Reducing Spurious Handovers in Dense LTE Networks based on Signal Strength Look-ahead

Soumadip Biswas, Sandip Chakraborty, Arobinda Gupta
Department of Computer Science & Engineering
Indian Institute of Technology Kharagpur
Kharagpur, India 721302
Email: soumadip.b@iitkgp.ac.in, sandipc@cse.iitkgp.ac.in, agupta@cse.iitkgp.ac.in

***Abstract*—Handover, the process of transferring a call or data session from one base station to another without disconnection, is an important problem in LTE networks. Several handover algorithms have been proposed for LTE networks in general. However, they mostly use the current signal strengths for making handover decisions, which can cause spurious handovers in a dense eNB deployment. In this paper, we investigate the use of look-ahead signal strength information for reducing spurious handovers. We first propose a novel graph-based framework that uses signal strength information along the mobile trajectory of the UE to make better handover decisions. Two algorithms are then presented based on this framework. The first algorithm assumes that exact signal measurements at the UE from all eNBs in its trajectory are available a priori for all time instances, and provides a baseline reference for finding the minimum number of handovers that can be achieved. The second algorithm uses the exact signal measurement for the current time instance only, and estimates the signal strengths for future time instances. The performances of the algorithms are compared with four existing LTE handover algorithms using simulation on real world data. It is shown that the proposed algorithms significantly reduce the number of handovers while still maintaining good signal quality for communication throughout the trajectory of the UE.**

***Index Terms*—Handover, Dense LTE, Signal estimation, Look-ahead**

I. Introduction

Handover in a cellular network refers to the process of transferring an ongoing call or a data session from one base station (cell) to another. The process of handover involves two steps, deciding when to initiate a handover and choosing an appropriate target base station. A good handover algorithm tries to reduce the number of handovers incurred while trying to maintain good signal quality at the user device at all times to avoid radio link failures during communication. Handover decisions are usually based on some function of the measured signal strength. If the handover decision is made too early, the number of handovers increases unnecessarily. On the other hand, taking the handover decision too late can cause more radio link failures due to weak signals. Also, choosing a wrong target base station for handover can cause the next handover to happen very soon. It is important that a handover algorithm tries to reduce such too-early, too-late, or wrong handovers.

The current generation of cellular networks, the Long Term Evolution (LTE), is architecturally different from its previous generations and handles both voice and data communication in a unified manner. Ensuring high-speed connection in LTE is primarily realized by allocating a higher amount of bandwidth per user. Consequently, the number of users that can be accommodated by a single LTE base station (commonly called as evolved Node B (eNB)) is less than its previous generations. Hence, to cope up with the increasing number of user devices (commonly called as user equipment (UE)) in the LTE networks more eNBs are deployed, which results in a dense eNB deployment. Due to such dense deployments, the problem of selecting a target eNB during handover becomes more challenging as there are many options.

Several algorithms have been proposed in the literature for addressing the handover problem in LTE networks [1]–[7]. The existing algorithms mostly use the current signal strengths for making the handover decisions. While this works well when the eNB density is low, a dense eNB deployment causes more options to be present at each handover decision for choosing the target base station. As the choice is made mostly based on the current information, the chance of choosing a wrong target increases. In this paper, we investigate the use of additional look-ahead information for making good handover decisions. In particular, we propose a novel graph-based framework that uses signal strength information along the mobile trajectory of the UE to make better handover decisions. Two algorithms are presented based on this framework. The first algorithm, *UE Association based on Complete Signal Strength Look-ahead (USSL-C)* assumes that exact signal measurements at the UE from all eNBs in its trajectory are available a priori for all time instances. This assumption is somewhat impractical but gives a good baseline reference for the minimum number of handovers that can be achieved. The second algorithm, *UE Association based on Look-ahead Signal Strength Approximation (USSL-A)* removes this assumption, and uses the exact signal measurement for the current time instance only; it uses the information about eNB positions and the route of the UE to estimate signal strengths from the different eNBs for future time instances. To reduce the chance of radio link failures, this algorithm also monitors the duration of low signal periods, if any, and adapts the handover decision appropriately based on an acceptable signal quality threshold. Both algorithms are extensively simulated in NS-3 on real-world areas from different cities with actual eNB placement data, and the results are compared with four well known existing LTE handover algorithms. The results indicate that the proposed algorithms incur a significantly lower number of handovers than the existing handover algorithms while maintaining good signal quality for communication.

The rest of this paper is organized as follows. Section II briefly discusses the existing works on LTE handover. Section III presents the system model and problem definition. Section IV and Section V describe the algorithms USSL-C and USSL-A respectively. The simulation setup and the results of the simulation are presented in Section VI. Finally, Section VII concludes the paper.

II. Related Works

Several algorithms have been proposed in the existing literature to address the handover problem in LTE networks. Amin and Yla-Jaaski [1] have proposed improvements of general handover mechanism which reduces packet forwarding from source eNB to target eNB during handovers. Xenakis et al. [2] have proposed a handover scheme for two-tier LTE networks which aims to reduce interference and energy consumption during transmissions considering the impact of the user mobility, interference, and power consumption. Baldo et al. [3] have described an LTE handover algorithm which uses the standard LTE handover measurement events A2 and A4 described in [8]. The algorithm, which we refer to as *A2 and A4 event based Handover Decision Algorithm (A2A4RSRQ)* in the rest of this paper, takes a handover decision whenever the received signal strength of the serving cell is lower than a threshold (A2 event) and selects a target from a list of neighbours having a signal strength above a certain threshold (A4 event). Herman et al. [4] present another algorithm based on the A3 measurement event in LTE. This algorithm, which is referred to as *A3 event based Handover Decision Algorithm (A3RSRP)* in the rest of this paper, makes its decision when some neighbouring cell's signal strength becomes stronger than the serving cell's signal strength by a certain threshold (A3 event). It also ensures that the signal strength stays consistently above the threshold for a predefined Time-to-trigger (TTT) period. Chen et al. [9] have proposed a location-based handover decision algorithm for high-speed trains equipped with vehicle speed sensors. Shehada et al. [10] propose a QoE-based resource reservation policy during handovers which utilizes a mobility prediction scheme that helps in reducing fluctuations in video quality during handover. Ray et al. in [5] present an *Orientation Matching Based Fast and Reliable Approach*, referred to as *OMBFRA* algorithm in the rest of this paper, which utilizes prior knowledge of eNB locations for predicting the UE's movement direction (orientation) and also tries to balance the load among possible target eNBs. The target eNB is chosen based on a combination of the UE's predicted orientation, a custom load metric, and the RSRP value.

