Communication Technologies for Smart Grid

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Outline

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- Smart Grid Communications Network (SGCN)
- Wired Communications Technologies
- Wireless Communications Technologies
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Most Popular Definition of Smart Grid

The Smart Grid is **"an automated, widely distributed energy delivery network characterized by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances"**

- **A smart grid has capable of providing electrical power from multiple and widely distributed sources, like from wind turbines, solar power systems, and perhaps even plug-in hybrid electric vehicles.**
- **The main aim of the smart grid system is to reduce energy cost and consumption as well as improve the reliability and transparency of the energy supply chain**

Smart Grid

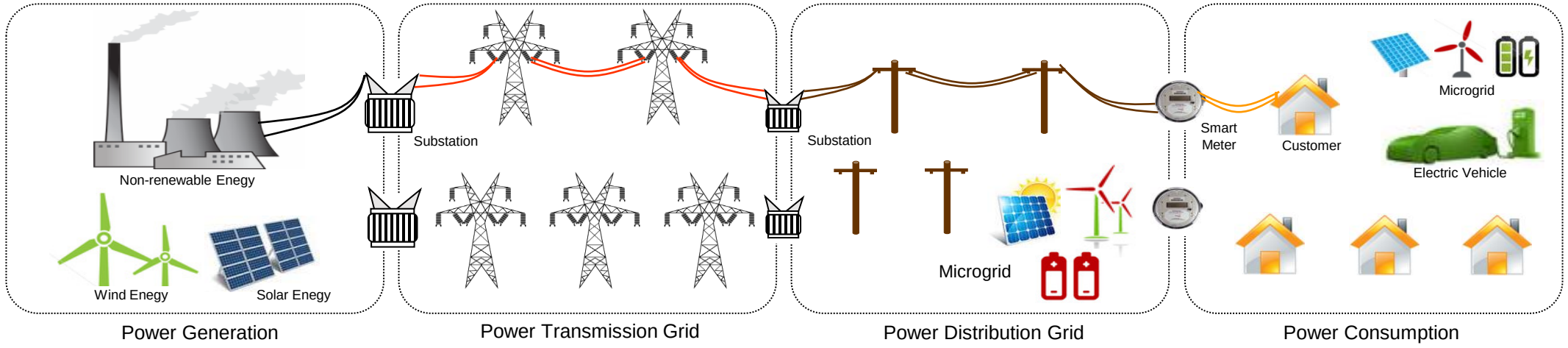
- **“Smart Grid” really means improving existing power systems by making them “smarter”. By integrating modern information and communications technology (ICT) into a power system.**
- **Smart Grid combines electrical network and smart digital communication technology.**
- **The communication infrastructure is critical for the successful operation of the modern smart grids.**
- **We can make it “smarter” by providing enhanced sensor, control and communication capabilities.**
- **These enhancements enable us to generate, collect, analyze and react to much more data about the physical condition of the electrical grid than before.**

Smart Grid Communications Network (SGCN)

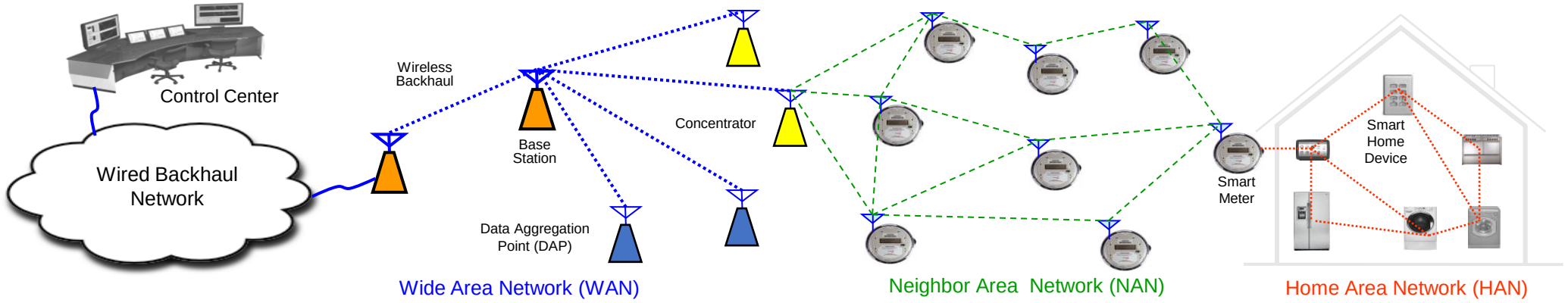
Successful build up Smart Grid Communications Network (SGCN) that can support all identified SG functionalities

