International Journal of Future Generation Communication and Networking
Vol. 13, No. 4, (2020), pp. 1461–1467

"Blockchain Framework for cyber-physical systems: Reengineering approach"

[1]Mr. Vinay Kumar Saini, [2]Dr. Sachin Gupta, [3]Dr. Bhoomi Gupta
[1] *Research Scholar, Computer Science and Engineering, MVN University*
[2] *Associate Professor, Computer Science and Engineering, MVN University*
[3] *Assistant Professor, Information Technology, Maharaja Agrasen institute of Technology, Rohini, Delhi*

Abstract
Blockchain technology implementations are on the rise with use cases spanning almost every sector as a complete solution for the digital transfer of value. Blockchain with its inherent features like distributed data storage and immutability can be utilized to build security and reliability in Cyber Physical Systems. But questions related to Scalability and cost-effectiveness of blockchain solutions remain unanswered that raise concerns of business managers regarding its implementation. Literature review suggests that the cost of implementation of blockchain solutions is significant, hence small and medium sized enterprises (SMEs) need a reengineering approach based solution. The purpose of this study is to conceptualize a blockchain framework which is suitable for SMEs in terms of cost, development time, performance, traceability of data tampering with minimal change in existing system. This paper proposes a blockchain framework based on reengineering approach and highlights its suitability for small and medium size organizations for their Cyber Physical Systems. Finally results of implementation based on proof of concept have been discussed.

Keywords: *Blockchain, Cyber-physical systems, Re-engineering, Security*

I. Introduction

Real world systems have undergone transformation ever since the First Industrial Revolution (IR), which introduced the capability of Steam and water to power industrial operations with mechanized production. Second IR brought electricity and it boosted mass production with the assembly lines powered by electricity. So far systems were physical in nature, but with Third IR conceptual systems started evolving. Third IR introduced the concept of information technology and computers to automate processes of physical systems that minimized human involvement and enhanced speed and accuracy of systems. We are again witnessing a transformation in terms of Fourth IR that focuses on enhanced automation and connectivity with Cyber-Physical Systems [1][2]. Figure 1 presents evolution on the Industrial Revolution.

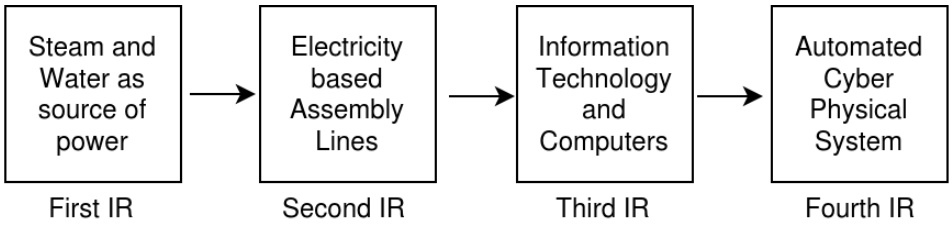

Figure1. Evolution of Industrial Revolution

Every industrial revolution impacts labour markets with machines replacing human labour. With Internet of things, cyber-physical system, and artificial intelligence (AI) Fourth Industrial Revolution will greatly change human intellectual labour[3][4]. Hence introduction of these systems with advanced automation will replace existing information systems and human resources and SMEs would be affected financially and socially.

A cyber-physical system (CPS) is an automation of physical systems where sensors based computers monitor and control physical processes. CPS is about building computation, communication and control interface between physical processes and the cyber systems. Computation function directs

ISSN: 2233-7857 IJFGCN

physical system based on feedback loop fed with data from sensors [14]. Here focus is on Data driven decision making, this requires complete assurance over integrity and availability of data. This can be addressed with the use of blockchain. But such implementations need to be evaluated in terms of their scalability and cost-effectiveness to address concerns of business managers. This paper presents findings related to existing research related to total cost of ownership of a blockchain based systems. Further Business process reengineering approach is applied to propose a cost effective and efficient blockchain framework for cyber physical systems to address integrity and availability. Finally implementation as proof of concept has been discussed along with results and conclusion.

