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BLOCKCHAIN CONTROL TO MANAGE THE MEDICAL SUPPLY CHAIN IN THE CONTEXT OF INTERNET OF THINGS (IoT)

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Abstract- Over the last decade, blockchain technology has increased in popularity, gaining interest from a wide range of industries, including finance, government, energy, and health. This article takes an in-depth look at how blockchain is being used in the healthcare business. In fact, research in this sector is moving at a dizzying speed right now. As a consequence, in the current state of the art, we've discovered a variety of use cases for blockchain technology, including transferring electronic medical data, remote patient monitoring, drug supply chain, and so on. After outlining the limitations of the examined approaches, we highlighted many open research topics and possible study domains.

Keywords: Block Chain, IoT, Medical Supply, Supply Chain.

1. INTRODUCTION

The transfer of various commodities, information, and services across different organizations in that particular business cycle necessitates the use of a secure network. Poor supply chain is an open invitation to many big challenges in any company, but there is an extra risk to patient health in the healthcare sector. The healthcare business demands efficient solutions that help smooth out various supply chain activities and procedures [1]. As in the healthcare industry, compromising with a fragile supply chain is equivalent to compromising with the patient's health, the amount to which a pharmaceutical organization disregards security in the business supply chain is directly proportionate to the severity of health risk. Among the many problems in the pharmaceutical industry, one of the most significant is providing an original product (medicine) to the customer following a lengthy process of medication formulation, clinical trials, and final development. In light of the recent COVID-19 epidemic, the presence of more labor increases the likelihood of viral propagation [2].

In the present pharmaceutical supply chain structure, each component, whether a manufacturer, distributor, or any other component, is establishing their own processes and systems for controlling medicine flow and production [3]. Because inventory management is an important factor to consider in a multi-layered supply chain, a lack of visibility in a supply chain raises many questions, such as how a manufacturing firm will know about raw material requirements and tracing of goods stored in warehouse in semi-finished and finished form. If a manufacturer and distributor do not have a clear vision of the raw materials present, the raw materials required, and the quantity of semi-finished and finished goods, this leads to inefficient inventory management, which causes many problems such as understocking, overstocking, resource waste, less profit, cost increment, and an imbalance in the overall business flow. In terms of volume, Morocco's pharmaceutical industry has emerged as the world's leading, dominant, and diverse pharmaceutical business [4].

Morocco's pharma exports climbed from 6.23 billion US dollars in 2006-2007 to 8.7 billion US dollars in 2008-2009 [5]. However, all of the discussed loopholes are important drivers of medicine shortages [6]. To minimize medication shortages, drug managers should have a clear perspective of the availability of inventory for the manufacture of medicines at their end. How would a distributor determine if the requested medications are coming from an authorized source or from a hostile intermediary? One medication out of ten is bogus or poor [7]. According to a WHO report, 20 million tablets and bottles of fake pharmaceuticals were discovered in Egypt during an ICPO operation in 2009 [8]. These counterfeited pharmaceuticals include harmful substances and, in many cases, active components in an improper amount or in an impure form, endangering patients' health. In certain circumstances, even the original drug fails to operate adequately after administration [9]. Counterfeiting is also an infringement of intellectual property rights. How would two entities learn the location of a patched drug during transportation? How would a consumer know the specifics regarding medicine, such as its genuine price, date of manufacture, date of expiry, and so on, in order to be certain of the drug's authenticity? All of these security aspects are currently lacking in the healthcare sector's supply chain infrastructure.

Cold chain transportation of temperature sensitive medications, which might lose their potency when exposed to high temperatures, is another difficulty. The term "cold chain" refers to the typical delivery of

commodities in a conventional supply chain that is managed for humidity and temperature [10]. Out of 50 medications, 26 must be transported through cold chain [11]. All of these issues, such as appropriate inventory management in order to grow up with market demand, changing data received by IoT sensors during cold chain transportation, and, last but not least, counterfeiting, may be handled by blockchain technology's transparency.

Blockchain is widely regarded as one of the most secure ledger systems on the globe [9]. Blockchain is described as a network of interconnected systems known as blocks. Each block of blockchain technology represents a collection of data. Each block will be duplicated by every entity in a blockchain network. And they'll all be aware of everything that's going on. As a result, if a new block is added or altered, it will necessitate verification from other organizations in the network, and only after this procedure will a person be able to access the information.

