SMART GRID Technologies

PE/PE/HT/324C

Professional Elective Course

Smart Grid Technologies

- Automatic Voltage Regulation (AVR)
- Automatic Generation Control (AGC)
- Energy Management System (EMS)
- Distribution Management Systems (DMS)
- Demand Side Management (DSM)
- Outage Management System (OMS)
- ~~Wide Area Monitoring System (WAMS)~~
- **Advanced Metering Infrastructure (AMI)**
- **Meter Data Management (MDM)**
- ~~Geographical Information System (GIS)~~

AMI - Definition

- According to the definition of electric power research institute (EPRI), AMI is a system consisting of modern electronic-digital hardware and software, which enables data measurement intermittently and remote communication continuously
- It is defined as a system that measure, collect, transfer and analyze energy usage and communicate with metering devices
- These systems have an infrastructure that can make detailed measurements, collect time-based information constantly and share this information with the parties as needed
- The AMI is the system that collects and analyzes data from smart meters using two-way communications, and giving intelligent management of various power-related applications and services based on that data
- It enables end users to participate in reducing peak demands and in contributing to energy management process
- Further, meters can also capture, receive and execute remote commands like load disconnect/connect

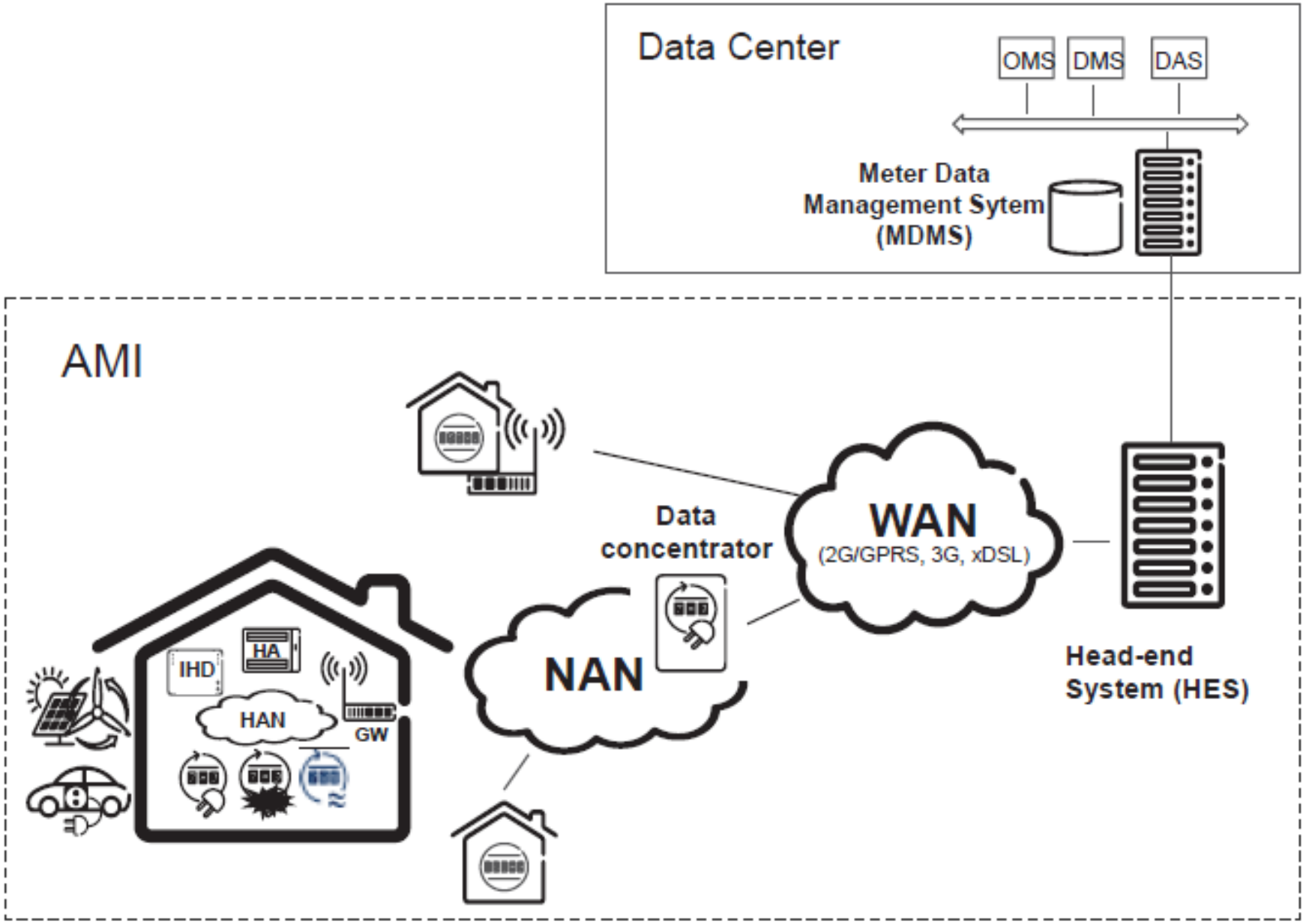
AMI - Features

- The main enabling features of an AMI infrastructure include:
  - smart meter
  - communication medium
  - meter data management (MDM)
  - load monitoring
  - demand response
  - load control
  - tamper detection
  - alarm handling
  - real time energy audit
  - Time of Day (ToD) tariff
  - Head End System (HES)
  - Web app / mobile app

