Lecture 2: Smart Grid Communications and measurement technology

George Konstantinou, University of Cyprus

01/08/2020

Nicosia, Cyprus

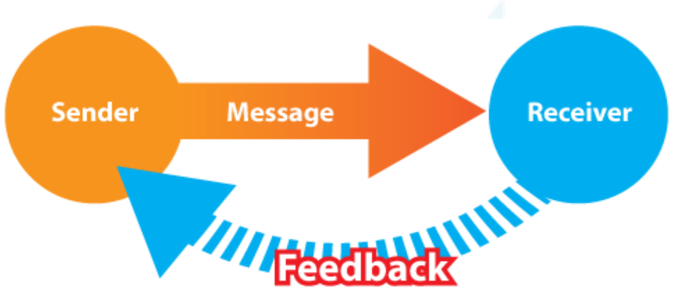
Course material developed in collaboration with Technical University of Sofia, University of Western Macedonia, International Hellenic University, University of Cyprus, Public Power Corporation S.A., K3Y Ltd and Software Company EOOD

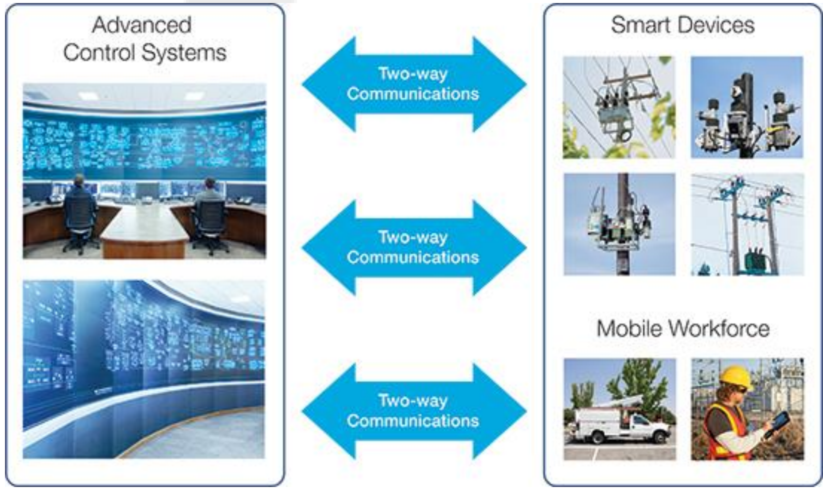
with support from Erasmus +

Content of the lecture

2.1 Communication and measurement

- Ultimately, high- speed, fully integrated, two - way communication technologies will allow the smart grid to be a dynamic, mega - infrastructure for real - time information and power exchange.
- The technology to measure, monitor, and control in real time plays an essential role in the functioning of the Smart Grid.
- Issues of standards, cyber security, and interoperability which are dealt more extensively in **Chapter 6** impact most definitely communication. There is a need for the formalization of the standards and protocols which will be enforced for the secured transmission of critical and highly sensitive information within the communications scheme.



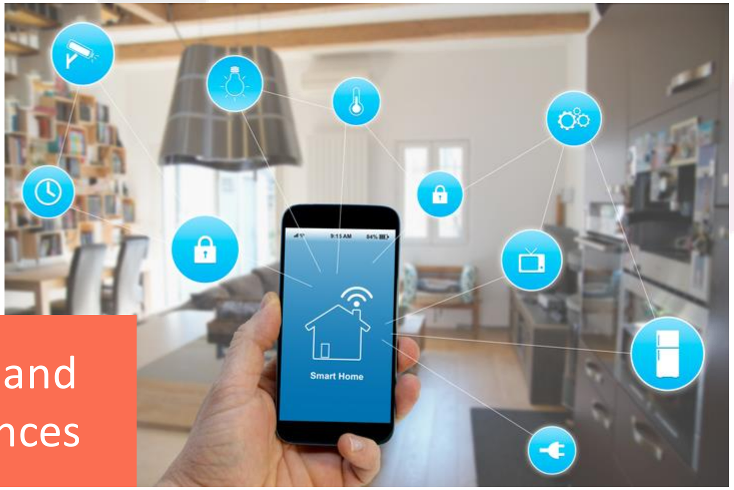


2.1 Communication and measurement

- Communication and measurement technologies are very important in the functioning of the Smart Grid, which is based on the following:

  1. Standards
  2. Cyber security
  3. Interoperability

- Establishing appropriate standards, cyber security, and interoperability requires careful study. For example, *formalizing the standards and protocols for the secure transmission of critical and highly sensitive information within the proposed communication scheme.*
- Moreover, open architecture's plug - and - play environment will provide secure network smart sensors and control devices, control centers, protection systems, and users.



Smart meter and Smart appliances

2.1 Communication and measurement

- Possible wired and wireless communications technologies can include:

1. **Multiprotocol Label Switching (MPLS):** high - performance telecommunications networks for data transmission between network nodes
2. **Worldwide Interoperability for Microwave Access (WiMax):** wireless telecommunication technology for point to multipoint data transmission utilizing Internet technology
3. **Broadband over Power Lines (BPL):** power line communication with Internet access
4. **Wi - Fi:** commonly used wireless local area network