2. PROBLEM STATEMENT

Blockchain is widely regarded as one of the most secure ledger systems on the globe [9]. Blockchain is described as a network of interconnected systems known as blocks. Each block of blockchain technology represents a collection of data. Each block will be duplicated by There are numerous problems in the existing system of supply chain in the healthcare sector; some of them are listed below [11].

Drug counterfeiting is developing as the most difficult problem for the pharmaceutical sector to address globally. Counterfeiting is the illicit process of creating duplicate items under the guise of a legitimate good. They get access to the pre-existing company supply chain by exploiting flaws in it. A counterfeit medication is one that either does not contain the correct dosage or does so in an incorrect manner. Counterfeiting drugs is a criminal offense since it endangers patients' health. According to WHO, of the 1 million malaria fatalities each year, 0.2 percent are the consequence of tainted medications [9]. In poor nations, 30 percent of the pharmaceuticals sold are counterfeit [9]. The sale of counterfeit medications has surged from 75 billion $ in 2009 to 600 billion in 2018 [8]. Because of the current system's lack of traceability, these fraudulent pharmaceuticals enter the supply chain mostly during transfer between separate companies.

In many situations, counterfeiters exploit real manufacturers' trademarks, infringing on intellectual property rights and IP laws. Making a phony medication also entails exploiting someone else's invention without their permission, which is prohibited. Drug counterfeiting is detrimental not just to consumers but also to legitimate producers. When compared to the creation of counterfeit pharmaceuticals, the production of original medicine necessitates more resources and people, as well as a higher cost. Furthermore, it is easy to sell counterfeit medications. Fake medications cost the pharmaceutical sector in the United States 200 billion $ [7]. The current system's lack of visibility in the pharmaceutical supply chain causes a drug shortage problem. Inventory managers frequently struggle to keep track of market demand, production costs, time necessary to make a finished medication, raw material quantities, and different sorts of commodities generated. When these circumstances combine to cause understocking, the market suffers from a medicine shortage.

After examining the undesirable qualities of centralized databases as a danger to data security, the security of acquired data is also a serious worry. Data collected is also unsafe to store in a centralized database since it is less secure than blockchain [12]. The following is the question posed in this chapter: Question: How can blockchain technology be used to promote visibility and traceability in a medication supply chain in order to overcome challenges such as drug shortages, counterfeiting, inventory management, and data security in cold chain shipping?

Blockchain technology is a network of interconnected systems known as blocks. Every block represents a single piece of data. Entities are all the systems that are connected to a blockchain. Every entity has a copy of every block, and any person or machine attempting to alter data in any block will reflect all entities in the network, making access operations impossible without the verification procedure. Existing systems will verify whether or not the system attempting to conduct a transaction is an authorized individual.

3. PROPOSED SOLUTION

The proposed approach, which includes blockchain as a primary solution, makes use of IoT-enabled cars for cold shipment after accounting for main difficulties, obstacles, and loopholes in the current system. The Internet of Things (IoT) is a network of interconnected smart items or gadgets that can gather and share data via the internet. Every object connected to every other object in an IoT network is referred to as a "thing". Sensors are installed in these smart gadgets, which are responsible for data collection. IoT-enabled trucks will be employed for cold chain delivery in the suggested model/solution. They will guarantee that drugs that must be moved between two entities in the supply chain are kept at the proper temperature so that they arrive at their destination in their original state. When the temperature sought for the medicine changes, the vehicle's sensor will automatically adjust the temperature to meet the drug's needs.

3.1. Blockchain in Supply Chain

This solution addresses the concerns of counterfeiting, inventory management, and data security in the pharmaceutical industry by utilizing blockchain technology for traceability and cold chain shipping through the usage of IoT-enabled cars to carry pharmaceuticals between different organizations. Entities on the blockchain who will have access to the information contained in blocks for the purpose of tracking the movement of pharmaceuticals and preventing counterfeiting at any step are categorized as follows [5]:

1. Manufacturers
2. Distributors
3. Pharmacies (retailers and wholesalers)
4. Hospitals
5. Consumers
6. Travel agencies

First of all, a highly authorized body needs to be establishing which will work under the surveillance of government. The major purpose of this organization is to issue a unique ID to all authentic and legal producers and distributors in the pharmaceutical business, as well as to govern batch mobility [14]. It will monitor the operations of manufacturers and distributors and explain the universal criteria that govern their operations.

