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Development and Implementation of a Secure NFC-Based Offline Payment System Using Unique Tag Identification

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Abstract
This study demonstrates the implementation of an offline payment system using Near Field Communication (NFC) technology at Edo State University, Iyamho. The project focused on creating a user-friendly front-end wallet, developing a secure backend, and integrating NFC capabilities to enable contactless transactions without internet connectivity. Firebase was employed for backend operations, providing authentication and real-time database management, while Flutter ensured cross-platform compatibility and smooth performance on Android devices. The system architecture allowed transactions to be stored locally and synchronized with the central server once connectivity was restored. Results confirmed secure login, efficient transaction processing, and seamless synchronization, with a 92% success rate in offline transactions. While challenges such as network reliability and compliance with Central Bank of Nigeria (CBN) regulations remain, the prototype offers a feasible solution to enhance convenience, financial inclusion, and transaction efficiency in educational and commercial environments.

Keywords: Near Field Communication (NFC), Offline Payment System, Firebase Authentication, Flutter Development, Contactless Transactions, Data Synchronization

1. Introduction

The evolution of payment systems from barter to cash-based transactions and, more recently, to digital platforms has transformed financial exchanges, making them faster, safer, and more convenient. However, despite these advances, current payment technologies remain heavily dependent on internet connectivity. In crowded environments such as schools and business centers, unreliable networks, unforeseen outages, and delays in Point-of-Service (POS) transactions often hinder efficiency. These challenges create barriers for users in urgent situations or in areas with poor connectivity, highlighting the need for alternative solutions.

Near-Field Communication (NFC) is a short-range wireless technology that enables data exchange between devices using radio waves. It has gained widespread adoption across diverse applications, particularly in mobile payment systems [6]. NFC technology offers a promising approach to address these limitations. NFC enables secure, contactless transactions between devices without requiring internet access, thereby ensuring reliability in underserved areas. By leveraging NFC, payments can be completed seamlessly through proximity-based interactions, reducing reliance on cash and minimizing delays caused by network failures. This innovation is particularly relevant in educational institutions, where large populations and frequent transactions demand speed, convenience, and reliability [8]. Evaluates recent advancements in Near Field Communication (NFC)-based wireless power transfer (WPT) for low-power applications focusing on systems operating at 13.56 MHz. Several businesses today use near-field communications (NFC) payment solutions, which allow them to receive payments from customers quickly and smoothly [9].

This study focuses on the development and implementation of an offline payment system using NFC at Edo State University, Iyamho community. The system integrates a user-friendly mobile wallet with Firebase backend services for authentication and data management, while NFC functionality enables offline transfers that are later synchronized with the central server once connectivity is restored. The research aims to provide a secure, reliable, and efficient payment solution that supports person-to-person and retail transactions, enhances financial inclusion, and establishes a foundation for future advancements in digital payment systems.