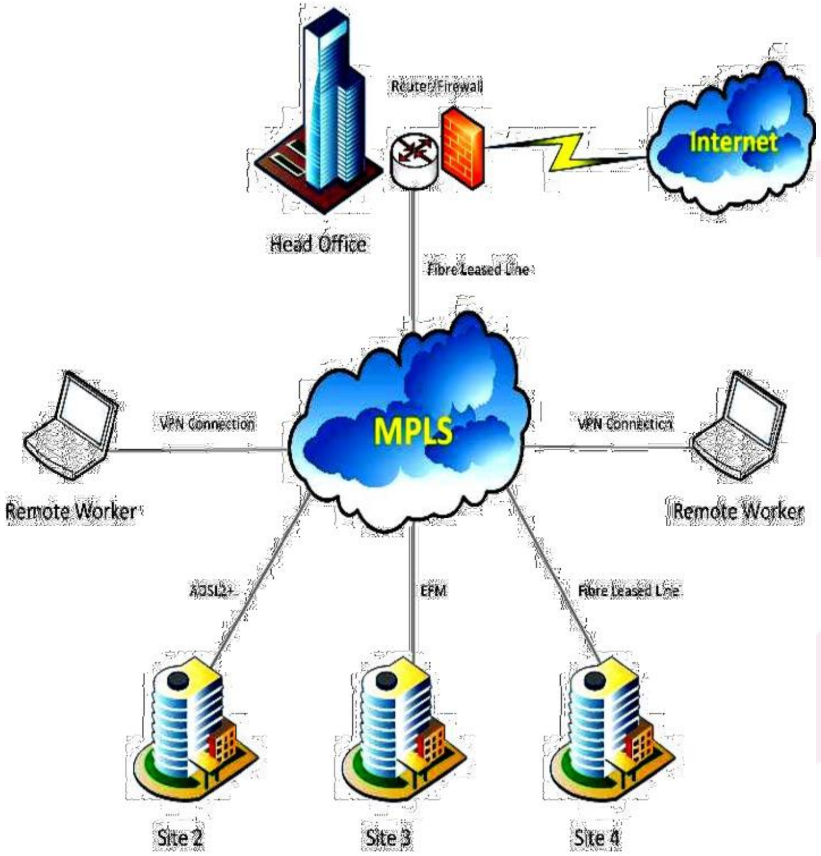
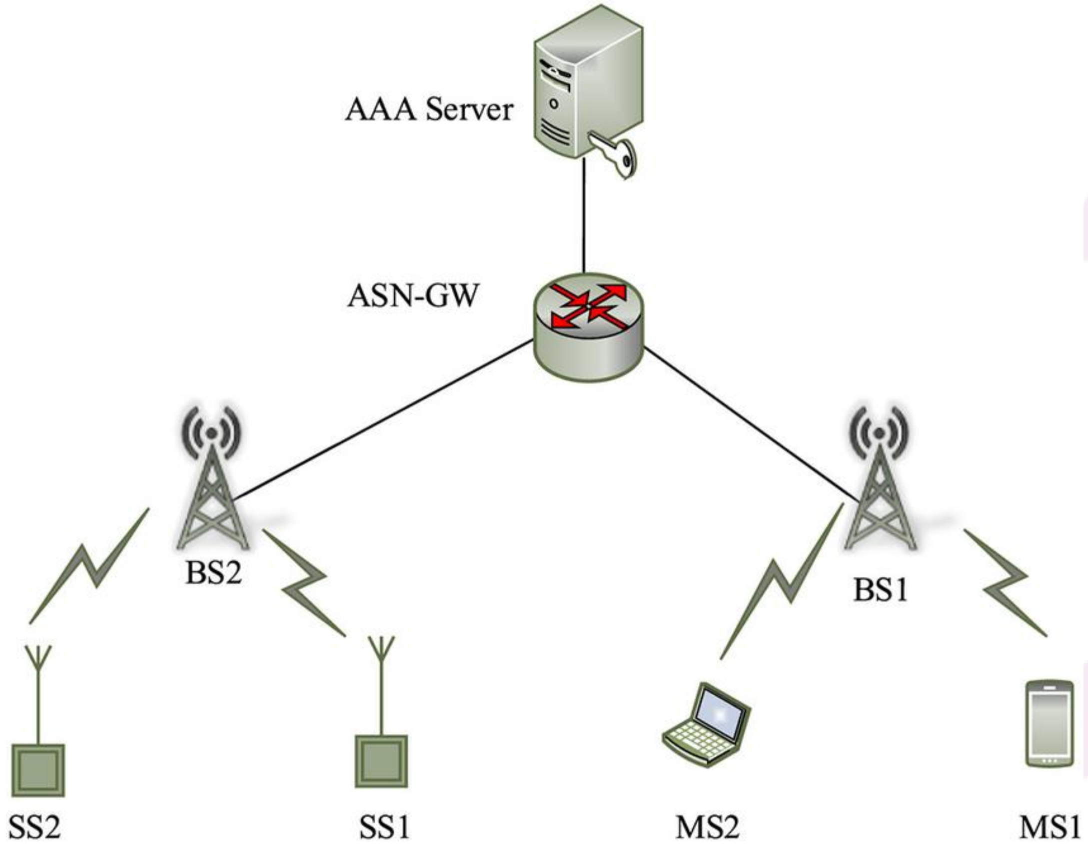


Figure 1: MPLS Infrastructure

2.1 Communication and measurement

- Additional technologies include optical fiber, mesh, and multipoint spread spectrum. The five characteristics of smart grid communications technology are:

1. High bandwidth
2. IP - enabled digital communication (IPv6 support is preferable)
3. Encryption
4. Cyber security
5. Support and quality of service and Voice over Internet Protocol (VoIP)



Worldwide Interoperability for Microwave Access architecture

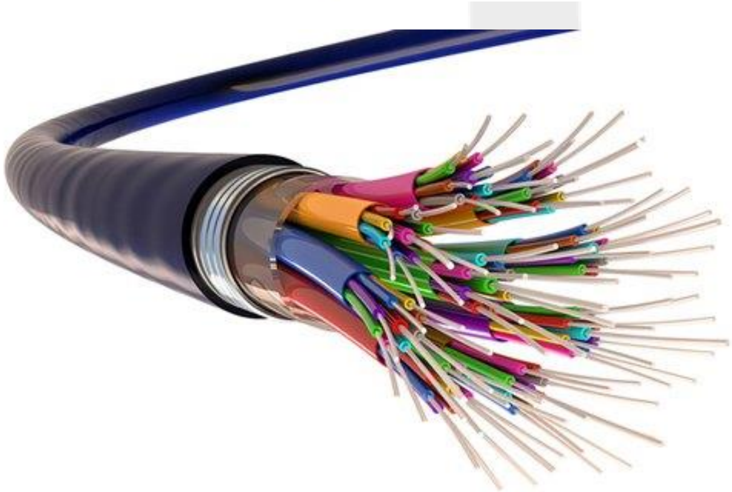
2.1.1 Network Topologies: LAN

- Local Area Network [1,2] consists of two or more components and high-capacity disk storage (file servers), which allow each computer in a network to access a common set of rules.
- LAN has an operating system software which interprets input, instructs network devices, and allows users to communicate with each other. Each hardware device (computer, printer, and so on) ***on a LAN is a node***.
- The LAN can operate or integrate up to several hundred computers. LAN combines high speed with a geographical spread of 1 – 10 km. LAN may also access other LANs or tap into Wide Area Networks.
- LAN with similar architectures are bridges which act as transfer points, while LAN with different architectures are gateways which convert data as it passes between systems.

2.1.1 Network Topologies: LAN

- LAN is a shared access technology, meaning that all of the attached devices share a common medium of communication such as coaxial, twisted pair, or fiber optics cable.
- A physical connection device, the Network Interface Card (NIC), connects to the network. The network software manages communication between stations on the system.

Network Interface Card



Fiber optics cable

2.1.1 Network Topologies: LAN

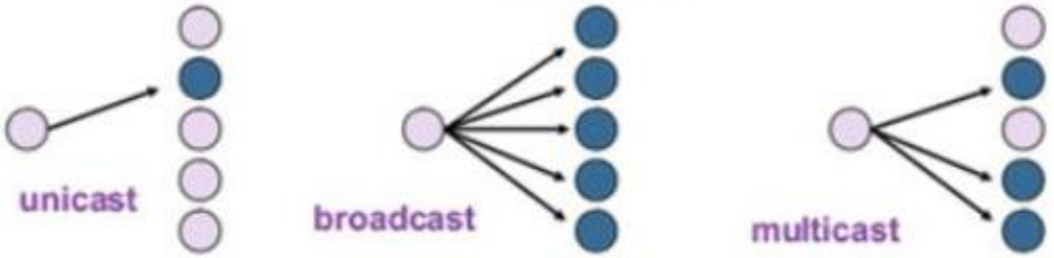
LAN characteristics

- **Resource sharing:** allows intelligent devices such as storage devices, programs, and data files to share resources, that is, LAN users can use the same printer on the network; the installed database and the software can be shared by multiple users
- **Area covered:** LAN is normally restricted to a small geographical area, for example, office building, utility, campus
- **Cost and availability:** application software and interface devices are affordable and off - the - shelf
- **High channel speed:** ability to transfer data at 10-100 million bits per second. Even Gbps speeds are possible.
- **Flexibility:** grow/expand with low probability of error; easy to maintain and operate

