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

Power: Instantaneous rate of consumption of energy, How hard you work!
Power = Voltage x Current
Watts = amps times volts (W)
Energy Consumption = Power * Time:

NIST (National Institute of Standard and Technology, USA)

NIST Conceptual Model for Smart Grid
Customers:
The end users of electricity
Typically, three types of customers: residential, commercial, and industrial
Customers may also generate, store, and manage the use of energy.
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
Service Providers:
Organizations providing service to both utilities and electricity 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.
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 to augment power grid operations
The transformation to a smart grid requires integrating
computation, networking, communications and control

Advanced Metering Infrastructure(AMI)
RTU (Remote Terminal Unit)
MTU (Master Terminal Unit)
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

Power Line Communications (PLC)
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.

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.”
Plain Language: in many respects, microgrids are smaller versions of the traditional power grid.

Electric Vehicles (EV)

Data Center Definition
A data center is a building/container used to house computing equipment such as servers, along with associated components such as networking devices, storage systems, power distribution units, and cooling systems.

Common features
• Power: equipped with a guaranteed power supply
• Communications: equipped with high bandwidth connectivity
• Reliability: redundant networks, power and IT infrastructure
• Environment: maintain a specified temperature and humidity
• Security: ensure that the facility and its data remain secure

“Top of Rack” (ToR)
ToR architecture refers to the physical placement of the switch in the top of a server rack. Servers are directly linked to the switch. Each rack usually has two switches. (Q: why two switches?)
All the ToR switches are connected to the aggregation switch. Only a small amount of cables are needed to run from server rack to aggregation switch. Aggregation switch will be further connected to the outside core switches.

Three kinds of IT equipments hosted in a typical data center
§ servers for data processing
§ storage equipment for data storage
§ network equipment for data communications

Uninterruptible Power Supply (UPS)

Data centers are huge energy consumers, in particular cooling systems, and § pay a lot for electricity bill § make power grid instable during peak hours Cooling system uses sea water from the Bay of Finland and reduces energy use

The largest energy consumer in a typical data center is the cooling infrastructure (50%), while servers and storage devices (26%) rank second in terms of energy consumption. [according to the statistics published by the Infotech group] (Note: that these values might differ from data center to data center) A breakdown of energy consumption by different components shows: the cooling infrastructure consumes a major portion of the data center energy followed by servers and storage, and other infrastructure elements.

In order to quantify the energy efficiency of data centers, several energy efficiency metrics have been proposed to help data center operators to improve the energy efficiency and reduce operation costs of data centers.
Two important energy efficiency metrics are
– Power Usage Effectiveness (PUE)
– Data Center energy Productivity (DCeP)

PUE: the most commonly used metric to indicate the energy efficiency of a data center.

$$PUE = \frac{Total\ Power\ Consumption\ of\ a\ Data\ Center}{Total\ Power\ Consumption\ of\ IT\ Equipment}$$

$$= \frac{Total\ Power\ Consumption\ of\ IT\ Equipment + Total\ Power\ Consumption\ of\ nonIT\ Equipment}{Total\ Power\ Consumption\ of\ IT\ Equipment}$$

$$= 1 + \frac{Total\ Power\ Consumption\ of\ nonIT\ Equipment}{Total\ Power\ Consumption\ of\ IT\ Equipment} > 1$$

Good result close to 1.0. Google average 1.12

A good PUE value may not be enough to guarantee the global efficiency of the data center. PUE metric does not consider the actual utilization (applications and workloads) of computational resources, some computation may not be Necessary.

Energy efficiency and energy productivity are closely related to each other.

Energy productivity measures the quantity of useful work done relative to the amount of power consumption of a data center in producing this work.