Some of the existing algorithms handle the dynamic nature of the environment by adapting the standard handover decision parameters such as Time-to-Trigger (TTT), hysteresis, Handover Margin (HOM) etc. Hegazy and Nasr [6] propose the *User Behaviour Based Handover Optimization* algorithm, referred to as *UBBHO* in the rest of this paper, that adapts the HOM value for different vehicle speeds and real and non-real type of data transfer. This algorithm makes handover decisions in a similar manner as the A3RSRP algorithm in [3]. However, the algorithm monitors the rate of ping-pong handovers (handovers to the same cell within a short duration) and the rate of radio link failures at each of the eNB devices and adjusts the HOM value accordingly. Jansen et al. [11] have presented a self-optimizing algorithm for LTE self-organizing networks, which tries to reduce the call dropping and handover failures by picking the best TTT-Hysteresis pair. Behjati et al. [12] have proposed a self-organizing handover strategy for Macro-Femto LTE networks and establish that the use of a self-configuration mechanism is beneficial in a multi-tier LTE network. Lee et al. [13] have proposed another self-optimized handover algorithm in LTE networks, which uses a combined score based on the load difference between target and serving cells, the velocity of UE, and the service type (real-time or non-real-time) to adjust the hysteresis value. Sinclair et al. [14] have used a neural network and self-organizing maps based approach to optimize Hysteresis and TTT, which is applicable in indoor environments. In the work by Munoz et al. [7], a joint optimization for load balancing and handover in LTE networks using fuzzy logic and reinforcement learning is presented.

In this paper, we propose two new LTE handover algorithms, and compare their performances with four existing algorithms, namely A2A4RSRQ, A3RSRP, UBBHO, and OMBFRA.

III. UE Association Based on Signal Strength Look-ahead

In this section, we give a broad idea of the solution strategy developed in this paper for UE association in a dense network. Additionally, we discuss the formal system model to solve the problem of user association with an objective of spurious handover minimization.

A. Solution Approach

We consider a scenario where a large number of eNBs are deployed over a region following a dense deployment pattern [15]. The UEs follow a certain mobility trajectory based on their target destinations while getting connected with the eNBs along the path. To mitigate the challenges of spurious handovers over a dense network, we propose to utilize the concept of *signal strength look-ahead* introduced in this paper, where we estimate the signal strengths from the eNBs in the coverage region over the trajectory through which the UE is expected to move. Based on the *signal strength look-ahead* over the mobility trajectory, we design an algorithm to select a sequence of eNBs for UE association such that the total number of handovers can be minimized while ensuring seamless communication. The proposed approach is termed as *UE Association based on Signal Strength Look-ahead* (USSL).

We consider two algorithm-variants of USSL in this paper. In the first variant, termed as *UE Association based on Complete Signal Strength Look-ahead* (USSL-C), we assume that the exact and complete look-ahead signal strength information over the mobility trajectory is known to the UE. With this assumption, the USSL-C algorithm returns a sequence of eNBs for handovers such that the total number of handovers is minimized over the mobility trajectory. This assumption is not practical; however, the USSL-C provides a baseline solution for the best-case scenario considering that the complete signal strength information is known a priori. The second variant of the USSL algorithm, which is termed as *UE Association based on Look-ahead Signal Strength Approximation* (USSL-A), gives a more practical solution where we apply an estimation mechanism to predict the look-ahead signal strengths over the mobility trajectory. In this section, we discuss the system model and problem definition for spurious handover minimization in a dense LTE network.

B. System Model

Without any loss of generality, we consider the scenario for a single UE, and the same procedure repeats for all the UEs in the system. The UE moves from a reference source location s to a reference destination location d. In a Euclidean space, let a region R contain the path from s to d as traversed by the UE and the locations of all the eNBs whose coverage areas intersect the path from s to d. Let $\mathbb{B}$ denote the set of such eNBs. We consider that the time interval is divided into consecutive slots of slot-length τ. We assume that $N\tau$ denotes the total travel time from s to d; therefore, the travel time is divided into N consecutive slots. At the beginning of each slot, a UE receives the signal strength from the set of eNBs in the coverage area using the standard LTE channel quality feedback procedure [16]. Let $\mathcal{S}(e_i, t)$ denote the signal strength measured from an eNB e_i at slot t. We measure the signal strength in the form of *Referenced Signal Received Power* (RSRP) which is the power of the LTE reference signal spread over the full bandwidth and narrowband [17]. Let λ be the RSRP threshold; we consider that a communication can be sustained if the measured RSRP from a eNB is above this threshold. The optimal choice of this threshold based on various environmental parameters has been discussed in the 3GPP standard [18]. At every slot $t \in [1, N]$, we consider a set of eNBs $\mathbb{M}_t = \{e_i \mid e_i \in \mathbb{B} \wedge \mathcal{S}(e_i, t) > \lambda\}$. $\mathbb{M}_t$ is called the set of feasible eNBs where a connection can sustain at least for the duration of τ. Let $\mathbb{M}$ be the candidate set of the set of feasible eNBs at every time-slot over the entire path from s to t; therefore, $\mathbb{M} = \{\mathbb{M}_t \mid \forall t \in [1, N]\}$. Next, we formally define the UE association problem for spurious handover reduction over the candidate set $\mathbb{M}$.

