Towards Deriving Analytical Model for Optimal Cell Overlap to Reduce Handover Signaling

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***Abstract*—The conventional network dimensioning and optimization approaches prioritize coverage and capacity as the most vital components. However, handover signaling overhead has emerged as a critical concern in the emerging cellular networks. This is particularly evident with the proliferation of network densification leading to a higher number of handovers. Hence, an optimal cell overlap is vital to ensure retainability and service continuity for the ever-growing fraction of mobile users and the expected cell densification. It is also crucial because the unprecedented signaling overhead can clog both the core network and air interface. To address this challenge, this paper presents an analytical model built on the control data separation architecture (CDSA) to quantify the handover signaling overhead as a function of cell overlap, user speed and cell density. We first compute probabilities for handover failures and successes and model the handover signaling overhead as a Markov chain. Numerical results demonstrate that for a given cell density and user velocity, a suitable cell overlap yields substantial reductions in handover signaling by improving handover success rate. The proposed model has the potential to become an integral element in the network planning process for emerging cellular networks.**

***Index Terms*—Cellular network planning, mobility signaling, Control-Plane User-Plane, 5G, 6G.**

I. INTRODUCTION

5G and beyond (5G&B) and 6G networks are anticipated to support 17.1 billion subscriptions by 2030 [1]. Moreover, a surge in traffic volume is expected due to the popularity of data hungry applications such as mobile video services, augmented reality and virtual reality. As a result, the traffic of global mobile networks is expected to reach 5016 EB/month in 2030 compared to 62 EB/month in 2020 according to estimation by ITU-R [2]. Base station (BS) densification and the inclusion of mmWave bands are considered as promising solutions to keep up with this exponential growth of mobile traffic [3]. The two major problems of interference and spectrum scarcity can be solved utilizing the short range and substantial empty spectrum of mmWave. However, it also results in a new challenging problem of user mobility management in an ultra dense network, which includes cells with variable radius and operates on a wide range of frequency bands. Increase in BS densification poses greater challenges to mobility management in such heterogeneous networks (HetNets) due to the reduced footprint of small cells. Consequently, user equipments (UEs) at moderate or high speeds may experience much higher handover (HO) rate.

The perennial occurrence of HO events poses a significant challenge in cellular networks, disrupting the seamless transmission of data between the BS and the UE. These frequent HO instances can lead to radio link failures (RLFs), which not only increase latency but also hinder the key performance indicator (KPI) of retainability. The research community has widely studied the techniques to address these issues, for instance, frequent HO mitigation [4], and HO skipping [5]. However, not much work has been done to reduce the significantly large amount of signaling overhead generated as a result of the HO instances of mobile UEs. Recent studies [6] have shed light on the need to mitigate this signaling overhead, which can significantly impact network performance and resource utilization. In fact, the current industrial practice for cell planning does not generally consider mobility and relies on post-deployment mobility management solutions [7].

Various signaling messages are exchanged both during and after the HO and RLF occurrences, and collectively, they can create a bottleneck due to the high BS density and large fraction of mobile UEs in the near future [6]. Even if we assume that the core network will have high speed fiber links along with large computational and processing capabilities, the air interface might be choked up due to multiple mobile UEs attempting HO or recovering from RLF at the same time. Note that multiple UEs can initiate random access channel (RACH) concurrently on a shared set of resources for the purpose of network accessibility. If the BS cannot decode these RACH message sent by the UE, the UE ramps up the uplink power and re-sends the RACH message. In a worst case scenario, spontaneous and recurring RACH attempts by multiple UEs can elevate the uplink received signal strength indicator (RSSI) at the BS. High uplink RSSI can be very detrimental to the UE experience and network KPIs, as the ensuing high uplink interference results in frequent re-transmissions. The aforementioned issue of high mobility signaling becomes important because very high HO rate in an ultra-dense network increases the HO signaling overhead and hence limits the utility of conventional approaches for ultra-dense future networks [8].

Drawing from the discourse presented, it becomes evident that traditional methodologies prioritize the signal-to-interference plus noise ratio (SINR) as the most vital component in network planning, dimensioning, and optimization. However, in the realm of emerging networks, mobility assumes an important role as an additional fundamental component in the design of mobile networks. Given the significance of mobility-based signaling overhead in emerging cellular networks, we advocate for the adoption of an optimal cell overlap criteria to mitigate the associated signaling load generated by mobility. By establishing an optimal cell overlap between adjacent cells, we anticipate an enhancement in handover success rates, thereby mitigating the occurrence of repeated failed handover attempts and consequent signaling overhead. This proactive approach to mobility management holds promise in enhancing network efficiency and performance, underscoring its relevance in the context of evolving cellular infrastructures.