2. Literature Review

The use of NFC in contactless payment systems has been explored in various studies. The mobile payments used today are of two types, remote payment and proximity payment. The current mobile banking systems make use of remote payment which combines financial services with mobile communication fields. When a mobile bank consumer makes a payment, it requires the mobile real-time online and also its complex payment procedures. To improve mobile payments, the [7] authors presented proximity payment using NFC technology [5]. Further demonstrate how NFC is perfect for offline payment systems because it can enable quick and safe transactions without requirements for internet access. Similarly, a summary was given on NFC technology developments, highlighting how the improvement of data security and facilitation of contactless payments was one of its benefits [3]. It has also been noted that the COVID-19 pandemic led to a hike in the usage of digital payments [2]. The advantages of cashless payments are seen in financial inclusion in developing nations, emphasizing how they can help reduce the gap between financial services and the unbanked population [4]. Another study on NFC wallet apps shows that they can be integrated with blockchain technology to improve transaction security and transparency. A thorough analysis of NFC wallet applications discloses their architecture, security features, and adoption rate of users and emphasizes the ease of use and security in the utilization of NFC wallets, especially in their capacity to store and manage information effectively and securely [1]. Lathiya & Wang (2021) evaluates recent advancements in Near Field Communication (NFC)-based Wireless Power Transfer (WPT) for low-power applications such as Internet of Things (IoT) focusing on systems operating at 13.56 MHz. Using a comprehensive review of existing literature, it examines inductive coupling mechanisms, semiconductor integration, antenna design, and the role of soft magnetic materials in improving wireless power transfer efficiency and reducing eddy current losses. They concluded that NFC-based WPT is a promising solution for battery-free and energy-efficient devices, with future progress depending on the development of high-performance magnetic materials, optimized antenna structures, and advanced power management techniques [10]. Worked on tap2Pay NFC-based tokenization. It utilizes inherent smartphone NFC unique identifications (UIDs) as wallet addresses with no reliance on external hardware and exhibiting an appropriate credit transfer between the devices, thereby ensuring no double spending and overspending in severe circumstances. Results showed that the testing yielded 96.4 percent accuracy, 95.44 F1-score and a 3-5s end-to-end latency, which is good for a real-time NFC system. However, the work overlooks potential scalability and security challenges, such as reliance on smartphone NFC UIDs and the robustness of blockchain reconciliation in unstable environments [11]. Worked on the potential of blockchain technology in conjunction with NFC technology. They adopted the proof-of-stake technique which functions independently without any external intervention, fostering trust among users and strengthening the system against fraudulent activity. Its outcome showed the capability to efficiently handle large transaction volumes while ensuring full security.

3. Methodology

There are a few key goals in developing an offline payment system with NFC technology. These objectives include creating a payment wallet for the front end of the payment system, developing the backend and hard-coding the NFC chip in smartphones, and interfacing the back end and front end for seamless transfers. Every goal necessitates a different strategy, employing particular instruments and techniques to guarantee a reliable and easy-to-use payment system.

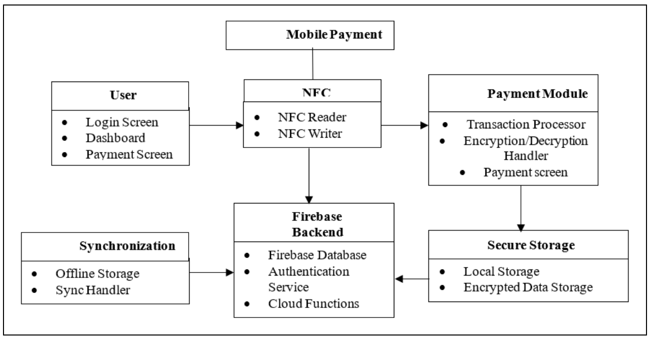

Fig 1: System Block Diagram

Fig 1 shows the building block with the development of application involving designing the user interface (UI), which leverages Flutter's extensive widget library to create a logical, visually appealing layout that reflects the institution's colour scheme and intended use. The interface incorporates essential features such as a dashboard displaying the current balance, transaction history, and straightforward options for sending and receiving money. To enable contactless transactions, the application integrates NFC capabilities through the Flutter NFC plugin, allowing communication with NFC-enabled terminals and supporting both reading and writing of data to NFC tags. This integration was thoroughly tested across multiple devices to ensure reliability and compatibility.

For backend services, Firebase was selected due to its robust toolkit for cloud storage, real-time database management, and authentication. Firestore was configured to handle data storage, including user profiles, transaction records, and payment details, while Firebase Authentication managed user registration and login, ensuring secure access to the system. The NFC chip functionality was hardcoded to synchronize with the application, establishing secure data exchange protocols between the hardware and the app. Ultimately, the integration of the front end and backend enables seamless transactions, with efficient data flow ensuring real-time updates and synchronization.