2.1.1 Network Topologies: LAN

- LAN has three categories of data transmission:

1. **Unicast transmission:** a single data packet is sent from a source node to a destination (address) on the network
2. **Multicast transmission:** a single data packet is copied and sent to a specific subset of nodes on the network; the source node addresses the packet by using the multicast addresses
3. **Broadcast transmission:** a single data packet is copied and sent to all nodes on the network; the source node addresses the packet by using the broadcast address



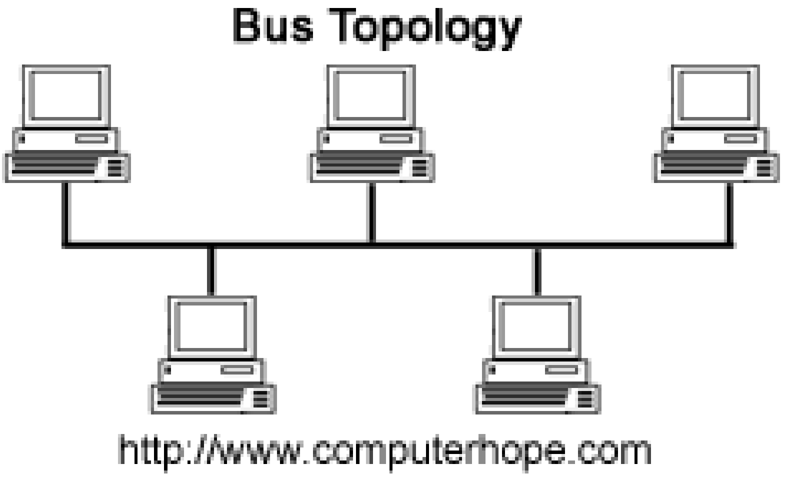
Transmission categories

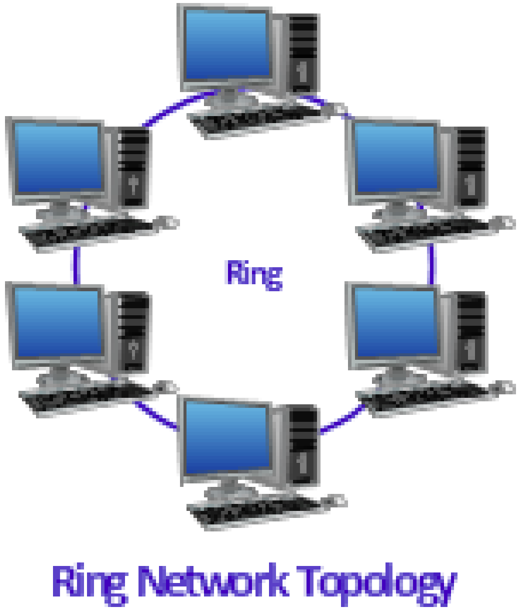
2.1.1 Network Topologies: LAN

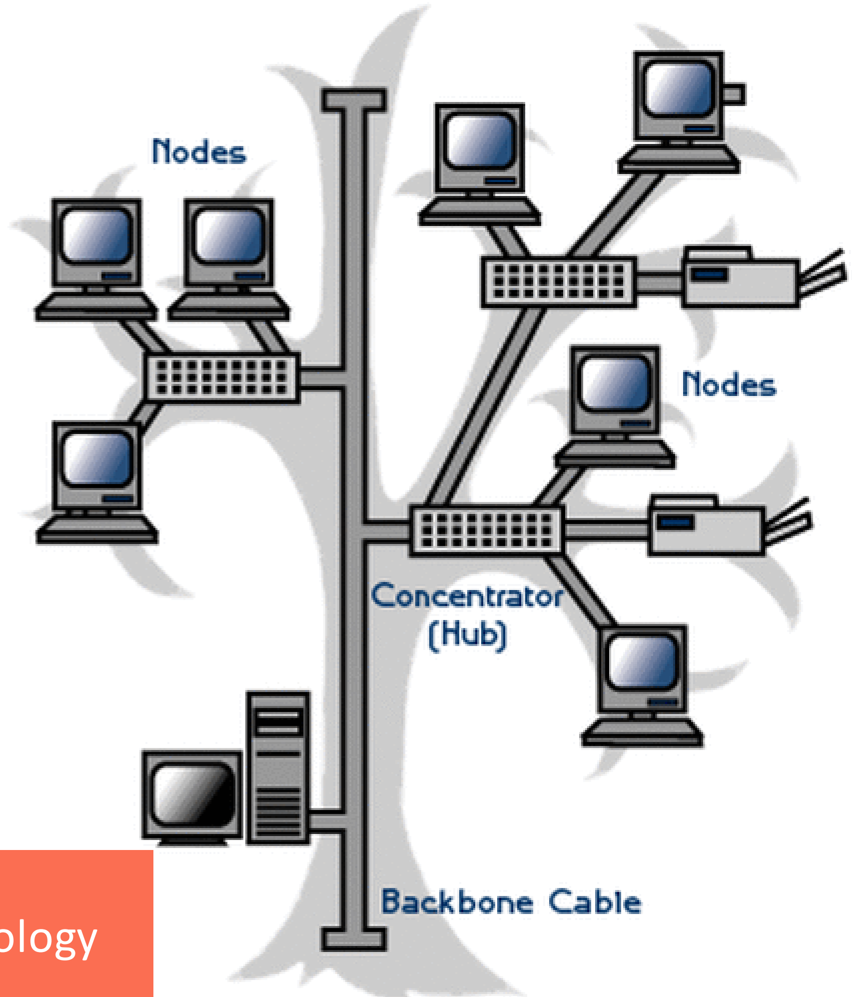
- LAN topologies define how network devices are organized. The four most common architectural structures are (see next slide):

1. Bus topology: linear LAN architecture in which transmission from network station propagates the length of the medium and is received by all other stations connected to it
2. Ring bus topology: a series of devices connected to one another by unidirectional transmission links to form a single closed loop
3. Star topology: the end points on a network are connected to a common central hub or switch by dedicated links
4. Tree topology: identical to the bus topology except that branches with multiple nodes are also possible