C. Problem Definition

At every time-slot $t \in [1, N]$ during the journey from s to d, the UE selects an eNB $e_i \in \mathbb{M}_t$ such that it remains connected throughout the journey. Therefore we obtain a sequence of eNBs $\mathcal{A} = \langle e_1, e_2, \ldots, e_N\rangle$ during the entire journey from s to d. We call this sequence as a *UE Association Sequence* (UE-AS). It can be noted that if $e_t = e_{t+1}$ for two consecutive time-slots $t, t+1 \in [1, N]$, then no handover is required. A handover is required if $e_t \neq e_{t+1}$. Our objective here is to find out a UE-AS from $\mathbb{M}$ such that the total number of handovers is minimized; hence, we can avoid spurious handovers due to a dense deployment of eNBs. Let $\mathbb{A}$ be the set of all possible UE-ASes.

Let $I(e_t, e_{t+1})$ be an indicator variable to capture whether we need a handover based on two consecutive eNBs e_t and e_{t+1} in a UE-AS $\mathcal{A}$ during a journey. $I(e_t, e_{t+1})$ is defined as follows.

$$I(e_t, e_{t+1}) = \begin{cases} 0 & \text{if } e_t = e_{t+1} \\ 1 & \text{otherwise} \end{cases} \tag{1}$$

Let $N_{HO}(\mathcal{A})$ denote the total number of handovers required for a given UE-AS $\mathcal{A}$. $N_{HO}(\mathcal{A})$ is computed as follows.

$$N_{HO}(\mathcal{A}) = \sum_{t=1}^{N-1} I(e_t, e_{t+1}) \tag{2}$$

Our objective is to find a UE-AS $\mathcal{A}^* \in \mathbb{A}$ such that $N_{HO}(\mathcal{A}^*)$ is minimum. Therefore, we formally define the *minimum UE-AS* problem as follows.

$$\mathcal{A}^* = \underset{\forall \mathcal{A} \in \mathbb{A}}{\arg\min}\, N_{HO}(\mathcal{A}) \tag{3}$$

To find out a solution of the optimization given in Equation (3), we need the information about all the US-ASes in $\mathbb{A}$; therefore, we need the RSRP information at every time-slot $t \in [1, N]$. In a practical scenario, it is not feasible to obtain the RSRP information at a point over the mobility trajectory, where the UE is yet to reach as the RSRP depends on various other environmental and interference conditions. However, we can estimate the RSRP at a future point given certain information, like the distributions of the eNBs over a targeted region, the open-space model and the path loss factors, etc., are known. These parameters are in general fixed for a service-provider and can be forwarded to the UEs periodically so that it can make a prediction of the environment over the mobility trajectory. In this paper, we first design an algorithm (USSL-C) to find out a feasible solution of the optimization given in Equation (3) assuming that the entire future information (complete signal strength look-ahead) is known a priori. Then we design a practical algorithm (USSL-A) based on the future RSRP prediction (signal strength look-ahead approximation) over the mobility trajectory.

IV. UE Association based on Complete Signal Strength Look-ahead

We first develop the USSL-C algorithm where we assume that the complete signal strength (RSRP) information at the location points over the mobility trajectory at every time-slot during the journey is known a priori. Under this assumption, we map the optimization problem given in Equation (3) as a minimum cost path finding problem over a directed weighted multi-partite graph.

A. Graph Construction

Based on $\mathbb{M}$, the set of candidate eNBs at every time-slot $t \in [1, N]$ during the journey, we construct a graph $\mathcal{G}(\mathbb{V}, \mathbb{E})$ where $\mathbb{V}$ is the set of vertices and $\mathbb{E}$ is the set of edges. A vertex $v_i^t \in \mathbb{V}$ corresponds to an eNB $e_i \in \mathbb{M}_t$ for time-slot $t \in [1, N]$. Let $\mathbb{S}_t$ denote the vertex set corresponding to the eNBs in $\mathbb{M}_t$. Additionally, we include two more vertices S and T in $\mathbb{V}$. Therefore, $\mathbb{V} = \bigcup_{t=1}^{N} \mathbb{S}_t \cup \{S, T\}$ and $|\mathbb{V}| = \sum_{t=1}^{N} |M_t| + 2$.

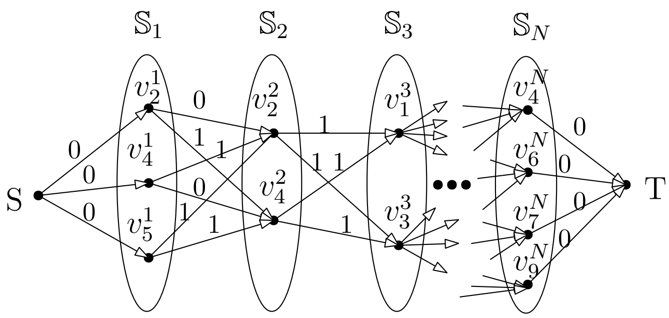


Fig. 1. An Instance of the Problem Mapped to the Graphical Model

For a pair of vertices $v_i^t \in \mathbb{S}_t$ and $v_j^{t+1} \in \mathbb{S}_{t+1}$, we add a directed edge (v_i^t, v_j^{t+1}) from v_i^t to v_j^{t+1}. It can be noted that we do not have an edge between two vertices $v_i^t, v_j^t \in \mathbb{S}_t$; the edges are directed from the vertices in $\mathbb{S}_t$ to the vertices in $\mathbb{S}_{t+1}$ for $t \in [1, N-1]$, as shown in Figure 1. We set the edge weight $\omega_{(v_i^t, v_j^{t+1})}$ as follows.

$$\omega_{(v_i^t, v_j^{t+1})} = \begin{cases} 0 & \text{if } i = j \\ 1 & \text{otherwise} \end{cases} \tag{4}$$

The edge weights indicate that a handover is not required if the UE remains connected to the same eNB in two consecutive time-slots.

