MW4BPM: A middleware for Blockchain-Based Business Process Monitoring*

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Abstract

Blockchain technology, originally designed as the foundation of cryptocurrencies like Bitcoin, has evolved into a powerful tool with wide-ranging applications across industries. One such application is in the realm of business process monitoring, where blockchain offers groundbreaking capabilities for enhancing transparency, security, and efficiency. In the context of inter-organizational business process monitoring, Blockchain technology has surfaced as a pioneering solution, offering a decentralized and secure framework. In the age of digital transformation, organizations are increasingly recognizing the value of blockchain technology as a catalyst for enhancing transparency, security, and efficiency across various business processes. In this direction, we present, in this current research work, our Blockchain-Based Middleware for Business Process Monitoring. This middleware is not just a technological entity; it is a bridge. It elegantly fills the chasm between conventional process monitoring systems and the potential of blockchain, incorporating features such as automated monitoring activation. We also present a case study on how blockchain-based business process monitoring can revolutionize the insurance industry. We conducted rigorous evaluations of how well our middleware could adapt to the evolving needs of the insurance industry. Additionally, we assessed its scalability, ensuring its ability to accommodate a burgeoning user base and increasing data volumes.

Keywords

Inter-organizational business process, monitoring, Blockchain, middleware, smart contracts

1. Introduction

In today's rapidly and highly competitive business landscape, organizations are constantly seeking ways to improve their operations and stay ahead of the curve. Efficient business process management (BPM) is a crucial aspect of achieving this goal [1, 2]. Several organizations have sought to improve their processes by investing in business process automation software, especially when faced with unstandardized processes and unstructured data [3]. The evolution from manual methods or rudimentary automation to advanced business process automation has been significant, though it's essential to acknowledge the various challenges and nuances in implementing such software.

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In today's dynamic and competitive business environment, the effective management and optimization of operational processes are essential for organizations striving to maintain a competitive edge [4]. Inter-organizational Business Process Monitoring, as a subset of Business Process Management, plays an important role in enhancing efficiency, reducing operational costs, and ensuring optimal resource utilization. This practice enables businesses to gain real-time visibility into their workflows, track performance metrics, and make informed decisions for process improvement. Indeed, Business Process Monitoring is the practice of tracking, observing, and evaluating business processes in real-time or near real-time to ensure they are running smoothly and efficiently. It involves the continuous collection and analysis of data related to various processes within an organization, enabling stakeholders to gain insights into performance, identify bottlenecks, and make informed decisions for process improvement. While automation has been a staple in Process Aware Information Systems, emerging technologies like blockchain and AI are pushing the boundaries of this automation, offering more profound transparency in inter-organizational business processes and equipping BPM systems with advanced predictive capabilities. In an era where businesses are constantly seeking ways to optimize their operations, reduce costs, and enhance transparency, the blockchain technology has emerged as revolutionary tool. Beyond its roots in cryptocurrency, blockchain has found a new and vital role in the monitoring of business processes. Blockchain, initially conceived as the underlying technology for cryptocurrencies like Bitcoin, is a decentralized and tamper-proof ledger system. Its core attributes include immutability, transparency, and security. It is a decentralized and distributed ledger technology (DLT) that records transactions or data across a network of computers (nodes) in a secure, transparent, and immutable manner [5, 6]. It provides decentralization, transparency, security, and immutability, making it a reliable platform to execute processes in a trustworthy manner. Furthermore, it holds the potential to revolutionize the environment in which inter-organizational processes are operated in a trusted infrastructure to guarantee the trust of collaborations among multiple partners in trustless environments. These features have made it an ideal candidate for a wide range of applications beyond digital currencies.

The emergence of blockchain in the monitoring of business processes represents a significant step forward in how organizations operate and manage their workflows [7]. Its capacity to enhance transparency, trust, automation, and data security is reshaping the way businesses monitor and optimize their operations.

Blockchain offers the potential for real-time monitoring in specific business processes, especially where tracking and auditing transactions or events with high transparency and immutability are paramount. With their guarantee of durability and immutability of the transactions, they are promising aids for monitoring the inter-organizational processes running. However, one should recognize that implementing blockchain into workflows requires careful planning and consideration of the specific use case. Not all workflows will benefit equally from blockchain integration, and the technology's complexities and potential drawbacks should be carefully evaluated.