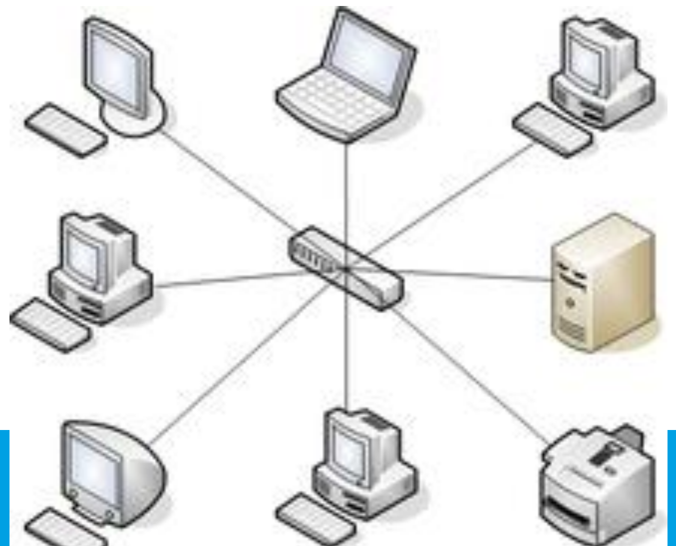
2.1.1 Network Topologies: LAN







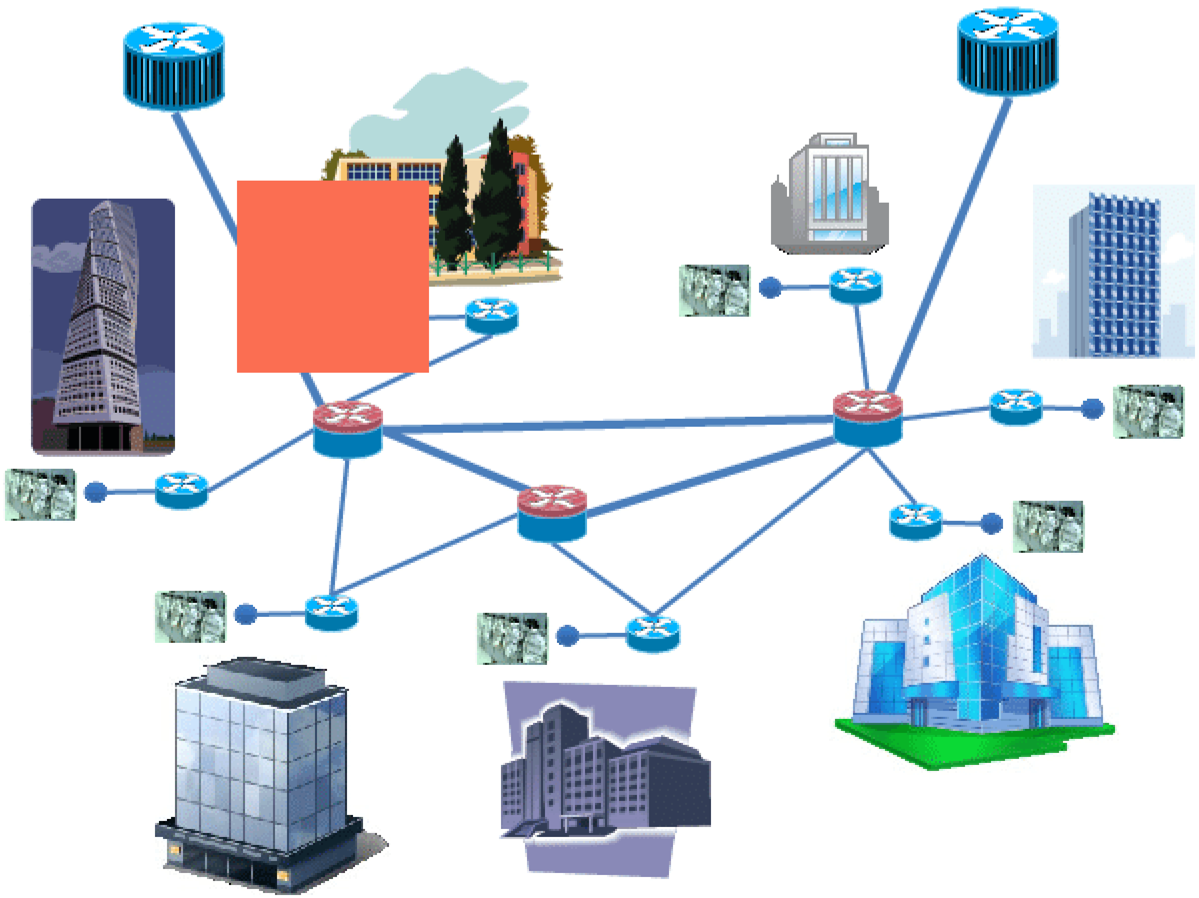
Tree topology



Star topology

2.1.2 Network Topologies: NAN

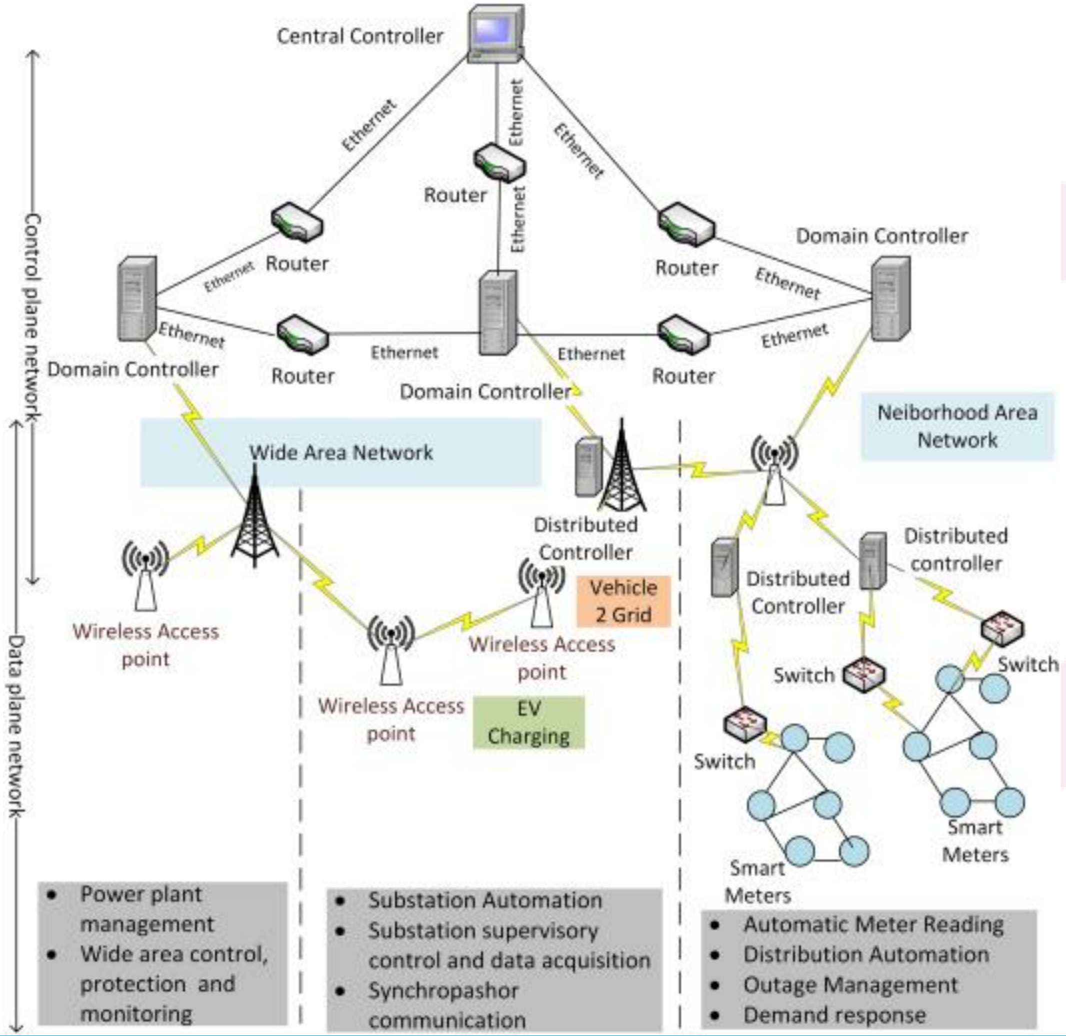
- Neighborhood Area Network (NAN) is a wireless community currently used for local distribution applications. Ideally, it will cover an area larger than a LAN.
- Some architectural structures will focus on the integration and interoperability of the various domains within the smart grid.



