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Analysis of Mobility Prediction and Future Passenger Directions for Maximizing Futuristic Optimization by using ML

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Abstract: *The NEWS framework employs an intelligent HO skipping scheme in combination with context-aware HO skipping for its operation. The proposed technique enables train passengers to skip HOs dynamically after evaluating the complex LUO train network dynamics which surpass traditional HO schemes for smooth HO operations. The NEWS framework uses ML to analyze mobility predictions and future passenger directions as its first step toward future optimization. The PPP-based HO skipping model is simulated using ML classification results to perform topology-aware multiple HO skipping schemes for efficient HO management. The HO schemes use passenger location and cell-size as well as path and velocities and travel direction and cell-loads to determine the HOs to bypass unnecessary cell changes on the passenger trajectory. The Context-aware HO skipping technique provided better performance than all traditionally equipped HO schemes based on evaluation through coverage probability and average throughput and HO cost measurements.*

Keywords: ML driven mobility predictions, Context-aware HO skipping, Logistic regression

I. INTRODUCTION

The 5G spectral efficiency standards demand network densification as an answer to enhance capacity along with throughput for targeting NGNs. The combination of minimal BS footprint along with efficient frequency reuse combined with user resource sharing achieves this outcome. The reduction of cell sizes through deployment increases unnecessary handovers while it limits the amount of time users can spend with high train mobility. The quick passage of trains through BS radio coverage footprints results in frequent handovers causing serious performance impacts on Quality of Service. The proposed framework adapts HO skipping through an innovative method using network data about trains trajectory and SINR alongside passenger movement statistics and traveling time information and frequency data. The framework depends on NEWS (North, East, West, and South) modeling that uses realistic Poisson point process (PPP) to model real-time mobility patterns for protecting mobile networks against overloads. Prediction of passenger movement based on NEWS mobility model with ML-based SVM classifier reaches an accuracy level of 94.51%. Our proposed scheme includes ML-based mobility prediction results which demonstrate equivalent coverage probability and average throughput levels when comparing to the non-skipping approach but results in significant reduction of HO costs. The paper presents a new mechanism that preserves privacy through blockchain technology during HO skipping while using train mobility data from London. Our system uses the dataset parameters to model train passenger flows on an individual train route by letting the blockchain log user entry and exit at stations thus enabling framework tracking through private user identifiers.

II. PROPOSED METHOD

The research develops an analytical model for NEWS framework optimization of LUO train passenger traffic while blockchain enhances train travel with HO skipping through PPP [1]. Following are the proposed elements. The framework utilizes ML to predict passenger movements for upcoming location predictions and planning purposes.

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Context-aware HO skipping.

An implementation of context-aware HO skipping with blockchain technology ensures privacy protection in such operations. NEWS adopts integrated approach to build its framework from the PPP mobility prediction model. Initially ML receives data inputs for classification that divides information between North, East, West and South directions alongside LUO train lines. The PPP simulation runs HO skipping tests by inserting data obtained from ML processing which includes trajectory information along with velocity and path data in combination with load and train direction and line data and traveling times. A detailed discussion about ML classification and PPP simulation appears in the next subsections.

2.1. ML-Driven Mobility Prediction

SL functions as the main ML tool in the proposed NEWS framework where it helps predict cardinal passenger traffic flows by employing algorithms such as LR and SVM and MLP[2,3]. We distributed the data into three parts where training received 70% and testing captured 20% of the data and validation obtained 10% of the data. We processed actual TfL data sets before applying them as inputs to three ML training classifiers. SL technique sorts data into four separate binary categories following a NEWS arrangement with Northbound, Eastbound, Westbound, Southbound [5,7]. The TfL train line names and station codes/names receive passengers frequency data while entry/exits numbers are distributed into early, AM peak, midday, PM Peak, evening and late traveling times. 15 minute time intervals classification involves the division of dataset into two sets: boarders containing train carriage passengers and alighters representing station alighting passengers.