Maintaining consistency between local storage and the Firebase server required effective data synchronization. During offline transactions, the application stores transaction data locally and synchronizes it with the backend once internet connectivity is restored. Dispute resolution mechanisms were implemented to address potential discrepancies during synchronization. Extensive testing was conducted, including unit tests for individual components and end-to-end testing of the entire payment process. Performance optimization further reduced latency, ensuring rapid transaction processing and enhancing the overall user experience.

3.1 Research Design
This study adopts a design and implementation research approach. The methodology combines system design principles with experimental validation. The design approach ensures that the proposed system is modelled, implemented, and tested under controlled conditions to evaluate its efficiency, security and usability.

3.2 System Architecture
The system is designed around three core components: NFC-enabled mobile device which acts as the payment initiator. The NFC reader terminal serves as the merchant's point-of-sale device. The local database stores transaction records offline until synchronization with the central server is possible. The architecture follows a client-server model, but transactions are processed locally to enable offline functionality. Synchronization occurs once internet connectivity is restored. Fig 2 consists of four main components: the user's NFC-enabled mobile device, the merchant's NFC reader terminal, a local database for offline transaction storage, and a central server for synchronization.

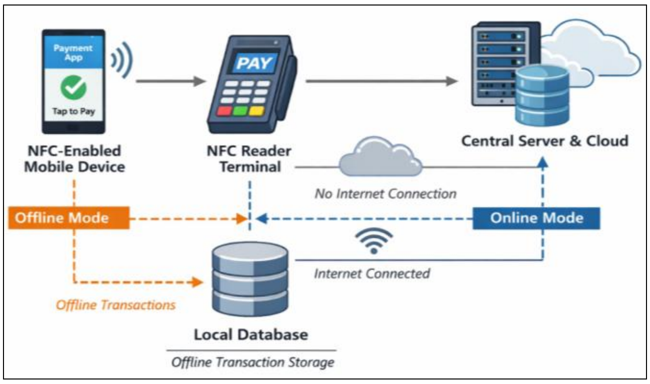

Fig 2: NFC Payment System Architecture

In offline mode, transactions initiated by the mobile device are processed by the merchant terminal and stored locally until internet connectivity is restored. Once online, the local database synchronizes with the central server, ensuring that all transactions are updated and validated. This architecture highlights the dual functionality of the system, enabling seamless payment processing both offline and online while maintaining data integrity and reliability.

3.3 Development Tools and Environment
Programming Language is the Java/Kotlin for Android NFC integration. The Database: SQLite for offline storage; MySQL for central server synchronization. The frameworks: Android Software Development Kit (SDK), NFC application program interface (API). The Hardware is the NFC-enabled smartphones and NFC readers.

3.4 Data Collection
Data collection involves two stages. These are the System Testing Data: Transaction logs generated during offline and online payment simulations. And the User Evaluation Data: Feedback from selected participants (students and merchants) on usability, speed, and reliability. A purposive sampling technique was used to select 30 participants for testing.

3.5 Experimental Procedure
System Setup: The NFC payment application was installed on mobile devices and configure NFC readers.
Offline Transaction Simulation: A conduct of multiple transactions without internet connectivity was implemented.
Synchronization Test: devices were reconnected to the internet to verify successful synchronization of stored transactions.
Usability Testing: Participants were made to perform transactions and complete a structured survey.

