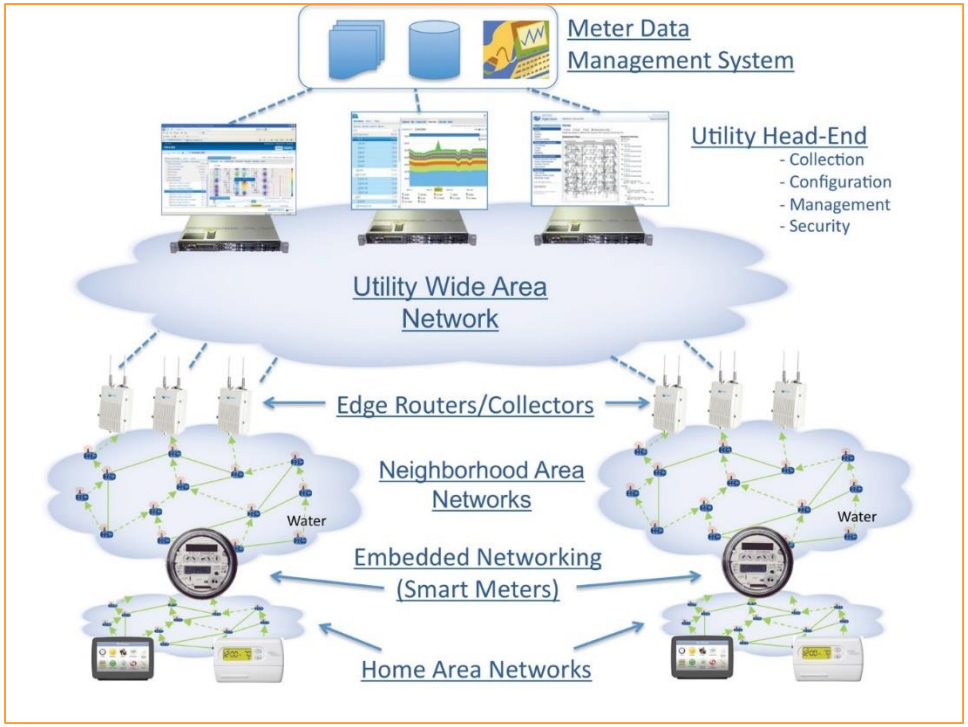
Source: zome energy networks

- 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:

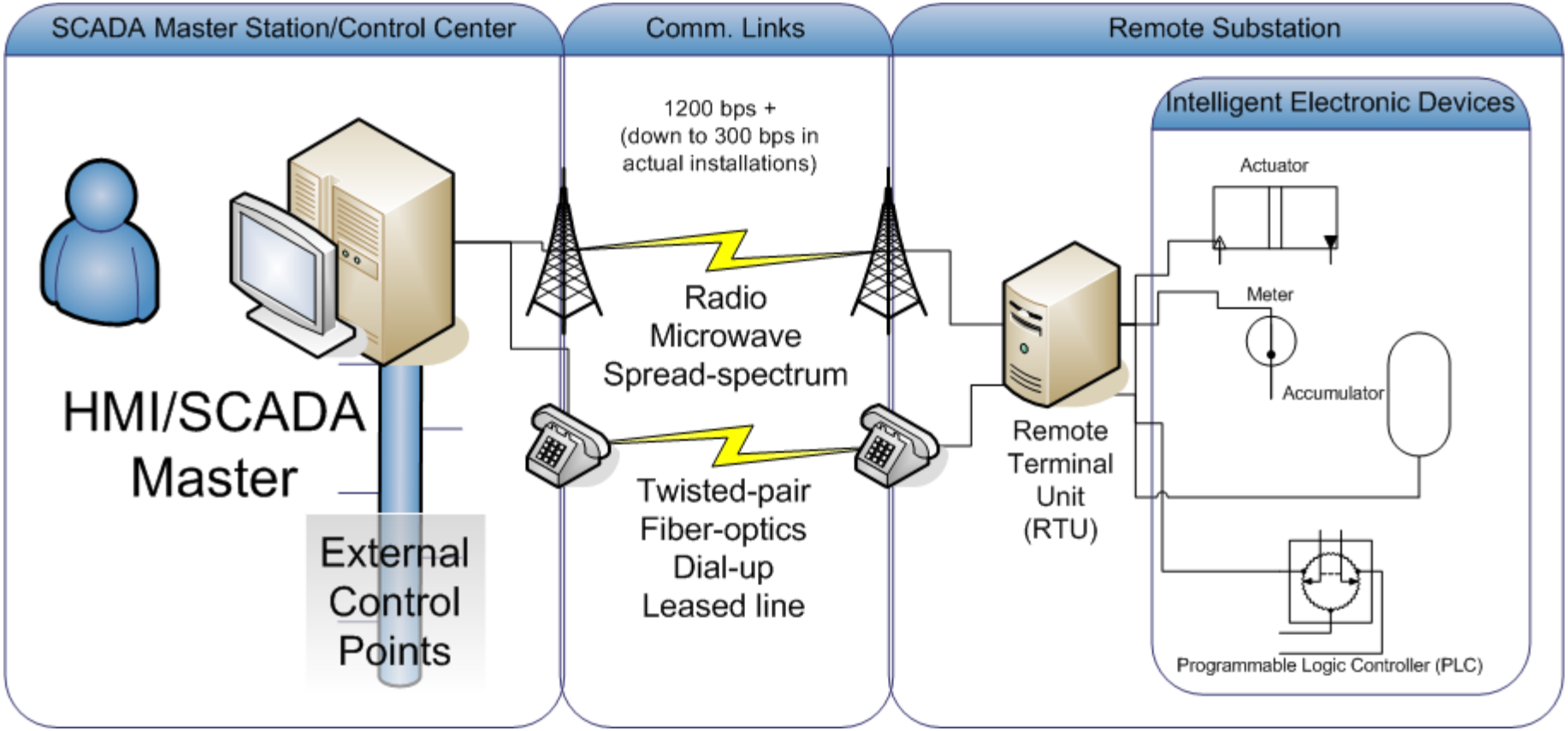
- **Smart meters at the consumer end**
- **Communication networks at different levels of the infrastructure hierarchy to connect two ends**
- **Meter Data Management Systems (MDMS)**
- **Platform integrating the collected data into application at utility provider**



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

Supervisory control and data acquisition (SCADA)

- **SCADA : It commences with measurement of the data in the field of application and collected, then transferring this data to a master station to implement the necessary processing and control algorithms.**