The training process for the framework uses historical passenger mobility records containing direction and path together with load information and time of travel along with cell IDs and RSRP measurements. A large-scale analysis along with normalization occurred for all LUO train lines in cardinal directions before performing ML model fitting. The normalization occurs through minimum, maximum and average scaling performed with scikitlearn functions. Transforming all features into [0, 1] allows each characteristic to convert its minimum, maximum and average value into 0s and 1s. Different features including Kurtosis along with skewness have been employed specifically for each classification system. Different features combined with normalization provide equal participation of all variables to model fit functions without producing biased results. The following section outlines the ML algorithms that serve for predicting traffic flows based on mobility prediction-based cardinal passenger count.

SVM in multi-class classification setting with a polynomial kernel.

The network incorporates an MLP design with input layers followed by hidden layers up to output layers as its feed forward architecture. The classifier goes through 100 training rounds and contains a single input layer followed by three hidden layers (1500, 512, 1500 neurons each) before concluding with an output layer made up of four nodes representing the North, East, West and South directions.

The logistic regression algorithm exists as one variant of machine learning that performs binary classification operations. LR serves to develop the most suitable model which connects features of interest with independent characteristics.

The outcome of an ML-driven system forms the basis to create PPP models for evaluating HO skipping decisions. A comparison involving coverage probability (number of users covered vs SINR) and average throughput as well as HO costs can be generated through simulated HO techniques. Various characteristics including passenger trajectories and velocities together with paths as well as train load and directions and lines constitute the main elements for HO skipping modeling.

2.2. Privacy Preserved Context-Aware HO Skipping

The architecture of this framework appears in Fig. 1a as a graphical representation which depicts mobile network train stations using black dots and shows train paths with a black line. The green cells in the figure show the BSs those users connected to through the network so far. Red cells indicate the skipped cells between user movements. Lastly the orange cells show cells belonging to non-participating operators.

non-participating cells. Fig. 1a illustrates the data recording procedure that occurs when users connect or disconnect from a train station hotspot for which they use Wi-Fi or cellular access to store their pseudonymous addresses and station information in the blockchain. Due to the assumption that different operators maintain each BS thus making each BS a blockchain node this framework operates. The blockchain functions as a reliable platform for connecting different providers who need to exchange data throughout their business operations. The mobile network implements HO skipping decisions for individual users through its access to historical data acquired in Steps (1) and (2) in Step (3). The technical overview of the proposed framework displays its data structure and data flow in Fig. 1b. Users can access their smart contract at the blockchain through a mobile application to input station entry and exit transactions which get recorded by the blockchain's smart contract. The data logging system stores both pseudonymous user addresses and station IDs for every recorded user entry or exit. The blockchain nodes based at train stations along with base stations perform mining operations on this submitted transaction. After validation these user-based transactions become available at BSs so these locations can leverage this information together with their previous data to make user history determinations and perform HO skipping with external algorithms. A hybrid HO skipping algorithm serves as the framework for this work by applying these two main criteria to determine whether each BS needs to be skipped. The system follows two conditions to determine skipping decisions: first, when a cell size reaches a predefined threshold value and second when an entering user links with a Base Station farther than the allowed threshold distance. The criteria function based on blockchain-recorded data points regarding user rail station exits and entrances as well as train movement paths and speed and temporary station occupancy.Thus, with all this information combined, an individual user skipping can be performed.

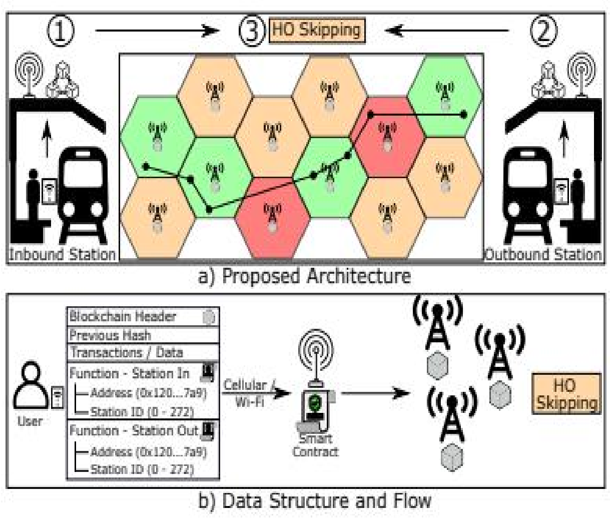

Figure 1: Proposed blockchain HO skipping architecture, data structure and flow. A specific train line in westbound direction is considered as a use-case.

