wMNLab NTPUCSIE

Chapter 8: Smart Grid Communication and Networking

Prof. **Yuh-Shyan Chen**

Department of Computer Science and Information Engineering

National Taipei University

國立臺北大學 資訊工程學系

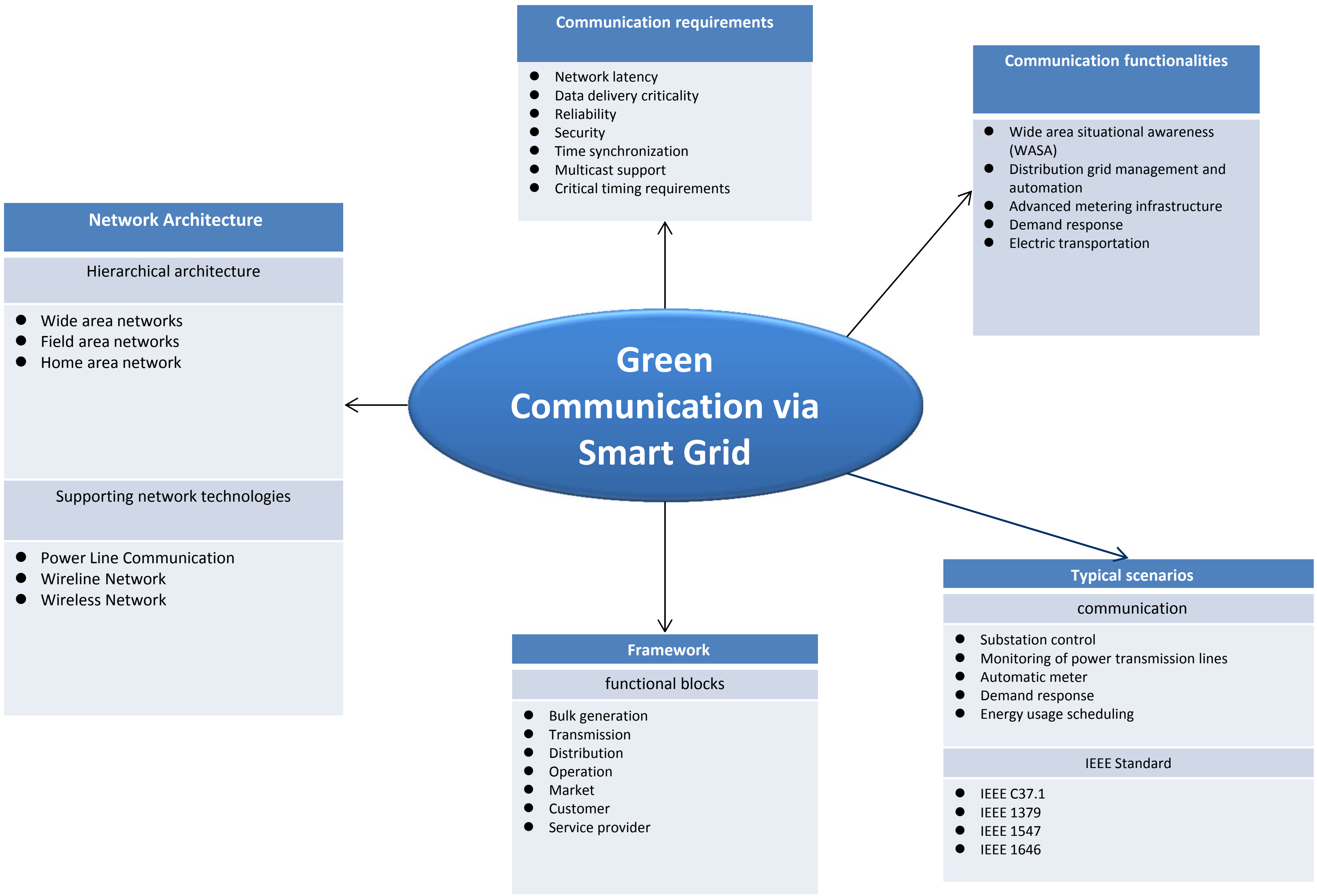
NTPU, Department of Computer Science and Information Engineering

Outline

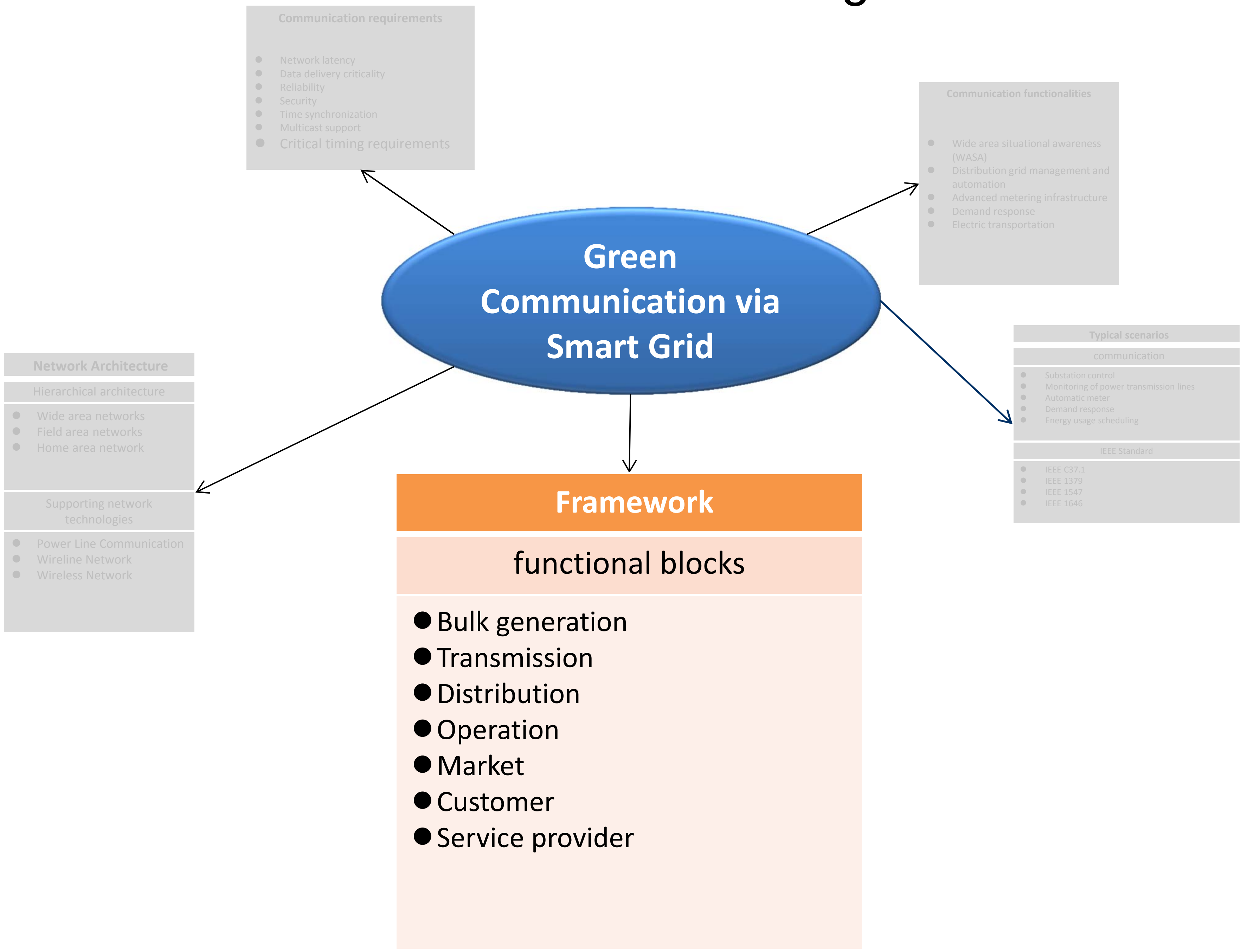
1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