Additionally, we include two more sets of edges. We include a directed edge with edge weight zero from the source vertex $S \in \mathbb{V}$ to to each vertex $v_i^1 \in \mathbb{S}_1$. Further, we include a directed edge with edge weight zero from each vertex $v_i^N \in \mathbb{S}_N$ to the target vertex $T \in \mathbb{V}$. Therefore, as shown in Figure 1, the complete set of edges $\mathbb{E}$ in the graph is as follows.

$$\mathbb{E} = \mathbb{E}_v \cup \mathbb{E}_S \cup \mathbb{E}_T \tag{5}$$

where,

$$\begin{aligned} \mathbb{E}_v &= \{(v_i^t, v_j^{t+1}) \mid \forall v_i^t \in \mathbb{S}_t \wedge \forall v_j^{t+1} \in \mathbb{S}_{t+1} \wedge \\ &\qquad \forall t \in [1, N-1]\} \\ \mathbb{E}_S &= \{(S, v_j^1) \mid \forall v_j^1 \in \mathbb{S}_1\} \\ \mathbb{E}_T &= \{(v_j^N, T) \mid \forall v_j^N \in \mathbb{S}_N\} \end{aligned}$$

Next, we model the USSL-C algorithm over the graph $\mathcal{G}(\mathbb{V}, \mathbb{E})$ as constructed above.

B. USSL-C as a Minimum Cost Path Problem

It can be noted that a path from S to T in $\mathcal{G}(\mathbb{V}, \mathbb{E})$ denotes a UE-AS where a path $(S, v_i^1 \in \mathbb{S}_1, v_j^2 \in \mathbb{S}_2, ..., v_k^N \in \mathbb{S}_N, T)$ indicates a sequence of eNBs (excluding S and T) $\langle e_i \in \mathbb{M}_1, e_j \in \mathbb{M}_2, ..., e_k \in \mathbb{M}_N \rangle$, with each eNB corresponding to a time-slot $t \in [1, N]$. An edge weight of zero for an edge (v_i^t, v_j^{t+1}) indicates that the eNBs $e_i \in \mathbb{M}_t$ and $e_j \in \mathbb{M}_{t+1}$ are the same, and no handover is required. Otherwise, an edge weight of one indicates that a handover is required. We consider that the total cost of a path is equal to the summation of the weights of the edges belonging to that path. Therefore, the minimum cost path between S and T in $\mathcal{G}(\mathbb{V}, \mathbb{E})$ gives the best UE-AS with minimum number of handovers for the UE.

We observe that the graph $\mathcal{G}(\mathbb{V}, \mathbb{E})$ as constructed above is a directed acyclic graph (DAG). Therefore, we can apply topological sorting of the vertices to find out the minimum cost path in $O(|\mathbb{V}| + |\mathbb{E}|)$ time complexity. In the worst case, $|\mathbb{V}| = O(|\mathbb{B}| \times N)$ and $|\mathbb{E}| = O(|\mathbb{B}|^2 \times N)$.

The USSL-C algorithm, as discussed above, considers the availability of complete look-ahead information of the signal strength from the eNBs during the entire journey from a source to a destination. However, the knowledge of complete signal strength is impossible to obtain in a practical scenario, before the UE has reached to the location and a signal measurement is obtained from the eNB. Therefore, based on the base algorithm we developed for USSL-C, we next design a more practical algorithm by estimating the approximate signal strength from the eNBs over the travel trajectory. The proposed algorithm, called USSL with approximate signal strength estimation (USSL-A), is discussed next in details.

V. UE Association based on Look-ahead Signal Strength Approximation

To design a practical algorithm based on USSL-C, we make the following assumptions: (a) The travel trajectory of a UE is known a priori. This assumption is practical because GPS based navigation is common now-a-days, and therefore we can know the travel path of a UE with a certain guarantee. (b) The positions of the eNBs from a service provider are fixed and are known a priori. This assumption is also practical; the GPS locations of all the eNBs in a region can be made available to the UEs during the initial connection establishment. (c) The uplink transmit power information is known a priori. It can be noted that the uplink transmit power is fully controlled by the eNBs and generally predefined or fixed for a service provider [19]. (d) We assume an outdoor signal propagation model, where *log distance path loss* model can be used for the estimation of received signal power [20]–[22].

Based on these assumptions, we design the USSL-A algorithm as follows. According to the average speed of the UE, we consider a set $\mathbb{P}$ of fixed anchor points over the UE travel trajectory, such that the average travel time between two anchor points is approximately τ, the time-slot length used in the USSL-C algorithm. Considering the distribution of the eNBs across an anchor point p, we measure the expected RSRP value at the anchor point p considering *log distance* *path loss* model, as used in the existing literature [20]–[22]. It can be noted that this is an approximation of the original signal strength value considering a free-space environment; however, such a model can give the candidate eNBs where a UE association is feasible. Let *predictsignal(e_i,p)* give the predicted RSRP value for an eNB e_i at the anchor point p. From this estimation, we compute the set of feasible eNBs for a UE association at the anchor point p; let this set be $\mathbb{M}_p^e = \{e_i \mid \textit{predictsignal}(e_i,p) > \lambda\}$ where λ is the RSRP threshold. Let $\mathbb{P}$ be the set of anchor points in the travel trajectory of the UE. Considering all the anchor points $p_i \in \mathbb{P}$, finally we get the candidate set of the set of feasible eNBs for UE association, $\mathbb{M}^e = \{\mathbb{M}_p^e \mid \forall p \in \mathbb{P}\}$. We use this set $\mathbb{M}^e$ in place of $\mathbb{M}$ in the USSL-C algorithm to find out the best suited UE-AS that minimizes the spurious handovers.