- **Advanced Metering Infrastructure (AMI)**
- **Demand Response (DR)**
- **Electric Vehicles (EVs)**
- **Wide-Area Situational Awareness (WASA)**
- **Distributed energy resources and storage**
- **Distribution grid management, etc.**

The overall layered architecture of SG



(a) Power System Layer



(b) Communications Layer

Wide Area Network (WAN)

- A WAN forms the backbone of the communication network in the power grid.
- It connects smaller distributed networks such as transmission substations, control systems and protection equipment, e.g., Supervisory Control and Data Acquisition (SCADA), Remote Terminal Unit (RTU), and Phasor Measurement Unit (PMU) to the utility companies' control centers.
- **Neighborhood Area Networks (NANs):** Gathers a huge volume of various types of data and distributes important control signals from and to millions of devices installed at customer premises. ⟹ vulnerable to privacy and security
- **Home Area Network (HAN):** is a network in a user's home where all the laptops, computers, smartphones, and other smart appliances and digital devices are connected into a network.

Smart Grid Communication Technologies

- **To achieve interoperability between different domains, various types of communication technologies, including both wired and wireless technologies, are needed to support the infrastructure.**
- **Communication technologies utilized in SG can be wired or wireless.**
- **Most power systems use a combination of different wired and wireless technologies, depending on the infrastructure.**
- **Wireless communication alternatives have some advantages over wired communication, such as low cost and connectivity in inaccessible areas.**
- **Wired communications can support more coverage area with potentially very high capacity.**

Wired Comm. : Power Line Communication (PLC)

- **Power line communication allows data exchange between devices through electrical power lines. PLC is implemented by adding a modulated carrier signal to the power cables.**
- **The data rate of OFDM based communication can be up to several Mbs.**
- **Data rates and distance limits vary widely over many power-line communication standards.**
- **Low-frequency (about 100 - 200 kHz) carriers impressed on high-voltage transmission lines may carry one or two analog voice circuits, or telemetry and control circuits**
- **Higher data rates generally imply shorter ranges.**
- **Suffer from Noisy channel conditions & Electromagnetic interference (EMI)**

Wired Comm. : Optical Fiber Communications

- **Fiber optical communication is well suited for control and monitoring, and backbone communication in WANs**
- **Has the advantages of long range, high bandwidth, and high data rate, and not being susceptible to electromagnetic disturbances**
- **Fiber optics are most commonly used for backbone communication, and to connect substations to the utility companies control centers**

- **Ethernet**

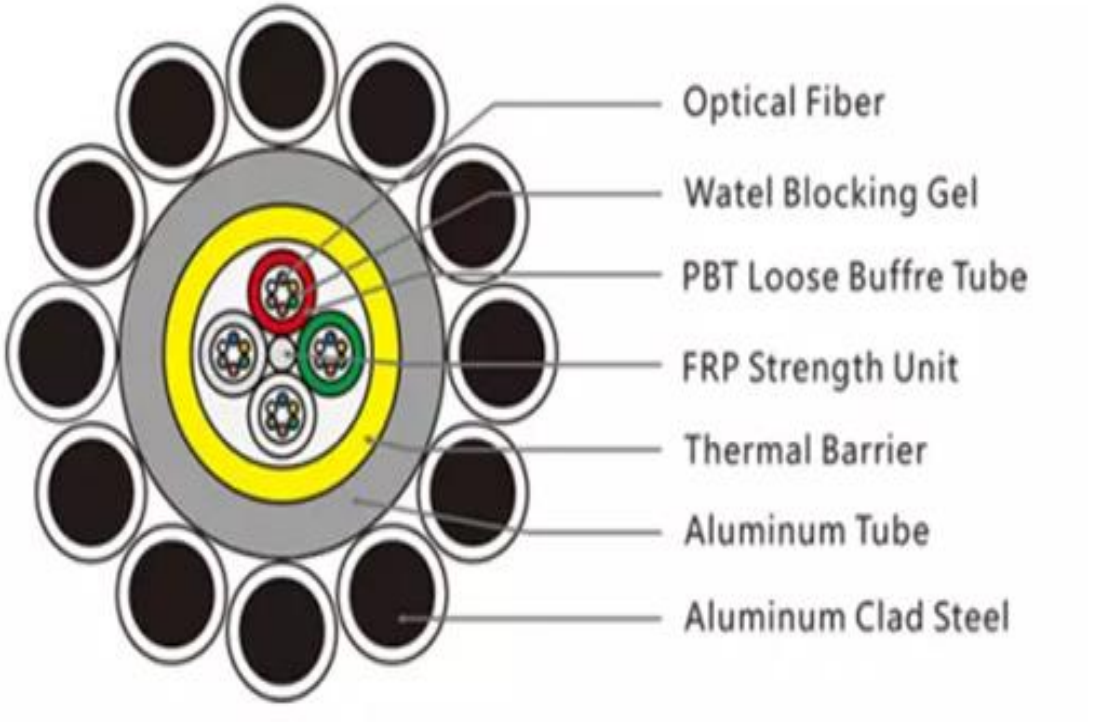
✓ **Suited for communication in WAN between substations and control centers.**