wMNLab NTPU CSIE

Smart Grid Communication and Network



1. The framework of smart grid



Outline

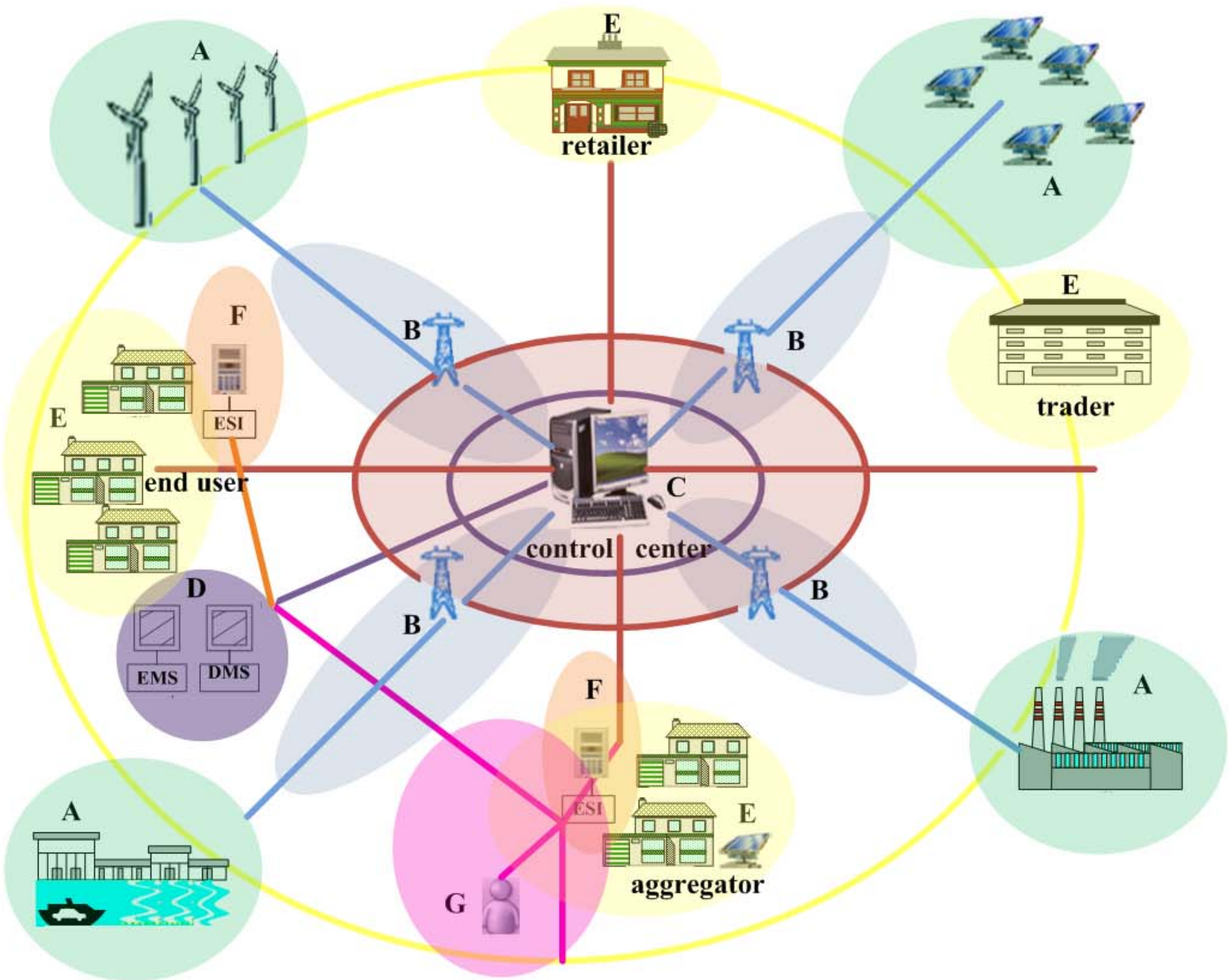
1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

wMNLab NTPU CSIE

1. The framework of smart grid

- In the smart grid, many distributed renewable energy sources will be connected into the power transmission and distribution systems as integral components.
- This system consists of seven functional blocks which are, namely, bulk generation, transmission, distribution, operation, market, customer, and service provider.

Figure 1. The framework of smart grid



A is bulk generation domain

B is transmission domain

C is distribution domain

D is operation domain

E is market domain

F is service provider domain

G is customer domain

Acronyms in smart grid.

Acronym	Definition
AMI	Automatic metering infrastructure
AMR	Automatic meter reading
BAS	Building automation system
DER	Distributed energy resource
DLC	Direct load control
DMS	Distribution management system
DR	Demand response
EMS	Energy management system
ESI	Energy services interface
GPS	Global positioning system
IED	Intelligent electronic device
IEM	Intelligent energy management
IFM	Intelligent fault management
IHD	In-home display
ISO	Independent system operator

Acronyms in smart grid.

LMS	Load management system
MDMS	Metering data management system
OMS	Outage management system
PEV	Plug-in electric vehicle
PLC	Power line communication
PMU	Phasor measurement unit
PTP	Precision time protocol
RTO	Regional transmission operator
RTP	Real Time Pricing
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
STNP	Simple time network protocol
WACS	Wide area control system
WAMS	Wide area monitoring system
WAPS	Wide area protection system
WASA	Wide area situational awareness

Bulk generation

- The bulk generation
  - It may store electricity to manage the variability of renewable resources such that the surplus electricity generated at times of resource richness can be stored up for **redistribution** at times of resource scarcity.
- **Communication**
  - The bulk generation domain is connected to the **transmission** domain. It also communicates with the market domain through a market services interface over Internet and with the operations domain over the wide area network (WAN).

Transmission

- The transmission domain
  - The generated electricity is transmitted to the distribution domain via multiple substations and transmission lines. The transmission is typically operated and managed by a **regional transmission operator** (RTO) or an **independent system operator** (ISO).

    The RTO is responsible for maintaining the stability of regional transmission lines by balancing between the demand and supply.
- **Communication**
  - A lot of information will be captured from the grid and sent to the control centers.
  - The control centers will also send responses to the devices in remote substations.
  - The **bidirectional communications** between control centers and substations are handled in the transmission domain too.

Distribution

- Distribution
  - This domain includes distribution feeders and transformers to supply electricity. It interacts with many different equipment, such as **distributed energy resource** (DERs), **plug in electric vehicles** (PEVs), **automatic metering infrastructure** (AMI), and **sensors** with communication capability.
  - It takes the responsibility of delivering electricity to energy consumers according to the user demands and the energy availability.
  - The dispatch of electricity to end users in the customer domain is implemented by making use of the electrical and communication infrastructures that connect the transmission, operator and customer domains

Operation

- Operation
  - This domain maintains efficient and optimal operations of the transmission and distribution domains using an **energy management system** (EMS) in the transmission domain and a **distribution management system** (DMS) in the distribution domain.
  - It uses field area and wide area networks in the transmission and distribution domains to obtain information of the power system activities like monitoring, control, fault management, maintenance, analysis and metering.
  - The information is obtained using the **supervisory control and data acquisition** (SCADA) systems.

Market

- Market domain
  - The balance between the supply and the demand of electricity is maintained by the market domain
- The consist of market
  - **Retailers**
    - They supply electricity to end users.
  - **Traders**
    - They buy electricity from suppliers of bulk electricity and sell it to retailers.
  - **Aggregators**
    - They combine smaller DER resources for sale.