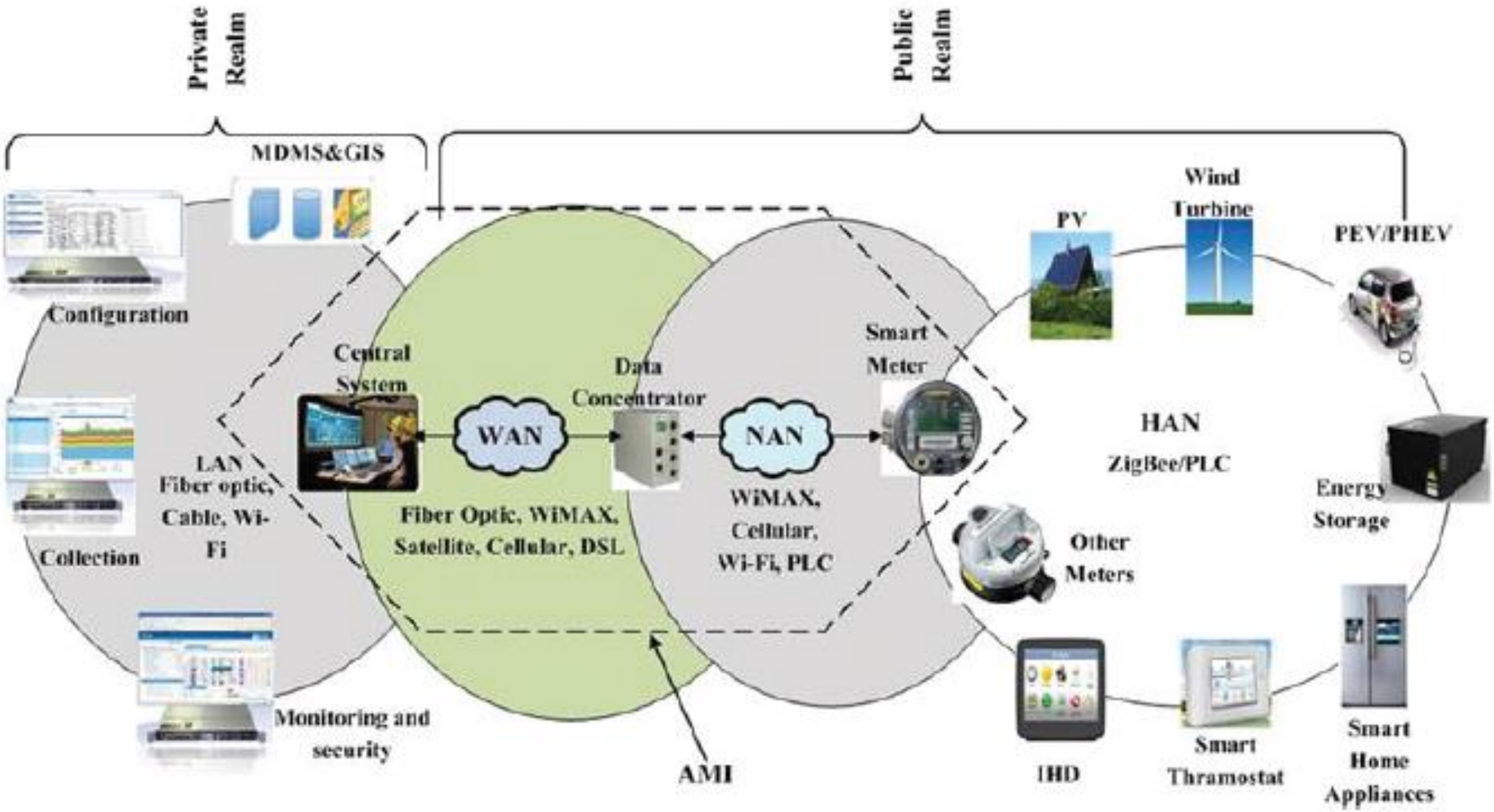
AMI Architecture

- The key components of AMI are:
  - Smart Energy Meter
    - Smart Energy Meters act as a source of information for consumer behaviour pattern, tamper and load control etc.
  - Data Concentrator Unit
    - The data from cluster of smart meters are aggregated by a data concentrator unit (DCU) and then send to the Smart Grid Control Centre
    - It also sends messages /signals received from the utility / consumer for a particular/all meters to the intended recipient.
  - Smart Grid Control Centre
    - Meter Data Acquisition System (MDAS) and Servers are located at Smart Grid Control Centre to perform periodic collection of information from smart meters
    - Logics and validation rules are defined in Meter Data Management System (MDM) to analyze the data
    - MDAS exchange meter data to meter data management systems coupled with analytics on standard data exchange model

AMI Architecture



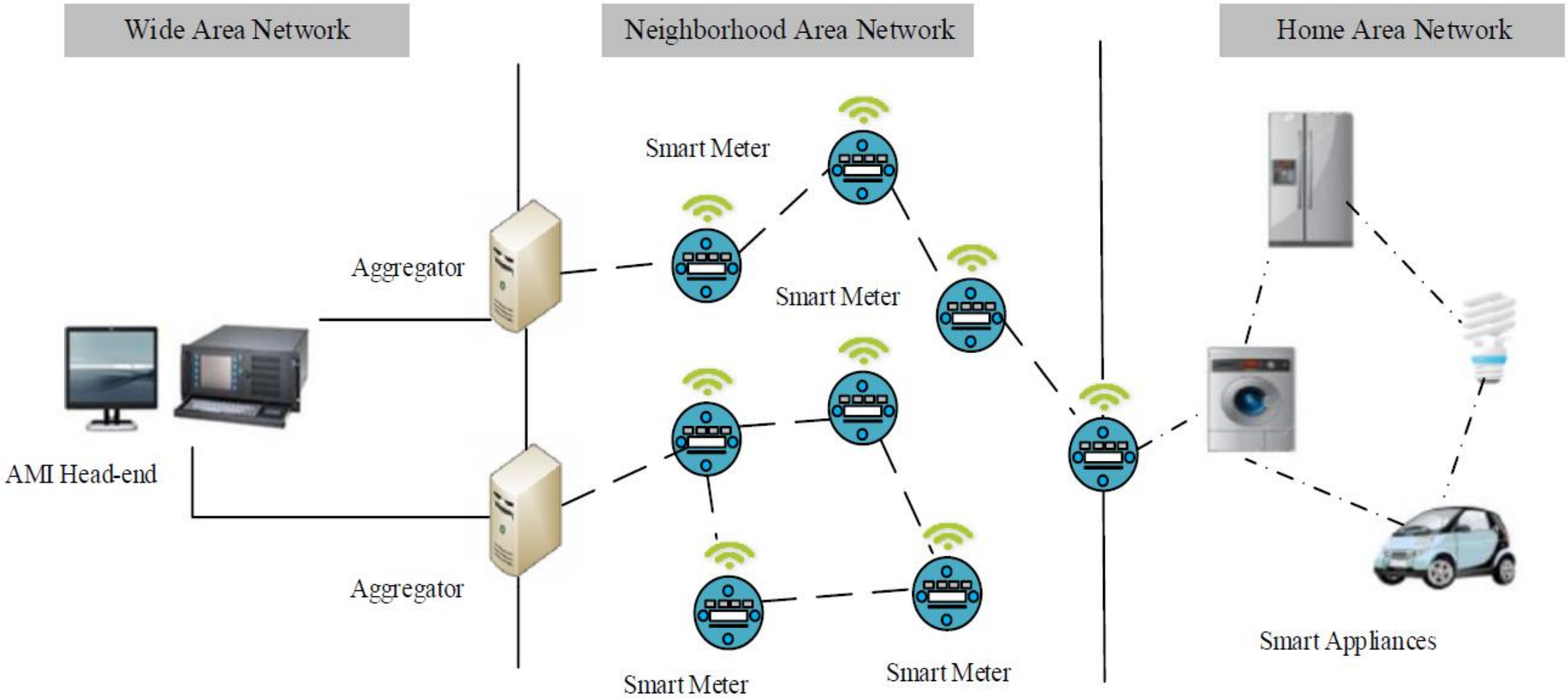
AMI Architecture



AMI Communication

- Communication systems of AMI can be organized into three classes:
  - HAN (Home Area Network)
    - It is used to establish a communication link between the smart meter and the smart appliances, other meters, in-home display, and the RES/EV. HAN provides centralized energy management, services, and facilities. The communication protocol can be a wired or wireless media.
  - NAN (Neighborhood Area Network)
    - It is used to transfer the data between neighboring smart meters
    - It facilitates diagnostic messages, firmware upgrades, and real-time messages
    - ZigBee communication protocol is widely used in NAN due to high speed of data transferring and low cost
  - WAN (Wide Area Network)
    - Some smart meters are connected to a remote server through a WAN
    - GSM, GPRS, 3G/4G, and WiMAX communication technologies can be used to connect the meter to the WAN