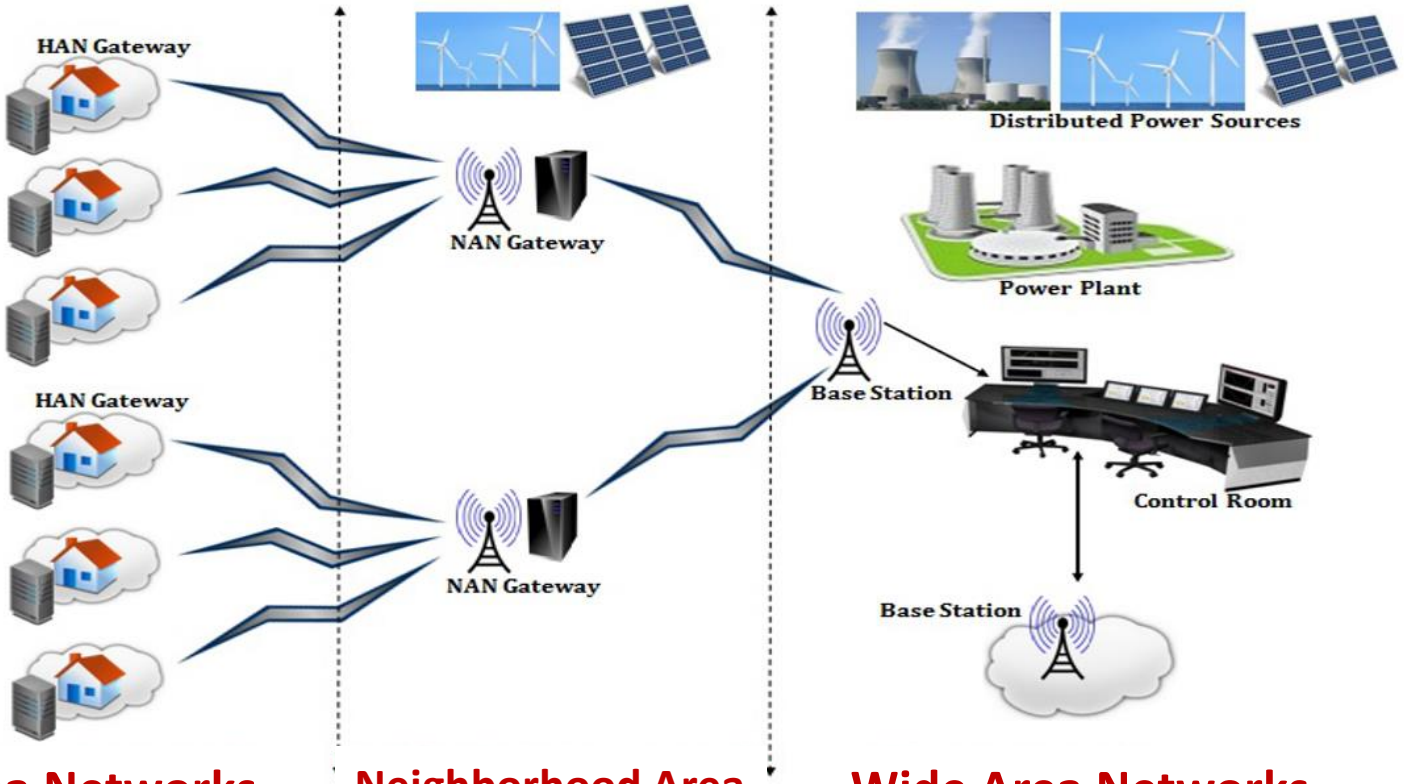


Picture: https://www.electricaltechnology.org/2015/09/scada-systems-for-electrical-distribution.html

Supervisory control and data acquisition (SCADA)

- SCADA systems consist of:
  - RTU (Remote Terminal Unit): conveys signals from sensors to the control centre.
  - 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.