However, there is a certain drawback of this algorithm. The RSRP prediction based on log normal path loss estimation is not perfect always. Therefore, the algorithm can select an eNB for a UE association, where the actual signal strength may get significantly different from the estimated signal strength for a radio communication due to external interference and shadowing objects in the signal propagation path. In case the predicted signal strength becomes higher than the actual signal strength, selecting candidate eNBs for a UE association based on RSRP threshold λ can lead to a radio link failure, and thus can disrupt the existing communication. We handle this problem as follows. We define a parameter called *Low Signal Run Length* (LSRL) ($\mathcal{L}$) which indicates a consecutive number of anchor points during the run-time, where the UE has experienced a signal drop below λ. Let $\mathcal{L}_T$ be a threshold on LSRL that can be tolerated by a UE for seamless communication. If the measured LSRL $\mathcal{L}$ goes beyond $\mathcal{L}_T$, we perform a forceful handover using a modification in the USSL-A algorithm as follows. First, for the current anchor point, we exclude the set of candidate eNBs $\mathbb{M}_p^e$ (computed based on signal strength estimation) from $\mathbb{M}^e$. Second, rather than considering the estimated signal strength for the construction of the set of feasible eNBs for the UE association, we consider the actual measured signal strength values from the eNBs, as this information is available at the current time instance. Therefore, the set of feasible eNBs based on actual signal strength measurement, $\mathbb{M}_p$, for the current anchor point p is included in $\mathbb{M}^e$. Finally, we apply the USSL-C algorithm using the updated $\mathbb{M}^e$ to find out a new UE-AS. The next UE association is done based on this updated UE-AS. This ensures quick restoration of the radio communication so that the UE can continue with seamless communication. The mechanism for the run-time update of UE-AS in USSL-A algorithm is presented in Procedure 1.

Procedure 1 Runtime update of UE-AS in USSL-A

```
procedure UPDATEUEAS(p_c, M^e, L, U)
    ▷ p_c is the current anchor point (location over the travel trajectory) of the UE
    ▷ L is the current measure of LSRL up to point p_c
    ▷ U is the UE-AS based on USSL-A
    U(e_{p_c}) ← Serving eNB at point p_c based on U
    if L ≥ L_T then
        M_p ← {e_i | S(e_i, p_c) ≥ λ}
    # S(e_i, p_c) is the measured RSRP at point p_c
        M^e ← {M^e_{p_i} | i ∈ [c + 1, n]} ∪ {M_{p_c}}
    # p_n is the last anchor point in the UE travel trajectory
        G ← Construct USSL-C graph using M^e
        U ← Shortest path in G based on USSL-C
        Initiate a forced handover to U(e_{p_c})
    end if
    return U
end procedure
```

VI. Performance Evaluation

Detailed simulation on the NS-3 network simulator has been performed to evaluate the performance of the two proposed algorithms, USSL-C and USSL-A, and compare their performances with four existing LTE handover algorithms. In this section, we first present the simulation setup and then present the results of the simulation.

A. Simulation Setup

All the algorithms are simulated using the network simulator NS-3.25 [23], with LTE components simulated using the LTE modules for NS-3 from the LTE-EPC Network Simulator (LENA) project [24]. The simulations are done on four areas, one each in Paris and Amsterdam, and two areas in New York (in Brooklyn and Bronx) obtained from the OpenStreetMap project [25]. In the rest of this paper, we refer to these areas as *Paris*, *Amsterdam*, *New York 1*, and *New York 2* respectively. These areas are chosen because they have a high density of LTE eNB deployments from different network operators as given by the OpenCelliD database [26]. The distributions of LTE eNBs belonging to a particular network operator in each of these regions are chosen as the set of eNBs used in the simulation. The UE device is assumed to be on a vehicle moving on road segments in the area with an average speed of 60 Km/hr. This mobility of the UE is generated using the SUMO traffic simulator [27]. Table I shows the approximate size, the operator chosen, and the corresponding eNB density for each of the four areas.

TABLE I
SIZE AND ENB DENSITY OF AREA CHOSEN

Area	Size (Sq.Km.)	Operator	eNB/Sq.Km.
Paris	8.61	Iliad	29
Amsterdam	9.62	T-Mobile	22
New York 1	3.99	Sprint	47
New York 2	8.51	T-Mobile	26

The communication-related parameters used for the simulations are shown in Table II.

The proposed algorithms are compared with four existing LTE handover algorithms, namely A2A4RSRQ [3], A3RSRP

TABLE II
COMMUNICATION PARAMETERS FOR SIMULATION

Parameter	Value(s)
eNB transmission power	46 dBm
Path loss model	Friis propagation loss model
Fading model	Trace fading model Parameters: 100 RBs, 100 number of samples per subframe, 18Mhz frequency, vehicular mobility related parameters values as specified in Annex B.2 of [28]
Spectrum channel type	Multi-model spectrum Channel
eNB mobility model	Constant position mobility model
UE mobility model	Constant velocity mobility model
RRC model	Ideal RRC
Fractional frequency reuse algorithm	LTE FFR soft algorithm
LTE MAC scheduler	Proportional fair fractional frequency MAC scheduler

[4], UBBHO [6], and OMBFRA [5]. These four algorithms have been briefly discussed earlier in Section II. The different values of the parameters of the algorithms used in the simulations are shown in Table III. These parameter values are found to give very good performance for the algorithms based on detailed simulations of the algorithms over a wide range of parameter values.