III. HO SKIPPING SIMULATION AND RESULTS

3.1. Simulation Scenario

The proposed scheme receives validation through MATLAB simulation. Multiple BSs exist randomly throughout a rectangular area as per the specified PPP conditions. The simulation establishes that 4 separate operators use 20 bands of 10 MHz bandwidth with 3 sectors per BS composed of 150 resource blocks. A total of 10 train stations are strategically placed within this area as per the London underground map. The train model demonstrates fixed western motion at 64 km/h speed together with varying user departures and entries at stations. The simulation parameters can be found in Table 1.

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Table 1 Simulation Parameters List

Parameter	Value
PPP rate (λ)	0.0001
Side of simulated area (L1)	2,000 meters
Height of simulated area (L2)	1,000 meters
Number of operators (No)	4
Bandwidth (W)	10MHz
Noise spectral density (N0)	-204 dBW
Active users (Nactive)	90%
Path loss exponent (α)	4 [48]
BS transmit power (Tx)	0dBW [48]
Train speed (v)	64 km/h
RB per BS (RB)	150
Coverage probability threshold (T)	[-15, ..., 15] dB [48]
Minimum SINR (SINRmin)	0 dB
User offset X position (xo)	±5 meters
User offset Y position (yo)	±2 meters
HO delay (d)	1 second [48]
Size Threshold (s)	9 km^2
Location Threshold (L)	85 meters
Hybrid Thresholds (s, L)	9 km^2 , 100 meters

The blockchain part involves a rectangular plot measuring 2, 000 meters per side and 1, 000 meters per side. A segment belonging to the Piccadilly line operating at 1:10 scale serves as the foundation for positioning the eleven train stations in this area. The mobile network deploys BSs according to a random PPP with λ = 0.0001 density and each Base Station utilizes 10 MHz bandwidth and possesses 50 RBs while operating at a Tx = 0 dBW power level. The simulation parameters include α = 4 for Rayleigh path loss exponent combined with N = −204 dBW noise spectral density along with v = 64km/h train speed and 8.5km2 cell area threshold and 88-meter BS distance threshold. The simulation analyzes u = 10 user travels which initiate at station 1 and terminate at station 9. The MATLAB simulation implements a scenario with results computed from ten successive randomly generated runs. The proposed framework undergoes evaluation against no skipping together with hybrid skipping [48] to determine HO cost, average throughput and last-hop signal strength and delay outcomes. Storage necessities along with TPS requirements are explored through evaluations of the simulated path, the Piccadilly line network and the entire LUO network.

IV. RESULTS DISCUSSION

4.1 .Machine Learning Classifiers

A scikit Python package contains all ML attributes which generated experimental findings concerning link traffic on a train line operating between East to West. The remainder of the simulations follows an exclusive use of the SVM classifier because it showed the highest performance among other classifiers. Empirical testing reveals that SVM reached better results because it is an algorithm optimized for high dimensional data spaces. SVM proves its efficiency when dealing with data that possesses more features compared to available training examples. The performance of SVM remains high whenever input data possesses distinct separating margins based on their attributes. Our framework implemented SVM using link direction, train trajectory, passengers movement, travelling time and frequency, carriage load and network load as classification variables.