A. Relevant Work and Contributions

While HO skipping [9] techniques lower the HO rate, the temporal negative SINR during HO skipping phase can have very poor implications, especially when considering the ultra low-latency requirements of the emerging networks. control data separation architecture (CDSA) [10] is considered as a promising solution to minimize the expected frequent HOs. In CDSA architecture, a macro BS operating at a low frequency band is responsible for the control plane (and user plane occasionally), and a number of high frequency micro BSs with much smaller footprints manage only the user plane. Thus, when a UE moves between two micro BSs serving under a common macro BS, the UE maintains the same control plane with the macro BS. Some control plane procedures (e.g., radio resource control (RRC) procedures) related to the mobility and connectivity within the micro BSs covered by the macro BS can be bypassed and replaced by Layer1/Layer2 signaling. That is, the user plane transitions among micro BSs do not involve control plane signaling. That provides the advantage of control plane signaling savings in CDSA . However, highly mobile and large speed UEs will still contribute to the frequent HO between macro cells providing control plane, and that issue is addressed in this paper.

Authors in [11] proposed dual connectivity between macro cells to prevent HO failures (HOF) and to minimize the resultant signaling data generated. However, the signaling data generated during dual connectivity establishment at cell edge and detachment when UE was at the cell center of the new cell, was not considered. Similarly, existing research on HetNets signaling reduction [12], [13] showed lower signaling only if the UE was confined to the coverage of macro cell. The authors in [14] provided an analytical framework for mobility signaling estimation in CDSA. However, this study focused mainly on HO success (HOS) and did not take into account HOF scenarios. In contrast to previous studies, [15], [16] presented automated post-deployment HO solutions for mobility parameters optimization, which could lead to reduced signaling by improving HOS.

The major contributions of this work can be summarized as below:

1) This paper presents an analytical model to quantify handover signaling as a function of cell overlap, user velocity and cell density. To increase the relevance of the proposed model and make it pertinent to the future networks, we build the model on state-of-the-art control data separation architecture.
2) In order to make the handover signaling model realistic, we first compute the probabilities for both HOF and HOS as a function of cell overlap, UE velocity and cell density. We then utilize Markov chain to estimate the expected signaling overhead due to HOF and HOS. To the best of authors' knowledge, the existing literature does not present a model to quantify both HOS and HOF signaling as proposed in this paper.
3) We perform numerical analysis of the analytical model to evaluate the impact of average UE velocity, cell overlap and cell density on the resulting HO signaling overhead. The results indicate that the proposed model can be used to identify the optimal cell overlap for minimizing the signaling overhead. As a result, the proposed model holds the potential to become a crucial component of future network planning., offering valuable insights for optimizing network performance and efficiency.

The rest of the paper is organized as follows. Section II proposes the system model and necessary parameters for the analysis. In Section III, we first derive an analytical model for HO probabilities while taking into account average velocity, cell overlap and cell density. In Section IV, we use the HO probabilities computed in Section III to derive the HO signaling load. Numerical results are presented in Section V followed by conclusion in Section VI.

II. SYSTEM MODEL

A system model similar to CDSA in [14] has been used in this paper. The framework in [14] assumes HOs takes place successfully 100% of the time and therefore is not applicable in the case of HOF. As both HOF and HOS happen in a real cellular network, this paper considers realistic scenario by evaluating both HOF and HOS. We consider a CDSA based network where one control base stations (CBS) has data base stations (DBSs) spatially distributed across its foot-print. Owing to the homogeneity of the CBS and DBS distribution, we assume that the average interference that a UE experiences from CBSs and DBSs while traversing in a random direction is constant. In this paper, we focus on the core network (CN) RRC related mobility signaling of cellular network during HO process as the first step. The air interface signaling analysis is out of scope for this paper and will be done in a future work. For this study, we consider cell overlap, UE velocity and cell density as the system variables while the the impact of other system parameters such as power, pathloss etc. on HO signaling is not studied in this paper. Other system parameters such as power, path loss etc. are given a constant value. However, as we are are considering signaling cost associated with HO between two neighboring CBSs, we incorporate the interference gradient as the UE moves from serving CBS to the coverage region of the neighboring CBS along the shortest path between the two CBS.