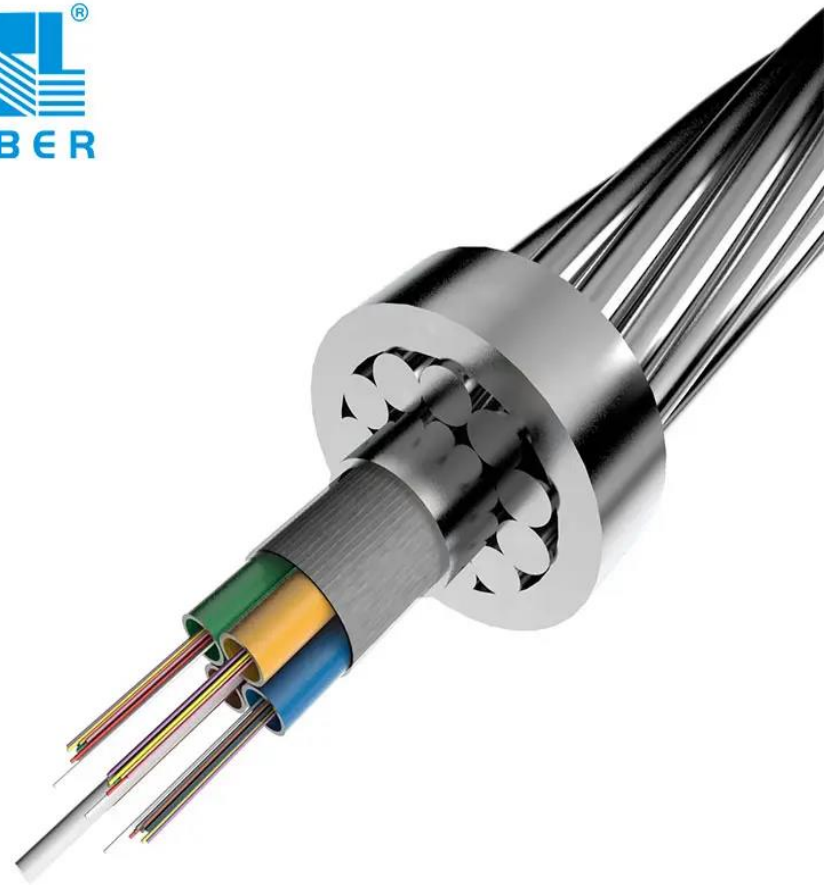
✓ **Advantages with this form of communications is its high availability and high reliability.**

✓ **Ethernet is also used in HAN for the communication between smart meters and home central**

Optical Ground Wire OPGW

- **Optical Ground Wire, abbreviated as OPGW, is an aerial shield wire containing optical fiber.**
- **A certain number of optical fiber strands in this wire are inside one or more aluminum or stainless steel tubes.**
- **OPGW: combine two functions: grounding and communications**





https://www.gl-fiber.com/opgw-typical-designs-of-aluminum-pbt-loose-buffer-tube-4.html