4.2. Context-Aware HO Skipping Network Analysis

Figure 2 illustrates how the best connected case delivers the maximum coverage probability while the proposed context-aware method attains performance that is almost identical to it. The context-aware scheme demonstrates high resistance since omitting some cells leads to very similar coverage probability results. The 2 solutions at the beginning exhibit high performance levels followed by the location-aware, size-aware and hybrid methods which display comparable results and ending with the alternate skipping solution that delivers worst performance by skipping every other cell. The space between the no skipping method and the proposed context-aware approach together with other solutions grows bigger when SINR threshold values decrease. Users can connect to adequate Base Stations when employing no skipping strategies or context-aware solutions, but the other approaches fail to provide suitable links. Each location-aware and size-aware and hybrid as well as alternate method has a set condition determining when it will skip its target base station. The network selects these BSs for skipping which could offer the first or second best connection leading to an extremely poor reception quality. SINR measurements and user load factors help the context-aware approach reduce the problem because poor-signal users must connect to those BSs despite strong SINR users having the option to bypass them. Users who join the no skipping selection option obtain the best performance because they link to the strongest available base station.

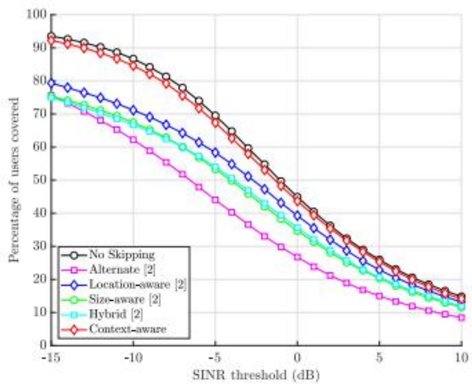

Figure 2: Coverage probability comparison of different HO skipping techniques vs SINR threshold.

Fig. 3 shows throughputs results that are extrapolated by spectral efficiencies based on SINR dependencies. The relationship between HO impacts and average throughput operates as a direct proportion which means that faster movements along with more frequent HOs lead to increased costs. Fig. 3 shows that the NEWS framework implements context-aware HO skipping surpasses all other no skipping methodologies though with minor differences. The overall throughput performance of our proposed scheme demonstrates superior values than all other PPP HO skipping methods.

Fig. 3 together with Fig. 4 show that non-kipping operations lead to the highest expenses and greatest average throughput between all considered schemes. With this scheme users maintain the best possible link because they do not skip any Base Stations. The highest throughput from all schemes comes with the additional cost of being most expensive. By analyzing the alternate skipping approach performance we can observe its expected operation because it skips every second Base Station while maintaining about 50% distance from no skipping. Although skipping reduces operational expenses by approximately 50 percent it does not show equivalent improvements in data throughput thus leading to a throughput reduction of 34 percent when compared to not skipping BSs.

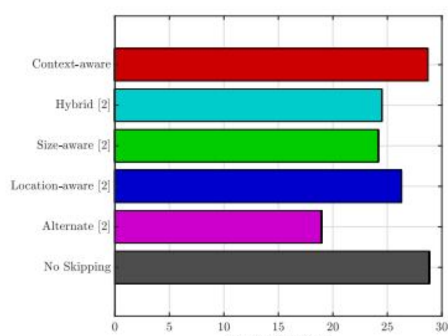

Figure 3: Average throughput comparison of different HO skipping techniques.

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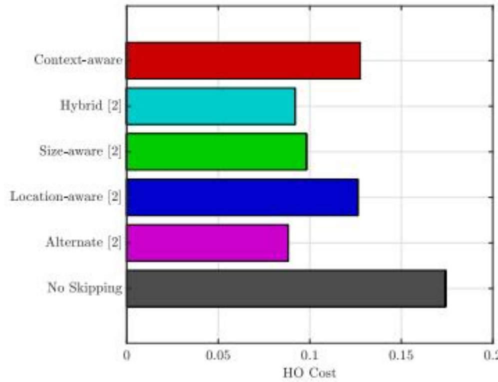

Figure 4: Average HO cost comparison of different HO skipping techniques.

Based on Fig. 4 it becomes clear that no skipping method shows the highest cost reduction while achieving the highest throughputs compared to other approaches. The scheme enables users to maintain constant connection with top-quality BSs since users avoid skipping any BSs thereby achieving maximum network throughput. Even though this scheme offers maximum throughput it produces the most expensive solution among available schemes. The alternate BS skipping strategy demonstrates its expected operational capabilities since users bypass every other base station for a 50% cost reduction compared to no skipping. The alternate skipping method cuts costs by almost 50% yet produces only a 34% loss in throughput when compared to skipping none of the base stations.