➢ Step 1: The approved authority will issue manufacturers a unique ID that will serve as a private key for transactions between manufacturers and distributors. According to the demand or order placed by the distributor, the manufacturing business would provide finished medications to them. This information will be uploaded as a block to the blockchain network, and as part of the blockchain's operating process, all entities will be notified of this transaction. This section will include the following information:

• Date of manufacturing
• Date of expiry
• Ingredients used and their composition
• Manufacturer's unique Id
• Manufacturing firm's name
• Date of dispatching

➢ Step 2: The specified medicine batch will be sent to the distributor. Transportation businesses will use IoT-enabled vehicles to maintain cold chain shipments. Because pharmaceuticals will be stored at the right temperature using IoT sensors embedded in the car, they will reach clients in their original form. This data will be entered as a new block, which will contain information such as:

• Vehicle no
• Travel agency's name (Figure 1)

➢ Step 3: The drugs will now be delivered to the distributor with the manufacturer's unique ID and other pertinent information. The IDs of the distributor and the manufacturer will be used as a private key between them. The arrival time will be noted upon receipt, and the distributor will submit new information through this transaction, letting all entities in the network know that the distributor has received the drugs. New added information are as follows:

• Distributor's Id
• Arrival time
• Name of distributing firm
• Quantity of medicines

➢ Step 4: Here because the travel agency is a part of the blockchain network, it will be alerted when the preceding transaction by the distributor on obtaining the drugs from the manufacturer is completed. As a result, they will collect drugs from distributors and distribute them to hospitals, retailer pharmacies, and wholesaler pharmacies. This is the moment at which counterfeiting is more likely. This transaction will also alert others, closing the supply chain gap. This section will include:

• Travel agency's details
• Vehicle no.
• Dispatched time from distributor's warehouse

➢ Step 5: Distributors can provide drugs directly to hospitals, as well as retailers and wholesale pharmacies. When medications are given directly to hospitals in this situation, a similar activity of adding a new block will occur with notification to all. This section will include the following information:

• Verification status
• Arrival time

➢ Step 6: The same approach will be followed if the distributor supplies drugs to pharmacies. Consumers can obtain medicine from retailers; but, as a member of the blockchain network, consumers will be aware of the source of medicine, whether it is from an approved source or not. Proper information tracking at every transaction in the supply chain would assist manufacturers in being aware of market demand and managing inventories properly to address the question of medicine scarcity. Blockchain's traceability feature will also help to eliminate counterfeiting.

Instead of a centralized database, blockchain will be used to store data collected by IoT-enabled vehicles while in transit. Data collected by sensors put in transportation vehicles is critical for future analysis, and sharing this data via a centralized database may represent a data threat. As with a centralized database, all data and records are stored in a single location. As a result, because it is the only copy, it is simple for a malicious entity to modify the data, yet accounting for the bad entity may be complicated and time consuming. With contrast, in a blockchain system, each entity will have its own blockchain (Figures 2 and 3).

3.2. Proposed Model

Authors propose a model that uses Ethereum's smart contracts to construct smart representations of existing medical records that are stored within individual nodes on the network. Main focus is building contracts to include metadata, permissions, and data validity of record ownership. Blockchain transactions of our network hold cryptographically signed instructions to handle certain properties. State-transition contract functions execute laws, only through legal transactions that implement data alteration [5] Such regulations can be designed to implement any set of rules that govern a specific medical record as long as it can be expressed in computational form. Such as, a policy can involve the sending of different consent transactions from both healthcare and patient's providers before granting permission to a third party to access.

So, a framework is developed for complex healthcare workflows that are based on blockchain smart contracts. In the healthcare environment, smart contracts were built for specific medical workflows, and then, data access permission was handled between various entities. A smart stored contract on blockchain technology could be built, where all the necessary conditions from handling various permissions to accessing data, as shown in Figure 4.