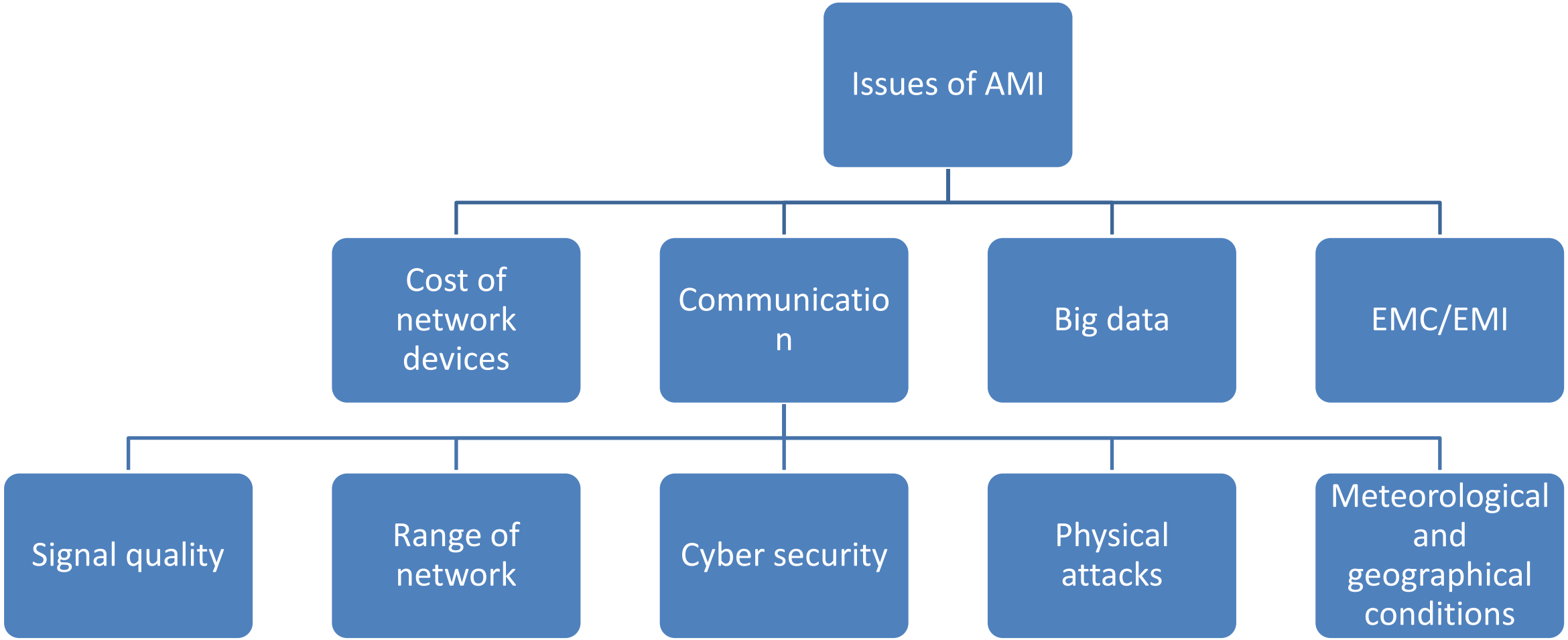
AMI Communication



AMI – In-Home Displays

- All data and notifications are transmitted by means of wireless communication protocols from the smart meters to home display devices
- Mobile phones and tablet PC can be converted to the interfaces of in-home displays via the application software to be installed
- Customer may monitor real-time energy flow and electric parameters, record power outages, contingences, blackouts, alerts, meteorological conditions, tariff, and assess load diagram of previous days or months

AMI – Challenges and Issues



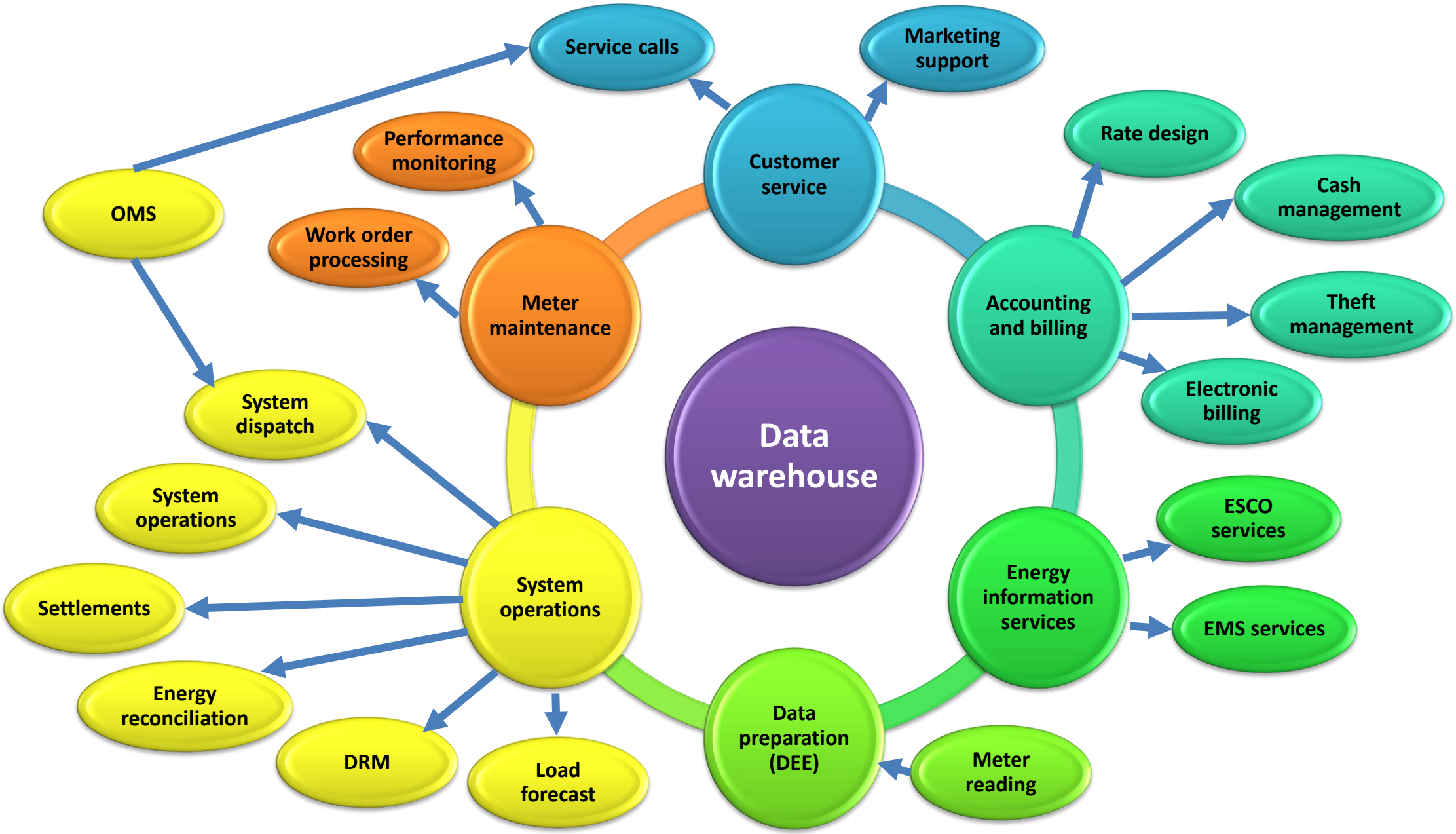
Security in AMI

- Due to the critical role of AMI in the SG, AMI security is special importance for the security of the SG.
- AMI security is required to protect both communication networks and power grid, because these two systems need to ensure their availability of access as well as survivability in different scenarios
- In a communication network, latency (delay) needs to be limited and bandwidth needs to be guaranteed, whereas data manipulation (placement of false data), destruction of data, and unauthorized access should be prevented
- Security of a power grid needs to ensure reliability, power quality, and stability
- Security between the two systems must be coordinated because the power grid and communication network can be used to launch attacks against each other
  - For instance, because the power supply in SG will be controlled by users, manipulation of usage data could create a fictitious grid imbalance leading to voltage variations that can create large-scale failures
  - Similarly, if the state information of the grid is poisoned, the grid could be destabilized with a potential for physical damage
- Physical damage could occur through overheating of transformers and relays or through voltage fluctuations in appliances

