An Analytical Model to Quantify the Effect of Handover and Cell Density on SINR in Emerging Cellular Networks

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***Abstract*—Existing SINR models are based on best server associations, which represent a network dominated by static users. During the handover (HO), users are not camped on the best-server, resulting in negative SINR. This is important because the emerging networks are likely to have a much higher HO rate due to higher base station density and an increased proportion of mobile devices. We derive a model that characterizes spatio-temporal downlink SINR as a function of BS density, user velocity, and HO delay duration.**

I. Introduction

With the number of 5G subscribers anticipated to be more than 2.6 billion by 2025 [1], the futuristic mobile networks need to have dense base station (BS) deployment to address the looming capacity crunch. However, with a 10-fold higher expected BS density [2] in future networks, mobile users will have to perform a proportionally larger number of handovers (HOs) per session.

The impact of resultant perennial HOs should be incorporated into SINR modeling and subsequent KPI analysis that builds on SINR models. This is necessary as, during a typical HO, a mobile user is not served by the best server cell.

HO delay occurs due to HO entering condition interval, HO request requirement, and processing delay. The HO entering condition interval is the time from equal signal strength of the participating BSs to the point where the signal strength of the target cell is greater than the serving cell by HO Margin. The HO entering condition should be maintained for a period equal to the Time-To-Trigger (TTT) before UE sends a HO request. Finally, the processing delay is due to the admission control and the accessibility of the target BS.

The ensuing SINR deterioration is directly proportional to the mobile user velocity as a) the mobile UE will penetrate deeper into the coverage of the target cell without performing timely HO, and b) due to the increase in HO rate per time.

II. System Model

We assume a uniform distribution of same-frequency BSs on a one-dimensional Euclidean space $\mathcal{R}$ as shown in Fig. 1. For tractability purposes, we assume BSs with isotropic antennas and a fully-loaded MAC layer, transmitting continuously with a constant transmission power P. The BSs with uniform density λ are separated by a uniform inter-site distance D.

Fig. 1 depicts a mobile user with a velocity V served by the BS s. Total interference, however, during the complete trajectory of the mobile user will be from all neighboring BSs up to the I-th BS from both directions (I represents the farthest interfering BS). The time taken by the mobile user to move from one BS to adjacent BS is denoted by T.

III. Analytical Model for Spatial SINR

Instantaneous SINR $\gamma^{\alpha}(t)$ for a mobile user at a distance d_s from serving BS s is presented in (1), where α denotes the pathloss exponent, i corresponds to the number of interfering BS with respect to s. For a mobile user traveling away from s as shown in Fig. 1, the distance of the mobile user from interfering BSs on each side of the serving BS s can be expressed as $iD + Vt$ and $iD - Vt$.

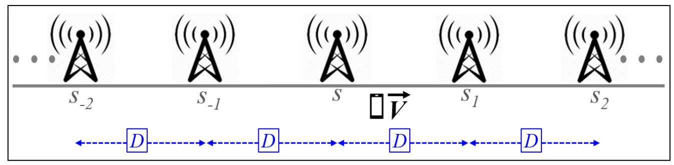

Figure 1: System model used for analytical SINR expression.

$$\gamma^{\alpha}(t) = \frac{(Vt)^{-\alpha}}{\left(\sum_{i=1}^{I}(iD+Vt)^{-\alpha}\right) + \left(\sum_{i=1}^{I}(iD-Vt)^{-\alpha}\right)}, \quad (1)$$

Theorem 1. *Combined interference from a fairly large number of BSs on each side of the serving BS can be represented by polygamma function. If $I \to \infty$,*

$$\sum_{i=1}^{I}(iD+Vt)^{-\alpha} \to \frac{1}{(\alpha-1)!D^{\alpha}} \times \Psi^{\alpha-1}\left(1+\frac{t}{T}\right)$$

and

$$\sum_{i=1}^{I}(iD-Vt)^{-\alpha} \to \frac{1}{(\alpha-1)!D^{\alpha}} \times \Psi^{\alpha-1}\left(1-\frac{t}{T}\right)$$

where $\Psi^{j}(k)$ is a polygamma functions of order j where $j>0$ and $Re[k]>0$.

Using Theorem 1, and for $\alpha \in 2\mathbb{Z}^{+}$ where $\mathbb{Z}^{+}$ represent set of positive integers, (1) can be further expanded by employing recurrence relation (2) and reflection formula (3) of polygamma function

$$\Psi^{j}(1+k) = \Psi^{j}(k) + (-1)^{j} j! k^{-j-1}, \quad (2)$$

$$\Psi^{j}(1-k) + (-1)^{j+1}\Psi^{j}(k) = (-1)^{j}\pi\frac{d^{j}}{dk^{j}}\cot(\pi k). \quad (3)$$

For $\alpha \in 2\mathbb{Z}^{+}$, the generic SINR expression will be:

$$\gamma^{\alpha}(t) = \frac{-(\alpha-1)!T^{\alpha}t^{-\alpha}}{(\alpha-1)!(V\lambda t)^{\alpha} + \pi\frac{d^{\alpha-1}}{d(V\lambda t)^{\alpha-1}}\cot(V\lambda\pi t)}. \quad (4)$$

Signal propagation loss is mainly governed by environmental characteristics and topography, and to a large extent can be characterized by the pathloss exponent α.