TABLE III
PARAMETERS OF A2A3RSRQ, A3RSRP, UBBHO, AND OMBFRA

Algorithm	Parameter	Values
A2A4RSRQ	Neighbour offset (dB)	4
A3RSRP	HOM (dBm)	4
	TTT (ms)	256
UBBHO	HOM (dBm)	4
	TTT (ms)	256
OMBFRA	HOM (dBm)	4
	TTT (ms)	256
	Score weights	0.25, 0.5, 0.25

For USSL-C and USSL-A, the values of some of the parameters used in the simulation are shown in Table IV. We choose λ to be slightly higher than the minimum signal strength required for good communication so that handover decisions can be made before the signal strength actually drops below the minimum. This minimum threshold for good communication, referred to as sst_{th} in this paper, is taken as -90 dBm [29].

TABLE IV
PARAMETERS OF THE PROPOSED ALGORITHMS

Parameter	Value
Signal estimation method	Log distance path loss
λ (dBm)	-85
sst_{th} (dBm)	-90
τ (ms)	1000

B. Results

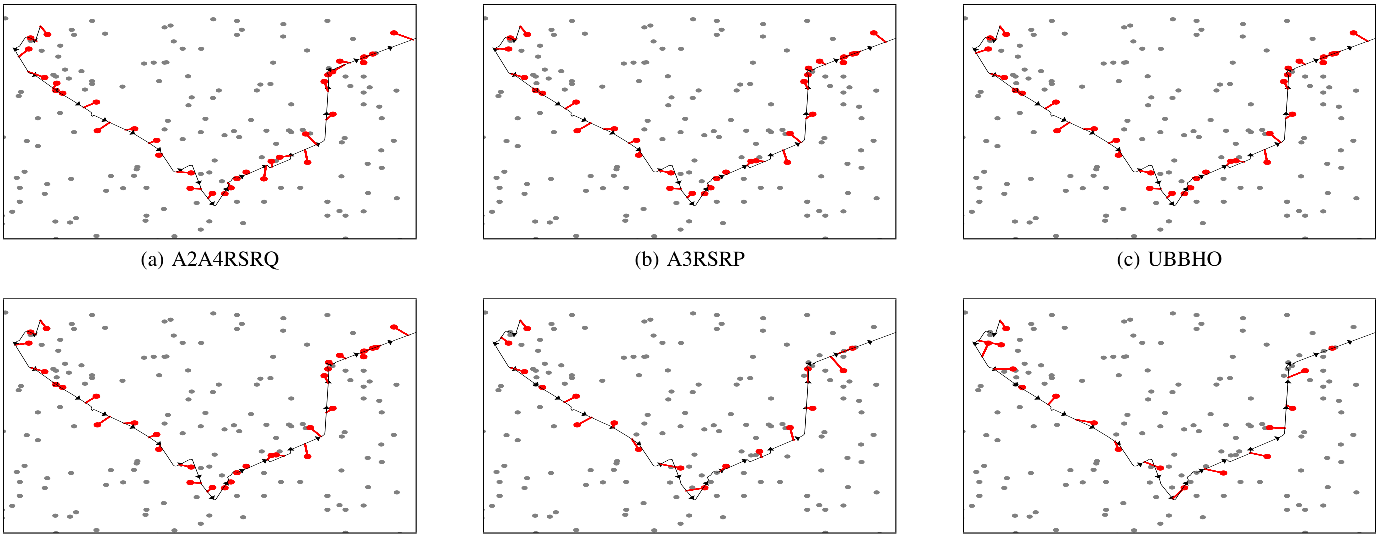
Table V shows the number of handovers obtained for the different algorithms, with different LSRL threshold ($\mathcal{L}_T$) values for USSL-A. For USSL-A, $\mathcal{L}_T = \infty$ signifies the case when the run length for low signal is not considered for forcing any handover. The results show that the numbers of handovers obtained with both USSL-C and USSL-A are much less than that obtained with the other four existing LTE handover algorithms for all cases, with around 20-40% reduction even with $\mathcal{L}_T = 1$. Note that even though USSL-C uses more exact information than USSL-A, there is no direct relationship between the number of handovers in USSL-C and USSL-A. The reason behind this is the difference in the set of measurement reports that are used in the algorithms. USSL-C assumes that the actual signal strengths seen by the UE over its entire trajectory are available a priori. However, for USSL-A, the actual measurement report is available only for the current time instance, and estimated values are used for the rest of the time instances. This estimation does not consider the effects of noise as it is unpredictable. As a result, the estimated signal value at some future time instance may be smaller or larger than the actual signal value the UE would have received at that point, causing USSL-A to trigger a handover when USSL-C would not have triggered one and vice-versa.

In order to investigate further the reason for the lower number of handovers in USSL-A, we looked at the actual handovers for the Paris area in detail for the four existing algorithms and for USSL-A with $\mathcal{L}_T$ values of 2 and 3. Figure 2 shows the trajectory of the UE (the black line), the position of all the eNBs (the dots) and the handovers done (the red lines). As is already mentioned, USSL-A shows much less number of handovers. To find the reasons for the extra handovers in the existing algorithms, we look at the number of two different types of spurious handovers that may occur, ping-pong handovers and wrong handovers, in each case. To count the ping-pong and wrong handovers, we slide w-sized windows over the complete UE-AS sequence (so there is a total of $N - w + 1$ windows where N is the number of eNBs in the UE-AS, one for each time-slot). Given such a window $\langle e_i, e_{i+1}, \ldots, e_{i+w-1} \rangle$, a ping-pong handover is said to have occurred if there exists a subsequence $\langle e_p, e_q, e_r \rangle$, $i \leq p < q < r \leq i + w - 1$, such that $e_p = e_r$, and $e_p \neq e_q$. Note that p, q, r need not be consecutive. Similarly, a wrong handover is said to have occurred if there exists a subsequence $\langle e_p, e_q, e_r \rangle$, $i \leq p < q < r \leq i+w-1$, such that $e_p \neq e_q \neq e_r$. The number of ping-pong and wrong handovers are counted over all such windows. We have counted these handovers for $w = 4$ as an example, i.e., for a very short four second window in our case. It is found that the number of ping-pong handovers in four second windows is nearly zero for all algorithms. However, the four existing algorithms show a much larger number of wrong handovers compared to USSL-A (Table VI), indicating that they encounter many spurious handovers.