DCeP measures the useful work performed by a data center relative to the energy consumed by the data center in performing the work

$$DCeP = \frac{Useful\ Work\ Produced}{Total\ Data\ Center\ Power\ Consumed\ for\ Producing\ this\ Work}$$

DCeP metric tracks the overall work product of a data center per unit of power consumption expended to produce this work.
-subjective and may not be easy to define “Useful Work”

Green Data Centers energy-aware, energy-efficient with minimum CO_2 emission designs, protocols, devices, infrastructures and algorithms for data centers

Smart Cooling and Thermal Management
Power Management - Chip Level
Power Management – Server Level
Power Management – Data Center Level

Power Management – Inter Data Center Level

Dynamic voltage and frequency scaling (DVFS) : is a commonly-used technique to save power at chip level power management

Main principle: DVFS reduces the power consumption of CPU by reducing the operating frequency or the supply voltage, as shown by

$$P = CfV^2 + P_{static}$$

physical capacitance

Operating frequency

Supply voltage

The voltage can be reduced as the frequency is reduced. This can yield a significant reduction in power consumption because of the V^2 relationship.

Each time the server completes current and all pending tasks, it transits to the nap state.
In the nap state: nearly all system components enter sleep mode. Power consumption is low, no processing can occur. Components that signal the arrival of new tasks, or expiration of a software timer, remain partially powered.
In the active state: When new tasks arrive, the system wakes and transitions back to the active state. When the work is complete, the system returns to the nap state again.

Dynamic Component Deactivation
Main idea: Allow servers to be dynamically turned off to save energy and only turn on minimum servers to finish tasks.

Inter Data Centers Level: exploiting location diversity
Different geographical distance from service requests – Your requests may be directed to the data center in Finland since you are geographically close to Finland
• Different working load – Your requests may be directed to the data center where there is low working load
• Different electricity price – Your requests may be directed to a data center with low electricity price to reduce energy cost
• Different renewal energy sources availability, greenness, and CO2 emission – Your requests may be directed to the data center where renewable energy is readily available

Energy Cost Problem – Workload Constraint

Requests at front server j

arrival rate of the tasks request s from front-end server *j* to data center *i*

$$\sum_{i=1}^{N} \lambda_{j,i} = \lambda_j ; j = 1,2 \ldots C \quad \Longleftrightarrow \quad \begin{cases} \lambda_1 = \lambda_{1,1} + \lambda_{1,2} + \lambda_{1,3} \\ \lambda_2 = \lambda_{2,1} + \lambda_{2,2} + \lambda_{2,3} \\ \lambda_3 = \lambda_{3,1} + \lambda_{3,2} + \lambda_{3,3} \end{cases}$$

Number of active servers

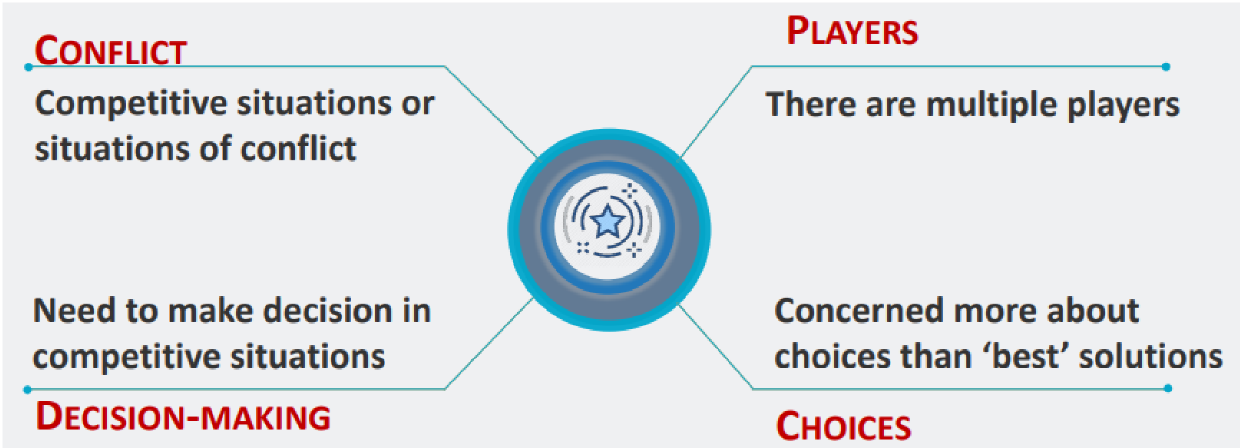
Total number of servers M_i at each data center i

$$m_i \leq M_i ; i = 1,2 \ldots N \quad \Longleftrightarrow \quad \begin{cases} m_1 \leq M_1 \\ m_2 \leq M_2 \\ m_3 \leq M_3 \end{cases}$$