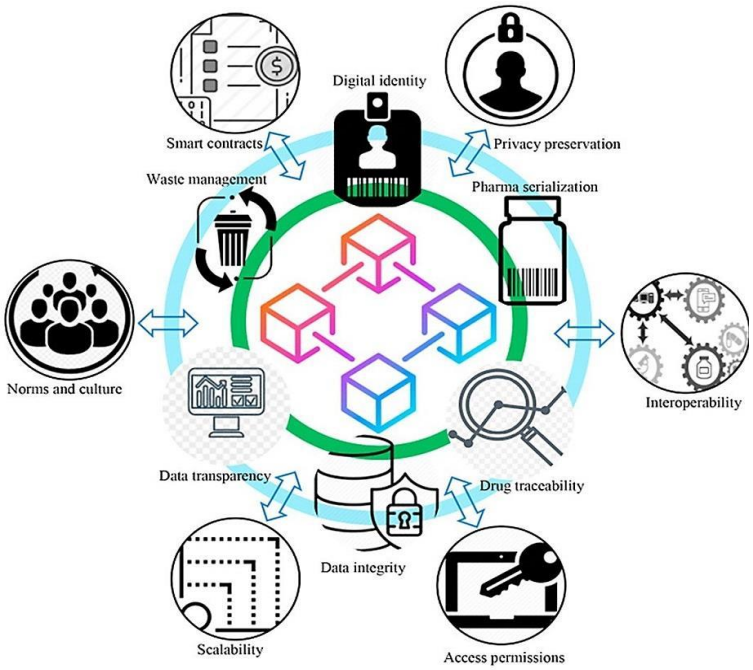

Figure 1. Drug flow from manufacturer to end users [18]

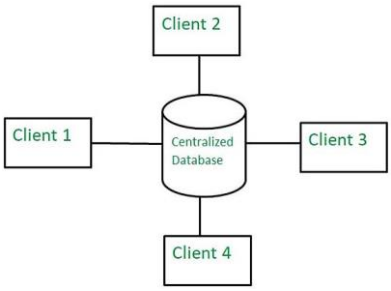

Figure 2. Centralized database [17]

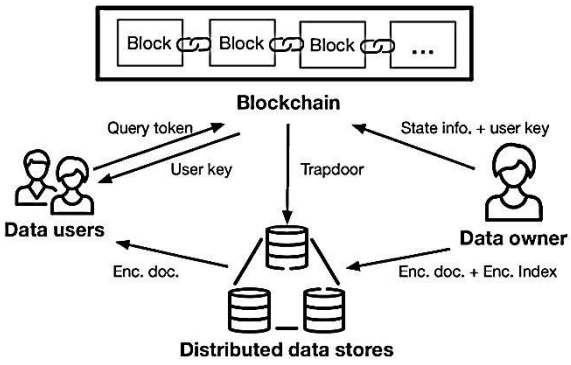

Figure 3. Blockchain distributed system [17]

It can be seen that a variety of stakeholders are interested in this scheme performing distinct activities. It would help to create stronger physician-patient experiences. The rules regulating data authorization are integrated into smart contracts [10]. This can also help monitor all actions from their origin to their surrender, with unique Id. Distinct scenarios have been explained and designed alongside all the processes embedded, and functions in the smart contracts are well described. There will be no need for a centralized body to oversee and authorize the project because it can be handled directly through the smart contract that will greatly reduce the management process administration costs. To ensure consistency and economic viability, all healthcare record data is stored in local database storage, and the hash of data is the data part of the blockchain block joined to the chain [11].

Table 1. Proposed model workflows

S. no.	Workflow
1	Issuing and filling of medical prescriptions process
2	Sharing results data/laboratory test
3	Enabling patients and service providers effective communication
4	Healthcare reimbursement data flow
5	Smart contracts for clinical trials based on Ethereum
6	Cost estimation method

The proposed model uses Aadhar card verification combined with smart contracts in Ethereum blockchain for verification of one's identity. This identity verification helps doctors to access the medical history of patients along with any current medications or treatments ongoing. The Andhra data transactions are private keys (patient or physician) signed by the owner.

The network's block content reflects data ownership and viewing authorization exchanged by various members of a private peer-to-peer network. Thus, blockchain technology helps the utilization of smart contracts that allow automating and monitoring particular state transitions. On an Ethereum blockchain, one logs patient–provider relationships through smart contracts using Aadhar card that joins a healthcare record with viewing data retrieval. Permissions instructions (essentially information pointers) for external server execution to ensure against manipulation provide a cryptographic hash of the medical record on the blockchain to ensure data integrity [13].