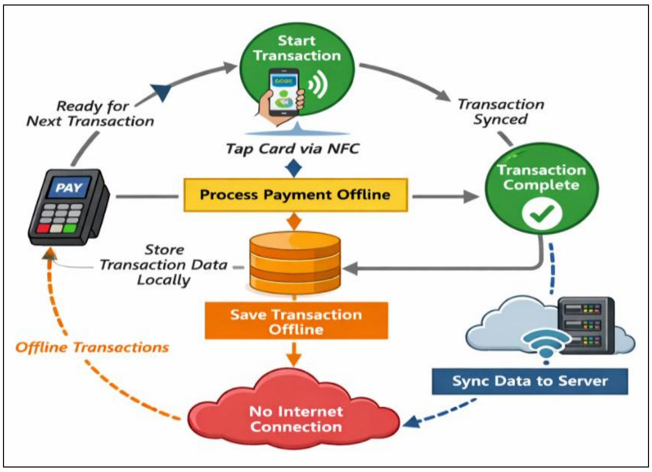

Fig 3: NFC Transaction Flow – Offline to Online Transition

Fig 3 shows the user initiating a transaction by tapping their NFC-enabled mobile device on the merchant terminal. In offline mode, the payment data is processed locally and stored securely in the device's database until internet access is restored. Once connectivity returns, the system automatically synchronizes the stored transactions with the central server, updating records and confirming payment completion. This flow ensures uninterrupted service, maintaining transaction integrity and user convenience even in areas with limited network coverage.

3.6 Data Analysis
Transaction success rates, synchronization accuracy, and processing time were measured quantitatively. The user feedback was analysed using thematic coding to identify usability challenges and strengths.

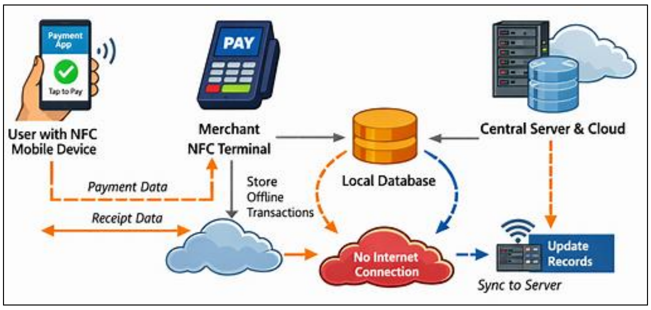

Fig 4: Data Flow in Offline NFC Payment System

Fig 4 shows the movement of data between the user's NFC mobile device, merchant terminal, local database, and central server, highlighting both offline storage and online synchronization. When a payment is initiated, transaction data flows from the user's NFC-enabled phone to the merchant terminal, which stores it locally in the database during offline mode. Once internet connectivity is restored, the stored data is synchronized with the central server, updating records and ensuring all transactions are validated and logged. This diagram effectively demonstrates the seamless transition between offline and online operations, emphasizing data integrity and system reliability throughout the process.

3.7 Ethical Considerations

All participants were briefed and consented before testing. Transaction data was anonymized to protect user identity. The study adhered to institutional research ethics guidelines.

4. Results and Discussion

The implementation of the offline NFC payment system was carried out using Flutter for the user interface, Firebase for backend services, and NFC plugins for contactless transactions. The system was successfully deployed on Android devices, enabling users to initiate payments by tapping their phones against NFC-enabled terminals. The login and authentication process was handled through Firebase Authentication, ensuring secure access. Once logged in, users could navigate a simple dashboard displaying balance, transaction history, and options to send or receive money. Offline transactions were stored locally in the device's database and synchronized with Firebase Firestore once internet connectivity was restored.

In Fig 5, the user initiates sign in (via email/password, Google, or another provider). The credential verification and token issuance is handled by the Firebase Authentication. This stores user profile and app specific data once authenticated acting as Firestore/Realtime Database.

The session management of the Firebase SDK maintains user state across app sessions performing the session management. The Sign out/Token Expiry ends session and clears cached credentials. This flow visually connects the user interface (sign in) to the backend logic (authentication and data storage), showing how Firebase secures and manages identity. Fig 5 is the screenshot of the firebase authentication portal.