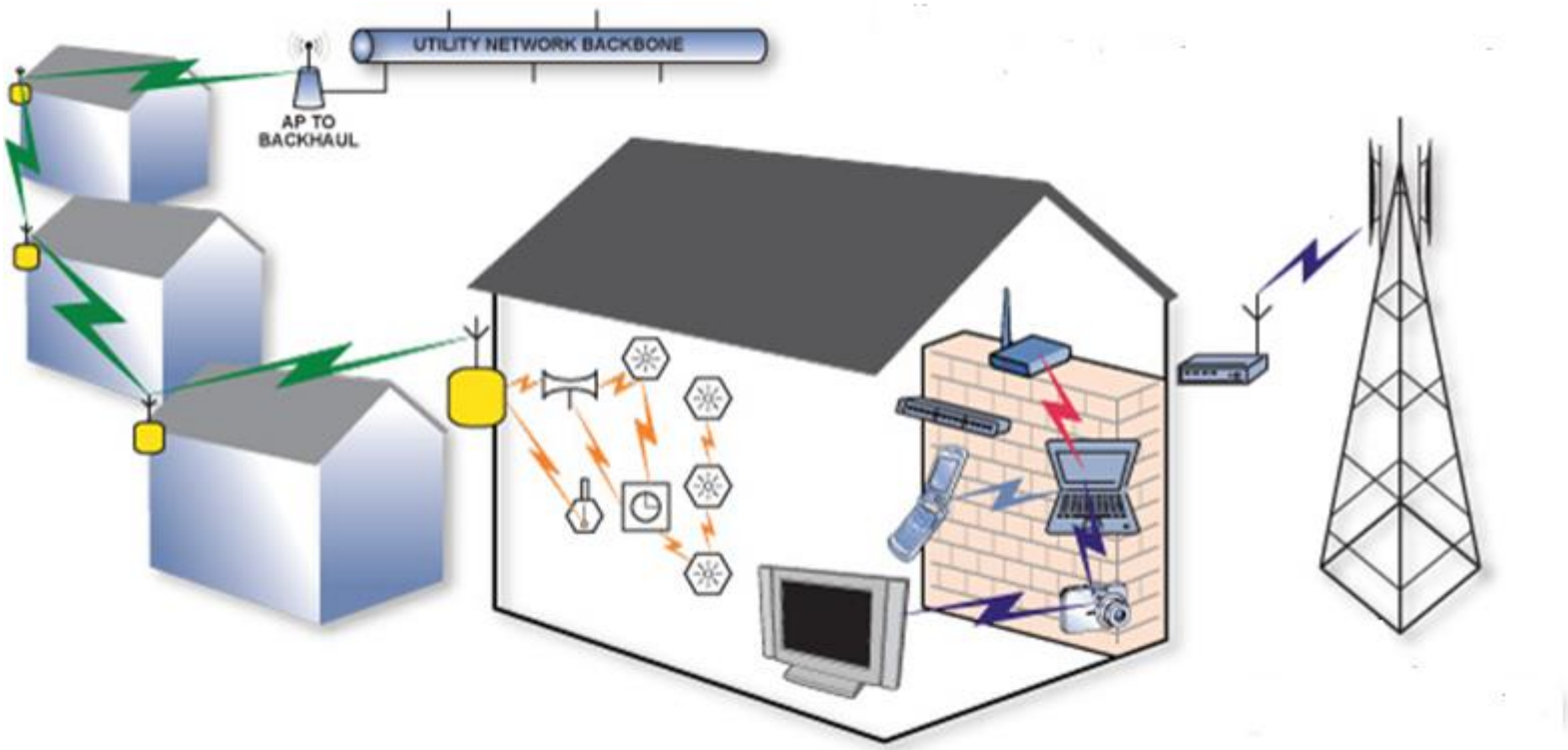
Neighborhood Area Networks

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

Wide Area Networks

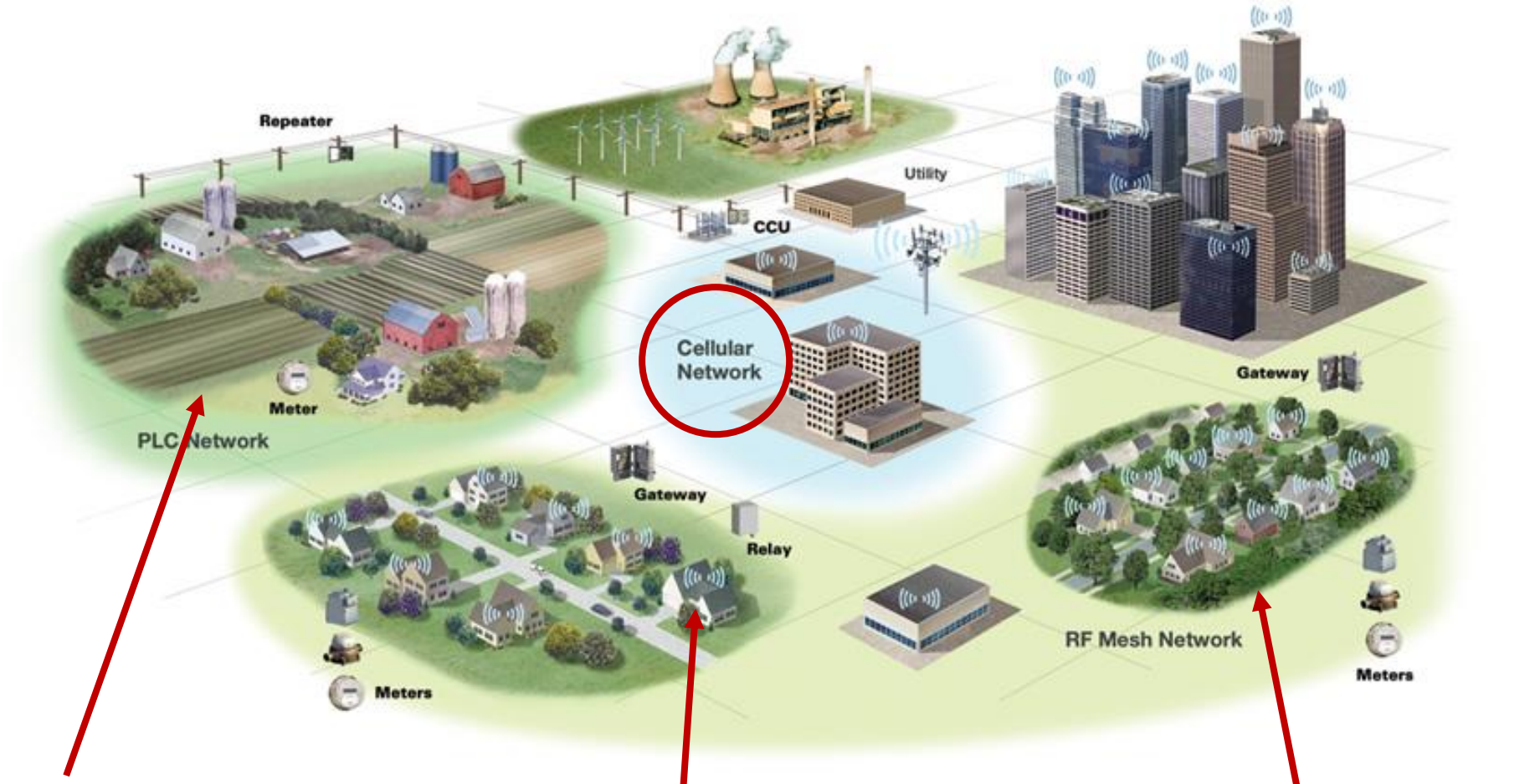
WAN: between the NANs and the utility systems to transfer information

Home Area Networks (HAN)



- HAN: gathers sensor information from a variety of devices within the home, send 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

Different communication technologies

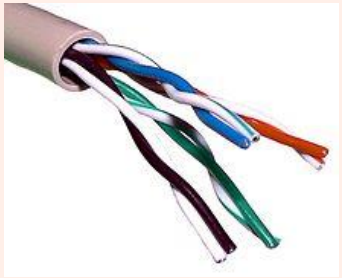


Powerline Communication (PLC)

Wireless Sensor Networks using Zigbee

Mesh Networks

Technologies comparison in home area networks

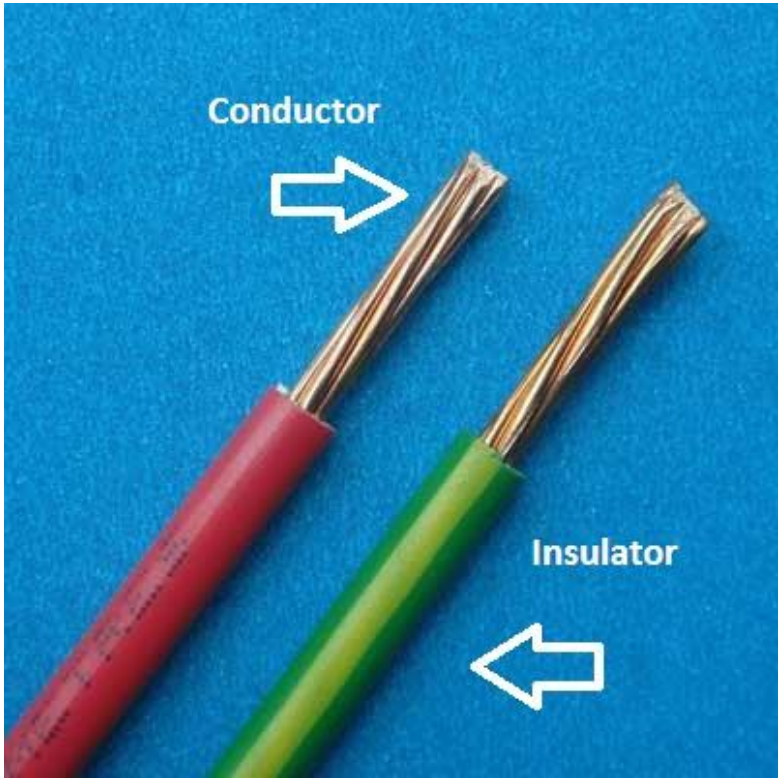
Technology	Data Rates	Coverage	Medium	Band Licensed
PLC	1-200Mbps	1500m	Power cable	Free
Ethernet	100Mpbs	100m	UTP (unshielded twisted pair) cable 	Free
WiFi	5-100Mpbs	30-100m	Wireless	Free
Zigbee	0.02-0.2Mbps	10-75m	Wireless	free

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.