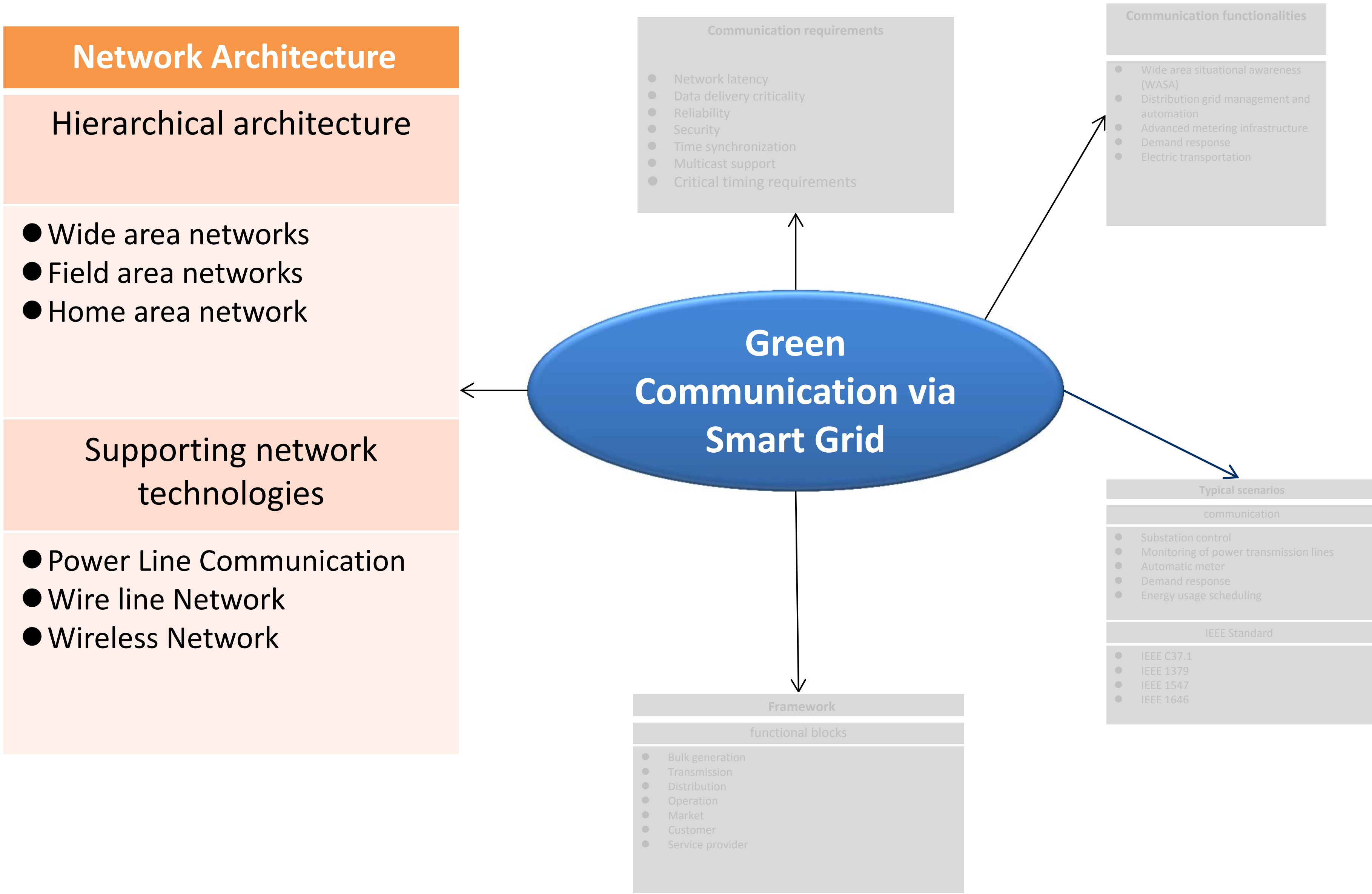
Customer

- Customers domain
  - Customers consume, generate (using **DERs** (**Distributed Energy Resources**), or store electricity.
  - To allow customers to actively participate in the grid, a two-way communication interface between the customer premises and the distribution domain in required. This is generally referred to as an **ESI** (**Energy Services Interface**) and is present at the customer premises
- **Communication**
  - A communication network within the customer premises is required to allow exchange of data and control commands between the utility and the smart customer devices. This network is referred to as a home area network.
  - It is electrically connected to the distribution domain and communicates with the distribution, operation, service provider and market domains.

Service provider

- Service providers
  - They manage services like billing and customer account management for utility companies, and provide electricity to customers and utilities.
- **Communication**
  - It communicates with the operation domain to get the metering information and for situational awareness and system control.
  - It must also communicate with HANs in the customer domain through the **energy service interface** (ESI) interface to provide smart services like **management of energy uses** and **home energy generation**.

2. Network Architecture



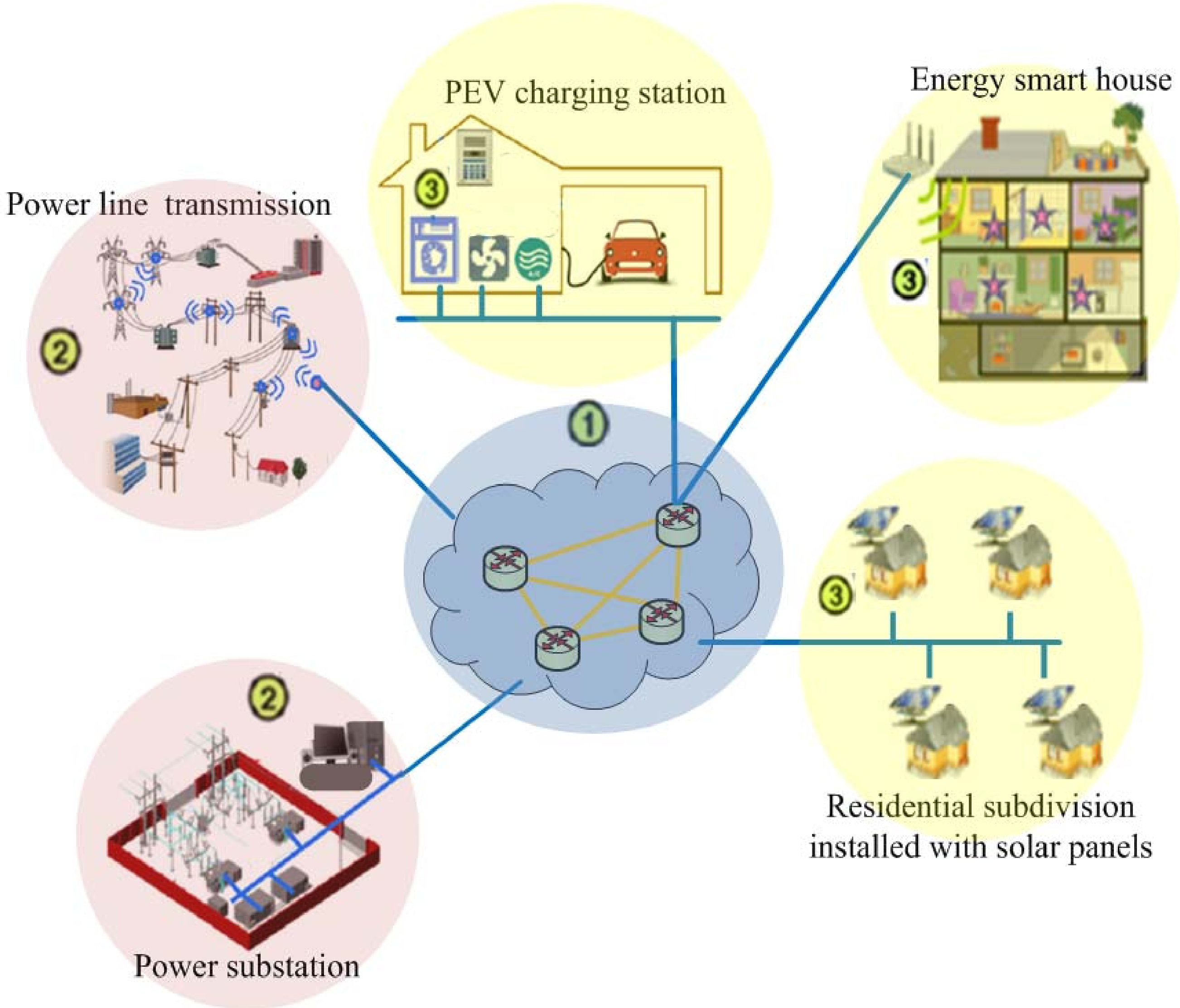
Outline

1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

2. Network architecture

- It is constructed in a hierarchical architecture with interconnected individual subnetworks and each taking responsibility of separate geographical regions
- The communication networks can be categorized into three classes : wide area networks, field area networks, and home area networks.

Figure 2. (1) Wide area networks (2) Filed area networks (3) Home area network



Wide area networks

- The wide area networks convey communications between the intelligent electronic device (IEDs) and the control centers. The (IEDs) are installed along transmission lines and in substations to capture local SCADA information and act upon the control and protection commands from the control centers.
- The wide area networks undertake the instruction communications from control centers to the electric devices.

Field area networks

- Field area networks form the communication facility for the electricity distribution systems.
- The power system applications operating in the distribution domain utilize field area networks to share and exchange information.

Home area networks

- Home area networks are needed in the customer domain to implement monitoring and control of smart devices in customer premises and to implement new functionalities like demand response (DR) and AMI.
- Within the customer premises, a secure two-way communication interface called energy services interface (ESI) acts as an interface between the utility and the customer.