However, a smaller number of handovers can have a negative impact on the signal strengths experienced by the UE throughout its trajectory. To understand the impact of the various algorithms on the signal strengths, we measure the percentage of total journey time for which the signal

TABLE V
NUMBER OF HANDOVERS [λ = -85 dBm]

Area Name	Existing Algorithms				USSL-C	USSL-A						
						$\mathcal{L}_T$						
	A2A4RSRQ	A3RSRP	UBBHO	OMBFRA		∞	1	2	3	4	5	6
Paris	31	30	30	30	10	7	20	16	15	13	11	10
Amsterdam	14	13	13	14	5	5	12	9	9	7	8	7
New York 1	18	16	14	15	7	4	10	9	7	6	6	6
New York 2	12	14	12	13	4	2	9	6	6	5	4	3



(a) A2A4RSRQ (b) A3RSRP (c) UBBHO

(d) OMBFRA (e) USSL-A, $\mathcal{L}_T = 2$ (f) USSL-A, $\mathcal{L}_T = 3$

Fig. 2. Handover Patterns in the Paris Area, $\lambda = -85\ dBm$

TABLE VI
NUMBER OF WRONG HANDOVERS [λ = -85 dBm, w = 4]

Area Name	Existing Algorithms				USSL-A						
					$\mathcal{L}_T$						
	A2A4RSRQ	A3RSRP	UBBHO	OMBFRA	∞	1	2	3	4	5	6
Paris	14	8	9	9	0	4	2	0	0	0	0
Amsterdam	3	3	3	5	0	3	1	0	0	0	0
New York 1	13	9	7	8	0	3	3	0	0	0	0
New York 2	8	9	9	8	0	3	0	0	0	0	0

strength experienced by the UE is less than the desired signal strength threshold sst_{th}. Table VII shows this results for all the algorithms. The results for USSL-C are not shown as by design, the percentage of time the signal stays below λ is 0 for this algorithm, and λ is greater than sst_{th}. For USSL-A, it is seen that the percentage of time the signal strength stays below the threshold for good communication depends crucially on a proper choice of the $\mathcal{L}_T$ value. Small values of $\mathcal{L}_T$ causes the algorithm to consider a handover just after the signal strength falls below λ even if the estimates earlier indicates no handover should be done. This increases the number of handovers slightly but maintains the signal strength at a level greater than or equal to λ, and hence greater than sst_{th}, most of the time. As the value of $\mathcal{L}_T$ is increased, overestimation of the signal strength done earlier can cause the algorithm to not trigger a handover even if the actual measured signal strength at the current time falls below λ or even below sst_{th}. Thus, as $\mathcal{L}_T$ is increased, the number of handovers remain the same or drops only slightly, but the signal quality deteriorates overall. A choice of $\mathcal{L}_T$ of 1 or 2 gives very good results compared to the other four existing algorithms. Note that for New York 2, the performances of all the algorithms are not very good; however USSL-A still performs similar to the other existing algorithms.

In summary, it can be concluded from the results that USSL-C and USSL-A perform very well as compared to existing LTE handover algorithms in reducing the number of spurious handovers while maintaining good signal quality. USSL-A is also practical to implement.

TABLE VII
PERCENTAGE OF TIME WITH SIGNAL STRENGTH LOWER THAN sst_{th} [λ = -85 dBm, sst_{th} = -90 dBm]

Area Name	Existing Algorithms				USSL-A						
	A2A4RSRQ	A3RSRP	UBBHO	OMBFRA	$\mathcal{L}_T$						
					∞	1	2	3	4	5	6
Paris	0	0	0	0	37	0	0	3	12	26	26
Amsterdam	0	0	0	0	43	0	0	15	14	18	20
New York 1	0	7	4	2	26	2	4	2	19	20	20
New York 2	20	20	17	20	56	17	22	27	34	39	46

VII. CONCLUSION

In this paper, we have addressed the problem of reducing the number of handovers in dense LTE networks using additional mobility information of the UE. A graph-based framework is presented to model the problem of finding the minimum number of handovers. Based on this framework, two handover algorithms are presented next, and their performances are compared with four existing LTE handover algorithms. It is shown that for suitably chosen parameters, the proposed algorithms give a much smaller number of handovers while maintaining good signal quality for communication. The work can be further extended to consider better estimation schemes and the effect of multiple UEs.

REFERENCES

[1] P. Amin and A. Ylä-Jääski, "Improved handover mechanisms to reduce packet forwarding in LTE-Advanced," in *Proc. of 9th International Wireless Communications and Mobile Computing Conference*. IEEE, 2013, pp. 831–836.

[2] D. Xenakis, N. Passas, L. Merakos, and C. Verikoukis, "Advanced mobility management for reduced interference and energy consumption in the two-tier LTE-Advanced network," *Computer Networks*, vol. 76, pp. 90–111, 2015.

[3] N. Baldo, M. Requena-Esteso, M. Miozzo, and R. Kwan, "An open source model for the simulation of LTE handover scenarios and algorithms in NS-3," in *Proc. of 16th ACM International Conference on Modeling, Analysis & Simulation of Wireless and Mobile Systems*. ACM, 2013, pp. 289–298.

[4] B. Herman, D. Petrov, J. Puttonen, and J. Kurjenniemi, "A3-based measurements and handover model for NS-3 LTE," in *Proc. of International Conference on Mobile Services, Resources, and Users*, 2013, pp. 20–23.