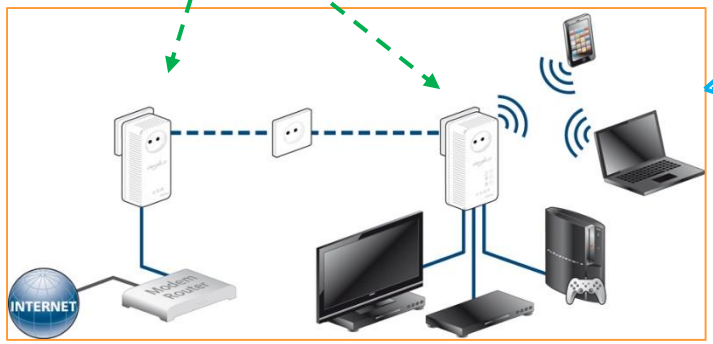
- PLC is a wired communications technology, it can compete with wireless technologies with low cost since the infrastructure already exists



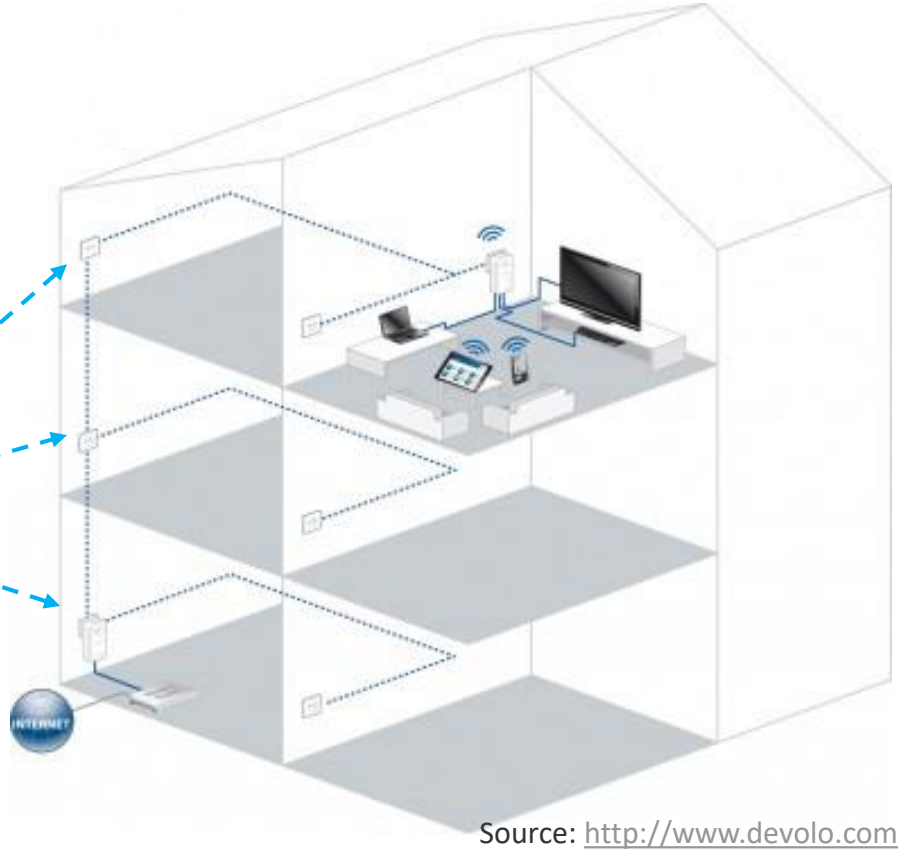
An example of PLC at home

- 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

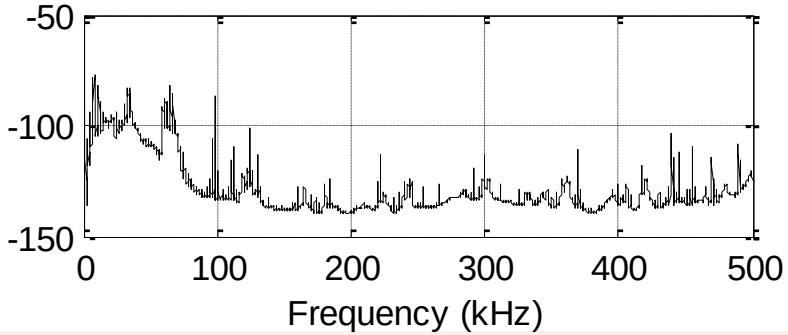


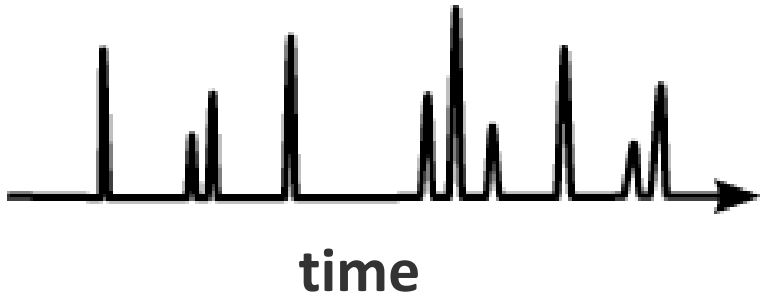
Source: http://www.devolo.com

PLC for Home Area Networks

Main challenge: powerline noise

Background Noise	Random Noise



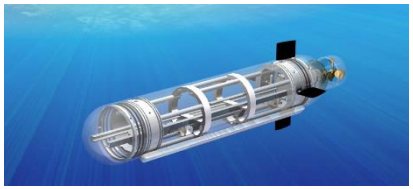


Challenge: harsh medium for data communication and unpredictable and varying characteristics: time, frequency, and location. Need to reduce sensitivity to the electrical noise present on power lines: signal attenuation, signal distortion and noise.

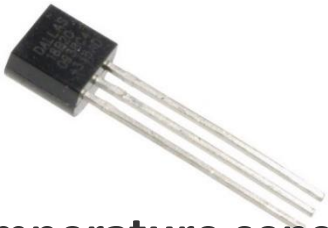
Consequence: the great amount of noise on the line limits practical transmission speed. Light dimmers and kitchen appliances are examples of noise sources that affect the performance of a power line-based home network.