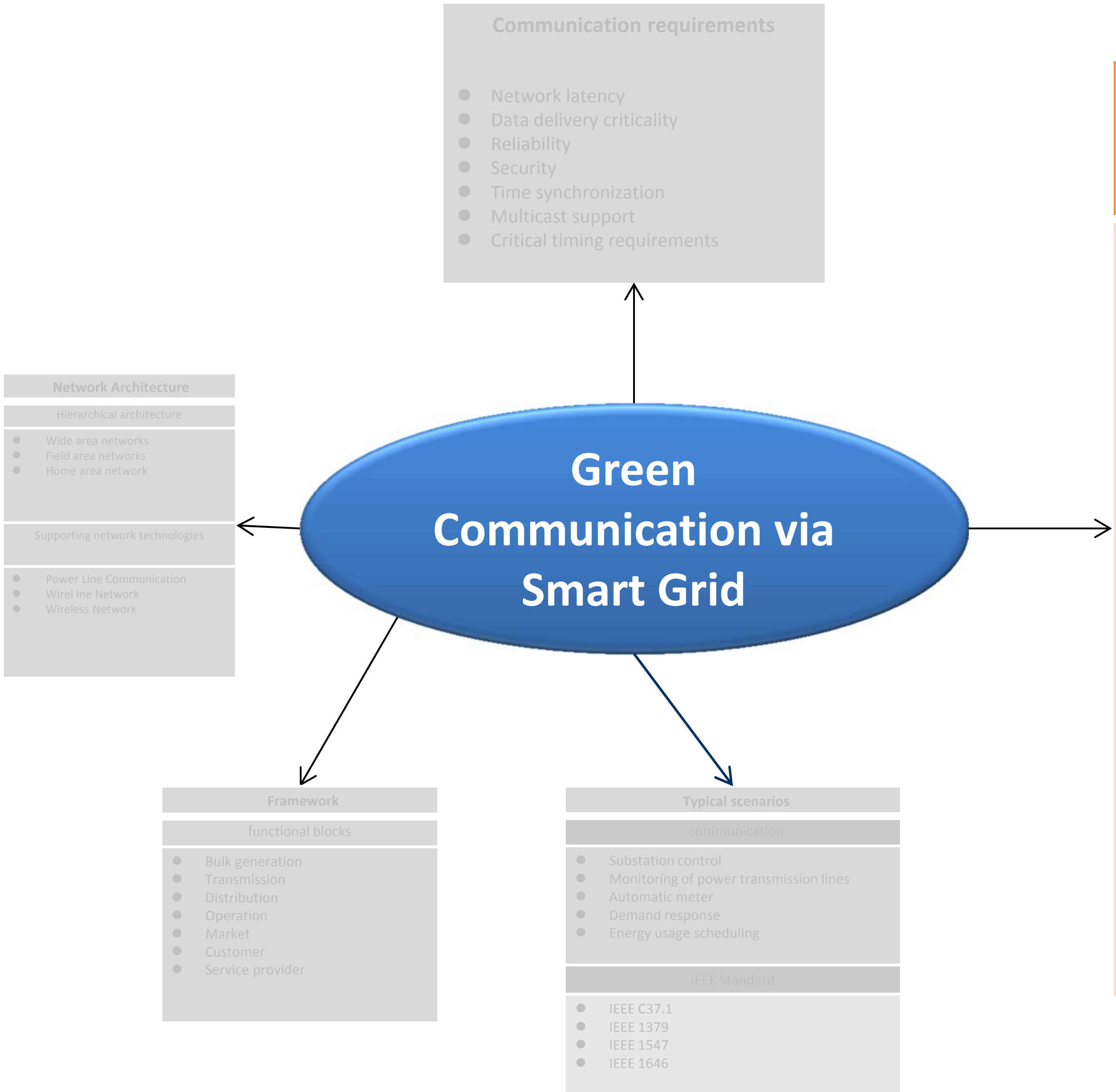
Supporting network technologies

- Power line communication
  - The power lines are mainly used for electrical power transmissions, but they can also be utilized for data transmissions.
  - The power line communication systems operate by sending modulated carrier signals on the power transmission wires.
  - Typically data signals cannot propagate through transformers and hence the power line communication is limited within each line segment between transformers.
  - Data rates on power lines vary from a few hundred of bits per second to millions of bits per second, in a reverse proportional relation to the power line distance.
  - Power line communication is mainly used for **in-door environment** to provide an alternative broadband networking infrastructure without installing dedicated network wires.

Supporting network technologies

- Wire line network
  - Dedicated wire line cables can be used to construct data communication networks that are separate from the electrical power lines.
- Wireless network
  - Advancement in wireless networking technology has enabled us to connect devices in a wireless way, eliminating the installation of wire lines.
  - The 802.11 networks are the most popularly used local area wireless networks. For home area applications and control, IEEE 802.11 WiFi and 802.15 ZigBee networks can be used for convenient and low cost data exchange

3. Communication functionalities



Communication functionalities

- Wide area situational awareness (WASA)
- Distribution grid management and automation
- Advanced metering infrastructure
- Demand response
- Electric transportation

Outline

1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

3. Communication functionalities

- Wide area situational awareness (WASA)
- Distribution grid management and automation
- Advanced metering infrastructure
- Demand response

Wide area situation awareness (WASA)

- The WASA system collects large amount of information about the current state of the power grid over a wide area from electric substations and power transmission lines.
- Using this information, **monitoring** (Wide Area Monitoring Systems – WAMS), **control** (Wide Area Control Systems – WACS) and **protection** (Wide Area Protection Systems – WAPS) functionalities can be implemented.
- The WASA systems use wide area networks in the transmission domain for their operation.

Distribution grid management and automation

- The future power grid will see extensive penetration of active elements (which can act as sources of energy) like DERs into the distribution grid that can exchange energy with the grid in a bidirectional manner.
- The **distribution grid** also needs to support the monitoring of PEVs and consumer based functionality, e.g., automatic metering and demand response systems.
- The **monitoring** process involves gathering of information from distribution feeders, transformers equipped with electrical sensors and communication capability.
- These applications use field area networks in the distribution domain for operation.

Advanced metering infrastructure

- The AMI system provides **a two-way communication** capability for interaction between the utility companies and end customers with smart meters.
- By using AMI, bidirectional communication capability, additional functionalities like the demand response system can be implemented.

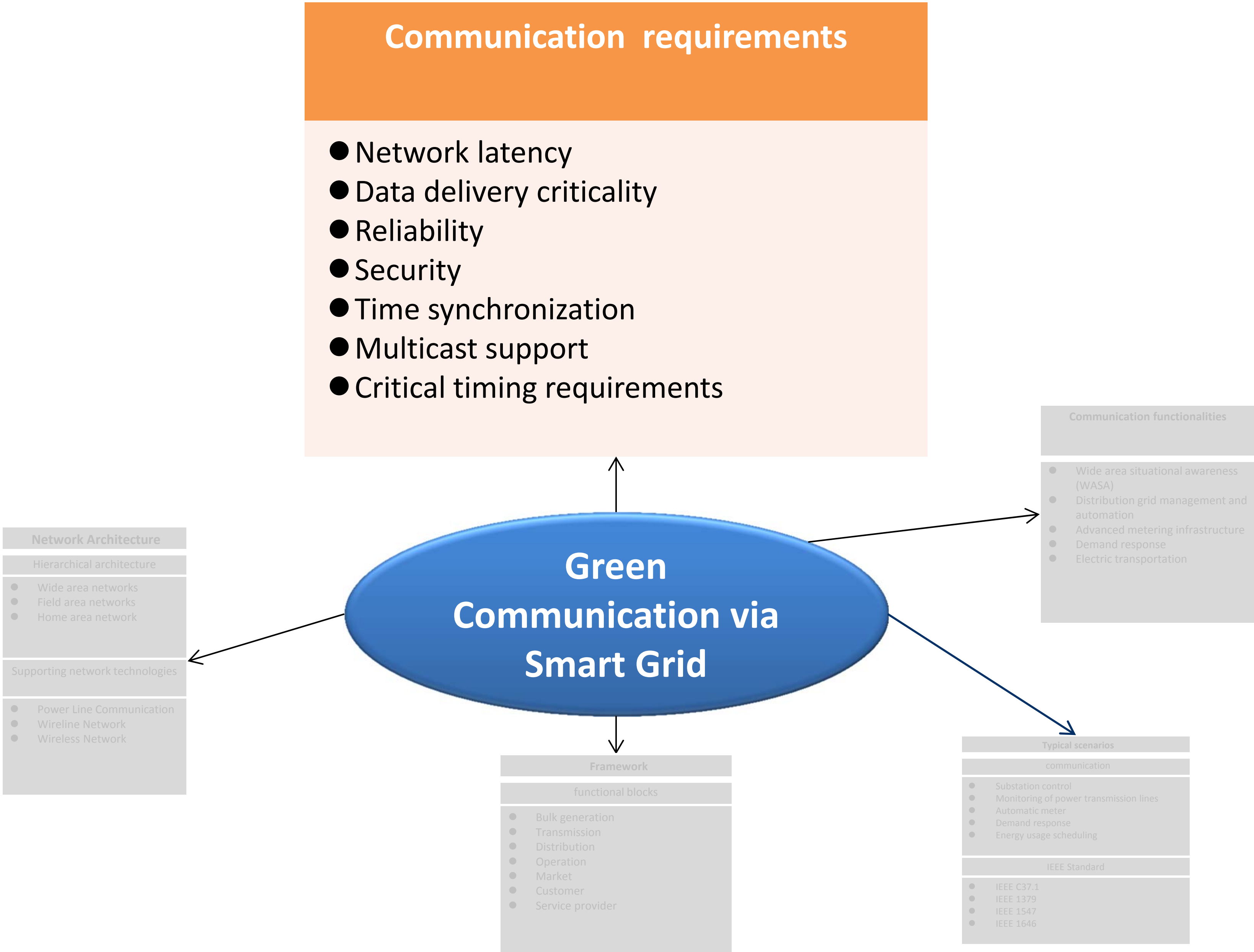
Demand response

- DR systems allow the utility companies to control the peak power conditions on the grid and flatten the consumption curves by shifting consumption times.
- The utility companies can provide **dynamic Real-Time Pricing** (RTP) information to the customers, thereby encouraging them to **shift their usage** to times of lower electricity demand.
- By setting up DERs and energy storage devices at their premises, customers can **sell** the excess electricity back to the utility

Electric transportation

- The PEV (**Plug-in electric vehicle**) batteries can also act as temporary sources of electricity and hence can contribute some electricity to the grid in times of peak demand.
- The applications for electric transportation are required to communicate with the PEVs to monitor their charging processes and send them RTP (**Precision time protocol**) information. It also needs to obtain data from PEVs.

4. Communication requirements



Outline

1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

4. Communication requirements

- Network latency
- Data delivery criticality
- Reliability
- Security
- Time synchronization
- Multicast support
- Critical timing requirements

Network latency

- Network latency defines the maximum time in which a particular message should reach its destination through a communication network.
- The messages communicated between various entities within the power grid, may have different network latency requirements.
  - For example, the protection information and commands exchanged between intelligent electronic devices (IEDs) in a distribution grid will require a lower network latency than the SCADA information messages exchanged between electrical sensors and control centers.