Despite the potential advantages of blockchain for business process monitoring, it is essential to acknowledge its limitations. The operational costs associated with blockchain can be substantial, especially given the energy-intensive nature of some consensus mechanisms. Transaction delays, which become pronounced during network congestion, pose performance challenges.

Alongside these, scalability constraints, potential vulnerabilities in smart contracts, and dilemmas concerning data storage emphasize the imperative of judiciously integrating blockchain into business settings. Continued research and the development of innovative solutions are crucial to overcoming these challenges.
Actually, the current approaches [8, 9, 10] do not over-look a commonly important aspect in reality as most inter-organizational process execution based on autonomous and self-executing Smart contracts. As a result, programming errors in these contracts can lead to significant financial losses. Monitoring and rigorous testing are required to minimize this risk. Moreover, a little focus of these approaches is taken from scalability issues of blockchain networks. This struggle to handle many large-scale transactions which can lead to delays and high costs.

The purpose of this paper is to detail our research on inter-organizational business process monitoring leveraging blockchain technology. By addressing pertinent research questions and delving into the intricacies of monitoring, we aim to place our study within the larger context of existing research in this domain. Following a background section, we describe, our Business monitoring approach based on blockchain technology and delve into the **MW4BPM** middleware we have crafted, which is integral for the seamless execution of smart contracts and Business Process Management (BPM).

The rest of the paper is structured as follows: In Section 2 and Section 3, we discuss the background and related works of our research work. Our approach is detailed in Section 4. In Section 5, we detail our MW4BPM middleware, and we evaluate our approach and highlight the practical implications of our middleware using an insurance management scenario. Finally, Section 6 concludes our research with a discussion on future directions.

2. Background

Inter-organizational process monitoring is the systematic collection and analysis of data about business processes to improve their efficiency and effectiveness [11]. The monitoring process is crucial to ensure the security, transparency, and integrity of decentralized networks. It involves constant supervision of transactions and activities on the blockchain to detect malicious behaviors, anomalies, and errors. Network nodes play a key role in this surveillance by verifying the validity of transactions and reporting any suspicious activity to network participants.
Blockchain is a tamper-proof ledger, ensuring that the data stored on it cannot be changed. This makes it ideal for storing data about business processes, as it ensures that the data is always accurate and reliable for enterprises. Ultimately, monitoring in blockchain aims to instill trust among users and prevent fraud, thereby contributing to the adoption and ongoing success of this revolutionary technology [12].
Blockchain is built on a transparent ledger; thus, every enterprise in the network has access to the data that is stored on it. This makes it possible to track the progress of business processes in real time and to identify any potential problems early on.
Enterprises can monitor the progress of their processes by recording each step. They are aware of the current status of the process and know that there are no delays or bottlenecks. For example, if a particular step in the process is taking longer than usual, this could be a sign of a

problem. This level of monitoring should provide any clues about the resource utilization of such node, the health of other nodes, or the latency experienced within the blockchain network Blockchain offers significant advantages for enhancing the efficiency, security, and trustworthiness of inter-organizational business processes. By leveraging blockchain, organizations can streamline operations, reduce costs, and create a more transparent and collaborative processes. Despite these benefits, it is important to carefully assess the specific use case and requirements to determine whether blockchain is the right solution for a given inter-organizational process.

3. Related work

Blockchain technology has garnered significant attention in recent years for its potential to revolutionize business process monitoring. This section aims to analyze and contrast different blockchain-based business process monitoring solutions, evaluating their advantages, limitations, and real-world applications.

At the forefront, Dumas et al [13] have explored the redefinition of B2B collaborations through blockchain technology, highlighting the decentralization benefits, cost reductions, and the possibility of collaboration without relying on centralized intermediaries. While they briefly discuss challenges such as compliance and scalability, their study primarily centers on the design and implementation stages of collaborations. A noticeable gap in their work is the in-depth exploration of real-time business process monitoring. Our work aims to fill this void, with a special focus on the crucial component of real-time monitoring, ensuring efficiency, security, and compliance in blockchain-based business processes.