We use poisson-point-process to model BS densities with ρ_c and ρ_d representing the CBS and DBS denisty respectively, where $\rho_d \geq \rho_c$. Note that in typical networks, $\rho_d \gg \rho_c$. Cell residence time, denoted by ϕ, refers to the duration during which a UE maintains its connection with a particular cell until a successful HO to a neighboring cell. Session duration is denoted by σ and represents the time an active UE has better reference signal received power (RSRP) from the serving cell than any neighboring cell. Subscripts c and d represent CBS and DBS, respectively, while superscript *r* represents residual cell residence time. The velocity of the mobile user is denoted by v. A bar on variable symbol represents the average value of the variable. According to [14], the CBS average residence time $\overline{\phi_c}$ is represented as:

$$\overline{\phi_c} = \frac{\pi}{4\bar{\mathrm{v}}\sqrt{\rho_c}}. \tag{1}$$

A. Handover Completion Time (T_{HO})

As a mobile UE reaches the cell-edge of the serving CBS, it reaches a stage where the reference signal receive power (RSRP) of the serving CBS becomes exactly similar to the RSRP of the neighboring CBS. However, the HO procedure starts only when the RSRP of the neighboring CBS is higher than the serving CBS by a set of network configured parameters, sum of which is known as HO Margin (HOM) [6]. HOM can be set to positive or negative and this stage is referred to as HO entering condition. UE then waits for a fixed time called time-to-trigger during which the UE locally processes the RSRP of both the participating CBS every transmission

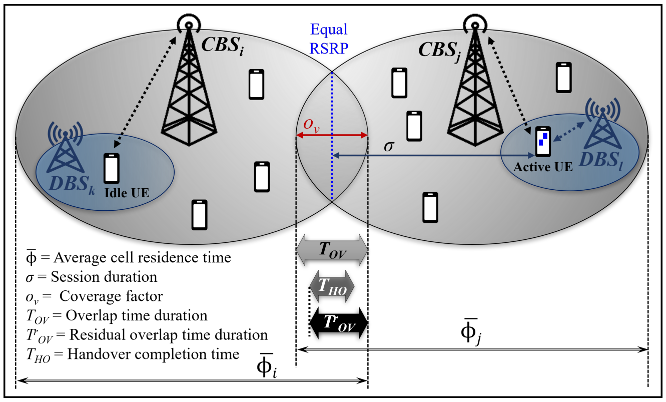

Figure 1. System model and timing diagram of the CDSA architecture.

time interval. This is to ensure that the neighboring CBS RSRP is strong and stable, and the neighboring BS is thus qualified to maintain the service continuity. Later on, the serving CBS receives a report from the UE requesting HO to the neighboring CBS. Serving CBS then exchanges admission control messages, and shares the UE context with the neighboring CBS. A successful response from the neighboring CBS is followed by the HO command being sent from the serving CBS to the UE. UE then attempts RACH to the neighboring CBS, which upon success concludes the HO process. The whole process can be summarized in three phases:

- Pre-HO phase from equal RSRP condition of serving and neighboring CBS to HO entering condition,
- HO criteria evaluation governed by HOM and time-to-trigger,
- HO decision between participating CBS and the time for successful RACH to the neighboring CBS.

We define handover completion time (T_{HO}) as the the time required to finish the above-defined three steps. To incorporate the signaling overhead for HOS and HOF, we have used an upper-bound delay value of 100ms for T_{HO} in this study.

B. Overlap Time Duration (T_{OV})

We define overlap time duration (T_{OV}) as the time duration a mobile UE takes to traverse through the shared coverage area between two adjacent CBS, where the UE can observe the RSRP from both the serving and neighboring CBS. An optimal coverage overlap will ensure that for a given UE velocity, $T_{OV} > T_{HO}$ (a condition necessary to observe successful HO), and thus, by avoiding HOF, signaling data generation will be minimized.