II. Related Work

There has been a significant rise in new projects and upgrade proposals in blockchain based cyber physical systems especially in the supply chain domain [5]. Private Blockchain scheme is more suitable for organizations as that can facilitate control on participating nodes and immutability and traceability of any manipulations [12]. Cost-benefit analysis of such plans needs to be evaluated before approving a business case. EY in their recent research used data from global client proof-of-concept, pilot and production engagements to estimate and forecast the cost of a production-scale blockchain solution [6]. Total cost of ownership of blockchain based system comprised of development cost, infrastructure costs and the cost of implementing the components needed for running the chain code. The results of their work shows that Total cost of ownership for blockchain solutions is primarily based on Transaction volume, Transaction size, Node hosting method and Consensus protocol. The results clearly shows that it is quite costly to deploy a fully developed private blockchain and public blockchain (ZKP Zero knowledge proof based) solution for both on-premises and cloud-based. Beside initial development and setup cost these systems have high operational cost that includes transaction cost as shown in figure 2 below. It is clear from the figure below that such implementations are only beneficial if owner organization has high transaction volume, small and medium size organizations don't have high transaction volume.

Transactions per day	25	160	1,000	**1,912**	10,000	300,000
Transactions per year	9,125	58,400	365,000	**697,880**	3,650,000	109,500,000
Private blockchains	$34.296	$5.359	$0.858	**$0.449**	$0.086	$0.003
ZKP – future state	$2.856	$0.798	$0.478	**$0.449**	$0.423	$0.417

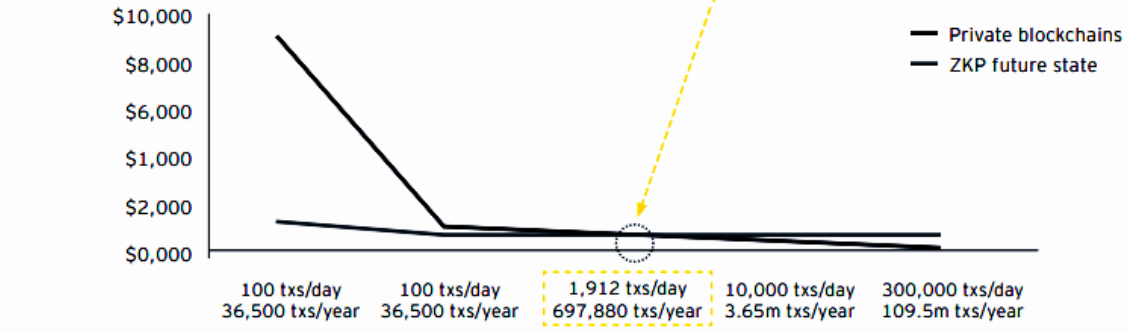

Figure2. Transaction Cost Comparison

Blockchain technology might increase the total net benefits as a result of improved efficiency of invoice processing [8]. Suppliers would enjoy the benefit if platform fee is less than upfront profit in hand. On the other side buyers might be benefited with extended due date of payment. From the funder's perspective benefits are achieved as a shorter processing time so as to complete more and more transactions in the same time frame using blockchain based solution. Platform provider in any case is going to get an amount per transaction. This again shows the blockchain benefits require huge investment up front and regular operational costs including maintenance expenses in developing and maintaining blockchain solutions.

SMEs use CPS that doesn't have high transaction volumes so a complete blockchain based system is not going to be a genuine business case for them to invest in. Reengineering approach can be used to prepare a framework that can help in integrating blockchain capabilities into existing CPS rather than developing a new blockchain based system, as it could be quite costly and existing system would be

ISSN: 2233-7857 IJFGCN

discarded. Applying Reengineering to redesign Process of CPS using blockchain is not a trivial task. Hybrid models are required to redesign inter-organizational transactions for blockchain based solutions based on smart contracts and other sensor based devices [9]. This is a serious challenge with issues related to cost and scalability and big question is what would happen to the existing system and how much time it would take to develop a new blockchain based system.

III. Blockchain based Cyber-physical system

Blockchain is a distributed ledger that keeps records of all the transactions with the capabilities like resiliency, trustworthiness, and security [13]. A typical blockchain has following components and transaction process is shown in figure 3.