AMI Functionalities

- The AMI system shall help utility to manage their resource and business process efficiently
- AMI system shall support the following minimum functionalities:
  - Remote Meter data reading at configurable intervals
  - Time of day (TOD)/TOU metering
  - Pre-paid functionality
  - Net Metering/Billing
  - Alarm/Event detection, notification and reporting
  - Remote Load Limiter and connection/ disconnection at defined/on demand conditions
  - Remote firmware upgrade
  - Integration with other existing systems like IVRS, Billing & collection software, GIS mapping, consumer indexing, new connections & disconnection, analysis software, Outage Management System (OMS) etc.
  - Import of legacy data from existing modules/ MDAS where ever possible
  - Security features to prevent unauthorized access to the AMI including Smart meter & meter data etc. and to ensure authentication of all AMI elements

AMI Summary


Service calls
Marketing support
Performance monitoring
Customer service
Rate design
OMS
Cash management
Work order processing
Meter maintenance
Accounting and billing
Theft management
Electronic billing
System dispatch
Data warehouse
System operations
ESCO services
Settlements
System operations
Energy information services
EMS services
Energy reconciliation
Data preparation (DEE)
DRM
Meter reading
Load forecast

Smart Energy Meter

Smart Energy Meters

EVOLUTION OF ENERGY METERING

Electromechanical

- Robust
- Mechanical dial
- No battery
- Limited measurements (No MDI, V, I etc.)
- Exposed to theft
- Less accurate
- Errors with ageing
- Regular calibration

Static

- No frictional Losses
- Better accuracy
- Better low V or I performance
- Digital display
- Difficult to tamper
- Able to measure Kwh, kVrh, kVAh, MDI etc.
- Accurate
- ToU tariff (Fixed)

Unresolved Issues

Higher AT&C Losses

- Tamper
- Bypass
- Wrong reading

Planning Support

- Inadequate data
- No interval data
- No Usage pattern on time scale

Consumer Power Quality Monitoring

- Voltage
- Outage

Lesser Consumer Satisfaction

- No visibility of consumption pattern

SMART METERS

- Static Watt hour meters consisting of
  - ❑ Built in / Plugged in Bi-directional Communication Module
  - ❑ ToU registers
  - ❑ Internal Connect-Disconnect Switch (In Direct Measurement)
  - ❑ Capable of Forward (Import) or both Forward (Import) and Reverse (Export) Energy Management- Net metering
  - ❑ Remotely accessible for collecting data / events, programming, firmware upgrade etc.
  - ❑ Can be configured as Prepaid / Postpaid

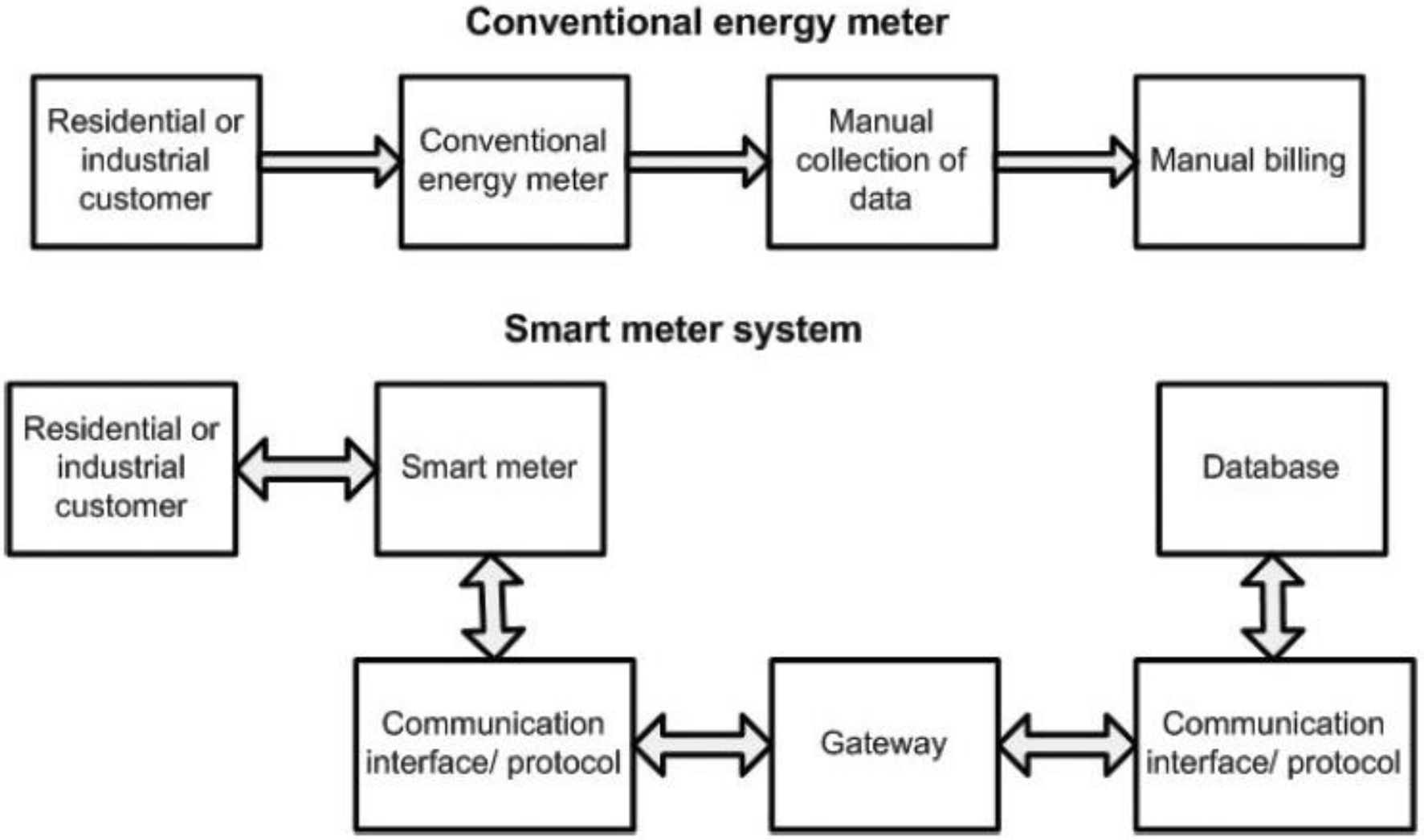
Energy Accounting	Outage Management	Better Billing Efficiency	Real time Tamper Alert	Usage Pattern	Demand Response	Power Quality