In a related vein, Weber and Staples [14] have investigated the concept of "programmable money" using distributed ledger systems, demonstrating how these systems can implement conditional payments akin to state-contingent contracts [15]. Their work highlights the potential applications of distributed ledgers in public policy and decentralized finance (DeFi), emphasizing the importance of transparency, decentralization, and compliance. However, This work does not take into account the realm of real-time business process monitoring, which is the cornerstone of our study.

Each blockchain-based business process monitoring solution has its own set of advantages and limitations. In their work [8], authors have proposed a framework that combines blockchain and IoT technologies to monitor and control business processes in real-time. Moreover, fernandez et al [9] have examined the use of blockchain and smart contracts in healthcare, where complex business processes and data monitoring are vital. They discuss how blockchain can secure and streamline patient data management and healthcare supply chains.

As another survey, the research work given in [10] have discussed the integration of blockchain technology with business process management. It highlights the potential impact of blockchain on process modeling, execution, and monitoring. It explores how blockchain can enhance transparency and trust in business processes and identifies opportunities for improving efficiency and reducing friction in process management through blockchain.

In [16], authors detail a framework that combines blockchain and IoT technologies to monitor and control business processes in real-time. It emphasizes the importance of real-time data in process monitoring for better decision-making and discusses how blockchain's immutability

and decentralization contribute to data integrity and security in monitoring.
Moreover, in [17], a comprehensive review of blockchain-integrated secure middlewares designed for a decentralized IIOT (Industrial Internet of Things) is provided. The study stands out for its proposition of a four-tiered architecture for middleware, anchored in the IIoT application framework. It underscores blockchain's prowess in mitigating single-point failure risks and addressing security lacunae inherent in traditional centralized IIoT solutions.
Collectively, these research endeavors illuminate the myriad benefits blockchain technology in enhancing transparency, security, automation, and operational efficiency across various business process monitoring facets. They also illustrate the challenges and strategic considerations pivotal for the seamless integration of blockchain in diverse industry domains.
While the aforementioned studies offer groundbreaking insights into the integration of blockchain with business process monitoring, each possesses certain limitations. For instance, while some focus predominantly on the benefits of blockchain and IoT integration, they may neglect the intricate complexities associated with the synchronization of these technologies. Others, while emphasizing the advantages of smart contracts in healthcare, might not delve deep enough into the scalability or adaptability concerns that arise in broader industry applications. The integration of blockchain with BPM, although promising in terms of transparency and efficiency, often lacks comprehensive exploration of the challenges faced during real-world implementation, particularly regarding integration, consensus mechanisms, and interoperability issues.
However, our research work intends to bridge these gaps. Recognizing the collective strengths and individual shortcomings of the above studies, our endeavor is to amalgamate the salient features of blockchain, the precision of smart contracts, and the robustness of BPM-based monitoring. By synthesizing these attributes, we aim to create a more holistic, scalable, and adaptable solution, poised to revolutionize business process monitoring across various industry verticals.

4. Proposed approach

Monitoring and management of the inter-organizational processes in blockchain are essential for ensuring its reliability, security, and efficiency. This complex role entails managing the network's nodes, guaranteeing data integrity, and taking precautions against any dangers. To identify and address security lapses and abnormalities, constant vigilance is necessary. Optimizing a business process performance, updating software, and scaling resources as necessary to accommodate expansion are other aspects of administering a blockchain system. The endurance and effectiveness of the blockchain are ultimately attributed to competent monitoring and administration, which lay the groundwork for trust and transparency in a decentralized digital environment.
Effective monitoring and management of inter-organizational processes on the blockchain are pivotal to ensure its reliability, security, and efficiency. This multifaceted role encompasses tasks such as network node management, safeguarding data integrity, and taking precautions against potential threats. Continuous vigilance is essential for identifying and rectifying security gaps and anomalies. Moreover, in the context of a blockchain system, optimizing performance entails

enhancing transaction processing speed and response time efficiency. Regular software maintenance ensures the system's robustness against vulnerabilities while updating its functionalities. Scaling resources involves augmenting the system's capability, through addition of nodes or computational power, to cater to increasing demands and ensuring seamless operation as the network grows.
Ultimately, the resilience and effectiveness of the blockchain in ensuring data integrity, processing transactions, and maintaining a secure network rely on competent monitoring transactions between stakeholders. These aspects establish a foundation for trust and transparency in a decentralized digital environment.

