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Time Bound Digital Ticketing Enforcement for Smart Urban Transport Systems

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Abstract

The objective of this research is to minimize the concept of fare evasion in urban public transport systems which poses an operational and revenue challenge to the system. Fare evasion exists in system where digital purchase of ticket is possible. This loophole gives way to strategic fare evasion by allowing the user to delay ticket purchase until inspection risk arises, this results in the compromise of system integrity and fairness. Our methodology overcomes this issue through imposing a **strict time bound digital ticket system** that restricts the purchase of ticket to a strict time window after boarding.

This can be done through implementing automated boarding time detection with the help of existing technologies such as Bluetooth Low Energy (BLE) or GPS based Geo-Fencing integrated with existing mobile applications. After the detection of a boarding event, a secure server side timer is initiated to trigger a purchase window within which the passenger has to buy the ticket through the mobile application. Ticket requests beyond the time frame are automatically rejected. This system is designed in a way that it can be seamlessly integrated into smart urban mobility platforms without requiring major hardware modifications. This allows us to keep the cost minimal while preserving commuter convenience.

Keywords: Fare Evasion, Smart Ticketing, Time-Bound Enforcement, BLE, NFC, GPS Geo Fencing, Urban Transport Systems

Introduction

The Urban Public Transportation Systems play a major role in the development and improvement of the sustainable mobility options of an urban region. Digitization has increased the usage of digital/mobile-based ticketing platforms. Applications such as UTS[1] on Mobile , introduced by the Indian Railways[1], and municipal service platforms such as Chennai One[2] have enhanced accessibility, reduced traffic for physical ticket and facilitated paperless ticketing system. Similar state transport applications follow the same QR based ticket validation system. This has resulted in a shift toward digital public services and smart urban transport systems

Despite these advancements, mobile ticketing platforms are prone to vulnerabilities, particularly in open entry environments such as a commuter bus and trains. In systems such as UTS on mo-

bile , passengers can not buy tickets after boarding a transport vehicle due to the Geo Fencing restrictions placed rather than having to impose any temporal based validation for the passengers to buy a ticket. But application such as Chennai One fail to implement any such implications. This allows the passengers to delay the process of buying a ticket until ticket inspection takes place. This creates a huge opportunity for fare evasion to take place.

For example, ticketing systems in other nations enforce a card-based validation system which allows the passenger to tap a card or mobile phone to be able to buy a ticket[3]. However, these types of systems require a totally different infrastructure compared to the existing or present systems in our nation. While QR-code validation and back-end logging enhance traceability, they do not constraint the interval between boarding and ticket purchase.

This gap highlights friction between digital convenience and enforcement integrity. Existing systems prioritize accessibility and user adoption but does not focus on a temporal enforcement framework that directly validates ticket purchasing ability with verified boarding time

To overcome this limitation, this study proposes a Time Bound Digital Ticketing Enforcement framework Bluetooth Low Energy(BLE), or GPS-based geo-fencing to register boarding events and initiate a secure server-side countdown timer. Ticket purchase attempts beyond the time interval are restricted and possibly a fine would be imposed.

This hereby would reduce strategic Fare evasion without requiring huge infrastructure modification. This framework aims to enhance Revenue and eliminate loop holes found within the present digital ticket systems in urban region.

Literature Review

The evolution of public transport ticketing system has been shaped by the technological advancements that had taken place in our society aimed at improving Efficiency, Security, and User Convenience. Modern day systems majorly focus on digital integration and automation, enforcement mechanisms often prioritize authentication and usage validation rather than constraining the timing of ticket purchase relative to boarding. Now let us take a look at some of the most established digital ticketing system and its working.

Smart-Card and Time-Based Ticketing systems

Smart-card systems represent one of the earliest large-scale digitization efforts in public transport. Contact-less smart cards, such as Oyster-style systems and similar RFID-based fare cards, bind ticket validity to the moment of first tap or activation. When a passenger taps the card at an entry point, the system records the transaction time and calculates fare or pass validity accordingly. Time-based passes, including hourly and daily passes, operate on a similar principle: validity begins at activation and extends for a predefined duration [3].