Data delivery criticality

- The following levels of data delivery criticality may be used:
  a) **high** is used where the confirmation of end-to-end data delivery is a must and absence of confirmation is followed by a retry.
     - Ex: SCADA control commands.

  b) **medium** is used where end-to-end confirmation is not required but the receiver is able to detect data loss, e.g., measured current and voltage values and disturbance recorder data.

  c) **non-critical** is used where data loss is acceptable to the receiver. In this case reliability can be improved by repetitive messages. For example, this may be used for periodic data for monitoring purpose.

Reliability

- The communicating devices in the smart grid rely on the communication backbone in their respective domains to send and receive critical messages to maintain the grid stability

Security

- Authorized access to the real time data and control functions, and use of encryption algorithms for wide area communications to prevent spoofing.

Time synchronization

- Some of the devices on power grid need to be synchronized in time. The requirements for time synchronization of a device depend on the criticality of the application.

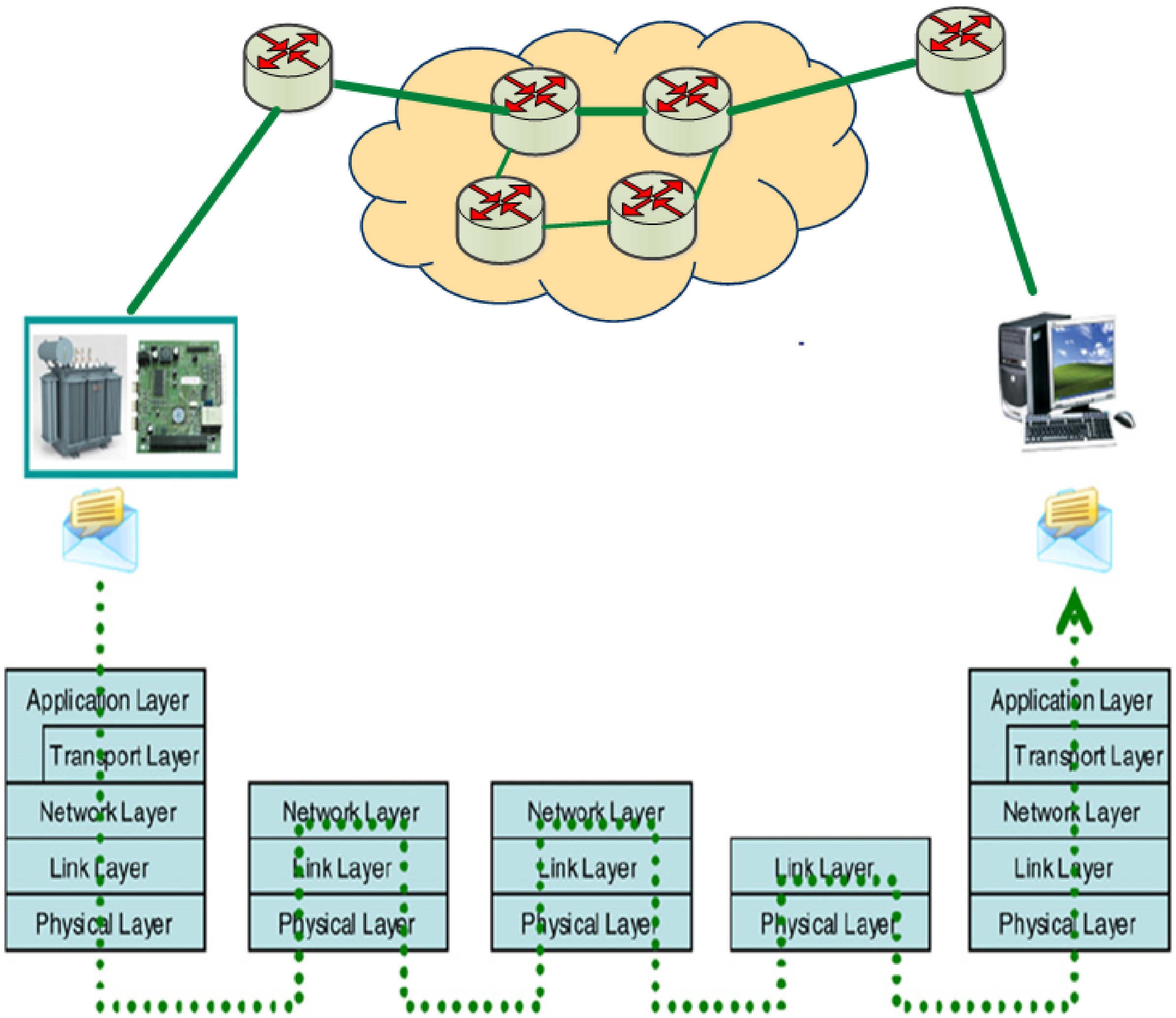
Multicast support

- The **multicast** concept is crucial for power system applications in which a message containing a given analog value, state change or command may have to be communicated to several peers at the same time.

Critical timing requirements

- Delay definition
  - The communication delay in smart grid is defined as the time lapse between the sending of a message at the source intelligent electric device (IED) and the receiving of message at the destination IED.
  - The end-to-end delay is the sum of all the time pieces spent by the message during its processing and transmission at every traversed node

Figure 3. The **message delay** in smart grid communications



wMNLab NTPU CSIE

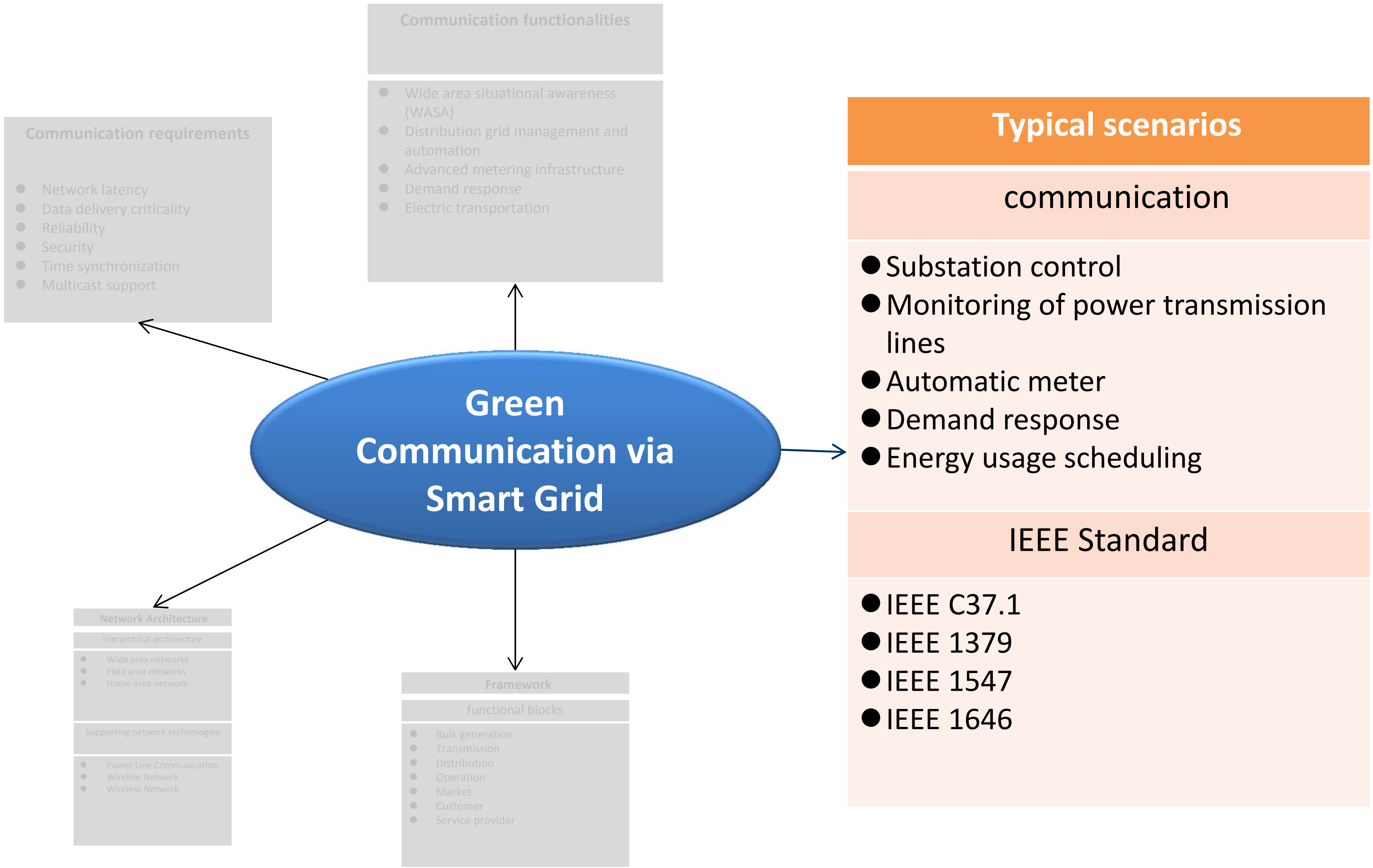
Table 1. communication timing requirements for electric substation automation

Information types	Internal to substation	External to substation
Protection information	4 ms ($\frac{1}{4}$ cycle of electrical wave)	8–12 ms
Monitoring and control Information	16 ms	1 s
Operations and maintenance information	1 s	10 s
Text strings	2 s	10 s
Processed data files	10 s	30 s
Program files	1 min	10 min
Image files	10 s	1 min
Audio and Video data streams	1 s	1 s

Table 2. communication requirements for functions and device models

Message Types	Definitions	Delay requirements
Type 1	Messages requiring immediate actions at receiving IEDs.	1A: 3 ms or 10 ms; 1B: 20 ms or 100 ms
Type 2	Messages requiring medium transmission speed	100 ms
Type 3	Messages for slow speed auto-control functions	500 ms
Type 4	Continuous data streams from IEDs	3 ms or 10 ms
Type 5	Large file transfers	1000 ms (not strict)
Type 6	Time synchronization messages	No requirement.
Type 7	Command messages with access control	Equivalent to Type 1 or Type 3.