- **Node:** a computing device that can help user to initiate a transaction
- **Transaction:** an action or activity that involves data related to transfer of value or asset
- **Block:** a set of transactions to be distributed to all nodes in the network
- **Chain:** blocks connected to each other in a specific order
- **Miners:** nodes which perform the block verification process referred as network nodes
- **Consensus:** a set of rules and arrangements to carry out blockchain operations

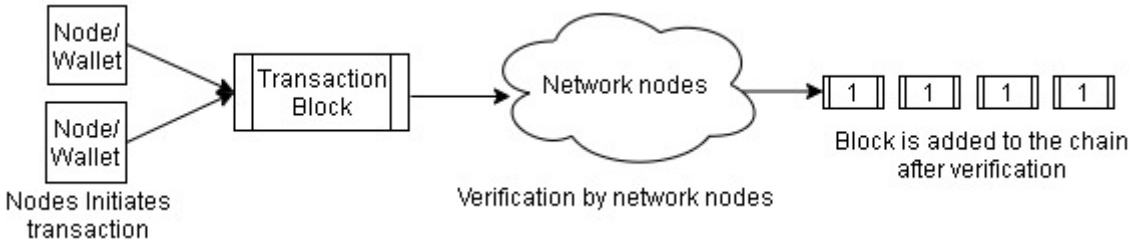

Figure 3: Transaction flow in a Blockchain

Application of blockchain in cyber-physical systems is an open area of research and development. In a recent research work the author proposes a blockchain based architecture for cyber-physical systems that supports real-time transactions to achieve safe and reliable operations [10]. A blockchain enabled Cyber Physical System (BCPS) structure consists of three layers namely, Connection Net, Cyber Net, and Management Net as shown in Figure 4.

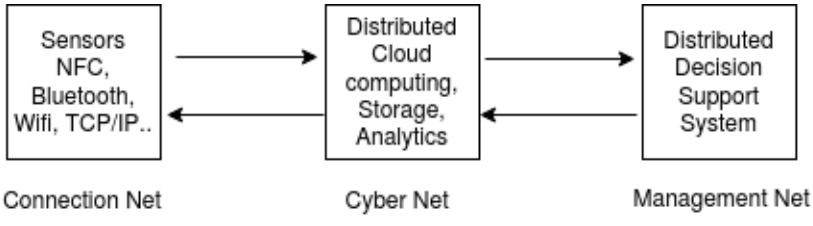

Figure 4: Structure of Blockchain based Cyber-physical system

Connection Net layer is directly connected to physical systems with different nodes like PCs, sensors, controllers, actuators, to gather data from site in a secure manner, and reliable data transfer to Cyber Net layer through various protocols like Wi-Fi, Bluetooth and TCP/IP. Cyber Net layers handle information technology infrastructure and computational services required for required transformation of data into meaningful information. This is the layer where blockchain technology can be integrated into the components of Cyber Net to ensure data integrity and reliability. Blockchain enhances Cyber net with distributed processing and data validation that make systems more robust. Management Net facilitate decision making using advanced info graphic tools and artificial intelligence models to support executive decision making for business process enhancement. Decisions made in cyberspace are passed to the physical space for enhancing manufacturing productivity, self-configuration, optimization, and condition adaptability across the manufacturing shop floor. Blockchain enhances the assurance regarding authenticity of feedback to the physical space. Blockchain can also provide traceability of all the events and actions related to the business processes of cyber-physical systems.

ISSN: 2233-7857 IJFGCN

IV. Reengineering Approach for Blockchain based CPS

Reengineering is about restructuring of the business process to achieve dramatic improvements in metrics like cost, development time, quality, service, and speed. To maintain profitability and competitive advantage, managers must clearly redefine objectives, and rethink and reinvent new business processes. Author proposes a conceptual blockchain-based framework where three entities Supplier, Logistics and Buyer are transacting over a blockchain-based system with smart contract [7]. Redesigning an existing system using this framework along with smart contracts can facilitate supply chain managers. They can track the progress of logistics and cash flows and consequently develop corresponding strategies to mitigate inefficiency. It has been observed in section II that a complete blockchain based cyber-physical system requires huge investment and time. So it is proposed that if we apply reengineering to restructure existing systems and add a Blockchain module based on the principles of Private blockchain alongside, we can achieve the desired benefits at low cost and with minimal changes in existing operations of the system. Figure 5(a) shows a typical cyber-physical system based on a centralized client server model with three components (Connection Net, Cyber Net and Management Net) in a small and medium size organization. Figure 5(b) shows the proposed Blockchain framework for CPS using reengineering.