What are the main challenges data centers face in using solar power?
Reliability
-Because of intermittency with power generation from solar panels, data centers must be prepared to store the power or supplement it.
- Centers typically use electricity from solar panels to power daytime operations, and apply any excess to charge UPS (uninterruptible power supply) systems.
- The real challenge is not to find alternatives to supplement solar power, but to have the intelligence to optimize the use of each power source.
Quality:
-The second issue must be addressed in order to protect sensitive IT assets i.e., power quality to stabilize against fluctuations is important.

A self-driving car generates 1 GB/second data and it requires realtime processing to make correct decisions. Needs mini-datasenter

Game theory



Game theory is an interdisciplinary field encompassing economics and mathematics and one that can be deployed to solve problems for numerous applications.
Game theory is a discipline for studying problems of conflict among interacting decision makers.

Players
Multiple players- Each player can be an individual, a group or an organization

Strategies
A plan of actions by which a player has a decision rule to determine their moves for every possible situation in a game

Payoff
Benefit received for a given strategy; often termed as utility

Non-cooperative game
A game with competition between individual players. Only self-enforcing (e.g. through credible threats) alliances (or competition between groups of players) are possible due to the absence of external means to enforce cooperative behavior (e.g. contract, law).
Cooperative game
A game with competition between groups of players due to the possibility of external enforcement of cooperative behavior (e.g. through contract) Cooperation generally leads to higher payoffs. For example: countries cooperate on trading (reduced tariffs) leading to boost in exports

Nash Equilibrium (NE)
A combination of strategies is called a Nash Equilibrium if neither player has an incentive to change strategy, given the other player's choice mutual best response.

Best response:
the strategy which produces the most favorable outcome, taking other players' strategies as given

Individual's best choice is not the group's best choice. An individual's rational choice may lead to group's non-rational choice

Mixed strategy A strategy is a plan of actions by which a player has a decision rule to determine their moves for every possible situation in a game

Two types of strategies

A PURE STRATEGY

at every stage in the game, it **specifies a particular move** with complete **certainty**

A MIXED STRATEGY

applied some **randomization** to at least one of the moves. The randomization is a set of fixed probabilities, where the sum of the probabilities is 1

Regulated energy market

- **Prices are determined by the regulatory/government bodies**
  - **- energy prices**
  - **- transmission and distribution prices**
- **You cannot choose supplier**

Deregulated energy market

- **Prices are determined by the "invisible hand" of the market. There is competition among a set of suppliers. Norwegian electricity market was deregulated in 1991.**
- **Deregulation allows different power suppliers to offer services to consumers. . Deregulation in the power market provides you the flexibility to choose your supplier.**

Transmission system operators (TSOs)
The TSO operates the transmission assets and is responsible for the power balance in the transmission system, e.g., Statnett
Distribution system operators (DSOs)
Power distribution system to operate the distribution grid and transmit electricity to residential customers, e.g., Hafslund

Energy market players
-Generating company
-Retailer
-Customers

rule and operate the game
-Regulators
-Market operator

Market clearing price P* when power supply is equal to power demand, i.e., Supply = Demand

Auction in electricity pool
All generation bids and consumption offers are placed at the same time No-one knows about others' bids and offers An algorithm decides about bids and offers that are retained Eventually, the system operator is informed about the trades that occurred

Electricity producers play the game using their price and production. By changing these two parameters, the market sharing changes.

Cournot strategy:
Two firms compete simultaneously on the quantity of output they produce of a homogeneous good.

Bertrand strategy:
Two firms compete simultaneously on the price of a homogenous good.

Demand Response Management (DRM)

Smart Grid = Power Grid + ICT(Information & Communication technologies)

DRM studies the interaction between the supply and the demand sides through bidirectional flow of power and information.