Sensors

Sound sensor



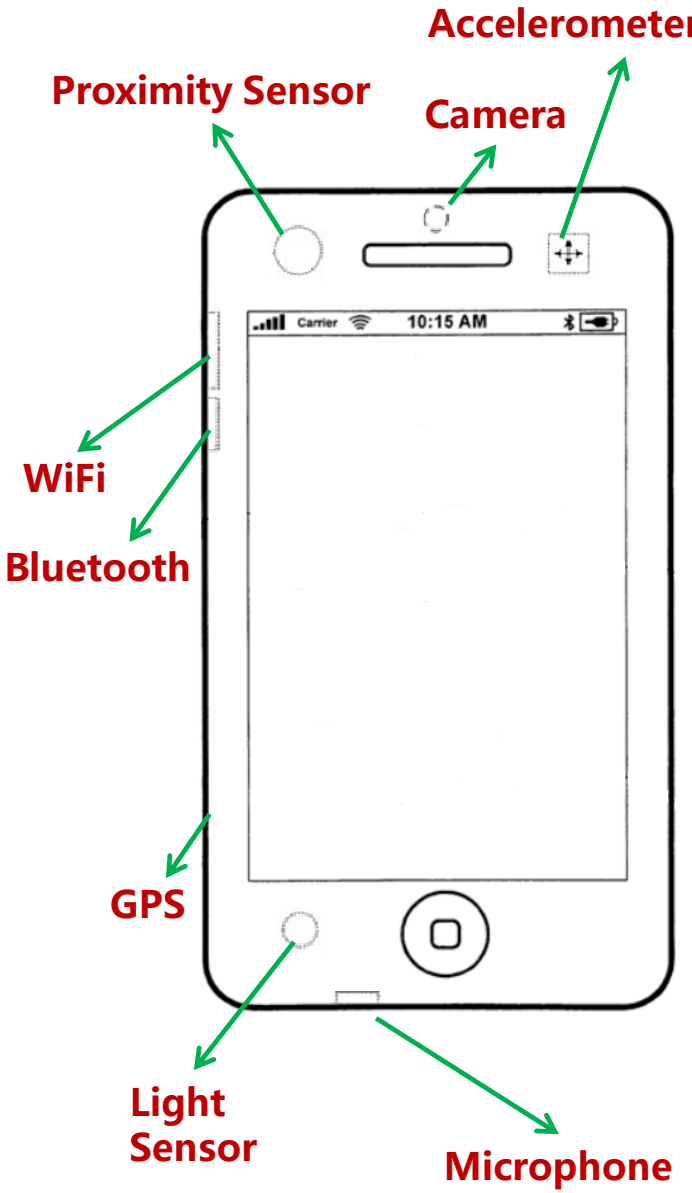
Underwater sensor



Temperature sensor

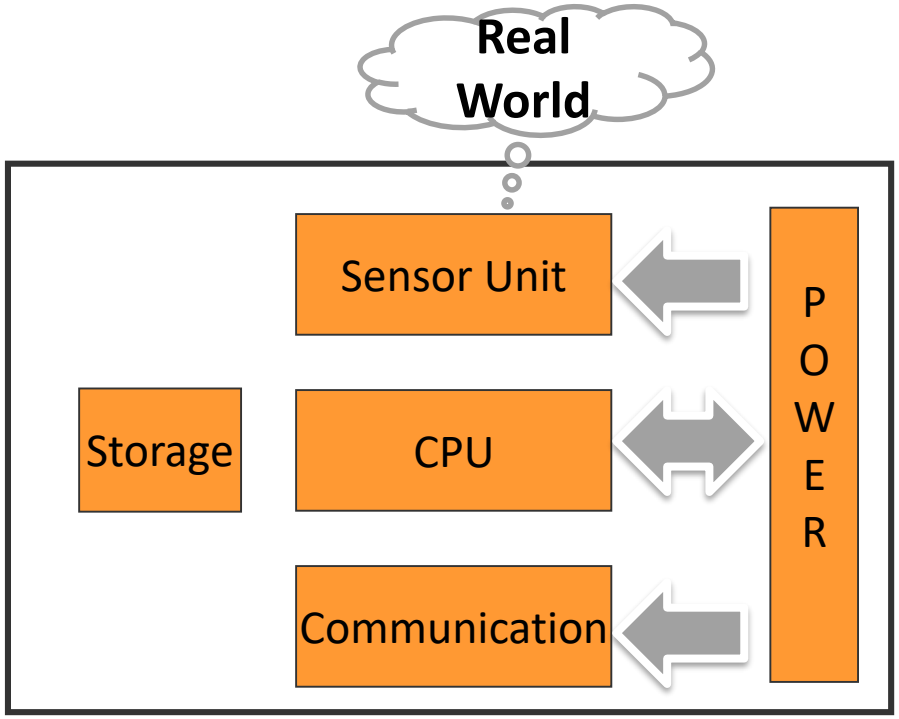
Pressure sensor

Sensor with solar panel



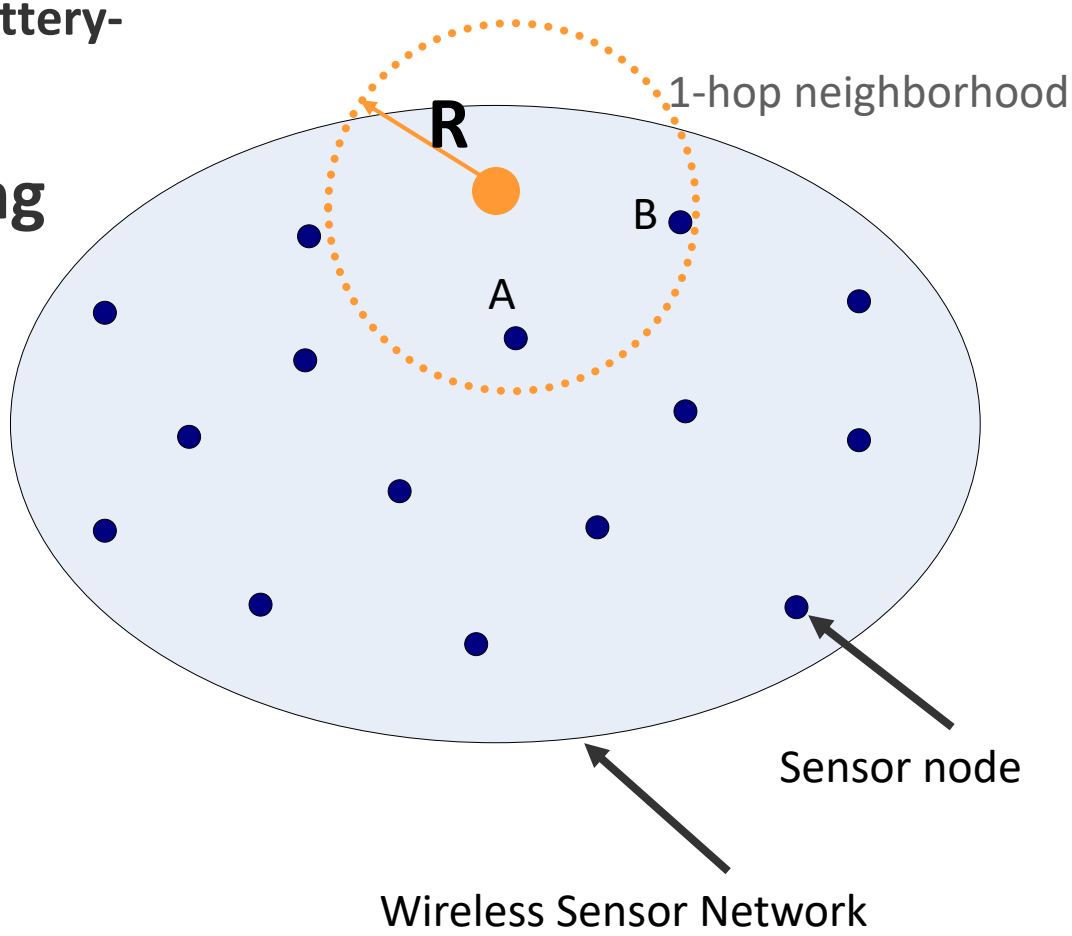
Sensor Nodes Model

- 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.