- Standards
  - ❑ BIS IS 16444 : PART 1 : 2015---AC Static Watthour Smart Meters, Direct Connected Class 1 and 2 – Specification
  - ❑ BIS IS 16444 : PART 2 : 2017---AC Static Transformer Operated Watthour and VAr-hour Smart Meter, Class 0.2S, 0.5S and 1.0S - Part 2 Specification

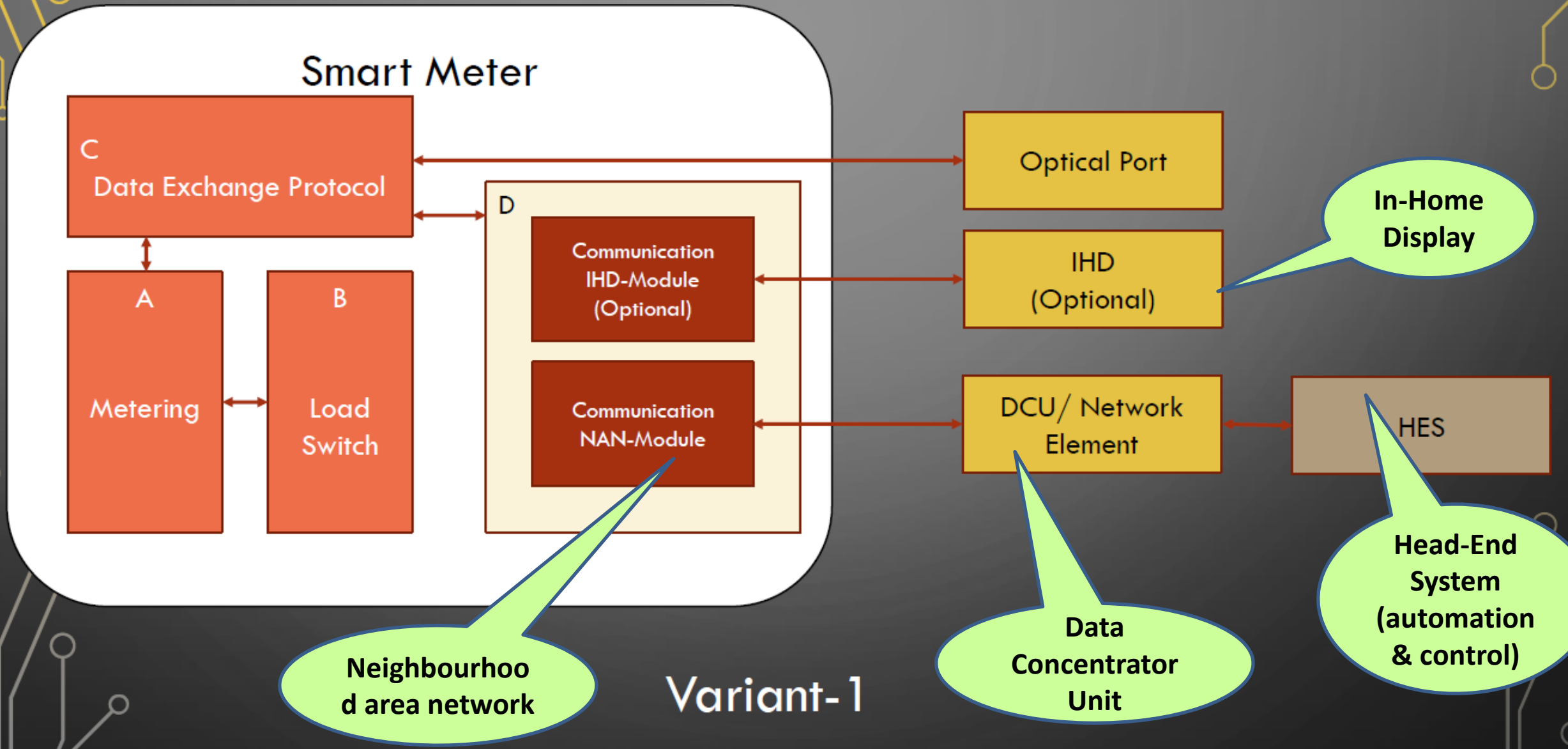
Smart Energy Meters

- Smart energy meter serves as a gateway between utility and consumer
- A smart Meter is an advanced meter that measures electrical magnitudes such as current, voltage, frequency, and their magnitudes and dedicates more detailed data than a traditional meter
- Implementation of AMI softwares into these meters support variety of controls, facilities and features
- Smart meters consist of control and calibration facilities and features
- Customers should be able to see the meter information since this information is the base for billing
- A display is also needed for DSM at customer side
- Timing synchronization is critical for reliable transmission of data to central hub or other collector systems for data analysis and billing
- Smart meter data has an important role in several Smart Grid applications and enables novel data analytics tasks, such as energy consumption behavior, tamper detection, outage management, automated demand response and energy feedback
- It also empowers consumers for better energy management
- In addition, by integrating smart meters in electricity grid, utility companies can detect and identify electricity theft and unauthorized consumption in view of improving the power quality and distribution efficiency