Power infrastructure is designed for peak loads.
Peaks have less than 1% of the time. Reducing peaks can then reduce power generation and save considerable costs and also save investments in the long run.

Demand Response Management (DRM) is defined as changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

DRM two objectives
Reduce energy consumption
§ encourage energy-aware
consumption patterns
§ Reduce power generation
Shift the energy consumption
• Mitigate power load during
the peak hours
• Improve grid reliability

Direct Load Control (DLC)

Intelligent Load Control / Pricing

Three pricing models
§ Time-of-Using (ToU) pricing
§ Real-time Pricing (RTP)
§ Inclining Block Rates (IBR)

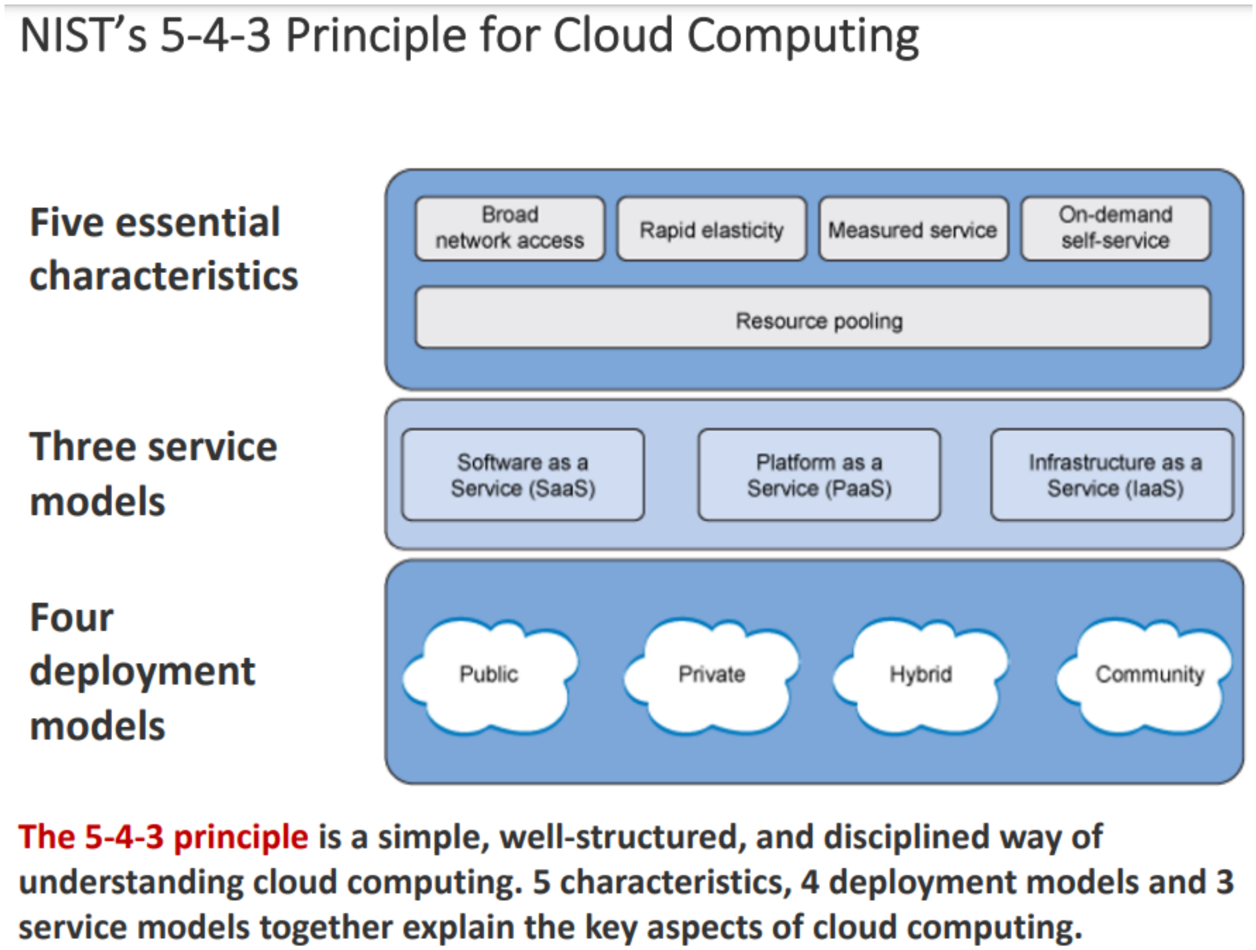
ToU pricing is usually released far in advance, and keeps unchanged for a long time period.