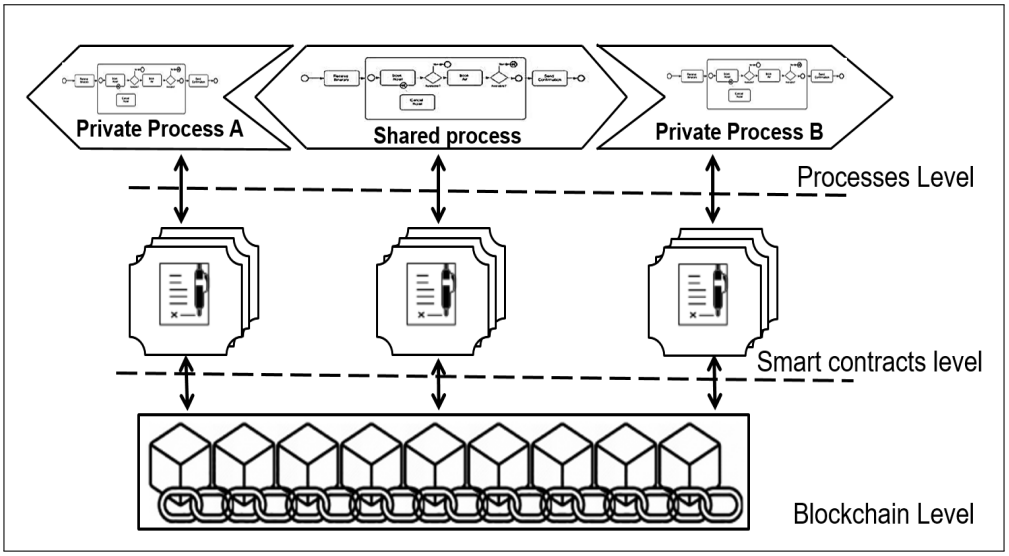

Figure 1: Blockchain based Monitoring Approach

Our proposed approach (as shown in Figure 1) involves the monitoring of business process based on blockchain. This approach delineates a three-layered structure emphasizing the interactions and dependencies amongst the "Process Level", "Monitoring Level", and "Smart Contract in Blockchain Level".

- **Process Level**: This level embodies the core business processes and operations. Here, business processes are articulated, managed, and executed. It encapsulates the functional dynamics that cater to the operational requisites of a business.
- **Smart contratct level**: An intermediary layer focused on oversight. It vigilantly watches over the Process Level, ensuring operational consistency. Discrepancies in business processes are swiftly detected. This layer also processes and offers data insights. Every unique process here is associated with a smart contract, either overseeing specific tasks or an entire business process. The integral connection between the Process Level and the Blockchain Level is maintained through these smart contracts, which act as conduits between the two. Essentially, this layer ensures processes are correctly executed and documented on the blockchain.

- **Blockchain Level**: Serving as the foundational stratum, this layer infuses trust, transparency, and automation into the system. Through smart contracts, it mandates specific preconditions be satisfied before sanctioning transactions or endorsing process steps. Moreover, the intrinsic features of blockchain—its immutability and decentralized nature—fortify this trust.

The Process Level feeds data and performance metrics to the Monitoring Level. Subsequently, based on certain predefined criteria or identified irregularities, the Monitoring Level may instigate specific smart contracts housed within the Smart Contract in Blockchain Level.
The approach outlined here offers a structured and effective way to harness blockchain's transformative potential in business process monitoring. As organizations increasingly recognize the value of transparent, efficient, and secure processes, blockchain-based monitoring is poised to drive innovation and competitiveness across diverse industries. It holds the promise of revolutionizing the way businesses monitor and optimize their operations.