NAN topology

2.1.2 Network Topologies: NAN

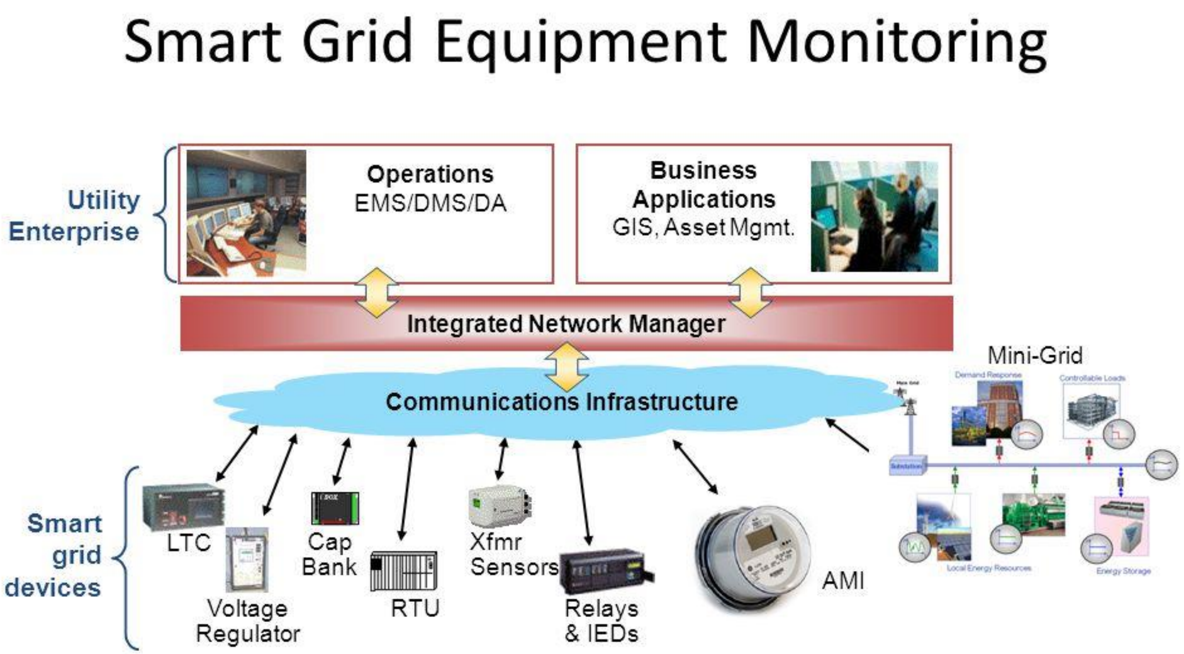
- Domains consist of groups of buildings, systems, individuals, or devices which have similar communications characteristics:
- **Bulk generation:** includes market services interface, plant control system, and generators; this domain interacts with the market operations and transmission domains through wide area networks, substation LANs, and the Internet
- **Transmission:** includes substation devices and controllers, data collectors, and electric storage; this domain interacts with bulk generation and operations through WANs and substation LANs; integrated with the distribution domain



2.1.2 Network Topologies: NAN

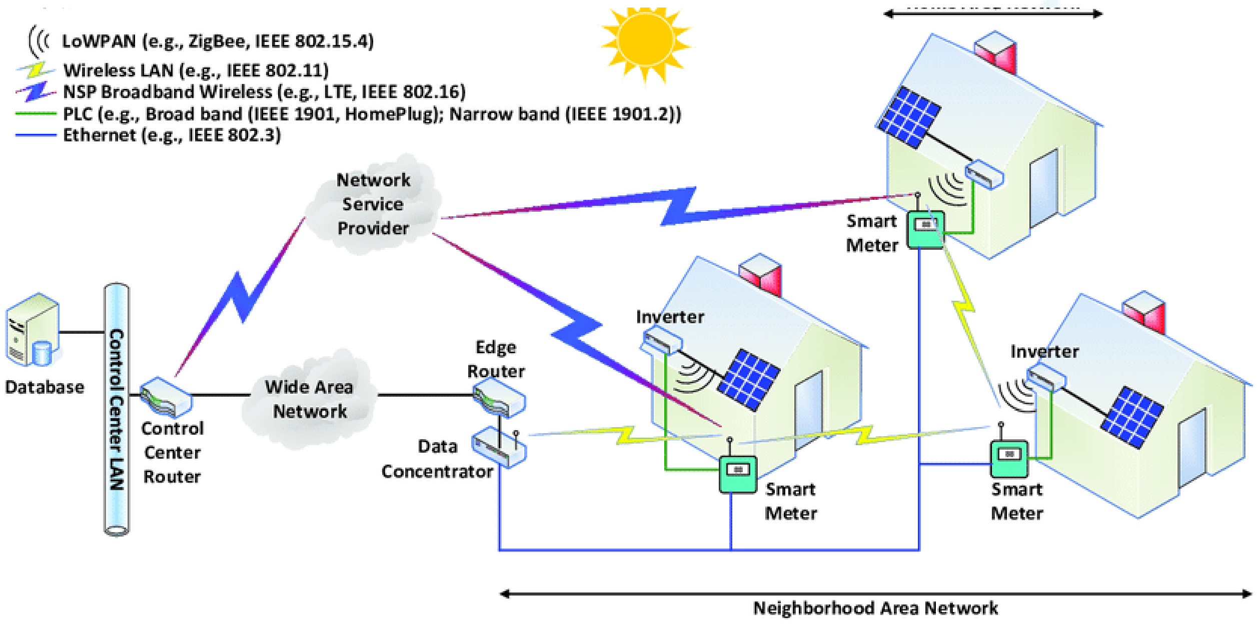
- **Distribution:** this domain interacts with operations and customers through Field Area Networks
- **Customer:** includes customer equipment, metering, Energy Management Systems (EMS), electric storage, appliances, PHEVs, and so on
- **Service Providers:** includes utility and third party providers which handle billing customer services, and so on; this domain interacts with operations and customers primarily through the Internet
- **Operations:** includes EMS, Web Access Management System (WAMS), and SCADA; this domain can be sub - divided into ISO/RTO, transmission, and distribution
- **Market:** includes/ISOs/RTOs, aggregators, and other market participants

- The smart grid environment requires the upgrade of tools for sensing, metering, and measurements at all levels of the grid. These components will provide the data necessary for monitoring the grid and the power market.
- Sensing provides outage detection and response, evaluates the health of equipment and the integrity of the grid, eliminates meter estimations, provides energy theft protection, enables consumer choice, DSM (Demand Side Management), and various grid monitoring functions.