[5] S. K. Ray, H. Sirisena, and D. Deka, "LTE-Advanced handover: An orientation matching-based fast and reliable approach," in *Proc. of IEEE 38th Conference on Local Computer Networks*. IEEE, 2013, pp. 280–283.

[6] R. D. Hegazy and O. A. Nasr, "A user behavior based handover optimization algorithm for LTE networks," in *Proc. of IEEE Wireless Communications and Networking Conference*. IEEE, 2015, pp. 1255–1260.

[7] P. Munoz, R. Barco, and I. de la Bandera, "Load balancing and handover joint optimization in LTE networks using fuzzy logic and reinforcement learning," *Computer Networks*, vol. 76, pp. 112 – 125, 2015.

[8] 3GPP, "TS 36 331 - V13.1.0 - technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); radio resource control (RRC); protocol specification," Apr. 2016.

[9] M. M. Chen, Y. Yang, and Z. D. Zhong, "Location-based handover decision algorithm in LTE networks under high-speed mobility scenario," in *Proc. of IEEE 79th Vehicular Technology Conference*. IEEE, 2014, pp. 1–5.

[10] M. Shehada, B. Fu, S. Thakolsri, and W. Kellerer, "QoE-based resource reservation for unperceivable video quality fluctuation during handover in LTE," in *Proc. of IEEE 10th Consumer Communications and Networking Conference*. IEEE, 2013, pp. 171–177.

[11] T. Jansen, I. Balan, J. Turk, I. Moerman, and T. Kurner, "Handover parameter optimization in LTE self-organizing networks," in *Proc. of IEEE 72nd Vehicular Technology Conference*. IEEE, 2010, pp. 1–5.

[12] M. Behjati, J. P. Cosmas, R. Nilavalan, G. Araniti, and M. Condoluci, "Self-organising comprehensive handover strategy for multi-tier LTE-Advanced heterogeneous networks," *IET Science, Measurement Technology*, vol. 8, no. 6, pp. 441–451, 2014.

[13] D. W. Lee, G. T. Gil, and D. H. Kim, "A cost-based adaptive handover hysteresis scheme to minimize the handover failure rate in 3GPP LTE system," *EURASIP Journal of Wireless Communications Networking*, vol. 2010, pp. 6:1–6:7, Feb. 2010.

[14] N. Sinclair, D. Harle, I. A. Glover, J. Irvine, and R. C. Atkinson, "Parameter optimization for LTE handover using an advanced SOM algorithm," in *Proc. of IEEE 77th Vehicular Technology Conference*, Jun 2013, pp. 1–6.

[15] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Sukhavasi, C. Patel, and S. Geirhofer, "Network densification: the dominant theme for wireless evolution into 5G," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 82–89, 2014.

[16] A. Elnashar and M. A. El-Saidny, "Looking at LTE in practice: A performance analysis of the LTE system based on field test results," *IEEE Vehicular Technology Magazine*, vol. 8, no. 3, pp. 81–92, 2013.

[17] Y. L. Lee, T. C. Chuah, J. Loo, and A. Vinel, "Recent advances in radio resource management for heterogeneous LTE/LTE-A networks," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 2142–2180, 2014.

[18] 3GPP, "TS 136 214 - V9.1.0 - LTE; evolved universal terrestrial radio access (E-UTRA); physical layer - measurements," Apr. 2010.

[19] X. Lin, J. Andrews, A. Ghosh, and R. Ratasuk, "An overview of 3GPP device-to-device proximity services," *IEEE Communications Magazine*, vol. 52, no. 4, pp. 40–48, 2014.

[20] A. AlAmmouri, J. G. Andrews, and F. Baccelli, "SINR and throughput of dense cellular networks with stretched exponential path loss," *IEEE Transactions on Wireless Communications*, vol. 17, no. 2, pp. 1147–1160, 2018.

[21] M. Koivisto, A. Hakkarainen, M. Costa, P. Kela, K. Leppanen, and M. Valkama, "High-efficiency device positioning and location-aware communications in dense 5G networks," *IEEE Communications Magazine*, vol. 55, no. 8, pp. 188–195, 2017.

[22] S. Sun, T. S. Rappaport, T. A. Thomas, A. Ghosh, H. C. Nguyen, I. Z. Kovács, I. Rodriguez, O. Koymen, and A. Partyka, "Investigation of prediction accuracy, sensitivity, and parameter stability of large-scale propagation path loss models for 5G wireless communications," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 5, pp. 2843–2860, 2016.

[23] G. F. Riley and T. R. Henderson, "The NS-3 network simulator," in *Proc. of Modeling and Tools for Network Simulation*. Springer, 2010, pp. 15–34.

[24] G. Piro, N. Baldo, and M. Miozzo, "An LTE module for the NS-3 network simulator," in *Proc. of 4th International Conference on Simulation Tools and Techniques*, 2011, pp. 415–422.

[25] M. M. Haklay and P. Weber, "OpenStreetMap: User-generated street maps," *IEEE Pervasive Computing*, vol. 7, no. 4, pp. 12–18, Oct. 2008.

[26] Unwired Labs, "OpenCelliD - the world's largest open database of cell towers." [Online]. Available: http://wiki.opencellid.org/wiki/

[27] D. Krajzewicz, G. Hertkorn, C. Rössel, and P. Wagner, "SUMO (Simulation of Urban MObility)-an open-source traffic simulation," in *Proc. of 4th Middle East Symposium on Simulation and Modelling*, 2002, pp. 183–187.

[28] 3GPP, "TS 136 104 - V10.2.0 - LTE; evolved universal terrestrial radio access network (E-UTRAN); base station (BS) radio transmission and reception," May 2011.

[29] L. Korowajczuk, *LTE, WiMAX and WLAN Network Design, Optimization and Performance Analysis*. John Wiley & Sons, 2011.