Recent analyses of ticketing evolution note that these systems emphasize authentication and payment security, but they do not enforce when the ticket must be purchased relative to the boarding event. Technological innovations such as contact-less cards, EMV integration, and mobile wallet compatibility have significantly improved payment efficiency. However, these systems bind validity to the time of first use rather than constraining when the ticket must be purchased relative to the boarding event itself. In other words, they determine how long a ticket remains valid, but not how soon after boarding it must be obtained.

Traditional time-based models assume that purchase or activation occurs at or before entry. They do not account for the scenario wherein the passengers board the bus first and then buy tickets later. Hence, though the systems improve efficiency, they do not, by themselves, address the fare evasion of delayed purchases.

Mobile Ticketing and QR Validation

Mobile ticketing has also changed the face of fare collection, with mobile tickets issued directly via mobile devices. In many systems, QR-code-based tickets are issued for bus and rail systems, wherein the tickets are validated via the conductor or the inspection device at the time of inspection.

In mobile ticketing systems, the primary mechanism for validating the tickets only checks whether the tickets exist and are valid at the time of inspection.

In many urban bus systems, it is common for passengers to board the bus and then buy a mobile ticket while the bus is still in motion. Hence, though the systems are effective in preventing fraudulent tickets, the systems do not address the fare evasion wherein passengers buy tickets strategically after boarding the bus.

The proposed time constraint mechanism addresses this gap by introducing time restricted approach at the transaction layer, rather than solely at the validation layer

Integrated and Multimodal Ticketing Models

Integrated ticketing system intends to unify multiple urban transportation modes under a single fare structure and digital interface.

They can be categorized as

- Distance-based systems
- Time-based systems
- Transfer-based systems

Strategic analyses of unified ticketing frameworks include interoperability, passenger convenience, and fare harmonization across agencies[4].However, existing models mainly focus on pricing and inter-modal integration. They do not introduce constraints linking ticket purchase timing to physical boarding detection.

This framework contributes a new concept: a boarding-time-constrained ticket model. By limiting ticket purchasing eligibility within a fixed time-frame after boarding is detected, the framework makes use of existing integrated ticketing architectures

Fare-Evasion Detection and AI-Based Solutions

Recent research has shown us the way in which Artificial Intelligence and IoT played a major role in surveillance systems to detect fare evasion. These approaches help us in implementing computer vision, sensor networks, anomaly detection algorithms, and passenger flow statistics to identify passengers of suspicious behaviour[5][6].

These systems help in improving detection accuracy, they help in detecting violations after it takes place. The present study helps in preventing late ticket purchase abuse through placing transactional constraints and helps in eradicating fare evasion.

Methodology / Architecture

This section analyses the framework and working mechanism of the Bound Digital Ticketing Enforcement framework. This system aims to introduce a boarding time constrained purchase window to prevent delayed ticket purchase after boarding. The architecture is designed to integrate seamlessly with existing multi modal ticketing systems such as Chennai One, requiring minimal structural modifications to current payment workflows.

System Overview

The given architecture consists of the following primary components:

- Mobile Application3.3 Foundational Structure

for users (Chennai One–style interface)

- Back-end Server for Ticketing (Ticketing Engine)
- Bus Ticket Conductor / Validator (Conductor's scanning device)
- Bus Entry points consisting BLE Beacons

The "Mobile Application for users serves as the passenger interface during boarding, ticket purchase and QR-based validation. Let us take a look at how the system works.

The "Back-end Server for Ticketing" helps in storing the digital tickets metadata an helps in validation as well our temporal enforcement

The "On bus validator" helps us to verify the tickets and act as a medium to purchase tickets when there exists a barrier in making a digital ticket purchase.

The "BLE Beacons " are positioned at bus entry point to initializes trigger the time-frame set. Geo-Fencing helps in locating the user and restrict the user to certain location constraints.