5. Typical scenarios



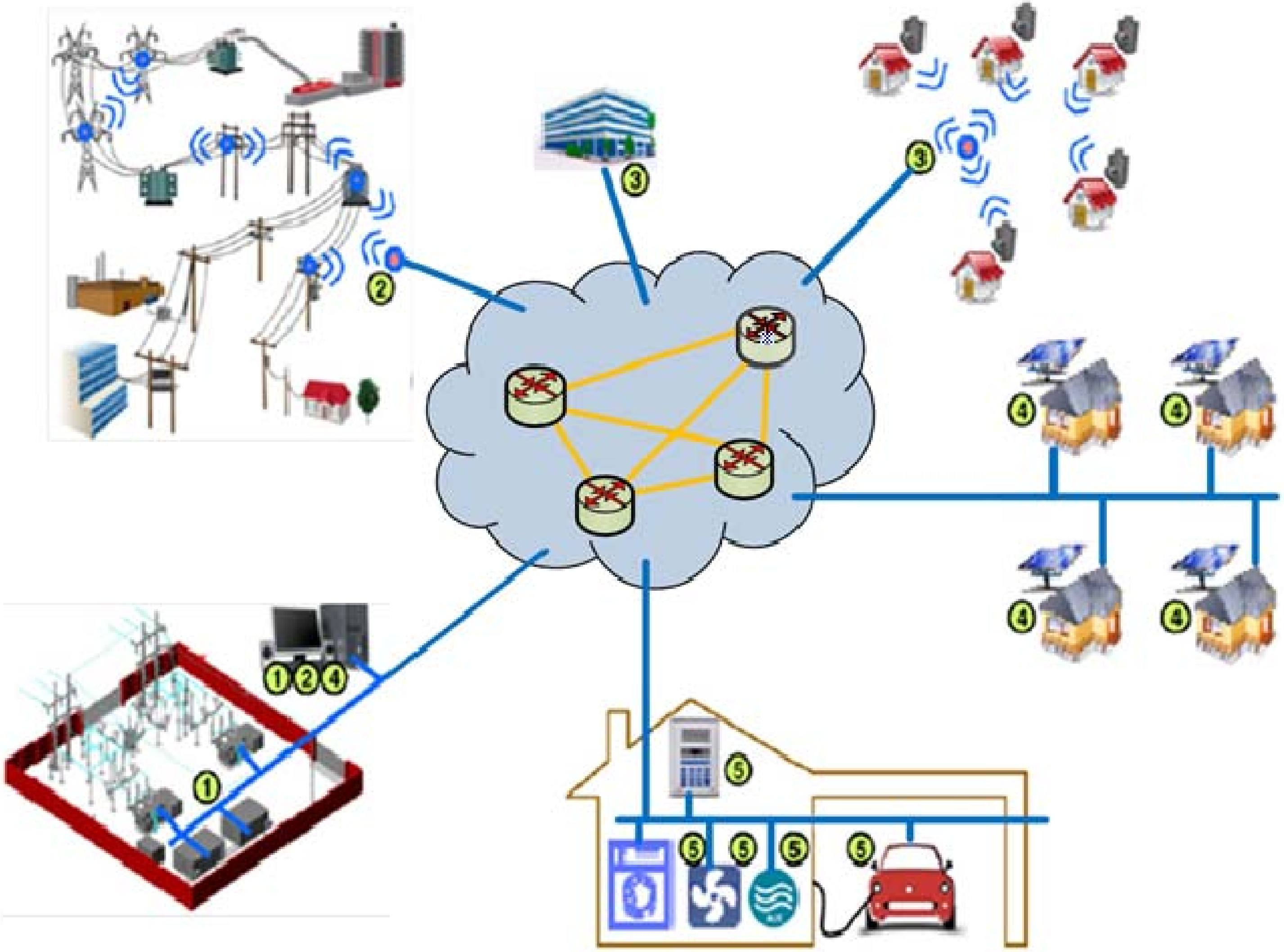
Outline

1. The framework of smart grid
2. Network Architecture
3. Communication functionalities
4. Communication requirements
5. Typical communication scenario

5. Typical communication scenarios

A. Substation control
B. Transmission line monitoring
C. Automatic meter reading
D. Demand response
E. Energy usage scheduling

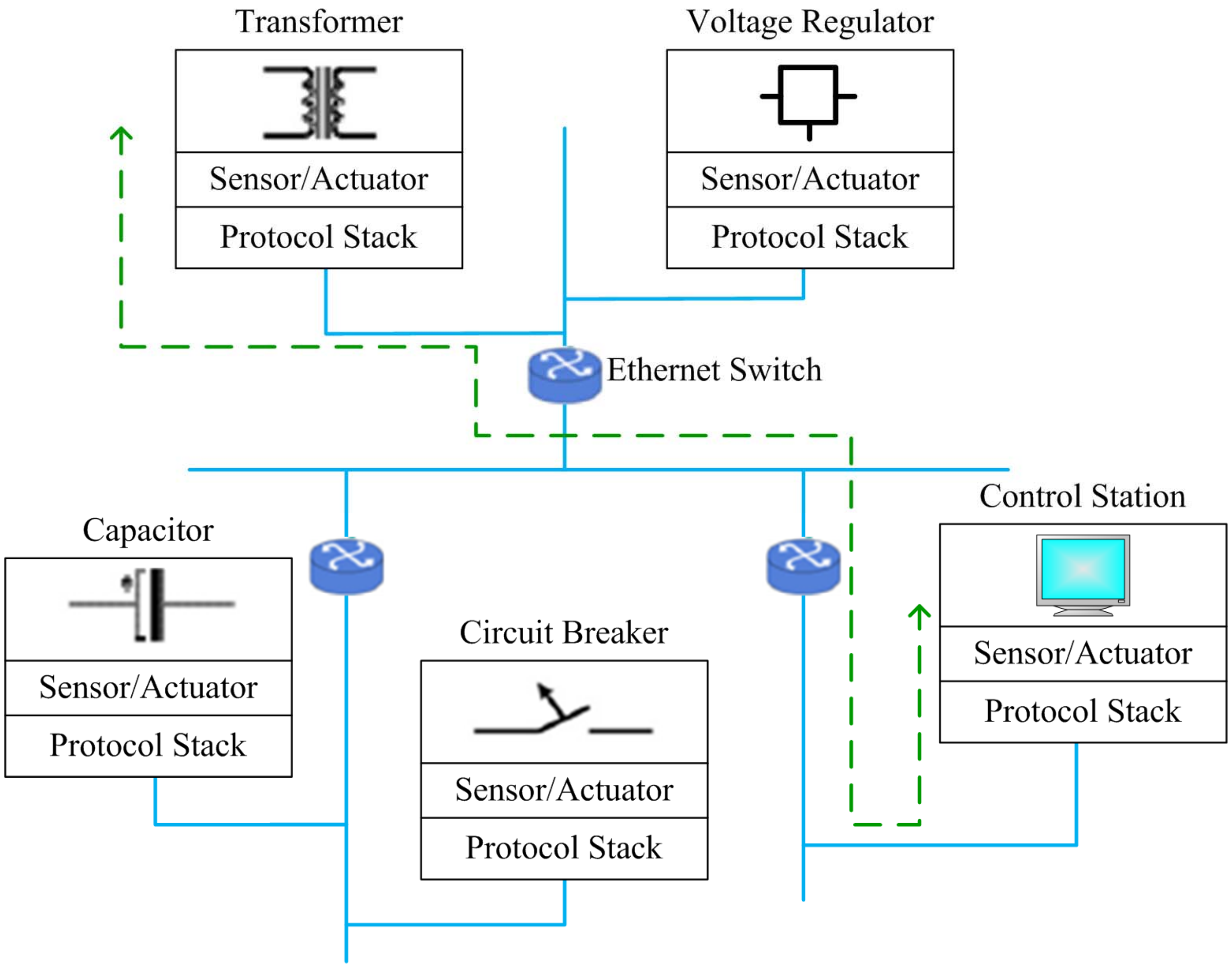
Figure 4. Typical communication scenarios.