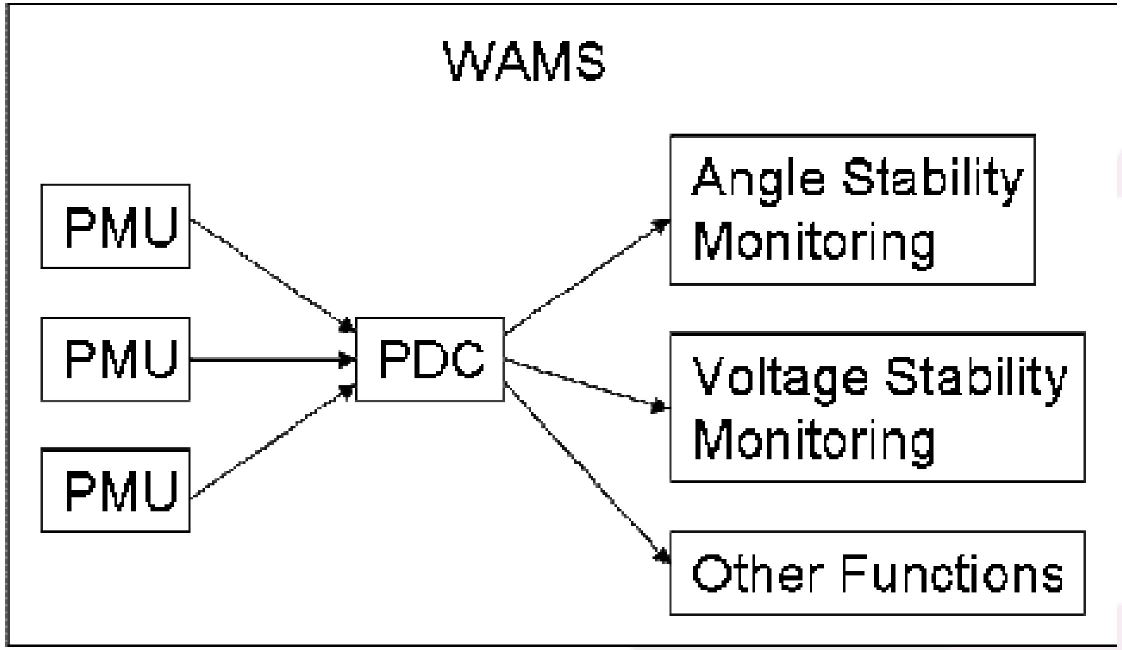
2.2 MONITORING, PMU, SMART METERS, AND MEASUREMENTS TECHNOLOGIES

- Regarding metering and measurement, new digital technologies using two - way communications, a variety of inputs (pricing signals, time - of - day tariff [3], curtailments for congestion relief), a variety of outputs (real time consumption data, power quality, electric parameters), the ability to connect and disconnect, and interfaces with generators, grid operators, and customer portals to enhance power measurement.



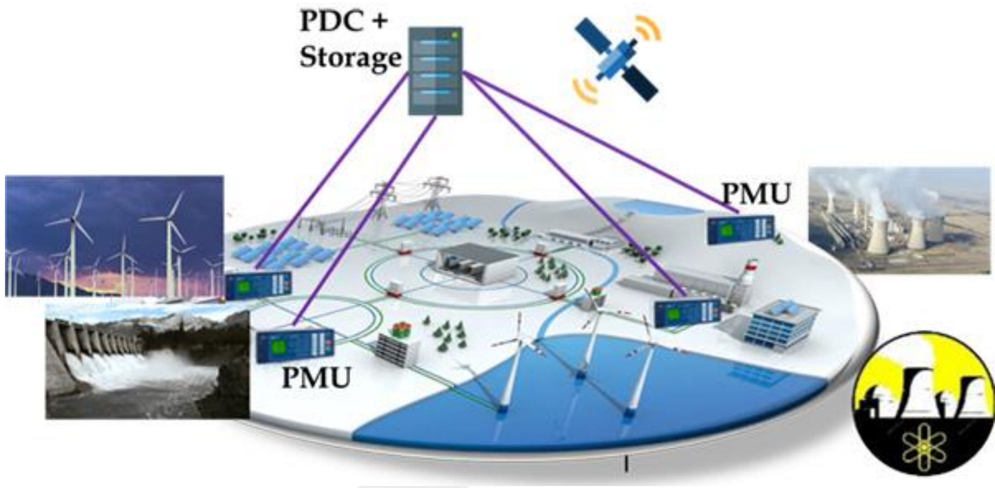
2.2.1 Wide Area Monitoring Systems (WAMS)

- WAMS are designed by the utilities for optimal capacity of the transmission grid and to prevent the spread of disturbances. By providing real - time information on stability and operating safety margins, WAMS give early warnings of system disturbances for the prevention and mitigation of system - wide blackouts.
- WAMS utilize sensors distributed throughout the network in conjunction with GPS satellites for precise time stamping of measurements in the transmission system.



2.2.2 Phasor Measurement Units (PMU)

- Phasor Measurement Units (PMUs) or Synchrophasors give operators a time - stamped snapshot of the power system.
- The PMUs consist of bus voltage phasors and branch current phasors, in addition to information such as locations and other network parameters.
- Phasor measurements are taken with high precision from different points of the power system at the same instant, allowing an operator to visualize the exact angular difference between different locations. PMUs are equipped with GPS receivers which allow synchronization of readings taken at distant points.



Monitoring Power Systems: A phasor measurement unit

2.2.2 Phasor Measurement Units (PMU)

- PMUs measure voltage and current with high accuracy at a rate of 2.88 kHz. They can calculate real power, reactive power, frequency, and phase angle 12 times per 60 hertz cycle.
- Offering wide - area situational awareness, phasor measurements work to ease congestion, bottlenecks and mitigate — or even prevent — blackouts. When integrated with Smart Grid communications technologies, the measurements taken will provide dynamic visibility into the power system.
- Adoption of the Smart Grid with real time measurement will enhance every facet of the electric delivery system including generation, transmission, distribution, and consumption. It will increase the possibilities of distributed generation, bringing generation closer to those it serves.