We utilize the average residence time $\bar{\phi}$ to mathematically represent T_{OV}. As $\bar{\phi}$ represents the time a UE spends in the coverage area of a CBS, T_{OV} is a fraction of $\bar{\phi}$ and is dependant on shared coverage overlap between the two adjacent CBS. The relationship between $\bar{\phi}$ and T_{OV} can be modeled as:

$$T_{OV} = \bar{\phi} \times o_v \times 10^3 \qquad (2)$$

where o_v is the cell coverage overlap also known as coverage factor between the two neighboring CBSs as shown in Fig. 1. In the system model considered in this paper, o_v does not have any dimension. We have added 10^3 as a scaling factor because we measure T_{OV} in milliseconds (depends on user velocity) while $\bar{\phi}$ is typically measured in seconds (depends on the cell size). The value of o_v ranges between 0.1 and 0.9. Ideally, o_v should be zero to achieve a better resource management and energy efficiency, however, $o_v > 0$ is essential to execute HO process for seamless service continuity. To propose an analytical framework that can quantify the handover signaling based on cell overlap, UE velocity and CBS density is the scope of this work. This analytical model can be utilized to find optimal o_v for minimizing the HO signaling overhead with varying UE velocity and CBS density. However, finding the optimal value of cell overlap is a future work and not considered in this study.

T_{OV} is more for larger o_v, and hence, UE will have adequate time to perform timely HO to the neighboring CBS. However, more coverage overlap also increases the area where UE experiences interference from the neighboring CBS. Since the signal propagation is an exponential function of the distance between the UE and BS, the UE will observe less interference from the point where the UE first observes RSRP of the neighboring CBS, to the point where RSRP of both participating CBS becomes similar (i.e. midpoint between the two CBS if we consider similar transmission power, height and topography). However, the interference will grow exponentially stronger from the midpoint to the edge of the coverage overlap where serving RSRP diminishes to null. As a result, larger o_v will give more chances to the slow speed users to perform HO successfully, however, high speed users might not benefit with the high coverage overlap due to increasing interference from the neighboring CBS. On the contrary, shorter coverage area will result in smaller T_{OV} and the chances of HOF increases even for slow speed users. The need for an optimal o_v for emerging network further signifies our work.

In order to keep the analysis generic to make it applicable for a range of deployment scenarios including CDSA based deployment or conventional small cell or macro cell based deployment, we want to derive the mobility signaling expression as a function of o_v but independent of the cell size. The first step to that end is to derive probability of HO. Probability of HO boils down to probability of HOS (P_h) and failure (P_f) that are in turn dependent upon T_{OV}, T_{HO}, cell density, velocity and coverage-overlap fraction o_v as follows:

$$\mathbf{T_{OV}} = \boldsymbol{f}\textbf{(cell residence time, cell overlap fraction)}$$

$$\boldsymbol{P_f} \textbf{ \textit{and} } \boldsymbol{P_h} = \boldsymbol{f(T_{OV}, T_{HO},} \textbf{ cell density, velocity)}$$

$$\textbf{signaling load} = \boldsymbol{f(P_f, P_h)}$$

III. DERIVING THE PROBABILITIES FOR HO FAILURE AND HO SUCCESS

In this section, we derive the P_h and P_f for quantifying the pertinent mobility signaling. These probabilities are computed as a function of T_{OV}, T_{HO}, user velocity, session duration and cell density. In this work, we assume HOF takes place due to too late HO. Other reasons for HOF such as radio conditions, early HO, partial HO etc., can be derived accordingly.

A. Probability of HO Failure

P_f is the probability of the event when T_{HO} exceeds beyond T^r_{OV} (residual overlap time duration), and σ is larger than ϕ. Such event occurs when session starts at CBS_x and ends unsuccessfully because of handover attempt to CBS_y, where $x \neq y$ and $T_{HO} > T^r_{OV}$. Following Fig. 1, P_f can be represented as following:

$$P_f = P(T_{HO} > T^r_{OV}) \times P(\sigma > \phi^r_c) \qquad (3)$$

where ϕ_c^r represents the residual ϕ for CBS. Assuming that σ and ϕ_c^r are independent, we can find the probability for σ larger than ϕ_c^r as following:

$$P(\sigma > \phi_c^r) = 1 - P(\sigma < \phi_c^r)$$

$$P(\sigma > \phi_c^r) = 1 - \int_{i=0}^{\infty} f_{\phi_c^r}(i) \int_{j=0}^{i} f_{\sigma}(j)\ dj\ di \tag{4}$$