A. Communication in a **substation**

- **Substation control**
  - It changes the voltages on the electrical transmission lines and controls the power flow in the transmission system.
  - The transmitted messages may be continuous data streams or isolated packets, depending on the particular controlling applications.
  - A message generated by the sensor attached to an electrical equipment is processed by the network protocol stack and then transmitted on the network.
  - The network may consist of a number of subnets connected through switches. Each switch on the path of packet transmission processes and forwards the packet. When the packet is received by the control station, a response may be made by the control station and a configuration message may be sent back to the electrical equipment

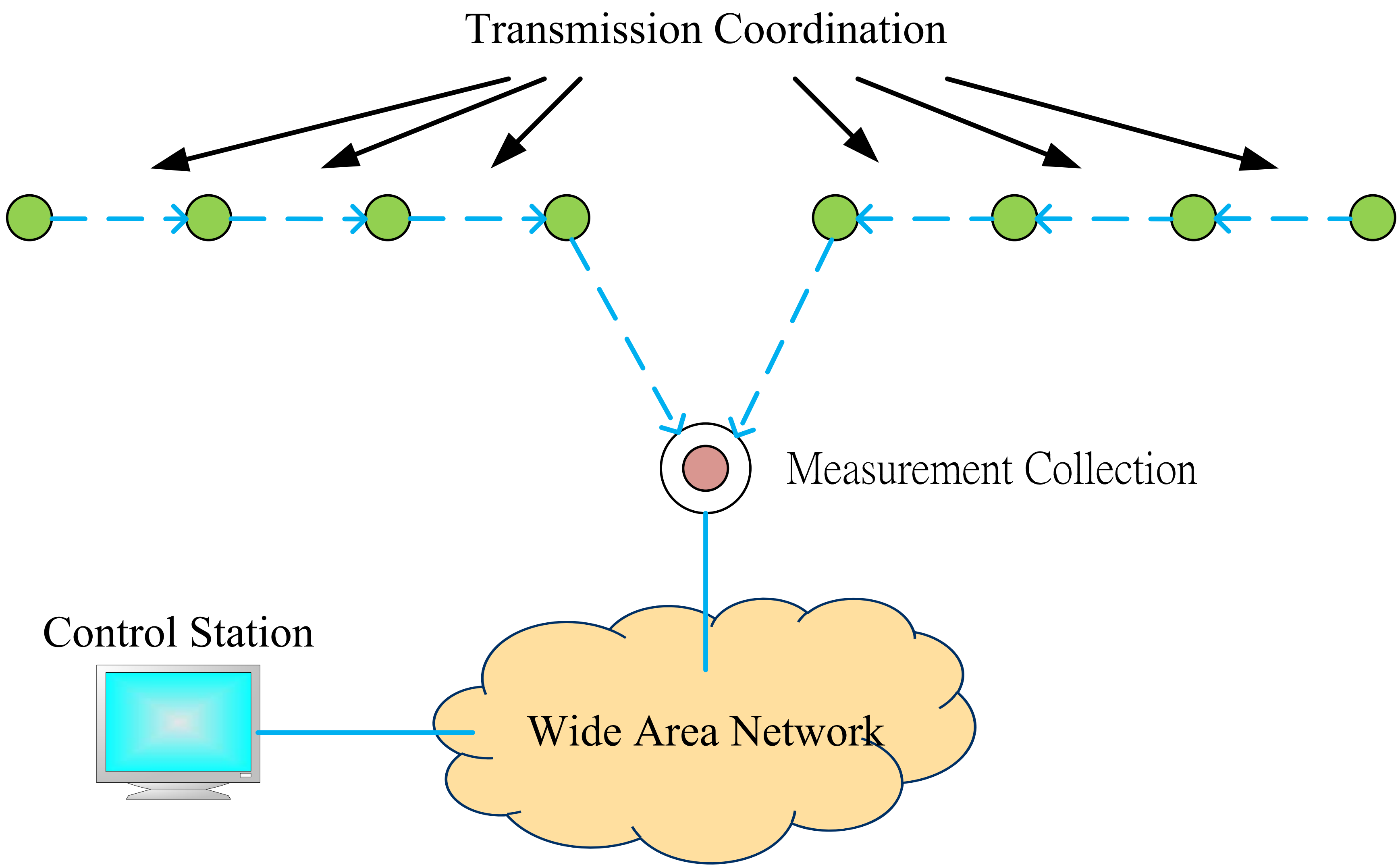
Figure 5. Communication in a substation



B. Monitoring of **power transmission lines**

- One method of automated transmission line monitoring is to install sensors along the lines to collect the real-time status measurements.
- Each sensor is equipped with wireless communication capability to exchange data with neighbors.
- The real-time measurements are relayed through the sensors until they reach a measurement collection site, which is connected to the wide area networks for communications to the control office.

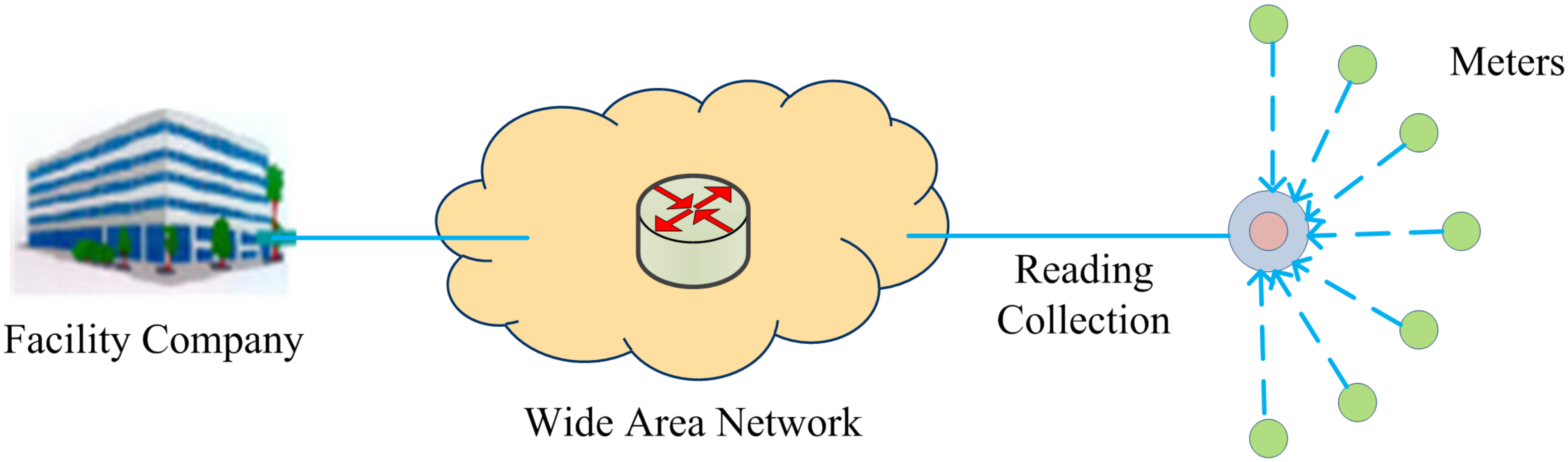
Figure 6. Communication in Monitoring of power transmission lines



C. Communications for **automatic meter reading**

- With the deployment of communication infrastructure, **meter reading** can be automated and simplified.
- A scheduling mechanism should be implemented to coordinate the transmissions from different meters to avoid transmission collisions.
- The collector then relays the readings through the wide area network to the facility company.