2.2.2 Phasor Measurement Units (PMU)

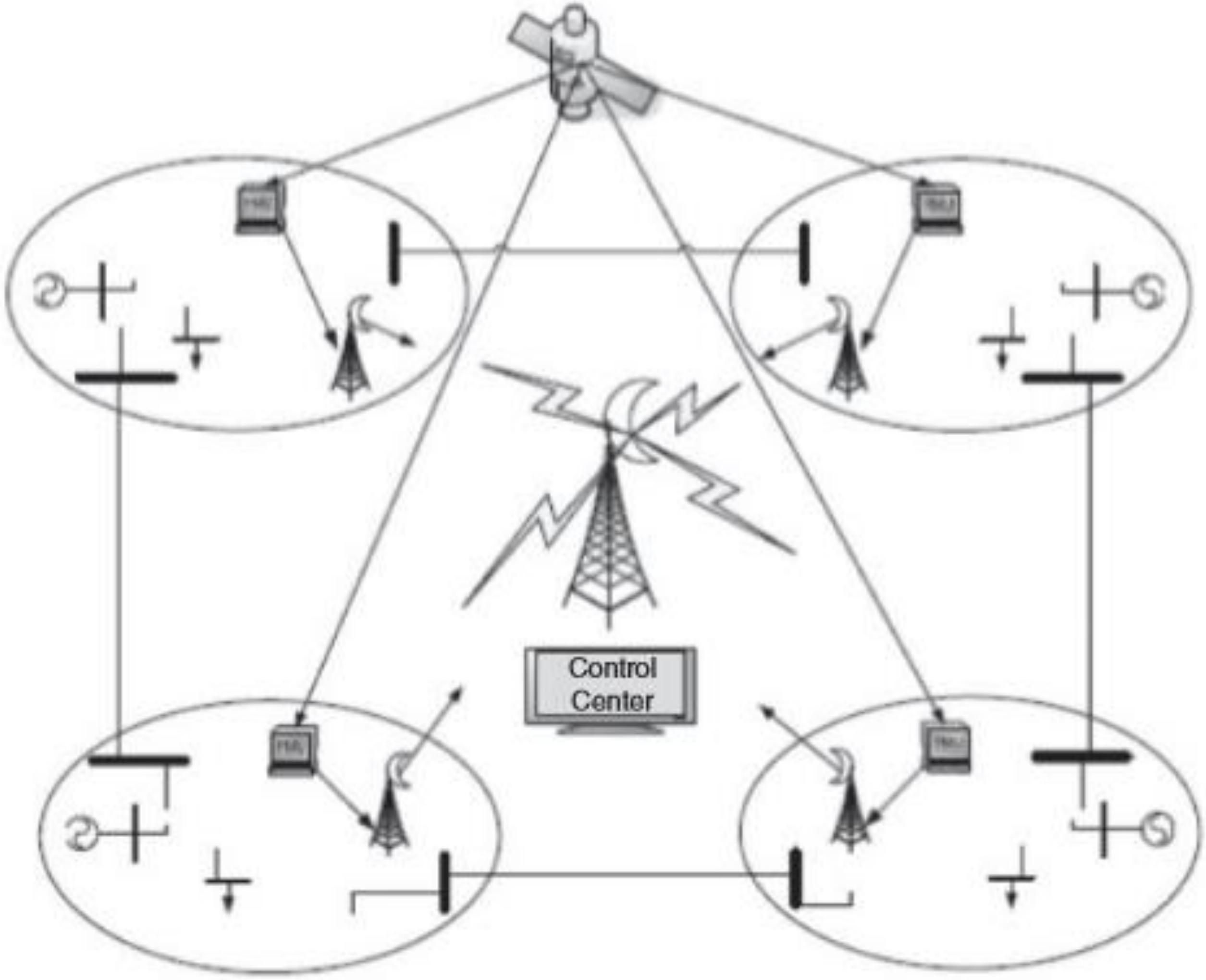


Fig.1: Conceptual diagram of a synchronized phasor measuring system

2.2.3 Smart Meters

- Smart meters have two functions:

1. providing data on energy usage to customers (end users) to help control cost and consumption;
2. sending data to the utility for load factor control, peak-load requirements, and the development of pricing strategies based on consumption information and so on. Automated data reading is an additional component of both smart meters and two - way communication between customers and utilities. [4,5]

2.2.3 Smart Meters

- Smart meters equip utility customers with knowledge about ***how much they pay per kilowatt hour and how and when they use energy***. This will result in better pricing information and more accurate bills in addition to ensuring faster outage detection and restoration by the utility.
- Additional features will allow for demand - response rates, tax credits, tariff options, and participation in voluntary rewards programs for reduced consumption.
- Basic characteristics:

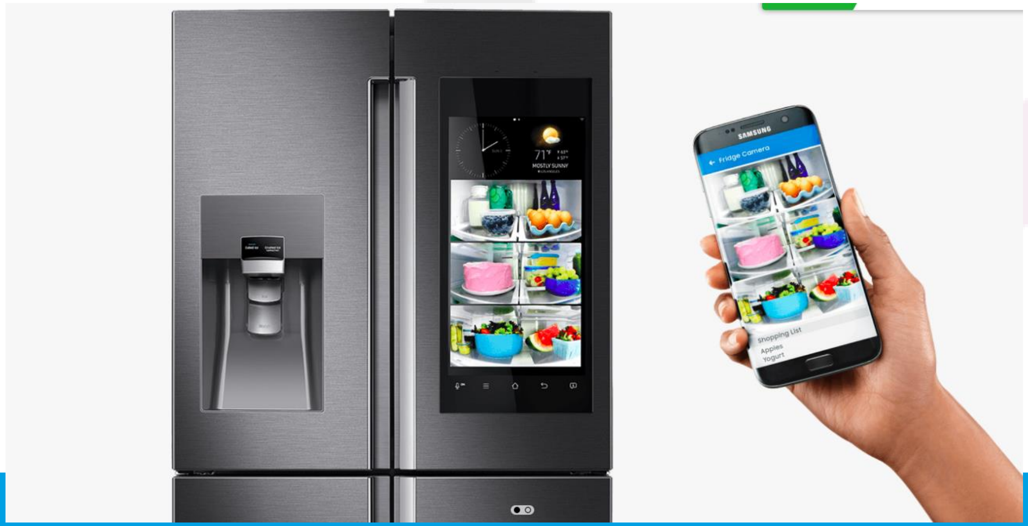
1. remote connect/disconnect of users,
2. appliance control and monitoring,
3. smart thermostat,
4. enhanced grid monitoring,
5. switching,
6. prepaid metering.

2.2.4 Smart Appliances

- Smart appliances cycle up and down in response to signals sent by the utility. The appliances enable customers to participate in voluntary demand response programs which award credits for limiting power use in peak demand periods or when the grid is under stress.
- An override function allows customers to control their appliances using the Internet.

2.2.4 Smart Appliances

- Air conditioners, space heaters, water heaters, refrigerators, washers, and dryers represent about 20% of total electric demand during most of the day and throughout the year [6] .
- Grid - friendly appliances use a simple computer chip that *can sense disturbances in the grid power frequency and can turn an appliance off for a few minutes to allow the grid to stabilize during a crisis.*



2.2.5 Advanced Metering Infrastructure (AMI)

- AMI is the convergence of the grid, the communication infrastructure, and the supporting information infrastructure.
- The network - centric AMI coupled with the lack of a composite set of cross industry AMI security requirements and implementation guidance, is the primary motivation for its development.
- The problem domains to be addressed within AMI implementations are relatively new to the utility industry; however, precedence exists for implementing large - scale, network - centric solutions with high information assurance requirements. The defense, cable, and telecom industries offer many examples of requirements, standards, and best practices that are directly applicable to AMI implementations.