Advantages of OPGW Cables

- **Fiber optic communication cables are neither subject to electromagnetic interference nor do they cause any interference.**
- **Aerial fiber optic cables and any related equipment can be electrically insulated from system components.**
- **The technology offers very long information transmission distances of up to 80 km (50 miles) without requiring the use of repeaters.**
- **Fiber optic technology offers extremely high transmission capacity which can result in data transfer of information at rates of up to 3 gigabytes per second (Gbps)**
- **Overhead transmission power line corridors provide the telecommunications industry with cost-effective alternative routes and at the same time benefit the electric utilities by generating additional revenues using existing facilities.**

Wireless Communication

- **Cellular Communication**

- **Advantages with using cellular communication technology is that it is already existing, it has widespread coverage, low cost, and high security.**
- **One disadvantage with cellular communication is the fact that the network is shared with many other users, this can in some cases result in network congestion.**
- **The fifth generation mobile communication network (5G) utilizes wide frequency range including millimeter wave (mm) spectra and operate at higher frequencies than LTE/4G system.**
- **the bandwidths of 5G are higher than previous generations.**
- **The advantages of 5G over earlier generations include higher data rate and low communication latency, improved security and reliability, low power consumption, and ability to connect a higher number of devices.**

- **WiMAX (IEEE 802.16)**
  - **Worldwide inter-operability for Microwave Access (WiMAX) is a short range wireless communication technology based on the IEEE 802.16 standards with a data rate up to 70 Mbps and a range of 50 km.**
- **ZigBee (IEEE 802.15.4)**
  - **ZigBee is an open wireless mesh network standard based on the IEEE 802.15.4 standard. It is a short range, low data rate, and energy efficient technology.**
  - **ZigBee operates on different frequency bands:**
    - **868 MHz (20 kbps per channel)**
    - **915 MHz (40 kbps per channel)**
    - **2.4 GHz (250 kbps per channel)**

- **Wi-Fi (IEEE 802.11)**

  - **Wi-Fi technology, based on the IEEE 802.11 family of standards**
  - **is a wireless networking technique that is being widely used for Internet access. It can also be a good choice in the context of smart grid, which enables consumers to monitor the improvement their energy use**
  - **Wi-Fi solutions are already being utilized in a number of devices that contribute to the so-called smart home**

- **Free-Space Optical (FSO) Communications**

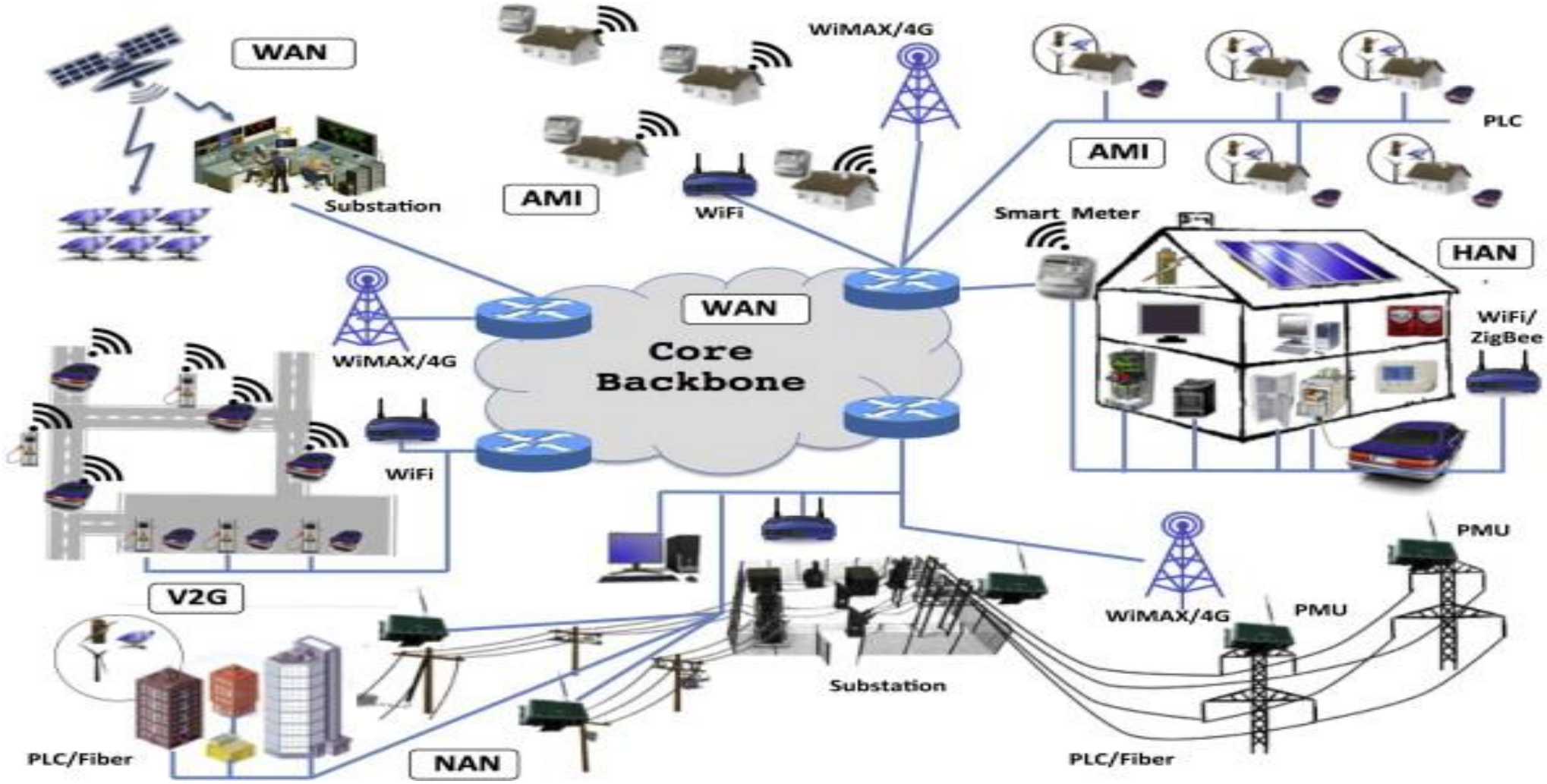
  - **Is one of the most promising technologies addressing the problem of large bandwidth and data rate requirements, as well as the "last mile bottleneck".**
  - **The FSO system functions by transmitting modulated laser light through the air between the transmitter and receiver** → **No need for Antennas**

