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Blockchain in Smart Grid for Sustainable Management of Environmental Resources Usage

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Blockchain is a distributed database that is shared among the nodes of a computer network. Blocks have certain storage capacity and, when filled, they are closed, and linked to the previously filled block, forming a chain. Blockchains are typically managed by a peer-to-peer method where nodes collectively adhere to a consensus algorithm protocol to add and validate new transaction blocks. The author makes a review of Blockchain applications in different areas, considerable challenges, her own experience with Blockchain in Smart Grid and other researchers` contributions. The paper presents the first stage of project "Smart Grid for Sustainable Management of Environmental Resources Usage"—describing Managed Objects classes for selected functional areas of Blockchain life cycle: Configuration, Security, and Performance. The author uses the life cycle of telecommunication networks as a reference. The models are designed for user interface developers, university professors, and students.

Keywords: Blockchain, Smart Grid, Sustainable Management, environmental resources

Introduction

Blockchain is a growing list of records, called *blocks*, that are securely linked together using cryptography. Each block contains a cryptographic hash (Bybit Learn, n.d.) of the previous block, a timestamp and transaction data. Smart contract is used in Blockchain technology while making the transaction between two parties, and it enables only the validated transaction to be included in the Blockchain (Bing, n.d.). To validate a transaction among Blockchain nodes, a consensus mechanism is introduced (Frankenfield, 2021), e.g., Proof-of-Work (PoW) etc. The Blockchain technology finds application in bright variety of areas: Industry 4.0 (Javaid et al., 2021), Mining Industry (Supply Chain, Recycling—Projects in University of Mining and Geology "Saint Ivan Rilski"—Sofia), Finance (Varma, 2019), Administration (Mazur, 2021), Computer Technologies (Macaulay, 2017), Power Supply (Agung & Handayani, 2022), Supply Chain (Wang, Wu, Chen, & Evans, 2020), Digital Purchasing (Müller, Janczura, & Ruppel, 2020), etc. The Blockchain Management is intended to be self-organized (Google Patents, n.d.). Despite this, some challenges could be considered: Risk Management (Deloitte, n.d.), Identity Management (Tykn.tech, n.d.), Build, Operate and Govern Blockchain (IBM, n.d.), Creating Multiple Transactions (Tutorialspoint, n.d.), Blockchain and Artificial Intelligence Integration (Zhang et al., 2021), Energy Efficiency Increasing (Gent, 2021), Management of Solar Panels (El‐Bayeh, Zellagui, Shirzadi, & Eicker, 2021),

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Big Data Management (Ivanova, Iliev, & Stoyanov, 2020), Design and Simulation (Bakardjieva & Raykov, 2022), Security Management Development (Pupaza et al., 2021). The author has experience with following topics of Blockchain in Smart Grid: Blockchain application in power supply management (Ilieva-Obretenova, 2017), detail models for node management (Ilieva-Obretenova, 2020a), detail models for network management (Ilieva-Obretenova, 2020b; 2021), scenarios for Blockchain transactions management (Mila Ilieva-Obretenova & Chaudhary, 2020). Other authors also show different aspects of Blockchain in Smart Grid: Du et al. (2021) describe a sustainable supply chain with Blockchain in Smart Grid. The focus is on layered theoretical framework and balance of multiple stakeholders. However, the research misses management services for the different actors. Musleh, Yao, and Muyeen (2019) outline frameworks of Blockchain in Smart Grid and particular Agent/Aggregator based Microgrid Architecture. The Aggregator is for Smart Meter, Wind Energy, Solar Energy, and Energy Storage. Blockchains record and share transactions, measure, control setpoints, power flow, etc. Projects for Industrial Blockchain Utilization are mentioned, but there are no details on functional areas. Mollah et al. (2020) point out WePower platform for energy management and trading solutions. The users look for sustainable renewable power source. They know the Energy Usage Pattern; functional area Accounting is presented, but without details. Alladi, Chamola, Rodrigues, and Kozlov (2019) and Hasan et al. (2022) show Blockchain based use cases and solutions in Smart Grid. The accent is on functional area Security, but without details. Jiang and Liu (2021) make detailed research and gives recommendations for two functional areas—Maintenance and Accounting. The article misses information models. The recent article has the following aims: (1) to represent the Blockchain in Smart Grid as a method for balance of environmental resources usage. This could be achieved with appropriate consensus mechanisms; (2) to illustrate these mechanisms with Transaction Management Services for selected functional areas from Blockchain life cycle: Configuration, Security, and Performance. The author uses functional areas of OSI model (ISO/IEC/IS, 1989) and of telecommunication networks (Magedanz, 1994); (3) to define Managed Objects (MO) classes with suitable attributes for each of the three areas.