Smart Energy Meter Architecture



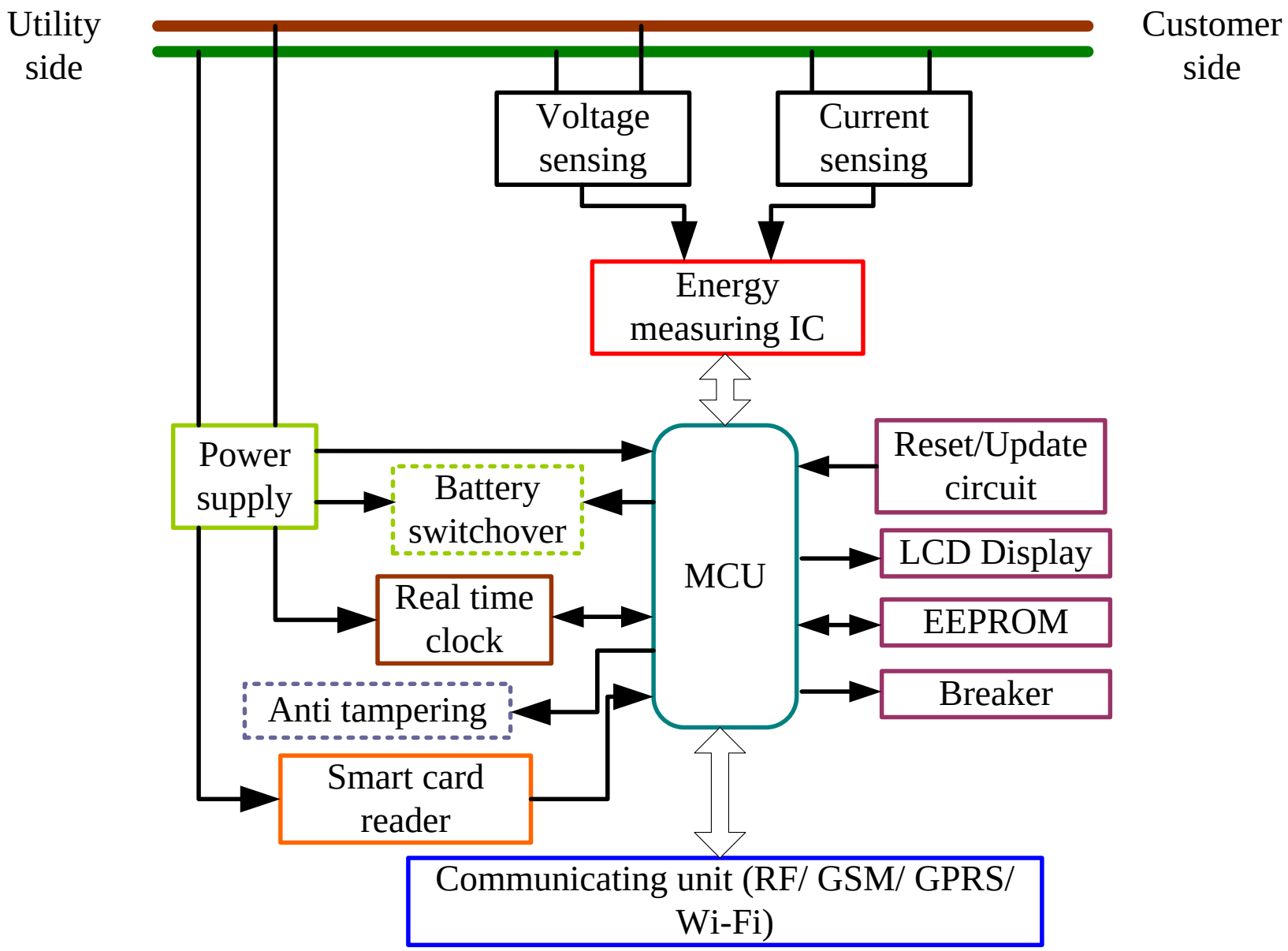
SMART METER ARCHITECTURE



Variant-1

Smart Energy Meters

Smart Energy Meter Internal Block Diagram



Smart Energy Meter Components

- A smart meter consists of miscellaneous hardware:
  - step down transformer
  - microprocessor core
    - It carries out various tasks, which are energy calculations, display electrical parameters, smartcard reading, data and power management, tamper detection, communication with other devices
  - a real-time clock (1 GHz frequency)
    - It keeps track of the current time. It provides time and date information and alarm signals
  - EEPROM memory unit
  - LCD for in-home display
    - Consumers can view instantly instantaneous energy consumption, notifications, warnings, and all meteorological data coming from service providers and market section of distribution companies
  - Communication module
  - Anti-tampering indicator module

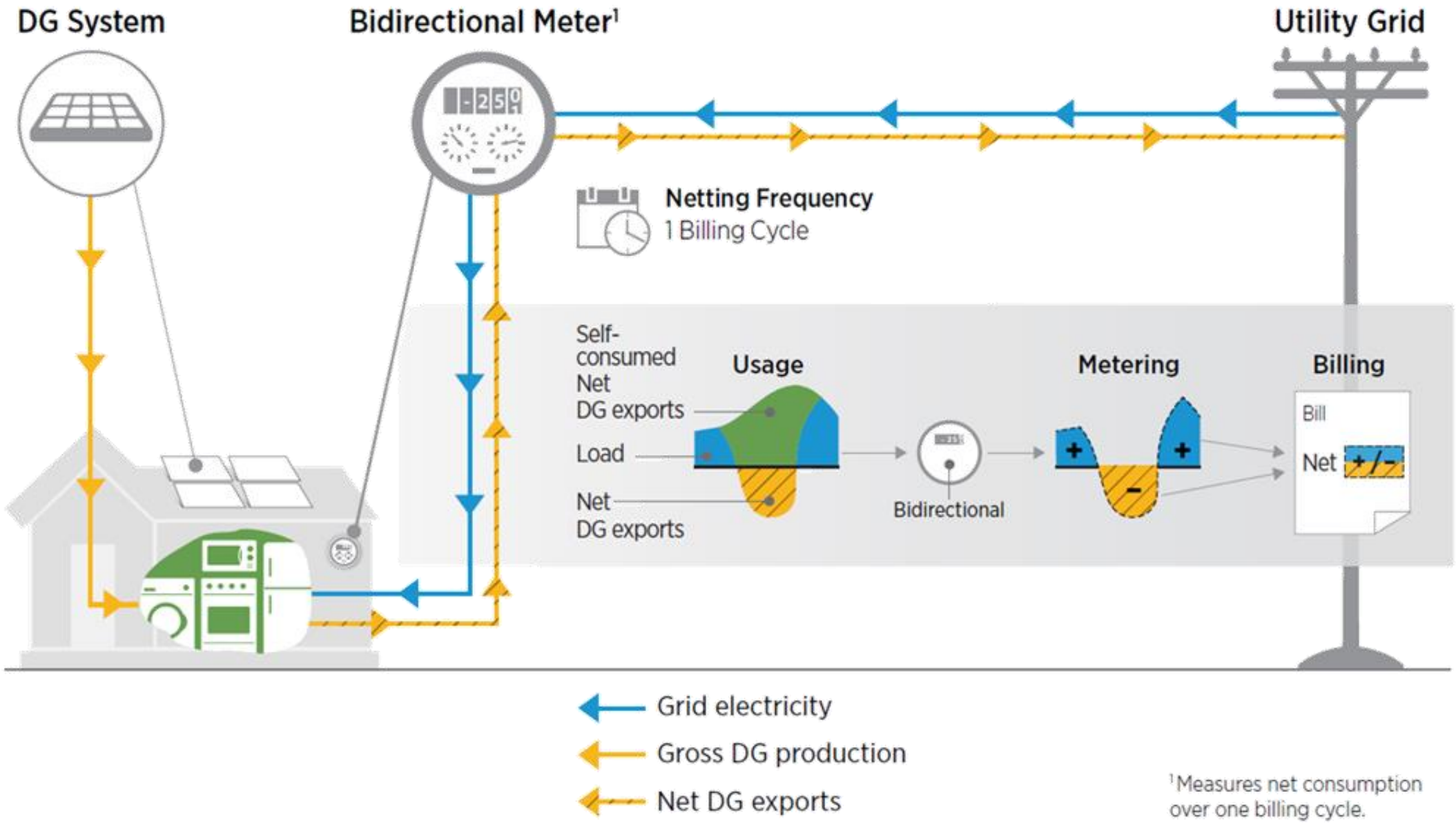
Smart Energy Meter Functionalities

- Quantitative measurement:
  - Smart meters have to accurately measure the quantity of the medium by using various topologies, physical principles, and approaches.
- Control and calibration:
  - Smart meters should be providing ability to compensate the small variations according to each system type.
- Security communication:
  - The meters have ability receiving operational commands and sending stored data as well as upgrades for its firmware trustworthily.
- Power management:
  - Smart meters have to help the system to exactly maintain its functionality when the primary source of energy is lost.
- Display:
  - Smart meters will send and display information usage of electricity energy to customers for billing in real time
  - Besides, the information of real time consumption displayed on smart meters helps customers to manage their demand efficiently
- Synchronization:
  - Typically, smart meters transmit data of customers to the collector systems or central hubs for billing and data analysis. Hence, timing synchronization is very important for reliable transmission of data, particularly in case of wireless communication.