On the same lines assuming that $P(T_{HO}$ and T_{OV}^r are independent,

$$P(T_{HO} > T_{OV}^r) = 1 - \int_{k=0}^{\infty} f_{T_{OV}^r}(k) \int_{l=0}^{k} f_{T_{HO}}(l)\ dl\ dk \tag{5}$$

In eq. (4) and eq. (5), the function $f(.)$ inside the integral represents the probability density function (pdf) of the respective variable. Substituting the values from eq. (4) and eq. (5) back in eq. (3), we get:

$$P_f = \left(1 - \int_{k=0}^{\infty} f_{T_{OV}^r}(k) \int_{l=0}^{k} f_{T_{HO}}(l)\ dl\ dk\right) \times \left(1 - \int_{i=0}^{\infty} f_{\phi_c^r}(i) \int_{j=0}^{i} f_{\sigma}(j)\ dj\ di\right) \tag{6}$$

The expressions in eq. (6), considers a general distribution for session duration. We assume an exponential distributions of σ, ϕ and T_{OV} for a closed form solution. According to [14], an exponential distribution of σ and ϕ results in exponential distribution of ϕ^r. As a result,

$$f_{\sigma}(t) = \frac{e^{-\frac{t}{\bar{\sigma}}}}{\bar{\sigma}} \tag{7}$$

$$f_{\phi_c}(t) = f_{\phi_c^r}(t) = \frac{e^{-\frac{t}{\overline{\phi_c}}}}{\overline{\phi_c}} \tag{8}$$

Since we have used ϕ to define T_{OV} and both are considered exponential, the pdf of T_{OV}^r is also exponential and can be represented as:

$$f_{T_{OV}^r}(t) = f_{T_{OV}}(t) = \frac{e^{\frac{-t}{\overline{T_{OV}}}}}{\overline{T_{OV}}} \tag{9}$$

Substituting the values from eq. (1), eq. (7), eq. (8) and eq. (9) in eq. (6), and after mathematical simplification, the probability of HOF can be given as:

$$P_f = \left[\frac{\overline{T_{HO}}}{\overline{T_{OV}^r} + \overline{T_{HO}}} \times \frac{4\bar{\sigma}\bar{\mathrm{v}}\sqrt{\rho}_c}{\pi + 4\bar{\sigma}\bar{\mathrm{v}}\sqrt{\rho}_c}\right] \tag{10}$$

B. Probability of HO Success

We consider the continuously mobile UE in our model, therefore, p_h can be obtained through the compliment of P_f, i.e.,

$$P_h = 1 - \left[\frac{\overline{T_{HO}}}{\overline{T_{OV}^r} + \overline{T_{HO}}} \times \frac{4\bar{\sigma}\bar{\mathrm{v}}\sqrt{\rho}_c}{\pi + 4\bar{\sigma}\bar{\mathrm{v}}\sqrt{\rho}_c}\right] \tag{11}$$

Since the signaling load for HOF case is higher than successful HO case, P_f and P_h will be used to derive the signaling load in the next section.

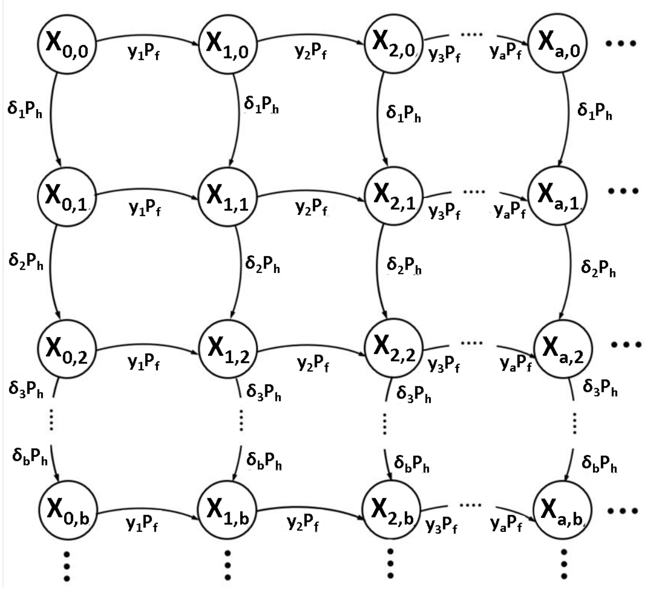

Figure 2. Markov chain indicating the core network signaling events due to HOS and HOF of continuous mobile users.