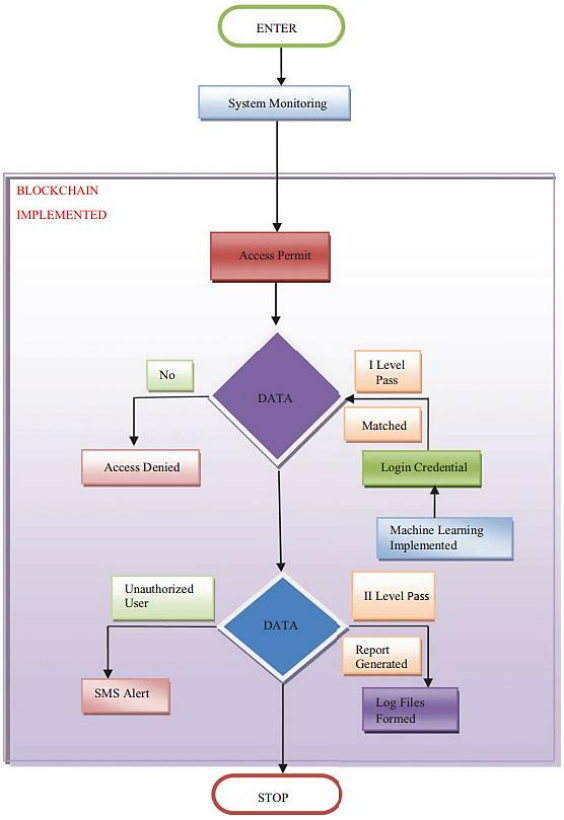

Figure 4. Integrated framework of healthcare system with the existing system

Figure 4 shows an integrated framework for the healthcare system with the existing system. Providers may attach a new record associated with a specific patient, and patients can require the sharing of records between providers. In both cases, the party receiving new information receives an automatic notification and may check the proposed record before approving or rejecting the data. That keeps the participants updated and involved in the evolution of their data and helps them decide and give control of data. This system prioritizes usability by also offering a designated contract based on Aadhar verification that aggregates references to all a user's patient-provider relationships, thus providing a single reference point for checking for any updates in healthcare history.

Also, it uses a public-key cryptography to handle identity verification and our utilization of a DNS-like implementation that maps the user's Ethereum address to an already defined and commonly accepted type of ids such as name or social security number. A syncing algorithm handles "off-chain" data exchange between a patient database and a provider database Table 2. After referring the blockchain to validate permissions through our database authentication service, the data will exchange.

3.3. Results and Discussions

Table 2 shows the parameters and values considered for the overhead evaluation of the proposed eHealth record management system, which uses the blockchain technology. The blockchain considered for the analysis is the Ethereum public cryptocurrency blockchain since the proposed system uses the Proof of Authority (PoA)-based Ethereum implementation. There are four different eHealth record management systems considered for comparison:

A: the eHealth record is kept at the hospital in plain format.

B: the eHealth records are encrypted and kept in the hospital.

C: the eHealth records are encrypted and placed in the hospital as well as in cloud.

D: the eHealth records encrypted and placed in the hospital, cloud or IPFS and meta-data on the blockchain.

Table 2. Patient database and a provider database

Feature	Existing system	Proposed system
Central dependency	Yes	No
Security	Low	Moderately
Smart contract management	No	high
Reimbursement, lab result timings	High	Low
Encryption	No	Public-key cryptogram
User privacy	Every doctor can view the record and user cannot.	Doctor can only view record with patient's consent.
Error rate	Moderate	Low
Patient admittance	Time taking with long paper trails	Easy as records are

Table 1 shows the space, access time, and computational time requirement of all systems. The given computational time for eHealth record encryption, and hashing is computed through the OpenSSL since these are not part of the blockchain activities. Table 2 shows that the systems C and D are computationally heavy when compared with the systems A and B; however, the systems A and B are not considered for overhead analysis since it lags in confidentiality and integrity while sharing the records.

The model is much secure as it uses smart contracts and various encryption algorithms to achieve that

1. There is no central dependency ensuring that each node participates in data flow, and the flow path cannot be predicted.
2. Timings of each and every task are reduced by much which will help to provide the best possible care to a patient.
3. Laboratory data can be directly shared with doctors thus eliminating the paper trail thus reducing errors.
4. Prescriptions are digitized making admittance of patients easier and simpler.

Figure 5 shows the computational time (latency) consumption of go Ethereum node for modified send Transaction validation and data access on the presence of a different number of participating nodes. The computational time plot HRhAc is for accessing the health record hash (meta-data) of a patient, and RTr is for the validation of modified send Transaction.