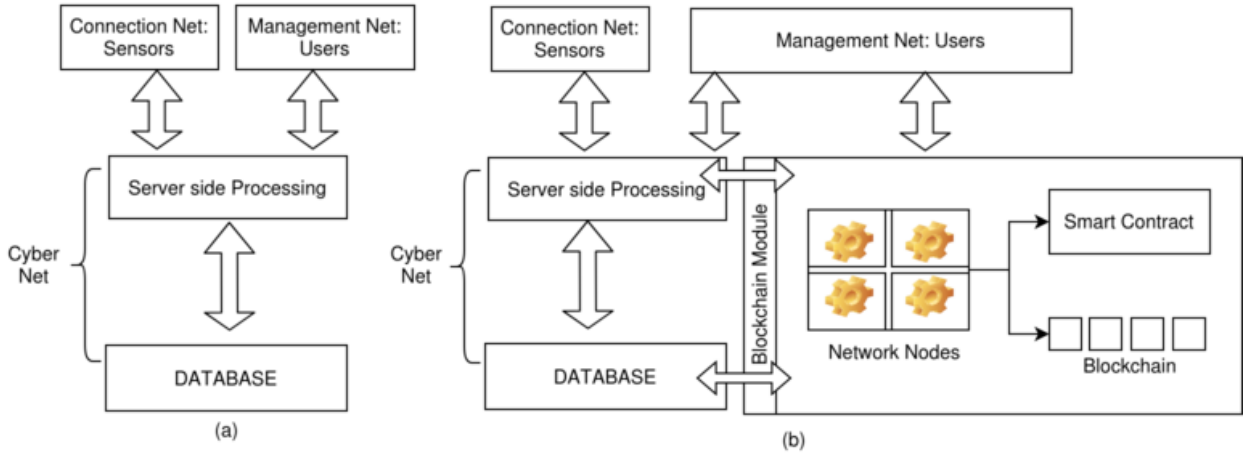

Figure-5 Blockchain framework for CPS using reengineering

A Blockchain Module has been added to the existing CPS system. Blockchain Module has following three components,

1) **Network nodes:** These nodes facilitate distributed transaction validation all nodes get the data about every single transaction initiated on existing system and all nodes use smart contract to validate the transaction and once the transaction is validated successfully it is added to the chain using an efficient scheme[11] to ensure real time update in effective manner.
2) **Smart Contract:** This component covers all business process logic, specification related to the transaction and clauses based on concerns of involved parties which help in validating the transaction. If some violation is detected the transaction is declined stating the flaw in the input data. Smart contract specifications are based on the agreed terms and conditions by all the stakeholders and participants of the system.
3) **Blockchain:** This component is the coded chain of transactions with their hash codes based on an efficient linear hash computation scheme to achieve traceability and optimization [11]. This chain of transactions is available on all the network nodes and hence addresses the risk of a single point of failure associated with a centralized system.

This Blockchain module can be integrated into the existing system like a plugin. The Blockchain module has three components and the size of the Blockchain module can be estimated using function point Analysis (FPA) method based on number of input data items, output items and files involved. Blockchain module require development efforts for following activities,

- Setting up network nodes through web application
- Coding and deploying smart contract code
- Script for consensus

ISSN: 2233-7857 IJFGCN

- Script for updating chain of transactions

The blockchain module is designed with the objective of minimal interaction with existing system and is cost effective as compared to a complete blockchain system.

V. Implementation Setup

Proposed framework was implemented as a proof of concept using a web application platform WampServer having following components on Windows 10 operating system on laptop with Intel Core i3 7th Gen with 4GB ram and clock speed of 2.3 GHz.

- Apache Web server(Apache 2.4.41)
- Mysql database(MySQL 5.7.28)
- PHP(PHP 5.6.40)

A prototype web application has been developed based on an existing cyber-physical system and the transactions from all the stakeholders are directed to the Blockchain module and after successful validation, the transaction is added to blockchain and the existing system doesn't get affected in any way. The only delay is the validation of transaction by blockchain module and that again is so small that it facilitates real time validation and has minimal effect on the performance of the system. Results of the Test cases are discussed in the following section.

VI. Results

Proposed system was implemented as a proof of concept and results are discussed below.

- **Benefit Realization:** Benefits realized with the implementation of proposed blockchain framework are discussed in table 1.