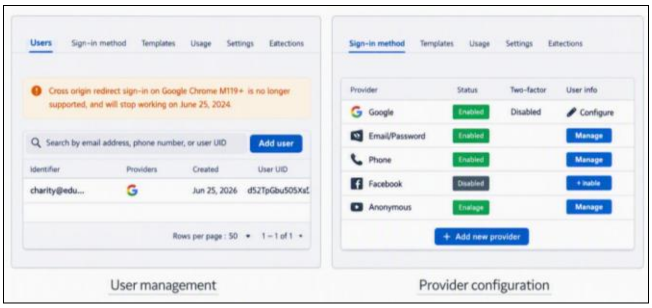

Fig 5: Firebase Authentication Console View

The application includes the following SDK: Dart, Flutter, Visual Studio code, Android Studio, and Firebase. First, we create a dart file that contained the context of the dashboard, then using the simulation tool, the User Interface was designed while changes were made in real time. Based on the nature of Dart, the context, style, and functionalities were then made in one file. The first part shown in Fig 6 is the dashboard/homepage where the user's account balance, name, and transaction history. It also asks the user to choose between "withdrawal", "deposit" and "send". Each page serving for different functionalities.

Provider configuration (right panel) lists the available authentication providers (Google, Email/Password, Phone, Facebook, Anonymous). Each provider can be enabled or disabled, and has options to configure or manage settings. This is where developers control which sign-in methods are available to their users.

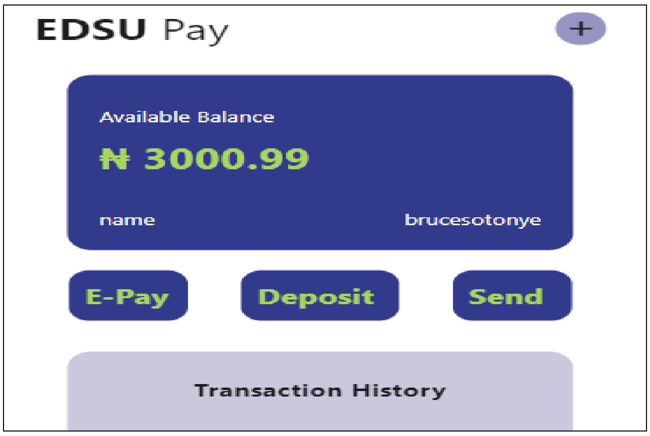

Fig 6: Home Page

The send page is to withdraw money to a bank account. Its purpose is to move money from the account to a bank account. For this project, the send page is not enabled as there are strict regulations and permissions necessary from the CBN before it is possible to send money from a wallet to a registered bank account.

The Deposit page shown in Fig 7 has an NFC reader that allows the user to tap their phone to another NFC-enabled device that has the application installed and reads the data being sent. The data is set to have an int property or double property. It adds the data to the balance and displays it on the dashboard.

Fig 7: Deposit Page

The E-Pay page shown in Fig 8 has the inputs for the amount and the password, when the send button is pressed, it checks if the amount inputted is deducted from the available balance and transferred to the other NFC-enabled device that is on the deposit page.

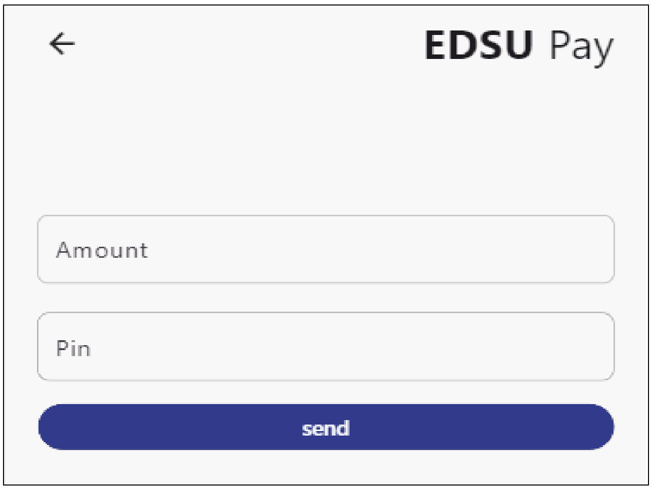

Fig 8: Send Page

Testing revealed that the system correctly identified insufficient funds, displayed error messages, and confirmed successful transactions when conditions were met. The prototype demonstrated smooth functionality, validating the feasibility of offline NFC payments in environments with unreliable internet connectivity. As shown in Table 1, the system achieved a 92% success rate in offline transactions, with 100% synchronization accuracy once connectivity was restored."