Comparison of typical communication technologies for a smart grid

Technology	Standards	Data rate[a]	Distance covered	Latency	Cost	Scope
ZigBee	IEEE 802.15.4	Low	100 m	50 ms	Low	HAN
WLAN	IEEE 802.11ax	Very high	70 m	3 ms	Medium	HAN and NAN
	IEEE 802.11ac	High	70 m	10 ms	Low	HAN and NAN
	IEEE 802.11n	Medium	50 m	15 ms	Low	HAN
	IEEE 802.11g	Medium	50 m	15 ms	Low	HAN
Cellular	2G	Low	35 km	300 ms	Low	HAN and NAN
	3G	High		100 ms	Low	HAN, NAN, and WAN
	4G	High		10 ms	Low	HAN, NAN, and WAN
	5G	Very high		<1 ms	Medium	HAN, NAN, and WAN
WiMAX	IEEE 802.16	Medium	30 km	50 ms	High	NAN and WAN
PLC	\	High	1–5 km	5 ms	Medium	HAN and NAN
Fiber-optic	\	Very high	>100 km	3 μs/km	High	NAN and WAN

[a]*Data rate: low (<1 Mbps), medium (1–100 Mbps), high (100 Mbps-1 Gbps), and very high (>1 Gbps).*

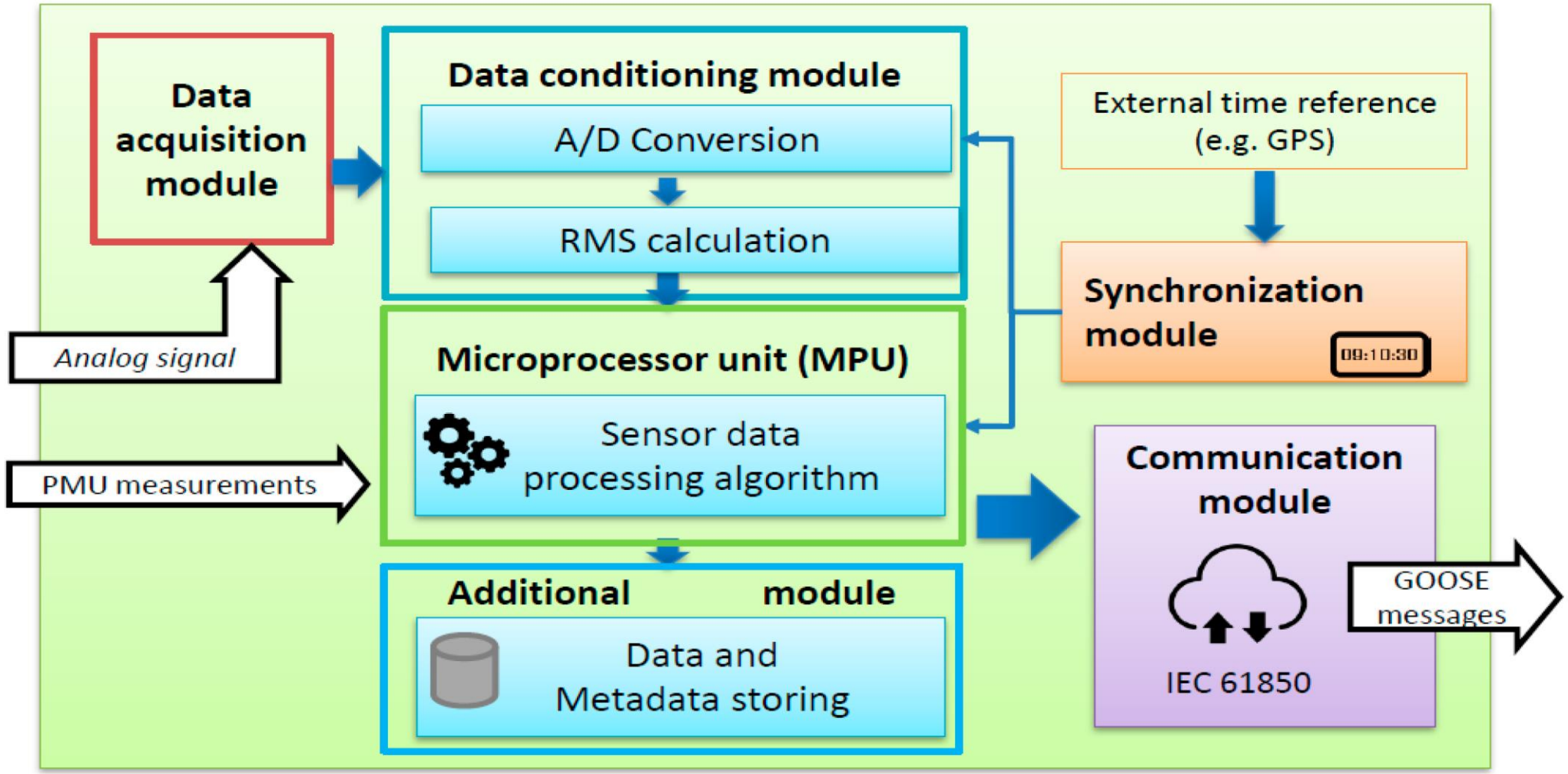
Infrastructure



Wireless Sensor Network

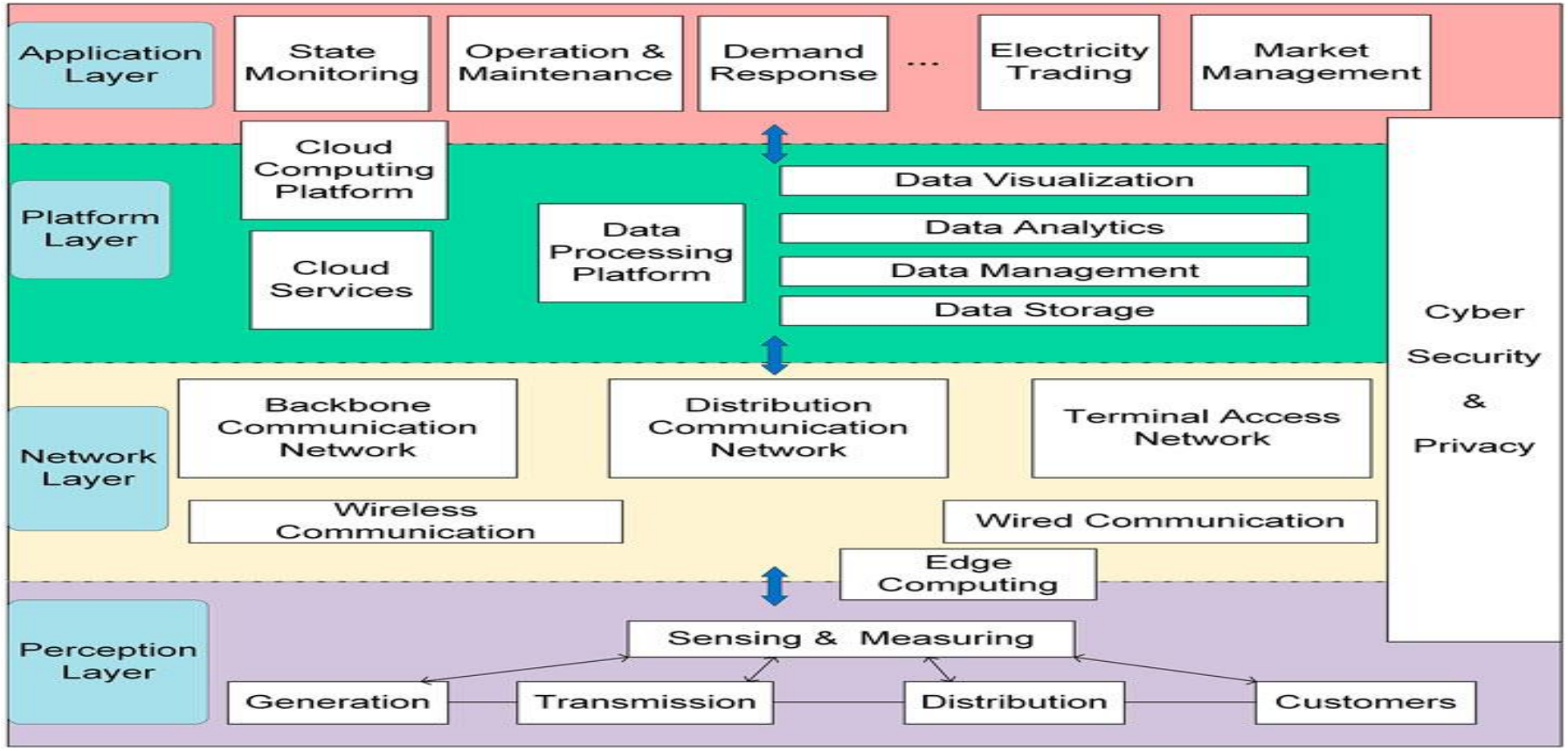
- **The wireless sensor network plays a critical role in many fields of the smart grid, such as wireless automatic meter reading, remote system monitoring, and equipment fault diagnosis.**