IV. DERIVING SIGNALING LOAD

Once the probabilities of HOF and HOS are derived, they can be used to compute the signaling load as a result of HO. In this section, we derive the signaling load as a function of P_f and P_h, which in turn are a function of T_{OV}, T_{HO}, user velocity, session duration and cell density. Each HO attempt by a UE produces either a HOS or HOF. A continuous mobile UE generates mobility signaling for both HOS and HOF. For HOF, we assume a stable RRC connection between the UE and CBS while the RRC connection is reestablished with the DBS. The HOF probability is the complement of the HOS probability. Fig. 2 shows this specific settings using a Markov chain. The complete CN signaling load for *a* HOF and *b* HOS is represented by $X_{a,b}$. The continuous HOF and HOS produce CN signaling overhead and we utilize the Markov chain for finding the expected signaling overhead. $P(X_{a,b})$ represents the probability of expected mobility related CN signaling due to continuous HO. A solution to the Markov chain presented in Fig. 2 can provide the values of $P(X_{a,b})$. The number of HO instances (both HOS and HOF) of mobile UEs and the associated signaling cost increases as time passes by. As a result, the probability is zero for transition from state $X_{y,z}$ to $X_{a,b}$ when $y, z > a, b$.

Based on this model, $P(X_{a,b})$ can be formulated as:

$$P(X_{a,b}) = \begin{cases} P(X_{0,0}) \text{ for } a = 0, b = 0 \\ \gamma_a P_f^a P(X_{0,0}) \text{ for } a > 0, b = 0 \\ \delta_b P_h^b P(X_{0,0}) \text{ for } a = 0, b > 0 \\ (a+b)\gamma_a P_f^a \delta_b P_h^b P(X_{0,0}) \text{ for } a > 0, b > 0 \end{cases} \tag{12}$$

where γ and δ are the coefficients for handover process and depict the varying HO probability when the user moves from one BS to another BS. Following Lemma 1 of [14], γ and δ will have the following values considering exponential ϕ and σ:

$$\delta_1 = \delta_2 = \delta_3 = \delta_4 =, ..., = \delta_b = 1$$

$$\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 =, ..., = \gamma_a = 1$$

A. Handover signaling Load for Continuous Mobility Users

The CN signaling load due to continuous HOs can be computed by utilizing the instances of HOF (a) and HOS (b). The expected signaling can be represented as:

$$\overline{X_{a,b}} = \sum_{a=0}^{\infty}\sum_{b=0}^{\infty} X_{a,b}\, P(X_{a,b}) \tag{13}$$

where,

$$\begin{aligned} X_{0,0} &= [0 \times L_f] + [0 \times L_h] \\ X_{a,0} &= [a \times L_f] + [0 \times L_h] \\ X_{0,b} &= [0 \times L_f] + [b \times L_h] \\ X_{a,b} &= [a \times L_f] + [b \times L_h] \end{aligned}$$

where L_f and L_h represent the normalized signaling overhead due to HOF and HOS, respectively. The probability of $\overline{X_{0,0}}$ i.e., $P(X_{0,0})$ should be computed to find the value of $\overline{X_{a,b}}$. Using the Markov chain shown in the Fig. 2:

$$\sum_{a=0}^{\infty}\sum_{b=0}^{\infty} P(X_{a,b}) = 1 \tag{14}$$

Expanding eq. (14) using Fig. 2

$$P(X_{0,0}) + \sum_{a=1}^{\infty} P(X_{a,0}) + \sum_{b=1}^{\infty} P(X_{0,b}) + \sum_{a=1}^{\infty}\sum_{b=1}^{\infty} P(X_{a,b}) = 1$$

We can solve to find the value of $P(X_{0,0})$ as following:

$$P(X_{0,0}) = \frac{1}{1 + \sum_{a=1}^{\infty} P(X_{a,0}) + \sum_{b=1}^{\infty} P(X_{0,b}) + \sum_{a=1}^{\infty}\sum_{b=1}^{\infty} P(X_{a,b})} \tag{15}$$

After further simplification of eq. (15), we get:

$$P(X_{0,0}) = \frac{P_h P_f}{P_h P_f + P_f^2 + P_h^2 + \ P_f + P_h} \tag{16}$$

After putting the value from eq. (16) back in eq. (13), we get:

$$\overline{X_{a,b}} = X_{0,0} \times P(X_{0,0}) + \sum_{a=1}^{\infty} X_{a,0} \times P(X_{a,0}) + \sum_{b=1}^{\infty} X_{0,b} \times P(X_{0,b}) + \ \sum_{a=1}^{\infty}\sum_{b=1}^{\infty} X_{a,b} \times P(X_{a,b}) \tag{17}$$