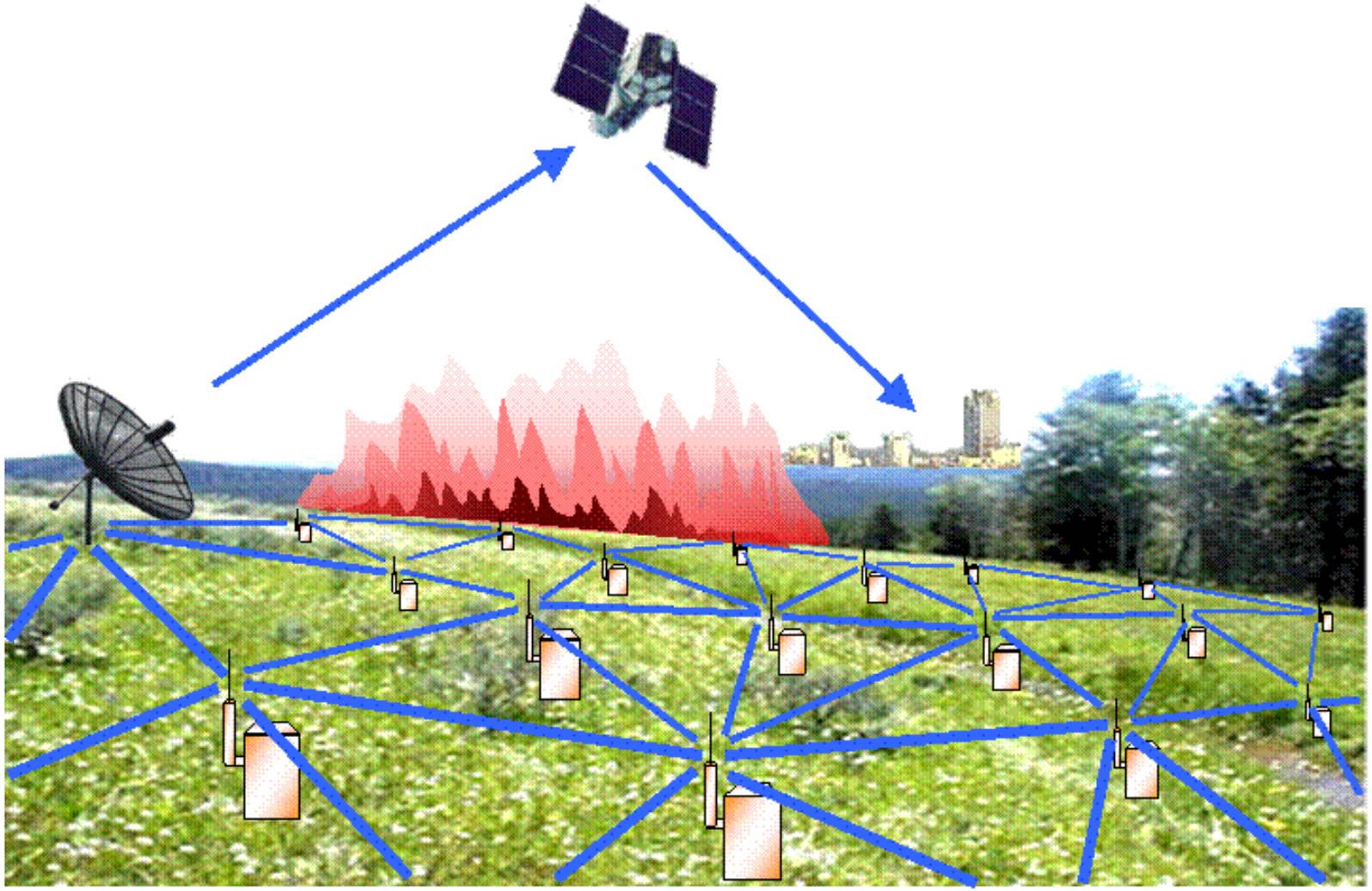
Wireless Sensor Networks

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

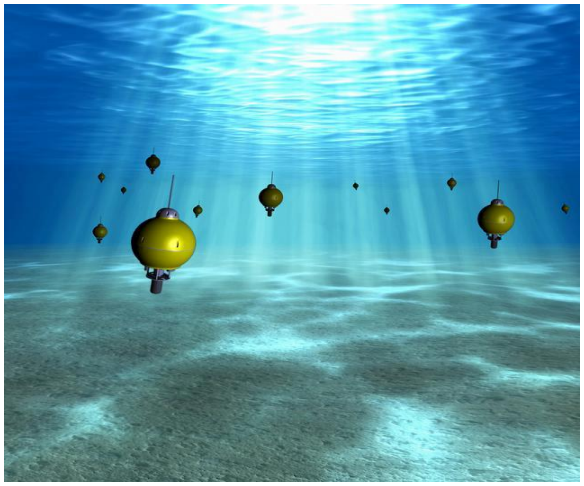


- R: transmission range
- *V*: the set of sensor nodes

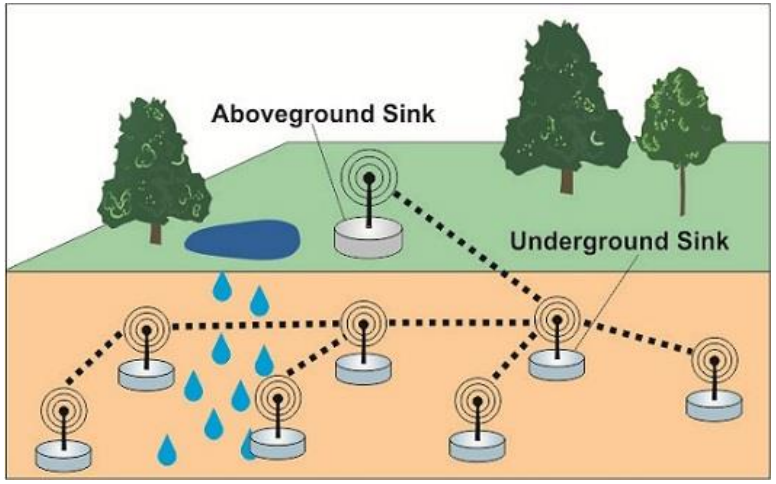
Typical application and system architecture: forest fire detection