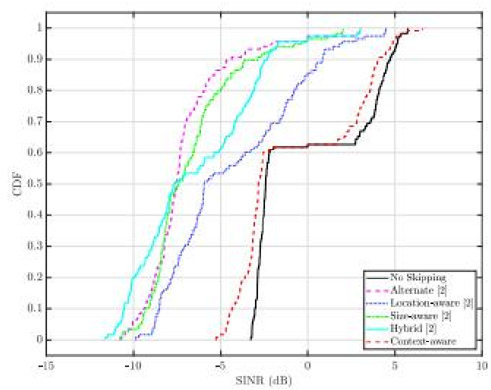

Figure 5: CDF of SINR for different HO skipping techniques.

When compared to regular skipping techniques the location-aware method delivers the highest throughput performance since it produces a throughput decrease of 9% from systems without skipping. The location-aware approach needs to join multiple cells which results in decreased HO costs but they amount to a total of 28% only. The performance measurements of the size-aware and hybrid approaches display comparable outcomes while they successfully minimize HO expenses to a level matching those of the alternate scheme by 44% and 47%, respectively. The size-aware and hybrid approaches show throughput results that are better than the alternate combination since they maintain 16% and 15% throughput respectively. The context-aware approach represents the skipping technique which provides the highest average throughput among all other options with the location-aware approach having comparable HO costs. The trial results strongly support skipping techniques since they produce HO cost reductions exceeding 25% through various levels of reduced network throughput. Context-aware positioning when combined with user load and SINR details helps to achieve significant HO cost reduction of 27% with minimal effects on throughput performance.

Results about average user SINR are presented through a CDF distribution in Fig. 5. The CDF displays identical patterns to coverage probability by showing superior results for the no skipping method accompanied by the proposed context-aware approach. The SINR user distribution concentrates between -5 to -2dB and from about 0 to 7dB according to the observation of these two curves. The proposed scenario has conditions where BSs would become overloaded which prevents them from serving all users. The distribution of users in these regions divides into two groups because one set uses the best available Base Station and another set connects to alternative Base Stations. The context-aware approach enables certain users to access the best available BS yet others must skip this BS because of which their SINR values become notably better than traditional skipping procedures. All users in previous methods face SINR reduction because the methods force users to skip their preferred Base Stations at some point despite lacking SINR awareness during decision-making. The location-aware technique demonstrates marginally better results than other methods yet both size-aware and hybrid produce almost equivalent outcomes. The alternate strategy delivers the more degrading results regarding SINR performance. Multiple speed tests and different time threshold combinations were used to evaluate our framework during empirical experiments when we determined parameter values for optimal HO cost-user throughput balance.

4.3. Privacy Preserved Context-Aware Analysis

Table 3 presents evaluations regarding HO costs and weighted average throughput and average SINR along with LH delay measurements of all discussed techniques. Throughput performance reaches its highest mark with the no skipping technique since this scheme omits the process of skipping any Base Stations. The implementation of this strategy results in the most expensive HO cost. Scalar HO cost remains lowest for the hybrid technique [4] and runs almost equal to blockchain-enabled skipping. The proposed framework reaches a somewhat superior throughput due to its utilization of historical user data from entry and departure stations together with train routing information. Users need to maintain network connectivity while exiting stations because they tend to contact others or access data so tests for Last Hop signal quality must be performed. The proposed technique produces results that match both the average SINR and delay metrics of the no skipping situation according to Table 4. When applying historical user-related data we can select which Base Station will be most beneficial for user termination resulting in enhanced signal quality than made possible by the hybrid approach. The hybrid technique lacks information about user outbound stations so its handover processes result in minimal costs at the expense of poor average SINR and maximum delays.