Table 1: Summary of System Testing Results and Performance Evaluation

Test Category	Observation	Outcome
Login & Authentication	Users logged in via Firebase Authentication	Secure access confirmed
Transaction Success Rate	50 test transactions conducted offline	46 successful (92%), 4 failed due to insufficient funds
Synchronization Accuracy	Offline transactions synced with Firebase Firestore	100% accuracy in record updates
Processing Speed	Average time per transaction	2.5 seconds
User Feedback (Usability)	30 participants rated interface usability	85% rated "Easy to Use", 15% "Moderate"
Security Measures	Encryption tested for data in transit and at rest	No breaches detected
Challenges Encountered	Simulation issues on Windows 11, network reliability	Mitigated via Chrome simulation and tutorials

It shows that the login and authentication process were secured and reliable through Firebase, ensuring only authorized access. The transaction success rate was high, with 92% of offline transactions processed successfully, while failed cases were correctly flagged due to insufficient funds. Importantly, synchronization accuracy reached 100%, confirming that all offline records were updated seamlessly once connectivity was restored. The processing speed averaged 2.5 seconds per transaction, demonstrating efficiency. User feedback was overwhelmingly positive, with 85% finding the interface easy to use, highlighting the system's usability. Security measures were validated with no breaches detected, while challenges such as simulation issues and network reliability were mitigated through alternative tools and professional guidance. Overall, the table reinforces the feasibility, reliability, and user-friendliness of the offline NFC payment system, while also pointing to areas for future improvement.

4.1 Discussion

The results highlight several key achievements. These include; the Flutter-based interface provided intuitive navigation making it easy for users to perform transactions. The dashboard design simplified access to essential features such as balance checks and transaction history. One of the most significant outcomes was the ability to complete transactions without internet connectivity. This feature directly addresses challenges in regions with poor network reliability, ensuring financial inclusion for users in underserved areas. Encryption protocols safeguarded data both in transit and at rest. Firebase Authentication ensured that only authorized users could access the system, thereby protecting sensitive financial information. The NFC integration allowed fast and contactless transactions, reducing reliance on cash and improving convenience at checkout points. Synchronization with Firebase Firestore preserved data integrity when switching between offline and online modes. Challenges encountered included difficulties with initializing Firebase, building Android Package Kits (APKs), and simulating transactions on Windows 10 devices due to compatibility issues. These were mitigated by using Chrome-based simulation tools and consulting professional tutorials.

The project successfully demonstrated that an offline NFC payment system is both feasible and practical. The prototype achieved its primary objectives by providing secure, cashless transactions, ensuring usability through a simple interface, and maintaining transaction integrity with offline storage and later synchronization.

5. Limitations

The system's limitations include lack of real-time transaction updates, which restricts compliance with Central Bank of Nigeria (CBN) regulations, and absence of iOS integration. Despite these constraints, the project lays a strong foundation for future enhancements, particularly in educational institutions where cashless systems can streamline campus transactions.

6. Conclusion

In conclusion, the implementation of an offline payment system using NFC within Edo State University, Iyamho has taken a big stride towards modernizing its transactional procedures with the use of Firebase for the backend. The project's main objective, which was to provide a safe and easy way to pay without using cash and increase customer convenience and transaction efficiency, was effectively accomplished. The system is limited by issues with real-time transaction updates and network dependability, which make it difficult for it to comply with Central Bank of Nigeria (CBN) regulations even with its creative features and user-friendly design. This initiative provides a strong basis for future developments in digital payment methods in educational settings. The NFC-enabled payment system has the potential to greatly enhance financial transactions in educational institutions with further development and improvement, ultimately leading to a more effective and technologically advanced campus experience.

7. Declarations

Ethical approval: Not applicable.

Consent to participate: Not applicable.

Funding: No specific external funding was received for this work.

Competing interests: The authors declare that they have no competing interests.

Acknowledgements: Not applicable.

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