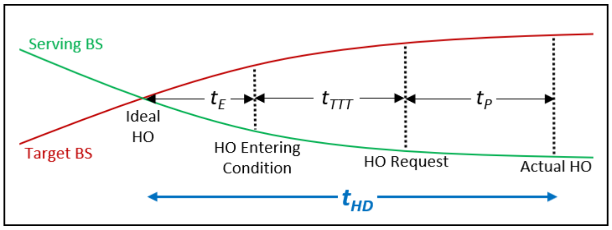

Figure 2: Factors affecting HO delay duration t_{HD}.

Table I: Pathloss exponent α corresponding to different environments

α	Environment	Reference
a) $\alpha \approx 2$	LoS Outdoor / Free Space	[3] [4]
b) $\alpha \approx 4$	NLoS Office / NLoS Home	[4]
c) $\alpha \approx 6$	NLoS mmWave / Vehicular	[3]

For different environment of LoS outdoor (α=2), NLoS indoor (α=4), and NLoS mmWave (α=6), HO aware SINR expression is given as (5), (6) and (7) respectively. Here, $\beta = V \cdot \lambda \cdot \pi$.

$$\gamma^2(t) = \frac{1}{[\beta t \csc(\beta t)]^2 - 1}. \tag{5}$$

$$\gamma^4(t) = \frac{3}{\beta^4 t^4 \csc^4(\beta t)[2\cos^2(\beta t)+1] - 3}. \tag{6}$$

$$\gamma^6(t) = \frac{15}{\beta^6 t^6 \csc^6(\beta t)\left[2\cos^4(\beta t) + 11\cos^2(\beta t) + 2\right] - 15} \tag{7}$$

IV. Quantifying SINR Degradation from HO Delay

When a mobile user travels from serving BS to adjacent BS, the average SINR γ^{α}_{Av} can be computed as (8), where $\Delta T = T - 2\epsilon$.

$$\gamma^{\alpha}_{Av} = \frac{2}{\Delta T}\int_{\epsilon}^{T/2} \gamma^{\alpha}(t)dt, \tag{8}$$

Note that (8) yields an average SINR for the case of best-server-association, however, HO takes place after a delay as shown in the Fig. 2.

Average SINR with HO delay t_{HD} will be:

$$\gamma^{n}_{Av} = \frac{1}{\Delta T}\left(\int_{\epsilon}^{T/2} \gamma^{\alpha}(t)dt + \underbrace{\int_{T/2}^{T/2+t_{HD}} \gamma^{\alpha}(t)dt}_{HO Delay} + \int_{T/2+t_{HD}}^{T-\epsilon} \gamma^{\alpha}(t)dt\right), \tag{9}$$

SINR function exhibits symmetry around mid point ($T/2$), hence γ^{α}_{Av} for a mobile user commuting for a duration T':

$$\gamma^{\alpha}_{Av} \approx \frac{n}{T'}\left(\int_{\epsilon}^{T/2+t_{HD}} \gamma^{\alpha}(t)dt + \int_{\epsilon}^{T/2-t_{HD}} \gamma^{\alpha}(t)dt\right) \tag{10}$$

V. Validation and Numerical Results

An increase in λ results in greater signal strength as the serving BS is now much closer to the mobile user (see Fig. 3). However, the interfering BSs are also comparatively nearer, and the composite interference from multiple neighboring BSs exceeds the signal strength of a single serving BS, resulting in poorer SINR.

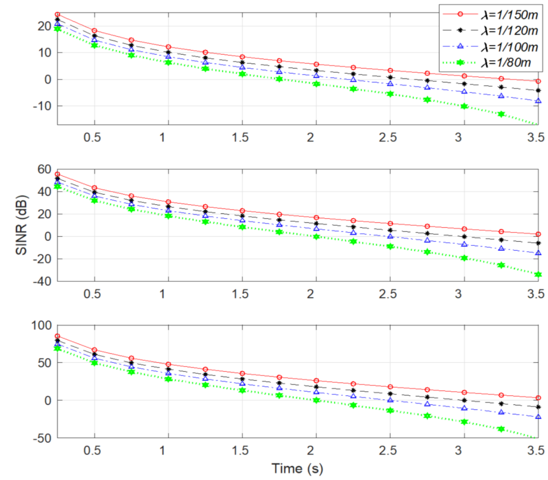

Figure 3: Effect of cell density on instantaneous SINR for V=36km/h, and α = 2, 4, 6 (top to bottom).

For t_{HD}>0, Fig. 4 shows that the average SINR drops as the user velocity increases for a given t_{HD}. The effect becomes more prominent for the mmWave band (α=6), as signal strength decays at a faster rate.

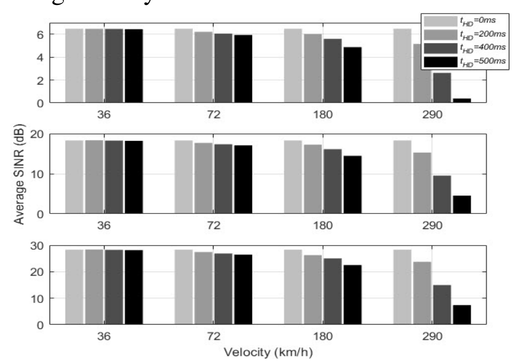

Figure 4: Effect of varying t_{HD} and V on average SINR for α = 2, 4, 6 (top to bottom).

VI. Conclusion

We presented a mobility-aware SINR model applicable to emerging networks having a large proportion of mobile users and a high HO rate. The main contribution of this poster is to quantify the temporal SINR degradation as a function of user velocity, HO delay duration, and BS density. Results show that by employing the practical mobility consideration, we can avoid overestimating the SINR distribution, which would be the case if we rely on existing mobility-agnostic SINR distribution models.

Acknowledgment

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