After algebraic manipulations of eq. (17), the CN mobility signaling due to HOS and HOF of continuous mobile UEs is given as:

$$\overline{X_{a,b}} = \left(\frac{P_f}{P_h^2} + \frac{(P_f+1)}{P_h^2} + \frac{1}{P_h P_f}\right) L_f P(X_{0,0}) + \left(\frac{P_h}{P_f^2} + \frac{(P_h+1)}{P_f^2} + \ \frac{1}{P_h P_f}\right) L_h P(X_{0,0}) \tag{18}$$

Eq. (18) gives CN mobility signaling as a function of P_f and P_h which are functions of coverage overlap fraction o_v, cell density, T_{OV}, T_{HO} and user velocity. Therefore, from a network designer perspective large value of o_v, and T_{OV} result in higher proportion of HOS as evident from eq. (11). This will in turn reduce the generated signaling load.

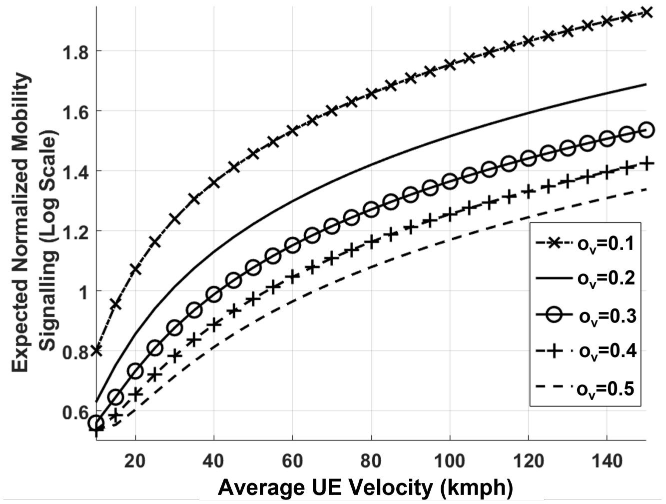

Figure 3. Expected mobility signaling as a function of average user velocity with varying cell coverage overlap o_v. L_f and L_h are used to normalize the signaling while the session duration ($\bar{\sigma}$) of 300s and cell density ($\bar{\rho}$) of 200 is used.

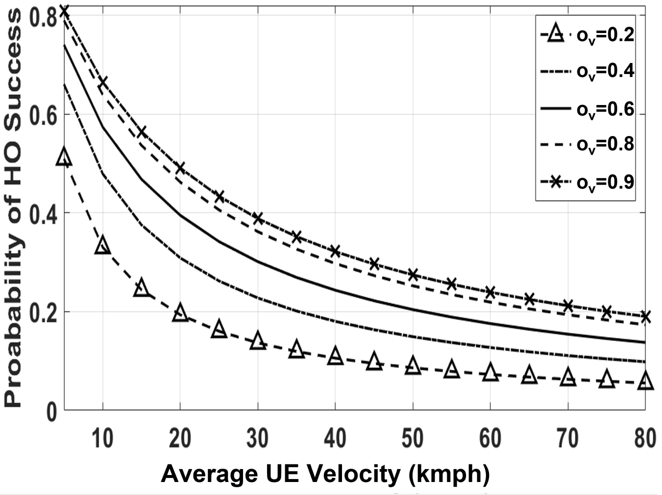

Figure 4. HOS probability (P_h) signaling as a function of average UE velocity with varying cell coverage overlap o_v. Session duration ($\bar{\sigma}$) of 300s and cell density ($\bar{\rho}$) of 200 is used.

V. NUMERICAL RESULTS

In this section, we present the numerical analysis using the signaling overhead derived in eq. (18). We analyze the trend of signaling overhead and HOS probability with varying UE velocity and cell overlap for fixed session duration and cell density. We also analyze the tend of signaling overhead with varying overlap time duration and cell density with fixed session duration and UE velocity.