Assessment Criteria	Offering by Blockchain Module
Cost Effective	Proposed Blockchain Module was developed as a proof of concept considering minimal data items of transaction between seller and buyer related to metallurgy industry. As the Blockchain Module doesn't require development of front end and backend based database it has less function points as compared to existing system itself. Hence total estimated effort of development is 84 hours that includes development and testing effort for Blockchain module and scripts for existing application.
Time to Market	Based of development time and implementation time the proof of concept was made operational in 2 days with User Acceptance Testing.
Change in Existing System	Two scripts were added to existing Module one script is called during new transaction between seller and buyer and other during report generation to validate past transaction data in the database
Performance	Average execution time was measured for two scripts and results are discussed in next section.
Tampering Detection	Validation script detected all the tampering test cases in transaction data of the database.
Complexity in Usage	The scripts were integrated in the existing functionalities of the system to avoid complexity in usage of system.

Table-1 Benefit realization with Blockchain framework

ISSN: 2233-7857 IJFGCN

- **Performance measurement of Blockchain Module:** The blockchain module has two scripts one for order processing transactions and the second for report generation of monthly transactions. Both scripts were executed 10 times and average execution time was recorded. The results are shown in the figure 6 showing average execution time for four test cases. It is clear that we can achieve blockchain benefits without much impact on performance. Order processing script with blockchain took 29 milliseconds more and Report generation script with blockchain took 58 milliseconds more.

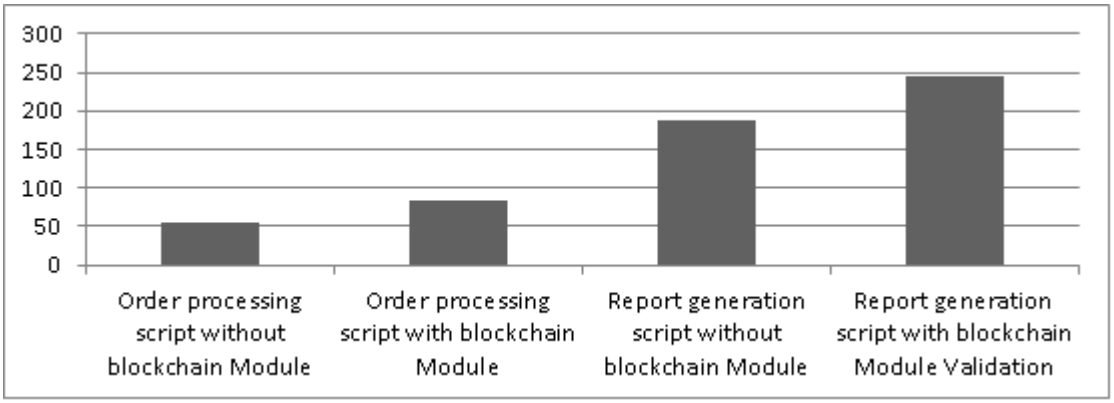

Figure-6 Average Execution Time of 10 transactions for four test cases

- **Effectiveness and performance of detecting manipulation in Database:** This test was focused on testing the effectiveness in detecting the manipulations in the database and tracing the source transaction. Four test cases were tried with 0, 1, 2 and 5 manipulations in the database data post transaction. All cases were successfully executed and results matched the expected results with execution time 387, 432, 451 and 485 milliseconds as shown in figure 7. This feature is very critical for managers as they feel manipulation of data post transactions has been a serious risk and it affects business operations with serious losses. This feature can help in auditing and ensure traceability of manipulation in the transaction in single click.