Method

Methodology for describing functional areas from Blockchain life cycle includes Unified Modelling Language (UML) (Fowler, 2004; StarUML, 2021; Smartdraw, n.d.). UML is a general-purpose, developmental, modelling language in the field of software engineering that is intended to provide a standard way to visualize the design of a system. The diagrams are organised into two distinct groups: structural diagrams and behavioural (interaction) diagrams. Structural UML Diagrams are Class Diagram, Package Diagram, Object Diagram, Component Diagram, Composite Structure Diagram, and Deployment Diagram. Behavioural UML Diagrams are Activity Diagram, Sequence Diagram, Use Case Diagram, State Diagram, Communication Diagram, Interaction Overview Diagram, and Timing Diagram. The author has experience with Use Case Diagram, Communication Diagram (Ilieva-Obretenova, 2017), and Class Diagram (El‑Bayeh et al., 2021; Ivanova et al., 2020; Bakardjieva & Raykov, 2022; Pupaza et al., 2021). Class Diagrams will be applied in this research, too. A Class Diagram describes object types in the system and the different types of static relationships between them. Diagrams show also features and operations of classes and limitations for the way connecting objects. Features are one term, but they are represented with two quite different notations: attributes and associations. The notation for an attribute describes a distinct feature as text line (second row) in the rectangle, symbolizing the class.

Association is a directed line between two classes and its direction is from class-source to class-aim. The name of the feature is set on the aimed end of the association with its majority. The aimed end of the association is connected to the class which is the feature type. The majority of a feature is a note for how many objects could complete the feature. Operations are actions which a class could realize. The "Part of"-relationship between objects is shown with a rhombus and a line. In the paper specific attributes of selected objects classes are represented. Operations are not represented.

Results

The results of the research show that Blockchain in Smart Grid could balance the usage of environmental resources. This could be achieved with appropriate Transactions Management. The Management is illustrated with three selected functional areas. Different consensus mechanisms for management of usage and provision are described in the first area Transaction Configuration. The nodes participating in different consensus mechanisms and ensuring privacy of usage and provision are the focus in the second area Transaction Security. Different statistics for Provider and Subscriber (User), aiming optimization, are collected in the third area. Data in functional areas are structured in Managed Objects (MO) classes.

Managed Objects Classes for Transaction Configuration

MO TConfiguration considers transaction configuration needed for provider or tailored especially on subscriber's order.

MO SConfiguration discusses subscriber's requirements for configuration of provided transactions.

MO TComponent consists of transaction parts which must be distributed on block's body.

MO TDFData comments an entry in functional element TDF (Transaction Data Function) for a specific transaction subscriber, e.g., requested/received/consumed/stored/sold power.

MO TriggerInfo recommends the description of a transaction trigger, necessary for request directing to transaction execution.

MO Program applies the description of a program with transaction logic (consensus mechanism). There are different consensus mechanisms aiming at better balance in different aspects. This article considers in detail the basic mechanism Proof of Work (PoW) and mechanisms ensuring ecological balance: Proof of Stake (PoS), Proof of Burn (PoB), Proof of Capacity (PoC), Proof of Importance (PoI), Proof of Service (PoSe).

By PoW the node with fastest processor proves finished work and receives the right to provide/use power.

By PoS the node with biggest stake receives the right to provide/use power.

By PoB the node with biggest donation/need receives the right to provide/use power.

By PoC the node with biggest hard disk and participation in most transactions receives the right to provide/use power.

By PoI the node with the most prolonged usage of hard disk receives as bonus the right to provide/use power.

By PoSe the node with service (management) functions receives the right to provide/use power.

Other consensus mechanisms are:

Proof of Activity (PoA), by which the node proving activity at the moment receives the right to provide/use power.

Proof of Elapsed Time (PoET), by which the node proving waiting of the shortest random generated time for one h-transformation receives the right to provide/use power.

Proof of History (PoH), by which the node proving waiting (history) with multiple h-transformations for one block receives the right to provide/use energy. This mechanism is applicable for renewables, waiting turn on/off.

Proof of Origin (PoO), by which the node proving its origin receives the right to provide/use power. This mechanism is applicable by advertising campaigns.

Proof of Authenticity (PoA), by which the node proving authenticity receives the right to provide/use power. This mechanism is applicable by newly launched nodes.

Proof of Process (PoP), by which the node proving a process receives the right to provide/use power. This mechanism is applicable by specific production/usage processes, e.g., thermal sources, burn of waste, etc.