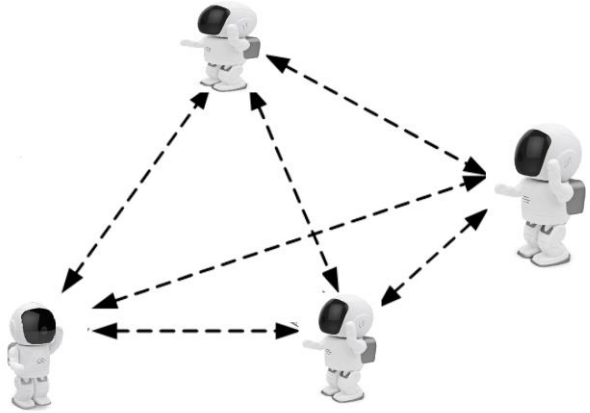
Different Types of Sensor Networks



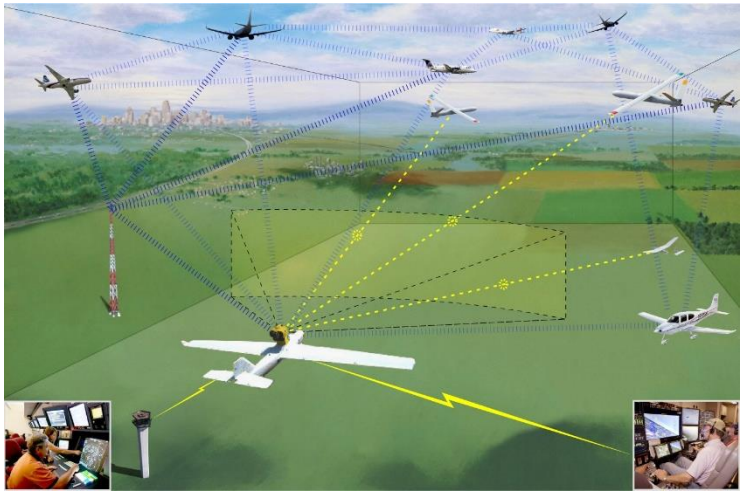
Underwater **Sensor Networks**



Underground **Sensor Networks**



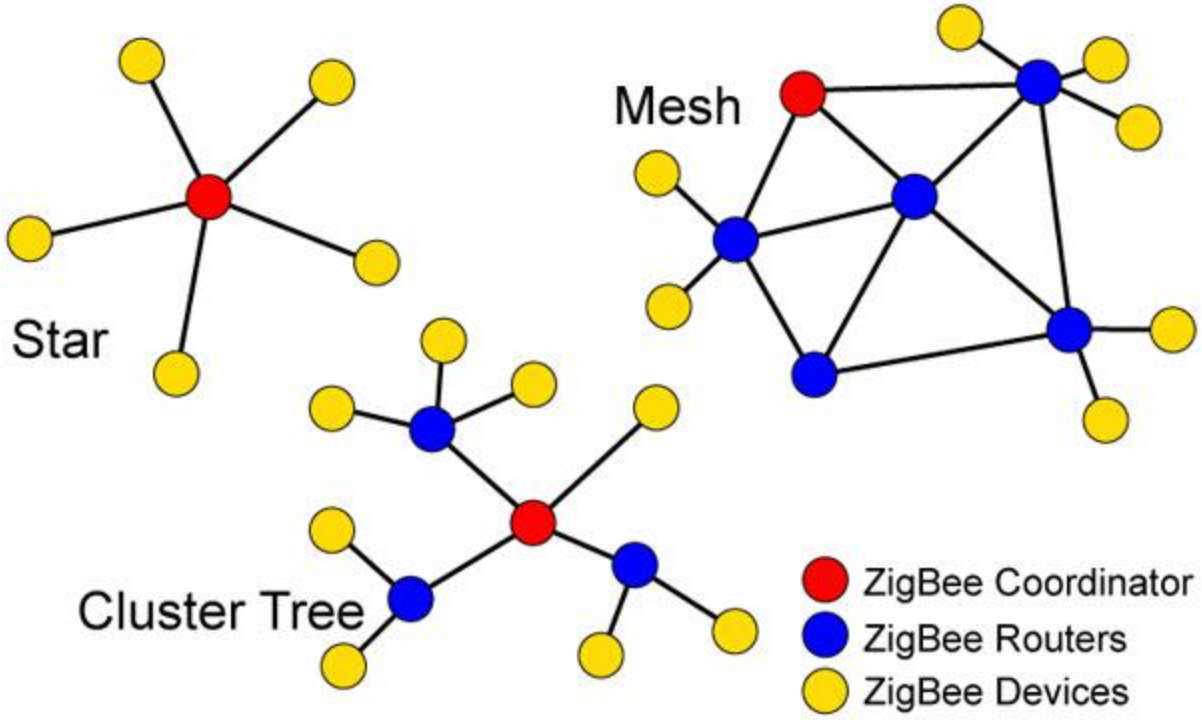
Mobile **Robot Networks**



UAV (Unmanned Aerial Vehicles)/Drones

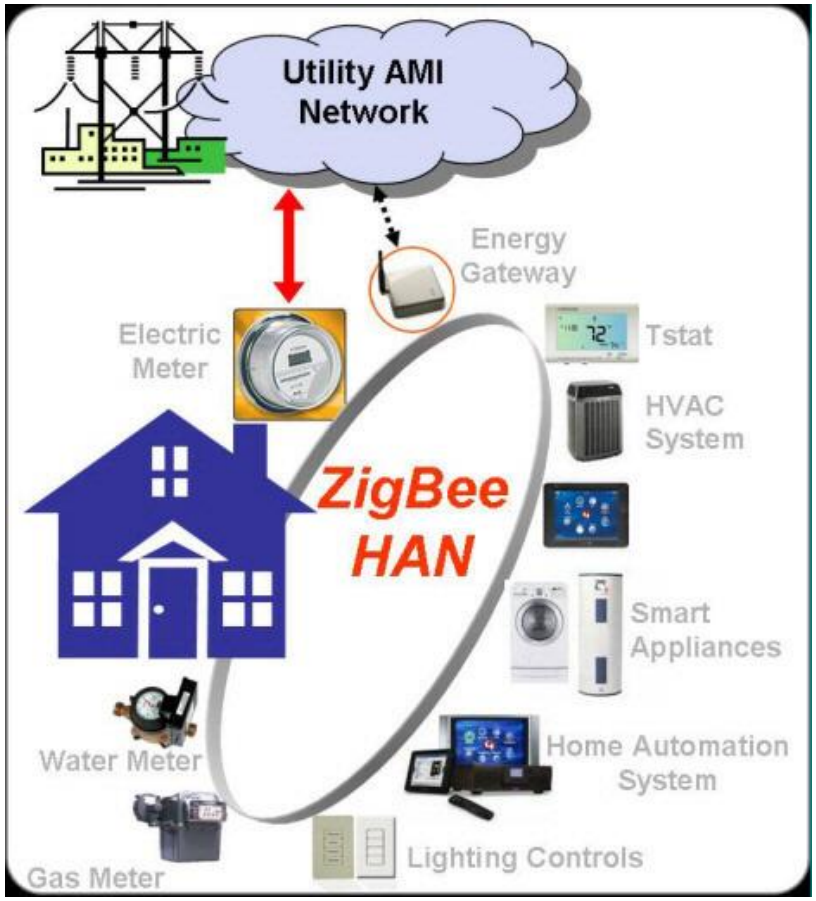
IEEE 802.15.4 - Zigbee

- Zigbee is a short-range, low-data rate, energy-efficient wireless protocol, supporting star, tree, mesh topology and suitable for WSN
- Zigbee utilizes 16 channels in the 2.4GHz ISM band worldwide. It supports data rate of 250kbps, 100kbps, 40kbps, and 20kbps.

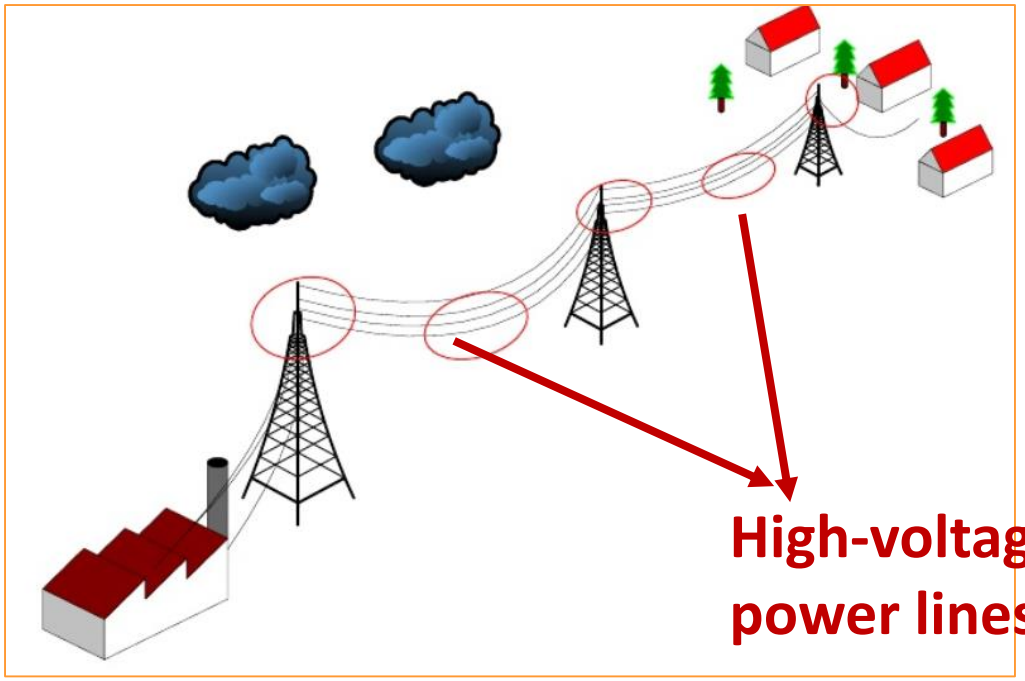


Zigbee for Smart Energy at Home

- 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
- Challenges: limited battery energy supply, memory and processing power



WSNs for Smart Grid - Transmission side