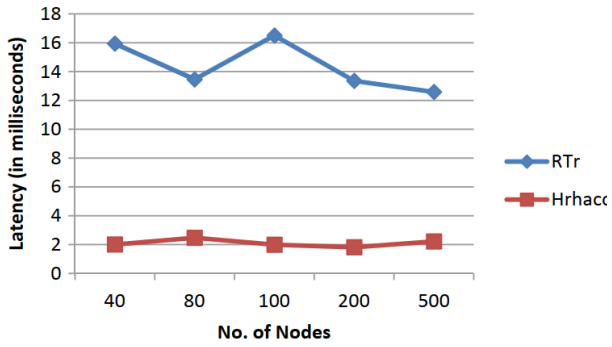

Figure 5. Computational latency for the transaction validation and data access

The experimental result shows that the transaction validation time is greater than the data access time. This is because of multiple validations such as signature and account existence. Also, the result in Figure 6 shows that the access to meta-data and validation of the transaction are not heavy and time-consuming. Figure 6 shows the latency difference of smart contract (SCAcc) and core world state MPT storage (MPTAcc)-based data access. The data access includes two steps in the case of core world state MPT storage and three steps in the case of smart contract storage. In the world state MPT storage-based data access, as the first step, the trie is traversed and the patient node is located using the patient pseudo-identity/Ethereum address and as the second step data is accessed. In smart contract storage-based data.

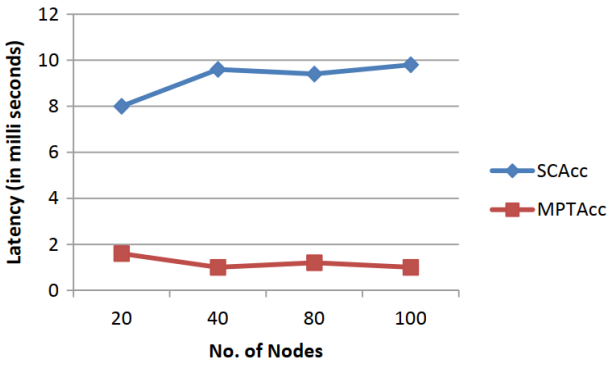

Figure 6. Computational latency for the world state MPT and smart contract storage data access

4. CONCLUSION

After a thorough examination of the pharmaceutical supply chain and knowledge of the various issues that exist in the current system, it can be concluded that there are numerous escape clauses in it that can lead to a variety of major issues such as drug shortages, counterfeiting of medicines, sensitive drug transportation, and compromises that can have a direct impact on a patient's health. As a solution to these key issues, blockchain technology has the potential to close the most escape clauses in the current system, increase visibility and traceability, and create a clear long-term vision for the pharmaceutical industry's stakeholders. This solution will not only increase the efficiency of a medicinal business cycle, but it will also open doors to incredible commercial potential in this field. This blockchain system might be employed in Morocco's impending COVID-19 vaccine delivery scenario. It will also result in fewer fatalities as a consequence of tainted pharmaceuticals and less suffering for patients as a result of market drug shortages.

Different medical workflows were planned and implemented through blockchain smart contract systems, involving unique medical procedures. Those involve providing simple medical prescriptions for the treatment of chronic diseases and their protocol for surgical patients as a recovery technique. The aim of developing these smart medical contracts is to promote the overcoming of administrative inefficiencies for the patients, doctors, and healthcare organizations. This program will assist in the recovery, review, and management of complex data and procedures in the healthcare sector. Table 1 shows the proposed model workflow for securing healthcare data by using blockchain. These workflows have been explained as separate entities with data flow in each of them.

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BIOGRAPHY

Yassine SABRI was born in Rabat, Morocco, on October 28, 1984. He received the B.Sc degree in the field of Science and Technology and Mathematics from Mohamed 5 University, Rabat, Morocco, in 2006. He completed the M.Sc. degree in the field of Engineering from University of Chouaib Douakaly, Morocco in 2008. Then he joined Laboratory of Science and Technology to continue his Ph.D. study in the field of WSN Technology. In 2013, he joined the Department of Science and Technology, ISGA Rabat, Morocco as an Assistant Professor. His research interests include wireless sensor networks, evolutionary computation, internet of things (iot) and mobile computing. in recent years, he has focused on processing of cloud computing, big data, artificial intelligence, machine learning evolutionary algorithms, software framework. He has collaborated actively with researchers in several other disciplines of science and technology.