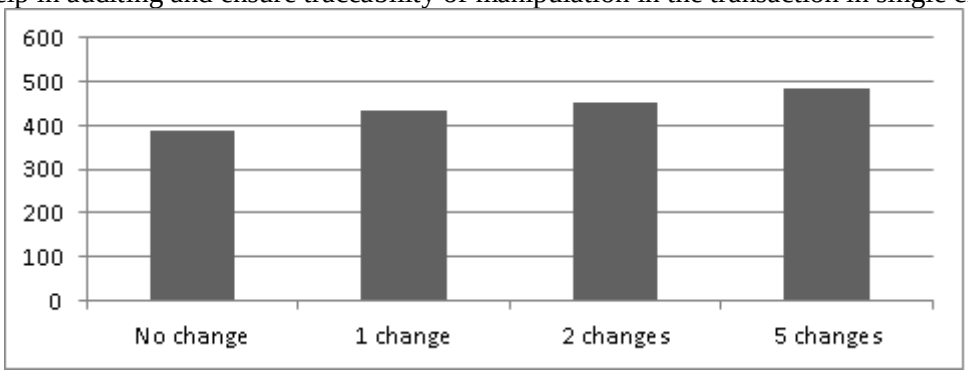

Figure-7 Execution Time of four test cases

VII. Conclusion

Fourth Industrial revolution is focused on advanced automation in the form of cyber physical systems having ability to deliver more value and blockchain can really make cyber-physical systems robust. On-going research in Blockchain based cyber-physical systems focus on various issues. This paper was intended to propose a cost effective blockchain framework for cyber-physical systems for SMEs which are already having systems but feel migration to blockchain based would be a costly affair and it may take significant time to develop new system and their existing system may turn obsolete. Proposed framework adds a blockchain module having capability to distributed validation and recording of transactions as a chain of encoded data. This can enable existing systems to integrate blockchain capability without replacing their existing system. Finally the framework was implemented as a proof of concept and results of tests have been discussed in paper. This framework is an efficient and cost effective alternative for systems that can't afford replacement and still want to have blockchain benefits in their system that address data integrity of transaction data.

ISSN: 2233-7857 IJFGCN

References

[1]. Kenett, Ron & Swarz, Robert & Zonnenshain, Avigdor. (2020). Systems Engineering in the Fourth Industrial Revolution. 10.1002/9781119513957.
[2]. Ko, T.; Lee, J.; Ryu, D. Blockchain Technology and Manufacturing Industry: Real-Time Transparency and Cost Savings. Sustainability 2018, 10, 4274. .
[3]. S.H. Ahn, M.-H. Lee, Fourth industrial revolution impact: how it changes jobs, Korean Acad Soc Bus Adm Integr Conf, 8 (2016), pp. 2344-2363 http://www.riss.kr/link?id=A102057938
[4]. G. Graetz, G. Michaels, Robots at Work, Rev Econ Stat, 100 (5) (2018), pp. 753-768
[5]. Saini, V., Gupta S(2019). Blockchain in Supply Chain: Journey from Disruptive to Sustainable. Journal of Mechanics of Continua and Mathematical Sciences. 14. 10.26782/jmcms.2019.04.00036.
[6]. Paul Brody, Arwin Holmes, Eli Wolfsohn, John Frechette, April 2019, Total cost of ownership for blockchain solutions, Ernst & Young LLP
[7]. Chang, Shuchih Ernest & Chen, Yi-Chian & Lu, Ming-Fang, 2019. "Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process," Technological Forecasting and Social Change, Elsevier, vol. 144(C), pages 1-11.
[8]. Patara Panuparb, May 2019, Cost-benefit Analysis of a Blockchain-based Supply Chain Finance Solution, research thesis, MIT Center of Transportation and Logistics, https://ctl.mit.edu/pub/thesis/cost-benefit-analysis-blockchain-based-supply-chain-finance-solution
[9]. Milani, Fredrik & García-Bañuelos, Luciano. (2018). Blockchain and Principles of Business Process Re-Engineering for Process Innovation.
[10]. Jay Lee, Moslem Azamfar, Jaskaran Singh, A blockchain enabled Cyber-Physical System architecture for Industry 4.0 manufacturing systems, Manufacturing Letters, Volume 20, 2019, Pages 34-39,
[11]. Saini, V., Gupta S. and Gupta B. (2020). Traceability and Optimization over Merkle Tree, Journal of Xi'an University of Architecture & Technology, Volume XII, Issue III, 2020, Page No: 4326-4333
[12]. Ma, Y., Sun, Y., Lei, Y. et al. A survey of blockchain technology on security, privacy, and trust in crowdsourcing services. World Wide Web (2019). https://doi.org/10.1007/s11280-019-00735-4
[13]. Syed, Toqeer & Alzahrani, Ali & Jan, Salman & Siddiqui, Muhammad Shoaib & Nadeem, Adnan & Alghamdi, Turki. (2019). A Comparative Analysis of Blockchain Architecture and Its Applications: Problems and Recommendations. IEEE Access. 7. 1-1. 10.1109/ACCESS.2019.2957660.
[14]. Melicher, M., Šišmišová, D., Vachálek, J., & Belavý, C. (2019). A Cyber-Physical Systems Paper Survey About the Concept, Architecture and Challenges for the Deployment within the Concept of Industry 4.0, Research Papers Faculty of Materials Science and Technology Slovak University of Technology, 27(45), 49-54. doi: https://doi.org/10.2478/rput-2019-0025

ISSN: 2233-7857 IJFGCN