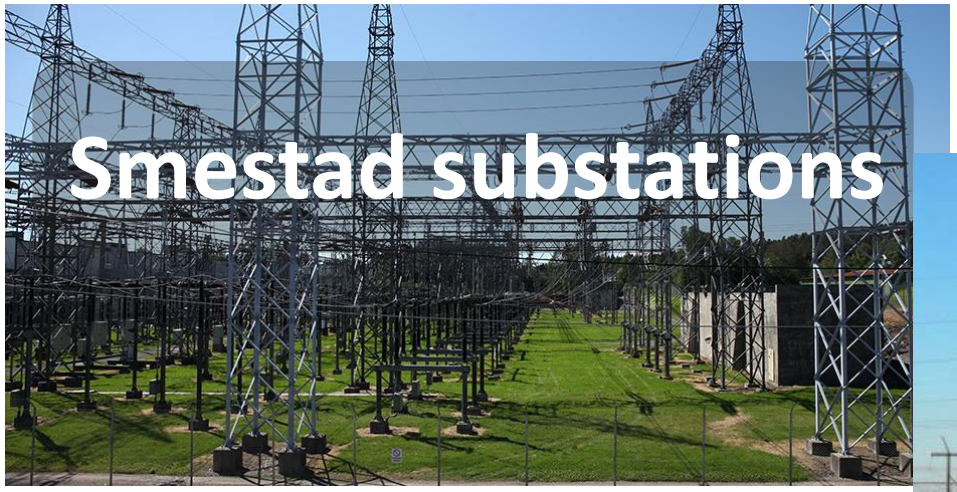


- Real-time monitoring and securing of the transmission lines
- Close monitoring in case of lightning, icing, hurricanes, land slides, overheating
- Locate failure of power lines; and detect failure and relay information to control stations

WSNs for Smart Grid: power generation side

- WSNs provide 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 - Distribution side



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

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 shall we need microgrid?

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

Microgrids could 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, there are information exchange requirements between EV, 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

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