The system enforces a temporal server side restriction over the time frame within which a user can purchase tickets with the help of the ticketing application

Assumptions

There are certain number of assumptions that we need to make before getting into the functioning of this system

1. Let us assume that the passenger's device is compatible with Bluetooth Low Energy or GPS -based location detection
2. Boarding detection can be detected using proximity signals using BLE or Geo-Fencing technology.
3. Network Latency between users device and server is within an acceptable range on the spectrum.
4. Offline transaction, purchase of ticket and validation is possible to make it fault tolerant with server fails and to ensure proper validation of tickets.

These assumptions ensure that enforcement logic remains centralized while boarding detection remains strong with user devices

Fundamental Structure

Now let us take a look at the core logic of our time bound digital ticketing system:

$$T\_board = boarding\ time\ detected\ by\ the\ mobile\ application$$

T_limit = time limit set to acquire ticket

$$T\_limit = T\_board + Fixed\ time\ window$$

Ticket purchase is permitted only if:

$$T\_now \leq T\_limit$$

Where represents the current server timestamp at purchase request

So therefore, server does not allow purchase of ticket once the server is closed

Each ticket record stored at the server contains:

- $route\_id$
- bus_id
- $boarding\_time$
- $expiry\_time$

route_id : mentions the route in which the transportation vessel travels

bus_id : refers to the unique id given to each bus

boarding_time : refers to the time of detected boarding

expiry_time : refers to expiry time of the ticket

$expiry\_time$

By storing **boarding_time** and **expiry_time** at the back-end, the system prevents manipulation of timestamps at the client level.

Working Mechanism

The first stage of the system is to detect the users location using the Geo-fencing technology, issue of ticket is only allowed after the user reaches within the fixed perimeter .

Next stage aims to detect the boarding event through the BLE Beacons, the BLE Beacons shoot a signal which would be received by the phones triggering the time window. T_board, T_now are initiated

Ticket Purchase Phase:

Server checks if $T\_now \leq T\_limit$

If yes, issues ticket.

If outside the window → "Late-ticket / Purchase Window Expired."

To keep flexibility and improve inclusivity, the system includes a controlled fallback mechanism that allows passengers to pay with cash when required. This section is particularly important for users who may face technical issues, lack access to digital payment methods, or experience temporary network connectivity problems. Rather than excluding these passengers, this system provides a structured and an inclusive way to handle physical payments.

With this mechanism, if the onboard ticket validator starts ticket verification and the passenger does not have a valid digital ticket, the passenger can request a "Pay with Cash" option through the mobile application. This request is sent to the back-end server and is shown on the conductor's device at the same time.

Inspection Phase:

Conductor scans QR/NFC; server checks authenticity and validity window.

If **T_issue < expiry_time → invalid ticket.**

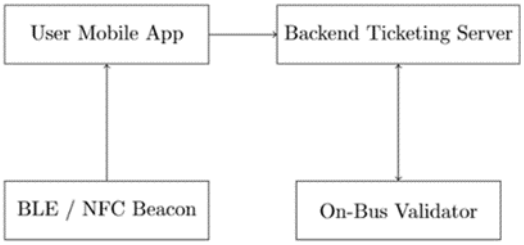

Figure 1 Workflow

3.5 Privacy and Security Considerations

The following factors are the security considerations that has been pinned down to be followed

• Limited data retention

• No fining system within the to avoid legal complexity

• Encrypted communication

• Privacy of users data which could be a matter of sensitivity

No continuous location tracking is required beyond boarding detection.

Conclusion and Future recommendations

The sole purpose of this study is to address the structural vulnerability in modern day digital urban transportation system. Proposed system allows us to counter this issue through implementing a time bound digital ticketing system. Through implementing our system we would be able to monitor data, ensure revenue protection, enhances fairness among passengers and most importantly plays a major role in societal welfare and contribution. This framework dos not require huge modifications or investment. This system is fundamentally built on the present-infrastructure, therefore making it really efficient and effective.

Future work will focus on implementing the mechanism on a small scale to evaluate the results under real word environment. Additional improvements include working on making the architecture work without a human ticket validator a conductor. This needs working on Fault tolerant server architecture and offline ticet generation systems. We can also work towards making the systems more accurate to improve results in real time

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