5. Implementation and evaluation

5.1. Case study

The insurance industry has long grappled with challenges related to transparency, fraud prevention, and operational efficiency. Traditional insurance processes are often characterized by lengthy verification procedures, fragmented data management, and a susceptibility to fraudulent activities. Blockchain technology has emerged as a transformative solution, offering a decentralized, tamper-resistant ledger system that can reshape the way insurance business processes are monitored and executed. In this case study, we will delve into a detailed examination of how our middleware solution, MW4BPM, can be strategically applied within the insurance sector to enhance commercial process monitoring, reinforce data transparency, and reduce operational costs.
Our BPMN model (Figure 2) includes three distinct lanes to ensure clarity and accessibility for all stakeholders:

- General Insurance Process: This component encompasses the broader insurance framework, including various types of insurance coverage. It represents the foundational layer of our BPMN, providing an overview of the insurance landscape.
- Customer Space: The Customer Space is designed with simplicity in mind to ensure ease of use for clients. Here, customers can perform basic tasks such as making payments, registering for insurance coverage, and handling administrative tasks related to their policies.
- Administrative Space: Within the Administrative Space, private and sensitive tasks associated with selected insurance policies are managed. This section is designed to handle confidential and policy-specific activities, ensuring data privacy and security.

By dividing our BPMN model into these three lanes, we aim to create a clear and comprehensible representation of the insurance process. This segmentation enables both insurance professionals

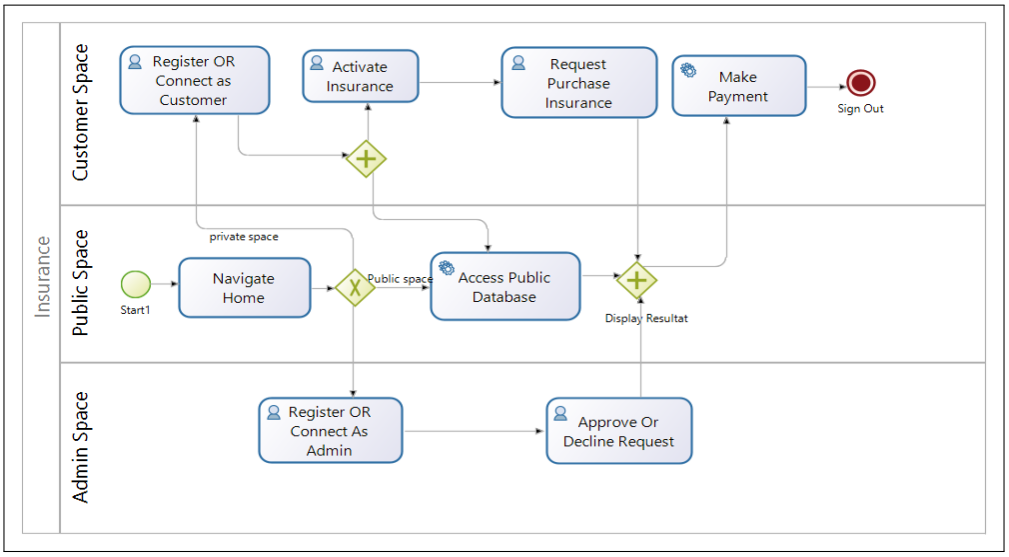

Figure 2: BPMN for Insurance process

and policyholders to understand and engage with the system more effectively. It also aligns with our overarching goal of improving transparency, efficiency, and security within the insurance sector.

In the next section, we will delve into the functionalities and benefits of each component in detail, highlighting how MW4BPM streamlines insurance processes, enhances customer experiences, and reinforces data integrity.

5.2. Implementation and evaluation

To elucidating our methodology and substantiate our approach, we are elucidating an application whose architectural blueprint is showcased in Figure 3:
This illustration presents a three-tiered architecture designed to enhance the efficiency and transparency of the insurance subscription process.

- **BPM Level (Business Process Management Level)**:
  Client: Here, the client initiates the interaction by accessing the application.
  Design & Architecture: Using Bootstudio, an initial design and architectural framework are conceived, setting the foundation for the system's structure and esthetics before technical implementation.
  Frontend: Angular is utilized to manage user interactions and seamlessly integrate with the design set by Bootstudio.
  Backend: Firebase, acting as a real-time database, facilitates the storage and retrieval of data. Firebase functions handle the server-side logic, while Crashlytics continuously monitors and reports potential real-time errors.