Smart Energy Meter Uses

- Data collected by smart meters is a combination of parameters such as a unique meter identifier, timestamp of the data, and the electricity consumption values
- Based on the information, smart meters can monitor and execute control commands for all home devices and appliances at the customer's premises remotely as well as locally
- Besides, smart meters can communicate with other meters in their reach using home area network (HAN) to collect diagnostic information about appliances at the customer as well as the distribution grid
- Moreover, smart meters can be programmed such that, only power consumed from the utility grid is billed whereas the power consumed from the distributed generation sources or storage devices owned by the customers is not billed
- As a result, they can limit the maximum electricity consumption, and can terminate or reconnect electricity supply to any customer remotely

Smart Energy Meter Uses



Meter Data Management (MDM)

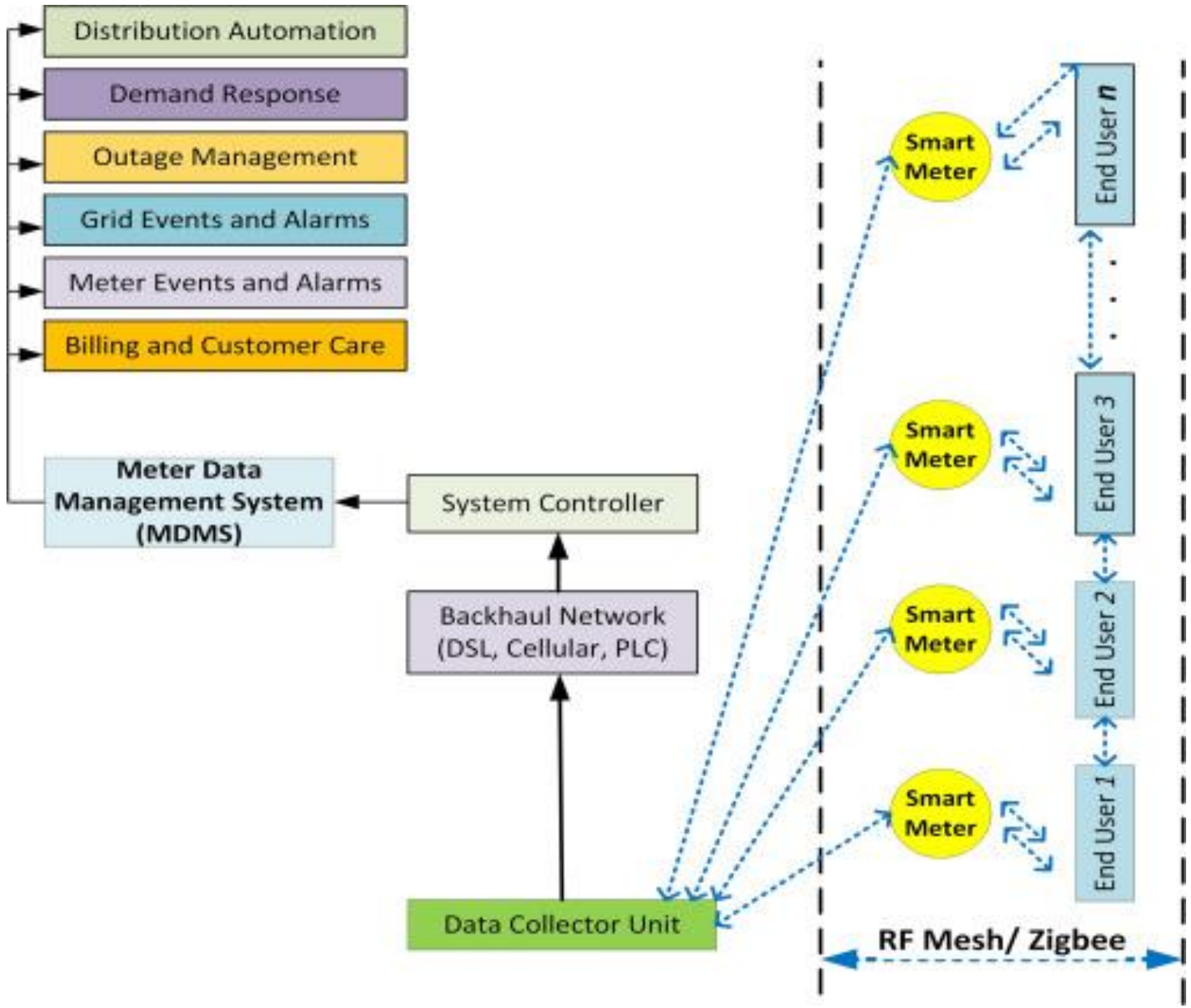
AMI – Meter Data Management (MDM)

- The MDM system shall support storage, archiving, retrieval & analysis of meter data and various other MIS along with validation & verification algorithms
- It shall act as a central data repository
- MDM shall have capability to import raw or unvalidated data in defined formats and export the processed and validated data to various other systems sources and services in the agreed format
- It shall provide validated data for upstream systems such as billing, consumer Information system, customer care, analytics, reporting, Network planning & analysis, load analysis/forecasting, Peak Load Management, Outage management etc.
- MDM should also support the future requirement of utility and should support the integration of other smart grid functionalities like Distribution Transformer Health Monitoring system, self-healing system etc. as and when implemented by the utility
- The MDM shall have the ability to selectively choose which data to be maintained and which to be purged or archived as per requirement of Utility (user selectable)

AMI – Meter Data Management (MDM)

- Data management systems consist of following different parts:
  - Consumer Information System (CIS), billing system
  - Outage Management System (OMS).
  - Enterprise Resource Planning (ERP)
  - Power quality management
  - Load forecasting systems
  - Mobile Workforce Management (MWM)
  - Geographic Information System (GIS)
  - Transformer Load Management (TLM)

AMI – Meter Data Management (MDM)



Functional Requirements of MDM

- Asset Management
- AMI Installation Support
- Data Validation, Estimation, and Editing (VEE)
- Alarm Generation
- Billing Determinants Calculations
- Exception Management
- Customer Service Support
- Analysis
- Reporting
- Revenue Protection Support
- Demand Control/Demand Response Support
- OMS/ other smart grid functionality support
- Additional features
  - Net metering
  - Pre-paid functionality

Functional Requirements of MDM

- Asset Management
  - The MDM shall maintain information and relationships between the currently installed meter location (apartment, shop, industry/ address etc.), Consumer information (Name etc.), Consumer account no, Meter ID, Type of Meter (type of consumer, 1 phase/3phase, with or without relay, etc.), Meter configuration (Demand integration period, Load profile capture period etc.), GIS supplied information (longitude, latitude , connection with feeder/ transformer/ pole etc.) etc.
  - Ability to report and log any damage / deterioration in the meter attributable to consumer /utility
- AMI Installation Support
  - The MDM shall also support device lifecycle management from device registration, installation, provisioning, operations and maintenance to decommissioning etc.
  - The MDM shall provide a reconciliation report that identifies the meters that have been installed but not communicating for a designated (configurable) period
  - MDM shall generate reports on the number of meters installed in comparison to the number of meters successfully communicating