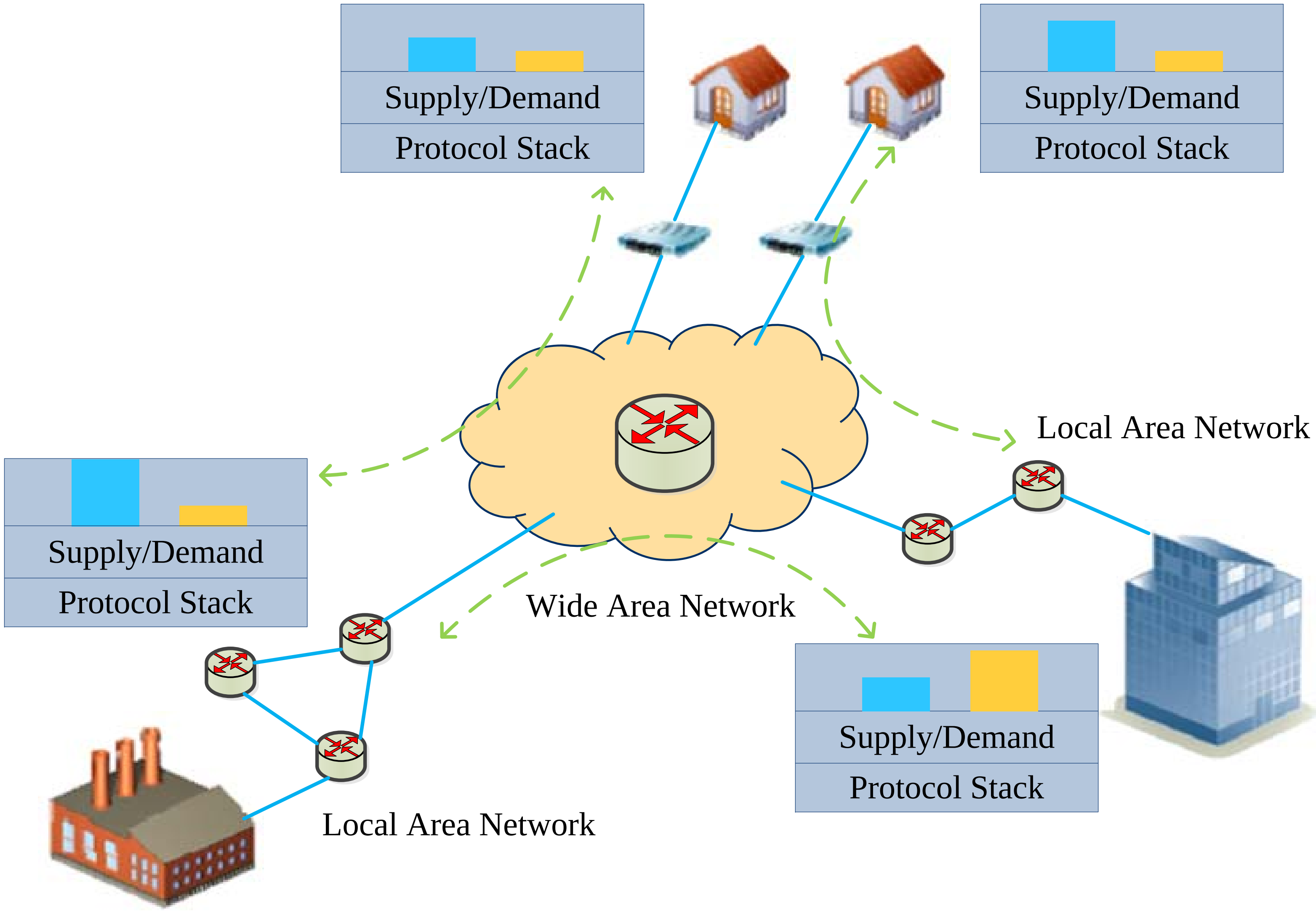
Figure 7. Communication for automatic meter reading



D. **Demand response**

- Supplementary to large power plants, many households are installed with solar panels to convert sunlight into usable electricity
- **Communications** regarding the electricity availability and price are exchanged through the network for each supplier and each customer to reach a balance between the supply and the demand.
- Each electricity supplier or customer publishes its amount of energy availability or demand through the wide area network. Different network access technologies may be used to connect the energy market participants.

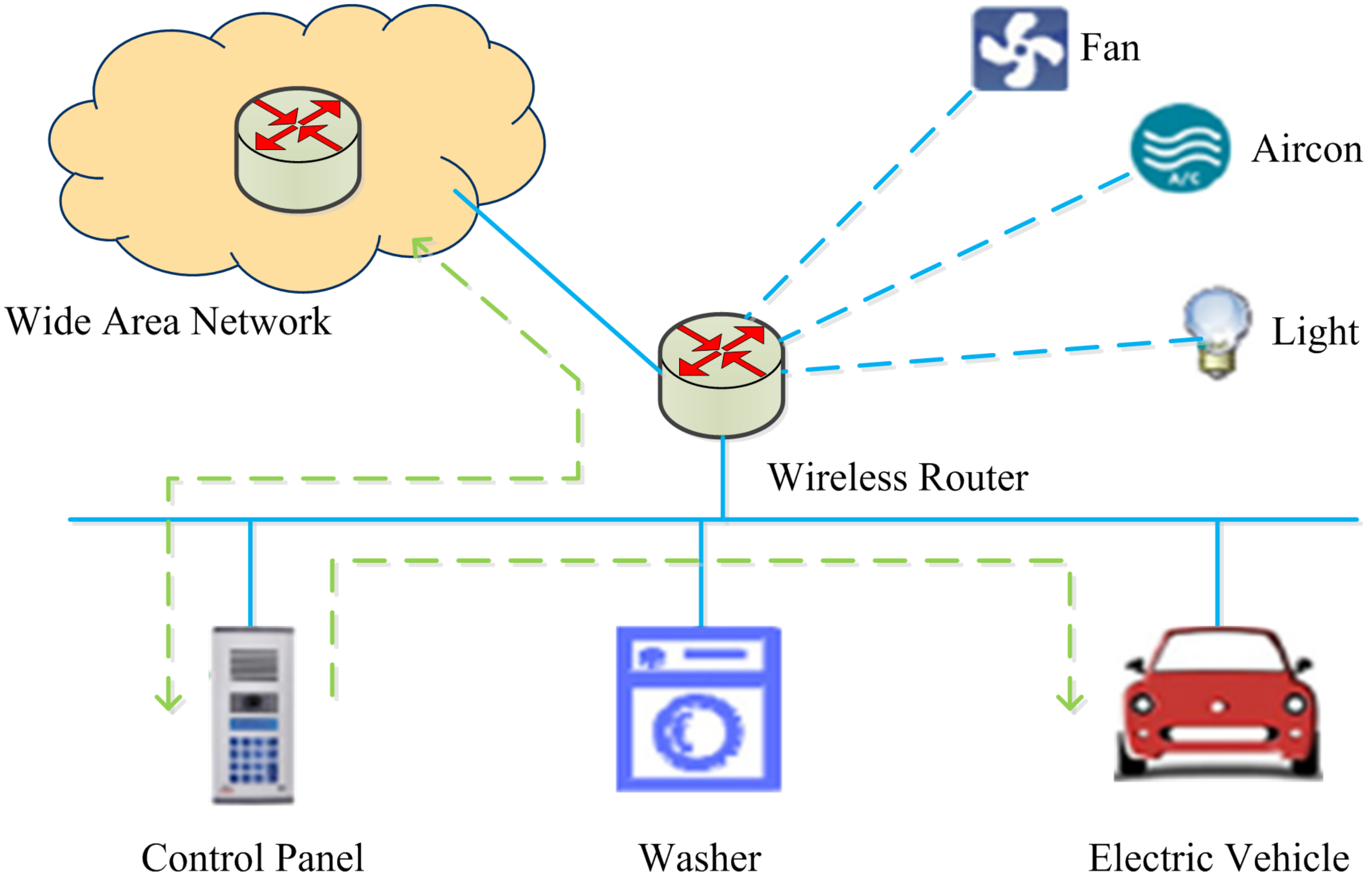
Figure 8. Communication among distributed energy supplier and customer



E. **Energy usage** scheduling

- To schedule the energy usage according to the electricity price, the electrical appliances in a home are connected to a **scheduling controller** through a home area network
- The scheduling controller requests electricity prices periodically from the energy market, based on which the controller determines an economic operation schedule to activate each appliance at appropriate time
- Home area networks can be deployed to connect the electrical appliances in a house to a scheduler, which activates each appliance at the appropriate time to minimize the cost of using electricity.

Figure 9. Communications in a home network to schedule electricity



IEEE standards

- IEEE C37.1
- IEEE 1379
- IEEE 1547
- IEEE 1646

IEEE C37.1

- This standard provides the basis for the definition, specification, performance analysis and application of SCADA and automation systems in electric substations.
- IEEE C37.1 defines the system architectures and functions in a substation including protocol selections, human machine interfaces and implementation issues.
- IEEE C37.1 also specifies the network performance requirements on reliability, maintainability, availability, security, expandability and changeability.

IEEE 1379

- IEEE 1379 provides examples of communication support in substations by using existing protocols.
- Processes are also discussed to expand the data elements and objects used in substation communications to improve the network functionalities

IEEE 1547

- IEEE 1547 defines and specifies the electric power system that interconnects distributed resources.
- IEEE 1547 the electric power system, the information exchange, and the compliance test In the power system
- Protocol and security issues are also considered in the IEEE 1547 standard.

IEEE 1646

- IEEE 1646 specifies the requirements on communication delivery times within and external to an electric substation.
- IEEE 1646 standard discusses further on the system and communication capabilities required to deliver information on time, including for example real-time support, message priority, data criticality, and system interfaces.

Reference

1. L.A. Barroso, H. Rudnick, F. Sensfuss, P. Linares, "The Green Effect," IEEE Power & Energy Magazine, 8 (5) (2010) 22–35.
2. F. Li, W. Qiao, H. Sun, H. Wan, J. Wang, Y. Xia, Z. Xu, P. Zhang, "Smart Transmission Grid: Vision and Framework," IEEE Transactions on Smart Grid (2010) 168–177.
3. J. Anatory, N. Theethayi, R. Thottappillil, "Channel Characterization for Indoor Power-Line Networks," IEEE Transactions on Power Delivery 24 (4) (2009) 1883–1888.
4. V.K. Chandna, M. Zahida, "Effect of Varying Topologies on the Performance of Broadband over Power Line," IEEE Transactions on Power Delivery 25 (4) (2010) 2371–2375
5. Wenye Wang , Yi Xu, Mohit Khanna, "A Survey on the Communication Architectures in Smart Grid," Computer Networks, (in press), 2011.

Homework #8

1. Try to describe the communication functionalities of smart grid.
2. Try to explain the system function block in smart grid.
3. Try to state the the network architecture of smart grid.