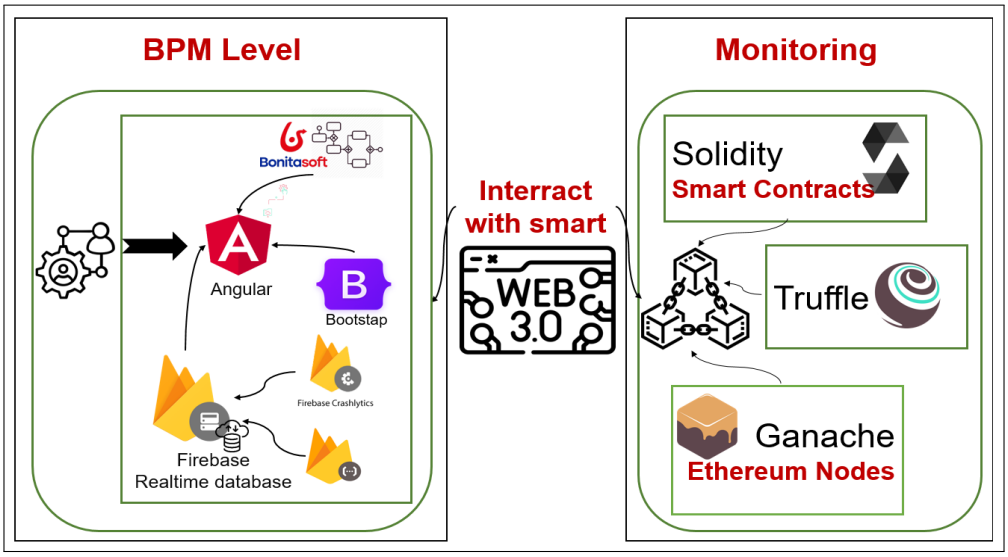

Figure 3: Overview of the MW4BPM middleware architecture

- **Smart Contract Interraction**:
  Web3.0: A pivotal interface between the application and the blockchain. Web3.0 enables real-time communication with the blockchain, allowing the sending, receiving, and managing of various requests. At this juncture, the BPM level information is channeled to the blockchain, ensuring a transparent and secure interaction.
- **Monitoring**:
  Solidity: This is the primary programming language used for drafting smart contracts on Ethereum. These autonomous contracts execute transactions ensuring data security, transparency, and integrity. With Solidity, rules, conditions, and subsequent actions are established to be executed once certain criteria are met.
  Truffle & Ganache: These tools, essential for the development and deployment of smart contracts, provide a robust ecosystem for Ethereum-centric work. Truffle serves as a development and testing environment, while Ganache, a private blockchain, assists in development by providing an isolated testing ground prior to actual deployment.
  Monitoring Mechanism: Monitoring primarily involves the oversight and validation of smart contract executions. A contract, once triggered by an action or condition (e.g., a client taking out insurance), is automatically implemented according to the guidelines set in Solidity. This automated process demands ongoing vigilance to ensure operations unfold correctly, free from faults or malicious intent. With Truffle and Ganache, developers have the means to monitor, test, and rectify their contracts in a secure environment, assuring flawless execution.

The interactions starts at the BPM level: Bootstudio establishes the architecture and design, while Angular brings this vision to life. The captured data is relayed to the blockchain through Web3.0, initiating the smart contracts. These contracts, scripted in Solidity and managed by Truffle and Ganache, make decisions based on pre-set criteria. These actions are constantly

observed to maintain their transparency and security.