Functional Requirements of MDM

- Meter Data
  - The MDM shall accept input, process, store, and analyze Meter data from HES and also meter data collected through hand held meter reading instruments and manual meter reads
  - The MDM should accept input, process, store, and analyze non-billing meter data such voltage and power quality data (like under/over voltage etc) as they are available from AMI Head End Systems
  - The MDM should also support scheduled and on-demand meter reads and pinging of meter energized states by authorized users and by other utility systems
  - The MDM shall provide storage of all collected Meter Data, events and alarm
  - It shall have capacity of storing 5 years data or more via archiving.
  - Provide complete history and audit trail for all data collected from meters including commands sent to meters and other devices for 30 days (configurable period)
  - Execute on-demand read processes
  - Handle special metering configurations like net metering/multiple meters at same premises.
  - Data Integrity- AMI Implementing Agency (AIA) shall ensure data integrity checks on all metered data received from data collection systems

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Functional Requirements of MDM

- Data Validation, Estimation, and Editing (VEE)
  - The validation and estimation of metered data shall be based on standard estimation methods
  - The MDM should also support and maintain following data-
    - Registered Read Data including register reads, daily billing cycle, as well as derived billing determinants like TOU
    - Calculated Data that is derived or computed such as billing determinants and aggregated loads.
    - Event data storage of all collected event and alarm data from meters, network equipment, and MDMS itself

- Alarm Generation
  - MDM shall flag and trigger alarm when the following anomalies occur:
    - Total read decrements within a billing cycle
    - Read increments are more than configurable threshold
    - Resets (to zero)
    - Future or old read dates
    - Too high read

Functional Requirements of MDM

- Billing Determinants Calculations
  - The MDM shall allow configuring multiple TOU/TOD options (e.g. the number and duration of TOU rate periods) by customer type, tariffs and day type (weekend, weekdays, and holidays) and by season.
  - The MOD shall determine billing mechanism based on:
    - Total Consumption
    - Consumption in different time blocks for ToU billing
    - Maximum Demand (in kW and kVA)
    - Number of tamper counts
    - Average power factor
- MDM shall have the ability to properly account for special metering situations such as check metering, sub metering, prepaid metering and net metering when calculating billing determinants and sending them to billing and other systems
- MDM shall have the ability to properly account for special situations including, but not limited to, curtailment requests, demand response scenarios when calculating billing determinants and sending them to billing software

Functional Requirements of MDM

- Exception Management
  - MDM shall generate exceptions based on configurable business rules including the following:
    - Meter tamper alerts
    - Communication module health alerts for Meter/DCU
    - If the consumption is less/more than pre-defined average consumption
    - Negative Consumption
    - Power outage indications received from the Smart meter
  - MDM shall have the ability to capture and log data exceptions, problems and failures and to generate management reports, provide trend analysis, automate generation of service requests and track corrective actions
  - MDM need to have the ability to group, prioritize, filter and send system generated alarms and events to predetermined email addresses, cellular text messages to phone numbers / SMS / customer care etc.

Functional Requirements of MDM

- Customer Service Support
  - MDM shall provide customers with access to current and historical consumption and interval data, outage flags, voltage and power quality indications
    - The data shall be displayed in graphical and tabular form depending on user choice
    - The solution shall integrate via a user friendly graphical interface.
  - MDM shall support email/SMS notification of configured alarms & events to selected users
  - MDM shall support the web portal or shall have the ability to interface with the 3rd party portal/utility portal to provide the consumer near real time online views of both usage and cost and helping consumers to understand electricity usage and cost information, alerts and notifications and energy savings tips with different levels of detail
  - The portal should support the view for past electricity usage, last week's, yesterday's, current days or other period etc. as per selection
  - The portal should provide user friendly access to consumer for their data via colorful graphs and charts and can download the data into a spreadsheet
- MDM shall support mobile app through which consumer shall be able to log in through android/iOS/Window based mobile app to see information related to his energy consumption
- App shall also provide platform for implementation of peak load management functionality by providing existing tariff & incentives rates, participation options etc.

Functional Requirements of MDM

- Analysis
  - The MDM shall have analysis capability based on configurable business rules including but not limited to the following:
    - Display consumption/load profiles by configurable period (15/30 min, hour, day, month, year etc.) day type (weekday, weekend, holiday, festival wise etc.) and by tariff, customer type, or any user specified collection of meters.
  - Generate peak, normal, & off-peak load patterns by aggregating all loads of DT / Feeder / consumer group.
  - Perform load analysis for different groups and categories of consumers
  - Ability to provide the data to load forecasting, load research or demand response applications and perform error management like: Missed reads and intermittent meter reads before taking into forecasting, load research or demand response
  - Ability to configure the system to effectively visualize consumption trends, identify unusual patterns, and visualize load analysis to understand which assets are being over utilized
  - • Analyzing data to identify new patterns of usage, Setting fraud alert / transformer overload alerts / demand – supply gap alert etc.
  - Ability to receive and store outage and restoration event data from smart meters and outage systems and to log all such events for analysis

Functional Requirements of MDM

- Reporting
  - The solution shall include a list of the standard reports that are provided with the MDM including but not limited to following:
    - Daily data collection report
    - Usage exceptions
    - VEE validation failures
    - Missing interval Read date and times (on hourly, daily, weekly & monthly basis)
    - Physical meter events (install, remove, connect, disconnect) & meter reset report
    - Meter flags
    - Meter inventory
    - defective meters
    - AMI performance measurements
- The MDM shall enable the Utility to deliver reports in standard digital format such as PDF, Excel, etc.
- Ability for GUI (Graphical User Interface) to address all through user driven drop down menu
- In case more than one technology of AMI (example PLC and RF between Smart Meter & DCU) deployed in the field, the MDM shall generate report on the performance and availability of data being delivered per AMI technology

Functional Requirements of MDM

- Revenue Protection Support
  - Ability to analyze meter tampering flags, power outages, usage trends and usage profiles to identify potential energy diversion situations, and produce daily reports, monthly reports and service order requests for investigation.
  - The business rules for revenue protection alerts shall be configurable via a user-friendly interface.
  - The MDM shall filter out revenue protection alerts that may be caused by field activities if the field activity information is provided to the MDM.
  - The MDM shall support the analytics/investigation (i.e. view current and historical usage patterns) to valid suspected revenue protection issues
- Demand Control/Demand Response Support
  - The MDM should support Smart Grid Demand Response programs involving Demand Response (DR) systems as part of PLM
    - Totaling the actual consumption during the DR event
    - Totaling the actual consumption of different groups that participated in the DR event
    - Comparing the actual to baseline consumption for the groups in above
  - The MDM shall support the tracking, monitoring and managing of Smart Meter and events, and monitors customer response to facilitate payment of customer incentives

Functional Requirements of MDM

- OMS/ other smart grid functionality support
  - MDM shall support Smart Grid OMS system as per the requirement of the utility
  - MDM shall support the interfacing with OMS software for providing AMI meter data needed for fault location identification and other requisite services like updating the data after attending the fault etc.
  - MDM should also support the interfacing of other smart grid functionalities like Distribution Transformer Health Monitoring system, self-healing system, electric vehicle etc. as and when implemented by the utility

- Additional features
  - Net metering
  - Pre-paid functionality