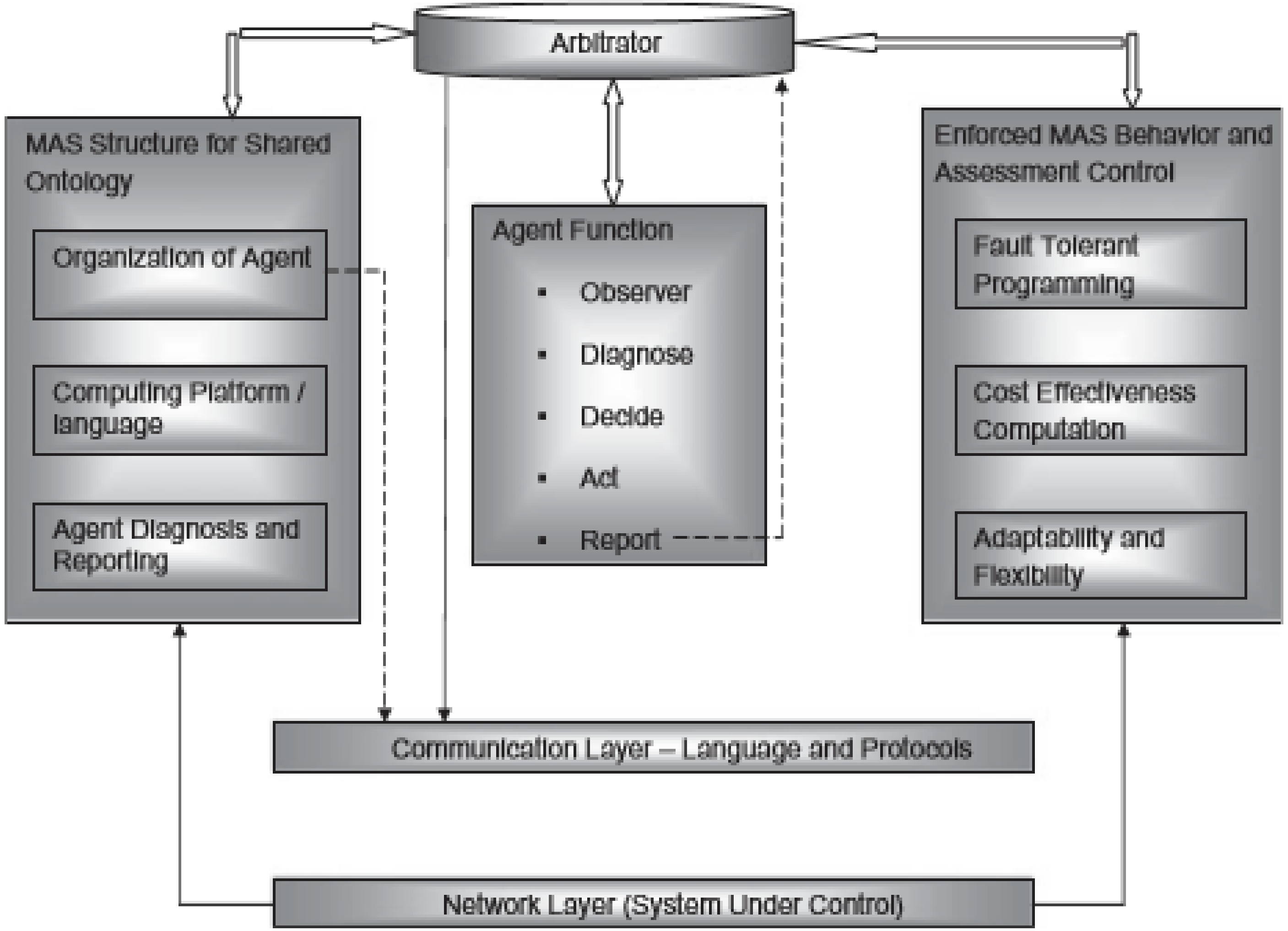
2.2.5 Advanced Metering Infrastructure (AMI)

The functions of AMI can be subdivided into three major categories:

- **Market applications:** reduce/eliminate labor, transportation, and infrastructure costs associated with meter reading and maintenance, increase accuracy of billing, and allow for time - based rates while reducing bad debts; facilitate informed customer participation for energy management.
- **Customer applications:** increase customer awareness about load reduction, reduce bad debt, improve cash flow, and enhance customer convenience and satisfaction; provide demand response and load management to improve system reliability and performance.
- **Distribution operations:** curtails customer load for grid management, optimizes network based on data collected, allows for the location of outages and restoration of service, improves customer satisfaction, reduces energy losses, improves performance in event of outage with reduced outage duration and optimization of the distribution system and distributed generation management, provides emergency demand response.

2.3 Multi-agent systems technology

- MAS are a computational system in which several agents cooperate to achieve a desired task. The performance of MAS can be decided by the interactions among various agents. Agents cooperate to achieve more than if they act individually.
- Increasingly, MAS are the preferential choice for developing distributed systems. The development of monitoring and measurement schemes within the smart grid environment can be enhanced through the use of MAS architecture (see Fig.)



2.3 Multi-agent systems technology

- As an example, MAS have been utilized as a detection and diagnosis device and in system monitoring.
- Such architectures utilize a collection of agents such as Arbitrator Agents (AA), System Monitoring Agents (SMA), Fault Detection Agents (FDA), Diagnosis Agents (DA), a Judgment Index Agent (JIA), and a Scheduling Agent (SA).
- Information passes between the agents about the appropriate actions to be taken. When implemented, the process repeats itself to constantly monitor the system so that management of system conditions can be implemented instantaneously.

2.3.1 Multiagent Systems for Smart Grid Implementation

- The smart grid is expected to have the following key characteristics:

1. self - healing
2. consumer friendly
3. attack resistant
4. provides power quality for 21st - century needs
5. accommodates all generation and storage options
6. enables markets
7. optimizes assets and operates efficiently

2.3.1 Multiagent Systems (MAS) for Smart Grid Implementation

- An important task regarding the operation of any power system is its control architecture consisting of hardware and software protocols for exchanging system status and control signals.
- In conventional electric power systems, this is accomplished by SCADA [1].
- Current trends to control and monitor system operations are moving towards the use of MAS. MAS is a combination of several agents working in together pursuing assigned tasks to achieve the overall goal of the system.
- MAS has become an increasingly powerful tool in developing complex systems that take advantages of agent properties: autonomy, sociality, reactivity and pro – activity [2].
- MAS is autonomous operating without human interventions. The multiagent system is also sociable in that it interacts with other agents via some kind of agent communication language.

Summary

- This chapter has focused on various communication aspects of the smart grid. The measurement techniques described included PMUs and smart meters.
- GIS (A geographic information system) was introduced as a planning tool to facilitate locating important components.
- The relationship of MAS to the smart grid developmental process was also described.

References

[1] A. Englebrecht. Computational Intelligence: An Introduction, John Wiley & Sons, 2007, ISBN-10: 0470035617

[2] M. Dorigo and T. Stuzle. Ant Colony Optimization. Massachusetts Institute of Technology, Cambridge, 2004, ISBN-10: 8120326849

[3] J. Si, A.G. Barto, W.B. Powell, and D.C. Wunsch Handbook of Learning and Approximate Dynamic Programming. Wiley-IEEE Press Series on Computational Intelligence, 2004, Online ISBN: 9780470544785

[4] W.H. Zhange and T. Gao. “A Min - Max Method with Adaptive Weightings for Uniformly Spaced Pareto Optimum Points.” Computers and Structures 2006, 84 (28), 1760 – 1769, doi: 10.1016/j.compstruc.2006.04.007

[5] P.K. Skula and K. Deb . “On Finding Multiple Pareto - Optimal Solutions Using Classical and Evolutional Generating Methods .” European Journal of Operational Research 2007, 181, 1630 – 1652, doi: /10.1016/j.ejor.2006.08.002