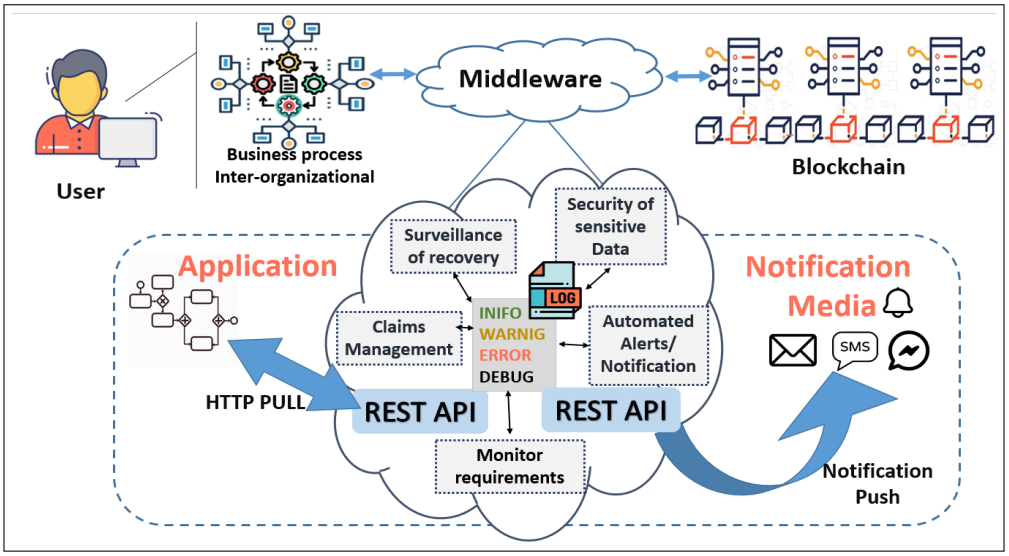

Figure 4: Overview of the MW4BPM middleware interaction

In today's evolving digital landscape, traditional server-side operations often face challenges related to efficiency, transparency, and security. Recognizing these challenges, we have developed a sophisticated middleware that leverages the transformative potential of blockchain technology. Central to our framework, this middleware serves not only as a bridge but as an empowered assembly of multifunctional lanes, each intricately designed to enhance performance and reliability (Figure 4).

- Surveillance of Recovery: Emphasizing system resilience, this component swiftly detects and mitigates potential disruptions, ensuring minimal downtime and upholding data integrity even during unforeseen events.
- Data Security Protocols: With data breaches becoming a rising concern, our middleware incorporates state-of-the-art encryption measures, providing a fortress for sensitive information against unauthorized access.
- Automated Alerts and Notifications: Proactive monitoring remains crucial. This feature diligently observes system behavior, sending out automated alerts for anomalies or critical events, ensuring that stakeholders can take immediate action.
- Claim Management System: Tailored for sectors such as insurance, this component expedites claim processing through its blockchain interface, minimizing fraud risks and boosting processing efficiency.
- Performance Monitoring: Acting as the system's watchdog, this module ensures alignment with performance benchmarks, shedding light on areas needing enhancement.

Seamless communication is achieved via REST APIs, enabling the middleware to dispatch "Push Notifications" to stakeholders and systems. The "HTTP PULL" mechanism further guarantees that data from the blockchain is always current and accessible.

Each operation within the middleware is meticulously logged. By categorizing logs as 'info', 'warning', 'error', or 'debug', it provides a multi-dimensional view of the system's health, aiding in diagnostics and ensuring optimal performance.
To conclude, our middleware is not just a technological solution; it is a paradigm shift. It paves the way for businesses to harness the full potential of their server operations, fortified by the unmatched advantages of blockchain technology.

6. Conclusion and future work

Blockchain-based business process monitoring represents a promising paradigm shift in the way organizations track and manage their operations. This technology offers significant advantages in terms of transparency, security, automation, and efficiency. The decentralized and immutable nature of blockchain ensures data integrity, while smart contracts automate tasks and reduce the need for manual intervention. Real-time monitoring provides immediate insights, leading to quicker issue resolution and improved decision-making. As a result, blockchain has found applications across various industries, from supply chain management to healthcare and finance.

In this direction, we have developed a blockchain-based approach for business processes monitoring. We also detailed our MW4BPM middleware and we evaluated our approach using an insurance management scenario.

As blockchain technology continues to mature and overcome existing challenges, it holds the promise of transforming business process monitoring into a more efficient, secure, and transparent practice, benefiting enterprises across various industries. The future of business process monitoring is undoubtedly intertwined with the continued evolution of blockchain technology. Combining blockchain with other emerging technologies such as artificial intelligence (AI) and Internet of Things (IoT) can lead to innovative solutions for business process monitoring .As part of our ongoing work, we are exploring how these technologies can complement each other. Our ongoing work will incorporate machine learning, adding a new layer of intelligence to our monitoring capabilities. This exciting endeavor promises to unlock the full potential of our blockchain middleware, allowing us to analyze data patterns, detect anomalies, and make data-driven predictions. Machine learning algorithms can leverage the wealth of data generated by blockchain transactions to detect patterns, anomalies, and trends that might otherwise remain hidden. This predictive capability can enable organizations to proactively address issues, optimize processes, and make informed decisions in real time.

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