RTP is usually released on an hour-a-head pricing or day-ahead pricing basis.

Two-level rate structures
§ base load and high load
§ Price increases sharply if energy usage exceeds threshold
Motivations
§ A user pays more when consuming more energy
§ Users evenly distribute loads among different times of a day to avoid higher rates

Energy consumption scheduler (ECS)

Cloud computing is a model for enabling convenient, ondemand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.



Five Essential Characteristics

On-demand self-service
A consumer can provision computing capabilities, such as server time and network storage, as needed, without requiring human interactions with each service provider.

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Resource pooling
The provider’s computing resources are pooled to serve multiple consumers with different resources dynamically (re)assigned according to consumer demand. Examples of resources include storage, processing, memory, and network bandwidth.

Rapid elasticity
Capabilities can be elastically provisioned and released to scale rapidly with dynamic demand.

Measured service
Cloud systems automatically control and optimize resource use by leveraging a metering capability appropriate to the type of service (e.g., storage, processing, bandwidth, active user accounts). Resource usage can be monitored, controlled, audited, and reported, providing transparency for both the provider and consumer.

Three Service Models
SaaS: Software as a Service
PaaS: Platform as a Service
IaaS: Infrastructure as a Service

Four Deployment Models

Public cloud
The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization.

Private cloud
The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by an organization, a third party, or a combination of them

Hybrid cloud
The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities. They are bound together by standardized technology that enables data and application portability.

Community cloud
The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or a combination of them.

With the growing data generation at the end, speed of data transmission is becoming the bottleneck for the cloud-based computing paradigm

Cloud may have high latency which does not fit certain applications

Storing data and important files on external service providers in cloud always opens up risks

Fog Computing
New challenges motivate to put computation, storages, services close to the end-users to significantly reduce latency and protect private data. Expectation: 45% of data will be stored, processed, analyzed, and acted upon close to, or at the edge of the network

Fog Computing extends the cloud computing paradigm that provides computation, storage, and networking services between end devices and traditional cloud servers. Fog computing nodes are typically located at the edge of network located away from the main cloud data centers.

We define “edge” as any computing and network resources between data sources and cloud data centers.

Fog computing now refers to a three-tier architecture (Clients ⇔ Fog nodes ⇔ Central Servers)

	Cloud Computing	Fog Computing
Target Users	General Internet users.	Mobile users
Service Type	Global information collected from worldwide	Limited localized information services related to specific deployment locations
Hardware	Ample and scalable storage space and compute power	Limited storage, compute power and wireless interface
Distance to Users	Faraway from users and communicate through IP networks	In the physical proximity and communicate through single-hop wireless connection
Working Environment	Warehouse-size building with air conditioning systems	Outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls, etc.)
Deployment	Centralized and maintained by Amazon, Google, etc.	Centralized or distributed in regional areas by local business (local telecommunication vendor, shopping mall retailer, etc.)

Fog Computing Challenges – Quality-of-Service
Connectivity:
fog nodes provide new opportunities for reducing cost and expanding connectivity. The selection of fog node from end users will heavily impact the performance. We can dynamically select a subset of fog nodes to increase the availability of fog services for a certain area.
Capacity:
It is important to investigate how data is placed in fog network since data locality for computation is very important. Need to consider two aspects: 1) network bandwidth, 2) storage capacity.

Computation offloading:
heavy computation tasks can be executed in fog or cloud instead of mobile devices. This saves storage and battery lifetime.