Proof of Location (PoL), by which the node proving a location receives the right to provide/use power. The mechanism is applicable by remote villages and disaster.

All these consensus mechanisms could be organised as attributes of MO Program.

MO Resource organize a description of specialised resource used from particular transaction, e.g., processor, hard disk.

MO Template generalizes the block format for different transactions kinds.

MO RoutingInfo outlines information for routing, considering the possible network access for specific subscriber. This object is necessary for transactions allowing subscriber several directions, e.g., routing depending on time and/or weather and whether the subscriber acts as a provider or as a consumer.

MO NumberingPlan consists of information about numbering of a respective user. This object is necessary for transactions of private microgrid, e.g., when the subscriber is an industrial enterprise, its departments receive user Identifier—so the consumption and accounting of each user could be managed transparent.

On Figure 1 is synthesized UML Diagram of Managed Objects classes for Transaction Configuration.

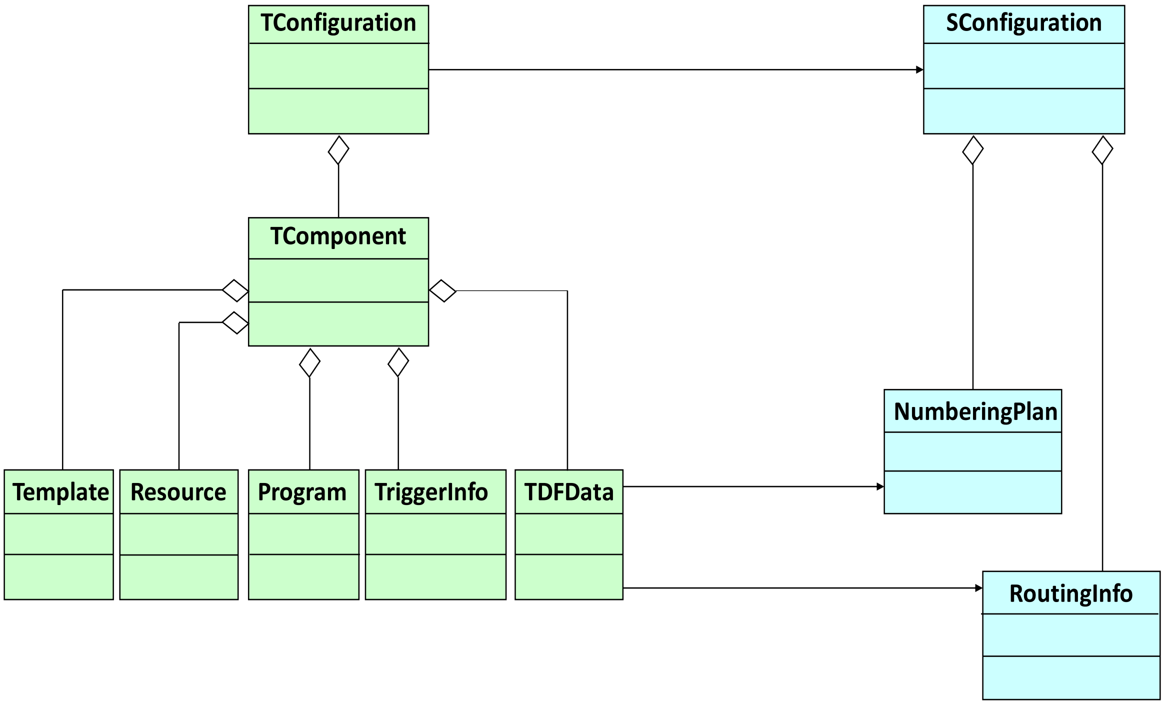

Figure 1. UML Diagram of Managed Objects classes for Transaction Configuration.

Managed Objects Classes for Transaction Security

MO TSecurity states security rights for a transaction and data necessary for security management aims.

MO SSecurity names security requirements of specific subscriber.

MO SecurityLog labels collected events transaction security.

MO SecurityAlarm identifies alarm-reaction when security is violated.

MO TDataSecurity summarizes the provider`s rights for data security. They involve the following attributes:

ProcessorNodes:List consists of list of nodes with powerful processor participating in blocks validation by consensus mechanism PoW.

StakeNodes:List describes a list of nodes with big stake for provision/usage participating in blocks validation by consensus mechanism PoS.

BurnNodes:List shows a list of nodes with biggest donation/needs participating in blocks validation by consensus mechanism PoB.