Fig. 3 illustrates the variation in the signaling load as the user velocity is increased for the coverage overlap factor o_v from 0.1 to 0.5 and a cell density $\bar{\rho}$ of 200. As expected from eq. (10) and eq. (11), Fig. 3 indicates that probability of failure (P_f) increases with increase in velocity while probability of success (P_h) decreases with increase in velocity. As HOF result in higher signaling overhead than HOS, the signaling overhead increases with increasing UE speed due to higher number of HOF for all the values of o_v. Moreover, it can

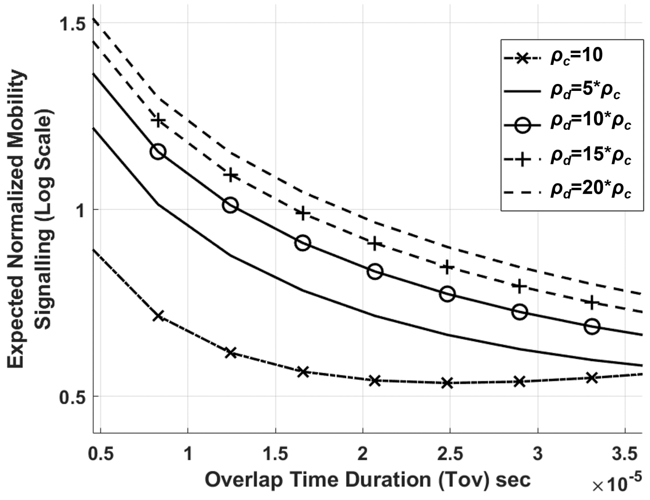

Figure 5. Expected mobility signaling as a function of overlap time duration. L_f and L_h are used to normalize the signaling while the session duration ($\bar{\sigma}$) of 300s and average user speed of 60 kmph is used.

be observed that the signaling overhead for all UE speeds is lower with o_v value of 0.1 when a high cell density of 200 is considered. Fig. 3 also demonstrate that the difference between the signaling load with o_v = 0.1 and o_v = 0.5 increases as the UE speed increases. This happens because the probability of HOF and the associated higher signaling increases more rapidly for high speed UEs with o_v = 0.1 compared to o_v = 0.5.

Probability of success (P_h) signaling for different UE velocity and coverage overlap is shown in Fig. 4. It is evident from Fig. 4 that at slow speeds, HOS signaling is initially high on account of large number of HOS occurrences. However, P_f increases at the expense of decrease in P_h when UE velocity increases, which is evident from Fig. 4 at high UE velocity. It means that the best cell overlap value to reduce mobility signaling overhead and ensure higher number of HOS can shift with varying UE velocity and cell density. From Fig. 4, it can be inferred that value of $o_v > 0.4$ should be used during network planning for high cell density in order to achieve better HOS rate and lower mobility signaling. This will ensure that P_f because of too late HO will start to reduce for $o_v >$ 0.4 while P_h starts to increase.

Fig. 5 indicates the expected signaling vs. T_{OV}, with varying CBS and DBS densities at v= 60 kmph. Fig. 5 highlights a general trend of higher signaling overhead with the decrease in T_{OV}, and increase in DBS density (ρ_d). Higher signaling overhead with decreasing T_{OV} is observed due to the higher number of HOF. On the other hand, more signaling overhead with increasing ρ_d is due to higher number UEs associating to DBS compared to CBS. It can also be observed that an optimal T_{OV} value to reduce the signaling overhead exists when ρ_c = 10. This optimal T_{OV} for this particular case is around 2.5×10^{-5}. For the other case with higher ρ_d, the signaling overhead decreases with increasing T_{OV}. These results demonstrate that the analytical model(s) in Sections III and IV can find the cell coverage overlap o_v, which minimizes the signaling overhead for a given network settings such as HO settings, UE mobility statistics and CBS as well as DBS density.

VI. CONCLUSION

The existing commercial networks are not deployed while keeping in view the mobility signaling generated due to various cell overlap sizes. This is important as both the core network and the air interface can be choked up with the increase in the fraction of mobile users and due to the ultra-densification of BSs expected in near future. To address this concern, we present a novel analytical model to quantify the mobility signaling reduction by choosing an optimal cell coverage overlap for a specific user velocity and BS density. We also highlight the percentage of HOS operators can expect as they change the coverage overlap between two neighboring BSs. Since more signaling overhead is generated due to the HOF, we can minimize HOF and the associated signaling data by considering an optimal cell overlap. The presented framework to minimize the CN mobility signaling by optimizing the cell coverage overlap can become an essential component of the future network planning.

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