Applications susceptible to latency:
Typical examples are manufacturing, urban transport and smart energy, where actuation has to be driven in real-time.
Geo-distributed applications:
Typical examples include environmental monitoring, which are based on the collection and processing of streams from thousands or even millions of sensors.
Mobile applications:
typical applications involving fast moving objects, e.g., autonomous cars. They require moving objects to access local resources (computing, storage) residing in their vicinity.

Distributed multi-user applications with privacy implications and need for fine-grained privacy control. These applications can benefit from a decentralization of the storage and management of private data to various edge servers, thus alleviating the risk of transferring, aggregating and processing all private datasets at the centralized cloud.

Mobile Edge Computing (MEC) is developed by ETSI Specification. MEC pushes the cloud computing capabilities close to the Radio Access Networks in 4G. MEC server can be a mini-data center located in either the base station storage close to the radio access networks

The amount of data in smart grid may be tremendous since: i) there are a huge number of smart meters/sensors; ii) each meter shall transmit data periodically to the control center.

Cloud/Fog Architecture for Smart Grid
Cloud computing:
all smart meter data is stored and processed in the cloud.

Cloud/Fog Architecture:
Various communication and computations need very low latency and improved privacy, which can be addressed by fog computing.

MDMS (Meter Data Management Systems) uses cloud computing to perform long-term data storage and management for the vast quantities of usage data and events. MDMS enables the interaction with operation and management systems that: (i) manages the billing and customer information, (ii) provides power quality report and load forecasting based on meter data

Blockchain:a globally maintained and shared distributed database. Everyone has all same database and there is no central organization to manage the database. There are no central nodes and all nodes are equal. •Blockchain records the transactions permanently. The data can only add and search; the data cannot be deleted or modified.

Blockchain types

	Public	Private	Consortium
Administration	No administrator	Single	Multiple
Permission	Permissionless	Permissioned	Permissioned
Computation cost	High	Low	Medium

Hash function: takes any size input text and returns a fixed size string (i.e., hash value).
–Easy to calculate a hash for any given data
–Hard to calculate the original text that has a given hash
–Two slightly different messages produce drastically different hash value

Tamper-proof: an adversary is not able to tamper data in any block without getting detected.

51% attack in Blockchain•Definition: malicious attackers control a majority (51%) of the total network's computation power and collude to attack bitcoin or other crypto.
Attackers add block faster with majority computation power. Rule in Blockchain: the longest chain wins
The old public chain is abandoned because it is shorter and its data is irrelevant. The attackers roll-back many blocks and start a new blockchain.

Consequence: spend coins twice (i.e., double-spending). The attacker can spend the same coins twice and buy two different cars.

Blockchain applications in general
Blockchain: decentralized database that keeps a record of all transactions.
This provides a perfect way for systems to record transactions that should be transparent and permanent.

Three conditions to use Blockchain•distributed environment
•nodes do not trust each other
•nodes perform transactions Role of Blockchain
•to record transactions permanently and updated securely among untrusted nodes

I for Blockchain: all transactions are saved in blockchain permanently. Machine learning can be used to analyze the data and find malicious transactions

Security –two concepts
Physical Security: this is the traditional "security" concept of power systems cascading failure
Cyber Security: technologies, processes and practices designed to protect networks, computers, programs and data from attack, damage or unauthorized access

Three Cyber Security Objectives in Smart Grid –NIST guideline

•The cyber security working group in NIST released a comprehensive guideline for Smart Grid cyber security
•CIA (NOTCentral Intelligence Agency): Confidentiality, Integrity, and Availability
•Loss of confidentiality—unauthorized disclosure of information
•Loss of integrity—unauthorized modification of information
•Loss of availability—disruption of access to or use of information or a system

Trusted third party (TTP) computes the bill, e.g., module in a grid operator

Anonymization –Instead of a user's real ID, a pseudonym (a fake ID, denoted by psidin the illustration below) is attached to the data. Thus, the receiver do not know to which individual the received data belong. Daily (or hourly) power consumption remains anonymous, user identity is only used at the end of each billing period when presenting all consumed credentials together.

Load Monitoring: the load monitoring center (LMC) collects the amount of electricity usage over a local area in order to monitor current activities of the power grid. •LMC only needs the total power consumption over the area at recent time units.