CapacityNodes:List points out list of nodes with big capacity (hard disk) participating in blocks validation by consensus mechanism PoC.

ImportantNodes:List represents a list of nodes with continued usage of hard disk participating in blocks validation by consensus mechanism PoI.

ServiceNodes:List consists of list of nodes with service (management) nodes participating in blocks validation by consensus mechanism PoSe.

MO SAuthorisation expresses security rights of specific subscriber and allows him to control the access to his profile and the changes in it. Authorisation could be a PIN-code, password, transaction authorisation card, private key, etc.

On Figure 2 is synthesized UML Diagram of Managed Objects classes for Transaction Security.

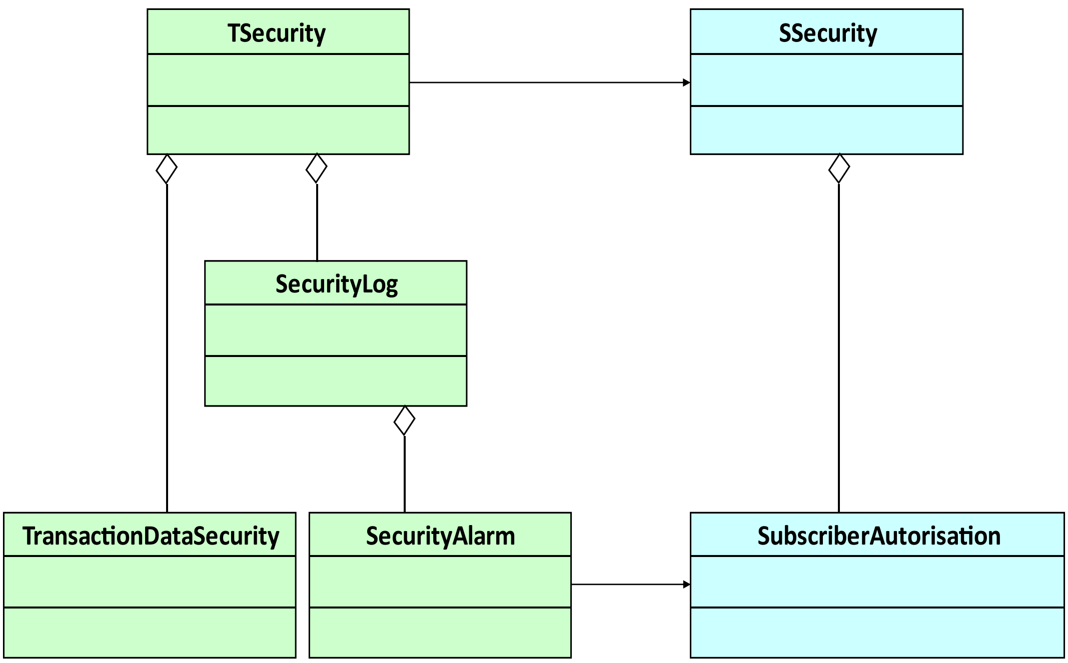

Figure 2. UML Diagram of Managed Objects classes for Transaction Security.

Managed Objects Classes for Transaction Performance

MO TPerformance consists of the recorded and generalised data needed for management of Transaction Performance.

MO SPerformance considers performance parameters needed for specific subscriber for each transaction.

MO UPerformance discusses information for legitimate transaction user. This object is required only for specific transactions, e.g., private microgrid of industrial subscriber where the transaction users are close related to the subscriber.

MO TStatusReport represents report for transaction status created on provider's request. The attributes are the following:

WaitingBlocksN:int comments the number of waiting blocks.

RejectedBlocksN:int explains the number of rejected blocks.

ValidatedBlocksN:int applies the number of validated blocks.

AddedBlocksN:int organizes the number of blocks, added to Blockchain.

RewardedNodesN:int generalizes the number of rewarded nodes which will provide/use power. The type of all attributes is integer.

MO TUsageLog outlines the collected events on usage of one transaction kind. The switchover between transactions is completed by a fork (Smith, 2022). The attributes are the following:

PoWNumber:int states the number of used PoW transactions.

PoSNumber:int names the number of used PoS transactions.

PoBNumber:int labels the number of used PoB transactions.

PoCNumber:int identifies the number of used PoC transactions.

PoSeNumber:int summarizes the number of used PoSe transactions.

PoINumber: int expresses the number of used PoI transactions.

The type of all attributes is integer.

MO RUsageLog considers the collected events on usage of specialised resource, part of the transaction. Attributes are the following:

ProcessorUN:int shows the number of processor usages.