- **Wireless sensor networks are inherently limited to battery life, processing capability, and cache capacity**
- **Intelligent sensors can increase the reliability.**
- **Typical sensor is a phasor measurement unit (PMU) that is used in wide-area measurement systems (WAMS) to measure the electric waves on an electricity grid using a common time source for synchronization**
- **Each sensor gathers the operating status of the transmission line and monitors its surrounding environment.**
- **Each sensor also delivers its monitoring data to the control center through the nearest gateway.**

Structure of the relay-based smart sensor



Smart Grid and 5G

- **The main idea of the Internet of Things (IoT) network is the integration of any objects, any time, anywhere into the global network → power system monitoring**
- **Power Internet of Things or PIoT: Integrating IoT into power grid**



Standards

- **Development Organizations (SDOs):**
  - **National Institute of Standards and Technology (NIST),**
  - **American National Standards Institute (ANSI),**
  - **International Electrotechnical Commission (IEC),**
  - **Institute of Electrical and Electronics Engineers (IEEE),**
  - **International Organization for Standardization (ISO), International Telecommunication Union (ITU),**
  - **etc.**
- **Alliances:**
  - **ZigBee Alliance, Wi-Fi Alliance, HomePlug Powerline Alliance, Z-Wave Alliance, etc.**

Future Smart Grid?

- **What will the Future Look Like?**
- **“Smart Grid means you fill up your car with hydrogen but cannot drive it the next day, because your teenage daughter has sold the hydrogen as electricity at peak tariff over the internet, and used the proceeds to charge her mobile phone card.”**

References

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- Smarter Grid in the 5G Era: A Framework Integrating Power Internet of Things With a Cyber Physical System
  https://www.frontiersin.org/articles/10.3389/frcmn.2021.689590/full#B14

Thank You