Table 3: Average HO Cost, and throughput comparison

	HOCost	**Avg TP(Mbps)**
No Skipping	0.231 (0%)	42.37 (0%)
Hybrid [48]	0.099 (57.14%)	40.62 (4.13%)
Proposed	0.115 (50.21%)	41.61 (1.79%)

Table 4: Last hop metrics comparison

	LH SINR(dB)	**LH Delay(ns)**
No Skipping	5.94dB = 3.92W (0%)	85 (0%)
Hybrid [48]	-33.6dB = 0.000437W (99.98%)	553 (-550.5%)
Proposed	5.79dB = 3.79W (3.31%)	85 (100%)

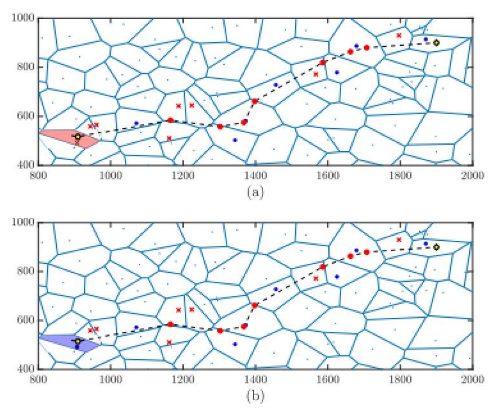

Figure 6: Simulated scenario shows the set of BSs skipped and connected for (a) the hybrid approach, and (b) the proposed approach.

A comparison of the simulated scenario for the hybrid and proposed frameworks in (a) and (b), respectively. The figure presents the dotted black train path together with yellow starting and ending stations and red circles depicting intermediate stops. The figure displays blue dots for BSs together with larger clip dots that indicate connected BSs and red crosses indicating unreachable BSs. The proposed approach based on the hybrid framework operates similarly to achieve connection at the last hop BS as shown by blue highlights in Figure 6 though the hybrid approach must skip that connection as indicated by red highlights in Figure 6. The proposed scheme functions atop any other HO skipping technique and retrieves user practical information through user input to deliver superior connection quality according to other experimental results.

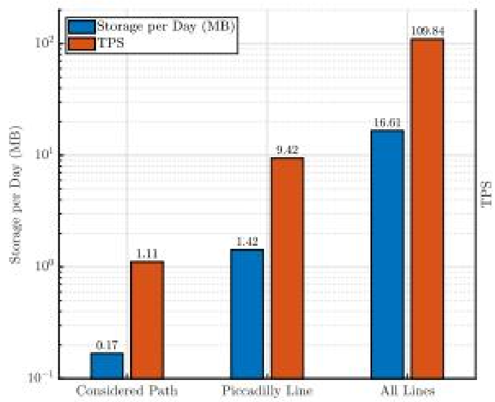

Figure 7: Estimated blockchain storage and transactions per second needed

Fig. 7 presents daily storage requirements and TPS measures for blockchain performance assessment. The storage requirements along with transaction processing speed at the blockchain grow in direct proportion to the counted passengers across one week for pre-defined paths that span Piccadilly line and extend to the entire LUO network. According to blockchain storage estimation the LUO network requires daily amounts of 17 MB for network operations throughout the year (about 6 GB). For the worst possible scenario the necessary TPS amounts to 110 transactions per second. Proof-of-stake based blockchain networks achieve TPS rates above 100 so storage along with number of transactions should not constrain the operational potential of the system.

V. CONCLUSION

The analysis of context-aware HO skipping uses blockchain-enabled privacy preservation to establish a secure system for predicting the future movements of train passengers. The HO schemes employ a blockchain-based approach to establish HO decisions through the analysis of passenger locations combined with cell-sizes and velocities and travelling paths encouraging maximum privacy when tracking passenger trajectories. The HO skipping approach with privacy-preserving context awareness demonstrates better performance than traditional Hybrid HO schemes because it yields both higher throughput for passengers and decreased connection expenses together with superior signal reception and shorter data transmission times. Intelligent schemes for future implementation should create methods which consider passengers' smart Handover skipping abilities in multi-level networks at various train speeds.

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