HardDiskUN:int discusses the number of hard disk usages. The type of both attributes is integer.

MO QoSInfo consists of information for parameters offered to subscriber during the transaction execution. Attributes are the following:

WaitingBlockID:string represents the identifier of waiting block.

RejectedBlockID:string explains the identifier of rejected block.

ValidatedBlockID:string applies the identifier of validated block.

AddedBlockID:string defines the identifier of block added to Blockchain.

RewardedNodeID:string shows the identifier of the rewarded node which will provide/use power. The type of all attributes is string.

MO SUsage consists of information for transaction usage from subscriber. Attributes are the following:

PoWcounter:int represents the transactions counter on PoW mechanism.

PoScounter:int describes the transactions counter on PoS mechanism.

PoBcounter:int outlines the transactions counter on PoB mechanism.

PoCcounter:int states the transactions counter on PoC mechanism.
PoSeCounter:int illustrates the transactions counter on PoSe mechanism.
PoIcounter:int traces the transactions counter on PoI mechanism.
ProcessorUcounter:int identifies the counter of processor usages.
HardDiskUcounter:int expresses the counter of hard disk usages. The type of all attributes is integer.
On Figure 3 is synthesized UML Diagram of Managed Objects classes for Transaction Performance.

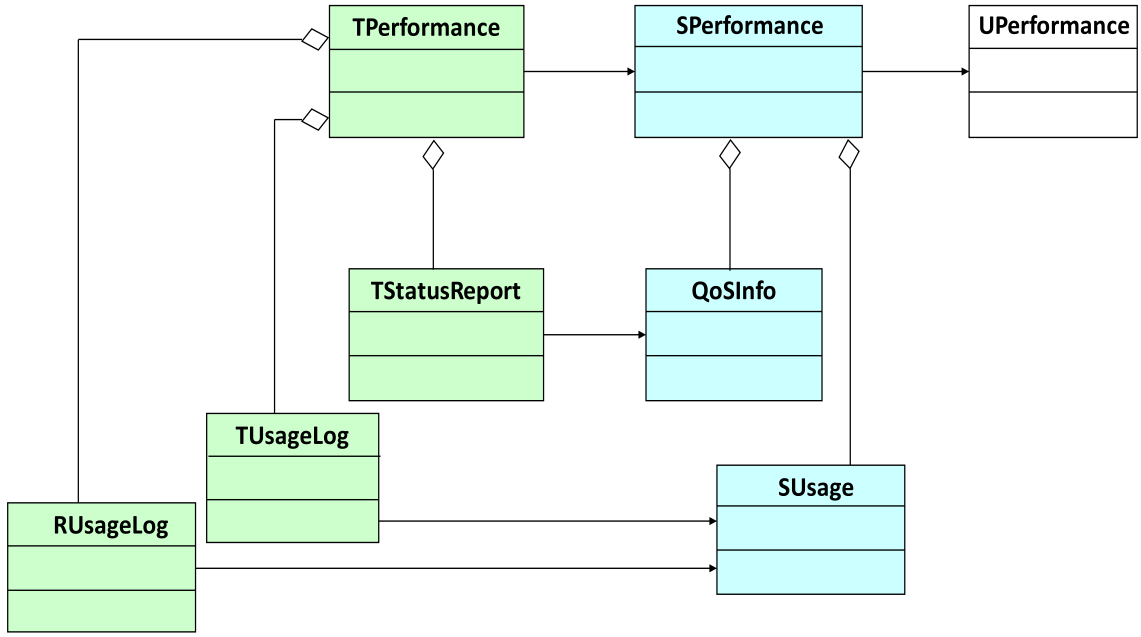

Figure 3. UML Diagram of Managed Objects classes for Transaction Performance.

Conclusion

The usage of environmental resources is a pressing issue of the modern society. One of the methods for fairly distribution is Smart Grid—developing technology in energy sector. The grid itself needs a mechanism for balanced management of transactions between the actors. Illustrated in article, three functional areas from the Blockchain life cycle—Configuration, Security, and Performance—show that with different consensus mechanisms, privacy, and statistics, a priority usage of renewable sources could be achieved. The future work could include the following topics: (1) adding of operations in defined Managed Objects classes; (2) development of Class Diagrams for other functional areas, e.g., Installation, Provision, Maintenance, Accounting, and Subscriber control; (3) development of Behavioural (activity) Diagrams for the functional areas; (4) modelling of other aspects of Environmental Management with Smart Grid: (a) adding of a new object for solid waste sorting (for conventional power plants) and (b) application of new mechanism, e.g., deep learning.

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